

2017 IEEE Pulsed Power Conference

Sunday, 18 June 2017 - Thursday, 22 June 2017

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Monday 19 June 2017

Plenary Session 1 - Invited Plenary Speaker : Michel Caron - Chair: Bucur Novac, Oxford hall (08:45-09:45)

08:45 [476] HIGH PULSED POWER AT CEA DAM

Presenter: CARON, Michel

High Pulsed Power (HPP) systems have been developed at CEA-DAM in France for the last 6 decades in order to assist with National Defence and Deterrence programmes in which they play a key role. HPP technologies are generally used as key subsystems of a more complex equipment such as large accelerators or laser facilities. This talk aims at giving an overview with an historical perspective on the HPP technologies that are currently operational or being developed at CEA-DAM. The main achievements in different fields of applications are reported according to a technology orientated approach.

First this talk briefly presents the main features of the pulse power systems for the Laser MegaJoule (LMJ). Then, the talk covers the contribution of HPP to the Lab-scale simulation of extreme environments (radiative and non-radiative). It presents the specifications, technologies and performances of HPP facilities developed at CEA in order to carry out a wide variety of experimental studies to assess the resistance of engineered systems to severe environment.

Pulsed power activities at CEA-DAM related to High-Power Microwave (HPM) systems for defence electromagnetic applications are also presented. A brief focus is given on a recent development of a compact and repetitive Marx generator. As the HPP expertise at CEA-DAM is also oriented towards enabling technologies and non-military applications in order to address key issues in various fields ranging from fundamental research to industry, few examples of recent achievements are shown to illustrate the potential of HPP for scientific and industrial applications.

Eventually, this talk presents the latest HPP development on flash X-ray radiography. The Teutates collaboration between the United Kingdom and France is introduced and the experimental facilities, EPURE in France and the Technology Development Centre (TDC) in the UK are presented through their main pulse power equipment that are the 20MeV Linear Induction Accelerator in operation as a 1st axis in EPURE and the 7.5MeV Inductive Voltage Adder currently commissioned in the TDC prior to being used as a 2nd axis in EPURE. The HPP work for the 3rd radiographic axis of the EPURE facility are highlighted as well.

Oral session 1 - High-Energy Density Storage, Opening and Closing Switches - Session Chair : Jiande Zhang - Room

Preston (10:00-12:30)

10:00 [129] A Greater Than 6 MV Laser Triggered Gas Switch Used on Z

Presenter: WAKELAND, Peter

The Z pulsed power driver at Sandia National Laboratories is used for a wide range of high energy density physics experiments in areas such as inertial confinement fusion, radiation effects, and dynamic material properties. Experimental demands are pushing for the highest energy attainable with more reliability and precision in timing and pulse compression. A previous version of the laser-triggered gas switch had been made reliable at voltages up to 5.7 MV, allowing 5 nanosecond load accuracy. The desire for higher energy and higher precision dictated a new laser-triggered switch design. In Z, 36 DC-charged Marx generators pulse-charge a water-insulated capacitor in 1.5 microseconds. The laser-triggered gas switch commutes the energy stored in the water-insulated capacitor to subsequent pulse compression stages that utilize self-closing water switches. The laser-triggered switch is the last command triggered switch in the chain, and largely determines the time accuracy of the total load current. Both switches consist of a laser triggered section and a self-closing cascade section. The previous design required a trigger plate to provide support for compressing the cascade section. With fixed laser energy, it was impossible to increase the triggered fraction of the switch. Because of the trigger support plate, establishing an operating pressure that provides a reliable balance between low pre-fire rate and low jitter becomes difficult, and more so at higher voltage. The new switch uses a cantilevered design that increases the electric stress in the self-closing section after triggering, even with a slightly-reduced triggered gap. It was required that the new design work within the same operating space and infrastructure as the previous. We will show details of the design and features necessary for reliable operation in the extreme electrical and mechanical environment presented by daily operation on Z.

emphasized text

10:30	<p>[20] The investigation of propylene carbonate based nano-fluids as an energy storage medium for pulsed power sources</p> <p><i>Presenter: ZHANG, Jiande</i></p> <p>Propylene carbonate (PC) is a promising dielectric for the compact pulsed power sources because of its large permittivity, high dielectric strength and broad operating temperature range. By adding nano-particle suspensions homogeneously to the dielectric liquid, the insulating properties of the dielectric liquid can largely be enhanced in the electrical engineering application. In this paper, the breakdown properties of PC based nano-fluids containing only 2 ppm TiO₂ nano-particles is experimentally studied and the result of more than 60% higher impulse breakdown voltage than that of base liquid is presented. It is found that the resistance of the test gap containing nano-fluids increases by a factor when the test gap is subjected to high amplitude voltage before the development of electrical breakdown, greatly differing from the invariable resistance in the pure PC case. Moreover, compared with pure PC, the streamers in nano-fluids are more complex branched. It implies that the charge carriers in nano-fluids can be effectively captured and scattered by nano-particles, which is verified by means of thermally stimulated current method.</p> <p>Based on these experimental results and theoretical analysis mentioned above, a nano-fluids-dielectric helical pulse forming line accelerator is developed, which has a 0.4-m diameter, a 1.2-m length, and a 7-Ω wave impedance. It can steadily operate at a 500-kV output voltage and a pulse width of 70 ns with better operation stabilities and 2.5 times higher output power than that of pure PC. These efforts set a good foundation for the development of a compact pulsed power generator with a new kind of high energy storage medium, and the results show an appealing application of PC based nano-fluids for the future.</p>
10:45	<p>[35] Modular, High-Energy, 4 MA driver for Exploding Foil Initiators*</p> <p><i>Presenter: RHODES, Mark</i></p> <p>An Exploding Foil Initiator (EFI) is one method used to detonate secondary high-explosives without the use of sensitive, primary high-explosives.</p> <p>We are developing a new, high-energy EFI system (also known as an E-gun) to replace and enhance an existing E-gun that is near its end of life. The existing E-gun stores 48 kJ at 40 kV and has been used at currents up to 1 MA. The new system will employ a modular design. Each module will store 61 kJ at 60 kV and be rated at 500 kA. The full system would be comprised of eight modules for a total possible current of up to 4 MA.</p> <p>We are building two prototype modules. The first design employs metal-can, traditional-style capacitors with Scyllac style bushings. The second design employs FATSCAP-style, plastic-case capacitors originally built for the Atlas facility.</p> <p>We are designing the modules to allow different types of closing switches to be utilized. Our two main switching approaches are the Railgap switch and a switch based on detonators.</p> <p>We will discuss our designs and present any available results from the prototypes.</p> <hr/> <p>* LLNL is operated by LLNS, LLC, for the U.S. D.O.E., NNSA under Contract DE-AC52-07NA27344.</p>
11:00	<p>[126] HIGH CURRENT AND CURRENT RISE RATE THYRISTOR BASED SWITCHES</p> <p><i>Presenter: GUSEV, Anton</i></p> <p>Thyristors of tablet design with diameters of silicon wafers of 40 to 56 mm and an operating voltage of 2 to 2.4 kV DC were triggered by an external overvoltage pulse applied across the thyristor main electrodes. In experiments a voltage rise rate across the thyristor was changed from 1 to 6 kV/ns. Under such conditions the thyristor closing process occurred due to initiation and propagation of a fast ionization front across the semiconductor structure, which fills the structure with dense electron-hole plasma within 200 to 400 ps. The thyristor based switches contained 2 to 9 series connected thyristors and operated in this triggering mode in different discharge circuits. Operating voltage was 5 to 20 kV, capacitance of discharge capacitors was 2 μF to 1.2 mF, and stored energy was 0.4 to 15 kJ. The experimental results obtained covered the following range of discharge parameters: discharge current amplitude of 10 to 200 kA, current-rise rate of 15 to 130 kA/μs, current rise time (0.1-0.9 level) of 0.4 to 5 μs, pulse duration (FWHM) of 1 to 20 μs, and switching efficiency of 0.85 to 0.97. Effect of the voltage rise rate at the triggering stage as well as temperature of the silicon wafer on the thyristors main switching characteristics will be shown. Results of the thyristors testing in pulse repetition mode will be given. The paper will discuss the experimental circuitry, tested switches design, and results obtained. The results of numerical simulations of the thyristor switching process will also be given.</p>

11:15	<p>[267] Implementation of High-Voltage Switch Using Inductive Energy for Switch Synchronization <i>Presenter: APPIAH, Gideon Nimo</i></p> <p>For discrete semiconductor switches with smaller ratings stacked for high-voltage high-current applications, there is the need to ensure reliable gate synchronization of all the switches in the stack. The delay of switching of separate stages must be minimized by reducing the effects of stray inductances in the switch operation. This paper describes the design of a HV switch for high-voltage, high-current pulsed power applications with reliable switch synchronization. In this design, insulated-gate bipolar transistor (IGBTs) and their gate driver circuits are compactly fitted on a switch module. A single power source serving as the primary of the isolation transformers of all stacked IGBTs provides synchronized gating signal to drive the stacked switches. Due to the fast di/dt rise of this inductive energy, switch turn-on delay time is greatly improved, allowing for reliable switch synchronization at fast speed. Rated pulse output voltage and current of 10 kV and 1.5 kA respectively were applied to a load using a configuration of the developed HV switch and a capacitor charger, and by experimental results, the operation of the proposed circuit was verified to be effectively used as a switch for pulse discharging</p> <p>Index Terms — High-voltage switches, gate drive circuit, switch synchronization, pulsed-power application</p>
11:30	<p>[460] HIGH CURRENT, HIGH VOLTAGE SOLID-STATE SWITCH PROGRESS AT AFRL <i>Presenter: HEIDGER, Susan</i></p> <p>A 50 kV solid-state switch has been developed using Thinpak™ Current Controlled SolidTRON® (CCS) thyristors from Silicon Power Corporation. A switch comprises thirty-six, series-connected thyristors and an internally powered, optically initiated trigger circuit. The trigger circuit drives the common primary winding of sixteen trigger transformer; each transformer has two output windings coupled to a pair of thyristor gates. This triggering arrangement provides simultaneous switching of all 36 thyristors. Because the only control signal is optical, these modules can be series-connected to switch higher voltages or floated to provide switching for Marx generators. Single switch modules have been operated at pulse widths from 300 ns up to 7 μs and pulsed currents from 250 A up to 2500 A with risetimes < 50 ns. The switching delay is approximately 100 ns with a pulse to pulse jitter of < 1.5 ns. This performance is achievable down to applied voltages as low as 2 kV. Testing at higher current is ongoing with a performance objective of 10 kA in a 300 ns pulse. A number of applications of these solid-state switch modules will be presented.</p>
11:45	<p>[62] Fast and efficient techniques for High Current Interruption using Electrical Exploding Fuses <i>Presenter: ASIF MEHMOOD KHAN</i></p> <p>Pulsed Power Technologies involved some electrical loads which required a fast rising (ns) input high current pulses. Pulse conditioning of slow rising (μs) high current pulse is very essential in this regard. A compact and an efficient solution based on metal fuses is modeled and experimentally verified the modal validity. Metal fuses referred as Electrically Exploding Fuses (EEF) consist of wires array and are used in pulsed power fields for pulse conditioning, current interruption, and opening and closing switches. Fuses operates as a consequence of overheating by the current, which they carry, resulting in their vaporization that causes their resistance to increase drastically and effectively cut off the current. Experimental results verified that the exploding time of the fuse depends on the type of the fuse material, length of the fuse wires, and total cross-sectional area of the fuse. Further it is investigated through experiments that the rise and fall time of the fuse resistivity depends on different quenching material used in the surrounding of the fuse material. By controlling the resistivity time, very fast high voltage pulse is generated, which when used with a dielectric switch caused very fast interruption of the high current (100's of KA) pulse in 100's of nanosecond time from originally microsecond high current pulses. A simulation code is developed for prediction of fuses operation based on thermodynamic and electrical properties of the EEF and much closer experimental and simulated results are achieved. Experimentally a slow current pulse (μs) is interrupted and transferred to the load in the alternated path by using dielectric switch with fast rising time (ns).</p>

12:00	<p>[291] Voltage Maintaining Performance of High Energy Density Capacitor <i>Presenter: LI, Hua</i></p> <p>The high energy density (HED) capacitor is the energy storage component in capacitive pulsed power systems. There is an obvious voltage decay phenomena when the capacitor is disconnected with the charge source, and the higher the energy density is, the faster the voltage decay. And the voltage maintaining performance (VMP) of capacitor is of special interests especially in the occasion that has high requirement of output energy efficiency. For the HED capacitor made of metallized films, there are three factors influencing the VMP: self-healing, dielectric leakage and polarization. In order to investigate the effect of above factors on VMP of HED capacitor, the experiments and analyses of self-healing characteristics, dielectric leakage in stable status and slow polarization are carried out. For a 3kV/1.4MJ/m³ HED capacitor, the self-healing is responsible for less than 12.5% of the whole voltage decay. And the dielectric leakage contributes for 32.5% with the fact that the conductivity is in the range of 3×10⁻¹⁶ S/m-1.5×10⁻¹⁵ S/m. The voltage decay is mainly caused by the slow polarization. Then a VMP simulation considering no self-healing process established by using Debye theory, and different working parameters such as charging rate, holding time are studied by using the VMP simulation. When the charging rate is 100 V/s, 300 V/s and 3000 V/s, the voltage decay in 1 minutes is 5.2%, 5.5% and 5.75% respectively, and when the holding time is 0 s, 10 s, 100 s and 1000 s, the percentage of 1min voltage drop of capacitor is 5.2%, 4.75%, 3.25% and 2% respectively. The results based on the space charge reveal the facts that faster charging rate or shorter holding time result in faster voltage decay. And, with the consideration of the energy output efficiency and voltage withstand characteristics of dielectric, the charging time and holding time will be compromise values.</p>
12:15	<p>[459] Photocurrent Efficiency in Bulk and PIN SiC Photoconductive Semiconductor Switches for Pulsed Power Applications <i>Presenter: MAUCH, Daniel</i></p> <p>A comprehensive picture of the relationship between optical fluence (30-30,000 μJ/cm²), optical wavelength (295-375-nm), electrical bias (8-64-kV/cm), and photocurrent efficiency (defined as the ratio of electrons extracted to electrons generated) in SiC photoconductive semiconductor switches (PCSSs) is presented. The behavior of SiC PCSSs including high electric field stress behavior (> 200-kV/cm) captured in self consistent drift-diffusion simulations, and associated failure modes are briefly highlighted.</p> <p>For a PCSS to be practical, a high photocurrent efficiency is desired. Typically, this efficiency is wavelength dependent, and in the case of the bulk PCSSs, the efficiency was observed to exhibit a broad peak over the wavelength range from 315 to 350 nm. Overall, a maximum photocurrent efficiency of at most 10 % was found, largely depending on the operating conditions. Thus, to overcome this efficiency limitation, a prototype PIN (as opposed to bulk) SiC PCSS was designed and evaluated. The PIN device was designed and optimized using TCAD Silvaco simulations along with a custom particle swarm optimization for the junction termination design. This approach yielded a 6x-10x improvement in photocurrent efficiency relative to bulk SiC PCSSs over the same parameter space with comparable voltage blocking performance.</p> <p>Bearing in mind presently available pulsed UV light sources, bulk SiC PCSSs are considered to be most practical for burst high voltage or single shot pulse applications (demonstrated up to 65 MHz repetition rate), while the PIN PCSS structure lends itself to high average power, continuous pulse operation in the single digit MHz repetition rate regime.</p> <p>*This work is supported by AFOSR grant FA95501010106, "Collaborative Research on Novel High Power Sources for and Physics of Ionospheric Modification."</p>

Oral session 2 - Medical, Biological and Environmental Applications - Session Chair : Wolfgang Frey - Room Stanmer

(10:00-12:30)

10:00	<p>[418] Study of OH Radical Generation Process in Pulsed Air Discharge Including Water Droplets <i>Presenter: SUGAI, Taichi</i></p> <p>Water purification technology that can decompose refractory organic compounds efficiently is required because eluent standard of factories became stricter. As one of methods of water purification, we have studied spraying polluted water into pulsed discharge. In this method, polluted water is purified by OH radical and ozone mainly, which are produced by the discharge. However, generation processes of those products have not confirmed in experiment. To confirm it, OH radicals in case of spraying into the pulsed discharge space and in case of spraying into ozone space without the discharge, were measured and compared. In this measurement, ozone concentration generated at the discharge space was equalized with ozone concentration in ozone space. OH radical was measured by a fluorescent method using terephthalic acid, and decomposition of acetic acid. As the result, OH radical concentration of both spaces was similar. Therefore, we expect that almost all OH radicals are generated via the reaction of ozone and OH minus ion.</p>
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10:15	<p>[429] Optimization of Persistent Organic Pollutants Treatment in Wastewater Using by Nanosecond Pulsed Non-Thermal Plasma</p> <p><i>Presenter: KODAMA, Shintaro</i></p> <p>The global water environment continues to worsen mainly due to organic pollution caused by agricultural and domestic and industrial wastewater. Wastewater includes many kinds of pollutants. Among them, persistent organic pollutants (POPs) present serious problems due to their high environmental persistence and hormone-like activation. Further, they are resistant to environmental degradation and thus cannot be decomposed by conventional water treatments. The search for a highly efficient POPs treatment method has brought attention to direct water treatment by discharge plasma. Especially, nano-second (ns) pulsed discharges enable higher energy efficiencies of plasma processing and have already demonstrated their advantages at such gas phase treatment processes as NO_x treatment and ozone generation. However, few reports exist on water treatment using ns pulsed discharge plasmas.</p> <p>This study reports on efforts to decompose industrial wastewater using ns pulsed discharge method by spraying wastewater into the oxygen gas phase plasma region; it also evaluates the pH, oxygen flow rate, discharge voltage, pulse repetition rate and discharge reactor constitution on wastewater decomposition. Concentration of Total Organic Carbon (TOC) in the solution and HPLC analysis is evaluated under several treatments.</p>
10:30	<p>[69] POWER MODULATOR FOR HIGH-YIELD PRODUCTION OF PLASMA ACTIVATED WATER</p> <p><i>Presenter: PEMEN, Guus</i></p> <p>Water can be activated by applying plasma in contact with the water. Plasma activated water (PAW) typically contains hydrogen peroxide, nitrates, nitrites, and peroxydinitrite, and typically has a pH ranging from 2-4. The components of PAW and the low pH have proven synergistic antimicrobial effects against bacteria, biofilms, yeasts and other microorganisms. In this contribution, we describe a system for the production of PAW at high yield and high production rate. A compact and solid-state dual resonant system has been realized and successfully demonstrated for industrial PAW production. The system generates up to 80 kV dual-resonant high-voltage pulses with an oscillation frequency of 1 MHz, pulse rep-rate up to 20 kHz and an average power of 300 W. The paper describes a detailed comparison of various topologies, a detailed design procedure, simulations and overview of the practical realization and verification of the power modulator. The system is able to activate around 100 L/hour.</p> <p>In addition, we will give an overview of several pilot demonstrations of promising applications of PAW. In agro applications, such as nitrogen fixation for fertilizer production, and the prevention of plant disinfections in horticulture.</p>
10:45	<p>[361] SUB-MICROSECOND DISCHARGES FOR THE DEGRADATION OF ORGANIC POLLUTANTS IN WATER*</p> <p><i>Presenter: KOLB, Juergen F.</i></p> <p>Persistent organic pollutants, such as pharmaceutical residues, often withstand treatment by conventional water treatments. Plasmas generated directly in water have shown to effectively decompose these compounds, presenting a promising new approach. Especially corona-discharges that are generated by short high voltage pulses are able to penetrate large volumes of water of different characteristics, including different conductivities and turbidities.</p> <p>We have therefore compared corona-discharges that are generated by rectangular high voltage pulses of either 100 ns, 300 ns and 650 ns duration and amplitudes of up to 100 kV in defined and comparable coaxial discharge geometries. The positive high voltage pulses were provided by Blumlein line pulse forming lines and networks in stacked configurations. Foremost we investigated degradation efficacies and efficiencies for six recalcitrant pharmaceuticals that are known to accumulate in surface waters, including diclofenac and ethinylestradiol. Shorter pulses result in higher degradation efficiencies despite a reduced plasma volume penetration. Accordingly we investigated plasma development and also associated reaction chemistries using phenol as a model system. Detailed studies of degradation pathways confirmed that OH-radicals are primarily responsible for the degradation of organic compounds. However, in the bulk they are primarily provided by secondary reactions, i.e. not directly by the plasma. Accordingly, in conjunction with plasma processes, Fenton reactions play a significant role. Concurrently, especially reactions with the ground electrode material, which have so far often been neglected, are important. Ground electrode corrosion due to electrochemical processes favors the catalytic decomposition of hydrogen peroxide that was formed as a secondary discharge product to OH-radicals again. Consequently, degradation efficacies of plasmas in water can be significantly enhanced by a combination with dedicated catalytic materials.</p> <p>*Work supported by the Federal Ministry of Education and Research of Germany (BMBF) under contract no. 13N1363.</p>

11:15	<p>[328] Tunable activation of platelet rich plasmas using electric pulses <i>Presenter: GARNER, Allen</i></p> <p>Activated platelet rich plasmas – platelet gels – have been successfully explored for enhancing wound healing [1]. These clinical workflows include a) drawing the patient's blood; b) centrifuging the blood to obtain platelet rich plasma (PRP); c) activating the platelets to trigger growth factor release and clotting; d) applying the activated PRP topically on the wound. The state of the art platelet activator is bovine thrombin (BT); however, it suffers from high cost, limited availability, and potential inducing side effects [2]. Electric pulses (EPs) have successfully activated platelets ex-vivo, opening opportunities for a clinical alternative to BT with lower cost, simplified workflow, no animal derived substances, and no known side effects [3]. We report current research on tuning platelet activation by using appropriate EP settings. While BT activation results in a specific growth factor mix and clotting time, manipulating the EP parameters, such as amplitude and duration, enables one to adjust these characteristics. For example, one of the main growth factors released during platelet activation, EGF (epidermal growth factor), controlling EP parameters can induce a lower, equal, or much higher EGF release level than BT. These results may open potential new avenues for platelet gels that could be optimized/tuned for the wound type and/or the specific stage of the wound healing cascade. The implications of EP tuned platelet activation will be discussed.</p> <p>[1] K. M. Lacci and A. Dardik, "Platelet-rich plasma: support for its use in wound healing. Yale J. Biol. Med., vol. 83, pp. 1-9, 2010.</p> <p>[2] D. L. Diesen and J. H. Lawson, "Bovine thrombin: history, use, and risk in the surgical patient," Vascular, vol. 16, Suppl. 1, pp. S29-S36, 2008.</p> <p>[3] A. S. Torres, et. al, "Platelet activation using electric pulse stimulation: Growth factor profile and clinical implications," J Trauma Acute Care Surg., vol. 77, S94-S100, 2014.</p>
11:30	<p>[324] Dose effect of high frequency nanosecond pulse bursts on muscle contraction of rabbit in vivo <i>Presenter: XU, Jin</i></p> <p>In the process of treating tumor with nanosecond pulsed electric fields, the muscle contraction is inevitable. The purpose of this paper was to study the effect of different parameters of high frequency nanosecond pulse bursts on the rabbit muscle contraction strength. Ten unipolar high frequency pulse bursts with different field intensities (3 kV/cm, 5 kV/cm and 10 kV/cm), intra-burst frequencies (10 kHz, 100 kHz and 1 MHz) and intra-burst pulse numbers (1, 10 and 100) were applied through a pair of plate electrode to the surface skin of the rabbit's biceps femoris, and the acceleration signal of muscle contraction near the electrode was measured with a three axis acceleration sensor. The time and frequency domain characteristics of the acceleration signal were analyzed. The time domain analysis of the acceleration signal shows that with the increase of the strength of the pulse sequence, the amplitude of the acceleration signal of the muscle contraction will also increase and the vibration of the acceleration signal is more intense when the parameters are stronger. The frequency domain analysis of the acceleration signal shows that the frequency spectrums of the acceleration signal measured under different pulse bursts are similar. This suggests that the frequency of muscle contraction is determined by the inherent resonance frequency of the muscle tissue. Further analysis of the experimental results illustrate when the intra-burst frequency is relatively low, appropriate increase in the intra-burst pulse numbers will not increase muscle contraction strength significantly; however when the intra-burst frequency is relatively high, the intra-burst pulse numbers should be minimized as far as possible. This will provide reference for the selection of parameters in the actual tumor treatment performed with high frequency nanosecond pulses in the future.</p>

11:45	<p>[387] Local Heating and Stresses Across Membranes of Microorganisms Exposed to Pulsed Electric Fields <i>Presenter: SONG, Bolin</i></p> <p>Pulsed electric fields (PEF) can cause irreversible damage to the bio-membranes of microorganisms, with the resulting electro-mechanical stresses induced across their membranes stretching and potentially rupturing these phospholipid bi-layers. The electro-mechanical stresses have an electrostrictive nature, as the membrane the cytoplasm inside the membrane and the external suspension have different dielectric and electrical properties. .</p> <p>PEF treatment is typically considered non-thermal because the direct effect of the forces due to the external electric field do not cause increases in the global temperature of the microbial liquid suspension. However, other factors, such as localised heating of the membrane, may potentially contribute to membrane damage.</p> <p>Analysis of this local heating effect is important for further understanding of the biological action of the externally-applied electric field as potentially the local heating may play non-negligible role in the PEF inactivation process.</p> <p>This paper presents an investigation of the transient local heating and transient stresses induced across bio-membranes of model microorganisms, stressed with an external electric field. A model of the PEF process was developed and studied using COMSOL Multiphysics software. The obtained results demonstrate that high-field impulses can result in the development of strong local thermal stresses across the membrane and significant local over-heating of the membrane and cell wall, as compared with the global temperature of the external suspension. Thus, the obtained results demonstrate that, even in the case of globally “non-thermal” PEF treatment, when the temperature of the suspension remains below the thermal inactivation threshold, local hot spots can be developed, which may result in further damage to the bio-membrane. The developed model can aid in further understanding the biological action of impulsive electric fields, and in further development and optimisation of PEF technology and its practical bio-medical, environmental and other applications.</p>
12:00	<p>[177] Pulsed Electric Field Processing of Fruits and Vegetables <i>Presenter: KEMPKE, Michael</i></p> <p>Diversified Technologies, Inc. has introduced a new PEF (Pulsed Electric Field) system for processing fruits and vegetables by softening their tissue at the cellular level which makes slicing, dicing, peeling, drying, and juicing easier.</p> <p>Diversified Technologies' PEF System for the tissue modification of fruits and vegetables lowers their processing cost by actually making more of the cell contents accessible. Utilizing microsecond 1-5 kV/cm high voltage pulses to perforate cell membranes, this system can prepare tons-per-hour of whole fruits and vegetables for downstream processing.</p> <p>Capable of up to 85% higher juicing yields, Diversified Technologies' PEF System is instantaneous and requires very low energy. Non-thermal and non-chemical, it reduces energy requirements for cutting and peeling by 20-50% with less waste and breakage, claims the firm. Systems start at 100 kW, packaged in a CE Marked NEMA 4 stainless steel enclosure.</p>
12:15	<p>[417] Atmospheric pressure dry- and mist-plasma jets using pulsed power generator and their effects on HeLa cells <i>Presenter: WATANABE, Ken</i></p> <p>Atmospheric-pressure plasma jets have recently received significant attention due to its unique capabilities as low temperature, low cost, portability, and ease of operation which are suitable to such novel applications as analytical chemistry, thin film processing, nanomaterial synthesis, surface modification, sterilization, and etching. In biological applications, chemical species including NO₂, HNO₃, O₃ and OH generated in air phase are rapidly dissolved and transported into liquid phase, and accompanied chemical stimuli can inactivate bacteria. The hydroxyl radical (OH) in particular plays an important role in plasma chemistry and plasma medicine due to its oxidation and disinfection potential, substantially higher than other oxidative species. Also reported is that H₂O₂ produced by plasma holds potential for inactivation of HeLa (human cancer) cell viability. In our previous study focusing on OH and H₂O₂ production, we developed a “mist plasma jet (MPJ)” generated using dry helium gas mixed with water mist to improve upon the traditional method using only dry helium gas, known as the “dry plasma jet (DPJ)”. This study focuses on observation and comparison of effects of both MPJ and DPJ on HeLa cells surrounded by cell culture medium immediately after irradiation by plasma and following 24 hours. First, we examined voltage dependency of saturation temperatures on DPJ and MPJ; next, we irradiated plasma to cell culture medium including cells and observed cells exposed to the plasma-treated culture medium after 24 hours. These experiments revealed that MPJ more greatly influences cell death than DPJ.</p>

Oral session 3 - High Power Microwave Systems and Sources - Session Chair : Steve Calico - Oxford hall (10:00-12:30)

10:00	<p>[455] Preliminary Development of a Modular Electromagnetic Pulse and High Power Microwave Simulator for Survivability Testing <i>Presenter: PARSON, Jonathan</i></p> <p>Many organizations are concerned with the survivability of communication electronics, radar systems, vehicle support and related computer systems from electromagnetic pulse (EMP) and high power microwave (HPM) threats. For effective protection against EMP and HPM threats, it is important to understand not only the threat physics, but also to quantify the effects on mission-critical electrical systems. In order to support testing of large systems, a scalable array of 100 kV TEM radiators has been considered and proposed as a possible path towards future full-scale experiments. For coherent or phase-able arrays, the timing control jitter must be very low. A low-cost, fast high voltage pulse charger and a compact, high power Q-switched laser source were designed and developed to drive 100 kV-capable GaAs photoconductive semiconductor switches (PCSS) for precision timing of large-scale EMP and HPM modular array simulators. This paper presents the preliminary testing results and discusses the development of a single EMP simulator module that includes a 1 m by 1 m TEM radiator and a low-inductance >30 kV pulse circuit.</p>
10:15	<p>[65] O-TYPE METAMATERIAL HIGH POWER MICROWAVE SOURCE WITH 310 MW OUTPUT POWER* <i>Presenter: YURT, Sabahattin</i></p> <p>Unusual electrodynamic properties of metamaterials naturally call for investigations of their applicability as slow wave structure (SWS) elements in modern microwave vacuum electron devices [1,2]. In this work, a novel microwave oscillator based on the idea of a cylindrical metamaterial SWS (MSWS) is designed. The designed MSWS, consisting of split ring resonators (SRRs) with oppositely oriented gaps with a period that is much less than a wavelength, shows metamaterial properties such as below cutoff propagation, negative dispersion, and double negative behavior. The interaction space is coupled with the outer coaxial channel through gaps between the SRRs.</p> <p>Using particle-in-cell (PIC) simulations, it was found that the electron beam in the interaction space forms a sequence of trapped electron bunches by the synchronous operating wave. The output parameters of this oscillator for an applied voltage $U=400$ kV, electron beam current $I=4.5$ kA, and guide axial magnetic field $B=2$ T are radiation power $P=310$ MW, radiation frequency $f=1.4$ GHz, and electronic efficiency $\eta=15\%$ when the total SWS length L consisting of 12 split rings is 34.5 cm. High output power is achieved with a very fast risetime of about 4 ns when the voltage risetime is 2 ns with a decreased overall size compared to conventional backward wave oscillators. This presentation will present a detailed overview of the design of this high power microwave oscillator.</p> <p>1. S.C. Yurt, M. Fuks, S. Prasad, and E. Schamiloglu, "Design of a Metamaterial Slow Wave Structure for an O-Type High Power Microwave Generator," <i>Phys. Plasmas</i>, vol. 23, pp. 123115-1-7 (2016).</p> <p>2. S.C. Yurt, A. Elfrgani, M. Fuks, K. Ilyenko, and E. Schamiloglu, "Similarity of properties of metamaterial slow wave structures and metallic periodic structure," <i>IEEE Trans. Plasma Sci.</i>, vol. 44, pp. 1280-1286 (2016).</p> <p>* Work supported by AFOSR MURI Grant FA9550-12-1-0489</p>
10:30	<p>[450] GW level microwave pulses in X-band from a combination of a relativistic BWO and a helical-waveguide compressor <i>Presenter: CROSS, Adrian</i></p> <p>Backward Wave Oscillators (BWO's) utilizing moderately relativistic (~500kV), high-current (~10 kA) electron beams are capable of producing hundreds of MWs of pulsed radiation in the centimeter wavelength range. Such relativistic BWOs (RBWOs) allow for relatively broadband, smooth, frequency-tuning via adjustment of the accelerating potential; making them an attractive source for use in frequency-swept pulse compression.</p> <p>A collaboration between the University of Strathclyde and the Institute of Applied Physics (IAP) resulted in the development of a 5-fold helically corrugated, frequency-swept, pulse compressor. In the experiment at Strathclyde, the maximum power compression ratio of 25 was achieved by compressing an input microwave pulse of 80 ns duration and 9.65 GHz to 9.05 GHz frequency swept range into a 1.6ns Gaussian-envelope pulse. For an average input power of 5.8 kW generated by a conventional traveling wave tube, a peak pulse output power of 145 kW was measured corresponding to an energy efficiency of 66% [1].</p> <p>An X-band relativistic BWO, designed to drive a similar compressor, was then built and tested at the IAP, with the accelerating potential provided by a SINUS-6 high-current accelerator. The experimental RBWO operated close to predicted powers (600 – 800MW) with its oscillation frequency varied from 10 – 9.6GHz via the falling edge of the voltage pulse. It was demonstrated that the ~15ns duration frequency-swept part of the RBWO pulse was effectively compressed resulting in about a 4.5-fold peak power increase with a maximum power of 3.2 GW generated [2]. Future experiments combining a 5-fold helical waveguide with a longer pulse RBWO will be discussed.</p> <p>[1] L. Zhang, et al, <i>IEEE Trans. Microw. Theory Tech.</i>, 63 (3), pp1090-1096, (2015). [2] V. L. Bratman, et al, <i>Phys. Plasmas</i> 17, 110703 (2010).</p>

10:45	<p>[391] RESULTS OF A COMPACT REFLEX TRIODE WITH MULTI CAVITY ADJUSTMENT <i>Presenter: BARNETT, David</i></p> <p>This study focuses on achieving wide tunability of a compact reflex triode virtual cathode oscillator (vircator). The cathode is of a bimodal carbon fiber (CF) material paired with a pyrolytic graphite anode. These materials display ideal operating characteristics which including but not limited to, long lifetime > 10⁶ shots, high operating temperatures > 1000 K, and large current densities ~200 A/cm². A 12 stage, 158 J pulse forming network (PFN) based Marx generator serves to drive the Vircator at 350 kV, 4 kA with ~100 ns pulsewidth. The operating frequency of interest is in the range of 1-6 GHz, where the tunability is achieved by varying the length of the anode-cathode (A-K) gap, the length from the back wall to the A-K gap, or/and the distance from the bottom of the cavity to the A-K gap. The primary focus in this experiment was to increase the achievable frequencies by placing a square waveguide within a sealed vacuum tube. This allows the bottom part of the waveguide to be easily adjusted while still maintaining the waveguide integrity. The resulting microwave frequencies are shown along with the system performance.</p>
11:00	<p>[286] TRANSPARENT CATHODE AS A NEW CHERENKOV OSCILLATOR <i>Presenter: SCHAMILOGLU, Edl</i></p> <p>The transparent cathode is a cathode in which separate longitudinal emitters are periodically placed about a fixed radius from the center [1]. Owing to the longitudinal current along each emitter there is a periodic azimuthal magnetic field in which electrons drift in an applied radial electric and longitudinal DC magnetic field. Thus, this cathode in a smooth-walled tube operates as an ubitron or free electron laser. In this device, with the transparent cathode placed in the center of a smooth-walled tube, slow eigenmodes exist. Therefore, synchronous interaction of electrons with slow eigenmodes, as in an M-type Cherenkov backward wave oscillator (BWO), is possible. In contrast with BWOs where the anode is the SWS and is where the electromagnetic (EM) fields are concentrated, in this device the EM fields are concentrated near the transparent cathode where electrons are emitted and drift around the cathode in crossed applied electrical and magnetic fields. Using computer simulations with the particle-in-cell (PIC) code MAGIC we demonstrate this new oscillator with high efficiency microwave generation. In this oscillator we use a transparent cathode comprising 8 emitters with length 2.5 cm, maximal radius 9 mm, minimal radius 6 mm, each with azimuthal width 30° and distance between emitters 15°, which are placed in a smooth-walled tube with radius 2.5 cm and length 9 cm. Preliminary results suggest that when an axial magnetic field of 7.5 kOe (over the cathode) and applied voltage 600 kV are applied, the output radiated power is 1.66 GW with 70% efficiency with output radiation frequency 5 GHz. Prospects for scaling this device to high frequency will be discussed.</p> <p>1. M.I. Fuks and E. Schamiloglu, "Rapid Start of Oscillations in a Magnetron with a Transparent Cathode," Phys. Rev. Lett., vol. 95, 205101-1-4 (2005).</p> <p>This research was supported by DARPA INVEST Grant #N66001-16-1-4042.</p>
11:15	<p>[115] DESIGN AND SIMULATION OF A RELATIVISTIC INVERTED MAGNETRON <i>Presenter: FLEMING, Timothy</i></p> <p>A high power inverted relativistic magnetron was designed and simulated using the massively parallel electromagnetic particle-in-cell code ICEPIC in conjunction with single particle smooth bore relativistic analysis. This Inverted Magnetron also known as the Inverted Magnetron Oscillator (IMO) has two design variations, the IMO-1 and the IMO-2. Both IMO models are designed to operate in L-band at very low magnetic fields ($B < 0.1$ T). Common to both designs is an axial RF power extraction structure. This structure consists of a conducting ring mounted to alternating vanes of the IMO slow wave structure. The IMO-2 employs two such rings. These rings achieve RF coupling to the downstream cylindrical waveguide where the TM₀₁ electromagnetic mode is excited. ICEPIC simulations predict that the above features combined with the IMO's stable, robust and reliable performance in the desired π mode over a large voltage range yield a class of high power microwave source notable for absence of downstream current loss as well as low confinement field performance. The IMO achieves high RF power output for input voltages ranging from 250 kV – 450 kV, a range that may be considered low voltage for an L-band relativistic magnetron.</p>
11:30	<p>[389] Refurbishment of the ORION System at NSWC Dahlgren <i>Presenter: KRILE, John</i></p> <p>Under the sponsorship of the Joint Non-Lethal Weapons Directorate (JNLWD), the Directed Energy Warfare Office (DEWO) at the Naval Surface Warfare Center (NSWC) Dahlgren Division has completed refurbishment of the Orion high-power radio-frequency (HPRF) system to support RF vulnerability testing. Orion is a flexible HPM source allowing for frequency agility from 1.07 GHz up to 3.3 GHz with output powers over 300MW across this operating band. The system provides repetition rates from single shot up to 100Hz with up to 1000 shots per burst, and is capable of variable pulse durations of 50 ns up to 500 ns. Orion is currently in operation at NSWC Dahlgren's outdoor test range and is proving a versatile resource for many HPM projects including vulnerability testing against vehicles, vessels and electronics. This brief will provide an overview of the refurbishment process, the system's capabilities, and future plans for this versatile asset.</p>

12:00	<p>[15] The wakefield excited by an ultra-short HPM pulse in an under dense plasma filled cylindrical waveguide <i>Presenter: LEOPOLD, J.G.</i> With the availability of very high power ($\sim 10^9$ W) and short duration ($\leq 10^{-9}$ s) microwave sources it is possible to study the non-linear interaction of powerful EM waves with under dense plasmas in a regime not studied so far. In contrast to the laser-plasma wakefield experiments, this approach addresses a significantly lower power, plasma density and electric field gradient regime but a larger time and space scale which allows for a more accessible experimental platform. We have built a super-radiant BWO, supplying microwave pulses of ~ 1 ns duration, ~ 0.7 GW power and ~ 10 GHz frequency which we intend to apply at the upstream end of a cylindrical waveguide filled with plasma of 10^{11}-10^{12} cm⁻³ density. We present a model which describes the physics of the formation of the wakefield traveling in the waveguide and Lsp-PIC simulations to verify the feasibility of our experiment.</p>
12:15	<p>[127] Experimental investigation of an L band all cavity axial extraction relativistic magnetron <i>Presenter: QIN, Fen</i> Abstract: Experimental results of an L band all cavity axial extraction relativistic magnetron (RM) working at 1.57 GHz is presented. In this 6-cavity RM configuration, the microwave from two adjacent cavities is coupled into an axially oriented coaxial sector waveguide through radial slots on the cavities. This configuration is more compact because only three sector waveguides are added outside the magnetron cavity without increasing the radial dimension significantly. Simulation results reveal that this tube could generate a microwave power of 700 MW at the frequency of 1.57 GHz, corresponding to a power conversion efficiency of 50 % when employing an electron beam of 350 kV and 4.0 kA. This tube is tested on a compact Marx generator which could generate a pulse power of about 2 GW. In experiment, this tube could generate a microwave power of over 500MW at 1.57 GHz when employing guiding magnetic field of 0.22T and input beam voltage of 345 kV and current of 4.8 kA, with a corresponding efficiency of about 30%. Experimental results reveal that this tube is a preferred configuration for a compact relativistic magnetron with relatively high power conversion efficiency.</p> <p>1. Dong Wang, Fen Qin, Yu-lin Yang, Yong Zhang, and Sha Xu, Design of L band all cavity axial extraction relativistic magnetron(in Chinese), HIGH POWER LASER AND PARTICLE BEAMS 28, 033013(2016). 2. Brad W. Hoff, Andrew D. Greenwood, Peter J. Mardahl, and Michael D. Haworth, All Cavi-ty-Magnetron Axial Extraction Technique, IEEE Trans. Plasma Sci., 40, 3046(2012).</p>

Poster session I - High Power Microwaves, RF Sources and Antennas - Hall 4 / Cambridge (13:30-15:00)

board

<p>[465] 4616V4 Tetrode and Klystron RF Resources for CSNS LINAC <i>Presenter: ZHOU, Wenzhong</i> At present, the infrastructure of China Spallation Neutron Source (CSNS) project is finished in Dongguan city, Guangdong province of south China. Now the system debugging is under way. CSNS accelerator consists of an H- linac and a proton rapid cycling synchrotron. The 324MHz RF linac is designed with beam energy of 81MeV and a peak current of 30mA, which mainly includes one RF Quadrupole (RFQ) accelerator and four Drift Tube Linac (DTL) accelerators. Each DTL accelerator is driven by a klystron RF source. The RFQ is driven by a 4616V4 tetrode RF source, which is used by the accelerator for the first time at 324MHz. Now, one of the four klystron RF sources has been operated stably over one year and the 4616V4 tetrode RF source has been operated steadily over two years for the beam debugging. In this paper, a description of R&D activities of the two types of RF source will be briefly presented.</p>	1
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<p>[451] Periodic Structures Manufactured by 3D Printing for Electron Beam Excitation of High Power Microwave Sources</p> <p><i>Presenter: CROSS, Adrian</i></p> <p>Periodic structures that reduce the velocity of electromagnetic wave propagation are widely used in electron beam driven high power microwave sources. When the frequency increases into the mm-wave region such structures become difficult to manufacture because of the small physical dimensions. "Additive Manufacturing" or "3D printing" offers the possibility of constructing certain types of components quickly, efficiently and relatively inexpensively [1]. Many questions arise however, including the structural resolution obtainable, the surface roughness, surface electrical resistivity and vacuum compatibility. To address some of these questions the performance of a periodic structure manufactured using a 3D printing technique and designed for W-band operation (75- 110GHz) is evaluated [2] and reported in the present work</p> <p>[1] I. Gibson, D. Rosen and B. Stucker, "Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing", 2nd Edition, (2015) Springer, New York, USA</p> <p>[2] A.R. Phipps, A.J. MacLachlan, C.W. Robertson, L. Zhang, I.V. Konoplev, A.W. Cross, A.D.R. Phelp, "Electron Beam Excitation of Coherent Sub-Terahertz Radiation in Periodic Structures Manufactured by 3D Printing", Nuclear Instruments and Methods in Physics Research B, accepted for publication 2017</p>	2
<p>[442] Laser induced plasma for HPM Compressor Switching</p> <p><i>Presenter: COHEN, Jacob</i></p> <p>A key parameter for the compressor operation is the switch performance, transferring from a storage (high Q) phase to release (low Q) phase. By initiation of plasma due to a gas discharge phenomenon it is possible to drastically change the boundary conditions and enable a fast phase transfer.</p> <p>In this work, we investigate the use of a high peak power laser pulse to generate seed electrons and initiate discharge. This mechanism, which utilizes multi-photon ionization in a strong RF environment, enables one to prevent the self breakdown (working slightly below the threshold) and yet to have a sub-ns buildup of seed electrons density followed by volume avalanche growth. This results in improved switching performance and greatly reduced time jitter.</p>	3
<p>[412] 35 kV Inductive Adder for Driving 50 Ω with Fast Rise Time</p> <p><i>Presenter: CARSCADDEN, John</i></p> <p>Eagle Harbor Technologies, Inc. (EHT) has developed a 35 kV pulser for driving 50 Ω loads with nanosecond-scale rise times. This inductive adder uses EHT's nanosecond pulser technology to drive nonlinear transmission lines (NLTL) to construct an all-solid-state RF plasma heating system for fusion science applications. The inductive adder configuration allows for independently adjustable control of the output voltage (20 kV), pulse width (20 – 200 ns), and pulse repetition frequency (up to 100 kHz). Previously, EHT has demonstrated 2 GHz RF production with a 20 kV version that can be pulsed 100 kHz. EHT will present results showing high voltage, fast rise time pulses into low impedance loads. In addition to RF generation, this inductive adder has applications to high voltage kickers for accelerations, plasma loads, high power modulators, and other tube-driving applications.</p>	4
<p>[399] Compact Marx Generator and High Power Microwave System</p> <p><i>Presenter: BARNETT, David</i></p> <p>K. Rainwater, D.H. Barnett, J. C. Dickens, A. Neuber and J. J. Mankowski Center for Pulsed Power and Power Electronics Dept. of Electrical and Computer Engineering Texas Tech University, Lubbock, TX, USA</p> <p>-----</p> <p>This paper presents the electrical and mechanical hardware considerations of a compact, 160 J modular pulse forming network (PFN) based Marx generator used to drive a high-power microwave (HPM) source with a time variant load at a PRF of 100 Hz. The modular Marx generator is designed to produce an open-circuit output voltage of 600 kV from a 50 kV capacitor charger using twelve stages. Each stage of the Marx is constructed from a PFN created with five, 2.1 nF, high voltage capacitors in parallel. Each Marx module was machined out of acetyl copolymer or Delrin to provide optimal strength, rigidity, and a dielectric constant that closely matches transformer oil. These Marx modules include air supply lines that are machined directly into each block of Delrin allowing airlines to connect to each module chamber rather than every spark gap. The spark gaps are comprised of two electrode inserts placed into the sealed pressure vessel contained within the Marx modules.</p> <p>After the Marx erects, the energy is delivered to the Virtual Cathode Oscillator where high power microwaves are created within a rectangular cavity resonator. The cavity resonator features several actuators and bellows to change the A-K gap distance, cavity height, and virtual cathode distance from the cavity back wall. The primary benefit of this design is that the vircator can operate in resonance conditions at multiple discrete frequencies. The entire system is controlled with a laptop based program. From this interface the user can control multiple settings including the aforementioned cavity conditions, repetition rate, charging voltage, and burst length.</p>	5

<p>[261] Results of an S-band Sheet Beam Klystron Development Effort</p> <p><i>Presenter: PERKINS, Michael</i></p> <p>Sheet beam klystrons have many advantages over traditional round beam klystrons that are desirable for a variety of applications. They can operate at a high efficiency and relatively low voltage by keeping the perveance per unit area of the electron beam low. This is achieved by spreading the beam out in one dimension which decreases the current density and power density. They can produce higher r.f. output power and operate at higher frequencies because of the decreased current density and decreased power density. Unfortunately, due to increasing the dimensions in one direction, the drift tube is often no longer cut-off and supports TE modes. The TE modes can interact with the electron beam in an undesirable way causing the well-known TE mode instability that has plagued previous sheet beam klystrons.</p> <p>A mitigation technique for the TE mode instability has been discovered and implemented in a 2.856 GHz sheet beam klystron. The tube was designed to operate nominally at 53 kV / 270 A to produce 6 MW peak / 6 kW average power of r.f. We will discuss various features of the design, some challenges overcome during the fabrication process, and test results.</p>	19
<p>[190] Experimental investigation of relativistic backward-wave oscillators operating in phase-induced regime</p> <p><i>Presenter: ROSTOV, Vladislav</i></p> <p>In the report we present new approach where radiation phase of Ka-band BWO is controlled by an external rf signal which is ultra-short. Thus, such excitation is not an amplification regime. Particle-in-cell simulation demonstrated that phase-induced BWO excitation is feasible for a seed power minimized to -38 dB with respect to the driven BWO.</p> <p>In experiments, two synchronized accelerators RADAN were used. We have a master source of a seed signal (superradiance BWO) and driven oscillators of two types. The first represents a similar, 0.5-GW superradiance oscillator. Alternatively, quasi-stationary, nanosecond-pulse BWO (>100 MW) was used. Driven HPM devices demonstrated phase-induced operation with a seed signal power minimized to -35 dB. Besides, phase-induced operation was confirmed when ~ 5 % frequency detuning between oscillators. Suggested method of phase control is less sensitive to the beam's front steepness and stability of the accelerating voltage. Thus, numerous parallel HPM generators could operate in coherent mode.</p> <p>This work was performed within the framework of budget projects (Nos. 0366-2014-0002, 0389-2014-0005, 5-17-2-47, 9P) and in part, by RFBR Grant No. 16-02-00029.</p>	13
<p>[63] High-Power RF Source for the Pulsed Fields Excitation in the Ground</p> <p><i>Presenter: TKACH, Yaroslav</i></p> <p>High-power electromagnetic fields and currents in the excitation and propagation in the ground is of a significant interest for numerous applied problems. A pulsed electromagnetic field source has been developed for the related purposes. The source is designed as a dipole (vibrator) antenna, excited by the high-current pulsed discharges.</p> <p>The usage of a dipole with a high input capacitance and a low input impedance is a distinctive feature of this source dipole antenna. The dipole antenna impedance being low improves antenna matching with the spark-gap, being the source of exciter signal. This approach is used to increase the source efficiency. The electromagnetic fields source length is 1.63 m while its diameter is 0.5 m. The source can operate either in single-burst or repetitive mode.</p> <p>The output source radiation parameters have been experimentally measured in the far field zone. The generated waveform is close to a sine-wave impulse with the central frequency of 60 MHz, E*R product of 450 kV and a peak pulsed power of greater than 2.5 GW with a burst length of 200 ns. Excellent coupling of this source signals through the soil has been shown experimentally.</p>	10

<p>[46] High Power Soliton Generation Using Hybrid Nonlinear Transmission lines</p> <p><i>Presenter: SILVA NETO, Lauro Paulo</i></p> <p>Nonlinear Transmission lines (NLTLS) have been studied for high power RF generation with good prospects of applications in pulsed radar systems, disruption of communications in battlefield, etc. Usually, NLTLS employ barium titanate (BT) ceramic-based capacitors or ferrite bead inductor as nonlinear elements, denominated as capacitive or inductive lines, respectively. On the other hand, a configuration that employs both nonlinear elements (LC), known as hybrid line, is an excellent method for exciting soliton oscillations more easily than inductive or capacitive lines. Other interesting aspect is that numerous publications on NLTLS with only one linear component [1] are easily found in the literature compared to just a few on hybrid [2]. In this work, a 30-section hybrid NLTLS built using both L & C of great nonlinearity (2.2 nF BT ceramic capacitors and 10 μH ferrite bead inductors) will be described. It will be shown that soliton generation packets have been obtained on the middle line section with a frequency of the order 33.0 MHz, peak power of 13.0 kW and voltage modulation depth (VMD) of around 700 V. Finally, it will be demonstrated that by using a proper design, hybrid lumped NLTLS may be suitable to achieve RF above 100 -200 MHz.</p> <p>[1] L.P. Silva Neto, J.O. Rossi, J.J. Barroso, "High power RF generation using nonlinear transmission lines using commercial ceramic capacitors as nonlinear elements, in Proc. 2015 IEEE Pulsed Power Conf., Austin, 2015, pp. 1-5.</p> <p>[2] N.S. Kuek, A.C. Liew, E. Schamiloglu, and J.O. Rossi, "RF pulse generator based on a nonlinear hybrid line" IEEE Trans. Plasma Sci., vol. 42, no. 10, pp. 3268-3273, Oct. 2014.</p> <p>*Work supported by SOARD/AFOSR under contract no. FA9550-14-1-0133.</p>	7
<p>[219] DEVELOPMENT AND TEST OF A COMPACT PFN MARX FOR 100 PPS REPETITIVE OPERATION AT 400 kV – 85 ns – 5 ns RISE TIME ON A 100 Ohm LOAD</p> <p><i>Presenter: TOURY, Martial</i></p> <p>A 400 kV - 85 ns PFN-Marx has been developed. Based on an innovative design [1], named the "zigzag design", the 16 stages of this generator, which delivers an open circuit output voltage of 720 kV, fit in a 650 mm length. For a slightly overmatched load ($Z_{load} = 100 \text{ Ohm}$), the output voltage reaches 400 kV with a rise time as less as 5ns. The inductance reduction associated to the innovative zigzag design, which allows this sharp rise time with no need for a peaking stage, is described. The 85 ns plateau duration of the pulse is given by the PFN construction of each stage, which is based on 6 ceramic capacitors (2.1 nF – 45 kV) connected within a strip line. The 16 PFN stages are housed in a 360 mm diameter gas pressurized vessel. Burst mode operation for a duration of 10 s at a pulse repetition frequency of 100 Hz is reported, for a resistive load and for the electron beam diode of a X-band relativistic BWO [2]. To reach further compactness, the BWO system is integrated on side of the generator vessel and a U shaped gas pressurized line connects both systems through a compact conical vacuum insulator.</p> <p>[1] This design is undergoing the patent request "Générateur d'impulsions de haute tension" number 15 52131, filed on the 16th of march 2015 at French's national institute for intellectual property INPI.</p> <p>[2] R. Vezinet, F. Lassalle, S. Tortel, J.C. Diot, A. Morell, A. Loyen, A. Catrain, Q. Saurin, A. Paupert; "Development of a Compact Narrow-band High Power Microwave System"; 2016 IEEE International Power Modulator and High Voltage Conference.</p> <p>This work is supported by the DGA (Direction Generale de l'Armement)</p>	16
<p>[51] Improved secondary windings for the Tesla transformer</p> <p><i>Presenter: SMITH, Ivor</i></p> <p>Following impulse excitation of the primary winding of a Tesla transformer, the secondary response contains a fundamental component plus higher-order mode. The paper will describe a winding technique that enables the higher-order modes to be suppressed, and so provide a transformer output with an improved spectral purity, that is better suited for use in many high-power applications than conventionally-wound transformers. Experimental results will demonstrate the benefits of the proposed technique.</p>	8
<p>[52] Magnetic Coupling in Tesla transformers</p> <p><i>Presenter: SMITH, Ivor</i></p> <p>The majority of publications dealing with Tesla transformers are confined to studies of their performance based on a familiar lumped equivalent circuit. This paper will differ from these in being concerned with the very important and practical issue of the coupling between the two transformer winding. It will consider the importance of the coupling factor for different practical applications and illustrate the different constructional features that may be involved.</p>	9

<p>[64] High-Current Test Stand for HPM Sources Testing Based on the Marx Generator</p> <p><i>Presenter: TKACH, Yaroslav</i></p> <p>Test stand complex for the testing of land and aerial based HPM sources is described. The stand utilizes low-inductance Marx generator operating in the repetitive burst regime with a rate 1-20 pulses/sec and total energy in pulse of 3kJ/pulse at 70Ω load. Marx generator produces pulses with the risetime of 10-12 ns, output voltage and current 250-650 kV and 10-55 kA, respectively.</p> <p>Marx generator utilizes low-inductance pulse capacitors, connected in pairs and installed in the common casing per pair. These capacitors are charged by two bi-polar capacitor charging supplies with 80kJ/s charging rate each. Marx generator stages are switched by low inductance high pressure spark-gaps with impulse gas purging. The spark-gaps are filled with \$N_2\$, \$SF_6\$ gases or their mix.</p> <p>The stand complex is controlled by the computerized system, which includes system of acquisition, storage and preliminary processing of operational data. The system utilizes proprietary software.</p>	11
<p>[67] Planar removable high voltage Vivaldi antenna</p> <p><i>Presenter: DIOT, Jean-Christophe</i></p> <p>The goal of this study is to design an Ultra-Wide Band (UWB) antenna for a High Power Microwaves (HPM) application. Classical antennas must be compatible with the bandwidth, the impedance of the system, and with the radiation characteristics (gain, directivity, and polarization). However, additional constraints such as high-voltage transient input signals have to be considered in the case of UWB HPM. A specific design has been established for this application considering a 100 kV peak bipolar signal. Furthermore, physical constraints have to be fulfilled as a high compactness (low thickness) is required in order to provide a good system packaging. The studied antenna has to be planar (2D) and its size must be lower than an A4 sheet of paper. A planar Vivaldi antenna design has been chosen as it's a travelling wave antenna allowing thus to limit the pulse dispersion and to reach a good directivity level. The antenna originality is related to its special high voltage feeding achieved through a THT20 coaxial connector. The THT20 connector is specifically designed in order to prevent electric disruptions, it has no balun and allows a fast and easy connection to the generator. This paper presents the design, the numerical simulation and a built antenna including high voltage parts. The measured parameters are compared to numerical simulations. Finally, experimentation with high voltage signal is showed.</p>	12
<p>[210] Phase control in a klystron-like relativistic backward wave oscillator operating at low guiding magnetic field with 10 kW input signal</p> <p><i>Presenter: XIAO, Renzhen</i></p> <p>Investigation of phase control in a klystron-like relativistic backward wave oscillator is presented in this paper. The guiding magnetic field, the distance between the input cavity and the pre-modulation cavity, the rise time of diode voltage, and the input signal frequency are optimized to decrease the phase jitter of output microwave. Particle-in-cell simulations show that when the diode voltage is 770 kV with rise time of 10 ns, the beam current is 8.8 kA, the guiding magnetic field is 0.75 T, and the input power is 10 kW, and the input signal frequency is 9.30 GHz, the output microwave power is 2.7 GW, and the phase jitter is controlled to be less than 30°, corresponding to a beam-wave conversion efficiency of 40% and an injection power ratio of -54.3 dB.</p>	14
<p>[211] An all circular waveguide four-way power combiner with ultra high power capacity and high combination efficiency</p> <p><i>Presenter: XIAO, Renzhen</i></p> <p>Abstract: The two-way power combiner consisting of two TM₀₁-TE₁₁ serpentine mode converters with a common output has demonstrated high power capacity and high combination efficiency for two phase-locked relativistic backward wave oscillators (RBWOs) [1]. To realize channel power combination for four phase-locked X-band RBWOs, we propose an all circular waveguide four-way power combiner based on the previous two-way power combiner. Four TM₀₁ modes are first combined into two TE₁₁ modes, then through two separate 90° bending waveguide and the radius enhanced transition waveguides, the two TE₁₁ modes is combined into one TE₁₁ mode. The transmission efficiencies of 90° bending waveguide and radius enhanced transition waveguides, and the combination efficiency of the two TE₁₁ modes into one TE₁₁ mode are larger than 99%. The maximum electric field is less than 750 kV/cm as the power in the common output port is 10 GW, and the total combination efficiency is more than 90%.</p> <p>[1] R. Z. Xiao, Y. Q. Deng, Y. Wang, Z. M. Song, J. W. Li, J. Sun, and C. H. Chen, Power combiner with high power capacity and high combination efficiency for two phase-locked relativistic backward wave oscillators. Appl. Phys. Lett. 107, 133502, 2015.</p>	15

<p>[258] EFFECTS OF PULSE SHAPES ON AXIAL VIRTUAL CATHODE OSCILLATOR</p> <p><i>Presenter: KIM, Se-Hoon</i></p> <p>Virtual cathode oscillator is a device that generates high power microwaves using oscillation of virtual cathode formed behind the anode. Virtual cathode oscillator has been studied due to its simple structure and tunability. Most virtual cathode oscillator system consists of prime power, pulsed power, microwave source, and antenna. In virtual cathode oscillator, pulsed power system produces high power pulses and shapes pulse waveforms. To build compact virtual cathode oscillator, it is required to analyze the influence of pulse forming, which possesses significant volume of the pulsed power system, on virtual cathode output. Marx generator and PFN-marx generator is used to analyze the influence of pulse shape on virtual cathode oscillator. Both input voltage is set to 300 kV. The time constant of marx generator is about 80 nsec and the pulse width of PFN-marx generator is about 80 nsec. When marx generator is used, the output power of virtual cathode oscillator is slightly lower than that of virtual cathode oscillator operated with PFN-marx generator. The difference of output power between two cases are not significant. Therefore, to achieve compact system, virtual cathode oscillator can operate without pulse forming.</p>	17
<p>[259] Analysis on Design Parameters of Plasma Limiter for Protecting against High Power Electromagnetic Pulse</p> <p><i>Presenter: CHO, Young-Maan</i></p> <p>The coupling path of high power electromagnetic (HPEM) to electronic devices is divided into following two ways, one is the Front-door coupling and the other is the Back-door coupling¹. The former is flow in an intended path such as antennas or sensors and the latter is inflow through an unintended path such as holes or cables. As HPEM pulse has higher power and it causes larger damage to electronic devices, it is necessary to research the protection method of RF systems affected by HPEM pulse in the front-end coupling path case.</p> <p>In this paper, the design parameters of the plasma limiter are analyzed for optimal design to protect against HPEM pulse. There are several limiters to reduce high power microwave power such as solid-state limiter and ferrite materials, etc². but the plasma limiter uses the discharge electrode in waveguide³. Therefore it is suitable to protect HPEM pulse before it reaches the RF front-end system. Despite the ability to defend high-power microwave, the plasma limiter has some problem such as its expensive cost and complicated process than semiconductor limiters, so the research for optimal design is essential. Using our analysis on design parameters of the plasma limiter, it is expected that to improve a protecting performance and to figure out the optimal design.</p>	18
<p>[263] A Test Stand used to Evaluate a Prototype S-band Sheet Beam Klystron</p> <p><i>Presenter: PERKINS, Michael</i></p> <p>A prototype S-band sheet beam klystron has been fabricated and tested. To enable testing of this one of a kind tube, a unique test stand was created that we will discuss in this presentation. The sheet beam klystron was designed to operate at 2.856 GHz and nominally produce 6 MW peak / 6 kW average r.f. power. A ScandiNova solid state modulator delivers the high voltage pulse to the potted electron gun which is designed to operate at 53 kV / 270 A. The electron beam is confined by an electromagnet which is wrapped directly on the tube body. For this prototype the electromagnet is composed of six individual windings that are powered by six different power supplies. This enables us to tune the magnetic field for maximum beam transmission. The cooling requirements of the test stand are provided by a ten ton chiller and dual manifold system. The two manifolds are needed to provide high pressure cooling to the modulator and r.f. loads as well as low pressure cooling to the electromagnet / klystron body, r.f. windows, and collector. Extreme care was taken to regulate the pressure on the klystron body. This was aided by various valves in the manifold design and by using two pumps from the chiller. Flow, pressure, and temperature sensors are used to monitor the coolant circuit. A control system was implemented to run the experiment which monitors and/or controls the modulator, filaments, solenoid power supplies, vacuum, electronically controlled valves, and coolant sensors. It can shut down the appropriate systems when a dangerous situation is detected and ensures various parameters are increased or decreased at safe rates. The control system also records various diagnostic signals needed to characterize the klystron performance.</p>	20
<p>[264] Multi-point Ignition Process in Methane-air Mixtures by Pulsed Microwave Power</p> <p><i>Presenter: LIU, Cheng</i></p> <p>Application of microwave plasma offers a potential method to produce faster combustion in internal combustion engine¹. In this paper, microwave multi-point ignition and spatial ignition had been confirmed via high-speed Schlieren imaging technique. The experiment was implemented with the microwave resonant ignition system and the Schlieren optical system. 2ms-3000W-2.45GHz pulsed microwave power was employed as the ignition energy source to produce initial flame kernel in the combustion chamber. The Schlieren imaging of reflected style was used to illustrate the flame development process with a high speed camera. A quartz glass coated with indium tin oxide (ITO), which ensured the sufficient microwave reflection characteristics and light transmission respectively², was used as the bottom of the microwave resonant chamber. Ignition experiments were conducted at high pressure of 2 bars of stoichiometric methane-air mixtures. It could be observed in Schlieren images that flame kernels were generated at more than one location simultaneously and flame propagated with different speeds in the combustion chamber. However, the number and the location of flame kernels seemed to be arbitrary.</p>	21

<p>[277] PARTICLE-IN-CELL CODE INVESTIGATION OF MAGNETIC FIELD EFFECT ON AXIAL VIRCATOR</p> <p><i>Presenter: CHUNG, Shen Shou Max</i></p> <p>Viricator can generate GW class microwave power and is the preferred device in certain military application due to its simple structure and lighter weight because no magnet is used. Previous investigation [1] leads to the conclusion that applying a magnetic field on vircator is going to decrease its output power, to the extent eventually a total cutoff. However, previous study was conducted analytically on a radially fired coaxial vircator with an axially directed magnetic field, the natural property of the magnetic field is to deflect the electron beam, and therefore the performance decrease is expected. On the other hand, magnetic field is used in many microwave tubes with electron beam parallel to the magnetic field and achieves beam confinement thus a more stable operation of the tube is obtained. In this article we investigate the effects of magnetic field on an axial vircator with a particle-in-cell code. We simulate with three scenarios: the externally applied magnetic field is larger, equal, or smaller than the beam current equivalent magnetic field, and observe its influence on the output power, spectrum, and particle dynamics.</p> <p>Ref: [1]. Peter A. Lindsay, Wee Kian Toh, and Xiaodong Chen, "The influence of an axial magnetic field on the performance of a coaxial vircator," IEEE Trans. on Plasma Sci., vol. 30, no. 3, June 2002.</p>	22
<p>[297] The Design Energy Saving Device for RF System at Taiwan Photon Source.</p> <p><i>Presenter: CHUNG, Fu-Tsai</i></p> <p>Taiwan Photon Source (TPS) is an accelerator particle ring. This facility provides with a high luminance and stabilize source in which electron beam is produced from linac via a booster ring to storage ring for user studies. After electron beam is stored in the ring, its power would lose due to the energy dissipation. A RF Cavity (Nb,5 Cells) in Booster Ring is used to compensate the lose power of the beam. A klystron is used to generate the needs for the RF system. It can provide the power up to 100kW (continuous wave).The driving requirements for a klystron are heater current, magnet current and accelerator current(6.5A) ,the cavity can build a gap voltage up to 900MV. This paper will discuss the saving power mechanism, if the system can be switched of during the injection time and shut-down for the rest of time period. This can dramatically reduce the power requirement for energy saving purpose.</p>	23
<p>[315] Emitter Residual Gas Effects in a High Power Microwave System</p> <p><i>Presenter: ÅBERG, Denny</i></p> <p>**This paper presents experimental results from a repetitive pulse HPM-system, consisting of a marx-generator driving a coaxial vircator under high vacuum. The experiments were performed at starting vacuum levels in the high-vacuum range at pressure levels of safe operation for the system. Data was monitored of the vircator voltages and currents from the driving pulse generator, the vacuum levels, and the emitted microwaves from the vircator. The pulse generator measurements were made with Pearson current probes and capacitive E-field and magnetic B-dot probes by R.E. Beverly III & Associates. Vacuum was monitored using MKS residual gas analyser and inverted magnetron vacuum gauges. The emitted microwaves were measured using two free field Prodyn sensors. The experiments show how residual gases from parts in the vacuum tube increase the vacuum to levels which deteriorate vircator performance during operation. Higher pressures reduce power and duration of the microwave pulses. Ongoing experiments will be presented in the paper which show how actions which reduce residual gas pressures improve vircator performance, and how the impedance of the load changes during operation.**</p>	24
<p>[345] Experimental Studies on Cathode Material Dependence of Microwave Power in Axially-Extracted Vircator with Resonance Cavity</p> <p><i>Presenter: TERAMAE, Motohiro</i></p> <p>High power microwave sources play a significant role in a variety of applications such as accelerators, basic physics, astronomy, high power radar, thermonuclear fusion, and various industrial applications. The virtual cathode oscillator (vircator) is one of the most promising high-power microwave sources among several types of pulsed high power microwave generators. The vircator is considered to be very attractive due to its conceptual simplicity, output power capability, and frequency tenability. However, the efficiency of converting an electron beam to microwave is still several percent and does not reach sufficient levels. Recent research efforts and experimental studies on vircators have been concentrated on the efficiency improvement and oscillation frequency control.</p> <p>High power microwaves generated in an axially extracted vircator have been studied experimentally in our laboratory. The vircator is driven by a Marx generator and pulse forming line (400 kV, 50 ns, 3 Ω). To improve the efficiency, we installed a resonator in vircator since the narrowing of the output microwave frequency leads to the improvement of the efficiency. The disc resonator with a center hole was placed at the distance x away from an anode with anode-cathode gap of 8 mm. The power of output microwaves were measured varying the distance x to analyze the resonator effect. In addition, the characteristics of high power microwaves depend sensitively on the electrode material and the anode-cathode (AK) gap distance. In this paper, We report the experimental studies on the output characteristics of high power microwaves from the axial vircator with resonance cavity for various anode-cathode (AK) gaps using different materials as a cathode material.</p>	25

<p>[381] Modification of Townsend Breakdown Theory for investigating the High-Power Microwave Propagation in the Atmosphere</p> <p><i>Presenter: QIAN, Bao-Liang</i></p> <p>The Townsend breakdown theory is generally applicable in the case in which a DC voltage is applied to a gap filled with gases. The result of Townsend breakdown theory is generally not applicable directly in the case in which a high-power microwave propagates in the atmosphere. In this paper, we develop a theoretical model to describe the breakdown of high-power microwave propagation in the atmosphere, which is a modification of the Townsend breakdown theory. The result of the new model shows that there is a minimum air pressure at which the breakdown threshold reaches the minimum value when the high-power microwave propagates in the atmosphere under certain conditions. The result of the present paper is of importance to the high-power microwave area and may be to the investigation of RF breakdowns in gases.</p>	27
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Poster session I - Pulsed Power Physics and Technology, Components and HV Insulation - Hall 4 / Cambridge

(13:30-15:00)

board

<p>[17] A Novel Technique for Fault and Lifetime Self-Diagnosis of Closed Transition Transfer Switch using Dual Lines</p> <p><i>Presenter: HEO, Sewan</i></p> <p>This paper proposes a dual-line closed transition transfer switch (CTTS) and a technique for fault and lifetime self-diagnosis. The proposed system consists of the dual-line CTTS, a closed transition operator, active and inactive channel inspectors that extract the switch characteristics, and a self-diagnosis block for fault and lifetime of the switch using the characteristics. The system controller coordinates the inspection and diagnosis based on a schedule.</p> <p>The proposed dual-line CTTS has an active channel connecting one input and output, and an inactive channel which has no connection. There are parallel main and sub switches in each phase and they constitute the dual lines, which can be used selectively. The switch characteristics in the active channel are obtained by detecting current variation in each line because the current flows in the channel. Whereas, those in the inactive channel are obtained by detecting voltage variation in each line because there is no current flow.</p> <p>The inspection procedure of the active channel is as follows. The two switches in each dual-line phase are turned on or off according to the defined sequence. At this time, the inspection does not affect the fundamental operation of the CTTS because at least one switch should maintain the connection. The current signals of the two lines may change according to the combination of the switch condition. Thus, the health information of the switches such as the operation speed and current division level between the two lines is obtained from the current signals. However, it is difficult to detect the current variation effectively because the current signal is AC type. For this reason, the current signal is transformed to the useful DC type signal by the axis transformation with the phase information. It was verified that the current variation was detected so fast and precisely with this method.</p> <p>Meanwhile, the inspection procedure of the inactive channel is as follows. Because every phases in the channel share the output with the active channel, the voltage of any phase in the active channel can be transferred to the inactive channel when the corresponding switch turns on. The operation speed characteristics are obtained by detecting the voltage variation. At this time, the cross voltage sensing method is used, which measures phase voltages of the inactive channel based on the neutral line voltage of not the inactive channel but the active channel. Similarly, the voltage signal is also transformed to the useful DC type.</p> <p>The closed transition operator consists of two synchronous reference frame phase-locked loops (PLL) finding the phase of each channel, a synchronization detector, and a switch sub-controller. The phase information of each channel is obtained by the PLLs based on the Clarke and Park transformation. The two phases are considered to be synchronous when the difference is less than 5 degrees. By the transition command, the CTTS changes the input source at the synchronized point through one or two cycles of overlap period.</p> <p>The proposed dual-line CTTS and self-diagnosis were verified by the PSIM simulator. The closed transition was successful although the frequencies of the two sources were different. The current and voltage were transformed to the DC type signals precisely during the inspection. Consequently, the signal variation was detected fast so the switch characteristics and even fault problem were detected fast as well. Therefore, the self-diagnosis was verified to be effective during the operation of the CTTS.</p>	28
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<p>[19] Multi-Pulse Nanosecond Electrical Breakdown in Perfluorinated Liquids at 140 kV</p> <p><i>Presenter: PUNANOV, Ivan</i></p> <p>Perfluorinated liquids are attractive for use in high-voltage devices because of their chemical stability under electrical discharges. For applications like liquid spark gaps, the breakdown velocity is an important parameter. In this work, we present the results of measurements of the anode-initiated electrical breakdown velocity at 140 kV in perfluorinated liquids of several chemical classes. The experimental setup [1] comprised of a nanosecond generator, breakdown cell, and digital oscilloscope. The generator impedance is 50 Ω, with a stored energy of 0.8 J and voltage under no-load of 140 kV. The pulse duration is 8 ns under load-matched conditions, and the rise time is less than 0.5 ns. We used a point-to-plane configuration of electrodes with positive point. We show that perfluorinated esters have close values of breakdown velocity over a wide range of gaps, and demonstrate relatively low jitter in gaps for which time to breakdown (up to 30 ns) is comparable to pulse duration. Measured breakdown velocities in these liquids are $5 \cdot 10^6 - 1.3 \cdot 10^7$ cm/s for gaps up to 2 mm, which is 3–8 times higher than in transformer oil under the same conditions [2]. The differential velocity of breakdown front propagation for all tested liquids substantially decreases in gaps wider than 1.5–2 mm, and is about $(2-3) \cdot 10^6$ cm/s. The time to breakdown in wider gaps grows linearly up to 6 mm. As soon as the differential velocity of breakdown remains nearly constant for a wide gap range, it can be considered as an electrophysical characteristic of the dielectric liquid under these pulsed conditions.</p> <p>[1] Punanov, I.F., Emlin, R.V., Kulikov, V.D. et al. Tech. Phys. (2014) 59: 503. DOI:10.1134/S1063784214040197</p> <p>[2] Punanov, I.F., Emlin, R.V., Morozov, P.A. et al. Russ Phys J (2012) 55: 191. DOI:10.1007/s11182-012-9794-5</p>	29
<p>[37] SOLID STATE LASER TRIGGERING SYSTEM FOR THE HERMES-III ACCELERATOR</p> <p><i>Presenter: GRABOWSKI, Chris</i></p> <p>The Hermes III accelerator at Sandia National Laboratories is a 20 cavity multi-stage linear induction voltage accelerator typically producing a 20-MV, 20-ns, 600-kA output pulse. Energy is initially stored in Marx banks that are each discharged into two intermediate store capacitors. Each of these capacitors are then switched with an SF6-insulated high voltage rim-fire gas switch into four pulse forming lines that further condition the pulse before finally delivering it to the induction cavities arrayed along the axis of the machine. Presently, a single 0.9-J KrF laser operating at 248 nm, the output of which is divided into twenty beams, is used to trigger the 20 rim-fire switches. As part of an upgrade to the accelerator, however, a new solid state laser triggering system is being designed to replace this system and provide additional capabilities for the accelerator. The laser triggering system will be made up of 10 discrete compact flash-lamp pumped, Q-switched Nd:YAG lasers (Tempest 300), each having an output energy of 40 mJ at a wavelength of 244 nm. As each laser will be responsible for triggering only two of the rim-fire switches, it becomes possible to shape the output pulse by varying the times at which the individual lasers fire. Overall reliability for the accelerator's operation with these new lasers will be increased, as well. The overall layout of this new laser triggering system design will be presented, and details pertaining to the triggering of the lasers and the optical beam paths will be shown.</p>	30
<p>[55] Development of a coaxial switched oscillator</p> <p><i>Presenter: NOVAC, Bucur</i></p> <p>A pulsed power system based on a coaxial switched oscillator was built and tested. The switched oscillator is charged to over 100 kV either by a Marx generator or a PZT-based autonomous power supply. When coupled to a helical antenna, the system generates electromagnetic radiation with a frequency bandwidth centred on 500 MHz.</p>	31
<p>[56] Techniques to generate high-voltage oscillations using a single-shot power supply</p> <p><i>Presenter: NOVAC, Bucur</i></p> <p>Two pulsed power arrangements have been designed and tested, both based on a circuit containing an air-core pulsed transformer and a miniature explosively-driven flux-compression generator. The power supply in both cases is provided either by a conventional HV charger or by a PZT autonomous power supply. For both pulsed power arrangements, output voltage oscillations with a peak close to 100 kV have been generated from single-shot tests.</p>	32

<p>[72] NEW EMBEDDED NANOSECOND PULSE GENERATOR BASED ON SPARK GAP AND IGBT</p> <p><i>Presenter: ACHOUR, Yahia</i></p> <p>A new architecture of high voltage pulse generator has been proposed. It is based on combining two types of switches' technologies, namely IGBT used as opening switch and spark gap used as closing one, and two types of energy storage, Inductive and capacitive, in order to get a compromise with a better performances dedicated especially for embedded applications.</p> <p>This new architecture has several advantages such as a simple architecture and driving system, high and stable repetition rate which can reach some kilo-Hertz, a very sort rising time of few nanoseconds, a very high gain and efficiency. The generator doesn't need a high voltage supply (i.e. Marx generator) just a tens of volts input suffices to produce a high voltage pulse of some kilo-volts that's why this architecture is adequate for embedded applications.</p> <p>A Matlab simulation has been implemented to check the functioning principal. A prototype generator has been built and tested in the high voltage laboratory, which belongs to the Faculty of Electrical Engineering Warsaw University of Technology. The obtained results confirm the theory behind it.</p> <p>Basically, the generator consists of an inductor, an IGBT, a diode, a capacitor, a spark gap and a load. In the first phase, the power flows from the input supply (batteries) to the inductor throw the closed IGBT, and then we open the IGBT, the current changes the path and flows throw the capacitor and makes it charging. When the voltage across the capacitor surpasses the breakdown value of the spark gap, a very short pulse occurs across the load. After the discharge of the capacitor and the end of the spark, the system enters in a waiting phase until the next closing of the IGBT.</p>	55
<p>[76] Dielectric Breakdown of Vaporized Organic Carbonates</p> <p><i>Presenter: WETZ, David</i></p> <p>Lithium-ion batteries are being more widely utilized as the prime power source of rep-rate pulsed power systems. Battery open circuit potentials as high as 1 kV have been proposed for use in naval shipboard power architectures. While this potential may not seem that high to engineers within the pulsed power and/or high-voltage power system communities, it is significant and must be designed with caution, especially when field enhancements are present that could significantly multiply the applied electric field. The amount of energy stored in a shipboard battery could exceed a few GJ in some instances making it critical that any potential electrical breakdown weaknesses be identified and studied in detail. Though it is likely easy to engineer the battery such that dielectric clearances well exceed any 1 kV potential in a normal operating conditions, it is unclear how failure of a cell, and the leakage of electrolyte gas from a sealed cell(s), may affect the surrounding environment and the dielectric strength between high voltage electrodes separated by air. Reduction in the dielectric strength could result in a cascading effect whereby more cells are allowed to fail. The dielectric strength of vented electrolyte gas has not been previously documented and it is the aim of this work to fill this knowledge gap.</p>	54
<p>[215] The Influence of Epoxy Encapsulation on the Lifetime of High Voltage Ceramic Capacitors</p> <p><i>Presenter: HAN, Ruoyu</i></p> <p>The lifetime of high voltage ceramic capacitors (HVCC) are always shorted because of suffering from circularly electrical, thermal and mechanical stresses, electric field concentrations and high current density. The reasons shall be analyzed and measures should be taken to prolong the lifetime of HVCC.</p> <p>In this paper, a repetitive frequency testing platform was setup to study the influence of thickness and toughness of epoxy encapsulation on lifetime of HVCC under repetitive pulses. The results showed that the samples whose thickness of epoxy encapsulation is 8.5mm own far more lifetime than the ones whose thickness are 13.5mm and 6mm under 25Hz repetitive pulses. What's more, the samples with the epoxy encapsulation toughened by agent EHTPB have the lower deterioration rate of parameters such as capacitance, dielectric loss and insulation resistance.</p> <p>Most of samples failed at the interface between ceramic and epoxy encapsulation. Besides the reason of concentrated electric field at the edge of electrodes, HVCC bear the circularly impact pressure and tensile stress during the repetitive charge and discharge process, resulting in mechanical fatigues at the interface between ceramic and epoxy encapsulation. Therefore, appropriate thickness and toughness of epoxy encapsulation could deterrent the mechanical fatigue at the interface and prolong the lifetime of HVCC.</p>	39

<p>[240] HIGH CURRENT SENSING THROUGH FARADAY ROTATION OF POLARIZED LIGHT OF VARYING WAVELENGTHS IN FIBERS</p> <p><i>Presenter: COFFEY, Sean</i></p> <p>Traditionally, large-amplitude, fast-rising currents and magnetic fields has been measured with electro-magnetic probes such as Rogowski coils or B-dot probes. Such probes are observed to work satisfactorily for many experimental configurations but the probe to digitizer signal is affected by cabling and cabling elements. Measurements must frequently be made in the presence of significant electromagnetic interference imposing unacceptable levels of noise on the probe signals. Furthermore, probe measurements on high voltage electrodes may be problematic if the probes are not sufficiently isolated. An alternative method for measuring currents and magnetic fields involves using the Faraday effect on linearly polarized light propagating in single mode fibers.</p> <p>Probes utilizing the Faraday effect have been used for many years. Their operation, whereby the magnetic field strength is proportional to the number of probe output "fringes", is relatively immune to signal cable attenuation losses. Fibers are dielectrics and their electrical insulation reduces breakdown problems near high voltage electrodes. The probe calibration is a material property so in-situ calibrations are unnecessary. Previously, the Faraday probe setup required an optical engineer to assemble and align the numerous discreet optical elements (i.e. beam expander, splitter, polarizers and focusing optics). This was time consuming work requiring realignment whenever the assembly was moved. Due to tele-communication advancements, a robust compact Faraday effect optical assembly with fixed alignments is now available at low cost. Also due to these advancements, measurements at many different wavelengths are now possible. Theory predicts the Faraday probe sensitivity is inversely proportional to laser wavelength, thus probes of varying sensitivities can be constructed. This paper details four Faraday probes optimized for wavelengths of 450 nm, 532 nm, 632 nm & 850 nm and includes probe calibration efforts.</p>	36
<p>[246] Field-Distortion Air-Insulated Switches for Next-Generation Pulsed-Power Accelerators</p> <p><i>Presenter: WISHER, Matthew</i></p> <p>We have developed two advanced designs of a field-distortion air-insulated spark-gap switch that reduce the size of a linear-transformer-driver (LTD) brick. Both designs operate at 200 kV and a peak current of ~50 kA. At these parameters, both achieve a jitter of less than 2 ns and a prefire rate of ~0.1% over 5000 shots. We have reduced the number of switch parts and assembly steps, which has resulted in a more uniform, design-driven assembly process. We will characterize the performance of tungsten-copper and graphite electrodes, and two different electrode geometries. The new switch designs will substantially improve the electrical and operational performance of next-generation pulsed-power accelerators.</p>	33
<p>[245] Benchmarking Multi-Fluid Plasma Electromagnetic Models for Pulsed Power Applications</p> <p><i>Presenter: BECKWITH, Kris</i></p> <p>The dynamical behavior of plasmas is strongly dependent on frequency. At the lowest frequency the plasma is in the regime of magnetohydrodynamics (MHD) and has been the focus of extensive research in fluid plasma modeling in the past few decades. At somewhat higher frequencies, the electrons and ions can move relative to each other, behaving like two charge separated, interpenetrating fluids. This is the regime of high-frequency, non-neutral two-fluid physics and is relevant to high-density, fast MHD phenomena encountered in pulsed-power devices like dense plasma focus, Z-pinches and field-reversed configurations. Here we present fully implicit schemes for solving the two fluid equations based on a combination of physics-based preconditioning and Jacobian-Free Newton Krylov solvers. We apply this approach to a range of problems, including shock physics, ambipolar expansion and shear flow. Results obtained from our approach will be compared to analytic theory and, where appropriate, magnetohydrodynamic and kinetic simulations.</p>	34
<p>[243] The evolution of the plasma in triggered vacuum switch</p> <p><i>Presenter: WUNG HOA, Park</i></p> <p>A triggered vacuum switch (TVS) was designed with a flat electrode at the beginning and developed to a multi-gap electrode which reduces heavy electrode erosion. Recently the demands of the TVS is increased, as the high power system is extended in the various fields. It invokes the improvement of the performance for a TVS, therefore, a fast camera experiment is suggested to research the fundamental discharge processes of the TVS. This research is a base of understanding the characteristics of the TVS. The fast camera is capable of 2ns exposure time. It measures for three discharging phases from trigger breakdown to main discharge. The camera images show the characteristics of trigger discharge, the diffusion of the plasma, characteristics of main discharge, and delay.</p>	35

<p>[239] Electrical Treeing Phenomenon under Rippled Fields in HVDC Cable Insulation</p> <p><i>Presenter: AZIZIAN FARD, M.</i></p> <p>Power cables are exposed to various stresses in their service lifetime due to loading and transient effects that appear in the system. These stresses degrade the insulation in the long term and can even result in premature failure depending on the severity of the deterioration. Electrical treeing is closely related with partial discharge (PD) and in some stages of its growth it can be monitored through PD measurement. Regarding the treeing phenomena under pure sinusoidal high voltage alternating current (HVAC) voltages and harmonic AC waveforms well established research work has been conducted and the knowledge is in mature stage. Harmonics have been reported to have undesirable effects both on insulation integrity and on the diagnostic process. However, less has been devoted under the condition of distorted or rippled high voltage direct current (HVDC) voltages. In this paper, artificial test samples of polymeric material have been developed in which the needle electrodes are embedded in polymeric insulation slabs in order to artificially initiate tree phenomenon. DC voltages superimposed with harmonic components that commonly appear on the output terminals of HVDC converters were simulated using a high voltage amplifier in the laboratory, and applied to the test samples and the growth of the developing trees recorded at different stages by digital microscope and also the corresponding PD pulses were acquired simultaneously using a wide-band HFCT sensor and high bandwidth sampling hardware. Results show that the superimposed abrupt waveforms result in rapid initiation and growth of treeing process in the samples with respect to pure DC waveform. Since treeing is one of the primary causes of failure in polymeric insulation, correlation of its features with simultaneously acquired PD data will have key implications for HVDC network operators, facilitating on-line monitoring and assessment of cable degradation and allowing preventative maintenance.</p>	37
<p>[234] Reconfigurable High Voltage Load for Pulsed Power Applications</p> <p><i>Presenter: KIM, Matthew</i></p> <p>Abstract- The evaluation of pulsed power systems and their constituent components requires unconventional loads with exceptional voltage, current, impulse energy, and continuous power dissipation capability. This paper presents the design and construction of a reconfigurable resistive load with active temperature monitoring for the evaluation of ultra-high voltage pulsed power modulators and semiconductor devices. The load consists of a network of 15 ceramic resistors (outer diameter of 2.54 cm and length of 30.48 cm) mounted vertically in an oil filled aluminum tank. To enable exceptionally high power dissipation, the oil is pumped through the tank and through a radiator. A microcontroller based module activates a fan on the radiator if a preset oil temperature is surpassed. Experimental results gathered demonstrate that the load withstood 1.5 kW at 12 kV for two hours, and that the temperature of the oil reached only 40 °C without activation of the radiator fan. Based on radiator efficiency calculations, the load is expected to be able to withstand 10 kW of continuous power dissipation.</p>	38
<p>[205] A NEW EQUIVALENT CIRCUIT OF HIGH-VOLTAGE PULSE TRANSFORMER AND AN ACCURATE METHOD TO MEASURE IT'S PARAMETERS</p> <p><i>Presenter: LIU, Xian</i></p> <p>This paper presents a new type of equivalent circuit of a high-voltage pulse transformer and an accurate method to measure it's parameters. The new equivalent circuit is obtained from the impedance characteristic curves when the primary and secondary coils are in different states (open circuit or short circuit). In the new equivalent circuit, the distributed capacitance between primary and secondary coils is equivalent to three capacitances, instead of a concentrated capacitance in the IEEE standard equivalent circuit. The parameters in the equivalent circuit are calculated by some equations which are deduced from resonance points when the primary and secondary coils are in some different states. Simulation and experimental results of impedance characteristic curves and the output waveform of the pulse transformer meets well, which confirm the accuracy of the equivalent circuit and the measuring method of it's parameters.</p>	40
<p>[193] The performance of a prototype sealed-off triggered vacuum switch</p> <p><i>Presenter: LEE, Byung-Joon</i></p> <p>A triggered vacuum switch (TVS) is widely used as a closing switch in the field of high pulsed power systems. A designed final sealed-off TVS is aimed to operate at maximum voltage of 20 kV with maximum current of 150 kA, a lifetime more than 1000 shots. Before we reach the final goals, a sealed-off prototype with Cu electrodes is fabricated to recognize a full producing process. This prototype is electrically tested in the 300 kJ test system. The preliminary tested results shows the prototype is operated at voltage of 17 kV with current of 84 kA for more than 100 shots. The maximum current is reached at 120 kA with a hold-off voltage of 20 kV. In the outlook, we will perform further experiments with the prototype TVS to get better understand and performance. After that we will use CuCr electrode instead of Cu one including upgraded triggering system in order to achieve the final goals.</p>	41

<p>[189] Design of Trigger System for Large LTD Facility</p> <p><i>Presenter: LIANGJI, Zhou</i></p> <p>High current facilities have been used for a wide variety of HEDP experiments, such as fusion energy, radiation-physics, equation-of-state, plasma-physics and astrophysics etc. Linear transformer driver (LTD) is a new technical approach that can deliver fast high current and high voltage pulses with very compact devices. One of the most difficult technical problems encountered in building large LTD facilities is that there so many switches to trigger. So the trigger system is critical. This paper presents a new technical scheme for large trigger system that based on two kinds of trigger unit(fore stage-trigger-unit and post-stage-trigger-unit). Two kinds of trigger units based on the same pulse forming scheme, in which many ceramic capacitors form a compact coaxial structure that can minimize inductance and output fast pulse. The fore-stage-trigger-unit using a laser triggered gas switch while the post-stage-trigger-unit using a electric triggered gas switch. detailed design and preliminary experimental results are presented.</p>	42
<p>[171] Combined Experimental and Theoretical Study of Barium Titanate Nanoparticles: Improving Fundamental Understanding of Pulsed Power Component Materials</p> <p><i>Presenter: VAN GINHOVEN, Renee</i></p> <p>To further the goal of optimized material design for pulsed power components, we aim to achieve a fundamental understanding of the model non linear dielectric material BaTiO₃, through concurrent experimental and theoretical study. This effort is intended to lead to improved synthesis and design control, and a validated model to enable material predictions difficult to obtain in controlled experiments. The ultimate goal is to improve packing factor and discharge characteristics through design models for capacitors that translate results from the molecular level to macroscopic device level, and incorporate virtual material design models where appropriate.</p> <p>BaTiO₃ particles were created using an alkoxide-hydroxide synthesis in water-ethanol solution. Subsets of the particles were functionalized with octadecylphosphonic acid (ODPA) through addition of ODPA to the suspension. The functionalized particles are characterized with several methods. The species bound to the particles are identified using FT-IR spectroscopy. We also expect to gain insight into ligand-nanoparticle surface interactions using FT-IR. Thermogravimetric analysis (TGA) is used to determine the ligand load in a particular sample and back out particle surface coverage.</p> <p>In addition, the bonding and arrangement of selected ligands and molecules adsorbed on the surfaces BaTiO₃ nanoparticles and thin films is examined theoretically, using density functional theory (DFT). Bond strengths and reaction mechanisms are examined in detail. These results are compared to and combined with experimental data to derive insight into surface characteristics of this material.</p> <p>Finally, the challenges inherent in characterization and simulation of a reacted composite bulk material are discussed.</p>	43
<p>[159] Modeling Bipolar Marx Generators for Maximum Pulse Repetition Rate Estimation</p> <p><i>Presenter: CANACSINH, Hiren</i></p> <p>This paper presents the n stage dynamic model generalization for bipolar Marx Generators, during the capacitors charging mode, to estimate the generator pulse repetition rate.</p> <p>Bipolar Marx Generators are based in modular solid-state switching stages. Their operating principle can be reduced to two operating modes; Mode-I - Capacitors charging and Mode-II – Output pulse forming. In mode I, n capacitors are charged, roughly in parallel, from a dc power supply, U_{dc}. In mode II the n stage capacitors are switched in series across the load. Using nowadays solid-state switching stages [1][2] it is possible to obtain positive and/or negative voltages pulses with higher frequencies in comparison with classic hard-tube switching. Nevertheless, as the number of stages increases the operating frequency is limited by internal parasitic impedances.</p> <p>This study presents the synthesis of state space model of the Marx Generator equivalent circuit for n stages operating during capacitors charging (Mode 1).</p> <p>The equivalent circuit consists of n stages connected in cascade, where each stage is an RC circuit in which the resistance R represents the impedances of the semiconductors and conductors in each stage.</p> <p>The model enables the evaluation of the charging time of the n stage capacitors. Then, the maximum pulse repetition rate for the n stage Marx Generator can be calculated as a function of the number of stages, and the voltage decay allowed for the capacitors (usually less than 10%). Given a needed pulse repetition rate the model can suggest the optimum number of stages (n) so that the working voltage of each stage can be selected.</p> <p>[1] L Rocha, J Silva, LMS Redondo, "Seven Levels Unipolar/Bipolar Pulsed Power Generator", IEEE-TPS, 2060-2064, 2016;</p> <p>[2] H Canacsinh, JF Silva, B Borges, "Voltage droop compensation based on resonant circuit for generalized high voltage solid state Marx modulator", IEEE-APEC, 3637-3640, 2016.</p>	44

<p>[158] CONTAMINATION PERFORMANCE OF HIGH VOLTAGE OUTDOOR INSULATORS IN HARSH MARINE POLLUTION ENVIRONMENT</p> <p><i>Presenter: HUSSAIN, Muhammad Majid</i></p> <p>This paper describes the results of an experimental investigation carried out to compare the contamination performance and surface degradation of outdoor insulators made from different polymeric materials. The tested insulators included silicone rubber (SR), ethylene propylene diene monomer (EPDM) and high-density polyethylene (HPDE), which were used for reference. To replicate typical harsh marine pollution environments, a modified solid layer contamination deposition method was used in the experimental work. This method represented conditions similar to those installed near shorelines exposed to saline and acid spray during winter and early spring. Tests were carried out in acidic and normal cold fog. The physico-chemical changes and electrical parameters were measured during the test to characterize the performance of each insulator. The analysis showed that the electrical performance of the insulators was significantly affected by the combined application of saline contamination and acidic cold fog. However, during clean cold fog application, the insulator material showed localized surface degradation while there was no evidence of serious dents and cracks. Saline contamination with normal cold fog generated a reduction of flashover voltage equal to 40%. This reduction was more pronounced in acidic fog conditions – 85%. The scanning electron microscopy (SEM) and hydrophobicity results showed that surface degradation is more strongly correlated with acidic cold fog contents than those of normal cold fog. It was found that SR insulators perform better than EPDM and HPDE in harsh environments.</p>	45
<p>[140] Multi-physical Fields Simulation and Structural Design for Energy Storage Coils with Brooks-type geometry</p> <p><i>Presenter: MA, Shangang</i></p> <p>The most prominent advantage of Brooks-type coil is that it can obtain the highest energy storage density and the resistance of per unit inductance coil is smaller. However, the biggest problem of the Brooks-type coil is that there is a very large fringe field around it. For preventing electromagnetic radiation interference, it is necessary to consider the safety distance between the coil and the switch elements and their control circuits when constructing the whole energy storage system. In addition, the current-carrying inductance coil in the magnetic field will be subjected by the electromagnetic force. Solving the problems of energy storage density, electromagnetic interference and electromagnetic vibration effectively is one of the key technical problems of inductive energy storage system research. Based on the coils with Brooks-type geometry, this paper firstly constructs the multi-physical fields simulation environment of the coil by using ANSYS software. And then analyzes the mutual influence among the energy storage density, electromagnetic force and electromagnetic interference by conducting simulation analysis of electromagnetic field - force field for the coil. At last, the optimized calculation of the coil structure is carried out. In order to design a coil structure with better comprehensive performance, the appropriate electromagnetic force and the lower limit of electromagnetic interference are determined as the constraint of the optimization problem. The coil turns, turns width, outer diameter and other structural parameters are taken as variables. And the optimization goal is obtaining the maximum energy storage density. The work in this paper offers important theory analysis and testing foundation for investigating the inductive pulsed-power supply with higher energies.</p> <p>Key words—Inductive storage, Brooks, Energy storage density, Electromagnetic interference, Electromagnetic vibration, Structural design</p>	46
<p>[114] Correlating Cygnus Diagnostics to Machine Reliability</p> <p><i>Presenter: MEEHAN, Bernard</i></p> <p>The Dual Beam Radiographic Facility (aka Cygnus) has been operating successfully for over 10 years providing invaluable data for our nation's stockpile mission. However successful, there have been some failures that may have been predicted, hence eradicated, during an uninterrupted operation phase. This report describes a statistical method to incorporate existing machine diagnostics, such as B-dots and D-dots, located at various positions throughout the pulsed power delivery chain to predict degraded performance and expose dormant failure modes. A basic graphical user interface (GUI) tool, which performs and displays the statistical computations and results, will also be described herein. The ability to leverage machine diagnostics, statistical inference, and historic data will prove invaluable to Cygnus operation and provide a foundation for predictive maintenance for other pulsed power facilities.</p> <p>*This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy.</p>	47

<p>[113] Skin effect and magnetization of strap toroid magnetic core of pulse transformer <i>Presenter: FRIDMAN, Boris</i></p> <p>The object of the study is a pulse transformer with a toroidal magnetic core wound by a transformer steel strap operating under short voltage pulses, at which the magnetic field has no time to steady in the core material. The pulse magnetic field diffusion in the steel strap of the core was analyzed using a 1-D model of dynamic losses, covering the effects of hysteretic and excess losses [1]. The dependence of excess losses in the core material on magnetic induction was measured in no-load experiments carried out while applying the rectangular voltage pulses to the transformer winding. The magnetic field diffusion in the strap was calculated at energization of the transformer winding from a constant voltage source. The oscillograms of current in the no-load experiments have verified the calculation results.</p> <p>[1] M.J. Hofmann and H-G. Herzog. Modeling Magnetic Power Losses in Electrical Steel Sheets in Respect of Arbitrary Alternating Induction Waveforms: Theoretical Considerations and Model Synthesis. IEEE Transactions on Magnetics., vol. 51, No. 2, February 2015, 6300211.</p>	48
<p>[111] DEVELOPMENT AND TESTING OF A 200kA, 10/350µs LIGHTNING IMPULSE CURRENT GENERATOR SWITCH MODULE <i>Presenter: KOUTSOUBIS, John</i></p> <p>A switch module assembly utilizing a power crowbar circuit and high-pressure plasma closing switch technology has been designed, constructed and tested. The switch module is the central block of a lightning impulse current generator under development, capable of producing a 10/350µs waveform at a peak magnitude in excess of 200kA ($W/R = 10MJ/\Omega$). The circuit consists of two separately charged capacitor banks, a fast start bank and a slow sustain bank responsible for the generation of the pulse wave-front and wave-tail respectively. These are switched in sequence to the load by means of two electrically triggered, graphite electrode high-action integral spark gap switches. The switch module assembly was tested for a number of different switch parameters and circuit operation modes. The produced output current pulse had a magnitude of 30kA for a start and sustain capacitor bank charging voltages of -40kV and +3.5kV respectively. In addition, the operational performance and trigger range characteristics of the two switches were investigated.</p>	49
<p>[107] Study on Surface Trap and Vacuum Surface Flashover Characteristics of Typical Polymeric Materials <i>Presenter: REN, Chengyan</i></p> <p>In present theory of vacuum surface flashover, secondary electron emission avalanche (SEEA) plays the dominant role in surface flashover development. But more and more researchers have the opinion that surface trapping can participate in the SEEA development and significantly affect the surface flashover characteristics of insulation materials in vacuum. The trap parameters of several typical polymeric materials were deduced based on the isothermal relaxation current (IRC) theory. The surface charging was fulfilled by needle-to-plane corona discharge, and the surface potential was measured by the method of static capacitance probe. The experiment of vacuum surface flashover in direct current (DC) and pulsed voltage was developed, and the relationship between trap parameter and flashover voltage was analyzed. The research results indicate that the trap energy level and trap density of polymeric materials have relation to their flashover characteristics. The shallow trap parameter has more important effect on the flashover voltage, and the flashover voltage decreases with the increase of shallow trap density. The deep trap parameter mainly affects the flashover characteristics after several times of discharges, namely conditioning. The trap parameters have more important effect on the flashover characteristics in DC voltage than in pulsed voltage. The results can not only help to understand the mechanism of vacuum surface flashover but also be used to guide the surface modification and improve the insulation performance of polymeric materials by modifying trap parameters.</p>	50
<p>[106] 2016 Cygnus Refurbishment <i>Presenter: FLORES, Paul</i></p> <p>Cygnus, a dual-beam x-ray source, supports the Subcritical Experiments Program at the Nevada National Security Site for both Los Alamos and Livermore National laboratories. Since 2004, Cygnus has been successfully fired over 3000 times and refurbishment activities were completed in 2012 and 2016. The major refurbishment in 2016, conducted over a six-month period, will rejuvenate Cygnus operations for a number of years. In this paper we describe discoveries and resulting actions performed during the 2016 refurbishment period, particularly those related to arc damage and oil leakage in the induction voltage adder (IVA) ring stack. Many engineering enhancements and improvements were made to Cygnus in 2016, including the addition of inspection windows for the Marx tank, diverter switch, and IVA oil manifold. Finally, many safety improvements were also implemented, such as installation of elevated work platforms for the Marx tank and IVA assembly.</p>	51

<p>[90] Design and calibration of a 3-D lightning current sensor</p> <p><i>Presenter: DE FERRON, Antoine</i></p> <p>During the last three years, a programme of research into studying the lightning impact on a high peak mountain tower has been undertaken at the SIAME Laboratory. Various diagnostics equipment has been mounted near the tower, such as fast speed cameras to capture the arc propagation and capacitive antennas for electric field measurement.</p> <p>The present paper presents the design and calibration of a current sensor dedicated to this project. The sensor will be used to measure the lightning current flowing through a complex metallic structure. For safety reasons, it was decided to measure the current using inductive techniques and therefore a system using three B-dot probes has been developed.</p> <p>The research reported includes an experimental parametric study of the dimensions and the positions of the three magnetic probes used as current sensor and the design validation using mathematical computation. The final step of the calibration presented in the paper consists on 3-D magnetic field measurements and their analysis to obtain the lightning current in a Simple Rod Air Terminal (SRAT) during a laboratory test.</p>	52
<p>[84] Helical Pulse-Forming Transmission Line Stack for Compact Pulsed Power Applications - Design and Simulation</p> <p><i>Presenter: RUDEN, Edward L.</i></p> <p>Design considerations and initial static charge and transient discharge simulations using COMSOL Multiphysics™ are presented for a stacked set of pulse-forming transmission (T-) line modules charged in parallel and discharged in series. Each module is designed to use a rigid injection-molded dielectric (cast in halves to accommodate the center conductor) with a helical discharge path of constant real impedance Z. High peak energy density U for high initial charge voltage V is possible with such materials made of ceramic or ceramic powder-polymer composite. The helical path permits a high volume utilization efficiency η (effective system mean energy density/U) for compact applications. Given the system's cylindrical return conductor housing of outer radius R and height H, $TV^2=4\pi R^2 H \eta U Z$ for an impedance-matched load. Here, T is the time interval for which the load current and voltage are within the ranges for which the load is effectively driven (neglecting rise and fall times). The model is fully parameterized so, for example, each module's rectangular cross-section T-line aspect ratio AT (width/height) and helical aspect ratio AH (T-line center to helical axis distance/T-line half-width) are free to be varied. This allows for a wide range of system configurations to be studied with minimal effort. Given an optimized T-line center conductor shape, the contribution to η from the T-line itself is about 0.33 for the $AT=1-4$ range studied. The minimum AH considered is 2, giving a T-line volume fraction upper bound of 8/9. Their product implies an upper bound on η of about 0.3. Other system requirements, such as extra length and possibly higher AH needed to accommodate a low-inductance multi-channel spark-gap switch between modules, a tri-axial charging and multichannel trigger circuit within each module, and insulation between stages and return conductor, typically lower η to the 0.15-0.25 range for cases studied.</p>	53
<p>[66] Pulsed Power Generators Based on Inductive Storage and Skin-Effect Opening Switches (Energy Correlation and Technical Applications)</p> <p><i>Presenter: EGOROV, Oleg</i></p> <p>References [1-3] studied contactless skin-effect opening switches (SEOS) in combination with semi-conductor opening switches (SOS) and plasma opening switches (POS). This paper proposes to review in greater detail one of these combinations: a SEOS and an SOS. This combination has several attractive properties: durable functioning of each component and a good ratio of charging time to energy output to the load $\sim 10^7 \div 10^8$. The stability of both SEOS and the SOS ensures synchronization at the nanosecond level. These properties allow this switch combination to be used in pulsed power generators based on transformer inductive storage (TIS).</p> <p>As an example, they can be used in generators for transmitting consecutive series of pulses along water-insulated radial transmission lines. The TIS has a torodial configuration and both the TIS and the radial transmission lines have the same axial symmetry. The number of TIS is determined by the voltage necessary for the load. Balance of inductivity in the TIS is controlled by a compensating coil.</p> <p>The proposed focus of this paper is:</p> <ul style="list-style-type: none"> -pulsed power generation efficiency, namely energy loss in SEOS at each of the following stages of pulse generation, -during energy storage collection in the TIS, -during current transformation from the first winding to the second one, -and during output of the energy to the load; -a possible variation of SEOS and SOS combination with goal of parallel function synchronization; -a design of a high power pulse generator for continuous wave pulses along a radial transmission line. <p>Compactness of the design and efficient energy output to a resistive load are characteristics of an TIS that incorporates a combination of SEOS with other opening switches.</p> <p>Reference</p> <ol style="list-style-type: none"> 1. Egorov O.G. Proc. 5th EAPPC, Kumamoto, Japan, 2014. 2. Egorov O.G. Proc. PPC2015, Austin, Texas, USA, pp.288-282, 2015. 3. Egorov O.G. Proc. 6th EAPPC, Lisbon, Portugal, 2016. 	56

[59] Development of High Performance Pulse Power Generator using FPGA and Arduino

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Presenter: KOMATSUDAIRA, Seiya

Pulse power generators have been used in various fields such as environment, biology, agriculture and so on. Therefore, many researchers demand functions such as high power, short pulse, safety, miniaturization, low cost and ease of use. Our research aim to develop a high performance pulse power generator. The generator has ease of use and miniaturization. It is able to output various trigger signals by PC. Even if without PC, it can output trigger signals of about 10 patterns. The generator consists of a capacitor discharge circuit, a controller and a high voltage DC power supply. IGBTs (Model number: IXGX32N170H1 of IXYS) are used for the switching element of the capacitor discharge circuit. The controller consists of a Field Programmable Gate Array (FPGA) and an Arduino. The FPGA (Model number: Spartan-3AN of Xilinx) is used for the control the trigger signal of IGBTs, and the Arduino is used for the communication with a PC and display on a monitor. As results, the maximum output voltage was about 1.7 kV without pulse transformer. In addition, the maximum output voltage with pulse transformer was about 10 kV. The ease of use will be important for industry applications of the pulse power field.

Poster session I - Pulsed Power Industrial and Bio-Medical Applications - Hall 4 / Cambridge (13:30-15:00)

board

[206] Design and Electromagnetic Analysis of an Induction Type Coilgun System with Pulse Power module

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Presenter: GO, Byeong-Soo

Electromagnetic launchers with pulse power have an advantage over the chemical guns in that they has the ability to use electromagnetic force to accelerate armature to high velocity. A multi-stage induction type coilgun system is one of the most important research items. Especially, the capacitor driven induction coilgun, which is almost free from physical contact between the barrels and projectile, has a longer gun lifetime compared to other electromagnetic launchers. Accurate analysis of multi-stage induction coilgun is usually necessary to establish full-size finite element model. Full-size finite element model is suitable for accurate and detailed analysis, but it cannot solve the problem quickly because the analysis time increases with complex geometric structures. It is necessary to find a way to ensure both accuracy as well as rapid calculation. In this paper we present design and electromagnetic analysis results of multi-stage induction type coilgun system with pulse power module obtained by using FEM program. The fundamental specifications of the induction type coilgun system were investigated via mathematical analysis model using MATLAB considering pulse power module. The voltage, current, force, velocity, acceleration, efficiency of the multi-stage coilgun system were analyzed using electromagnetic analysis. The electromagnetic analysis results were compared with mathematical analysis results to confirm the reliability of the FEM simulation model.

As a result, voltage, current, force, velocity, and projectile acceleration of the multi-stage coilgun system were very similar to mathematical analysis results, and the designed coilgun system has higher energy efficiency. The stress of the coil structure was less than the allowable stress of the materials, and the increasing temperature was within the permissible range. The design specifications and the FEM analysis results of the coilgun can effectively be utilized to develop a large-scale multi-stage induction type coilgun system.

[201] Design of pulsed power system for permitting to utilize attractive force of multi-stages synchronous induction coilgun

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Presenter: SONG, Myung-Geun

The capacitor bank topology with a load side crowbar diode is well known as a pulsed power system for the electromagnetic launcher such as coilgun and railgun because of its controllability, reliability, technical maturity. In general case of multi-stages synchronous induction coilgun accelerates a projectile using the electromagnetic force that converts electrical energy to kinetic energy; the pulsed power system is storing slowly and supplying rapidly electrical energy to a stator coil. The current of a stator coil induces the current on the armature coil; these current directions are opposite and it generates repulsive force. The crowbar diode, which is placed at load side, not only prevents the capacitor from the damage of voltage reversal caused by inductive load during pulsed power supplying period but also blocks induced current caused by the previous stator coil.

This paper presents new capacitor bank topology of pulsed power system for multi-stages synchronous induction coilgun to improve the efficiency.

Proposed method is inserting a switch such as GTO(Gate Turn-Off thyristor) parallel to the crowbar diode and load in order to permit generating Attractive force between next stator and armature. The switch is controlling induced current of the stator caused by the previous stator which is being supplied with pulsed power from a capacitor. The current directions of stator and armature coils are the same. Then cause generating attractive force between each other. A mathematical model and FEM simulation in Magnet/Comsol were developed to verify the suggested topology.

The result indicates usefulness in an aspect improving the energy efficiency and launching velocity with same control method, structure and supplied energy. The energy efficiency increase over 1% is confirmed with simulation results of three stages synchronous induction coilgun.

<p>[195] Mathematical Design of a Pulsed Power Induction Coilgun System using Taguchi Method</p> <p><i>Presenter: LE, Dinh-Vuong</i></p> <p>A pulsed power induction coilgun system is a multi-physics system that is too complicated and difficult to simulate and design. Several studies presented design and simulation schemes of a coilgun system by a finite-element method (FEM) which is not cost-effective and need time-consuming process. The impact on the energy efficiency by capacitance, voltage level, and initial position of armature coil has been presented in other reports. But there are still lack of studies to determine the geometry variables, number of turn-layer, switching time, which have major effects on operation and energy efficiency.</p> <p>One of the difficulties to design the coilgun system is that the mathematical model of the coilgun system seems unable to be solved by general analytics method. The Taguchi method, one of statistical methods, has been studied and verified as an economical and effective method to improve the quality of manufactured goods, performance of antenna design and network. Therefore, we believe that the Taguchi method could be applied for determining the geometry variables of the coilgun system.</p> <p>This paper presents a mathematical design of a multi-stage pulsed power induction coilgun system using Taguchi method to maximize its efficiency and reduce cost and time of design process. The coil gun system was analyzed and designed in mathematics using state-space equation. The Taguchi method is applied to evaluate and determine geometry variables, number of turn-layer of both stator and armature coils, and switching time. A FEM model of the coilgun system is developed to compare the results to the mathematical design. The results of the FEM and mathematical design match well. The energy efficiency of the three-stage coilgun system is above 22.6% and expected to be increased along with number of stages. The design method and results are consequential data for research and development of the coilgun system.</p>	60
<p>[170] RONS detection in plasma activated water</p> <p><i>Presenter: HOEBEN, W.F.L.M.</i></p> <p>Activation of water using pulsed electric discharges serves several important agricultural and biomedical applications. Plasma activated water (PAW) contains reactive oxygen and nitrogen molecular species (RNOS) like hydrogen peroxide H₂O₂, nitric acid HNO₃, nitrous acid HNO₂ and peroxyntirite ONOO⁻, exhibiting strong antiseptic power. TU/e spin-off company VitalFluid develops generators for production of PAW, successfully applied for plant growth enhancement via combined plant disease control and nutrition; in the biomedical field, promising results have been obtained with skin disinfection.</p> <p>Both in PAW synthesis optimization and PAW quality control, knowledge on the actual RONS composition is crucial. Due to its high degree of reactivity, peroxyntirite is regarded as primary marker for PAW activity. However, direct measurement of peroxyntirite is not possible. Based on a theoretical model from literature, accepting hydrogen peroxide, nitrite and acidity data, peroxyntirite levels can be determined. This enables an investigation of the influence of synthesis process parameters on PAW activity. An overview will be presented.</p>	61
<p>[162] ASELSAN EMFY-1 Electromagnetic Launcher: First Experiments</p> <p><i>Presenter: KARAGOZ, Mustafa</i></p> <p>ASELSAN Inc. has been conducting experimental research on electromagnetic launchers since 2014. A 1 MJ Pulsed Power Supply (PPS) and 25 mm x 25 mm square bore 3 meters EMFY-1 Electromagnetic Launcher have been built at ASELSAN. This paper represents results of the first experiments of EMFY-1 Electromagnetic Launcher with 1 MJ PPS and c-type aluminum armature. The pulse currents of the PPS modules are measured by Rogowski current probes. The muzzle voltage of the launcher is measured to analyze the contact quality between armature and the rails. The velocity of the projectile is calculated from the B-dot probes' outputs.</p>	86
<p>[151] Preparation of Plasma Activated Water by Gas-Jet assisted Nanosecond Pulsed Discharge in the Water</p> <p><i>Presenter: JIN, Yun Sik</i></p> <p>Plasma activated water (PAW) has gained increasing attentions for a wide range of applications in the biomedical fields. Especially PAW are known to inactivate microbial cells effectively. Gas-jet assisted nanosecond pulsed discharge in the water was used to produce PAW. Nanosecond high voltage pulses from a five-stage Marx-generator were applied to two electrodes installed in the distilled water. During the pulse application, compressed air jet makes an air channel between the two electrodes. The physicochemical properties of the PAW at different process time were evaluated, including pH, oxidation reduction potential (ORP), conductivity and nitrate ion density. The results showed that this type of discharge was very effective to produce a large amount of PAW in short time.</p>	82

<p>[120] Application of High-Voltage Nanosecond Pulses to Surface Modification of Geomaterials</p> <p><i>Presenter: BUNIN, Igor</i></p> <p>The application of High-Power Electromagnetic Pulses (HPEMP) in dressing of resistant gold- containing ores appears attractive as this technique provides for a significant increase in precious metal recovery in hydrometallurgical (gold and silver) and gravitational (PGM) processes (V.A.Chanturiya et al, Pulsed Power Conference, 2005 IEEE). The present work studies the effect of high-voltage nanosecond pulses on the phase composition of surface layers, physical-chemical and technological properties of sulfide minerals with different semiconductor properties and natural dielectric minerals using a complex of physical and chemical methods (XPS, DRIFTS, SEM-EDX, AFM), microhardness measurement (Vickers indentation method). High-voltage nanosecond pulses cause changes in the chemical and phase surface composition of sulfide minerals and their sorption, flotation, and chemical activities. The influence of the conditions and parameters of the electric-pulse effect on the change in the amount of elemental sulfur and iron (metal) oxide on the surface of mineral particles has been studied. The parameters of preliminary pulsed treatment of sulfide minerals (for example, pyrrhotite and pentlandite; pyrite and arsenopyrite) that lead to improvement of flotation separation of minerals have been determined. Pulse energy actions damage the surface microstructure of dielectric minerals with the subsequent formation of traces of surface breakdowns and microcracks, loosening rock-forming minerals, and reducing their microhardness by 40–66% overall. The softening effect of natural dielectric minerals is mainly connected with the damage of microstructure of surface layers, new-formed defects at different structural levels (dislocation, microcracks, and incomplete surface break-ups), disordering and amorphisation of the mineral surface. Our results show that it is possible in principle to use pulse energy actions to improve the efficiency of softening rock-forming minerals in diamond-bearing kimberlites and making targeted changes in the functional chemical (structural phase) state of natural dielectric and semiconductive minerals.</p>	79
<p>[123] Analysis of the sequential discharge characteristics of a parallel-type pulsed power supply with an inductance load</p> <p><i>Presenter: LEE, Byungha</i></p> <p>In the sequential discharge of the pulsed power modules connected in parallel, the occurrence of a surge voltage at the crowbar diodes of the triggered modules afterward is analyzed and the elimination method of the surge voltage is suggested. In the case using two 100 kJ pulsed power modules and the muzzle-shorter railgun as a load, the surge voltage is generated during the crowbarring period of the module triggered first, and the condition on the reciprocal of time constants between the source module and the inductive load is derived. The effect eliminating the surge voltage by the insertion of a short-circuit resistor is verified by analyses and experimental results. The optimal values of the interconnecting resistor to eliminate surge voltages in the six 100 kJ pulsed power modules are calculated by simulation, and the results reflected in the six sequential pulsed power modules are presented.</p>	78
<p>[105] CHARACTERISTICS OF THE TIME SEQUENCE FOR THE HIGH-SPEED METAL JET UNDER AXIAL STRONG PULSED MAGNETIC FIELD</p> <p><i>Presenter: XIANG, Hongjun</i></p> <p>The tanks and armor vehicles can be damaged by high-speed metal jet caused by the High Explosive Anti-Tank (HEAT). In order to improve the effective length and the penetration capacity of the metal jet, the electromagnetic enhancing system for the metal jet is put forward. Aiming to the effect of the time sequence to the performance of the metal jet, the relationship between the times of the high-speed metal jet and the strong pulsed magnetic field is analyzed, and then a numerical simulation model is established based on the Transient Magnetic Solver. After that the validity of the electromagnetic enhancing system for high-speed metal jet is verified, and the distribution characteristics of the magnetic field and the current density are obtained. It can draw the conclusion that the high-speed metal jet can become deformed with the effect of the axial pulsed magnetic field. And then the high-speed metal jet cannot be put off by the stretching force caused by the uneven velocity distribution. Furthermore, the radius of metal jet may become more even and the effective length will be extended. Thus, the penetration capacity of the metal jet will be improved. It also can be seen from the paper that as to the system analyzed in the paper, the best delay time of the metal jet is 122.5 μs when the velocity is 3000 m/s. Meanwhile, the best delay time is to make the peak point of the discharge current just coincide with the time when the center sections of the metal jet and the magnetic field coil are consistent.</p>	77

<p>[104] ANALYSIS OF THREE-STATE REACTOR IN THE INDUSTRIAL WASTEWATER TREATMENT SYSTEM BASED ON PULSED DISCHARGE PLASMA</p> <p><i>Presenter: XIANG, Hongjun</i></p> <p>The effective treatment of the industrial wastewater is very significant to the protection of our environment. The system of wastewater treatment based on pulsed discharge plasma provides a new way for the disposal of industrial wastewater. However, the traditional reactor cannot meet the demand of degradation rate and the treatment efficiency. In order to improve the degradation rate and disposal efficiency of the wastewater, a solid-liquid-gas (SLG) three-state reactor for the high voltage pulsed discharge plasma system is put forward, and then the working principle of the reactor is introduced. Furthermore, a simulation model of the reactor is built. After that the electric field distribution of the SLG reactor is analyzed by numerical simulation. The contrast between the traditional reactor and the SLG reactor is carried out. Furthermore, the effect of the voltage and the diameter of the solid ball in the reactor are analyzed. It can be seen from the results of the analysis that the SLG reactor of the wastewater treatment system based on the high voltage pulsed discharge plasma has better effect than two-state reactors. The conclusion that the discharge voltage has great effect on the disposal efficiency can also be drawn. Meanwhile, the diameter of the solid packing can affect the distribution of the electric field. The research results are very important to the application of the SLG reactor in the wastewater treatment system.</p>	76
<p>[96] Characteristics of Discharge Plasma in Liquid using less than 3 kV</p> <p><i>Presenter: HOSONO, Masahiro</i></p> <p>Discharge plasma in liquid is generated by high voltage such as 15 kV. Our previous experiments succeed with around 3 kV in under water discharges. Our work aim to generate the discharge plasma in liquid less than 3 kV using capacitor discharges. Electrical capacitance is as follows for discharge: 0.5 μF, 1.0 μF of film capacitor and 4 nF of ceramic capacitor. A charger is used DC power supply (HAR-5P6), and A size of reactor is 10x10x10 cm. We compared capacitors liquid conductivity and plasma size. As a result, the discharge plasma in liquid was generated between 0.5 μF, 1.0 μF and 4 nF. Ratio of generation was not changed between 0.5μF and 1.0 μF. Scale of discharge plasma in liquid changed, the capacitor of 1.0 μF is biggest among three capacitor, and 0.5 μF is bigger than 4 nF. Small capacitance with low voltage and current is important to electrical circuit. In higher conductivity, plasma generation in liquid was observed lower voltage.</p>	75
<p>[60] Comparison of Bubbles due to Frequency Change and Electrode Direction in High Repetitive Plasma in Water</p> <p><i>Presenter: KIMURA, Kazuki</i></p> <p>Underwater discharges are applied in industrial fields. However, phenomena of underwater discharges have not been completely clarified. The purpose of our study is to clarify characteristics of underwater discharges. In high repetitive underwater discharges, bubbles generated by discharges are gathered to the tip of an electrode. Discharge plasma forms under the influence of the bubbles may change to a ball shaped bubble. Our study focused on bubbles and investigated the movement of bubbles generated by discharges. Experimental environments are as follows: pulse discharge by MPC method with maximum output 1 J/pulse, the water conductivity of about 110 μS/cm, the electrode made of copper with a diameter of 0.8 mm, the repetition frequency of up to 500 pps (pulses per second), a high speed camera with the frame rate of 57000 fps (frames per second) and image processing software.</p> <p>This paper has three contents: comparison of the movement of bubbles on 250 and 500 pps, observation of discharge plasma forms every 10 pps on 150 to 500 pps and comparison of discharge plasma forms on 250 and 500 pps when the direction of the electrode was changed.</p> <p>The bubbles in high frequency were easy to be gathered to the tip of the electrode. As the frequency rises, the discharge plasma forms tend to be ball shaped bubble. The downward electrode is easier to gather bubbles than the upward electrode.</p>	74
<p>[57] Magneto-forming studies at Loughborough University</p> <p><i>Presenter: NOVAC, Bucur</i></p> <p>The paper will describe experimental studies of magneto-forming technology, undertaken at Loughborough University and using the existing 2 MA/100 kJ Quattro capacitor bank as power supply. Five different practical arrangements will be detailed and results presented that illustrate:</p> <ul style="list-style-type: none"> - Welding aluminium cylinders with galvanized steel cylinders in theta-pinch geometry - Welding stainless steel cylinders with stainless steel cylinders in theta-pinch geometry - Forming magnesium cylinders in theta-pinch geometry - Forming magnesium plates in flat plane geometry - Forming aluminium cylinders in Z-pinch geometry <p>For each arrangement, the joining quality obtained with magneto-forming is analysed at the interface as well in the adjoined materials in comparison with their pre-manufacture (as delivered) state. The used characterisation techniques include micro- and nano-indentation as well as X-ray diffraction, optical microscopy and scanning electron microscopy.</p>	72

<p>[49] An All Solid-State Nanosecond pulse generator for the waste water treatment</p> <p><i>Presenter: RAO, Junfeng</i></p> <p>Industrial pollutants and in particular pharmaceutical residues have caused large-scale pollution to the potable water in China. Many pharmaceuticals and macromolecular organic matter withstand conventional water treatment technologies. Consequently, advanced oxidation processes (AOP), and especially low-temperature plasmas with their ability to create reactive species including the hydroxyl radical which is currently one of the strongest oxidants in nature directly in water, may offer a promising solution. We developed a plasma reactor with a coaxial geometry to generate large volume corona discharges directly in water. To avoid that the corona discharges develop into arc discharges, high-voltage pulses with the duration of only a few hundreds of nanoseconds are required. Moreover, since the impedance of the waste water in the plasma reactor varies all the time, it is better not to require the impedance matching for the pulse generator. Therefore, an all solid-state nanosecond pulse generator using RF MOSFETs is constructed in Marx topology. FPGA is utilized to generate the nanosecond signals and the driving circuits are precisely designed to trigger 36 MOSFETs synchronously in a few nanoseconds. Finally, nanosecond pulses with voltage amplitude up to 30 kV, current amplitude up to 100 A, duration of 300 ns, rise time of shorter than 30 ns and frequency of 50 Hz are generated. Besides, all these parameters can be adjusted easily and the whole system is very compact and portable.</p> <p>**Key words■**solid-state, low-temperature plasma, Marx, nanosecond pulse, water treatment</p>	71
<p>[48] Energy Control of Pulsed Power using Embedded System and Magnetic Pulsed Compression Circuits</p> <p><i>Presenter: AKIYAMA, Masahiro</i></p> <p>Pulsed power has long been used in many applications such as ozonizers, sterilization, and bioelectrics; the use of embedded systems for pulse power has been researched. However, certain factors such as the embedded system design make development difficult and complicate system use. Additionally, many fields require certain functions, safety that has noise protection and ease of operations.</p> <p>The present work aims to develop an energy control of pulsed power using a field programmable gate array (FPGA) and magnetic pulsed compression circuits. The design specifications are as follows: voltage rise time of less than 50 ns; charging energy to 1.0 J/pulse; a peak output voltage of 35 kV; a repetition rate to 500 pps (pulses per second); and flexible control of pulse interval, pulse shot number, pulse repetition and output energy. This pulsed power generator is composed of a controller using an FPGA, a charger and a pulsed power unit with magnetic pulsed compression circuits. Flexible control of pulse interval, pulse shot number and pulse repetition are made from a control of trigger timings in the pulsed power unit, and energy control is from charging timings to a primary capacitor for pulsed power. These improvements by energy control and others are very important for some applications of pulsed power.</p>	70
<p>[47] Numerical Analysis on the Resistive Overlay Rail of Electromagnetic Launcher using Finite Element Method</p> <p><i>Presenter: AN, Sanghyuk</i></p> <p>The gouging phenomenon on the surface of the sliding contact of an electromagnetic launcher is one of the major problems to realize it in practical uses. The resistive overlay is known as one of the solutions to overcome the gouging on the rail surface even though the energy transfer efficiency to the projectile is reduced due to the increase of the rail resistance.</p> <p>We conducted the launching experiment with a resistive overlay on the copper rail and the result shows that the gouging was not induced with the velocity over 2 kilometer per second using a C-shaped aluminum armature whose bore dimensions are 40 mm by 50 mm. In this paper, the transient velocity skin effect (VSE) is analyzed from the point of view of the current diffusion using two and three dimensional finite element methods (FEM). As the current spreads into the rail and armature, VSE induces the variation of the amount of currents in the inner and outer metals. From the transient variation of current profile, the propulsive inductance gradient obtained from the axial Lorentz force on the armature varies with its movement. Also, the rail inductance gradient is calculated without an armature and compared with the propulsive one. Finally, we conduct the circuit simulation using the calculated inductance gradients and compare the simulation result with the experiment data.</p>	69

<p>[41] Triggering Strategy of Railgun Power Supply for the Accurate Control of the Armature Muzzle Velocity <i>Presenter: CHANG, Xinyue</i></p> <p>As a new kind of kinetic-energy weapon system, electromagnetic railgun possesses one major advantage of high muzzle velocity which can be controlled artificially and accurately. Since the muzzle velocity error has a great influence on the hit rate, accurate velocity control is of importance. However, existing literatures focus more on the maximization (or promotion) of the muzzle velocity, rather than the accurate control. In other words, studies on muzzle velocity control are still inadequate. The paper proposes a solution to this problem, namely a triggering strategy of the PFUs (Pulsed Forming Unit) of the pulsed power supplies. In this strategy, the armature acceleration process is equivalent to the uniform acceleration motion. And several velocity detecting devices are equidistantly placed along the barrel. The triggering time of each PFU group is the moment when the armature passes by each velocity detecting device. The unit number of each PFU group is selected, based on the principle of minimizing the error between the actual velocity and the ideal velocity (uniform acceleration) at the next velocity detecting device. In this way, the actual armature velocity waveform can coincide quite well with that of the ideal uniform acceleration process, thus the armature muzzle velocity can be controlled quite accurately. Simulations show that, with 0.15-kg armature mass and 6-m barrel length, if the target velocity is between 1.5 km/s to 2 km/s, the control precision of the muzzle velocity is within 0.5%.</p> <p>Moreover, optimization on the positions of the velocity detecting devices is conducted, in order to further decrease the muzzle velocity error. Simulations show that, with the optimal device positions, the control precision can be improved, within 0.05%.</p>	68
<p>[31] EXPLORATION OF THE HIGH SPEED PROCESSES IN DESIGNING OF PULSED ELECTROTECHNOLOGIES <i>Presenter: GURBANOV, Elchin</i></p> <p>This article is dedicated to the 100th anniversary of operation of the first main water pipeline in Azerbaijan, named "Schollar-Baku", designed in 1917 by English engineer William Lindley, provided to this day Baku by clean drinking water. In recent years, due to the depletion of resources, violation of ecological balance on the planet, climate change, etc., pays great attention to development of energy-efficient, energy-saving devices and environmentally clear technologies. For solution of the energy efficiency of such electric technologies is required the gradual transition from the low-frequency exposure methods to short duration (micro and nanosecond) high-frequency pulsed ones. This provides a powerful and useful liberation of the huge energy of pulsed source on explored object for shortest time and realization of high-speed processes, beneficial effected on treated mediums. This article to development of high-frequency electric technologies (micro and nanosecond) for cleaning and disinfection of drinking and waste water from dispersible and bacteriological pollutants is devoted. Complex explorations of high-speed processes in the water medium, the optimal electrical parameters of the energy source and impact modes (crown and spark discharges) on investigated objects are considered. Empirical formulas for determination of the main discharge characteristics (delay time, breakdown time, emitted energy) and parameters of water gap (inter-electrode distance), at which an effective work regime of high voltage equipment is reached, are given. The possible mechanisms of water breakdown and high speed processes, volt-second diagrams are presented. It is shown, that on spark regime in water medium and positive polarity of potential electrode is achieving the maximum inactivation level of bacteriological cells (1010). It was found, that combination of micro and nanosecond effects on water medium may lead to formation of high-energy run away electrons, generating shortwave radiation and promoting penetration of nanosecond electric fields into nucleus, suspending the further reproduction of cells.</p>	67
<p>[28] Inductive-Capacitive Hybrid Pulsed Power Supply for Energy Recovery <i>Presenter: LIU, Xukun</i></p> <p>As a relatively new kind of the pulsed power supplies for electromagnetic launchers, the IPPS (inductive pulsed power supply) attracts researchers' attentions with the major advantage of high energy storage density. However, it possesses one major disadvantage: too much energy remained in the energy storage inductors and then wasted in the muzzle resistor after the projectile (or armature) leaves the muzzle. And when high energy level and low energy loss are major considerations during the inductors' design, this problem will get worse. The reason is simple. Under this circumstance, the inductors will have relatively large inductance $*L*$, small resistance $*R*$, and high ratio of inductance and resistance $*L*/R*$, and the discharging time will be relatively long, which leads to relatively high remaining energy.</p> <p>This paper proposes a solution to this problem, namely hybridizing the IPPS and the CPPS (capacitive pulsed power supply). To be more specific, during the projectile acceleration process, the IPPS and the CPPS supply the load together; after the projectile leaves the muzzle, the remaining energy in the IPPS turns to charge the CPPS. It should be noted that, since all IPPS modules and CPPS modules are connected in parallel and relatively independent, one CPPS modules can recapture several IPPS modules' remaining energy, which brings possibility to the energy self-recovery of the CPPS modules. In this paper, the working process of this hybrid power supply is analyzed stage by stage. And then the practical feasibility is verified through experiments, in which the load is a small railgun with 0.3-m length, 10-mm×10-mm caliber, 2.7-g armature. Results show that most of the remaining energy in the IPPS module is recaptured, which leads to the energy self-recovery of the CPPS module.</p>	65

[26] High temperature materials for spraying of anti-corrosion coatings

64

Presenter: CHIZHKO, Oleg

For production of stable protectors against thermal and chemical influence, we introduce the technology of their spraying on technological surface. Everybody knows that metallic compounds are combustible. This fuel produces the flame of plasma. The processes of oxidation, which take place of burning chamber, are directed to the creation of ideal mixtures for oxy-ionic gases. In the gaseous phase, the constituents react and build the initial compounds for condensation on coated details. The duration of thermal treatment for our agglomerates could be prolonged with discharge of voltage capacitor. The plasma is super conductor and used as working body for generating of energy and formation of electric arc, which is the area of increased temperature and pressure.

Let us regard a generator of plasma. It is the short circuit between aluminum electrodes in the environment of combustion gases, ionized with thallic and ferric oxy-substances. We calculate static pressure in correspondence with the term for burning temperature at a constant volume. There is the point of equality of thermodynamic functions for components and phases at minimum of Gibbs energy. It becomes higher and the reaction products are moving in the direction to a surface, which is prepared for covering. The acceleration of plasma propulsion is succeeded with dynamic pressure of streaming fluids, which are executed with Lorentz force after impulse of electric current.

In the conditions of high pressures for our ionized conglomerates, we expect an invention of new modifications for the routine compounds after the technological collision with defended surfaces, the crystal cells of which introduce the closed packed symmetries. In this extreme state of matter, we combine Ti-Fe-Al-O-gaseous quantities of the complex polymers with opportunity of preparation for homogeneous compositions of the stoichiometric oxides and the precise mixtures for condensation of crystal structures.

[16] TRIGGER SYSTEM CHANGES FOR THE HERMES III ACCELERATOR

63

Presenter: COFFEY, SEAN

This paper describes the hardware changes made to the triggering systems of the HERMES III accelerator at the Simulation Technology Laboratory (STL) at Sandia National Laboratories, New Mexico. The HERMES III accelerator is a gamma ray simulator producing 100kRad dose per shot with a full width half max pulse duration of ~25 nanoseconds and averages six shots per day. For each accelerator test approximately 400 probe signals are recorded over approximately 65 digitizers. The original digitizer trigger system employed numerous independent legacy signal generators resulting in non-referenceable digitizer time bases. Also, the HERMES III accelerator is operated as a "work for others" and some users want the HERMES III x-ray pulse to occur at pre-determined times with respect to their local time reference thereby requiring these users initiate the triggering of the HERMES III accelerator. Our solution to these issues is twofold. First, to reference the digitizer time bases together we employed a modular and scalable approach using commercial off the shelf components. Second we added an inhibit-able trigger system that users may access allowing them to safely trigger the HERMES III accelerator. This upgraded trigger system presently measures a maximum scope trigger time spread of less than two nanoseconds across the 65+ scopes.

This document details the hardware changes, provides a summary of the accelerator charging process, presents "one-line" trigger system diagrams and summarizes the times of interest for a typical HERMES accelerator shot.

* Work supported by Dept. of Energy

<p>[11] Pulsed plasma chemical synthesis of carbon-bearing nanocomposites based on silicon and titanium oxides</p> <p><i>Presenter: KONUSOV, Fedor</i></p> <p>The paper presents the study on the plasma chemical synthesis of nanocomposite carbon-bearing powders based on SiO₂ and TiO₂ and the analysis of their main characteristics. The nanopowders were synthesized in the plasma chemical reactor using a pulsed electron beam for the low-temperature plasma generation. The experiments on the synthesis of powders were carried out using a TEA-500 pulsed electron accelerator. The main characteristics of the electron beam are as follows: 400-450 keV electron energy, 60 ns half-amplitude pulse duration, up to 200 J pulse energy, and 5 cm beam diameter. The following precursors were used for the production of carbon-bearing composites based on silicon and titanium oxides: SiCl₄, TiCl₄, O₂, and H₂.</p> <p>The morphology of the synthesized particles was studied using the LEO EVO 50 scanning electron microscope and the JEOL-II-100 transmission electron microscope with an accelerating voltage of 100 kV. To determine a crystal structure of nanopowder, the common technique of X-ray phase analysis was used. The reaction products were analyzed using a DRON-07 diffractometer; the elemental composition was examined using the Oxford ED2000 X-ray fluorescence analyzer. The substances included in the composite nanopowder were identified using Nicolet 5700 FT-IR spectrometer.</p> <p>The synthesized composites can be applied as composite photocatalysts with a high efficiency and acting in the region of visible light, as well as the composites possessing electrophysical properties required for the manufacture of the improved lithium-ion batteries.</p> <p>* Work supported by RFBR, project no. 16-38-00055 mol_a.</p>	62
<p>[58] Studies of pulsed electro plasticity in metals</p> <p><i>Presenter: NOVAC, Bucur</i></p> <p>Application of high-intensity electric fields and/or currents is known to enhance materials' deformability. For instance, a high-density electric fields/currents applied continuously (CC: continuous current) or in short pulses (PC: pulsed current) on metals and ceramics may significantly affect their deformation response to external loads. This phenomenon is commonly referred to as electroplasticity or electroplastic effect (EP).</p> <p>In the present study, we carry out mechanical tensile experiments in combination with the application of high intensity electric currents for very short durations in copper samples. Our study captures the enhanced plasticity induced in the metal due to EP. Post-event microstructural studies highlight the effect of high intensity electric current in the material.</p>	73
<p>[138] NOVEL PULSED POWER SYSTEM FOR INDUCTIVE OUTPUT TUBES</p> <p><i>Presenter: CABALEIRO MAGALLANES, Francisco</i></p> <p>Inductive Output tubes (IOT) or klystrodes are used to produce RF power in several industrial, research and medical applications. TV broadcasting and industrial heating represent the biggest percentage of these applications. In these cases the RF power is required continuously, and therefore classical IOT power system topologies are based on a high voltage DC power supply, together with several power supplies floating on a high voltage potential.</p> <p>In linear particle accelerators, Inductive Output tubes are also used to power accelerating structures (e.g. Radiofrequency Quadrupoles). In this case the RF power is only required during a small fraction of time at a certain repetition rate, in pulsed mode. Classical DC topologies are also used in accelerator applications, presenting some drawbacks like excessive size due to isolation requirements, difficulties to ramp-down the high voltage in a few microseconds in case of arc, etc. This papers proposes a new pulsed IOT power system topology which is better adapted for linear accelerator applications, which allows for cost and size reduction. Compared with a state-of-the-art solution based on Solid-State technology, the proposed pulsed IOT power system topology is more compact for applications requiring >50kW of RF peak power.</p> <p>The paper will first present the proposed novel IOT power system topology and then compare it with an equivalent classical topology. The comparison will be illustrated by means of dimensioning a 100kW IOT power system. Furthermore the design methodology to dimension the different power converters of the system and the operation mode will be reviewed.</p> <p>Finally, an evaluation of the proposed IOT power system topology for Linear accelerators for Medical applications will also be presented.</p>	80

<p>[148] Essential Launching Characteristics of Four Typical Electromagnetic Railguns Launchers</p> <p><i>Presenter: XIANG, Hongjun</i></p> <p>Abstract■The essential launching characteristics of four typical electromagnetic railguns models were comparatively reviewed referring to the current distribution in conductors. Such four models were as a small conductive simple railgun, the large resistive simple one, the large conductive simple one, and the large conductive complex one. First, according to strict physical theories, a small conductive copper-and-aluminum simple railgun and the proportionally-enlarged big simple railgun with deliberately-designed resistive materials could satisfy the same equations, the similar forms of current distributions, the same temperatures at the corresponding positions, and the same launch velocity, etc. The small model can absolutely express the large one and vice versa. Second, the large resistive simple railgun could launch slightly heavier projectiles to the same velocity than a conductive copper-and-aluminum simple railgun with the same structures. The two have the same temperature distribution on the surfaces at the corresponding positions. The large conductive railgun is a little excellent than the large resistive one, because the conductive one had less Ohmic loss than the resistive one. Third, the large conductive simple railgun carried a mal-distributed current and had a limited launching ability, while, a large conductive complex railgun carried a much even distributed current and had a more powerful launching ability. The conclusion reached were: according to the large resistive simple model as a key reference lever, the small conductive simple railgun was an economic experimental facility to research the launching characteristics of both small and large railguns; the large conductive complex model was a practical railgun model deserving investments for research.</p> <p>Key words: electromagnetic launching, railguns, scaling method of physical models, practical launcher model</p>	81
<p>[152] Performance Analysis of Passive Compulsators used for EML Application with Different Compensation Shield Thickness</p> <p><i>Presenter: KULKARNI, Apurva</i></p> <p>Compulsators (compensated pulsed alternators) are ac generators designed maximize the short circuit current that could be delivered to the load. The role of the compensation (active/passive/selectively passive) is to minimize the inductance of the alternator during the discharge process. Over the last three decades, many topologies of the compulsator have been evolved in order to achieve a better performance.</p> <p>It was required to design and develop a compulsator for the railgun which is already available in the author's laboratory. The parameters of the existing railgun (the inductance and the resistance gradient) are calculated using a commercially available FEM software. The topology of the compulsator to be designed is rotating field, iron core, 2 poles, passive compensation. This paper discusses the variation in the performance of the system with variation in the thickness of the compensating shield of the compulsator.</p> <p>From the initial performance analysis of the passive compulsators driven railgun with two different compensating shield thicknesses, two designs which result in the same peak current were selected for a detailed analysis. By performing the transient electromagnetic analysis, the following parameters are compared between the two: (a) magnetization curve, (b) flux density distribution in the air gap on no load (radial and angular), (c) current density distribution on the shield during the discharge phase of the compulsator, (d) diffusion of the magnetic field in the compensating shield produced by the armature reaction, (e) maximum stress on the armature conductors and on the compensation shield, (f) magnetic field seen by the armature conductors, (g) transient field winding current during the discharge.</p> <p>The results of the study will be presented and discussed in the final manuscript.</p>	83
<p>[155] Design and Experiment Study of a Novel Electrothermal Pulsed Plasma Thruster for Space Applications</p> <p><i>Presenter: HAN, Ruoyu</i></p> <p>Pulsed plasma thrusters (PPTs) are relatively mature electric propulsion devices for small/micro satellites to complete specific space missions. PPTs are mainly divided into two categories, electromagnetic PPTs and electrothermal PPTs. Under the effect of a current pulse, propellant is ablated and decomposed to form plasma bulk. Afterwards, charged particles are accelerated by Lorentz force or gas dynamic effect to generate thrust. In low power level, the main factor that restrict the development of PPTs is the comparatively low efficiency. Compared to the electromagnetic PPTs, electrothermal PPTs will accelerate neutral particles more effectively to enhance the overall efficiency. Therefore, in the case of low stored energy, electrothermal PPTs have great potential to research and develop.</p> <p>In this paper, a novel electrothermal PPT, which is based on the capillary discharge, was designed. The prototype has a PTFE cavity with variable dimensions, an inner anode and a hollow outer cathode. Meanwhile, a high-performance spark plug was developed and laid in the slot of cathode to ignite main discharge. The main capacitor capacitance ranged from 0.1μF to 3μF, the main voltage ranged from 1kV to 3kV. The trigger capacitor capacitance was 0.1μF, the trigger voltage was 1kV. Discharge waves were measured and analyzed. Generally, the main discharge was a typical underdamped RLC discharge and the duration time was several microseconds. However, the main discharge is aperiodic for the resistance and inductance in the plasma channel were not constant. The deposition energy in the arc channel was calculated, according to the calculation result, the effect of circuit parameters and structure parameters on the energy deposition efficiency was concluded. Meanwhile, the time delay between the ignition discharge and the main discharge was measured. These parameters also had influence on the time delay, the relationship between these parameters and the time delay was studied.</p>	84

<p>[160] Direct and indirect NO removal with (sub)nanosecond pulses: yield and by-product formation <i>Presenter: HUISKAMP, Tom</i></p> <p>In this contribution we show results of direct and indirect removal of nitric oxide (NO) with (sub)nanosecond pulses. The nanosecond pulse source is the 0.5-10-ns, 0-50-kV (positive and negative), 0.2-ns rise time pulse source that we recently developed at Eindhoven University of Technology. The direct-removal setup is an in-plasma removal setup, where the polluted air (with NO) is flushed directly through a pulsed corona plasma generated with the nanosecond pulses. In the indirect-removal setup, we generate ozone in clean air in the corona plasma reactor and mix this with the polluted gas stream after the plasma reactor. In this method, NO is removed by reaction with ozone and not directly in the plasma. We report on removal yields and by-product formation.</p>	85
<p>[163] Simulation of pore density and pore radius based on cell electrofusion <i>Presenter: KE, Qiang</i></p> <p>The existing fusion technology is mainly based on the microsecond pulse electric field. However, there is a great defect in the traditional fusion technology: the microsecond pulse electric field is sensitive to the cell size, and it is difficult to realize the effective fusion of cells with different sizes. There was a significant positive correlation between the transmembrane potential and the cell radius, when smaller cells are perforated, the larger cells may have been in a state of excessive perforation. The nanosecond pulsed electric field has the characteristics of insensitive to the size, this is more conducive to the integration of different sizes of cells. Therefore, in the current work, present paper use finite element method to establish the cell fusion model, and put forward the innovative idea of "electric fusion induced by nanosecond pulsed electric field (ns)". By comparing the numerical value and distribution of the pore density and hole radius of the cells under nanosecond, with the microsecond pulse compared the nanosecond pulsed electric field under the effect of perforation of fusion cells regardless of pore radius or hole density is concentrated in the two cell contact area, ns pulse can better induce cell fusion. The aim of this paper is to provide a new and effective physical method for cell electrofusion, which is of great significance for the development of cell electrofusion technology.</p>	87
<p>[165] An Experimental Facility Design of Pulsed Inductive Thrusters <i>Presenter: CHE, Bixuan</i></p> <p>The BEEMP laboratory in NUDT is now undertaking the research of a promising electric propulsion concept—the pulsed inductive thrusters (PIT). An experimental facility has been set up including a specially-optimized driving coil, a high-voltage pulsed circuit, and a constant-current high-voltage power supply. This paper introduces the design of the experimental facility with special emphasize on the optimization of driving coil geometry. Based on comprehensive study on the electromagnetic properties of the driving coil, a fast calculating method for the mutual inductance between driving coil and plasma load is given. In order to properly predict the performance of a PIT, a 1-D snowplow acceleration model is modified with a LTE plasma model. Combing aforementioned two research efforts, design principles for a pulsed inductive thruster is derived and subsequently an experiment system operated in vacuum is set up following these principles. Primary experiments demonstrate the feasibility of the design and a bright puff of circular plasma is obtained.</p>	88

Oral session 4 - Fusion Research, Large High-Current and High-Energy Systems - Session Chair : Sergey Garanin - Oxford hall (15:00-17:30)

15:00	<p>[117] Inertial confinement fusion and other applications enabled by high energy excimer laser technologies <i>Presenter: MEHLHORN, Tom</i></p> <p>NRLs' Nike laser produces up to 3 kJ at 248 nm on target, and was the culmination of simultaneous advancements in pulsed power, the production and control of large area high-energy electron beams, and excimer laser physics. Nike has demonstrated excellent beam smoothing via ISI, the ability to mitigate CBET via focal zooming, the efficient acceleration of targets to high velocity, and the suppression of laser imprint via high-Z layers. KrF is a candidate for providing laser preheat on a future MagLIF facility at Sandia. Excimer lasers are attractive candidates for a future high yield ICF facility because they have broad bandwidth (>1 THz), good target coupling and decreased LPI growth rates (deep uV), and the gas laser media avoids internal damage and facilitates cooling. The driver development path is to demonstrate a 20 kJ amplifier and beamline, which would be the building block of a future high-yield facility (e.g. 1 MJ using 50x20-kJ beamlines). We studying an e-beam pumped ArF (193 nm) system because of its potential for higher intrinsic efficiency and decreased LPI. Inertial fusion energy (IFE) requires repetitive operation at 5-10 Hz. The Electra KrF facility has produced up to 700 joules at a 5 Hz repetition rate, and achieved 105 shot continuous operations with laser-triggered spark gap switched pulsed power. An all solid-state switched pulsed power module has demonstrated >107 shot operation and could be incorporated into Electra. We are also exploring the use of LTD technologies to make a more compact pulsed power driver. The underlying repetitive pulsed power and electron beam technologies have also created the opportunity for derivative applications including the removal of NO_x and SO_x from the flue gas of fossil fuel plants, the production of biofuels, and material modifications. We will report on preliminary results towards these commercial applications.</p>
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15:30	<p>[343] Pulsed power performance of the Z machine: ten years after the upgrade <i>Presenter: SAVAGE, Mark</i></p> <p>The Z machine is a 36-module, multi-megavolt, low impedance driver for high-energy-density physics experiments. In 2007, a major rebuild doubled the stored energy and increased the peak current that could be delivered. The upgraded system can drive 27 MA through dynamic plasma loads with 110 nanosecond time to peak current. The Z pulsed power system is expected to be prepared for a full-energy experiment every day, with a negligible chance of failure and ± 2 ns timing precision. To maintain that schedule with 20 MJ stored, it becomes essential to minimize failures that can damage hardware. We will show the results of several improvements made to the system that reduce spurious breakdowns and improve precision. In most cases, controlling electric fields is key, both to reliable insulation and to precision switching. The upgraded Z pulsed power system was originally intended to operate with 5 MV peak voltage in the pulse-forming section. Recent operation has been well above 6 MV. Critical items in the pulsed power system are the DC-charged Marx generators, oil-water barriers, laser-triggered gas switches, and the vacuum insulator. We will show major improvements to the laser-triggered gas switches, and the water-insulated pulse forming lines. Work on understanding and improving the vacuum insulator is ongoing. The goal of the present round of improvements is to enable operation with 25% more energy while maintaining the present reliability and precision.</p> <p>*Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.*</p>
15:45	<p>[14] MagLIF performance on the Z-machine: simulations of present and future experiments <i>Presenter: SLUTZ, Stephen</i></p> <p>The MagLIF (Magnetized Liner Inertial Fusion) concept [S.A. Slutz et al. Phys. Plasmas 17, 056303, 2010] has produced $3 \cdot 10^{12}$ DD neutrons on the Z-machine [M.R. Gomez et al. Phys. Rev. Lett. 113, 155003, 2014]. 2D simulations using the measured fuel preheat, 800 J, and drive current, 17 MA, predict $6 \cdot 10^{12}$ DD neutrons. We show that even better agreement is obtained when the effect of electrode material mixed into the fuel is included. Calculations indicate that mix should have only a small effect on the yield if all electrode surfaces are constructed of beryllium, lithium or frozen isotopes of hydrogen. Numerical simulations indicate that much higher yields should be possible on Z if the current and fuel preheat can be increased [S.A. Slutz et al. Phys. Plasmas 23, 022702, 2016]. The existing MagLIF experiments had low drive currents (< 18 MA) due to the high inductance of the power feed, which induces current loss in the device that adds current from four magnetically insulated transmission lines. We present simulations of low inductance MagLIF designs, which indicate that the drive current should be increased to 22 MA with a predicted fusion yield of $2 \cdot 10^{14}$ DD neutrons. This would correspond to a 50 kJ DT yield and a fuel gain greater than unity.</p>
16:00	<p>[61] Pulsed Power Projects within the National Ignition Facility <i>Presenter: JAMES, Glen</i></p> <p>The National Ignition Facility, the most energetic laser in the world, focuses 192 laser beams on a pea size target inside a vacuum chamber to create temperatures and pressures that exist naturally only in the cores of stars and giant planets. Besides relying on three major pulsed power systems, the NIF facility is the shell for several other pulsed power developments, with applications ranging from the front end of the laser to the diagnostics of the physics experiments. In this presentation we will discuss our work and provide a projection into the future of the NIF pulsed power projects such as a diode pumped 1" Nd: Glass amplifier, RF tools development for monitoring the health of the Main Amplifiers capacitor banks, and solid state pulser development that allows (timescale) triple pulsing of the Plasma Electrode Pockels Cells (PEPC) during Advanced X-Ray Radiography Capability shots (ARC). We will also describe other projects that are not part of the laser design but contribute to the success of the physics experiments such as the design of a pulser that will provide a uniform multi-Tera Gauss magnetic field, and finally the contribution from the pulsed power group on a fast gated cathode design for streak cameras permitting significant reduction of the effects from background light.</p> <p>*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC.</p>

16:15	<p>[185] First Measurements of Negative Particles Contributing to Current Loss in Z-Machine Post-Hole Convolute <i>Presenter: LAMPPA, Derek</i></p> <p>Sandia's Z Machine can deliver up to 27 MA in ~100 ns to drive high-energy density physics experiments. These parameters are achieved in part via use of four parallel Magnetically Insulated Transmission Lines (MITLs) that reduce overall system inductance. A Double Post-Hole Convolute (DPHC) acts as a current adder to combine the four parallel MITLs into a single transmission line. The DPHC is a complex three-dimensional structure that perturbs the azimuthally-symmetric topology of the insulating magnetic field. This perturbation to otherwise efficient vacuum power transport introduces current shunt paths that can reduce load current up to 5 MA, significantly impacting experiment performance.</p> <p>We report on the first-ever direct measurements of negative particles contributing to current loss in the convolute during Z shots. Specialized DPHC anode posts use embedded faraday cups to provide time-resolved measurements of negatively charged particle fluence. Apertures spatially collimate charged species shunted across the vacuum gap. We employ filtering to discriminate negative ions and low-energy electrons from higher-energy electrons.</p> <p>Data is presented from two aperture configurations. The DPHC's 3D structure introduces null regions where magnetic insulation is lost between convolute electrodes. We present quantitative measurements that suggest these channels cannot support the entire shunt current. Another aperture provides insight about plasma dynamics prior to magnetic insulation in the region downstream of the DPHC, where simulation and spectroscopic measurements show vacuum gap closure velocities greatly exceeding conventional MITL theory.</p> <p>Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.</p>
16:30	<p>[191] Fusion Ignition Driven by Pulse Power <i>Presenter: LI, GE</i></p> <p>A low-current-fusion (LCF) ignition path below 6 MA is hinted by high-gain high-field (HGHF) plasma within tokamak vacuum vessel due to recent successful experiments of magneto-inertial fusion (MIF) [M. R. Gomez et al., Phys. Rev. Lett. 113, 155003 (2014)] and earlier experiments of compressed plasma in tokamaks. MIF shares the same principle of magnetic compression and physical process as HGHF tokamak plasma suggested in [Li. G., Sci. Rep. 5, 15790 (2015)], although they are operated at opposite extremes in density and time scale. In an energy confinement time, the two should have similar physical process in different time scale ■ MIF in ns scale and LCF in 10ms to several seconds scale. Scales of pulse power are discussed for fusion ignitions with LCF and MIF. In LCF case, a plasma current below 6 MA is found to reach ignition by HGHF with the extended Ohmic region.</p>
16:45	<p>[226] Design of a 5-MA 100-ns Z-pinch accelerator based on linear transformer driver <i>Presenter: ZHOU, Lin</i></p> <p>we are planning to build an linear-transformer-driver (LTD) based accelerator for driving wire-array Z-pinch loads. The accelerator comprises six modules in parallel, each of which has eight series 0.8-MA LTD cavities in a voltage-adder configuration. Vacuum transmission lines are used from the interior of the adder to the central vacuum chamber where the load is placed. Thus the traditional stack-flashover problem is eliminated. The machine is 3.2 m tall and 12 m in outer diameter including supports.</p> <p>A prototype cavity was built and tested for more than 6000 shots intermittently at a repetition rate of 0.1 Hz. A novel trigger, in which only one input trigger pulse is needed by utilizing an internal trigger brick, was developed and successfully verified in these shots.</p> <p>A full circuit modeling was conducted for the accelerator. The simulation result shows that a current pulse rising to 5.2 MA in 91 ns (10%–90%) can be delivered to the wire-array load, which is 1.5 cm in height, 1.2 cm in initial radius, and 1 mg in mass. The maximum implosion velocity of the load is 32 cm/μs when compressed to 0.1 of the initial radius. The maximum kinetic energy is 78 kJ, which is 11.7% of the electric energy stored in the capacitors. This accelerator is supposed to enable a radiation energy efficiency of 20%–30%, providing a high efficient facility for research on the fast Z pinch and technologies for repetition-rate-operated accelerators.</p>

17:00	<p>[288] Pulsed power developments at First light Fusion <i>Presenter: HOLLIGAN, Paul</i></p> <p>First Light Fusion Ltd is a privately funded company in the early stages of researching energy generation using inertial confinement fusion. Efforts are currently centred around developing both simulation and experimental capabilities. First Light Fusion (FLF) currently operates a two stage light gas gun which is capable of projectile velocities approaching 8 km/s, and two low inductance capacitor bank pulsed power drivers which deliver 1 MA and 3.5 MA into various load configurations. Experimental campaigns are focussed on validation of Hytrac, the simulation tool developed by FLF, increasing the understanding of the target physics, and developing electro-magnetic launch technologies to enhance the experimental programme.</p> <p>World class diagnostic capabilities have been established at FLF, including ultra-high speed images (~ 3 ns exposure), streak spectroscopy, VISAR and dynamic x-ray radiography providing a greater understanding of electro-magnetic launch and target interactions. This feedback enables rapid iterations within experimental campaigns and continuous improvement of engineering designs.</p> <p>Ongoing pulsed power developments, simulations and experimental data will feed in to the design and construction of a future driver which will be designed to demonstrate fusion in the laboratory. A conceptual design of this much larger machine will be presented, along with experimental images and results from the existing facilities.</p>
17:15	<p>[372] Magnetic-Field Driver for Magnetized Plasma – Laser Experiments on the Z Beamlet Laser Facility <i>Presenter: STRUVE, K. W.</i></p> <p>A modular pulsed-power driver has been developed to create an applied magnetic field for high-intensity laser experiments. The system is presently being using on Sandia's Z Beamlet Laser facility and was previously used at the Texas Petawatt laser facility at the University of Texas at Austin.. Its design includes use of low inductance circuit elements, a single-turn coil, up to six 3.1 μF 100 kV high energy density capacitors (15.5 kJ each), and one high voltage spark gap switch per capacitor. Each capacitor discharges via six high voltage cables into a newly-designed vacuum interface and vacuum transmission line. Current rise time is 1.7 μs with peak current that can exceed 1.2 MA at full charge voltage with six capacitors. System inductance is about 48 nH, including the single-turn coil. A major challenge has been to deliver current to the coil in vacuum without a significant inductance penalty or damage to the vacuum system. The system is presently configured with a single-turn cm-scale coil to create a magnetic field up to 20 T, which is achieved at much less than full charge voltage using 4 capacitor/switch modules. At these levels the coil is not destroyed with each shot. We will describe implementation of this system on the Z Beamlet Laser system and initial results from magnetized plasma experiments. We will also describe potential design upgrades that enable even more energetic, compact, and portable drivers.</p>

Oral session 6 - Pulsed Power Diagnostics - Session Chair : Laurent Pecastaing - Room Preston (15:00-17:30)

15:00	<p>[75] Cygnus Precision Dosimetry – Calibration and Measurements <i>Presenter: ORMOND, Eugene</i></p> <p>The Cygnus Dual Beam Radiographic Facility consists of two identical radiographic sources each with a dose rating of 4-rad at 1 m, and a 1-mm diameter spot size. The development of the rod pinch diode was responsible for the ability to meet these criteria¹. The rod pinch diode in a Cygnus machine uses a 0.75-mm diameter, tapered tip, tungsten anode rod extended through a 9-mm diameter, aluminum cathode aperture. When properly configured, the electron beam born off the aperture edge can self-insulate and pinch onto the tip of the rod creating an intense, small x-ray source. The Cygnus sources are utilized as the primary diagnostic on Subcritical Experiments that are single-shot, high-value events. In such an application, there is a necessity for reliability and reproducibility, as well as a precise measurement of these qualities. On Cygnus, the primary diagnostic for reliability and reproducibility is dosimetry. Thermoluminescent² dosimeters (TLDs) are used for time-integrated dose, and PIN diodes are used for time-resolved dose. Precision dosimetry calibration methods and results will be presented. Cygnus reliability and reproducibility using TLD dosimetry measurements will be given.</p> <p>*Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.</p> <p>1. G. Cooperstein et al., "Theoretical Modeling and Experimental Characterization of a Rod-Pinch Diode," in <i>Physics of Plasmas</i>, Vol. 8, Number 10, October 2001.</p> <p>2. J. Smith et al., "Performance of the Cygnus X-ray Source" in <i>Proceedings of the 15th IEEE Pulsed Power Conf.</i>, 13-17 June 2005, pp. 334-337.</p>
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15:15	<p>[53] Theoretical and Experimental Studies of Off-the-Shelf V-dot Sensors <i>Presenter: NOVAC, Bucur</i></p> <p>Initially this paper will outline a theoretical study, using commercially available software CST, into the use of off-the-shelf V-dot sensors made from N and SMA type adaptors and connectors. A complex issue arising from the distortion of the signal measured within a pulse forming line when the sensor is mounted close to a spark gap will be clarified.</p> <p>Other issues relating to calibration of the sensors will then be discussed and calibration techniques presented that employ a number of different high-frequency arrangements. Finally, typical case studies will be described and conclusions drawn.</p>
15:30	<p>[209] Experimental and Theoretical Studies on the Effect of Electrode Area on Static Performance of Gas Switches <i>Presenter: LUO, Weixi</i></p> <p>Based on the self-breakdown experiments of gas switches, relationship between the electrode area and the switch static performance has been studied. In the experiments, structure of the switch is fixed, but the disc electrodes of the switch are replaceable to change the electrode area. Diameters of the electrodes are respectively 30mm, 35mm, 40mm, and 45mm. The gas pressure, gas type and discharge circuit are constant. As the electrode diameter has grown, distribution curve of the self-breakdown voltage has been regularly changed and both Average and deviation of the voltage decreased. In order to describe the experimental results, a semi-empirical model based on mathematics has been proposed. The calculated self-breakdown voltage distribution curves agree well with those in experiments .</p>
15:45	<p>[216] Development of a 0.6 MV ultra-compact magnetic core pulsed transformer for high power applications <i>Presenter: PECASTAING, Laurent</i></p> <p>The generation of high-power electromagnetic waves is one of the major applications in the field of high-intensity pulsed power. The conventional structure of a pulsed power generator contains a primary energy source and a load, separated by a power-amplification system. The latter performs a time-compression of the slow input energy pulse and delivers a high-intensity power output to the load. Usually, either a Marx generator or a Tesla transformer is used as a power-amplifier. In the present case a system termed MOUNA (French acronym for 'Module Oscillant Utilisant une Nouvelle Architecture'), uses an innovative and very compact resonant pulsed transformer to drive a dipole antenna. The pulsed transformer can generate voltage pulses of up to 0.6MV, with a rise time of less than 270ns. The paper describes the ultra-compact multi-primary winding resonant pulsed transformer developed in common by Université de Pau and Hi Pulse Company. The transformer design has four primary windings, with two secondary windings in parallel and a Metglas® 2605SA1 amorphous iron magnetic core with an innovative bi-conic geometry used to optimize the leakage inductance. The overall pulsed transformer has a weight of 6kg and a volume of only 3.4 litres. The paper presents in detail the design procedure, with each of the main characteristics being separately analyzed. In particular, simple but accurate analytical calculations of both the leakage inductance and the stray capacitance between the primary and secondary windings are presented and successfully compared with results from CST simulations while core losses and saturation induction are also studied. The resonant power-amplifier output characteristics are obtained when attached to a compact capacitive load, coupled with a capacitive voltage probe developed jointly with Loughborough University. Finally, an LTspice-based model of the power-amplifier is introduced and its predictions are compared with results obtained from a thorough experimental study.</p>
16:00	<p>[235] Evaluation of the Impact of Drive Impedance on the Performance of Spark Gap Switches <i>Presenter: LECKBEE, Joshua</i></p> <p>Spark gap switch resistance and inductance are important parameters in pulsed power systems. However, the variation of switch resistance can be a difficult parameter to measure in very high voltage environments where the arc resistance is a small fraction of the total impedance. To improve our ability to model spark gap switches, we built a coaxial geometry system and tested switches with a range of drive impedance. The switch is pressurized with dry air. Testing includes evaluation of switch breakdown when connected to DC charged coaxial cables up to 60-ohms. When the switch closes, the system is discharged through a matched impedance cable into a matched resistance. The relatively simple switch geometry when fielded in a coaxial system allows for setup of a simple, yet accurate circuit model of the system. Circuit models are then compared with the experimental results and adjustments are made to the switch arc resistance model to improve agreement with experimental results. Simulation and experimental results will be presented for a range of switch arc length (1.5-10.0 mm) and cable impedance (11-60 ohms).</p> <p>1. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.</p>

16:15	<p>[241] PUSHING DIELECTRICS TO THE LIMIT - SELF-HEALING METALIZED FILM CAPACITORS FOR HIGH ENERGY DENSITY <i>Presenter: ENNIS, Joel</i> Abstract</p> <p>Capacitors for pulse power applications have been custom-designed to maximize specific energy while operating with specific circuit requirements such as charge voltage, peak current, voltage reversal, series inductance and resistance, charge time, hold time at peak voltage, and pulse repetition rate. In addition, these capacitor designs had to meet application-specific constraints such as operating temperature and pressure ranges, lifetime, and reliability. To simultaneously minimize size and/or weight, not only was the packing factor addressed, but the electric field in the dielectric system was maximized within the performance constraints. Pulse power applications with moderate high voltages (< 50 kV) and peak currents (< 5.0×10^7 A-V/μF) have been addressed using self-healing metallized electrodes to both increase packing factor and electric field. Higher voltages and peak currents require discrete foil, non-self-healing designs. In laboratory environments where pulse power capacitors are operated in single-shot mode, very high electric fields, approaching the intrinsic strength of the dielectric, have been employed. In industrial environments with continuous, high pulse repetition rate operations, electric fields had to be significantly reduced, but were still much higher than those that could be used in non-self-healing capacitors in the same applications. This paper will describe examples of self-healing capacitors custom-designed for a wide range of pulse power and related applications, employing a variety of materials to achieve optimum solutions.</p>
16:30	<p>[9] Characterization of Individual Pulsed Power Modules on the Saturn Accelerator <i>Presenter: JOSEPH, Nathan</i></p> <p>In 2014 the Saturn accelerator located at Sandia National Laboratories was brought back online after nearly a year of inactivity. The Saturn accelerator is made up of 36 individual pulsed power lines which consist of a 2.7-MV Marx generator, intermediate storage capacitor, 3-MV rim fire gas switch, pulse forming and transmission line. Each component has an individual diagnostic that measures either voltage or current. In this paper I will describe the methods used to characterize each diagnostic and how a full single line system characterization was accomplished.</p>
17:00	<p>[208] Effects of parameters on runtime and jitter of a MV SF6 switch <i>Presenter: YIN, Jiahui</i></p> <p>Parameters affecting the runtime and jitter of a MV electrical triggered SF6 switch have been studied. Experiments tested a variety of switch parameters including gas pressure, trigger disc position and pulse duration. The effects of trigger parameters were also considered, including trigger time, trigger voltage and the isolation units. The coincidence of switches, the failures of switches and their influences to the accelerator were also studied. The experiments were performed on the "Jianguang-I" and "2x2 IVA" accelerator, whose peak voltage of pulsing forming line are about 2.8 MV, the duration are 450 and 350 ns respectively. The tests show that, when the charging voltage is 1.8 MV and the trigger time varies from 175 to 210 ns (from 50% to 64% self-breakdown time), the mean trigger delays of four switches are 117.8, 121.2, 117.6, 117.1 ns, the jitter are 5.5, 4.1, 5.6, 5.1 ns, respectively. Current research will determine improved design and optimal conditions for switch.</p>
17:15	<p>[145] First Test of an Aerogel Cherenkov Detector for Characterizing the Cygnus X-ray Source <i>Presenter: GEHRING, Mandie</i></p> <p>A dual-module Aerogel Cherenkov Detector for Cygnus (ACD/C) was used to measure the X-ray energy spectrum from Cygnus – an intense flash X-ray source operated at the Nevada National Security Site. The ACD/C employs an array of SiO₂ aerogels & solids (i.e., quartz) at different densities (50 – 2500 mg/cc) and hence varying Cherenkov energy thresholds (2.8 MeV X-ray energy for aerogel with 50 mg/cc down to 0.4 MeV X-ray energy for quartz with 2500 mg/cc). The energy range of ACD/C is adequate to characterize the Cygnus spectrum, where the maximum energy of the spectrum is normally around 2.25 MeV. The ACD/C also has a fast-time response, on the order of 1 ns, which can provide the temporal resolution needed to characterize the ~ 50 ns radiation pulse of Cygnus.</p> <p>For the initial proof-of-concept test, two energy thresholds (0.4 MeV by quartz and 1.1 MeV by aerogel with 260 mg/cc) were tested simultaneously. For a 50 ns full width at half maximum (FWHM) Cygnus pulse, the quartz signal of 0.4 MeV threshold was approximately 32 ns FWHM and the aerogel signal of 1.1 MeV threshold was approximately 18 ns FWHM. These data qualitatively suggest that the Cygnus X-ray spectrum is evolving in time, and the high-energy X-ray peak exists on a shorter timescale than the Cygnus voltage or current pulse. In addition, the ACD/C signal ratio of the 1.1 MeV module to the 0.4 MeV module responded to variations in diode voltage intended to vary the spectral end point energy. This will be further quantified by comparison with magnetic spectrometer data.</p> <p>This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy. DOE/NV/25946--3119.</p>

Oral session 5 - Pulse Forming Networks and Alternate Technologies (part I) - Session Chair : John Mankowski - Room**Stanmer (15:00-17:30)**

15:00	<p>[172] Modular, Highly Dynamic and Ultra-Low Ripple Arbitrary Current Source for Kicker Magnets and Plasma Research</p> <p><i>Presenter: TSOLARIDIS, Georgios</i></p> <p>Various modern applications like fusion reactors for plasma generation, beam deflecting equipment in accelerators, equipment for magnetic resonance imaging (MRI) and test equipment for future HVDC breakers, require highly dynamic, high power pulsed current sources. Such current sources must provide a high current gradient combined with an ultra-low ripple and a stable operation under dynamically changing loads. Designing a flexible current source that could meet these requirements is challenging and requires a systematic approach when it comes to the choice of the converter topology and its control concept.</p> <p>In previous work, a novel topology that could be used for such a current source was introduced. In short, a low voltage converter is used in series with a modular multilevel Marx-type converter in order to generate the required high output voltage levels. However, the applied relatively simple control concept, limited the dynamic performance of the topology and its robustness under load disturbances.</p> <p>Therefore, an enhanced topology capable to produce high current pulses with high current gradients ($> 15 \text{ A}/\mu\text{s}$) and ultra-low ripple ($< 1 \%$) is presented in this paper, along with a novel control concept able to harness the full potential of the chosen topology. This ensures that the requirements are met without compromising neither the stability of the system during sudden load changes nor its precision at steady state due to parameter mismatches.</p> <p>In the full paper, the operation principle of the system is described and the potential of the topology is identified. Simulation results of the system, controlled by an advanced control concept, verify the capabilities of the chosen topology and its control. Finally, a behavioral chaos-based DC arc model, with a frequency spectrum that matches the spectrum of a realistic DC arc, is presented in order to simulate the system's behavior when plasma is used as load.</p>
15:15	<p>[404] Compact energy storage with a high-power pulsed MHD generator</p> <p><i>Presenter: SHVETSOV, Gennady</i></p> <p>The standard solid propellant fueled pulsed MHD generators with an electric power of 10–600 MW developed in the 1970-80s provided reliable autonomous power supply of various consumers. The time required for such MHD generators with self-excitation to reach the rated operating conditions is about one second. Recently new scientific, engineering, and technological results have been obtained that allow significant improvements in the size, weight, life, and other characteristics of high-power pulsed MHD generators.</p> <p>This paper presents the results of a numerical study of the characteristics of a compact electric power system based on a pulsed MHD generator and discusses its potential as a source of high-power current pulses. The system consists of a new-generation solid-propellant-fueled pulsed MHD generator with an electrical power of 50 MW with a superconducting magnet system and a step-up transformer with superconducting windings. The primary and secondary windings of the transformer operate as inductive energy storage with current gain. After accumulating energy, the secondary winding of the transformer can be connected to various pulsed electrophysical devices with operating currents of hundreds of kilo-amperes using switching devices. Configurations of the system with transformer stored energy of 50 and 100 MJ at currents up to 500 kA were designed. The operation of the system, including the supersonic plasma flow in the MHD generator channel and the magnetic field distribution in the transformer, was analyzed. The operation time, consumption, and mass of the plasma-generating propellant and the main characteristics of the MHD generator were determined and the weight and size parameters of the system were evaluated. The results of the study show that the proposed pulsed electrical power system holds promise as a multipurpose source of current pulses up to 1 MA with a duration of a few milliseconds to hundreds of milliseconds.</p>

15:30	<p>[237] Multilevel Voltage Hysteresis Modulation and Control for High Voltage Modulators <i>Presenter: SLEPCHENKOV, Mikhail</i></p> <p>High voltage modulators (HVM) have been used widely for broadcast, medical, industrial and research applications. The most common modulation techniques for HVM are Pulsed Step Modulation, Coarse Step Modulation, PWM and their hybrid modifications.</p> <p>All these methods require a presence of PI-controller with additional Feedforward loop in control system to estimate a modulation index or duty cycle at every step of discretization. Although all mentioned control algorithms have been used by engineers for a long time, there are still some disadvantages. For instance, low frequency pulsations of output voltage usually occur due to unbalance of DC-link voltages, variation in parameters of passive elements and deviations of duty cycles of series connected modules. Another drawback, especially in plasma research applications, is a strong correlation between parameters of PI-controller and load parameters. In case if plasma characteristics change rapidly and in wide range, then PI voltage controller is not capable of operating efficiently.</p> <p>A novel Multilevel Voltage Hysteresis Modulation and Control (MVH-MC) technique is proposed, which can be applied to HVM with any number of series connected modules. This MVH-MC allows very accurate voltage regulation in a wide range of load parameters fluctuations. The output voltage is free of low frequency oscillations and its deviation from the reference value is always kept at the minimum preset value. The MVH-MC system performs a rotation of the modules at every switching period and the width of individual voltage pulses is adjusted automatically in such a way to maintain a minimum regulation error. There is no need in DC-link voltage regulation loops, because DC-link voltages are balanced by rotation technique, which is also ensured by reduced hysteresis frequency bandwidth using a parabolic shrinking of boundary levels. The MVH-MC is planned to be used in 10kV/4kA Electrode Power Supplies of C-2W experiment at Tri-Alpha Energy Inc.</p>
15:45	<p>[338] PARALLELED IDENTICAL MARX GENERATORS DRIVING A KLYSTRON THROUGH A PULSE TRANSFORMER IN A RADIATION ENVIRONMENT <i>Presenter: YECKEL, Christopher</i></p> <p>Two parallel Marx generators drive the primary of a pulse transformer with the transformer secondary driving a Klystron as part of a novel system developed by Stangenes Industries. A parallel Marx topology is used to reduce the current contribution of each Marx to an acceptable level so as to not require an export-controlled switch. This allows the system freedom of commercial convenience.</p> <p>The Marx generator is designed to meet strict volume, lifetime, serviceability and environmental constraints as it must integrate into an existing system and operate quietly in a neutron environment for many years. High power IGBT switches are run at reduced voltages to minimize the probability of radiation damage. The system is water cooled with no forced air cooling to achieve a small footprint with minimal audible noise.</p> <p>Comprised entirely of solid-state components, the MTTF of the system is reduced as various failure modes can be tightly controlled and prevented. A balance was achieved between performance and cost to maximize commercial viability. For instance, the two parallel Marx generators in the system are identical and replaceable reducing the cost of ownership and streamlining serviceability.</p> <p>This paper reports experimental data and summarizes the operation of the parallel Marx driver into a Klystron load. Various fault modes and subsequent recovery are analyzed and projected lifetimes are considered. Methods of commercialization via reduced component cost and enhanced serviceability are discussed.</p>
16:15	<p>[149] Investigation and Application of Quasi-coaxial Output Spiral Pulse Forming Network <i>Presenter: LI, Rui</i></p> <p>A high voltage pulse was obtained by putting low voltage resistant pulse-forming line (PFL) in series usually in pulse power field. A long-pulse generator TPG700L based on a Tesla transformer and a set of pulse-forming network (PFN) output electrical pulses by use of mixed PFL, which consists of a series PFN formed with ceramic capacitors placed between two unclosed annular plates and a coaxial PFL. Because of the impedance mismatch of the mixed PFL, the inductance existing between stages, and the inter-stage electromagnetic coupling in the process of pulse transmission, the fluctuation of the top of high voltage pulse produced by TPG700L is more than 25%. In order to improve the quality of output waveform, a novel quasi-coaxial output spiral PFN is developed. A single stage PFN with parameters of 2.44Ω, 15ns, and 60kV is composed of three dual-plate PFN which have the same impedance and electrical length connected in parallel. Because three dual-plate PFN is discharged in parallel, the mode is more close to the coaxial output, the module has smaller distributed inductance and better high frequency response capability; at the same time, due to the adoption of shielding electrode structure on both sides of the module, the inter-stage electromagnetic coupling is eliminated. On this basis, A Tesla-PFN type pulse power generator is developed. Furthermore, the problem of impedance mismatch of the mixed PFL is solved. The PFN part consists of 18 stages series PFN modules, with the parameters of 44Ω, 15ns, and 1MV. The generator can output electrical pulses with a width as long as 40ns at a level of 5GW and a repetition rate of 50Hz on the matched load. When the pulse rise time is about 5ns, the fluctuation of the top of output pulse is smaller than 6%.</p>

16:30	<p>[121] A soft Switch circuit to improve the efficiency of a solid-state Marx generator <i>Presenter: TONG, liqing</i></p> <p>Nowadays, it is important to improve the power efficiency with the growing variety of environmental, biological, medical, and especially for homogeneous dielectric barrier discharges (DBD) industry application using a repetitive high-voltage solid-state Marx generator. However, most solid-state pulse generators are action at hard switching on or off, such as a huge current for the DBD load, which will increase power loss, enlarge thermal stress and have to enlarge the heat sinks or decrease their repetitive rate.</p> <p>In order to improve the power efficiency of the repetitive high-voltage solid-state Marx generator applied in DBD, a series resonant soft switch technology is proposed in this paper. It is series in an inductor matched to DBD capacitor, where series resonant for soft switching will be happened. The influence of the Q-factor and the value of the series inductor will also be analyzed. Studies have shown that the new circuit will provide us a quasi-zero current switching on and zero current switching off. If we select a high Q of the inductor will improve the radiant power and system efficiency of KrCl* lamp, a typical DBD load.</p> <p>A laboratory prototype pulse generator is implemented operated with the voltage range 5 kV, the repetition rate from 0.1 Hz to 100 kHz, pulse width from 1 μs to 5 μs and the rise time less than 100 ns. The efficiency of the Marx generator improves over 30% and the radiant power improves over 25%.</p>
16:45	<p>[218] The changes of Inductors' inductances and resistances with frequency in Inductive Pulse Power Supply <i>Presenter: LI, Zhen</i></p> <p>In an Inductive Pulse Power Supply (IPPS), when the inductors are charged and discharged, they face different capacitive loads, i.e. the frequencies of charging and discharging are different. According to our experiences, inductors' inductances and resistances may change with frequencies. If constant inductance and resistance for one inductor are used in simulation, errors may occur. So it is important to study the change rules of inductors' inductances and resistances with frequency in IPPS. However, it is hard to directly measure the inductances and resistances because the oscillation frequencies are very low in high energy level IPPS and are out of the measuring ranges of most instruments. This paper uses experiment method to solve this problem. First, we use different capacitors with pre-charged voltages to construct under-damped second-order circuits with one inductor. The changing voltages of the capacitors can be measured accurately. With known capacitances, the inductance and resistance of the inductor can be obtained by fitting the voltages values with the under-damped oscillations. This paper uses 7 capacitors to do the experiments with 3 inductors respectively, and thus obtains 21 inductances and 21 resistances through the above fitting method. Using these numbers, we can further fit out the curves of inductances and resistances changing along with frequencies. The curves show that the inductances change slightly and the resistances change dramatically along with the frequencies in the range of 5-300Hz. After normalization, these curves may have more extensive applications especially when using inductors in low frequencies.</p>
17:00	<p>[302] Status of a 140 kV Solid State Marx modulator <i>Presenter: CASSANY, Bruno</i></p> <p>In the framework of a collaboration, CEA and CERN are working on an air insulated solid state pulse modulator to drive LEETCHI electron gun, source of future high current, long pulse RF accelerator. The requirements are pulses in the range of 140kV (1% flat top), 10A, 150μs width, at a repetition rate up to 50Hz and a reproducibility pulse-to-pulse better than 10⁻³. The proposed modulator is based on a Marx topology which employs standard solid state components. This topology is of particular interest in reducing size and cost. It has also the main advantage of transformerless operation. We describe here the status on this modulator with the most recent experimental results and repeatability analysis.</p>
17:15	<p>[154] A HYBRID BOUNCER SYSTEM FOR HIGHLY REPEATABLE AND PRECISE KLYSTRON MODULATORS <i>Presenter: BONNIN, Xavier</i></p> <p>In the framework of the CLIC project at CERN, the team in charge of the study of the klystron modulators faces new challenges to achieve high precision and repeatable pulses. This challenge consists in generating precise and repeatable pulses of 140μs at 50Hz. The pulsed power is 30MW at a voltage of 180kV.</p> <p>This paper presents the study and the evaluation of a new hybrid bouncer circuit. It is intended to be used in a high voltage modulator based on a capacitor discharge topology, to increase the pulses quality (precision and repeatability). This hybrid bouncer circuit is based on the association of the well-known passive resonant L-C bouncer, and a closed-loop controlled active circuit using switches in linear mode. The latter aims at compensating the inherent inaccuracies and drifts of the passive elements at the cost of a slightly increased losses.</p> <p>After evaluating this circuit through analytical calculations and numerical simulations, this paper focuses on the design procedure by providing methods to help the designer in the choice of the components (passive elements and switches). In addition, the design of the closed loop is discussed and the limiting factors in the gaining of a large bandwidth are identified and translated in requirements for the components. Then, the measurements performed on a reduced scale prototype are presented and analysed.</p>

Tuesday 20 June 2017

Memorial session in the memory of Boris Kovalchuk - Chair: Vladislav Rostov - Oxford hall (08:15-08:45)

Plenary Session 2 - Marx Award Winner : Sergei Rukin - Chair: William Stygar, Oxford hall (08:45-09:45)

08:45	<p>[477] SOLID-STATE PULSED POWER BASED ON SEMICONDUCTOR OPENING SWITCHES <i>Presenter: RUKIN, Sergei</i></p> <p>The presentation reviews the results of studies on the SOS effect – nanosecond interruption of superdense currents in semiconductor diodes – and its application in high-current electronics for powerful nanosecond pulse generation. The base physical processes that determine the mechanism of operation of opening switches, which are based on the SOS effect, are considered. Design and characteristics of the SOS diodes – high-power semiconductor opening switches – are given. Solid-state SOS based generators having an output peak voltage up to 1 MV, a peak power over 10 GW, and a pulse repetition frequency up to kHz-range are described. Applications of the SOS generators in various fields of pulsed power electronics are given. Future prospects on SOS based pulsed power systems are discussed.</p>
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Oral session 7 - Power Conditioning , Linear Transformer Drivers (LTDs), Pulse Forming Lines and Transformers - Session Chair : Weihua Jiang - Room Preston (10:00-12:30)

10:00	<p>[350] Conceptual design of a 900-TW pulsed-power accelerator driven by impedance-matched Marx generators <i>Presenter: STYGAR, William</i></p> <p>We have developed a conceptual design of a next-generation pulsed-power accelerator that is optimized for high-energy-density-physics experiments. The design is based on an architecture that is founded on two concepts: single-stage electrical-pulse compression and impedance matching [Phys. Rev. Accel. Beams **10**, 030401 (2007); **18**, 110401 (2015)]. The prime power source of the machine consists of 210 impedance-matched Marx generators (IMGs). Each IMG comprises 40 stages connected electrically in series; each stage is driven by 20 bricks connected electrically in parallel. Each brick consists of two 100-kV 80-nF capacitors connected in series with a 200-kV gas switch. Six water-insulated radial-transmission-line impedance transformers transport the power generated by the IMGs to a six-level vacuum-insulator stack. The stack serves as the accelerator's water-vacuum interface. The stack is connected to six conical outer magnetically insulated vacuum transmission lines (MITLs), which are joined in parallel at a 10-cm radius by a triple-post-hole vacuum convolute. The convolute sums the electrical currents at the outputs of the six outer MITLs, and delivers the combined current to a single short inner MITL. The inner MITL transmits the combined current to the accelerator's physics load. The accelerator is 72 m in diameter, stores 134 MJ of electrical energy, and generates 900 TW of peak electrical power at the output of the IMG system. The accelerator delivers 66 MA and 8.7 MJ in 113 ns to a magnetized-liner inertial-fusion (MagLIF) target [Phys. Plasmas **17**, 056303 (2010); **23**, 022702 (2016)]. The principal goal of the machine is to achieve high-yield thermonuclear fusion; i.e., a fusion yield that exceeds the energy initially stored by the accelerator's capacitors.</p>
10:30	<p>[12] A Fast Rise Time Air Insulated Linear Transformer Driver for High Energy Density Physics <i>Presenter: RODGERS, Casey</i></p> <p>A fast rise time air insulated Linear Transformer Driver (LTD) has been constructed by a collaboration between the University of New Mexico and the Naval Research Laboratory to drive high energy density physics experiments. The LTD is comprised of 12 bricks, each consisting of two 100 kV capacitors tied to a multi-electrode low inductance switch. Details of the construction, including charging and triggering schemes will be presented. The results of circuit and electrostatic simulations of the device will be shown as well as the results of experiments using a dummy load. The load will have resistances of 0.1 to 10 ohms and results will be shown using varying charging voltages. Preliminary results from UNM dense plasma focus load will be given as well.</p>

10:45	<p>[179] Pulse Width Lengthening Technique for Compact Pulsed Power Generator <i>Presenter: ZHANG, Zicheng</i></p> <p>Recent trends in the further development of pulsed power technology are towards higher power, longer duration and more compact structures. Compact pulsed power generators based on a Tesla transformer, configured using coaxial pulse forming lines, are widely used in the application of pulsed power systems. Limited by the low permittivity of the traditional energy storage medium (transformer oil), the typical output pulse duration is several nanoseconds for a 1 m length. For this reason, a high permittivity energy storage medium is proposed to replace transformer oil, in order to increase the duration of the output pulse. Propylene carbonate, due to its high relative permittivity of 65, high dielectric insulating strength and low freezing point of -50°C, has great potential as an energy storage medium for pulsed power systems. In this paper, the high permittivity liquid dielectric and a spiral structure are adopted to lengthen the pulse width of a compact pulsed power generator. Firstly, the operational principles of the compact pulsed power generator are described. The techniques used to lengthen the pulse width are then presented and analyzed. Prior to its use, the propylene carbonate was purified by filtering to remove particles, de-ionizing, and de-gassing. The high voltage insulation was designed using insulation matching to ensure optimal distribution of the electromagnetic field. Finally, a compact pulsed power generator with longer output pulse duration was developed. For a generator length of 1 m, an output voltage of 100 kV was developed across a 30 Ω resistive load, with a pulse duration of 33 ns. This paper sets the foundations for the future development of compact pulsed power generators using propylene carbonate as an energy storage medium.</p>
11:00	<p>[184] Experiments on the Clam Shell Magnetically Insulated Transmission Line (CSMITL2) on Saturn <i>Presenter: ULMEN, Ben</i></p> <p>Large multi-megampere pulsed power accelerators face current loss issues in combining multiple magnetically insulated transmission lines (MITLs) into a single radial disk feed for loads such as Z-pinch radiation sources, shock physics experiments and fusion studies. The method used in many of these machines is the post-hole convolute (PHC) where the MITLs are joined very near the load region. This region is highly stressed, has abrupt changes in the geometry, has electron loss through magnetic nulls, and significant, but currently not understood losses for high-impedance loads. A radically different alternative, the Clam Shell MITL (CSMITL) is designed to combine power from different levels at a large radius where the electric field is below the emission threshold and to transport the power to a single central load without abrupt changes in the geometry. Whether or not the CSMITL has the same anomalous losses as the PHC remains to be determined and may help illuminate the source of the losses.</p> <p>The first generation CSMITL design was tested at the Saturn accelerator at Sandia National Laboratories in Albuquerque in 2011, utilizing half of its 36 pulse-forming lines. The results of that experiment proved promising and a second experiment was constructed, the CSMITL2, the results of which are presented here. In this second design, all 36 pulse-forming lines were combined through three of Saturn's six vacuum insulator sections into a radial disk feed and the pulse was inverted to drive a large area ion diode load. We report the results of power transport by current and voltage measurements, loss in the CSMITL through x-ray pin-hole camera imaging, and ion beam production with multiple diagnostics.</p>
11:15	<p>[188] Square Pulse LTD Stage Based on Simplified Pulse Forming Network <i>Presenter: LIANGJI, Zhou</i></p> <p>Linear transformer driver (LTD) is a new technical approach that can deliver fast high current and high voltage pulses with very compact devices. Traditional LTDs generate sinusoidal shape pulse by LC discharge, while many situations such as FXR and HPM need square pulse. This paper presents a new technical scheme for square pulse LTD in which simplified PFN take the place of LC "bricks" in traditional LTD. The PFN just consists of two capacitors in parallel with one common switch. This technology does not increase the number of switches and complexity of the system. A LTD stage with ten PFN branches has been designed and tested. When charged to ±80 kV and load resistance is about 0.5 Ω, the peak output voltage is ~91 kV, the pulse width is about 103 ns, and rise time is about 22ns.</p>
11:30	<p>[192] Investigation of a repetitive frequency square-wave generator based on coupled magnetic switches and inductive voltage adder <i>Presenter: LIU, Hongwei</i></p> <p>In this paper, a repetitive frequency squarewave generator based on magnetic switches (Mss) and inductive voltage adder (IVA) has been investigated numerically and experimentally. The generator comprises three modules and each module consists of a core-type pulse transformer, a two-stage magnetic compression unit, a pulse forming network and a magnetic switch. The module can generate four parallel pulses to a four-stage IVA cavity via high voltage fast recovery diode and high voltage cables. An output square-wave pulse with burst frequency of 100 kHz can be achieved through different discharge time of the modules. A full circuit model was developed using pspice software to analyze key factors that influence output characteristics of the generator. The module was manufactured and experimental research was carried out on the whole system. Preliminary results show a 15kV voltage and 190ns pulse-width with four 50 ohm cables and matched dummy load which means a 50kV output voltage through the IVA cavities.</p>

11:45	<p>[213] A bipolar, high repetition rate nanosecond pulse generator based on Blumlein-line and TLT <i>Presenter: BIAN, changhao</i></p> <p>Abstract: Bipolar pulses have advantages in reducing muscle contraction and increasing electric field uniformity in the treatment of tumors. In order to study the bio-medical effects in the treatment of tumors exposed to bipolar and high pulse repetition frequency (PRF) nanosecond pulse electric fields, a compact pulse generator which meets the requirements above is needed. A novel configuration which can provide bipolar and high PRF pulses based on Blumlein-line and transmission line transformer (TLT) is proposed in this paper. Utilizing the wave processes in charging and discharging of the Blumlein-line, the generator can produce bipolar nanosecond pulses. The use of fast solid-state power switches allowed the system work at high frequencies. TLT was applied to the generator, so that the number of switches used was greatly reduced and compact system was achieved. In this paper, the pulse forming processes of the topology under impedance matching conditions are theoretically analyzed. And the changes of the output waveforms with mismatched loads are explained. Then the design of the generator is introduced in the paper, including the design of the Blumlein-line and TLT and the control strategy of the power switches. Additionally, the generator has been simulated in a PSpice platform, and a prototype has been developed in the laboratory. The simulation and test results verify the operation of the generator. Finally, the generator produced bipolar pulses for matched loads with amplitudes of 0-3 kV, pulse width of 100 ns, and repetition frequencies of 0-100 kHz. It can provide a hardware foundation for research on the bio-medical effects of exposure to bipolar high PRF nanosecond pulse electric fields.</p>
12:00	<p>[335] Power Amplification with Static and Dynamic Load Current Multipliers <i>Presenter: CHUVATIN, A.S.</i></p> <p>We describe new opportunities of pulse power multiplication using the load current multiplier concept (LCM) [1]. The LCMs were already demonstrated to increase current both in inductive energy storage and pulse forming line systems [2], including experiments at the enhanced current of 1.7 MA on Zebra [3]. Recent successful validation of this approach on Z for the current up to 10 MA [4] allows to envision evolution of the concept on large pulse power generators when the load current rise-time could be decreased and the load power could be amplified. This would allow higher temperatures attainable in magnetically compressed plasmas such as MagLIF [5] when sharper load current ramp implies mitigation of the magnetic Rayleigh-Taylor instability dominantly limiting the compression ratio. We first analyze operation of a static LCM having its proper parameters unchanged in time and a plasma inductive or a plasma flow switch prior to load. We further consider the dynamic current multiplier concept in which the magnetic flux extruder inductance increases in time during the pulse power event. The abovementioned configurations are theoretically shown to provide both higher load current and peak power with respect to unmodified generator. Numerical examples are given for 1 MA generator as an example of proof-of-principle experiment, for Z accelerator and for Petawatt-class generator [6] parameters.</p> <p>[1] A.S. Chuvatin et al, Rev. Sci. Instrum. 76, 063501 (2005). [2] A.S. Chuvatin et al, Phys. Rev. ST Accel. Beams 13, 010401 (2010). [3] V.L. Kantysrev et al, Phys. Plasma 21, 031204 (2014). [4] G. Laity et al, "Initial Evaluation of the LCM Concept on Sandia Z Accelerator", Int. Power Modulator and High Voltage Conference, July 5-9, San Francisco, CA, USA, 2016. [5] S.A. Slutz, et al., Phys. Plasmas 17, 056303 (2010). [6] W.A. Stygar et al, Phys. Rev. ST Accel. Beams 18, 110401 (2015).</p>
12:15	<p>[364] Impedance matching of pulsed power accelerator for megajoule-class dynamic-material-physics experiments <i>Presenter: JIHAO, Jiang</i></p> <p>The pulsed-power accelerator uses its parallel branches triggered to shape the load-current pulse as required for a material physics experiment. We obtained the energy efficiencies is only depended of the pulsed power accelerator impedance and the load impedance with any order of the branches triggered. It is the highest that the pulsed power accelerator impedance (impedance of the parrallel branches) is equalled to the load impedance.</p>

Oral session 8 - Industrial and Commercial Applications - Session Chair : Guus Pemen - Room Stanmer (10:00-12:30)

10:00	<p>[54] Remote generation of intense pulsed electric fields in water <i>Presenter: NOVAC, Bucur</i></p> <p>The work will present the most recent phase in the development of a GW-class pulsed power generator intended for medical and biological applications. Based on a Tesla transformer charged Blumlein pulse forming line, the generator output is connected to a bipolar former capable of producing approximately sinusoidal 1 GHz, 600 kV peak-to-peak voltage impulses. The bipolar output feeds an elliptical reflector immersed in water to focus the electromagnetic radiation in a small volume. The design of the overall arrangement will be outlined, together with the best results obtained by the use of a high-frequency bandwidth electro-optic sensor.</p>
10:15	<p>[175] AN INVESTIGATION OF PULSED FILAMENT CURRENTS IN DIELECTRIC BARRIER DISCHARGES WITH MESHED ELECTRODES <i>Presenter: WANG, Tao</i></p> <p>It is known that the properties of pulsed current filaments can affect the efficiency of ozone generation[1]. In this paper, a statistical analysis was made to investigate the properties of the current filaments observed in dielectric barrier discharges with meshed electrodes. Two stainless-steel sheets with 0.96 mm apertures were used as the meshed electrodes. A 5 kHz smart power supply was used to energize the dielectric barrier discharge reactor, filled with high purity oxygen. Discharges were found to be volumetric, with milliamp-level pulsed filament currents. Multiple filaments were observed to develop simultaneously and the discharge zone expanded with increasing applied voltage.</p> <p>The average peak current and the peak current distribution were investigated under various applied voltages, gas pressures and wire diameters. With an increase of the applied voltage from 4.5 kV to 6.5 kV, the average peak current increased dramatically from 2.0 mA to 22.3 mA and the width of the current distribution became much wider. By increasing the gas pressure from 1 bar to 2 bar absolute, the average peak current decreased and the width of the current distribution was narrower. The average peak current increased by three times when the aperture size was increased from 0.96 mm to 1.7 mm. The ozone efficiency was investigated under different conditions, and it was found that the maximum ozone efficiency achieved by manipulating the discharge current was 334 g/kWh.</p> <p>[1] Y. Zhou et al., "Optimization of Ozone Generation by Investigation of Filament Current Characteristics Under Dielectric Barrier Discharge," in IEEE Transactions on Plasma Science, vol. 44, no. 10, pp. 2129-2136, Oct. 2016. doi: 10.1109/TPS.2016.2579167</p> <p>-----</p>
10:30	<p>[252] Investigation of Underwater Shock Wave Intensity in Different Electrical Breakdown Discharge Modes <i>Presenter: LIU, Siwei</i></p> <p>Powerful dynamic shock waves induced by pulsed discharge in water has been widely adopted in many industry applications, such as material processing, rock fragmentation, electrohydraulic cleaning, high intensity ultrasound source, et al. It is necessary to research on how to induce shock waves steadily and efficiently. An experiment stand of pulsed discharge is designed and constructed, based on the pin-to-plate electrode construction with the gap distance of 10 mm. Combining the measured waveform and optical images captured by a high-speed camera, it can be concluded that the discharge modes are classified as subsonic bush-like streamers or supersonic filamentary streamers. The mechanism of the subsonic streamer under lower applied voltage propagates as bubble clusters. The microbubbles are firstly generated and then discharge occurs in the bubble cluster. The volume of bubble clusters grows towards the cathode until the breakdown of the underwater gap. Experimental results demonstrate that the amplitude of applied voltage have a great influence on the discharge modes. Under higher voltage, the supersonic streamer propagates at the speed from 5 km/s to 50 km/s accompanied by higher intensity shock wave. Based on the experimental results, the morphology and shape characteristics including streamer length and number of branches under different discharge modes are discussed and the effect of the electrical breakdown discharge modes on the shock wave intensity in water is evaluated. The time delay of the pre-breakdown process, the propagation velocity of the streamer, the energy loss in the pre-breakdown process, the energy conversion efficiency, etc., are analyzed and compared under different discharge modes. In the experimental conditions a threshold value of 22.5kV is necessary for the subsonic streamers turning into supersonic streamers, which is a remarkable measure to reduce the energy loss and improve the energy conversion efficiency and eventually enhances the shock wave intensity.</p>

10:45	<p>[320] Marx Generators for Electroporation Devices <i>Presenter: SACK, Martin</i></p> <p>Many industrial-scale electroporation devices are driven by Marx generators. Thereby, the pulse circuit comprising the Marx generator and the electroporation reactor needs to be tailored specifically to the requirements of the application. Biological material for electroporation-assisted extraction processes is treated at pulse lengths on the order of several microseconds. For large-scale electroporation devices Marx generators equipped with spark gap switches are in use which are connected to ground either symmetrically or unsymmetrically, depending on the electrode arrangement inside the electroporation reactor. The pulse shape is adjusted near to the critically damped case of the circuit. Forced cooling of the ark at each spark gap switch by means of a gas flow enables a reliable operation at a pulse repetition rate of around 40 Hz. In the publication measurement results of a Marx generator for an electroporation device for crushed grapes are presented. Marx generators for small-scale devices comprise semiconductor switches, e.g. IGBTs. Adapting the circuit topology of large-scale devices results in a Marx generator with one switch per stage only which is operated efficiently as closing switch under soft-switching conditions. In order to lower costs bypass-diodes at each stage have been omitted. Instead, when interrupting the current in case of a flash-over at the load the voltage across the IGBTs is clamped to a save level by means of an active clamping circuit. In the publication, both types of Marx generators are described and compared to each other based on measurement results with respect to the intended application.</p>
11:15	<p>[200] PULSED CORONA DISCHARGE FOR HYDROGEN PEROXIDE PRODUCTION <i>Presenter: ZHAO, Yiyi</i></p> <p>Plasma in contact with water has been widely investigated for the production of reactive species such as H₂O₂ and OH radicals [1]. In this research, both positive and negative pulsed corona discharges, with duration of the order of microseconds, were used to investigate hydrogen peroxide formation in a pin-to-water electrode system.</p> <p>Under positive pulsed corona discharge, hydrogen peroxide formation was observed to increase linearly with time and reached 15 μmol, 5.5 μmol, 9.9 μmol and 11.5 μmol after a treatment time of one hour in oxygen, air, nitrogen and helium, respectively. The corresponding ratio of the electric charge transferred to the water surface and H₂O₂ formed (yield) is 1:1.8, 1:1, 1:15 and 1:1.4. The OH radical dimerization contributes to 7%, 86% and 46% of the H₂O₂ formation using air, nitrogen and helium, respectively. The solution conductivity was observed to increase linearly with time under positive corona discharge and reached 200 μScm⁻¹ and 150 μScm⁻¹ in air and nitrogen, respectively; no change was observed in helium.</p> <p>The formation of H₂O₂ under negative pulsed corona discharge is generally much lower than that for positive polarity, being 8 μmol, 0.2 μmol, 1.1 μmol and 2.3 μmol for one hour of treatment in oxygen, air, nitrogen and helium, respectively; no significant change was observed to the solution conductivity. The results highlight the polarity effect, suggesting the involvement of different reaction mechanisms in H₂O₂ formation for positive and negative pulsed corona discharges.</p> <p>[1] S. M. Thagard and K. Takashima. "Chemistry of the Positive and Negative Electrical Discharges Formed in Liquid Water and Above a Gas-Liquid Surface Plasma", Chemistry and Plasma Processing, 2009, 29, pp. 455–473.</p>
11:30	<p>[136] Downhole generator based on a line pulse transformer for electro pulse drilling. <i>Presenter: DENIS, Molchanov</i></p> <p>Ever-increasing energy demands require new energy sources. Modern oil extraction industry is targeted at extracting oil products at larger depths [1]. Some European countries, for example, Switzerland, Germany, develop technologies for geothermal energy harvesting from the natural heat of the Earth [2]. Accomplishing these goals needs new scientific approach to deep and ultra-deep drilling. One of the most efficient methods of ultra-deep drilling is electro pulse disintegration of rocks [3], which is based on the effect of discharge channel penetration into a solid (discovered in Tomsk, Russia [4–6]). Clearly, the energy transfer to the bottom of a well from a high-voltage pulse generator located on the surface decreases the drilling efficiency. For enhancing the efficiency, the generator should be located in the immediate proximity to the drill head, i.e., it should be downhole. Here we consider the possibility of designing and using a downhole generator based on a line pulse transformer (LPT generator) for electro pulse drilling of rocks. Preliminary laboratory tests on different rock samples demonstrate that the LPT generator provides a 30 % higher specific output compared to Marx generators conventionally used in the technology. The LPT generator design is rather simple and admits a smaller number of switches, which increases its reliability and lifetime. It is also possible to realize an LPT circuit with a pulse current generator (LPT-PCG circuit) to further enhance the discharge energy and the generator efficiency compared to Marx generators.</p>

11:45	<p>[280] A testbed for an augmented railgun to be powered by superconducting coils <i>Presenter: SCHNEIDER, Markus</i></p> <p>A very important topic in the field of electromagnetic accelerators of the railgun-type is the realization of an appropriate power supply. So far, three different ways of storing energy for railguns have been explored: electric fields, magnetic fields and kinetic energy corresponding to capacitors, storage coils and fly wheels respectively. The project to be presented here and funded by the French DGA consists in building a railgun which is powered by superconducting magnetic energy storage (SMES).</p> <p>Augmented electromagnetic railguns are offering interesting options in comparison to simple classical railguns. For instance, if the same action integral is applied to the armature, an augmented railgun allows for obtaining higher kinetic energies. In the context of the project described here, the augmented railgun allows for an elegant setup as the augmented coils are made from superconducting materials and are therefore used as energy storage.</p> <p>The paper describes the current phase of the project from the launcher point of view. This phase is characterized by developments taking place in different laboratories. The SMES is developed jointly by the company Sigmaphi (Vannes) and the Néel institute (Grenoble) and is assembled in Grenoble, whereas the augmented railgun is built and studied at the French-German institute of Saint-Louis (ISL). Therefore, the ISL has to develop a testbed which allows the operation of the augmented railgun under similar conditions as in the SMES circuit. Only during the last phase of the project, the joint operation of both devices will be studied in Grenoble.</p> <p>The project does not yet aim at competing with currently available high power launchers. The stored energy is about 30 kJ and the goal for the velocity of the launch is 100 m/s. The aim is about exploring the technical potential of a combination of superconductivity and electromagnetic launch.</p>
12:00	<p>[88] Measurements on Combined 12.5/17.5 kV Prototype Inductive Adder for the CLIC DR Kickers <i>Presenter: HOLMA, Janne</i></p> <p>The CLIC study is investigating the technical feasibility of an electron-positron collider with high luminosity and a nominal centre-of-mass energy of 3 TeV. The pre-damping rings and damping rings (DRs) will produce ultra-low emittance beam with high bunch charge. To avoid beam emittance increase, the DR kicker systems must provide extremely stable field pulses during injection and extraction of bunches. The DR extraction kicker system consists of a stripline kicker and two pulse modulators. The present specification for the modulators calls for pulses with 160 ns or 900 ns flat-top duration of nominally +/-12.5 kV and 305 A, with ripple of not more than +/-0.02 % (+/-2.5 V). In addition, there is a proposal to use the same modulators and striplines for dumping the beam, with +/-17.5 kV stripline pulse voltage. An inductive adder is a very promising approach to meeting the CLIC DR extraction kicker specifications because analogue modulation methods can be applied to adjust the shape of the flat-top of the output waveform. Furthermore, the inductive adder can be operated with all or only a portion of the constant voltage layers triggered during the pulse, which allows two different operation modes: 12.5 kV for extraction of the beam and 17.5 kV for the beam dump. Recently, a 28-layer, 12.5/17.5 kV prototype inductive adder has been assembled at CERN and testing has commenced. The goal is test operation with two operation modes. The results of the initial tests and measurements are presented.</p>
12:15	<p>[68] Advantages of pulsed power driven transient plasmas. <i>Presenter: PEMEN, Guus</i></p> <p>Plasmas exhibit properties that make them useful in a wide range of applications, such as lighting, semiconductor processing, nanometer lithography, surface treatments, fusion energy, plasma medicine, future fuels, plasma agriculture and environmental applications. Within this large area, pulsed-power driven, transient plasmas perform much better in energy efficiency and processing performance, and this paper provides an overview of the developments in this field in our group in Eindhoven.</p> <p>Rapid progress is being made in the fields of nanosecond pulsed-power techniques, fast and heavy duty solid state switches, electrical diagnostics, multiscale modelling of plasma, optical and laser-based diagnostics of transient plasmas and chemical characterization of transient plasmas. Considerable progress has been made in pulsed-power levels for industrial applications (current status is an industrial 20 kW, 80 kV pulsed-power system for gas treatment). Detailed research on the electrical and chemical processes in pulsed-power driven transient plasmas resulted in a boost of efficiencies. Electrical efficiency was raised to above 90 %. Simultaneous improvement of plasma chemistry resulted in record high processing yields for plasma driven processes as ozone production and the abatement of nitrogen oxides.</p> <p>The following examples of pulsed power driven plasma processes will be discussed: CO₂ methanation, medical plasmas (plasma plasters), processing of gas and liquid flows (pollution control), and plasma agriculture (e.g. plasma based nitrogen fixation for decentralized production of fertilizer, and plasma activated water as a sustainable alternative for pesticides in horticulture).</p>

Oral session 9 - Imploding Solid Liners, EOS and ICE - Session Chair : Thomas Awe - Oxford hall (10:00-12:30)

10:00	<p>[43] Fusion Reactor Based on the Inductively Driven Metal Liner Compression of an FRC Target <i>Presenter: SLOUGH, John</i></p> <p>The Inductively Driven Liner (IDL) concept represents a transformational solution to the generation of fusion energy. A fusion gain demonstration device is described that would serve as a smaller-scale, prototype of the commercial fusion reactor, and would demonstrate all essential aspects of the reactor from the ability to form, heat, and confine plasmas at performance levels and establish the viability of the concept for low-cost fusion energy generation. The IDL fusion reactor is based on results from current research being done at MSNW and the University of Washington on the magnetically driven implosion of thin (0.5–1 mm) Aluminum hoops, as well as the simultaneous merging and magnetic compression of two FRC plasmoids to form a suitable target inside the metal bands. Both the driver and the target have been studied experimentally and theoretically by the MSNW/UW team. FRCs have been formed, translated and merged inside compression coils at the scale desired for the IDL concept. The FRC has been magnetically compressed up to ion temperatures over 3 keV with observed target lifetimes in excess of that required. Aluminum liners with radii from 6 to over 40 cm have been successfully imploded reaching speeds of 2 km/sec, and resulting in compression fields greater than 100 T. Due to limited funding, it was not possible to perform the most critical step - the combined, simultaneous operations of FRC merging and liner compression. The prime objective of the IDL project in future work is to perform this crucial test, and to do it at sufficient power and scale to achieve fusion gain. Comprehensive plans for this next step will be discussed including a detailed 1D model of the liner electrical and physical behavior, as well as a full, non-linear, dynamical calculation of the liner assembly using the ANSYS 3D Explicit Dynamics® solver.</p>
10:15	<p>[187] Explosive Magnetic Flux Generator Researching Development and Its application in IFP, CAEP <i>Presenter: GU, Zhuowei</i></p> <p>The Explosive Magnetic Flux Generator (EMFG) technology is a kind of unique kilotesla magnetic field producing method in a large volume and would have wide use in extreme condition physics. The Institute of Fluid Physics, Chinese Academy of Engineering Physics (IFP, CAEP) have developed EMFG technologies in recent years and an EMFG set up of CJS-100 have been built up. In the experiments, a stainless steel of liner with 100 mm in outer diameter (1.5mm in thickness) has been imploded by high explosive to velocities 4-5 km/s. The liner instabilities during the implosion were effectively suppressed and a maximum axial magnetic field of over 1000T was obtained.</p> <p>The dynamic compression characters of CJS-100 including circle loading uniformity and axial loading uniformity were measured and the results verified the excellent compression ability of CJS-100. In the isentropic compression experiment, a new experiment method is proposed and a cylindrical structure of target is designed. The target is divided into 2 parts, one is standard material and the other one is the sample to be measured. The inner free surface velocities of both standard material and the sample parts are measured by PDV technique. Because the field distribution of CJS-100 is symmetrically along middle plane and loading magnetic pressure could be obtained by 1-D MHD simulation calibrated with standard material target data. With the inner free surface velocity data and loading magnetic pressure condition, we could finally obtain the isentropie of the sample to be measured. Materials like iron, copper have been compressed by CJS-100 and the maximum magnetic pressure is over 300GPa.</p> <p>Except of CJS-100, another kind of cascades EMFG set up of CJM-120 has also been designed in IFP. The set up parameter of CJM-120 was introduced and dynamic experiment has been carried out and effective magnetic flux compression was realized.</p>
10:30	<p>[220] Axial magnetic field injection on scaled-down MagLIF platforms <i>Presenter: GOURDAIN, Pierre</i></p> <p>MagLIF is a promising inertial fusion based platform studied on the Z machine, at Sandia National Laboratories. This fusion scheme combines z-pinch liner implosion, laser heating and magnetic field confinement. A wealth of physical processes can be studied using this platform, from electron heat conduction to magnetic field compression, from magnetic Rayleigh-Taylor instabilities to particle confinement. Critical plasma parameters of the MagLIF concept are dimensionless. This suggests that most of the physics can be studied using university-scale pulsed-power drivers. However other parameters do not scale. One of them is the electrical resistivity, that is much larger on smaller devices. So one can expect magnetic field compression on mega-ampere-class pulsed-power drivers to be much less effective. This work uses numerical simulations to demonstrate that if the return current posts surrounding the liner are tilted, a time-varying axial magnetic field is generated by the pulsed power driver. This field can diffuse inward, across the liner wall at the same speed that the initial axial field diffuses out. By picking the right angle for the posts, the inward and outward diffusions of both axial fields completely balance out, allowing to reach much more relevant dimensionless parameters. In fact, the rate of injection of the outer axial field can be much faster than the rate at which the inner axial field escapes, increasing the total field inside the liner even when no compression takes place. The injected axial field distribution is also much different from the initial compressed field. The inward diffusion generates a magnetic well that can improve particle confinement from inward gradB drifts. We will conclude by showing that axial field injection can also work for MagLIF on Z.</p>

10:45	<p>[108] Isentropic Compression Experiments on the PTS Facility: Numerical Design, Simulation and Analyses <i>Presenter: ZHANG, Yang</i></p> <p>The most powerful pulse power generator in China - the 10MA PTS facility was used to compress Al samples to pressures over 100GPa. Tens of isentropic compression experiments (ICE) have been conducted at the time of this conference, among which two distinct loading profiles were designed to get different compression processes. A smoothly increasing current was applied to get a shockless and adiabatic compression. A bisection current with a mild start and a sharp increase was designed to make an artificial 'turn-point' in the velocity history, which is used to verify the numerical code. The current profile, as well as the sample thickness, is optimized by a 1D MHD code 'MIC1D' coupled with a Full Circuit Model for the PTS facility ('FCM-PTS'). The geometry of the stripline loads is designed with a 2D magnetic field analysis code, to ensure a one-dimensional, planar load condition. Experimental results show that MHD simulations with the circuit model are able to show the main process of the loading history, and help to analyze and elucidate the phenomena contributing to the compression. The loading process shows a satisfying planar quality with a maximum relative velocity variance of 2%, and the rotation in the axial and horizontal direction is no more than 0.8 degree. In the center 5mm width, the edge effect is prevented from influencing the measurement over the loading time scales. Velocity histories for samples with same thickness suggest that the loading identity is better than 1.5%.</p>
11:00	<p>[217] ICE-16, A DEMONSTRATOR FOR AN UPGRADE OF GEPI DRIVER, TOWARDS ISENTROPIC COMPRESSION EXPERIMENTS AT 6 MA, 1 MICROSECOND LEVEL <i>Presenter: TOURY, Martial</i></p> <p>GEPI, developed in 2002 [1], has been the first compact pulsed power driver using strip line loads for isentropic compression experiments (ICE). Still in full operation, it delivers 3.5 MA with a 500 ns rise time and its main use is for ICE around or below GPa level, with load width less or equal to 70 mm. Because of its high availability, its reliability and ease of operation, this kind of compact driver is a key tool for dynamic material studies ongoing at CEA.</p> <p>An upgrade of GEPI was decided last year, with two main goals. First goal is to maintain capabilities of ICE for long term (beyond 2020). Second goal is to improve these capabilities, mainly in terms of 1D time analysis of the response of thicker samples and in terms of sample shapes (plane or curved), for pressure levels equivalent to GEPI's. This upgrade, named GEPI-2, also includes a cost reduction objective. The idea for that is to reuse the Trench capacitors (4 μF – 90 kV – 10 nH) coming from SPHINX, which was a microsecond Z-pinch driver.</p> <p>Based on these performances and cost criteria, GEPI-2 design studies lead to a 6MA - 1 microsecond rise time ICE driver. A demonstrator, named ICE-16, has been developed to test the main performances and collateral designs solutions leading to an optimized GEPI-2. Design, circuit and EM simulations and preliminary tests on ICE-16 are presented.</p> <p>[1] P.-L. Hereil, F. Lassalle, G. Avriilaud, "GEPI : an ICE generator for dynamic material characterization and hypervelocity impact", Proceedings of the 2003 APS Conference SCCM, AIP Conf. Proceedings, 706, p. 1209-1212 (2004).</p> <p>This work is supported by the DGA (Direction Générale de l'Armement)</p>

11:15	<p>[248] CONDENSED MATTER, ELECTROMAGNETIC, LINER-IMPACTORS FOR SHOCK WAVE AND WARM DENSE MATTER APPLICATIONS</p> <p><i>Presenter: REINOVSKY, Robert</i></p> <p>Traditional shock wave physics experiments require the high precision (uniform) impact by a solid driver at well known, and controllable, velocity upon a target. Combining initial shock heating with controlled compression can provide access to the challenging conditions called warm-dense matter. High velocity, electromagnetically driven cylindrical liners can be a convenient and controllable technique for accessing both shock states inaccessible with normal techniques and warm dense matter states.</p> <p>The basics techniques of controlled, condensed matter implosion have been developed over the last two decades, with the principle obstacle to achieving very high velocities and high precision (accurately cylindrical) impacts is the development instabilities. The growth of magneto-Rayleigh Taylor-like (MRT) instability at the (outer) magnetic field / liner can be limited by materials strength in some cases, but under high acceleration frequently feeds through the thickness of the liner distorting the inner surface so that high precision is not attained.</p> <p>Where large amounts of kinetic energy, high efficiency of conversion of electrical to kinetic energy, and/or high final implosion velocities are required, the traditional approach is to match the liner implosion time to the energy delivery time of the pulsed power driver, but this approach favors MRT growth. An alternate approach is to introduce the driving impulse, and hence momentum to the liner early in the implosion ("kick") when radii are large, circumferential current density, ohmic heating rates and acceleration are relatively low, but allowing the nearly incompressible line to "coast" during the later stages of the implosion. Nearly incompressible convergence accelerates the inner surface, while maintaining overall liner momentum and kinetic energy unchanged in these later stages.</p> <p>Analytic and circuit-model (zero D) calculations will be presented indicating that significant advantages are to be realized by this approach, additional modeling further supports the conclusion of the simple models. (LA-UR-17-21235)</p>
11:30	<p>[116] PHELIX Driven Study of the Richtmyer-Meshkov Instability in Tin in Cylindrical Geometry</p> <p><i>Presenter: ROUSCULP, Christopher</i></p> <p>The Richtmyer-Meshkov Instability (RMI) has been extensively studied in fluids in planar geometry. Not so well studied are the effects of converging geometry. The portable LANL PHELIX capacitor bank ($V_{peak} = 100$ kV, $U_{stored} = 340$ kJ) coupled with the LANL LANSCE multi-frame proton radiography (pRad) facility radiography makes this possible. The PHELIX pulse ($t_{pulse} \sim 6$ μs, $1 < I_{peak} < 5$ MAmps) magnetically accelerates a cylindrical aluminum liner ($R = 1.5$ cm, $dr = 0.6$ mm) to high velocities ($1.0 < v < 3.0$ km/s). In a set of three experiments, the variable capacitor bank charge is used to precisely determine liner velocity, shock pressure, and thus the release state of the target making rigorous study of RMI possible. The first Crenulation experiment was fielded in 2015 at the where a thin-walled ($R = 0.5$ cm, $dr = 1$ mm) tin cylinder with single-mode perturbations ($kh = 0.1, 0.2, 0.3$) on the inside surface was shocked to a pure fluid state on release ($P > 35$ GPa). The perturbation inversion and growth was diagnosed with a 21-image pRad movie. The RMI growth rates compared well to fluid theory and calculations. The second and third Crenulation experiments were conducted in Nov/Dec 2016 with identical liner/target configurations. In the second experiment, the tin target was shocked to a mixed fluid/solid phase on release ($20 > P > 35$ kbar). In the third experiment, the target was shocked to solid phase on release ($P < 20$ kbar). In the former, a pRad movie shows traditional RMI spike evolution. In the latter, growth is mitigated by the material strength. Analysis of the growth rates, comparison to previous experiments, as well as theory and computations will be presented.</p>
12:00	<p>[112] FLYER ACCELERATION BY MAGNETIC PRESSURE ON ANGARA 5-1 INSTALLATION</p> <p><i>Presenter: TKACHENKO, Svetlana</i></p> <p>The high pressure created by magnetic field which was induced by the current flowing through the flyer allows one to reach the megabar pressures and to accelerate the flyers to high velocities. For intense impact of this flyer onto the studied substance it is necessary that a significant portion of the flyer had the density close to the density of the solid. But a part of the stored energy would be spent to the Joule heating and the formation of shock waves in the flyer. The effectiveness of the flyer acceleration was studied on the Angara-5-1 installation at the linear current density up to 5 MA/cm.</p> <p>The experimental and numerical study of the evolution of the aluminum flyer under flowing of sub-microsecond megaampere current pulse with linear current density up to 5 MA/cm through it was carried out. It was obtained that by the time ~ 500 ns the substance of the flyer near its back surface and at a depth of about 0.3 mm is in the solid state, and the velocity of the back surface by this time is ~ 10 km/s.</p>

12:15	<p>[167] Advances in Electromagnetic Flux-compression Research <i>Presenter: ZHOU, Zhongyu</i></p> <p>The ElectroMagnetic Flux Compression (EMFC) has important applications in solid-state physics (ultrahigh magnetic field physics, high pressure science), and is also likely to find applications in fusion and high-energy density researches. In the Institute of Fluid Physics (IFP), Chinese Academy of Engineering Physics (CAEP), a medium-sized EMFC device has been developed to carry out some extreme physics researches. The device includes a 1 MJ main capacitor bank (20x40 uF, 50 kV) and a 200 kJ initial field capacitor bank (4x830 uF, 11 kV). The capacitors of the main bank are connected to a flat parallel-plate transmission line and then to the load via explosive closing switches. At present, we have finished a detailed design of the device, and a prototype has been fabricated to verify key technologies.</p> <p>Meanwhile, a 2D numerical model is developed to estimate the performance of the device. In the model, the filamentary method was employed to solve the electromagnetic problem of the EMFC process, while the mechanical part was calculated by the commercial software. The numerical simulation estimated that the peak current of main bank is over 3 MA, and the peak field is about 350 T (Φ11mm) and 550 T (Φ6mm) respectively.</p> <p>In addition, a novel driving coil based on a unique multi-layer solenoid of close-packed thin wires is introduced to fully avoid the 'feed gap' problem of the common single-turn driving coil. The analysis shows that the coil is able to drastically improve implosion stability of the liner and generate higher magnetic field under the same energy.</p> <p>Due to the space limitation, the above-mentioned aspects was only shortly presented here, however the oral presentation will give more details.</p>
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Poster session II - Pulsed Power Industrial and Bio-Medical Applications - Hall 4 / Cambridge (13:30-15:00)

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[331]	<p>Upgrade of Triggering System of the SPS Beam Dumping System at CERN <i>Presenter: RODZIEWICZ, Janusz Pawel</i></p> <p>In order to prevent uncontrolled beam losses in the Super Proton Synchrotron (SPS) at CERN, which can cause thermal and radiation damages to machine components, an internal beam dumping system is used. It consists of three fast pulsed magnets which deflect the circulating beam vertically onto an absorber block within one accelerator revolution. The excitation current for each magnet is generated by the discharge of a Pulse Forming Network (PFN) through the magnet into a matched terminating resistor. Until now, thyratrons with a column of ignitrons in parallel have been used as switching element. Since the development of new power semiconductor devices now offers a good alternative and thanks to the experience gained with the use a solid state switches within the LHC beam dumping system, the replacement of the thyratrons and ignitrons with two parallel stacks of twelve Fast High Current Thyristors (FHCT) has been decided. As triggering circuits are one of the most critical components that will determine the global performance of a pulsed power system, a matched triggering system with the stacks of FHCT has been developed with the objectives to improve FHCT stack performance by reducing switching losses and turn on spread. The baseline triggering solution will be discussed in this paper with few alternative solutions that have been evaluated during prototyping such as pulse compression or the use of a Laser Pumped Silicon Thyristor. Power switches identified for this application are briefly described and compared in terms of performance in an equivalent triggering configuration of a 10-stage high power GTO stack. The limiting factors of the different switching techniques are highlighted in this comparative review.</p>	48
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<p>[329] Molecular Dynamics Assessment of Bipolar Electric Pulses on Lipid Bilayers</p> <p><i>Presenter: GARNER, Allen</i></p> <p>Electric pulses (EPs) are well established for manipulating both the plasma and intracellular membranes depending upon pulse duration. Conventional electroporation uses EPs with durations on the order of microseconds to milliseconds. While submicrosecond EPs can manipulate intracellular structures, they still induce membrane nanopores that can allow ion transport [1]. Recent studies have demonstrated the impact of applying EPs with alternating positive and negative polarity to cells depends strongly on the pulse duration and time between EPs [2,3]. Bipolar nanosecond EPs (NSEPs) actually induce dramatically lower effects than monopolar EPs of the same electric field amplitude and duration [2]; however, increasing either the time between EPs or EP duration results in an additive effect [3]. One hypothesis is that NSEPs induce shock waves that drive the behavior on nanosecond timescales rather than electric phenomena [2]. As a first assessment of this phenomenon, we perform molecular dynamics (MD) simulations of a typical lipid exposed to bipolar EPs. We will report the impact of membrane voltage, duration, and ion size on membrane permeabilization and ion transport for both bipolar and monopolar EPs. We will assess this electrically driven behavior in relation to the observed experimental results [2] and discuss the potential implications and contributions of other multiphysics phenomena, such as shock waves [2] and temperature gradients.</p> <p>[1] T. B. Napotnik, et. al, "Effects of high voltage nanosecond electric pulses on eukaryotic cells (in vitro): A systematic review," <i>Bioelectrochemistry</i>, vol. 110, pp. 1-12, 2016.</p> <p>[2] C. C. Roth, et. al, "Characterization of pressure transients generated by nanosecond electrical pulse (nsEP) exposure," <i>Sci. Rep.</i>, vol. 5, art. no. 15063, 2015.</p> <p>[3] M. B. Sano, et. al, "In-vitro bipolar nano- and microsecond electro-pulse bursts for irreversible electroporation therapies," <i>Bioelectrochemistry</i>, vol. 100, pp. 69-79, 2014.</p>	49
<p>[325] Mechanism of metal removal from CD-ROM by pulsed power</p> <p><i>Presenter: YAMASHITA, Tomohiko</i></p> <p>Recycling of valuable materials such as metals and plastics is regarded as important from the viewpoint of resource conservation and environmental protection. In recent years, application of pulsed power technology to the recycling field has attracted attention. The authors have been investigating on metal and plastic separation from optical discs using pulsed power. In this study, CD-ROM was used as a separation processing target. A magnetic pulse compression pulsed power generator was used to provide a positive pulsed voltage to the electrodes on a CD-ROM. The coating layer containing metal was separated from the plastic substrate in the atmospheric air. However, details of the mechanism of metal separation were not revealed. In order to clarify a mechanism of metal separation, the authors have investigated the discharge formation by a high speed camera. As a result, two different type discharges have been observed at the first shot; one is the dielectric breakdown of the protective layer, and the other one is the surface discharge. There was no effect on metal separation by the surface discharge. Therefore, the surface discharge observed at the first shot was supposed to be a streamer-like discharge. Furthermore, burning and shock wave were observed by knife-edge Schlieren method. Pulsed voltage was applied to a rod-rod electrode on the CD-ROM. Burning and shock wave due to large current have been observed during metal separation. The Mach number was calculated from the image of the shock wave obtained by Schlieren method.</p>	50
<p>[322] NITRIC OXIDE (NO) REMOVAL AND PULSED DISCHARGE CURRENT ANALYSIS IN VARIOUS NO, N2, O2 AND H2O GAS MIXTURES</p> <p><i>Presenter: ZHOU, Linghe</i></p> <p>In this paper, dielectric barrier discharges were investigated for nitric oxide removal in a cylindrical electrode configuration. Reactive species like O, O3 and OH were analyzed in various different NO, N2, O2 and H2O gas mixtures.</p> <p>The mechanism of nitric oxide removal was found to be dependent upon the reactive species participating in the NO removal reaction. For a gas mixture of N2, O2 and NO (concentration of NO in the range from 200 ppm to 1000 ppm), NO2 formation was independent of O2 concentration from 4.76% to 16.67%, due to the reverse reaction of NO2 and O to form NO and O2. However, when the initial concentration of NO was reduced to 100 ppm or lower, NO oxidation was due to the oxidation of O3, and higher NO oxidation rate was observed with increasing oxygen concentration. When H2O vapor was added, OH radicals were produced; these OH radicals catalytically destroyed O and O3, but also reacted with NO and NO2 to form nitrite and nitrate.</p> <p>In terms of the pulsed discharge current, when the composition of the gas mixture was N2 and O2 (concentration of O2 was 4.76%), the pulsed current had a magnitude of approximately 10 to 30 mA. When 1000ppm NO was added to the gas mixture, the magnitude of the pulsed current increased significantly, to hundreds of mA. However, when 2.26% of H2O vapor was added, no matter whether or not 1000ppm NO was present, the magnitude of the pulsed current fell to lower than 20 mA.</p>	51

<p>[319] Effect of Discharge Gas on Water Treatment Using Nanosecond Pulsed Power Discharges</p> <p><i>Presenter: SHIMOMURA, Yudai</i></p> <p>Nowadays, water pollution is one of the environmental problems. We have studied a sewage treatment using nanosecond pulsed power discharges. A surfactant was chosen as a treatment object because much surfactant occupies to domestic and industrial wastewater.</p> <p>In order to reduce the costs for treatment, treatment using air gas as a discharge gas was studied. The treatments using streamer discharges in oxygen gas and simulated air gas, consisting of 20 % oxygen and 80 % nitrogen, were evaluated. The surfactant treatment was assessed by the height of foam in the reservoir, which was one of the characteristics. The 0.04 % surfactant solution of 1.0 L was treated for 80 minutes. The treatment by oxygen gas as discharge gas reduced the foam in reservoir faster than by using simulated air gas. Because ozone concentration produced in oxygen gas was higher, more OH radicals, having a stronger oxidizing power than ozone, would be produced and treat the surfactants. On the other hand, by the treatment in using simulated air gas, the foam in reservoir rapidly reduced for 0-20 minutes treatment. Then, absorbance at 220 nm of treated solution increased with treatment time. Because the absorption wavelength of nitric acid is approximately 220 nm, it suggested the production of nitric acid. Under the presence of low-concentrated NO₂, OH radicals would be actively produced; the foam decreased rapidly. However, the decrease of foam decelerated in simulated air gas for 20-80 minutes treatment. As NO₂ concentration increased after 20 minutes, OH radical would be consumed for oxidation of NO₂, and nitric acid was produced. When nitrogen is contained in the discharge gas, the decrease of form height became a discriminative variation in comparison with discharge gas consisting of only oxygen.</p>	52
<p>[289] Exploratory study of shock wave production mechanisms during the process of underwater electrical wire explosion</p> <p><i>Presenter: HAN, Ruoyu</i></p> <p>The pressure waveforms of shock waves generated by exploding copper and tungsten wires have been recorded and analyzed. A test platform including a microsecond time scale pulsed current source, loads, a chamber, and a diagnostic system has been established. Current and voltage waveforms were recorded by a Pearson coil and a North Star probe, respectively. Shock waves were obtained by a PVDF needle probe located 145 mm away from the source. If the stored energy of the system was enough, for a fine and long wire, there would be a quite long current pause, also known as "dwell time". In this case, the pressure probe could detect two separate shock waves. The first shock wave mainly came from vaporization of the metal wire whereas the other should come from expansion of discharge plasma channel. For a thick wire with the same length, its current pause would become shorter. The period between two shock waves would also be shorter. When the pause disappeared, the processes of vaporization and breakdown were close and only one shock wave could be found in the field area. However, with the help of a specially designed bypass switch, shock waves caused by vaporization could be separated and compared. The results illustrated that for wires with same sizes, tungsten wires could generate more powerful vaporization shock waves whereas copper wires could produce stronger expansion shock waves.</p>	60
<p>[282] The Optimization of the Treatment Planning for Achieving Complete Ablation of Human Liver Tumor during Irreversible Electroporation by Genetic Algorithm</p> <p><i>Presenter: DONG, Shoulong</i></p> <p>Irreversible electroporation (IRE) is a novel tumor ablation technology. Now it has been used by clinicians for several trials. The clinical trials showed that the effect of the IRE is greatly limited by the inadequate treatment planning. The outcome of IRE depends on the effective electric field distribution in tumors. In order to analyze the effect of real tumor ablation by irreversible electroporation, a three-dimensional model of real liver tumor and liver was established, using CT slice from a patient with liver cancer, and the use of finite element analysis software COMSOL helped build the numerical model of the tumor and normal tissues. The genetic algorithm was used to optimize electrode arrangement and pulse parameters. The irreversible electroporation electric field distribution and effects of tumors and liver ablation were obtained. The simulation results reveal that with the use of the parameters optimized by genetic algorithm, the pulsed electric field can achieve ablation of real tumors, and minimize damage to normal tissues, which indicates the feasibility of genetic algorithm to optimize the irreversible electroporation electric field distribution. With the help of genetic algorithm, this paper successfully optimized and attained electrode arrangement and pulse parameters to ablate real tumors. This will be helpful to make treatment planning in clinical.</p>	59

<p>[276] The matching of the coaxial cylindrical dielectric barrier discharge ozone reactor and the sub-microsecond pulsed power</p> <p><i>Presenter: WANG, YIFAN</i></p> <p>Under the conditions of sub-microsecond pulsed dielectric barrier discharge, the ozone production yields depends on many characteristics. In previous papers, researchers focus mainly on voltage, frequency, gas flow rate, oxygen concentration, temperature and pressure which may not help the physical dimension design of the reactor, especially for length of the discharge gap, material and thickness of the dielectric, diameter of the inner electrode, length of the reactor, etc. The key point of this paper is the matching of parameters of the sub-microsecond pulsed power and physical dimensions of the coaxial cylindrical dielectric barrier discharge ozone reactor. Based on the mature technology of the sub-microsecond pulsed power, which may replace the traditional sine-waves high voltage power in the future, we develop a high voltage pulsed power with a adjustable duration from 500ns to 5us, adjustable peak voltage up to 25kv and adjustable frequency from 10pps to 5000pps. In order to get higher ozone production yield and ozone concentration, we study the matching conditions of parameters of the sub-microsecond pulsed power and physical dimensions of the coaxial cylindrical dielectric barrier discharge ozone reactor through theory analysis and experiment research, meanwhile, a numerical model which describes the influence and relations of the every parameter on ozone yield is developed. With the comparison of numerical data and experimental data, we get the best matching conditions of electrical and physical dimensions parameters of the coaxial cylindrical dielectric barrier discharge ozone reactor.</p>	58
<p>[229] 115kV solid state long pulse modulator for the European spallation source (ESS)</p> <p><i>Presenter: JARITZ, Michael</i></p> <p>For generating such pulses, a long pulse modulator based on a modular series parallel resonant converter (SPRC) topology has been developed [1]. This converter is operated at a high switching frequency (100kHz) to minimize the dimensions of the reactive components and the transformer. In order to generate the required output voltage of 115kV, 8 SPRC modules each with a transformer secondary side voltage of 14.4 kV are connected in series [2]. Due to the series connection of the secondary windings, the electrical insulation of the oil isolated transformer has to withstand the full pulse voltage of 115kV. In this paper the comprehensive design procedure of the key components of the solid state long pulse modulator is summarized. This procedure also includes the high frequency transformer design, the control design and the analytical output voltage ripple calculation. The design is verified by measurement results performed with a full-scale prototype which is operated under nominal load conditions.</p> <p>[1] M. Jaritz, et al., "Optimal Design of a Modular Series Parallel Resonant Converter for a Solid State 2.88 MW/115-kV Long Pulse Modulator", IEEE Transactions on Plasma Science, Volume: 42, Issue: 10, Page(s): 3014 - 3022, October 2014.</p> <p>[2] M. Jaritz, et al., "Control of a modular series parallel resonant converter system for a solid state 2.88 MW/115-kV long pulse modulator," IEEE European Conf. Power Electron. Appl., 2015.</p>	55
<p>[225] TRANSIENT THERMAL EFFECTS AND RAIL DAMAGE IN ELECTROMAGNETIC LAUNCHING</p> <p><i>Presenter: JIA, Lijie</i></p> <p>When solid armature moves along rail at high speed, the thermal effect will destroy good contact between armature and rail in the process of electromagnetic rail propulsion. It has a lot of damage to rail, and which will affect launching's precision and efficiency. In this paper, the simulation, measurement and characteristic analysis of the contact surface temperature are carried out for the high speed sliding electrical contact between armature and rail. Based on the theory of electrical contact, it analyzed the temperature source of the armature and rail contact surface, established the temperature model, and studied the different effects of different contact temperature on the armature and rail.</p> <p>The self-made device of electromagnetic rail launch was used as the test platform. Based on infrared radiation thermometry, measurement system measured contact temperature between rail and armature in the the device. The correctness of the simulation was verified by the data comparison of experiment and simulation. The analyzing experimental results obtained the influence of different parameters on the temperature characteristics of armature and rail's contact surface.</p> <p>Comparison of the rail's damage under the different conditions, further analysis combined the temperature effect with the damage result. The simulation results showed that the temperature model could be obtained macroscopic characteristics, such as temperature, displacement, velocity, etc. The experimental results also reflected rail's damage with the temperature change of contact temperature between rail and armature in the electromagnetic rail propulsion. It is significance for the efficient launching of electromagnetic railgun, and provide an effective basis for the contact analysis of armature and rail.</p>	53

<p>[207] RESEARCH ON THE ARMATURE VELOCITY CONTROL BASED ON COMPLICATED DYNAMIC MODEL</p> <p><i>Presenter: WANG, Zhenchun</i></p> <p>The energy of the electromagnetic railgun comes from the pulse power which has ability to adjust parameters, furthermore, it can adjust the armature velocity in bore.</p> <p>The electromagnetic force of the traditional railgun is easy to be obtained by relying on the relationship between the inductance gradient and the current, however, the electromagnetic force of the augmented railgun is not able to be accurately described in this way. Based on the consideration of the skin effect and proximity effect, through calculating the electromagnetic force from the inner and the outer rail respectively, mathematic model of the accurate electromagnetic force is obtained. In the meantime, by analyzing the armature velocity curve, the motion process can be divided into static model and dynamic model. Extreme physical processes such as ablation, plasma and planning, are analyzed as dynamic models. After that, the complicated dynamic model of the armature motion is established.</p> <p>Based on the actual test and simulation test, we divide the armature motion into two stages: low velocity and high velocity. During the low velocity stage, a number of kinds of electric and thermal effects lead to the complicated dynamic model of armature. During the high velocity stage, the sliding friction has little change and the armature acceleration decreases. The discharge time of the last PFN is given by the velocity feedback and the intelligent algorithm.</p> <p>In conclusion, the rise time of current is similar to that of static friction force, and the complicated dynamic model of armature leads to the difficult velocity control in the low velocity stage. Meanwhile, the dynamic model of the augmented electromagnetic railgun is established, and the relationship between the discharge sequence and the muzzle velocity is obtained. The intelligent algorithm can be carried out in the high velocity stage.</p>	54
<p>[250] Power transmission through the long coaxial cable for the underwater pulsed spark discharge</p> <p><i>Presenter: CHUNG, Kyoung-Jae</i></p> <p>Underwater pulsed spark discharge has been proposed to rehabilitate the clogged wells in the ground water intake system in recent years. It has been proved that the shock wave developed in the surrounding water by the rapid expansion of the spark channel efficiently eliminates incrustations on the well screen. Of the various well structures, horizontal wells are practically important as they have no way of cleaning up to now. In order to accommodate this technical application, a simple capacitive discharge system is constructed with a capacitor bank, and electrode assembly, and the coaxial cable has been extended to 110 meters. Prior to the field application, the effect of the extended coaxial cable has been analyzed by the integrated simulations of the underwater spark discharge process. This paper presents the numerical model which describes the electrical power transmission thorough the transmission line. This model enables us to consider the pulse forming action of the coaxial cable in the non-linear interaction of the spark channel and capacitor bank. From the numerical analysis, it has been revealed that if the initial conditions of the spark channel are the same, no further reduction of the peak value of the pressure wave at the position of the well screen occurs even if the cable length is increased to more than 50 meters. Parametric study demonstrates that the degraded peak pressure at longer cable is mainly due to the reduction of the initial density of the spark channel.</p>	
<p>[273] The effect of current rising rate on the deposited energy and light emission intensity characteristic of a capillary based pulsed plasma thruster</p> <p><i>Presenter: HAN, Ruoyu</i></p> <p>The capillary based pulsed plasma thruster has a huge potential in the small satellite application. It features with higher overall efficiency in low energy level beyond the advantages of traditional pulsed plasma thruster. The typical physical process of the thruster mainly includes discharge, ablation and thrust production. The discharge characteristic reflects the energy transfer efficiency which affects the ablation and thrust production process. In this paper, the effect of current rising rate on the deposited energy, energy transfer efficiency and equivalent circuit parameters and light emission intensity were focused on.</p> <p>The capillary based pulsed plasma thruster was connected to a low inductance capacitor. The current rising rate could be adjusted conveniently by changing the capacitance of capacitor. In this experiment, the main capacitor was ranged from 1μF to 4.5μF which caused the current rising rate changed from 6kA/μs to 16kA/μs. The results showed that deposited energy decreased with fast current-rate, as well as equivalent plasma resistance. The energy transfer efficiency has the similar tendency. The time-dependent deposited power and energy characteristic were also analyzed.</p> <p>The light emission intensity characteristic was studied. With the PMT sensor, the time-dependent light emission intensity was measured. It had the similar properties with current waveform. Based on the modified grey-body radiation model, the electron temperature was estimated which was used in the calculation of arc resistance. Moreover, the plasma plume velocity was measured based on the time-flight method with PMT sensors. It showed that the plume velocity could reach 12km/s. More analysis of relation between light emission intensity and discharge characteristic would be conducted.</p>	57

<p>[290] The Improvement of Energy Efficiency by Generating Hydroxyl Radical on the Surface of Droplets for the Water Treatment Using Pulsed Power Discharge</p> <p><i>Presenter: SATO, Yoshihiro</i></p> <p>Pulsed power discharge in water has been investigated as one of advanced water treatment technologies. Pulsed power discharge in water generates many active species (ozone, OH radical, ultraviolet rays etc.). All of them could be utilized to the decomposition of organic substances in water. However, since the lifetime of OH radical is short, there is a problem that it reacts and disappears before reacting to the substances.</p> <p>Therefore we are studying the water treatment method utilizing OH radical efficiently. The feature of our system is that contaminated water is sprayed as droplets from the top into the reactor that generates pulsed plasma in the gas phase. Contaminated water reacts with active species in the streamer discharge directly. Hence this method has so much high efficiency for the water treatment [1]. However, since OH radical that has short lifetime is generated near the streamer, some OH radicals would react before the reaction to the droplets.</p> <p>In this study, we designed a new reactor that the pulsed discharge occurs on the surface of the water droplets. By this design, it has been observed to improve the energy efficiency for water treatment. In other words, it is possible to decompose the organic substances in water with less energy and to come faster treatment.</p> <p>References:</p> <p>[1] Malik, M. A., Water Purification by Plasmas: Which Reactors are Most Energy Efficient?, Plasma Chem. Plasma Process, Vol. 30(1), 21-31 (2010)</p>	61
<p>[294] Light emission and shock wave characteristics of metal wires exploded in water with small hydrostatic pressures</p> <p><i>Presenter: HAN, Ruoyu</i></p> <p>In the application of reservoir stimulation, pulsed discharges may happen in a liquid environment with a quite high hydrostatic pressure (from several mega Pascal to a few tens of mega Pascal). It might be meaningful to investigate the behaviors of the wire explosion process under some hydrostatic pressures. Current and voltage waveforms were recorded by a Pearson coil and a North Star probe, respectively. In this study, copper wires and tungsten wires were exploded in water with 0.4 MPa and 0.8 MPa hydrostatic pressures. A photodiode and a calibrated time-integrated spectrometer were adopted to measure the light intensity and the spectra. Shock waves were obtained by a PVDF needle probe located 145 mm away from the source. The results revealed that environmental pressure could decrease the intensity of light emission. However, on the other hand, the pressure could increase the value of peak pressures. Nevertheless, it should also be pointed out that the conclusions could only be valid for the cases with small hydrostatic pressures.</p>	62
<p>[298] A Flexible Capacitive Pulsed Power Supply to the High Magnetic Fields for the Magnetization Measurement</p> <p><i>Presenter: ZHAO, Zhangfei</i></p> <p>High magnetic field is an important research tool for magnetization measurement, which can help scientists to observe the physical phenomena and collect data such as Feimi surface structure and the superconductivity critical parameters. In order to meet the testing requirements of various materials, a new flexible capacitive pulsed power supply to the high magnetic fields for the magnetization measurement is designed and developed at the Wuhan National High Magnetic Field Center (WHMFC), which includes 48 capacitors (83.3 μF/25 kV), a thyristor switch (25 kV/60 kA/10 ms) with an antiparallel diode (25 kV/40 kA/10 ms), a charging unit (25 kV/2.2 A), 6 switchgears and the dump circuit. To energize different magnets and provide different pulse waveforms, the 48 capacitors are divided into three parallel modules, respectively a 8 capacitors module, a 16 capacitors module and a 24 capacitors module. These three modules can power magnets separately or in combination through three group switchgears. The power system can provide current pulses with different amplitudes and durations by adjusting charging voltage and different combinations of the three modules. The output of the power system can energize three different measurement cells through setting switchgears. In order to verify the validity of the design, the experiment is carried out. In this paper, the configuration of power supply and the system setting are introduced firstly. Then, the details of the power system are described. Finally, the experiment results are presented.</p> <p>Acknowledgement: The supports of the National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.</p>	63

<p>[300] Experimental Characterization of Tissue Electroporation Based on the Feedback Signal of a New Measurement Method</p> <p><i>Presenter: LIU, Hongmei</i></p> <p>Pulsed electric fields have recently demonstrated their broad application potential in novel non-thermal minimally invasive techniques to treat cancer because of their unique biomedical and therapeutic effects. However, their practical clinical applications are limited by poor understanding of the interaction mechanism between pulsed electric fields and tissue, particularly in the process of electroporation and development. This paper proposes a new measurement method to provide insight into the dynamic process of tissue ablation exposed to a pulsed electrical field. The tissue capacitance, cell membrane electroporation, and relaxation and resealing between the pulses are presented by analyzing the feedback signal of a measured pulse. Under the application of a pulsed electric field, complex electroporation occurs and the pulse parameters determine which dominates. For the traditional irreversible electroporation pulse with a width of 100 μs and a repetitive frequency of 1 Hz, the intensity of the electric field increases with an increasing number of pulses. The conversion from reversible electroporation to irreversible electroporation is the main form. Meanwhile, the release of electroporation between pulse intervals mainly occurred at the ms level. After 1s, the main electroporation form was irreversible electroporation. We are confident that the proposed measurement method can be expanded for using in both detailed experimental research of electroporation, and better real-time observed degree of electroporation or treatment.</p>	64
<p>[304] An Updated IGBT Pulse Power Supply for TPS LTB Injection Kicker</p> <p><i>Presenter: LIN, Ke-Kang</i></p> <p>Linac to Booster (LTB) injection kicker for Taiwan Photon Source (TPS) was first commissioned using conventional Pulse Forming Network (PFN) pulse power supply equipped with a thyatron switch in 2015. The injection kicker magnet was designed to prevent high-voltage breakdown, and this caused the resultant inductance was increased dramatically. Due to this constrain of high-inductance magnet load, the overall output current waveform was directly influenced on rise time, fall time and postpulse oscillation. An insulated-gate bipolar transistor (IGBT) switch was introduced to provide with an alternative choice of turning on and off rapidly other than a thyatron. The characteristics of using IGBT switch in the injection kicker pulse power supply has been studied carefully for a high inductive load. Under the circumstance of a high inductive magnetic load, the IGBT switch could improve the output current and provide with shorter rise time and fall time than PFN pulser, and minimize the postpulse oscillation. This paper describes the detail electrical designs of using IGBT as a switch. Moreover, this paper shows a comparison of PFN and IGBT pulsers under the same high-inductive load condition.</p>	65
<p>[305] A High Energy Hybrid Pulsed Power System for Multi-coil Magnet</p> <p><i>Presenter: ZHAO, Zhangfei</i></p> <p>High pulsed magnetic field is an important research tool for frontier science. In order to achieve 100 Tesla pulsed magnetic field, a high energy hybrid pulsed power system consisting of pulsed generator, battery banks and capacitor banks is designed to energize the magnet at the Wuhan National High Magnetic Field Center (WHMFC). The magnet has a structure of three coaxially nested coils. The outer coil is powered by pulsed generator and battery banks in series, the middle coil and the inner coil are energized by capacitor banks separately. Each coil of multi-coil magnet is fired in designed sequence. Because of the coupling effect between the outer coil and the middle coil, the current of the outer coil will drop when the middle coil is fired. And this current drop will bring adverse effects that the burden of the power supply and the stress of magnet increase. To ensure safety and reliable operation, the current drop of the outer coil should be reduced as far as possible. Based on the mathematic model of the high pulsed magnet power supply established in this paper, the mutual voltage causing current drop can be derived. And an auxiliary power supply composed by capacitors is adopted to restrain the current drop in the outer coil. The parameters, circuit topology and control strategy of capacitors are also discussed. To verify the validity of the design scheme, the simulation model is established, and the result shows that the auxiliary power supply can restrain current drop dramatically.</p> <p>Acknowledgement: The supports of the National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.</p>	66

<p>[307] High Frequency Irreversible Electroporation Ablate Tissues with Plate Electrodes Inhibiting Muscle Contraction</p> <p><i>Presenter: DONG, Shoulong</i></p> <p>Irreversible electroporation (IRE) with non-thermal has quickly translated into clinical applications for solid tumors ablation. However, muscle contractions and tumors recurrence also come with IRE. Bursts of high frequency bipolar pulses have been reported may solve these problems appropriately, but muscle contractions need further reduction and the ablation effects and uniform electric field distribution in heterogeneous tissues also need experimental validation. We presented rabbit livers ablation experiments with the bursts of bipolar high frequency pulses (which are called H-FIRE) and IRE pulses through Plate Electrodes. Plate electrodes can eliminate non-uniform electric field distribution which come with needle electrodes, and minimize current flow outside of the treatment volume to limit muscle contractions. The results from the animal experiments and simulations showed that H-FIRE can be less susceptible to distortions due to the vessels without muscle contractions, and the parameters of the bursts should be optimized for better ablation effect. Integrating into account the ablation effect and muscle contraction, we consider that the bipolar bursts with the individual pulse durations for 5 μs and 10 μs, electric field intensity for 2000 V/cm, can replace the traditional IRE, which have a good ablation effects and less extent of muscle contractions for animals.</p>	67
<p>[313] A Novel Design of Repetitive Pulsed Magnetic Stimulator</p> <p><i>Presenter: FANG, Xiao</i></p> <p>Repetitive pulsed magnetic stimulator has been verified as an important device for psychological and neurological disorders. However, repetitive pulsed current in time-varying magnetic field produces large Joule heat in coil which undermines curative efficacy and prevents repetitive high frequency stimulation.</p> <p>After analyzing the advantages of existing coils and the unique nonplanar structure of human brain, an innovative geometric coil design applied in transcranial stimulation is proposed. The stimulating coil is designed into coil pair with an irregular form of cambered surface based on the inspiration of special-shaped magnet. From the front view, the overall structure is in arc-shaped whose inner arc radius is set at 115 mm (a bit larger than the average radius of human brain). From the vertical view, the outline is rectangular. The stimulator is mainly composed of a charging circuit, a discharge circuit and a stimulating coil. The discharge circuit is a feedback loop using a bidirectional thyristor where the energy of the capacitor is recovered. Repeating charging the capacitor to expected value and energizing the stimulating coil, the repetitive pulsed current is produced.</p> <p>The Finite-Element Method(FEM) is adopted to analyze the 3D spatial distributions of intracranial induced electromagnetic field. To unify coil evaluation standard and enable meaningful comparison for new design's feasibility, a comparison function reflecting medical efficacy is constructed. Comparing to conventional structure, it has been proved that the optimization of this design can enhance the peak of induced electric field for 11%, raise the value of RPN for 20% while improving the overall efficacy by 40%. This design makes it possible to obtain superior intracranial focusing field in targeted tissues with lower stimulation current.</p> <p>Acknowledgement: The supports of the National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.</p>	68
<p>[316] Consideration of Pulse-Width Effects of Nanosecond Pulsed Electric Fields Application on Cancer Cell</p> <p><i>Presenter: YAMAMOTO, Yasuo</i></p> <p>In recent years, treatment approach of malignant neoplasm (cancer), which has high death ratio, has been actively studied. There are several current cancer therapy as radiation therapy, surgical therapy, and chemotherapy (anticancer drugs), but these therapy have some disadvantages. The purpose of this study was to establish a new cancer therapy, using nanosecond pulsed electric fields (nsPEFs), with the less disadvantages.</p> <p>In vivo and ex vivo experiments using embryonic chick assay and in vitro experiment have been conducted to pulsed electric fields application experiments with 2ns-PEFs for mouse breast cancer cells: EMT6. The pulse-application experiments were carried out with mouse melanoma cells: B16-F10. When 2ns-PEFs were applied on solid tumors and cell suspension in an electroporation cuvette, significant effects were not observed. The cancer cells surviving fraction in suspension measured with WST-1 assay was not different to that of controls. Therefore, a pulse-application experiment with 14ns-PEFs was performed in vitro experiment using cell suspension, and compared with 2ns-PEFs. In this experiment, the cancer cells surviving fraction was measured with WST-1 assay and crystal violet assay. When the 2ns-PEFs were applied, the cancer cells surviving fraction did not change regardless of the number of pulses. On the other hand, the cancer cells surviving fraction decreased as the number of pulses increased in comparison with controls, when 14ns-PEFs were applied. The effect of pulse width and difference of effect between B16-F10 cells and EMT6 should be considered circumstantially.</p>	69

<p>[318] Effect of Reactor Diameter on NO_x Treatment Using Nanosecond Pulsed Powers <i>Presenter: ISHINO, Shingo</i></p> <p>Nowadays, environmental problems such as global warming, air pollution and acid rain are getting worse. Nitrogen oxides (NO_x) are one of causative substances of them. NO_x adversely affects not only the environment but also human body. Development of the NO_x treatment measure is, therefore, an important issue. In the conventional NO_x treatment method, the treatment equipment is large and expensive and requires large costs for maintenance as well. The efficient and low-cost equipment is indispensable in order for the equipment to spread even to developing countries. NO_x treatment using streamer discharges generated by nanosecond pulsed powers was studied. The streamer discharges are generated in the reactor using nanosecond pulse power would treat NO_x gas efficiently by plasma-chemical reactions. In order to obtain a more efficient removal treatment, adoption of thinner coaxial reactor was considered. Because streamer discharges distribute thickly around the inner wire electrode in the coaxial reactor driven by pulsed powers, the thinner coaxial reactor could utilize dense streamer discharges in the vicinity of the inner wire electrode. While the removal ratio was improved with decreasing the reactor diameter until 14 mm, the removal ratio decreased in using reactor of 10 mm. To discuss the phenomena, discharges in reactor were observed through an aperture on the outer electrode of an experimentally produced reactor. The appearance of discharges at downstream end of reactor in 10 mm reactor differed from 14 mm reactor. It was regarded as spark discharges occurred with electric field enhancement by shorter electrodes separation and voltage-wave reflection at the end. However, the dependence of appearance of spark discharges on NO_x removal did not become clear. Furthermore, the phenomena should be considered in detail, with waveforms of voltage and current of the reactor for an example, in order to optimize the reactor configurations for higher removal efficiency.</p>	70
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Poster session II - Pulsed Power Physics and Technology, Components and HV Insulation - Hall 4 / Cambridge

(13:30-15:00)

board

<p>[336] Dynamic Analysis of Streamer Discharge in Propylene Carbonate Due to Variation in Background Temperature <i>Presenter: ZHANG, Zicheng</i></p> <p>At present, liquid media are frequently used as energy storage dielectrics in pulsed power systems. The physicochemical properties of the liquid have a significant influence on the structure and properties of pulsed power devices. Propylene carbonate (PC) has great potential to be used as an energy storage dielectric in compact pulsed power sources due to its high dielectric constant, high resistivity and wide applicable temperature range. In this paper, experimental research on the development of streamer discharges in a needle-plane electrode system in PC at different background temperatures was carried out, using a compact pulsed power source based on a Tesla transformer, with an output pulse with duration in the microsecond regime. The dynamic changes of the breakdown voltage were recorded in real-time using an oscilloscope when the background temperature was constantly varying. At the same time, images of the streamer formation and propagation were obtained using an ultra-high-speed camera. The experimental data demonstrate that the variation of the breakdown voltage is closely related to that of the temperature. It was found that the expansion velocity of the streamer varied regularly with increasing temperature. An empirical formula based on the experimental data is provided and the streamer mechanism is analyzed. The experimental results offer a visualized dynamic analysis of streamer discharge in PC at different background temperatures, which will further promote the practical adoption of PC in pulsed power technology.</p>	71
<p>[354] An Analysis of Strike and Restrike Characteristics of the Exploding Film Phenomenon Under Different Temperature and Pressure Conditions <i>Presenter: ALLEN, James Nick</i></p> <p>Exploding films have potential applications as fast opening switches, current interrupters, and in the ignition of explosive materials. The exploding film phenomenon is a process in which a high voltage capacitive discharge is passed through a thin layer of metal particles on the surface of a dielectric film. Heat generated from the increase in current forces the aluminum particles from a solid state to a liquid state during an initial strike. While in this liquid state, a rise in current can initiate a restrike, causing a flashover event. In this work, an aluminum metallized polypropylene film (MPPF) is subjected to a 5 kV capacitive discharge under different temperatures and pressures. A comparison of electrical characteristics including current, voltage, and time for MPPFs during restrike is presented as a precursor to applications in dynamic environmental conditions.</p>	72

<p>[353] Long Term Evaluation of GaN HEMT under Overcurrent Operations</p> <p><i>Presenter: KIM, Matthew</i></p> <p>Abstract- As Silicon is reaching the theoretical limit, wide bandgap devices such as Gallium Nitride (GaN) transistors are being investigated as replacements for Silicon in high voltage and high temperature applications. To have a better understanding of GaN power devices operating under long term high peak current conditions, GaN devices were switched under the following conditions: high peak current of 330 A, 20-65 V, 0.5 – 75 Hz, and 20 μs pulse width. The device under test was rated for forward blocking voltage of 100 V and continuous drain current at 90 A and threshold voltage of 1.5 V. The device is a HEMT device and was manufactured by GaN Systems. This paper will discuss the long term evaluation and failure analysis of the devices. Results will show the peak current and IV characteristics both forward and reverse as a function of the number of shots taken. The RLC ring down circuit that was used as the testbed of the experiments will be shown in the paper. The device operated up to 5 million shots. Measurements taken were IV curves and transconductance, and threshold voltage of the device.</p>	73
<p>[351] Effect of Electrode Composition on the Partial Discharge Activity of a Pre-Stretched Dielectric Elastomer Actuator</p> <p><i>Presenter: MARTINEZ, Andrea</i></p> <p>Dielectric Elastomer Actuators (DEAs) are a class of electroactive polymers, materials which exhibit a mechanical strain as a response to an electrical stimulus, capable of achieving high actuation strains over 100 %. A key hindrance in the application of DEAs is their need for high voltage in order to actuate, leaving their operating range close to their breakdown range. Therefore, this work explores the analysis of partial discharge activity as a precursor to breakdown of DEAs. The voltage induced strain of a DEA is affected by their surrounding electrodes, which add stiffness to the system. The DEA may also be limited by electromechanical instability, a positive feedback loop caused by an increasing electric field and thinning elastomer, leading to electrical breakdown. Pre-stretching the elastomer results in the suppression of electromechanical instability. This paper presents a comparison of partial discharge and breakdown characteristics of a pre-stretched DEA based on electrode composition.</p>	74
<p>[341] Transmission-line-circuit simulations of Z with an ion-diode current-loss mechanism</p> <p><i>Presenter: HUTSEL, Brian</i></p> <p>A transmission-line-circuit model of the Z accelerator has been developed to aid in the design and analysis of experiments conducted on Z. The circuit model is based on the Bertha circuit code. Transmission line elements are used to represent Z's 36 pulse-forming modules, water convolute, vacuum insulator stack, outer magnetically insulated transmission lines (MITLs), vacuum post-hole convolute, inner MITL, and load. A 1D model of an enhanced ion diode has been implemented to simulate current loss within the high-current-density regions of Z, including the vacuum post-hole convolute and inner MITL. We present details of the transmission line circuit model and ion-diode current-loss subroutine. We compare simulation results with experimental data acquired on approximately 50 Z shots that were conducted with a variety of accelerator configurations and load-impedance time histories. The simulation results agree with power-flow and pinch-implosion measurements to within 2%.</p>	75
<p>[296] Impulse Breakdown Strength of Zinc Oxide / Epoxy Resin Nanocomposites</p> <p><i>Presenter: TURNER, Paul</i></p> <p>Over the past two decades, polymeric nanocomposite materials have been the centre of great attention in the research community. Mixing low concentrations of metal or metal-oxide nanoparticles into polymeric insulators has been shown to improve key characteristics of the material, such as thermal behaviour, mechanical strength and resistance to long-term degradation. Unlike traditional microcomposites, these advantages do not come at the price of electrical strength; investigations have shown that nanocomposites have similar or greater electrical strength when compared to their unaltered polymer form.</p> <p>This study focuses on the change in impulse breakdown strength of epoxy resin when nanoparticles are introduced into the host material. Nanocomposite samples are produced by mixing epoxy resin with zinc oxide nanoparticles at concentrations of 0.5, 1 and 2 wt%; unaltered epoxy resin samples are also produced to act as a control in the experiment. During mixing, nanoparticles are likely to cluster together, so ultrasonic waves are applied to the mixture to encourage their dispersion. Once cured, the samples are analysed with an electron microscope to ensure that the nanoparticles have been adequately dispersed.</p> <p>Each sample is subjected to high voltage impulses of increasing magnitude until a breakdown through the bulk of the sample is achieved. The test cell uses a needle-sphere electrode configuration (36 μm needle radius) with a gap of 6 mm to generate an electrical field sufficient to cause bulk breakdown of the sample. The interior of the test cell is filled with oil to prevent the occurrence of flashover events. Bulk breakdown of an unaltered epoxy sample is achieved by an impulse with 222 kV peak voltage and rise time of 100 ns.</p> <p>In future experiments, the samples will be electrically prestressed before the impulse is fired, with the aim of observing any changes in space charge behaviour within the nanocomposite samples.</p>	85

<p>[309] Characterisation of a Corona-stabilised Switch in Alternative Gas Mixtures</p> <p><i>Presenter: MACPHERSON, Ruairidh</i></p> <p>Sulphur hexafluoride (SF6) has traditionally been used as a switching medium within corona-stabilised switches (CSS). Due to its high global warming potential (GWP), however, other gases are under test in order to find a suitable alternative that can be used within CSS, without compromising on switching performance. Design changes may have to be made in order for the switch to remain at the high level of performance achieved when filled with SF6. This paper reports preliminary results obtained using a CSS operated with the refrigerant 1,3,3,3-tetrafluoropropene, known as HFO-1234ze, as the basis of the operating gas. The electronegativity of HFO-1234ze makes it an attractive option to replace SF6 for switching applications. Additionally, the global warming potential (GWP) of this gas is 6 in a 100-year time horizon, compared to SF6 with a value of 23900.</p> <p>The performance of the switch has been characterized in terms of voltage recovery, triggering range, delay time and jitter over a range of pressures when filled with dry air as a reference, as well as with HFO-1234ze in various mixtures with high proportions (>90%) of buffer gases such as carbon dioxide (CO2) and nitrogen (N2). The results presented provide data on the feasibility of the approach of using HFO-1234ze as the operating gas in corona stabilised switches. They will also provide the initial basis for work refining the use of buffer gases, and for the development of optimised switch configurations.</p>	89
<p>[306] A novel electrode material for spark switches</p> <p><i>Presenter: WU, Jiawei</i></p> <p>Although W-Cu alloy is widely adopted in breakers and spark switches as a kind of anti-ablation material, a series of problems including restriking, flashover, etc. still exist. For spark switches in pulsed power equipment, electrode erosion will cause a lot of problems. Not only the electrode surface, but the insulator surface can also be altered from shot to shot. Therefore, the selection of electrode material is vital for the stability and lifetime of spark switches. In this study, W-Ni-Fe alloy (90% mass percentage of tungsten) was utilized as the electrode material innovatively. W-Cu alloy (90% mass percentage of tungsten) was also adopted as a reference. A test platform including a microsecond time scale pulsed current source, loads, a chamber, and a diagnostic system has been established. Current and voltage waveforms were recorded by a Pearson coil and a North Star probe, respectively. Both the two pair of electrodes were tested for 10000 shots (~22000 C transfer). Both the two kinds of electrode were observed and measured by a confocal microscopy and an aspheric surface measuring instrument every 2000 shots. And the elements of the surface were also determined by XPS and XRD methods. The results demonstrated that W-Ni-Fe alloy was much better than W-Cu alloy when they were in spark switches.</p>	87
<p>[284] A 50 T high-stability flat-top pulsed magnetic field energized by a 100 MW pulsed generator-rectifier power supply with parameters self-adjusting model predictive control</p> <p><i>Presenter: YONGHENG, Huang</i></p> <p>High-stability flat-top pulsed magnetic field, which combines the advantages of pulsed high magnetic field and steady high magnetic field, is an important tool of scientific experiments in the fields of physics, biology, and chemistry. The pulsed generator-rectifier power supply, with controllable output voltage, is commonly used to power multi-coil magnet to generate synthetic flat-top magnetic field with high parameters. However, the coupling characteristics of coil current and the disturbance factors in the power supply side (such as the voltage amplitude fluctuation and the phase fluctuation) bring challenges to generate a high-stability flat-top pulsed magnetic field. Based on the 100 MW generator-rectifier power supply and the 50 T dual-coil magnet in WHMFC, this paper firstly propose a coupling transformer to decouple the dual-coil magnet. The mutual inductance of coupling transformer and dual-coil magnet are the same in value and opposite in direction, so the adverse effects, caused by the coupling characteristics between the coil current, can be eliminated. Then we propose a control method of high-stability flat-top pulsed magnetic field based on the parameters self-adjusting model predictive control. A prediction model of rectifier trigger angle is established by using characteristic equations of the rectifier and coupling equations between resistance of the magnet and output voltage of the rectifier. Considering the errors caused by equivalent model, PI close-loop control is used to automatically adjust the parameters of the model predictive control method. A simulation model is built by MATLAB/Simulink to simulate the discharge process, and a 50 T/470 ppm flat-top pulsed magnetic field is generated. The final experiment is expected to be completed in the spring of 2018.</p> <p>Acknowledgements: The National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.</p>	83

<p>[272] The Phenomena of Abnormal Discharges in Pseudospark Switch</p> <p><i>Presenter: HAN, Ruoyu</i></p> <p>Pseudospark switch, as a kind of low-pressure cold cathode gas switch, has broad application prospects and was studied for more than 30 years. Few researches reported the abnormal discharge in the switch which happened frequently in experiments. In our experiments, different from the hollow cathode discharge, three abnormal discharge modes, cathode sidewall to anode sidewall, cathode sidewall to anode hole and cathode plane to anode plane, were observed. The self breakdown of hollow cathode discharge only took a small proportion. Different voltage and pressure levels were tested and it was found that abnormal discharge occurred for several dozens of times and then disappeared which implied that they were irrelevant to applied voltage and gas pressure. These phenomena might be caused by the defects, salient and absorbed gas at the surface of electrodes which distorted the local electric field and were likely to emit electrons. What's more, asymmetric layout of electrodes may also lead to the abnormal discharge. All abnormal discharges developed along the relatively long path which was the characteristic feature of low pressure discharge and at the left side of Paschen curve. Therefore, when designing the switch, it shall be carefully noticed that concentration of electric field and long discharge path should be avoided.</p>	82
<p>[271] Experimental Study of Dielectric Insulator Behaviour under High Voltage Pulse</p> <p><i>Presenter: DE FERRON, Antoine</i></p> <p>Nowadays, in pulsed power applications, during the design of a modulator, it is necessary to take into account all problems linked to insulators and their capability to withstand a dielectric strength. Indeed, many of these modulators integrate transformers, allowing a significant increase of voltage. So, the first objective is to provide an adequate insulation to maintain compact size.</p> <p>This paper deals with the conception of a multi-primary pulse transformer, allowing a voltage increase of 40kV to 600kV with durations of 1μs. The constraints related to the size of the insulation have a direct impact on the value of the stray elements (leakage inductance and primary/secondary stray capacitance) which is directly related to the pulse waveform. It is therefore important to define a sufficient insulation without over-dimensioning it.</p> <p>An important criterion concerning the choice of the material is its dielectric strength but generally, the latter is characterized according to the IEC standard 60243-1 which defines this behaviour under DC and AC conditions. The data is not provided in pulsed mode. The problematic is then to choose a dielectric material without knowing this data.</p> <p>The aim of this paper is to carry out a comparative study of the dielectric properties of materials commonly used in pulsed power modulators in order to compare their behaviour in pulsed mode in relation to AC/DC mode.</p>	81
<p>[269] Nanosecond repetitive pulsed discharges under turbulent flow in atmospheric air flow</p> <p><i>Presenter: TANG, Miao</i></p> <p>The research of nanosecond repetitive pulsed discharges has received extensive attention [1-2]. It is valuable to study on gas discharges under the airflow, as well as flow control, discharge mode, etc. In this paper, we are focus on the discharges under motion law of charged particle of nanosecond pulsed discharges in the vortex flow, applied voltages and repetitive frequencies.</p> <p>FIG. 1. Schematic of experimental setup.</p> <p>This experimental setup is schematically shown in Fig. 1, which consists of DBD (dielectric barrier discharge) configuration, detour flow configuration and airflow system.</p> <p>The turbulence intensity and pressure of flow field under detour flow configuration obtained from the fluent model are visualized in Figure 2a and Figure 2c. The intensity and pressure of flow field have a periodic change and the simulation results are common to Karman Vortex Street. The discharge photographs are captured by a high speed camera with 1/1000 s exposure time in Figure 2c.</p> <p>a b c</p> <p>Fig.2 Experimental and Simulation Results</p> <p>a The simulation of turbulence intensity b The simulation of pressure</p> <p>c The patterns of discharge</p> <p>For the voltage amplitude of 20 kV and frequency of 1000 Hz, top view images of DBDs like simple-harmonic wave that has periodic change good agreement with the simulation results. When the discharge is generated in detour flow, it presents as a bunch of parallel filaments distributed in the discharge gap. The spatial distribution of microdischarge is significantly influenced by detour flow effect. Therefore, nanosecond repetitive pulses of the discharge can be affected by detour flow under the condition of a certain voltage amplitude and frequency.</p> <p>[1] De-Zheng Yang . APL 102, 194102.</p> <p>[2]M. S. Bak. APL 98, 011502.</p>	80

<p>[247] Some scaling rules for ferrite-loaded coaxial lines <i>Presenter: MOTTA, Claudio</i></p> <p>In this work a description of behavior of ferrite-loaded coaxial lines is carried out by solving the gyromagnetic magnetization equation for the ferrite coupled with the Maxwell equation for transmission line in time domain. The influence of induced radial and axial magnetic field components in the ferrite magnetization is investigated as well the rise time of input high voltage. The model is used for different ferrite types. From the results is possible to outline some scaling rules concerning magnetic properties, physical dimension of ferrites and the coaxial lines.</p>	76
<p>[254] Development of a novel insulation aging test system based on the high-voltage high-frequency square pulse generator <i>Presenter: ZUO, Zhou</i></p> <p>In the recent decades, together with power electronics technological advancements, an emerging technology, solid state transformer (SST), has attracted great attention and been extensively investigated for smart grid, while mainly focusing on the research of available and efficient circuit topologies. As the core component of SST, the high frequency power transformer, which replaces the traditional 50/60 Hz transformer to the achievement of voltage converting and power transmission, operates in the high voltage, high power, and high frequency (HV-HP-HF) condition, subjected to the square impulse voltage with steep front edge, high amplitude and high pulse repetition frequency. Compared with the conventional transformer, less space is expected and oil-free operation is preferred in the high frequency transformer. As a consequence, the insulating system would face austerity challenge. With the advancements of SST to increasingly high voltage and power rating, severe insulation issues and challenges need to be addressed. In order to investigate the dielectric properties and ageing of insulation materials of the high frequency transformer subjected to the square pulse output from electrical electronic inverter, a novel insulation aging test system, consisting of a high direct-current voltage source, a full bridge converter utilized single-tube IGBTs with a control circuit, drive circuits and overcurrent protection circuits, and test unit, was developed to simulate the real operation condition. The designed and final performance specifications are as follows, the bi-directional voltage with the maximum of 5kV, the adjustable peak-to-peak value from 0 to 10 kV, the adjustable frequency from 100Hz to 1 kHz, duty circle closer to 50%, the rise time about 300ns, at least 5kW output power depending on the high direct-current voltage source, additional over-current and over-voltage protection functions.</p>	77
<p>[255] The measurement of pulsed magnetic field by a non-contact differential ring <i>Presenter: ZHOU, Wenting</i></p> <p>ABSTRACT:A high-current pulse generator of 112.5kJ capacitor bank has been developed for electromagnetic pulse welding. It made up of six paralleled 18.75kJ modules, every module is mainly made up of four paralleled capacitor and a trigger vacuum switch. The high-current pulse generator has been designed and fabricated for maximum operating voltage of 25kV, peak current of 1MA. Using a non-contact measuring method for the measurement of pulsed magnetic field and pulsed current, it can design the structure of a differential ring. The main principle is that when the pulsed magnetic field passed through the center of the differential ring, due to electromagnetic induction principle, the differential ring generates a pulse current with respect to the pulsed magnetic field. At the same time, the load part of differential loop is connected with a low resistance. By measuring the voltage generated of the resistor and the Faraday's law of electromagnetic induction, can it calculate the size of the pulse current and pulse magnetic field.</p>	78
<p>[257] Pulsed Power Calibration and Test Benches at Epure <i>Presenter: GEORGES, Alain</i></p> <p>The 1st radiographic axis of Epure, shared French and British facility, is a linear induction accelerator, a complex system with parts standing out as more critical. Those parts are tested and calibrated on dedicated benches. Two such benches are described here.</p> <p>The beam evaluation is essential to the right performance of the whole machine. To have good quality assessment of beam relevant characteristics, we benefit on one hand, from both good quality initial conception and built of Beam Position Monitors, on the other hand, from newly developed and precise test benches. Assessment of the measurements quality and reliability is presented.</p> <p>Another critical component is the magnetic material used as a core for inductive insulation of the accelerating cells. Full characterization of the B-H hysteresis curves of those cores requires a specific test bench, able to reach high frequencies and large magnetization swing, in order to meet both ease of use to follow core production needs and the electrical requirements of an accelerating cell. Qualification methodology is presented.</p>	79

<p>[295] Optimal Design of High Frequency Transformer Based on Fe-based Amorphous</p> <p><i>Presenter: XU, Yun</i></p> <p>With the wide application of power electronic technology in pulsed power supply, high frequency and high voltage transformer has become one of the research hotspots. Magnetic core materials such as Ferrite and Nanocrystalline have excellent high frequency performance. However, they are seldom applied to high power situation by the limits of its manufacturing process. Though Fe-based amorphous has been widely used in the power frequency transformers, this material is rarely applied to high frequency high power transformer. In view of the fact that Fe-based amorphous is easy to cut, convenient to wind and capable of high power, the feasibility of Fe-based amorphous in high frequency transformer is presented in this paper, and the optimal design based on the finite element method and genetic algorithm of Fe-based amorphous transformer is proposed to achieve maximum efficiency.</p> <p>The optimization objective of efficiency is achieved by changing the geometric parameters to optimize the winding size and the number of turns. Besides the main objective, it has four constraints: total losses, temperature, flux density and core window. Through the combination of Comsol and Matlab, the total losses and temperature of the transformer calculated by finite element method were plugged into the genetic algorithm instead of the theoretical value. It has improved the optimization accuracy and solved the theoretical problem in calculating the Fe-based amorphous loss and temperature. According to the optimal design results, a 15 kHz, 2.5kVA prototype transformer with 230V input voltage and 1.5 kV output voltage has been designed and tested in the series resonant power supply. Experimental results are presented to indicate the Fe-based amorphous can satisfy the efficiency requirements of high frequency transformer using the optimization algorithm. The optimal design has a strong guiding significance for the application of Fe-based amorphous magnetic cores in the high frequency and high power devices.</p>	84
<p>[303] Preliminary pulsed power design of an induction injector for radiographic applications.</p> <p><i>Presenter: CASSANY, Bruno</i></p> <p>In order to be able to propose a dual pulse accelerator for future flash X-rays capabilities, a preliminary design of a high current induction injector has been developed. This design is based on the use of dual pulsed power generators actually available in the lab. The architecture, the number of cells needed and the dimensions of the conductors are evaluated with the hypothesis of using large METGLAS magnetic core similar to those used on RITS-6 IVA machine and breakdown probability in the insulating oil. The dynamical behavior of the magnetic material under two pulses excitation is analyzed with a non-linear magnetic diffusion model. The choice of the impedance coupling between the generators and cells is based on the flat top requirement on the output energy of the electron beam. Additionally, the results of global spice simulations are illustrated.</p>	86
<p>[268] The triggered vacuum switch test based on the electromagnetic pulse welding</p> <p><i>Presenter: WANG, Xiaoyu</i></p> <p>Abstract: A new triggered vacuum switch (TVS) was designed and tested. The TVS was successfully tested up from 500V to 10kV peak charging voltage. Compared to other typical switches, the tested switch showed high reliability of trigger voltage, trigger current. The TVS is used for a high-current pulse generator of 112.5kJ capacitor bank, which has been developed for electromagnetic pulse welding. The equipment is made up of six paralleled 18.75kJ modules, every module is mainly made up of four paralleled capacitors and a TVS</p>	88
<p>[312] The Behaviour of Surface Discharges on a Liquid Nanocomposite Interface</p> <p><i>Presenter: GIVEN, Martin</i></p> <p>The addition of nanoparticles with conducting and semiconducting properties to liquid and solid insulation systems is a current area of active research interest. In liquid insulation the nanoparticles have been shown to improve the breakdown strength of certain liquids due to their ability to scavenge free electrons from the system. In solid nanocomposites improvements in the physical properties of the insulation system such as tracking resistance, mechanical strength and thermal conductivity, have been achieved. In terms of their dielectric properties the behaviour of these nanocomposites is complex and traditional approaches to determining these properties using the approaches of Bruggerman or Maxwell Garnet have not been successful. It is believed that the changes in the dielectric properties do not come simply from the properties of the nanoparticle itself but also from the changes in the structure in the matrix surrounding the nanoparticle. This leads to a 3 phase system with more complicated behaviour in both effective medium approximations and in percolation.</p> <p>The optical and electrical behaviour of surface discharges, caused by the application of 50 Hz sinusoidal voltages in the range of 30 to 45KV, on epoxy based nano composites under mineral oil have been measured. The solid nanocomposites used contained either ZnO nano particles at concentrations between 0.1wt% and 3wt% or Al₂O₃ nanoparticles at 0.1wt% and 0.5wt%. The optical behaviour of the surface discharge has been quantified in terms of: maximum discharge channel length; integrated optical emission and fractal dimension. The electrical behaviour of the discharge has been quantified in terms of the measured partial discharge activity. The behaviour of the surface discharge activity is discussed in terms of the changes in these measured parameters as the applied voltage, the type of nanoparticle and the nanoparticle concentration is varied.</p>	90

Poster session II - High-Energy Density Physics and Technology - Hall 4 / Cambridge (13:30-15:00)

board

[402] The pulsed plasma accelerator with focusing electrodes experiments

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Presenter: ZHUKESHOV, Anuar

Today, the efforts of scientists to solve problems of fusion associated mainly with magnetic systems, primarily with tokamaks and etc. One of alternative method is plasma focus (PF) installations, based on the focusing of the plasma beam in a small area with high density. Using of coaxial pulsed plasma accelerator equipment, the authors had aim of creation of focus reactor with current about 1 MA . In this work, the experiments are conducted on the basic of pulsed plasma accelerator "CPA-30" with a new focusing electrodes from massive copper cylinders. The experimental device consist of vacuum chamber of Mather type, the capacitive energy bank 75 microF, 50 kV , vacuum switch and current leads.

First, the discharge current dates is obtained when the charging voltage of the capacitor bank variety from 6 to 20 kV. Then we interpret the current curves using of electrodynamic models and calculations. Experimental results show that the discharge current does not exceed 300 kA even at the maximum charge of 30 kV.

Analysis of experiments and calculations show, that the curve of the discharge current of a new PF installation has a period 14 microsec. It is equal to the previously obtained values for the accelerator CPU-30, which is determined by the inductance of the vacuum switch. Current limit amplitude, here, apparently due to the size of the electrodes so as to form a focus on a large scale requires more current. Therefore, to increase the discharge current is requiring increasing the capacity and voltage, or reducing the electrodes size. With existing energy equipment, the second way seems more acceptable. On this way, now we are development the device with small focus electrodes and without vacuum switch.

[394] Measuring the compression velocity of a Z pinch in an axial magnetic field

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Presenter: BAKSHT, Rina

Presentation demonstrates the results of measurements of the plasma boundary velocity during the compression of a metallic gas-puff Z pinch in an axial magnetic field. The experiment was conducted on the IMRI-5 facility (current pulse of 450-kA amplitude with a 450-ns rise time); the initial magnetic field B_z0 was varied in the range 0.15–0.6 T. The trajectories of radius vs time were constructed using two independent methods. First is well known technique: it is determination of an "inductance radius" rind using the dependence of the pinch inductance vs time. Second is a new techniques: it is using the B-dot probes for the determination of current sheath motion. The data obtained with the B-dot probes agree with the results obtained by other methods (optical imaging and determination of the pinch radius as a function of the time-varying pinch inductance $L(t)$). It is shown that the plasma compression velocity is $(1-1.5)\times 10^7$ cm/s at the implosion without the field B_z and 0.6×10^7 cm/s at at the implosion with $B_z = 0.6T$.

Work supported by the grant of the Russian Foundation for Basic Research (grant No.17-08-00131-■ and No.15-08-03845-■)

[357] Status of Linear Transformer Driver Facilities for High Energy Density Physics Experiments at the University of Michigan

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Presenter: MCBRIDE, R. D.

The Michigan Accelerator for Inductive Z-pinch Experiments (MAIZE) is a 3-m-diameter, single-cavity Linear Transformer Driver (LTD). MAIZE supplies a fast electrical pulse (0–1 MA in 100 ns) to various experimental configurations, including wire-array z-pinches and cylindrical foil loads. MAIZE is the first LTD of its kind in the United States, and it has been operational at the University of Michigan (UM) since 2008. The MAIZE cavity was originally developed at the Institute for High Current Electronics in Tomsk, Russia, and later transported to UM through a collaboration with Sandia National Laboratories.

This talk will report on the progress of several projects aimed at upgrading the MAIZE facility. Within the next 12 months, MAIZE will be equipped with a new ultraviolet laser shadowgraphy system; a 2-frame, 1–20 keV x-ray radiography system based on x-pinch backlighting; and one or more time-gated 4-frame extreme ultraviolet imaging systems. These diagnostics will complement the existing 12-frame laser shadowgraphy system recently developed for MAIZE. In addition to new diagnostics, MAIZE will be equipped with a gas-puff z-pinch nozzle and/or a dense plasma focus (DPF) head. This will enable neutron source development as well as projects to better diagnose these neutron sources (e.g., advanced neutron imaging).

In addition to MAIZE, UM will be constructing a second, smaller LTD facility consisting of four 1.25-m-diameter cavities. These cavities were previously part of Sandia's 21-cavity Ursa Minor facility, which is being reconfigured to serve new missions. These 4 cavities will be assembled at UM such that experiments can be driven with 1, 2, 3, or 4 cavities stacked together. Stacking multiple cavities together increases the voltage and impedance of the driver while leaving the current nominally unchanged. This will enable the investigation of driver impedance (or machine "stiffness") effects on pinch performance.

*Work supported by grants/contracts US-NRC#:F043636 and US-DOE#:DE-AC04-94AL85000.

<p>[339] An Oil-Free Compact and Portable X-Pinch Radiation Source: Overview and Radiation Performance</p> <p><i>Presenter: SPIELMAN, Rick</i></p> <p>This work presents a novel, compact, and portable x-pinch radiation source developed and tested at Idaho State University. The salient features of our x-pinch radiation source are its simplicity, compactness, and portability: there is no oil, no water, and no SF6. It can be easily relocated to any place where a compact x-pinch radiation source is wanted. Despite its simplicity, it generates a very fast and bright radiation pulses comparable to other x-pinch drivers. Measurements indicate that 2- to 6-ns wide XRD signals were reproducibly formed in the 190-ns to 250-ns time window after the current start from 2x30-μm Mo x pinches. Source size measurements indicate that this radiation originates from a small, 12-μm in diameter dense plasma, known as a "hot spot".</p>	27
<p>[334] GeV-positron beams as a novel branch of the experimental basis for HEDP.</p> <p><i>Presenter: GOREV, Vladimir</i></p> <p>It is now becoming clear that future applications of the readily available form of antimatter, namely positrons, especially in the form of power high brightness positron beams, will lead to the excellent progress in a few avenue of inquires of HEDP and, consequently, it will be next stop for HEDP experimental basis. Especially, this is concerning with clue and stubborn problems as high velocity macroparticle acceleration for physical ballistics research, trims the size of heavy ion accelerator for ICF, radiation for giant resonance investigations and any others. In this report we will discuss modern theoretical research and suitable nowadays experimental chances.</p>	28
<p>[292] The efficiency of the pulsed power input in the limited plasma diode</p> <p><i>Presenter: HRECHKO, Yaroslav</i></p> <p>The work deals with obtaining the high pulsed power in the high-current plasma diode. Under certain conditions in the diode, the space charge electric double layer is formed in the current-carrying plasma. Almost all active discharge voltage focuses on it. The powerful electron and ion beams accelerated in the layer can be used both for the solid surface treatment, and for the plasma heating. In the last case the fast and local energy input into the plasma occurs.</p> <p>The investigations were carried out using the high-current plasma diode with a limited working surface of high-voltage electrode. Such scheme provides the stable double layer localization near the work surface. The working surface limitation was carried out by means of ceramic insulator which closed the high-voltage electrode side surface. The current density on the electrode could reach up to 2 A/cm^2. Under conditions of the double layer formation at relatively small stored energy in capacitor bank (up to 200 J) it is possible to get over 100 MW pulsed power inputted into the discharge. This allows using such diode for generating the powerful directional EUV radiation. The observed radiation power at a wavelength of 13.5 nm reached up to 3 MW.</p> <p>For correct calculation of the active power dynamics inputted into the discharge it has been developed the calculation method based on the discharge current dynamics. The key points that influence on the results accuracy have been determined.</p> <p>Since the double layer is a powerful dynamic system, the works on separation of the double layer current capacitive component from the discharge current have been carried out. The obtained in quasi-MHD approximation the expression for the strong double layer capacity shows that in our case at the layer voltage $V_{DL} \sim 100$ V, the layer capacity reached $C_{DL} \sim 0,5$ μF!</p>	45
<p>[260] Effects of the Transport Properties of Gaseous Medium on Arc Behaviors in a Supersonic Nozzle</p> <p><i>Presenter: ZHANG, Jinling</i></p> <p>Modern high-voltage auto-expansion circuit breakers utilize the gaseous medium flowing through a supersonic nozzle to produce adequate conditions for arc quenching at current zero. The behaviors of arcs burning in such nozzles are closely related to the properties of the medium. SF6 is currently used as working medium because of its excellent dielectric properties. However SF6 is a strong greenhouse gas. The replacement of SF6 with a more environmentally friendly gas is becoming an increasingly interesting research topic. PC-based arc modelling has been carried out for a supersonic nozzle with geometry and dimensions comparable to industrial products [1]. The influence of material properties on arc quenching capabilities has been studied for the three different gases of SF6, CO2, and N2. The results show that, with the nozzle geometry under investigation, the temperature fields with the three fillings are similar during the high current period. However, when the current drops below 30 kA, especially when the current drops towards its final zero, the arc column could not shrink in radial direction properly with CO2 and N2. This phenomenon also was found in a 245 kV auto-expansion circuit breaker [2]. The work reported here is an extension of the work in [1] and [2]. It focuses on the effects of the transport material properties of the mediums on arc behaviors. The supersonic nozzle of Campbell et al [3] used in [1] is also used in the present work for the comparison's sake. The thermal recovery and dielectric recovery processes following the extinction of an arc in the supersonic nozzle have been simulated. The RRRVs (rate of rise of recovery voltage) have been predicted for the different transport properties under the same thermodynamic properties and other operation conditions. The effects of transport properties on the interruption capability will be analyzed in detail.</p>	44

<p>[168] Scaled DC Lifetime, Test and Evaluation of Advanced Nanocomposite Materials for Compact High Voltage Capacitors</p> <p><i>Presenter: CURRY, Randy</i></p> <p>A high dielectric, nanodielectric, composite material, MU100, was originally developed by the University of Missouri for use in dielectric loaded antennas. Based on its material properties, dielectric strength and losses, it was determined that MU100 had possible uses in the development for high energy-density capacitors.</p> <p>This paper presents the dielectric properties of the materials under development for high energy-density pulsed power applications, relevant to the application of compact high voltage capacitors, as well as recent advances which have been demonstrated during the test and evaluation of these materials. Small scale tests have shown that the average dielectric strength of MU100 to be 225kV/cm with a peak break down field of 328kV/cm. These same small scale capacitors, when potted, have been demonstrated to have lifetimes in excess of 800,000 discharges at 80% of their maximum rated field strength.</p> <p>■Work supported by the JNLWD under contract number W15QKN-14-9-1001</p>	40
<p>[156] Experimental simulation of primordial nucleosynthesis nuclear processes by applying high-powered lasers.</p> <p><i>Presenter: LOBANOV, Alexey</i></p> <p>Recently the research pace in the field of laboratory astrophysics is rather high. Powerful lasers became an important class of experimental setups for laboratory astrophysics. Currently, it became possible to increase the laser pulse energy up to hundreds of joules while reducing the duration to hundreds of femtoseconds, which corresponds to reaching the petawatt power level. By this means the peak intensity at the target surface reaches 10^{22} W/cm². When the matter is exposed by multiterawatt laser radiation, plasma occurs with unique parameters – ions energy on the MeV (10^6 eV) level, magnetic field up to gigagauss (10^9 G) and a pressure exceeding a billion of atmospheres. As such lasers were developed physics got a unique tool to study various astrophysical processes through their laboratory simulation. For the experimental simulation of primordial nucleosynthesis nuclear processes by applying powerful lasers it is necessary to obtain the laser plasma temperature $T \sim (0.4 - 0.9) \times 10^9$ K and the average energy of the particles $\overline{\epsilon}_{\text{particles}} = \frac{3}{2} kT \sim (50 - 110)$ keV and of the photons $\overline{\epsilon}_{\text{gamma}} \approx 2.7kT \sim (90 - 210)$ keV, that are common for primordial nucleosynthesis conditions.</p> <p>The results of experimental studies of our laboratory show that in laser-produced plasma with laser intensity of 2×10^{18} W/cm² it is possible to obtain such characteristics of the plasma. The results on the initiation of nuclear fusion reactions of primordial nucleosynthesis, including $D(d, n)^3\text{He}$, $^3\text{He}(d, p)^4\text{He}$, $^7\text{Li}(p, \alpha)^4\text{He}$, $^6\text{Li}(d, \alpha)^4\text{He}$, $^{11}\text{B}(p, 3\alpha)$ nuclear reactions in laser-produced plasma were obtained.</p> <p>In our opinion, the study of nuclear reactions in laser plasma which parameters are similar to parameters of primordial nucleosynthesis plasma is the most promising way to study the problems of primordial nucleosynthesis, including the lithium problem.</p> <p>The work is supported by RFBR Grant No. 16-02-00350.</p>	39
<p>[125] The study of three-dimensional compression of wire arrays at the Angara-5-1 facility.</p> <p><i>Presenter: GRITSUK, Arkadii</i></p> <p>Implosion of quasi-spherical wire arrays opens the possibility of more efficient use of the kinetic energy of the material being compressed to create a source of soft X-rays (SXR), compared to two-dimensional compression in the case of a cylindrical wire array. This is due to the contribution of the kinetic energy of the axial movement of the plasma into the internal energy of SXR source. An additional advantage of three-dimensional implosion is more symmetrical spatial distribution of the plasma, which allows achieving greater uniformity of energy flux on the target. The purpose of the experiments was to achieve three-dimensional synchronous compression of the plasma in the geometric center of a quasi-spherical array. Quasispherical arrays with different initial distribution of linear mass on the wires have been used to find optimal synchronization conditions. We used a set of independent diagnostic techniques for measuring spatial-temporal characteristics of the plasma compression dynamics and its dependence on the linear mass profile of quasi-spherical arrays. It is shown that the measurement of the magnetic field in the plasma of quasi-spherical array provides information about the production and dynamics of the plasma flow from different regions of the array. For the optimal linear mass profile ($m_l(\theta) = m_0/\sin\theta$), it follows from the measured distribution of the azimuthal magnetic field that, in the stage of plasma production up to the SXR pulse, the plasma with the frozen-in magnetic field penetrates the array from the polar and equatorial regions almost synchronously. The size and shape of the X-ray radiation source in quasispherical current implosion were inferred from plasma emission spectrum measurement with spatial resolution and registration of framing X-ray images. Estimation of the radiation flux on the surface of such a source was received.</p>	37

<p>[87] RADIOGRAPHIC RESEARCH OF THE METAL-PUFF PLASMA JETS FORMED BY THE VACUUM ARC DISCHARGE</p> <p><i>Presenter: ROUSSKIKH, Alexander</i></p> <p>Soft x-ray radiography ($\approx 1\div 2$ keV) of a bismuth and aluminum metal-puff plasma formed by the high-current vacuum arc discharge is presented. The plasma gun with the arc current ≈ 60 kA and the current rise time ≈ 7 μs was used to produce a metal-puff plasma jets. The compact pulsed radiograph XPG-1 (250 kA, 220 ns) with X-pinch and PZ-pinch load was used as a source of the soft X-ray radiation. X-pinch load consisted of four Mo wires with diameter 25 μm. PZ-pinch load is a miniature plasma jet. Jet length is equal to 1.5 mm. The spatial and temporal parameters of the radiating hot spot of X-pinch and PZ-pinch loads are close to each other. X-ray backlighting images of the researched plasma jet and the Bi step-wedge with a step thickness of ≈ 100 nm were recorded simultaneously at the experiment. The comparison of the plasma jet x-ray image has enabled to estimate the dependencies of the jet linear mass on the arc current. Experiments have shown that when the arc current density reaches $\approx 3\cdot 10^5$ A/cm² the evaporation rate of the electrode material reaches ≈ 100 μg/μs, that under the plasma velocity ≈ 0.5 cm/μs provides a plasma jet linear mass ≈ 200 μg/cm. At a distance of $\approx 1-2$ mm from the arc cathode surface the sharp increase of jet linear mass (up to ≈ 500 μg/cm) was occurred.</p> <p>Work supported by the grant Russian Scientific Foundation # 16-19-10142.</p>	35
<p>[83] Surface Current Density Distribution Measurements of an Electrically Exploded Foil via B-dot Probe Array Data Inversion, Revised</p> <p><i>Presenter: RUDEN, Edward L.</i></p> <p>Measurements are presented of the current per unit length as a function of time and transverse distance from the center of a water-tamped 80 μm thick Al foil as it explodes into warm dense matter by Ohmic heating. The foil width narrows smoothly to a central width of 15.2 cm, across which the measurements take place. Current is delivered from a 36 μF capacitor bank charged to 30 kV and discharged to a peak current of 342 kA in 2.0 μs. The distribution is calculated by the linear regularized inversion of signals from an array of B-dot probes distributed along the foil's central half-width. The probes are far enough away from the foil (1 cm) to be noninvasive and mechanically undisturbed during the time of interest. These results are compared to 3-D MHD ALEGRA simulations of the geometry externally coupled to a two-loop lumped circuit model representing the driver. Surface current density is strongly peaked at the foil edges for low-current calibration tests, where conductivity is essentially constant. It is broadly peaked in the center at the time of peak current for the high energy shot, though, due to the foil fusing first at the edges, which subsequently reduces current density there relative to the center by the time of peak current. There is broad agreement in this regard between the experiment and ALEGRA using thermal and electrical conductivity model SNL Sesame 29373. ALEGRA calculates that current peaks 0.5 μs earlier, though, and with a 50 kA higher current. This may be due to error in the conductivity tables or effects not well-modeled, such as an electro-thermal instability that results in higher total resistance, but with a distance scale too small for the present simulation to represent. This work is a revision of that presented at IPPC 2015.</p>	34
<p>[79] A portable X-pinch driver for hard X-ray radiography, diffraction and absorption measurements</p> <p><i>Presenter: BLAND, Simon</i></p> <p>High energy density physics experiments often require the use of short pulses of hard X-ray probing radiation to make measurements of the conditions produced – for instance using X-ray diffraction to examine phase changes as a material is subject to multi-Mbar pressures. In pulsed power experiments such probing radiation has often been produced by an X-pinch, where two or more crossed fine metallic wires are driven by a ~ 100kA 100ns current and the magnetically driven implosion at the crossing point of the wires causes the formation of a micro-diode.</p> <p>Until recently the pulsed power requirements for driving X-pinchs have limited their use. Often the X-pinch has utilized the same current pulse driving the experiment it is probing – limiting the time scale over which it can probe - and many 'portable' drivers in reality weigh several 100kgs, and have the location of the X-pinch fixed directly on top of a capacitor bank/water line making them difficult to field.</p> <p>We report on a new X-pinch driver in development at Imperial College London. The driver is based on LTD brick technology, utilizing ball gap switches and dry air/plastic insulation. The overall size of the driver is $\sim 30\times 30\times 90$ cm including a stalk of 7cm diameter, 25cm long to enable insertion into external vacuum chambers. The weight of the driver is $\ll 100$kg, and it can be orientated in any direction. It should be capable of producing currents up to ~ 200kA in 270ns; resulting in ~ 100mJ bursts of 22keV radiation from a silver wire load.</p> <p>Acknowledgements This work was supported by the Institute of Shock Physics, funded by AWE Aldermaston, and the NNSA under DOE Cooperative Agreement Nos. DE-F03-02NA00057 and DE-SC-0001063.</p>	31

<p>[34] OVERHEATING INSTABILITY OF A THIN CONDUCTOR WITH RESPECT TO STRATIFICATION</p> <p><i>Presenter: GARANIN, Sergey</i></p> <p>We consider an overheating instability of a thin (compared to the skin depth) conductor with respect to stratification at the stage when its resistivity rises up to an electrical explosion. Temperature perturbations under such conditions are shown to grow in proportion to resistivity. In the model, when resistivity is proportional to temperature, perturbations grow in proportion to temperature and hence exhibit no relative growth. For a conductor with initial thickness perturbations, temperature perturbations grow in proportion to resistivity and current action integral, i.e., somewhat faster than perturbations in the problem of constant thickness conductor. Comparison of our results with simulations of the growth of stratification during electrical explosion of foils in warm dense matter systems [1, 2] demonstrates their close agreement.</p> <p>1. S. F. Garanin, S. D. Kuznetsov, R. E. Reinovsky, "Feasibility of Warm Dense Matter generation using aluminum and copper foil electrical explosion under the PHELIX facility current drive," J. Appl. Mech. Tech. Phys., V. 56, No. 1, pp. 10-15, 2015.</p> <p>2. S. F. Garanin, S. D. Kuznetsov, and R. E. Reinovsky, "Study of the feasibility of Warm Dense Matter generation using metal foil electrical explosion under megaampere current drive," Digest of Technical Papers, 20-th IEEE Int. Pulsed Power Conf., Austin, TX, USA, 2015, pp. 622-627.</p>	29
<p>[40] A numerical plasma model of DBD Xenon Light source for VUV Radiation Emission</p> <p><i>Presenter: LOUKIL, Halima</i></p> <p>Abstract-</p> <p>We study in this article by a numerical model the plasma characteristics of dielectric barrier discharge in pure xenon. The 1D Siglo T-R model developed in this paper is based on the resolution of two moments of Boltzmann equation with approximation of local electric field. The discharge model is driven by an external sinusoidal voltage waveform and was achieved and studied in the pressure of 200 torr, at frequency of 50 kHz. The results discuss time variation of current density, plasma and dielectric voltages. Also, spatiotemporal evolution of electric field, ion and electron densities was calculated.</p> <p>Key-words-</p> <p>Sinusoidal voltage, Dielectric barrier discharge (DBD), Xenon, 1D model, electric field.</p>	30
<p>[81] Implosion of shock wave generated by an underwater electrical explosion of spherical wire array</p> <p><i>Presenter: EFIMOV, Sergey</i></p> <p>Recent experimental results on strong shock wave (SSW) convergence are presented. Converging SSW was generated using underwater electrical explosion of a spherical wire array with radius of either 10 mm or 15 mm. Arrays were composed of 40 either Al or Cu wires. Wire diameter was adjusted to obtain the aperiodic discharge current with amplitude ≤ 240 kA and rise time of ≤ 800 ns. As a result of SSW implosion a strong light emission of a water with duration of ~ 60 ns was obtained in the vicinity of the array origin. The continuous spectrum of this light emission was analyzed using spectrometer with array of 16 photomultiplier tubes at its output. Applying black body approximation, the temperature of the surface of the light emitted volume was estimated of ~ 0.7 eV. It was shown that the obtained time-of-flight of the SSW and emission spectra agree well with the results of the 2D hydrodynamic simulation coupled with equation of state for water and radiative transfer model. Namely, these simulations showed that the water density, temperature and pressure should be larger than ~ 3 g/cm³, ~ 1.4 eV and $\sim 2 \cdot 10^{11}$ Pa, respectively, at radii < 25 μm with respect to the origin of the SSW implosion.</p>	32

<p>[82] Modern radiographic complexes based on ironless pulsed betatrons. Conception of radiographic complex for small-angle tomography.</p> <p><i>Presenter: SHAMRO, Oleg</i></p> <p>The conception of creating a mobile radiographic complex based on ironless pulsed betatrons is proposed for radiography of dynamic objects having large optical thicknesses. Realization of this conception allows: a) optimizing of a geometry of the hydrodynamic experiment at the expense of the radiation source and recorder position relatively to the test object, located in the explosion-proof chamber(EPC). This lets increasing twice intensity of the x-ray radiation in the recorder plane compared with available Russian complexes; b) creating an efficient environment protection system at the expense of localization of dangerous explosion products and caused shock wave; c) significantly decreasing of the cost of the complex due to lack of expensive heavy casemates and their infrastructure. Instead of them it is possible to use cheap rapidly erected constructions. The mobile radiographic complex is described. Its achieved characteristics during the testing exploration were adduced. Thickness of the lead test at 1,5m from the tantalum target at the limiting energy of the betatron electron beam $E_{lim} \sim 13$ MeV(it is determined by the value of a capacitive storage of the pulsed powering system of the electromagnet) was ~ 120 mm. Conception of a multibeam complex creation based on ironless pulsed betatron for small-angle tomography was also considered.</p>	33
<p>[118] RESULTS OF OVERMASS Z-PINCH IMPLOSION IN EXPERIMENT WITH MAGNETO-CUMULATIVE GENERATOR</p> <p><i>Presenter: REPIN, Boris</i></p> <p>This paper demonstrates experimentally recorded peculiarities of a dynamical Z-pinch powered with the current from a magneto-cumulative generator. The overmass load represents a cylindrical multiwire array consisted of 680 tungsten wires of diameter $d^* = 11 \mu\text{m}$ and length $l^* = 1.5$ cm (total mass $M^* = 4.14$ mg). The wires were evenly located on a cylindrical surface of the radius $R^* = 3$ cm. Maximum amplitude of a current passed through the load was $I^* \approx 4.3$ MA (current rise time $\tau^* \approx 0.9 \mu\text{s}$ on a level of 0.1...0.9). That was significantly lower than the current of ~ 14 MA that was used in optimal implosion regime of arrays with such initial mass and radius.</p> <p>In spite of significantly underpowering of the load, in the experiment we recorded soft x-ray radiation (SXR) pulse that have characteristic full width at a half maximum of ~ 10 ns and energy of several hundreds of kilojoules.</p> <p>Two-dimensional magneto-hydrodynamic (MHD) code FLUX-rz (developed in RFNC-VNIIEF) was used for numerical simulation and analysis of the obtained results. The calculation-physical model includes the radiation transfer in a multi-group diffuse approximation [1]. The process of a substance ablation from the array wires under the influence of the conducting current is described in the model of prolonged plasma formation [2].</p> <p>Performed simulation allowed to find a number of peculiarities of the overmass load implosion and reproduce the main SXR pulses parameters (implosion time, full width at a half maximum, irradiated energy) that were recorded with scintillation detectors, and derive the plasma temperature of the pinch.</p> <p>References</p> <p>[1]. B.G. Repin, A.P. Orlov, P.B. Repin, and V.D. Selemir // IEEE Trans. on Plasma Science, 2010, v.38, ■ 8, pp.1822-1827.</p> <p>[2]. B.G. Repin, A.P. Orlov // Int. Conf. XII Khariton's Topical Sci. Readings, Dig. Tech. Papers, Sarov, Russia, 2010, pp. 526–531.</p>	36
<p>[130] SOME CAPABILITIES OF MAGNETIC IMPLOSION OF HIGH-VELOCITY CONDENSED-MATTER LINERS IN THE ALT-3 DRIVER</p> <p><i>Presenter: BUYKO, Anatoly</i></p> <p>In the ALT-3 driver design – with a 0.4-meter-diameter disk explosive magnetic generator and an electrically exploded opening switch – load currents can reach 70MA, which is high enough for driving a 3-mm-thick Al liner having a radius and a height of 4 cm to 20 km/s at an impact radius of 1 cm. The azimuthal magnetic field on the liner in this case grows to 6MG (magnetic pressure, up to 1.4 Mbar), and the temperature, to 15 eV, while the liner's interior part of about ~ 40 % of liner mass remains solid and can generate pressures above 5 Mbar when hitting an Al target.</p> <p>The paper reports the results of driver simulations with various parameters of the opening switch, the liner and the target. The liner implosion simulations were done in the one-dimensional magnetohydrodynamic approximation. They demonstrate the driver's capabilities, such as driving the liner to higher velocities and generating pressures up to 10-40 Mbar, - for high-accuracy Hugoniot measurements.</p> <p>This work is of interest for high energy density research and studies of material properties under extreme conditions.</p>	38

<p>[228] Hydride lithium compression investigation in the megabar area by means of ultrahigh magnetic field pressure of the generator MC-1</p> <p><i>Presenter: BYKOV, Alexander</i></p> <p>One of the main characteristics of the equation of states (EOS) is zero isotherm (i.e. a curve of the “cold compression”). Particularly, it defines the substance compression in the condensed phase. The substance behavior study and, first of all, the study of their equation of states at ultrahigh pressures and low temperatures is one of the fundamental tasks of high energy density physics.</p> <p>The zero hydride lithium LiH investigation experiments are provided in the megabar area of pressures at isentropic compression by means of ultrahigh magnetic field pressure of the generator MC-1. The points up to 5Mbar are obtained on the P- ρ phase diagram.</p>	41
<p>[232] Helical magneto-cumulative generator to power plasma focus chamber</p> <p><i>Presenter: DEMIDOV, Vasily</i></p> <p>This paper presents investigation results of the helical magneto-cumulative generator of 100 mm diameter intended for plasma focus powering by the current of more than 2 MA. A cylindrical explosive current opening switch with copper foil located on the 100 mm diameter is used to form a current pulse with a steep front in the plasma load. The magneto-cumulative generator has an effective magnetic flux finish pressing out after the opening switch operation start to compensate current decrease due to the growing load inductance.</p>	42
<p>[233] Disk magneto-cumulative generator with opening switch of large diameter</p> <p><i>Presenter: VLASOV, Yuri</i></p> <p>Disk magneto-cumulative generators with opening switches are used to generate current pulses of tens of megaamperes with a front of less than 1 μs in the liner loads. It is necessary to locate the foil at the large diameter to decrease the linear current density in the destroyed conductor; and hereby, to decrease the specific power of the thermal energy dissipating in the opening switch. This paper presents investigation results of the device based on the disk generator with high-explosive charges of 240 mm diameter and opening switch; its foil is located at the diameter of 600 mm.</p>	43
<p>[293] Capabilities of Gamma facility to study material properties in the range of warm dense matter and pressure up to 100 GPa.</p> <p><i>Presenter: KUZNETSOV, Sergey</i></p> <p>High power Gamma facility is being developed at Russian Federal Nuclear Center (VNIIEF) for generation of X-rays. Potential of this facility at full 16 module variant (maximal current to the load up to 10 MA) and initial 4 module variant (maximal current to the load 3 MA) can be used to study the warm dense matter (WDM) and material properties in the megabar pressure range. Some results are presented in this paper of modeling of experiments for WDM generation, shock and quasi isentropic compression of some materials (Ta, Cu, Al) with the Gamma facility currents. The current curves in the load was obtained with the parameters of the facility and its transmission lines and also based on experiments with the single working module. Physical schemes of possible experiments and the ranges of velocity, pressure and temperature attainable in these experiments are presented.</p>	46
<p>[317] PLASMA FORMATION PROCESSES AT THE SURFACE OF THE DOUBLE-LAYER CONDUCTORS IN A FAST-RISING MEGAGAUSS MAGNETIC FIELDS</p> <p><i>Presenter: BAKSHT, Rina</i></p> <p>Surface plasma formation processes in fast rising (\approx 100 ns) megagauss magnetic fields are interesting from the viewpoint of various applications. If the magnetic field penetration depth is lower than conductor thickness, the plasma formation should be attributed to so called skin or ultrafast electrical explosion. The dense plasma is formed due to Joule energy release when the magnetic field at the surface of the metal attains few megagauss [1, 2]. The problem of plasma formation on the surface of the conductor should be accounted in the design of multi-megaampere pulse generators. The report presents the experimental data obtained on the pulse power MIG facility (the current amplitude up to 2.5 MA and rise time to 100 ns) in course of the investigations of the plasma formation at the surface of the cylindrical conductors. The aim of the experiments was to compare skin electrical explosion of homogeneous and double-layer conductors in magnetic fields up to 4 MG. The copper and aluminum conductors with diameters of 2 and 3 mm were used. Half of the each conductor had an additional layer with thickness up to hundred microns. The layer was made of titanium by vacuum-sputtering. A four frame optical camera HSFC-Pro with the frame duration of 3 ns was used to detect self-emission of the surface plasma. It was shown that titanium layer with thickness (20-80) microns provides significant delay of the plasma formation and instabilities development. The work was partially supported by grants of the Russian foundation of the basic researches #16-32-00631 and #16-08-00658.</p> <p>1. T. J. Awe, B. S. Bauer, S. Fuelling, R. E. Siemon, PRL, 2010. – V.104. – 035001. 2. S. A. Chaikovskiy, V. I. Oreshkin, I. M. Datsko, N. A. Labetskaya, D. V. Rybka, N. A. Ratakhin, Phys. Plasmas, 2015. – V.22. – 112704.</p>	47

Poster session II - Particle Beam and Accelerator Technologies - Hall 4 / Cambridge (13:30-15:00)

board

[231] Plasma Characterization in a Repetitively Pulsed Electron Beam Diode**Presenter: MYERS, Matthew*

Electron beam (e-beam) generation in high power vacuum diodes results in anode and cathode plasma formation. It is well documented that expansion of these plasmas into the A-K gap can adversely affect diode performance during the main e-beam pulse. However, ionized gases may exist for many microseconds afterward and can contribute to localized breakdowns in the diode gap if transient voltage reflections appear later in time. These post pulse discharges can be destructive to anode and cathode elements. Furthermore, weakly ionized and/or neutral gas remaining in the A-K gap can affect e-beam generation on subsequent shots in repetitively pulsed diodes. For a given, repetitively pulsed driver, diode physics will depend largely on the emitter material used in the cathode, the anode material, the electric field E , dE/dt , current density, vacuum pumping speed, the pulse width, and the pulse repetition frequency. For single shot and various pulse repetition rates on the NRL solid state pulser (200 kV, 5 kA, 250 ns, 1 – 10 pps), the plasma density and AK gap closure velocity are measured for various cathode and anode materials. Materials include dielectric fiber velvet, carbon fiber flocked onto a carbon base, ceramic honeycomb secondary emitter with a carbon fiber base, and stainless steel. A fiber laser interferometer is used to measure the line density at the cathode and anode surfaces. Voltage and current probes are used to calculate the gap closure rate. A gated camera is fielded for nanosecond resolution of plasma emissions both at the cathode and anode.

* Work was supported by the Naval Research Laboratory Base Program

[221] ALTERNATIVE CONFIGURATION AND TIMING CONTROL FOR BEAM CHOPPING SYSTEM AT THE SNS LINAC*Presenter: PEPLOV, Vladimir*

The Spallation Neutron Source (SNS) beam chopping system uses a segmented electrostatic lens in the Low Energy Beam Transport (LEBT) to deflect the beam out of the RFQ input aperture to create gaps in the 1ms beam macro-pulse for extraction from the Ring, or fully displace the beam. The lens is split azimuthally into four quadrants which are pulsed independently by four bipolar high voltage pulse generators. The chopper timing control system creates trigger pulses to the pulse generators which deflect the beam sequentially to four positions on the diagnostic plate. In the present chopper configuration, all four segments are powered simultaneously with a 1MHz burst repetition rate within the macro-pulse. To improve chopping performance, faster switches and higher voltages are required. An alternative chopping system configuration which can meet this request has been proposed, where only two opposite segments are used at a time. This will facilitate pulse generator performance by reducing switching frequency and power dissipation in high voltage switches while operating at increased voltages, and make beam deflection more effective, stable and reliable. The new chopping configuration requires changes in the LEBT timing control patterns, upgrading the pulse generator, and changing the azimuthal position of the lens segments in the LEBT structure.

This paper will review the timing control patterns for present and suggested configurations, compare the pulse generator performance for both cases, and show the advantages of new chopping modes. The results of the simulation of the phase-space distribution of the beam at the RFQ input at different deflecting voltages also will be presented.

****strong text****

<p>[204] Ion source for shallow implantation <i>Presenter: SAKUDO, Noriyuki</i></p> <p>Regarding semiconductor-device production, ion-implant energy is decreasing since the junction depth becomes shallower along with the shrinkage of device size. The lowest energy level for practical use has been around several 100eV and will become lower than 100eV in a near future [1]. For realizing such low-energy beams, ions are decelerated before implantation. We reported in the past that the exact energy value of such low-energy ion beam was determined not only by the potential difference between the ionization chamber and the target, but by the summation of the potential difference and the plasma potential in the chamber [2]. For the case of low ion energy of several 100 eV the plasma potential is comparable with the potential difference.</p> <p>Up to now the plasma potential has been given under the assumption that the plasma was in a stationary condition in which both the ion and electron fluxes going out from the plasma were equal in absolute value and balanced at every point of the plasma boundary, i.e., there was no electric current intersecting the boundary. However, only ions go out and electrons are retarded backwards at the ion-exit slit of the practical discharge chamber. Thus, there exists a one-directional electric current intersecting the plasma boundary at the exit slit. In this study we deduce a new formula by taking into account the ion electric current at the slit. Resultantly it is found the plasma potential is changed not only by the electron temperature as usual but also by the chamber structure.</p> <p>[1] N. Suetsugu, M. Tsukihara, M. Kabasawa, F. Sato and T. Yagita, Proc. of 20th International Conference on Ion Implantation Technology, (2014) 157-160. [2] N. Sakudo, K. Hayashi, Rev. Sci. Instr. 67 (1996) 1218-1220.</p>	3
<p>[202] The performance results of the LIA in double pulse mode <i>Presenter: STAROSTENKO, Dmitrii</i></p> <p>Linear induction accelerator LIA is designed and developed at the Budker Institute of Nuclear Physics in 2010 year as injector for fullscale radiographic machine. Now it is currently used as independent radiographic X-ray source for testing objects with an optical thickness up to 70 mm lead equivalent. In 2014 year the high-voltage power supply system was upgraded. Accelerator operates in one pulse and in a double-pulse mode – up to 2 MeV. Time delay between two frames can be changed in the range of 2 ÷ 100 us with a minimum pitch of 5 ns. Energy spread in each pulse does not exceed ± 0.5% [1].</p> <p>The operation results in single-pulse mode and double-pulse mode are presented. The maximum possible emittance electron beam, allowing to compress beam spot size to about 1 mm on the target, is estimated.</p> <p>1. D.A. Starostenko, P.V. Logatchev et al. «Status of the LIA-2. Double-pulse mode», ISSN 1531-8567 published in Physics of Particles and Nuclei Letters, December 2016, Volume 13, Issue 7, pp. 962–965. © Pleiades Publishing, Ltd. 2016.</p>	4
<p>[199] Observation of Beam Spot Dynamics During LIA Shot <i>Presenter: TRUNEV, Yuriy</i></p> <p>Dynamics of beam spot on high Z target is key quality factor of LIA radiographic machines [1]. To obtain direct observation of beam spot evolution during the LIA shot the experimental procedure with time resolution of tens of nanoseconds was introduced [2]. It based on pinhole camera and scintillator with segmented structure. In this report the measurements of beam spot dynamics on the 2 MeV LIA constructed by BINP are presented [3]. Principally, diagnostic was based on the same approach as mentioned above. The detector had array of pixels with cruciform structure. Each pixel was made from discrete plastic scintillator (NE101-like) for time resolution. Several modes of beam spot dynamics were observed during the shot. The interrelation between dynamical focusing and defocusing of the beam and prehistory of Ta target was registered.</p> <p>[1] C. Ekdahl, Modern electron accelerators for radiography// IEEE Transactions on Plasma Science, 30, 254-261 (2002). [2] McCuistian B. T., Moir D., Evan Rose L. Temporal spot size evolution of the DARHT first axis radiographic source// Proceedings of EPAC08, Genoa, Italy (2008). [3] P. V. Logachev, et al. LIU linear induction accelerator// Instruments and Experimental Techniques, 56.6, 672-679 (2013).</p>	5
<p>[198] Numerical Simulations of Electron Beam Neutralization by Backstreaming Ions in LIA <i>Presenter: DANILOV, Valerii</i></p> <p>This work presents numerical modeling of interaction between intense electron beam and target plasma in LIA accelerator. Well-focused electron beam hit tantalum target that causes producing of high-density target plasma. This plasma consists of electrons and ions of tantalum and different contaminations adsorbed on the target surface [1]. Because of negative potential of the electron beam, ions from target plasma forms upstreaming flow. Interaction between electron beam and ions causes disrupting effect on beam's focusing. We used particle-in-cell code KARAT [2]. For modeling we used the next parameters: electron beam energy 2 MeV, current 2 kA, beam radius 5 cm, focusing length 10 cm.</p> <p>[1] Hai-jun Yu, et. al. Numerical simulations and experiments of beam-target interaction for multipulse bremsstrahlung converter applications// PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, 15, 060401 (2012). [2] V. P. Tarakanov, User's Manual for Code KARAT// Berkley Research Associates, Springfield, VA (1992).</p>	23

<p>[183] Long Pulse and Positive Polarity Operation of a Reflex Triode at the Saturn Accelerator</p> <p><i>Presenter: ULMEN, Ben</i></p> <p>The Saturn Accelerator at Sandia National Laboratories was originally designed as a short pulse, negative polarity machine with a power pulse width of approximately 28 ns feeding a three ring diode bremsstrahlung x-ray source supporting the machine's primary function as a high dose-rate x-ray simulator. For upcoming x-ray source designs such as the reflex triode, the machine must be operated in positive polarity. This is a non-trivial setup on Saturn since the pulsed power cannot be easily reconfigured. The solution utilized in this work was to connect the upper and lower cathodes directly to machine ground inside the vacuum stack through a large (~250 nH) ballast inductance, driving the anodes positive. In the short pulse configuration that means that approximately 1/3 of the current is not available for making bremsstrahlung radiation because the main power pulse is over before the power reflected from the ballast inductances has time to reach the load.</p> <p>In an attempt to recapture some of this current, recent experiments were run to reconfigure the machine to run in a long pulse mode. This configuration involves shorting the self-break water switches in the pulse forming line. The results indicate that the current pulse rises to a peak after ~190 ns compared to the normal ~18 ns rise time. The long rise means that, in the mode where the cathodes are shorted to ground, the power pulse has time to go through the 18.6 nanosecond radial disk feed in the water section, reflect, and travel back to the rods and onto the other side of the disk feed before peak radiation. This means that the current losses are less and that more of the machine power can contribute to making radiation. Machine data are presenting showing this increase in performance.</p>	22
<p>[164] Time-dependent Energy Deposition Characteristics on Different Anode Position of a Weak-pinched Diode</p> <p><i>Presenter: HU, Yang</i></p> <p>The energy deposition plays an important role in the study of the thermal mechanical effect of intense electron beam. A new method to obtain the time-dependent electron beam energy deposition at different anode target position was presented. First, the electron beam energy should be discretized according to diode working time every 5ns, so that the electron beam in each time period is considered to one single energy value. Then the energy deposition profile at this position can be calculated accurately by Monte Carlo method only the incidence angle here is available. A method of incidence angle measurement based on small Faraday cup array, called Modified Multi-Layer Stacking (MMLS), was given in this work. The time-dependent energy deposition characteristics in r and z direction of a weak-pinched diode working at 600kV and 7Ω were analyzed by means of MMLS. The results show that the energy deposition characteristics are related to the incidence angle in the case of the energy of the electron beam has been confirmed in each time period. The experimental results are in good agreement with the simulation results the deviations are less than 10%. The energy deposition at different position of the target is different due to the time-dependent incident energy and incidence angle. Under the influence of the beam pinching, the incidence angle changes greatly with time at the position where more than 25mm away from the center of the target surface. When the incidence angle is less than 40°, the peak depth of the high current electron beam energy deposition is about 0.2mm. When the incidence angle exceeds 40°, the energy deposition peak depth is reduced to about 0.1mm. At the positions near the center of the target, the influence of the beam pinching is weakened. The energy deposition characteristics of these locations are closer to the case of the deposition with small incidence angles ($<40^\circ$).</p>	20
<p>[166] RF System of Linear Accelerator for Natural Rubber Research</p> <p><i>Presenter: SAISUT, Jatuporn</i></p> <p>The natural rubber research is ongoing project at the Plasma and Beam Physics Research Facility, Chiang Mai University, Thailand. The project aims to use electron beam irradiation for high quality vulcanization process for natural rubber. The main accelerator system consists of a DC thermionic electron gun, 5-cell linear accelerator structure, control system, RF system and electron beam irradiation system. This accelerator system aims to generate adjustable electron beam energy range from 0.5 to 4.0 MeV with pulse current of 10 – 100 mA and pulse repetition rate of 20 – 400 Hz. The 4 MeV electron beam with current of 100 mA produced at pulse repetition rate of 400Hz is expected to achieve the maximum absorbed dose of 640 Gy. The control system is designed and built in-house to fit the accelerator system requirement. The RF system consists of Pulse Forming Network (PFN), trigger board and thyatron switch, pulse transformer and pulse magnetron. This RF system can achieve RF power of 0.9 to 2.0 MW with pulse width of 4 μs. The pulse repetition rate can be varied from 20 to 400 Hz to control RF average power. The performance of control system and RF system as well as the results of RF commissioning will be present and discussed.</p>	21

<p>[153] Long pulse electron accelerator GESA-SOFIE: A numerical study of the beam characteristics <i>Presenter: FETZER, Renate</i></p> <p>The new electron accelerator GESA-SOFIE for long pulse operation was specially designed for in-situ diagnostics and investigation of the beam characteristics and operation performance under different conditions. One of the new features is the possibility to tune the shape and position of the electrodes. The use of a planar cathode necessary to optimize the diagnostics, for instance, makes an optimum alignment of electric and magnetic fields in the region of beam generation impossible. The specific requirements on the geometry pose a new challenge on the design optimization. Further, different impedance regimes are of interest for the diagnostics and characterization. In this presentation, a numerical study of the beam performance of GESA-SOFIE under different conditions is conducted using the PIC code simulation package MAGIC3d. The geometry of various components of the facility as well as the coil currents are modified. The external magnetic field is calculated, taking into account the induced eddy currents, in a fully 3-dimensional time dependent study using the FEM code COMSOL Multiphysics. The B-field results serve as input for the PIC simulations of the beam characteristics. The numerical results of the GESA-SOFIE beam performance are compared with respective experimental data.</p>	19
<p>[139] Researching On the Power Sources Decoupling at IFP's Dielectric Wall Accelerator <i>Presenter: YE, MAO</i></p> <p>Dielectric Wall Accelerator (DWA) is a new type of pulsed linear accelerator. Its working mechanism is regulating the discharge order of different power sources to keep the accelerating electric field present near the particles all the time, and it is really suitable for heavy ions acceleration. The Institute of Fluid Physics, China Academy of Engineering Physics (IFP, CAEP) began the research on DWA since 2011, and had built a sample DWA for proton acceleration. During the debugging process of the DWA, it was found that the coupling between adjacent power sources in the discharge circuit will lead to a sharp drop of the accelerating voltage on the accelerating cavity, and the energy gain of proton is much less than expected. In this paper, the research on the coupling between power sources was studied and a new electrode structure which can reduce the coupling between adjacent power sources was put forward. And three-dimensional electromagnetic simulation software was used to compute the electric field distribution under the new structure. The results showed that the new electrode structure successfully blocked the discharge circuit between power sources, and the coupling between the power sources was effectively suppressed, the voltage on a single accelerating cavity was significantly increased. Even though there will get decelerating electric field presenting at the new electrode structure. The simulation result showed the amplitude of decelerating electric field was limited, and the influence to particle energy gain was negligible by the electric field path integration, particles can still get high gradient acceleration. The experimental results of the voltage loading on the accelerating structure also showed the effectiveness of the improved structure.</p>	18
<p>[110] Numerical study of a 1 MV Linear Transformer Driver <i>Presenter: MAISONNY, R.</i></p> <p>A numerical model using both electromagnetic and Monte-Carlo simulations is used to investigate the performances of a 1 MV LTD pulsed high-power accelerator [1]. Particle-In-Cell calculations were employed to examine the beam dynamics throughout the Magnetically Insulated Transmission Line which governs the coupling between the generator and the electron diode. Based on the information provided by the study of the beam dynamics, and using Monte-Carlo methods, the main properties of the resulting X-radiation were predicted. Good agreement was found between these simulations and experimental results [2]. This work provides a detailed understanding of mechanisms affecting the performances of this type of high current, high-voltage pulsed accelerator.</p> <p>[1]M. Ribière et al, "Contribution of electromagnetic perturbation to the transient response of an electronic circuit exposed to a high multi-MeV X-ray flux", Trans. Nucl. Sci. 62, 1383 (2015)</p> <p>[2] R. Maisonnny et al, "Investigating the performances of a 1 MV high pulsed power linear transformer driver: from beam dynamics to x radiation", Phys. Rev. Accel. Beams 19, 120401 (2016).</p>	17

<p>[39] Plasma Generation by a Pulsed Nanosecond Discharge on a Surface of Porous Dielectric Saturated with Liquid</p> <p><i>Presenter: PUNANOV, Ivan</i></p> <p>Pulsed plasma thrusters utilizing solid propellants have relatively low efficiency [1]. As alternative propellants, liquids are considered to be used in PPTs. However, using of liquid arises the problem of supplying it to the discharge area [2]. This work presents the results of the estimation of plasma formation efficiency of the discharge unit utilizing vacuum pump oil as a propellant. It was supplied to the discharge area through the ceramic diffusion element which is 5 mm thick with a porosity of 20%. We used coaxial electrode system with 12-mm central anode and 30-mm ring cathode. Pulse generator used has a coaxial forming line with an impedance of 20 Ω and stored energy of 2 J. Pulse width is 10 ns, pulse repetition frequency is up to 100 pps. Voltage of 100 kV was applied to the central electrode at frequency of 3 Hz. The experiment was carried out in vacuum at pressure of 10^{-2} Pa. The liquid was pushed into the diffusion element by pressures of 500, 260, and 60 Pa. Propellant consumption at these pressures are 50, 12, and 8 $\mu\text{g/pulse}$, respectively. We consider propellant consumption efficiency as a ratio of total ion charge in a unit solid angle to the total propellant weight loss. The resulting values are 1.5, 4.0, and 4.9 $\text{C}/(\text{g}\cdot\text{s})$, respectively. We assume that the thinner the liquid layer formed at the surface of the diffusion element, the higher ionization efficiency of the propellant, because of more homogeneous heating of the layer. Higher degrees of ionization may be achieved by adjustment of pulse frequency at fixed propellant supply value.</p> <p>[1] Schönherr T., Komurasaki K., Herdrich G. Journal of Propulsion and Power, 2013, vol. 29, No. 6, pp. 1478-1487. DOI: 10.2514/1.B34789</p> <p>[2] Koizimi H., Kakami A., Furuta Y. et al. 28th IEPC, March 17-21, 2003, IEPC-03-087. DOI:10.1063/1.1790568</p>	7
<p>[22] Generation of anode plasma and its effects on diode characteristics</p> <p><i>Presenter: WAN, Hong</i></p> <p>Generally, the performances of high power electron beam diode, such as current levels, impedance collapse, and plasma expansion, have been attributed to the combination of the cathode and anode instead of just the cathode. The issues of anode have been paid more and more attention in research and practical applications. In this paper, five kinds of anode materials, stainless steel, titanium (Ti), molybdenum (Mo), graphite, and graphite modified by titanium carbide (TiC/Graphite), were investigated to figure out the influence of anode material on the characteristics of the diode. The results, both of experiments and theoretical analyses, point out that anode plasma plays a vital part in the characteristics of the diode. The changes of diode voltage and current waveforms were analyzed by the impedance data. It was found that the diode voltage and current follow different space-charge limited flow models when different anode materials were used. The anode and cathode plasma expansion velocities were calculated based on three cases, without anode plasma in the duration of a pulse, with anode plasma in the later stage of a pulse, and with anode plasma at the earlier stage of a pulse, which were classified by occurrence time of anode plasma. This analysis was supported and proved by the results of diode plasma photographs. The causes of anode plasma were inferred from the changes of anode materials after several pulses, which were also in conformity with the classification of the three mentioned cases. This study reveals that the diode performances are easily affected by anode plasma when Ti, Mo, and stainless steel are used as anode materials, respectively. Considering the drawbacks of porous and carbon contamination of pure graphite material, however, TiC/Graphite may be better choice for anode material at the similar conditions.</p>	6
<p>[70] 250kV - 60ns double pulses generator as an induction cell driver for a flash radiography LIA</p> <p><i>Presenter: CADILHON, Baptiste</i></p> <p>The design of multi-pulses, multi giga-watt, high voltage generators is of particular interest for electron beam induction accelerators. The major requirements for this type of pulsed power generators are a few percent flat top, a jitter in the range of 1 ns, high pulse reproducibility shot to shot and a drastic reliability. As an opportunity for future flash X-rays machines, CEA is developing a HV generator able to produce either one or two 250 kV - 60 ns square pulses.</p> <p>The two pulses are created, independently, by the discharge of two 500 kV, 12.5 ohms water insulated pulse forming lines in serie. As it is composed of two sets of lines in parallel, generator's impedance is 6.25 ohms. Air pressurized main spark-gap switches are triggered by a low divergence 266nm Nd:YAG laser.</p> <p>Single pulse version of this generator has been validated thanks to many tests at nominal voltage and default mode experiments. Works presented in this paper concern the double pulses version of the generator. Results of experimental tests on matched resistive load and coupled to ferrite induction cells will be exposed.</p>	8

<p>[71] Prototype Development and Testing of the Alternate Topology HVCM modulator to support the Proton Power Upgrade (PPU) at SNS.</p> <p><i>Presenter: SOLLEY, Dennis</i></p> <p>*The Proton Power Upgrade(PPU)project at SNS is planned to accelerate 38mA of beam current to 1.3GV, effectively doubling the accelerator power capability to support the planned Second Target Station. This project required three additional modulators to power the 28 additional 700kW klystrons and associated high beta cavities. An alternate topology high voltage converter modulator (AT-HVCM) has been developed by modifying the existing SNS HVCMs by series-stacking the dual-duty resonant/filter capacitors and relocating them after the rectifiers. This paper discusses the modulator requirements to power the klystrons, advantages of the topology modification over the existing HVCM systems and the scope of modifications required. Results from the prototype testing campaign and future planned activities will also be discussed.*</p>	9
<p>[85] Voltage Stability Improvement and Analysis of Pulsed Klystron Modulator for RF Linac Applications</p> <p><i>Presenter: JANG, Sung-Duck</i></p> <p>Recently, demands on high-coherent, ultra-bright, and ultra-fast X-ray photon beams are increased for an ultra-fast basic science applications. The pulse-to-pulse stability of RF linac klystron modulators is one of critical issues in 3rd generation synchrotron machine for the top-up operation of the PLS-II linac. This machine requires highly stable RF sources with a stability of 0.01% rms, to meet the beam stability requirements. We renovated the existing SCR modulator with de-Q'ing to an inverter modulator to attain the low electron beam energy fluctuation for the PLS-II linac in 2014. By adopting a fine inverter and a DSP controller, we achieved the beam voltage with less than a 100 ppm stability for the PLS-II klystron modulator (KM). The pulse stability of KM is highly influenced by the inverter power supply (PS). The target charging voltage for a modulator PFN is realized by regulating small buckets operated by the PWM mode of an ultra-fine inverter PS. In this paper we discuss the results of the voltage stability improvement and the measurement of the KM system. Some issues on the inverter modulator for the stability improvement will be also presented.</p>	10
<p>[94] Signals from Cygnus</p> <p><i>Presenter: TRUONG, Hoai-Tam</i></p> <p>*NSTec product number: DOE/NV/25946--3117</p> <p>After the 1992 moratorium on underground nuclear testing, the Subcritical Experiment (SCE) program was initiated to support stockpile stewardship. The SCE laboratory is located in a tunnel complex 1,000 feet below ground surface at the Nevada National Security Site (NNSS). Cygnus is a radiographic x-ray source which is a primary diagnostic for the SCE program. The Cygnus Dual Beam Radiographic Facility consists of two identical radiographic sources, Cygnus 1 and Cygnus 2. From end to end, the Cygnus machines utilize the following components: oil-filled Marx generator, water-filled pulse-forming line (PFL), water-filled coaxial transmission line (CTL), three-cell vacuum induction voltage adder (IVA), and rod-pinch diode. The diode pulse has the following electrical specifications: 2.25 MV, 60 kA, 60 ns. Each source has the following X-ray specifications: 1-mm diameter, 4 rad at 1 m, 50 ns. SCE shots are both single-event and high-value, therefore reliability and reproducibility are key issues of Cygnus. Prior to a SCE, there are a series of test shots performed for confirmation of high levels of reliability and reproducibility. For every shot on Cygnus, voltages and currents along the machine are recorded and monitored. In this paper we present extensive analysis of electrical waveforms which includes examination of multiple parameters (e.g. amplitude, pulse width, pulse shape). The results will involve a statistically meaningful shot sample where machine setup parameters are held consistent. A computer application will be developed for automated shot analysis. Correlation between waveform characteristics and dose performance will be established. This type of extensive, automated analysis will contribute to optimized Cygnus performance on SCEs.</p> <p>*This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy.</p>	11
<p>[98] Single – triple pulse Power supply for 2 kA, 20 MeV Linear Induction Accelerator</p> <p><i>Presenter: AKIMOV, Aleksandr</i></p> <p>A pulsed system for a 2 kA, 20 MeV linear induction accelerator power supply was developed. On a first stage of operation it is capable of producing a 336 kV, 2 kA, 60 ns single pulse at the accelerating inductive cells. Each cell is supplied by 8 pulse modulators based on an inductive voltage adder principle. Each modulator is designed to produce pulses up to 21 kV, 10 kA with a different flattop duration of 60 or 380 ns, also it can be used in a triple pulse mode operation with a time shift between pulses which can be set from 2 to 10 μs. The modulator's single and triple pulse mode as well as the auxiliary charging and biasing systems test results are presented. Also the pseudospark switches batch testing is described.</p>	12

<p>[99] Development and testing of high-voltage cells for 2 kA, 20 MeV Linear Induction Accelerator</p> <p><i>Presenter: AKIMOV, Aleksandr</i></p> <p>Two types of the high-voltage cells are developed for a 20 MeV, 2 kA linear induction accelerator and a 2 MeV injector. Each accelerator's cell incorporates 16 inductors, it is supplied in an inductive voltage adder manner with a pulse voltage up to 336 kV and different flattop duration of 60-380 ns. At the first stage the cells were tested in a 60 ns pulse mode, the test results with an overvoltage up to 400 kV are presented. Few imperfections have been discovered during experiments and fixed. The inductors are made of an iron-based alloy, test results of magnet cores batch are presented.</p>	13
<p>[100] Pulse forming networks development for a 60-380 ns Pulsed Power Supply for 2 kA, 20 MeV Linear Induction Accelerator</p> <p><i>Presenter: AKIMOV, Aleksandr</i></p> <p>The pulse forming networks (PFN) were developed to provide a 2 kA, 20 MeV linear induction accelerator cells power supply. A PFN's and high-voltage capacitors manufacturing is organized at BINP. The PFN is a LC-network with nonuniform impedance made of capacitive sections with a combined paper-film dielectric filled with a castor oil in a polypropylene case. A PFN's isolation is rated at 50 kV charging voltage. The two types of PFNs are developed for 60 and 380 ns flattop duration. They are capable of producing the pulses up to 21 kV, 10 kA with a $\pm 0.5-1\%$ flattop voltage uniformity at a complex inductive-resistive load of the accelerating cell. The PFNs test results in the nominal regime are presented. The PFNs life test results at a higher electrical field in the dielectric are described.</p>	14
<p>[102] Development of a 100 kV Pulse Generator for Driving an Electron Scanner used in Proton Beam Profile Measurements</p> <p><i>Presenter: MORRIS, Ben</i></p> <p>The Spallation Neutron Source (SNS) utilizes an electron scanner in the accumulator ring for non-destructive transverse profiling of the proton beam. The electron scanner consists of a high voltage pulse generator driving an electron gun, a medium voltage ramp generator, and a CCD camera. A new high voltage pulse generator that provides 100 kV pulses with rise times of less than 200 ns, flattop of 200ns, and regulation of <5% has been designed, delivered, and undergone extensive testing. The pulse generator has been operationally verified with the existing control system and simulated loads. Full system testing with the actual electron scanner is planned. This paper details the requirements, design, setup, and test results of the high voltage pulse generator.</p>	15
<p>[109] Modeling and experimental characterization of the plasma produced by velvet cathode in a linear induction accelerator</p> <p><i>Presenter: PLEWA, J.M.</i></p> <p>At the EPURE facility, in France, a high power electron diode is used to generate an intense high quality pulsed electron beam in order to produce a bremsstrahlung radiation pulse for flash radiography. For this purpose, a cold cathode is driven by a 75 Ω graded transmission line, which delivers a 3.8 MV, 95 ns (FWHM) high power electrical pulse across a diode gap of 17.2 cm. The cathode is composed of a dielectric material (cloth velvet) on a metal substrate. The application of the strong electric field results in plasma formation induced by a surface flashover [1-3]. A space charge limited electron flow is, then, extracted from this plasma. Therefore, to optimize the design of diodes and to have a better understanding of plasma dynamics, we have developed a 0D Collisional-Radiative Model (CRM) which describes the time-dependent evolution of the density of the plasma species. The non-equilibrium electron energy distribution function (EEDF) is pre-calculated for a large range of reduced electric field E/n [4]. EEDF versus E/n are then used to determine the electron rate coefficients needed to calculate time-dependent plasma species densities. We have performed visible spectroscopy measurements in order to investigate the plasma composition and temperature. The emission spectroscopy results are compared to the CRM and plasma characteristics.</p> <p>[1] R. B. Miller, Journal of Applied Physics, vol. 84, n°17, 1998.</p> <p>[2] Y. E. Krasik, J. Z. Gleizer, D. Yarmolich, A. Krokhmal, V. T. Gurovich, S. Efimov, J. Felsteiner, V. Bernshtam and Y. M. Saveliev, Journal of Applied Physics, n°198, 2005</p> <p>[3] J. Coleman, D. Moir, M. Crawford, D. Welch and D. Offermann, Physics of Plasmas, n° 122, 2015.</p> <p>[4] M. Yousfi, A. Hennad and A. Alkaa Physical Review E, vol. 49, n°14, pp. 3264-3273, 1994.</p>	16

Oral session 11 - Plasma Z-Pinches, X-ray Sources - Session Chair : Michael Mazarakis - Oxford hall (15:00-17:30)

15:00	<p>[337] Direct observation of electrothermal instability structures in the skin layer of an intensely Ohmically heated conductor</p> <p><i>Presenter: AWE, Thomas</i></p> <p>Magnetically driven implosions on the Z Facility assemble high-energy-density plasmas for radiation effects and ICF experiments. MDIs are hampered by the Magneto-Rayleigh-Taylor (MRT) instability, which can limit achievable stagnation pressures and temperatures. The metallic liners used in Magnetized Liner Inertial Fusion (MagLIF) experiments include astonishingly small (~10 nm RMS) initial surface roughness perturbations; nevertheless, unexpectedly large MRT amplitudes are observed in experiments.</p> <p>Early in the implosion, an electrothermal instability (ETI) may provide a perturbation which exceeds the liner's initial surface roughness. For a condensed metal, resistivity increases with temperature. Locations of higher resistivity can undergo increased Ohmic heating, resulting in locally higher temperature, and thus still higher resistivity. This drives unstable temperature and pressure growth which produces density perturbations when the locally overheated metal changes phase. Such ETI-driven surface perturbations then seed MRT growth. For liners imploded on Z, ETI seeding of MRT is inferred by evaluating MRT amplitude late in the experiment. A direct observation of ETI is vital to ensure simulations accurately represent the seed of the MRT instability.</p> <p>ETI growth was directly observed on the surface of 1.0-mm-diameter solid Al rods which were pulsed with 1 MA of current in 100 ns. Fine structures resulting from ETI-driven temperature variations were observed directly through high resolution gated optical imaging (2ns temporal and 3 micron spatial resolution). Data from two Aluminum alloys (6061 and 5N) with a variety of surface finishes enabled the determination of which types of imperfections most rapidly drive overheating. Surfaces coated with ~70 microns of mass-tamping dielectric evolve very differently than uncoated surfaces. Data are relevant to the early stages of MagLIF liner implosions, when the ETI seed of MRT may be initiated. We present a fundamentally new and highly 3-dimensional dataset which informs ETI physics, and provides a unique test for state-of-the-art simulation tools.</p>
15:15	<p>[77] Results of comparison between underwater explosions of Cu and Al wires and investigation of symmetry of a shock wave generated by a cylindrical wire array explosion</p> <p><i>Presenter: YANUKA, David</i></p> <p>Underwater electrical explosion of an Al wire can be accompanied by an exothermic process resulting in additional energy transferred to the generated water flow. Here, we report on recent results of a comparison between underwater electrical explosions of single Cu and Al wires. Experiments were carried out using a high-current pulse generator (70 kV, 40 kA, 100 ns). Using fast frame and streak intensified cameras, we compare the radial expansion of the exploding wires, the velocities of the generated shock waves, and the intensity of the light emission to make a conclusion regarding possible combustion of Al wires. We also compare these results to explosions of these wires in Glycerol in order to see whether it contributes to the generated shock waves' velocities.</p> <p>In additions, we report on the results of preliminary experiments carried out to investigate the symmetry of a shock wave generated by an underwater explosion of a cylindrical wire array at radii <100 μm with respect to the axis of symmetry. The shock wave convergence symmetry is extremely important for generation of extreme states of matter in the vicinity of implosion, as well as for research of converging shock wave instabilities.</p>
15:30	<p>[80] Preconditioned wire array Z-pinch driven by a double-pulse current generator</p> <p><i>Presenter: WU, Jian</i></p> <p>Recently, the concept of the preconditioned wire array Z-pinch was proposed in which the ablation phase was suppressed and the implosion involved all mass of the array. On MAGPIE facility, this was achieved for aluminum wire array by the employing a specially designed two stage wire array, which allowed the generation of a short prepulse current through the wires of the top imploding array, sufficient to volumetrically vaporize all mass of the wire, instead of the core-corona structures. In order to fulfill the preconditioned wire array Z pinch more flexibly, a double-pulsed current generator "Qin-1" facility has been setup, which can produce a 10 kA prepulse current and then a 800 kA main current. The output current of the prepulse current driver to a matched resistive load (5 Ω) has a peak value of 10 kA, a rise time of 30-50 ns, and a pulse width of 50-80 ns. The main current driver is composed by 42 capacitor-switch bricks. Each brick is composed of two 90 nF low inductance capacitors, a multigap gas switch, and electrical buses connections. The output current to a short load is 0.8 MA, 170 ns under a charging voltage of ± 50 kV. Since the prepulse current driver and the main current driver can be triggered individually, the time interval between the prepulse current and the main current is adjustable. Completely vaporization of a tungsten, aluminum, or silver wire array is achieved by preheating the wire array using the prepulse current (10 kA, 50 ns) on "Qin-1" facility, and greatly suppression of the significant asymmetrical structures, including the core-corona structure, the precursor plasma, the Magneto-Rayleigh-Taylor (MRT) instability, and etc., are observed under the main current (~0.8 MA, 170 ns).</p>

15:45	<p>[78] Generation of cylindrically convergent shockwaves in water on the MACH facility <i>Presenter: BLAND, Simon</i></p> <p>We report on initial shock physics experiments performed on the MACH – Mega Ampere Compression and Hydrodynamics – facility at Imperial College London.</p> <p>The MACH generator is a 2MA, 400ns, 100kV 'dry air' Linear Transformer Driver cavity, which can be readily expanded to higher currents and drive voltages. The generator was designed for ease of use, and rapid turnaround with a load region that can be readily reconfigured to drive a variety of HEDP experiments from the ramp and shock loading of condensed matter to the generation of dense streams of plasma for astrophysics research.</p> <p>Here we report on the first experiments utilizing MACH to explode copper wire arrays in water, generating highly symmetric, cylindrical convergent shockwaves. The experiments were carried out with 10mm diameter arrays consisting of 60 x 130µm wires, and currents >500kA were achieved despite the high inductance load. Laser backlit framing images and streak photography of the implosion showed a highly uniform, stable shockwave that travelled towards the axis at velocities up to ~7.5kms⁻¹. For the first time, imaging of the shock front has been carried at radii < 0.5mm, and there is strong evidence that even at radii <0.1mm the shock front remains stable, resulting in a convergence ratio of 50:1. 2D hydrodynamic simulations that match the experimentally obtained implosion trajectory suggest pressures of >1Mbar are produced within 10µm of the axis, with water densities 3gcm⁻³ and temperatures of many 1000s of Kelvin. The results represent a significant step in the application of the technique to drive different material samples, and calculations of scaling the technique to larger pulsed power facilities are presented.</p> <p>Acknowledgements This work was supported by the Institute of Shock Physics, funded by AWE Aldermaston, and the NNSA under DOE Cooperative Agreement Nos. DE-F03-02NA00057 and DE-SC-0001063.</p>
16:15	<p>[122] Recent progress in implosion of a quasi-spherical shock waves and x-ray imaging of exploding wires <i>Presenter: NITISHINSKIY, Mikhail</i></p> <p>Recent results on implosion of strong shock wave (SSW) generated by underwater electrical explosion of a spherical wire array are presented. Microsecond pulse generator (≤ 38 kV, ≤ 380 kA, rise time ~ 1.3 µs) was used for explosion of *Cu* and *Al* arrays with radii of 20mm, 25mm and 30mm. A strong light emission from water in the vicinity of the array origin was used to determine the SSW time-of-flight (TOF) and the time-resolved spectrum of this emission was analyzed to estimate the temperature of the surface of the light emitted volume. The experimental results coincides with the results of the 2D hydrodynamic simulation coupled with equation of state for water and radiative transfer model showing that the water density, temperature and pressure at radii < 25 µm should be larger than ~ 3 g/cm³, ~ 1.4 eV and ~ 0.2 TPa, respectively. In addition, the recent results on development of the compact ns-time duration hard x-ray source for study of radial density distribution of the single wire during its underwater electrical explosion will be presented. The x-ray flux is generated in vacuum diode with external magnetic field and powered by all solid state pulse generator (200 kV, 1 kA, 5 ns).</p>
16:30	<p>[146] Cygnus Performance on Five Subcritical Experiments <i>Presenter: SMITH, John</i></p> <p>The Cygnus Dual Beam Radiographic Facility includes two identical radiographic sources - Cygnus 1 and Cygnus 2. Cygnus is the radiography source used in Subcritical Experiments (SCEs) at the Nevada National Security Site (NNSS). The machine specifications are: Electric - 2.25 MV, 60 kA, 60 ns; Radiation - 4 Rad, 1 mm, 50 ns; Operation - single shot, 2-shots/day. Cygnus has operated at the NNSS since February 2004. In this period, it has participated on five SCE experiments - Armando, Bacchus, Barolo A, Barolo B, and Pollux. SCE projects typically require over a hundred preparatory shots culminating in a single full-fidelity or SCE shot, and typically take over a year for completion. Therefore, SCE shots are high risk and high value making reproducibility and reliability utmost priority. In this regard, major effort is focused on operational performance. A quantitative performance measurement is valuable for tracking and maintaining Cygnus preparedness. In this work, we present a new model for analysis of Cygnus performance. This model uses dose distribution as the basis for calculation of reproducibility and reliability. It will be applied both to long-term (historical) and short-term (readiness) periods for each of the five SCEs.</p> <p>*Work supported by the U.S. Department of Energy.</p>

16:45	<p>[212] Magnetic-field evolution in Z-pinch implosion with preembedded axial magnetic field</p> <p><i>Presenter: MIKITCHUK, Dmitry</i></p> <p>We investigate the effects of an axial magnetic field (B_z) on the current distribution in imploding plasma and the efficiency of the B_z-field compression by the imploding plasma. In the experiment, a cylindrical argon gas puff, in which is initially embedded quasi-static magnetic flux (up to 0.4 T), prefills the volume between two electrodes. Subsequently, a pulsed-current (rising to 300 kA, in 1.6 μs) driven through the gas, ionizes it, and generates an azimuthal magnetic field that compresses the plasma and the embedded B_z-field. Here, for the first time, we directly and simultaneously measure the evolution of the axial and azimuthal magnetic fields during the implosion and stagnation. This measurement was achieved by employing a spectroscopic technique based on the polarization properties of Zeeman split emission, combined with laser-doping technique that provided mm-scale spatial resolution. The measurements show that for implosions with $B_z(t=0) = 0.4$ T, the azimuthal magnetic field (B_θ) in the imploding argon plasma shell is much smaller than expected from the measured current and plasma radius, demonstrating that B_z dramatically affects the current distribution. It is found that in the presence of a low B_z, a significant part of the current flows at large radii through a non-imploding dilute plasma ($n_e \leq 10^{17}$ cm⁻³). In addition, simultaneous B_z and B_θ measurements at stagnation for $B_z(t=0) = 0.4$ T show that B_z is compressed about 12 \times relative to its initial value, giving at stagnation a B_z-magnitude $\sim 4 \times$ larger than B_θ. The pressure in the stagnated plasma (including the thermal pressure) becomes 16 \times higher than the pressure of B_θ. This demonstrates the large role of the ram pressure of the imploding plasma on the compression of B_z in this experiment.</p> <p>This work is supported by the US-Israel Binational Foundation under Grant 2012096.</p>
17:00	<p>[86] OVERVIEW OF THE EXPERIMENTAL DATA ON THE USE OF A VACUUM ARC DISCHARGE FOR Z-PINCHES</p> <p><i>Presenter: ROUSSKIKH, Alexander</i></p> <p>Development of the technology of using a vacuum arc discharge system for the formation of the metallic gas puff is going in two directions.</p> <p>The first direction is the use of a plasma jet for the X-ray radiography. We have compared the spatial dimensions of the radiating hot spot based on the use of X-pinch and Point Z-pinch (PZ-pinch is a regular Z-pinch with a small initial size (diameter of about 1 mm and the height is 1.3 mm)). Comparison showed that in the radiation range below 3 keV, the spatial dimensions had almost the same characteristics. A clear advantage of PZ-pinch over X-pinch is multiple using of high-current generator load without a disassembly. This report presents the latest data on the distribution of the linear mass of metallic gas puff obtained by X-ray radiography, based on X-pinch and PZ-pinch.</p> <p>Second direction is the use of a vacuum arc discharge system to form a metallic gas-puff pinch. The report presents the results of the use of the jet metallic gas-puff pinch and the shell-on-jet metallic gas-puff pinch. Experiments were carried out on the IMRI-5 (450 kA, 450 ns) and MIG (2.1 MA, 100 ns) high-current generators. It was shown that Raleigh-Taylor instabilities are suppressed almost completely at the implosion of Z-pinch with power-law density profile [1]. In fact, the plasma boundary is stable during the run-in-phase of implosion. The instabilities with $m=0$ and $m=1$ appear only in the stagnation phase [2,3].</p> <p>[1] A.L. Velikovich, F.L. Cochran, and J. Davis, Phys. Rev. Lett. 77, 853 (1996). [2] A.G. Rousskikh, A.S. Zhigalin, V.I. Oreshkin, et al, Phys. of Plasmas, 21, 052701 (2014). [3] A.G. Rousskikh, A.S. Zhigalin, V.I. Oreshkin, et al, Phys. of Plasmas 23, iss.6, 063502 (2016).</p> <p>Work supported by the grant Russian Scientific Foundation # 16-19-10142.</p>

17:15	<p>[50] Experimental Platform Development for Studying Vacuum Power Flow Physics at the Sandia Z Accelerator <i>Presenter: LAITY, George</i></p> <p>While the Z Facility can routinely deliver 25-27MA current pulses to a variety of high energy density physics experiments, load configurations which require high-inductance (>3.0 nH) hardware typically suffer from reduced current coupling in the form of charged particle losses in magnetically insulated transmission lines (MITLs). These losses: (1) can be difficult to model with conventional simulation techniques; (2) can be caused by a number of coupled physical processes including space charge limited electron and ion flows, plasma formation in desorbed neutral layers, and negative ion transport; and (3) can potentially become even more severe for higher current, next-generation pulsed power accelerator concepts under consideration.</p> <p>In order to provide critical experimental data for improving predictive models of vacuum power flow, we have developed a dedicated experimental platform based on a raised extension of the radial transmission line coupling a simple Al liner target to the Z vacuum convolute. This raised extension has been optimized to allow for multi-dimensional, chordal lines-of-sight for new spectroscopic diagnostics in development. New particle diagnostics, coupled with laser velocimetry and spectroscopic techniques, can be leveraged to explain the contributions of electrons and/or ions in global current loss. A combination of imploding and non-imploding liner concepts are used to separate dynamic impedance effects on current loss late in the current pulse. This paper will describe the ongoing development of this platform, examples of key diagnostics, and results from upcoming Z experimental campaigns dedicated to exploring vacuum power flow physics on large pulsed power accelerators.</p> <p>Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.</p>
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Oral session 12 - Semiconductor components, Pulse Forming Networks and Alternate Technologies (part II) - Session

Chair : Luis Redondo - Room Preston (15:00-17:30)

15:00	<p>[74] Solid State Spark Gap and Ignitron Replacements <i>Presenter: WALDRON, John</i></p> <p>RoHS regulations (i.e. prohibition of Mercury) have created a need for suitable replacements of legacy tube-based high power discharge switches like Spark Gaps and Ignitrons. Silicon Power now introduces solid state discharge solutions with favorable performance to legacy products, longer usable lifetime and the ability to comply with RoHS.</p> <p>Silicon Power's underlying technology, Solidtron, is fundamentally designed to outperform currently available thyristor and IGBT based solid state discharge switches. Being a vertically integrated company with extensive success in the pulse power field Silicon Power designs solid state discharge assemblies from the semiconductor up to the final deliverable. This approach yields more compact solid state switches compared to our competitors'; simplifying the adaptation of solid state technology into legacy tube dependent discharge applications.</p> <p>Replacing the gas plasma utilized in tubes with a solid state plasma offers orders of magnitude improvement in power density, unmatched repeatability from unit to unit and pulse to pulse, higher achievable frequency capability, RoHS compatibility and eliminates performance degradation due to electrode erosion.</p> <p>Despite replacing a single unit gas discharge switch with an assembly of several semiconductors reliability is improved and simple low power Galvanically isolated gating is provided (high accuracy self-triggered designs are also achievable). The jitter of Solidtron technology is less than 1ns, combined with our unique package and assembly designs current sharing through the constituent components is greatly improved. To date, preliminary designs have demonstrated reliable discharges of over 1MA at 20kV with a smaller assembly volume, higher efficiency and simpler gating compared to press pack thyristor based switches.</p> <p>Silicon Power's improvements over its preliminary designs offer true solutions to the challenges facing engineers in the design of pulse power applications where high reliability and exceptional performance is required.</p>
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15:15	<p>[214] HIGH-VOLTAGE PICOSECOND-RANGE AVALANCHE SWITCHING OF SEMICONDUCTOR STRUCTURES WITHOUT PN-JUNCTIONS</p> <p><i>Presenter: RODIN, Pavel</i></p> <p>The well-known effect of delayed impact-ionization breakdown manifests itself in 100-ps avalanche switching of Si or GaAs diode p+-n-n+ structure that is triggered by a steep voltage ramp [1-3]. Here we report first experimental observations of delayed impact ionization breakdown in Si and ZnSe semiconductor structures that do not contain any p-n junctions. Si n+-n-n+ structures with the n-base length from 80 to 180 μm, the n+-layers length from 7 to 60 μm, the n-base doping level $1.7 \times 10^{14} \text{ cm}^{-3}$ and the cross-section area $\sim 1 \text{ mm}^2$ were fabricated. Experimental setup consists of pulse generator, resistive coupler and two 50-Ω high-quality matched measuring lines connected to 20 GHz oscilloscope and allows measuring device voltage and current with accuracy better than 50 ps. 4 kV pulse with 15-25 kV/ns ramp was applied to n+-n-n+ structure and in-series load.</p> <p>We observe avalanche switching with risetime about 200 ps, residual voltage 300..700 V and current amplitude $\sim 70 \text{ A}$. These values are comparable to those obtained for p+-n-n+ structures with similar parameters, although the voltage ramp applied to n+-n-n+ structure is much steeper. Numerical simulations indicate quasi-uniform impact ionization in the whole structure volume, whereas switching of diode structures is believed to occur via ionizing front propagation [1]. Successful subnanosecond switching, although to higher residual voltage, has been also observed on ZnSe samples with Ohmic contacts.</p> <p>Our discovery opens a possibility for ultrafast generation of large volumes of dense electron-hole plasma in semiconductor samples without p-n junctions, which is particularly important for such promising wideband semiconductors as ZnSe and CdS.</p> <p>[1] R.J. Focia, E. Schamiloglu, C.B. Fleddermann, F.J. Agee, J. Gaudet, IEEE Transaction on Plasma Science 25, 138 (1997). [2] A.F. Kardo-Sysoev, in Ultra-Wideband Radar Technology, J.D. Taylor, Ed., CRC Press, 2001, pp.205-290. [3] V.I. Brylevskiy et al, IEEE Trans. Plasma Sci. 44, 1941 (2016).</p>
15:30	<p>[174] Diode Pump Laser Upgrade for the NIF Pre-amplifier Module</p> <p><i>Presenter: CARROLL, Evan</i></p> <p>The National Ignition Facility, the most energetic laser in the world, relies on flash-lamp pumped, solid-state amplification for its 192 laser beams. The multi-pass amplifier, within the pre-amplifier module, amplifies each joule level beam to a few kJ with flash lamps, before continuing to the main amplifier. Although flash lamps are economical, they exhibit short lifetimes, a broad output spectrum and require high voltage. Currently, a multi-pass amplifier that uses diodes instead of flash lamps is being investigated to improve output energy stability, efficiency, and reduce maintenance. A custom, compact laser diode driver has been developed, capable of delivering up to 1 kA pulses at several hertz to each diode bar and features output pulse shape control. The following paper discusses the design and investigation of the diode drivers for this potential NIF application.</p> <p>This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.</p>
15:45	<p>[355] The Progression of Silicon Carbide Power Devices Under The Army's High Voltage Power Technology Program</p> <p><i>Presenter: HINOJOSA, Miguel</i></p> <p>Recent advances in silicon carbide (SiC) device process, fabrication, design, and packaging have made possible the development of single die, high voltage Insulated-Gate Bipolar Transistors (IGBTs) and Junction Barrier Schottky (JBS) diodes with avalanche breakdown voltages up to 27 kV and 15 kV, respectively [1-2]. SiC power semiconductor devices fabricated on wide epitaxial drift regions [160 μm -230 μm] are desirable for many pulsed-power and continuous low-duty cycle power conversion systems, as they offer an advantage in critical electric field and thermal conductivity over conventional silicon devices.</p> <p>In collaboration with Wolfspeed (a Cree company) and Texas Tech University, the Army Research Laboratory (ARL) is evaluating the performance of these state-of-the-art devices for their possible use in survivability and lethality systems, power modulators, and micro-grids. The aim of this work is to present the current progress in the development of R&D-grade, >20-kV, 20 A 4H-SiC IGBTs and 10-15 kV, 17 A JBS diodes. This paper expands on previous work reported on similar devices [3-4], with an emphasis on pushing for higher power, voltage operation, and reliability.</p> <p>1. S. H. Ryu, et al, "20 kV 4H-SiC N-IGBTs", Materials Science Forum, Vols. 778-780, pp. 1030-1033, 2014 2. E. van Brunt, L. Cheng, M. J. O'Loughlin, J. Richmond, V. Pala, J. Palmour, C. W. Tipton, C. Scozzie, "27 kV, 20 A 4H-SiC n-IGBTs", Materials Science Forum, Vols. 821-823, pp. 847-850, 2015. 3. M. Hinojosa, H. O'Brien, E. Van Brunt, A. Ogunniyi and C. Scozzie, "Solid-state Marx generator with 24 kV 4H-SiC IGBTs", 2015 IEEE Pulsed Power Conference (PPC), Austin, TX, 2015, pp. 1-5. 4. M. Hinojosa, A. Ogunniyi, "High Voltage, Step-Down Converter Design using 20-kV Silicon Carbide IGBTs", 2016 IEEE International Power Modulator and High Voltage Conference, San Francisco, CA. 2016.</p>

16:00	<p>[227] Study on the high-power semi-insulating GaAs PCSS with quantum well structure <i>Presenter: LUAN, Chongbiao</i></p> <p>A high-power semi-insulating GaAs photoconductive semiconductor switch (PCSS) with quantum well structure was fabricated. The AlGaAs layer was deposited on the surface of the GaAs material, and the reflecting film and the antireflection film have been made on the surface of the GaAs and AlGaAs, respectively. When the prepared PCSS worked at a bias voltage of 9.8 kV and triggered by a laser pulse with an incident optical energy of 5.4 mJ, a wavelength of 1064 nm and an optical pulse width of 25 ns, the on-state resistance of the AlGaAs/GaAs PCSS was only 0.45 Ω, and the longevity of the AlGaAs/GaAs PCSS was larger than 106 shots. The results show that this structure reduces the on-state resistance and extends the longevity of the GaAs PCSS.</p>
16:15	<p>[326] Narrow Pulse Evaluation of 15 kV SiC MOSFETs and IGBTs <i>Presenter: BAYNE, Stephen</i></p> <p>With the progression of silicon carbide (SiC) technologies, single semiconductor switches with higher voltage and current capabilities are emerging. Evaluating the pulsed current capability of SiC semiconductor devices for pulsed power and power electronics applications is required to understand their performance and reliability. This paper presents the narrow pulse evaluation of 15 kV SiC MOSFETs (0.25 cm² active area) and IGBTs (0.32 cm² active area) with pulse widths in the range of 500 ns to 2 μs. Testing results are presented with an 8 kV charge voltage and 50 A or 90 A peak conduction current for the MOSFET and IGBT, respectively. A low inductance RLC circuit was used to generate the pulses and the device under test (DUT) was switched off during the pulse to create a square-wave type current waveform through the device. Transient characteristics, such as turn-on and turn-off times and energy, were measured to benchmark the devices' narrow pulse characteristics. The long term reliability of each device was evaluated by pulsing the device for tens of thousands of cycles with periodic measurement of the static characteristics. Testing has revealed that the 15 kV SiC IGBTs withstood tens of thousands of pulses in the range of 60 A to 95 A. The results presented in this paper demonstrate the reliability of these devices for narrow pulse applications.</p>
16:30	<p>[203] INVESTIGATION OF FAST THYRISTOR SWITCHING MODULES TRIGGERED BY DIRECT OVERHEAD IGNITION <i>Presenter: BISCHOFF, Rainer</i></p> <p>We report on the development of fast high-voltage kilo-ampere thyristor-based switching modules, which can be easily scaled by means of series connection of the thyristors. The thyristors are in each case getting triggered by the overhead ignition of breakover diodes, with the anode of the breakover diode being connected to the anode of the thyristor and the cathode of the breakover diode being connected to the gate of the thyristor. A low-inductive 10-kV module with two layers of each five IXYS 1600-V CS60-16io1 Si-based thyristors and 1000-V IXYS IXBOD breakover diodes is presented. This switching concept can also be transferred to MOS-gated thyristor structures, simply by adding a resistive divider to the circuit. The turn-on time depends on the gate voltage, which can be optimized by adaptation of the divider ratio. Minimum turn-on time has been attained by hard switching with a peak gate voltage of about 80 V. Two versions of 16-kV switching modules based on IXYS 1500-V MOS-gated thyristors have been set up and successfully tested to a low resistive load of 2.3 Ohm, reaching a peak current of 2.1 kA and a current rise time of 105 ns. Because of their kilo-ampere current carrier capability, these MOS-gated thyristor modules turned out to be a very suitable semiconductor closing switch for the transformer coupled LC inversion generator (TCLCG), which is an interesting high voltage pulse generator for driving electromagnetic effector systems. A peak-to-peak output voltage of 115 kV at a voltage rise time of 95 ns has been achieved with an asymmetrically compensated 3-stage test TCLCG. Generator efficiency was 67%, only 9% lower than with a gas spark gap.</p>
17:00	<p>[25] Silvaco-based evaluation of 10 kV 4H-SiC MOSFET as a solid-state switch in narrow-pulse application <i>Presenter: PUSHPAKARAN, Bejoy</i></p> <p>Key requirements for a solid state switch in a fast switching pulsed power circuit include high blocking voltage, high current conduction and fast switching. The wide bandgap properties of silicon carbide has enabled the development and commercialization of high voltage MOSFET whose steady state and transient characteristics meet the requirements for narrow pulse width applications. Even though SiC MOSFETs are gaining acceptance in the field of high power electronics, commercial viability and reliability has been demonstrated for devices under 2 kV out of which 1.2 kV appears to be the blocking voltage of choice. Typical pulsed power applications like plasma initiation and high-energy LASER require operating voltages in the order of several kilovolts. The development of a multi-kilovolt SiC MOSFET for fast switching pulsed power application would require detailed analysis of the device switching characteristics. Since Metal Oxide Semiconductor (MOS) capacitances play a crucial role in determining the switching characteristics of the MOSFET, it becomes critical to have a comprehensive understanding of the device capacitance and its effect on the gate driver requirements for narrow-pulse switching. In this research, a 2D model of 4H-SiC MOSFET was developed using Silvaco ATLAS TCAD software and simulated for its steady state and AC characteristics. The device was designed for 10 kV blocking voltage and 100 A/cm² drain current density. The C-V data for the SiC MOSFET was generated via Silvaco AC simulation and the data was used to mathematically estimate the gate drive requirements for the device under fast switching.</p>

17:15	<p>[134] New Type of Semiconductor Opening Switch Structure <i>Presenter: LYUBLINSKY, Alexander</i></p> <p>SOS-diodes (SOS – Semiconductor Opening Switch) have been discovered in 1993 at Institute of Electrophysics, Ural Branch, Russian Academy of Sciences. Currently SOS-diodes are the most powerful semiconductor switches used in nanosecond range pulse power devices. The effect of fast breaking of the reverse current with a density of 10^{3-4} A/cm² upon switching from direct to reverse applied voltage allows designing the generators with up to gigawatt output peak power. SOS-diode structure formed by deep diffusion of boron and aluminum from one side and phosphorus from another side into N-type silicon wafer have been thoroughly investigated. The main drawbacks of SOS-diodes are relatively high commutation losses and rather slow turn-off process.</p> <p>The way for semiconductor structure optimization has been discussed in this presentation. Alternative SOS-diodes based on P-type silicon wafer have been theoretically and experimentally studied. It was shown that they have two times less commutation losses and faster switching-off time.</p>
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Oral session 10 - Compact and Repetitive Pulsed Power Systems and NLTLs - Session Chair : Richard Ness - Room Stanmer (15:00-17:30)

15:00	<p>[124] Electronic steering of radiation beam by phase control in the arrays of uncoupled nonlinear transmission lines and Cherenkov-type HPM oscillators <i>Presenter: ROSTOV, Vladislav</i></p> <p>In the past few years, we have developed two approaches for creation of electronically controlled RF radiation beam steering: the first one is based on two- and four-channel gyromagnetic nonlinear transmission lines (NLTL) operating at the GW power level, which represents decimeter wavelength RF sources of nanosecond pulses and the second approach is based on Cherenkov superradiance two- and four-channel sources with 38 GHz carrier frequency. In the report, we present the results obtained earlier and analyze the further prospects from the point of view of physical and technical limitations to arrange new two-dimensional arrays. As an example, the project of a 7-channel RF source with gyromagnetic NLTLs is presented.</p> <p>The work is supported by the Russian Science Foundation (Grant No. 16-19-10312).</p>
15:30	<p>[144] Analysis of Nonlinear Gyromagnetic Line Operation Using LLG Equation* <i>Presenter: ROSSI, Jose Osvaldo</i></p> <p>Nowadays gyromagnetic nonlinear transmission lines (NLTL) have been studied with great interest [1] since they can generate RF up to frequencies up to 2-4 GHz at high power (hundreds of MW) as demonstrated recently [2]. As they are all solid-state devices, they can be used as compact RF sources. On these devices, microwaves are induced by the damped gyromagnetic precession of the magnetic moments in the ferromagnetic material as their coaxial structure are loaded with ferrite material as a magnetic medium. As observed, the gyromagnetic NLTLs strongly depend on the amplitude of the incident pulse and on the static magnetic bias. In principle, this phenomenon could be predicted using the precession Larmor frequency, which is proportional to the effective magnetic field. However, as shown in [2] the NLTL performance does not confirm this result. As not expected the experimental trend observed indicates that the center frequency decreases with static axial magnetic, but increases with the incident input pulse amplitude because of the azimuthal field. A possible explanation for this is that the TEM mode wave propagates down the coaxial line coupled to the azimuthal magnetic field. Thus, the objective of this paper is to address this problem correctly by doing a mathematical analysis using the LLG equation for the TEM mode without the damping term. With this proper formulation, it will be demonstrated the experimental frequency dependence observed for the gyromagnetic NLTL.</p> <p>1) F.S. Yamasaki, E. Schamiloglu, J.O. Rossi, J.J. Barroso, "Simulation studies of distributed nonlinear gyromagnetic lines based on LC lumped model". IEEE Trans. Plasma Sci. 44 (10), pp. 2232-2239, 2016.</p> <p>2) J-W. B. Bragg, J.C. Dickens, and A.A. Neuber, "Material selection considerations for coaxial, ferrimagnetic-based nonlinear transmission lines," Journal of Applied Physics 113, 064904 (2013).</p> <p>*Supported by SOARD/USAF, contract no. FA9550-14-1-0133.</p>

15:45	<p>[373] A Battery-Powered, 60-kJ, 6-RPS Rep-Rate Pulsed Power System <i>Presenter: HUHMAN, Brett</i></p> <p>The US Naval Research Laboratory (NRL) has constructed a pulsed power system designed to operate with batteries as the exclusive source of input electrical energy. Each capacitor bank uses 192 lithium-ion batteries in series with a custom DC-DC converter to charge the capacitor to 5 kV in approximately 10 seconds. For now, the capacitor is being discharged into a resistive load through an inductor. The system is intended to be used as a testbed to expose challenges presented by a high rep-rate pulsed power system on a mobile platform.</p> <p>The system will eventually be made up of sixteen battery-capacitor modules. A single frame within the system encapsulates four complete pulsed forming networks, each of which is comprised of a battery pack, DC-DC converter, capacitor, inductor, and associated pulsed power switches. Each frame is a self-contained system, with the only interfaces being fiber optic networking, 120 VAC for controls, and capacitor discharge cables. In contrast to a typical single shot pulsed power system that is energized by grid-tied electricity, NRL has developed a holistic control scheme devoted to the safe operation and monitoring of the battery packs and pulse forming network (PFN). One frame of PFNs requires more data point monitoring than the entirety of the 12-MJ NRL electromagnetic launcher pulsed power driver, significantly increasing the complexity and computing power necessary for apposite operation. The system will be discussed, the lessons learned will be presented, and preliminary experimental results from a full frame will be presented.</p>
16:00	<p>[36] HV Cables for Remotely Located Pulsed Magnetron Applications <i>Presenter: HUTLEY, Joe</i></p> <p>In the majority of applications for e2v's direct-switched solid-state modulators, the modulator is connected to the magnetron with a short length of cable. This collocation of modulator and magnetron imposes very little pulse distortion and yields a high-quality, flat current pulse with good RF fidelity.</p> <p>Typically, the modulator output cable is not rated for the full operating voltage of the magnetron; voltage breakdown is instead prevented by mechanically ensuring suitable separation of the cable from earthed surfaces. This approach limits modularity and the topological layout of systems.</p> <p>Some applications demand a more modular approach, where the magnetron is physically separated from the modulator. Applications such as linear accelerator gantries or steerable antennae could benefit from the reduction in mass associated with the remote location of the modulator system, thereby reducing the mechanical demands of their rotating platforms.</p> <p>To achieve this design flexibility, the practicalities and considerations for transmitting high-power electrical pulse energy over a number of metres, via commercially available cables, need to be determined.</p> <p>This paper details the considerations for such an HV cable to be able to operate a pulsed magnetron, remote from the modulator source. It reviews the construction of HV cables from adjacent applications, and outlines the electromechanical performance factors that determine suitability for the aforementioned scenarios. Magnetron and modulator performance limiting factors are also identified and discussed. Finally, a time-domain transient analysis is presented, with supporting evidence from experimental test results.</p>
16:15	<p>[141] Design of a 700-kV Modulator for High-Power Radiofrequency Sources above 200 GHz <i>Presenter: LAMPASI, Alessandro</i></p> <p>The availability of a high-power radiofrequency (RF) source above 200 GHz would introduce a remarkable progress in many applications, as in nuclear fusion plasma heating and diagnostics, in high-gradient accelerators, in RF undulators. For this reason, ENEA is running a project for the realization of a Cyclotron Auto Resonance Maser (CARM).</p> <p>The operational parameters of the CARM were selected taking into account the expected requirements of the future DEMO reactor. Since the DEMO electron cyclotron frequency should exceed 200 GHz with an optimal range 230-280 GHz, the frequency was fixed at 250 GHz, that is also suitable to perform second-harmonic tests in the FTU tokamak.</p> <p>This frequency can be produced by a beam power supply (PS) up to 700 kV. Its input electrical power is at least 4 MW with an efficiency $\approx 30\%$, leading to ≈ 1 MW of useful RF power.</p> <p>The first CARM prototype will be supplied by a specific high voltage modulator able to generate pulses in the range 500-700 kV with a rise time ≈ 1 μs and with a flat-top within $\pm 0.1\%$ (including stability and droop) longer than 5 μs. The final stage of the modulator is a pulse transformer immersed in an oil tank together with a ballast/dummy load. The CARM load can be regarded as a resistance (capacitance < 5 pF) depending only on the filament temperature (controlled by a dedicated ≈ 27 kW PS). The very low calculated perveance ($< 10^{-7}$) does not help the limitation of the overshoot that shall be $< 2\%$. A current increasing up to 100 A is being evaluated to reach the RF power necessary in accelerators and in short-wavelength undulators for X-ray free electron lasers.</p> <p>After the success of the first phase of the project, a new PS design will be adopted to achieve long (up to continuous wave) and amplifier-mode operations.</p>

16:30	<p>[223] Development of a solid-state high-voltage switch device for an insulation oil-filled klystron modulator <i>Presenter: INAGAKI, Takahiro</i></p> <p>Although many high-voltage pulse modulators for high-power pulse klystrons use thyratrons as a high voltage switch device, their instability and short lifetime are headache for large accelerator facilities including the X-ray free electron laser facility SACLA (Spring-8 Angstrom Compact free electron LAsER). In SACLA, 78 klystron modulators for an 8 GeV linac are operated as high-power rf sources. Since the typical lifetime of the thyatron is short for about 4 years, its high-maintenance cost are serious problem. In order to overcome this problem, we have developed a solid-state high voltage switch having a long lifetime for thyatron replacement.</p> <p>The high-voltage switch device of our modulator should run at a 60 pps repetition rate and conducts a large current of 5 kA with a 5 us pulse width from the pulse forming network circuit charged at 50 kV in maximum. We employ the static-induction (SI) thyristor as the high-voltage switch, because it has suitable characteristics for the thyatron replacement; a high off-state voltage, large pulse current capacity, a fast switching time, and a low conduction loss. In total, the 192 SI-thyristors (24 series, 8 parallel) are used in a 50 kV switch module. Since our modulator is filled with an insulation-oil, water cooling of the device is not so easy. Hence, we attach the SI-thyristors on aluminum heat sinks forcibly cooled by oil circulation. Performance check in high-voltage operation for the switch was carried out by connecting it to the actual klystron and modulator. The switch stably run at a 50 kV charging voltage, a 5 kA pulse current and a 60 pps repetition rate. A temperature rise of the SI-thyristor is about 7 degree, which is low enough. Validity of employing the module for the high-voltage switching is well confirmed.</p>
16:45	<p>[347] AN/TPS-43/70/75 Transmitter Modernization Kits <i>Presenter: KEMPKE, Michael</i></p> <p>Diversified Technologies, Inc. has introduced a new series of AN/TPS-43/70/75 transportable radar transmitter upgrade kits that replace all outdated components with solid-state components.</p> <p>DTI PowerMod™ transmitter upgrade kits deliver a complete solid-state modulator to replace the thyristor, trigger amplifier, regulator, pulse forming networks (PFN), pulse transformer, SF6 tank, and oil tank used in the AN/TPS-43, 70 and 75 family of air surveillance radars. The radar upgrade kits replicate the original transmitter functions and feature enhanced pulse agility from 0-8 μs. These radar upgrade kits provide reliability measured in decades.</p> <p>Incorporating a modulator with a solid-state series-switch design, benefits of the DTI PowerMod™ AN/TPS-43/70/75 upgrade kits include retention of existing interfaces, potential for future interface expansion through Ethernet, PLC control with circuit board high-speed fault detection, built-in self-diagnostics, touch-screen interface, simplified turn-on procedure, and control board access from outside of the transmitter cabinet.</p>
17:00	<p>[42] Rearch of compact repetitive pulsed power system based on Marx generator <i>Presenter: HAO, Shirong</i></p> <p>By adopting Marx generator technology, a compact repetitive pulsed power system has been developed which consists of a repetitive power supply and a Marx generator. By utilizing multiplex inverter boost-doubling rectifier circuits to operate in parallel, we designed and tested a repetitive power supply which can transform 30V DC to 100kV DC and charge the capacitor to 100kV repetitively. The Marx consists of 16 stages with integrated folder configuration. Each stage of the Marx consists of three 22nF capacitors in parallel. By integrating the Marx with the repetitive power supply, a compact repetitive pulsed power system has been developed. We have obtained 5 pulses with repetition rate of 5Hz on a 14Ω load. The peak voltage and peak power are more than 700kV and 35GW respectively.</p>
17:15	<p>[33] Analysis of wide-angle scanning of High Power Microwave Waveguide slot Array antenna <i>Presenter: LIAO, Yong</i></p> <p>In the design of HPM waveguide array of longitudinal shunt slots, the mutual coupling of slots in different waveguide can badly decrease the capability of wide-angle scanning of array. The choke groove was designed to restrain the mutual coupling of slots of array. The result of simulation verified that the scanning angle with gain decreased -3dB is only 24.7° when there is no choke groove and that is 33° when there is choke groove structure. The result of simulation also verified that the wideband of active reflection of array have been improved with choke groove structure. The window with high dielectric capacitance (for example ceramic window) can badly decrease the capability of wide-angle scanning of array, but for the low dielectric capacitance window (for example Teflon window), there is little influence on the the capability of wide-angle scanning of array.</p>

Wednesday 21 June 2017

Plenary Session 3 - Haas Award Winner : Ronald Gilgenbach - Chair: Edl Schamiloglou, Oxford hall (08:45-09:45)

08:45	<p>[478] Plasma Physics Education and Research Enabled by Pulsed Power*</p> <p><i>Presenter: GILGENBACH, Ronald M.</i></p> <p>This presentation will retrace the author's ~40-year journey to transform pulsed power machines into plasma physics experiments for the purpose of educating students in research. Early experiments on electron beam instabilities (ion-hose, beam-breakup-instability), relativistic gyrotrons, magnetrons and recent Recirculating Planar Magnetron (RPM) experiments utilized an Marx-Abramyan generator (MELBA). The Abramyan circuit flattened the voltage (up to -1MV +-7%) for critical physics experiments at 1-10 kA, over one-microsecond pulselength. A ceramic insulator upgrade permitted vacuum on the 10⁻⁷ Torr scale for cathode and surface electron emission studies.</p> <p>During the past decade, experiments at UM have developed the (first in USA) 1MA, 100 kV, 200 ns, Linear Transformer Driver (LTD, originally constructed at IHCE, Russia) into a z-pinch experiment (MAIZE) that has been utilized to explore MHD instabilities in imploding and exploding liner-foil plasmas and x-ray generation from Planar-Wire-Arrays. In particular, growth rates and mitigation strategies have been characterized for the magneto-Rayleigh Taylor (MRT) Instability in planar and cylindrical foil-plasma geometries.</p> <p>*Research supported by AFOSR, AFRL, ONR, DoD-MURI, DoE, NSF, L-3 Communications Electron Devices Division and Sandia National Laboratories. Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.</p>
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Oral session 13 - High-Voltage Insulation and Dielectric Breakdown Phenomena, Explosively-Driven Pulsed Power -

Session Chair : Yakov Krasik - Oxford hall (10:00-12:30)

10:00	<p>[73] The Effect of Metal Temper on Explosively-Formed Fuse Performance</p> <p><i>Presenter: TASKER, Douglas</i></p> <p>A strong dependence of the dynamic resistivity of Explosively-Formed Fuses (EFF) on metal temper is reported. The EFF is a high-power opening switch that uses an explosive charge to interrupt megampere-currents in aluminum conductors. The switch has been effective in a wide range of large-scale experiments but good, predictive, computational models of its performance have proven elusive, possibly because the metal temper has not been considered.</p> <p>Small-scale experiments were employed to study many parameters, including: electrical conduction through the explosive products; magnetic loading; current density; explosive initiation; insulator type; conductor thickness; conductor metal; metal temper; and on. However, of all these parameters the role of metal temper has not been published.</p> <p>Identical aluminum pieces were cut from the same single sheet of 813-μm thick, rolled 6061-T6 aluminum and then heat-treated to change their temper. Some of the pieces were annealed to a dead-soft temper, other pieces were left in the T6 hardness state, while other pieces were hardened beyond the original T6 temper to a brittle condition. These aluminum sheets were then tested in identical baseline explosive assemblies. In this way, only the temper of the metal was changed, the chemical composition of the metal and all other experimental parameters were held constant from experiment to experiment.</p> <p>It was found that the dynamic resistivity of the switch increased significantly with metal hardness; the dynamic resistivity of the brittle sheets being approximately three times that of the dead-soft material. By comparison, before the experiments were performed the resistances of the soft, T6, and brittle sheets were similar: 110 $\mu\Omega$, 125 $\mu\Omega$ and 150 $\mu\Omega$. The aluminum was found to be fragmented into small chips after the shots, so the possibility of metal fracture being involved in the switch mechanism will be discussed.</p>
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10:30	<p>[10] Hybrid kinetic-liquid model of the nanosecond discharge initiated by runaway electrons <i>Presenter: KOZHEVNIKOV, Vasily</i></p> <p>The direct solution of Boltzmann kinetic equation is of great interest for theoretical investigations of various gas discharges. Such approach is known to be the most fundamental because it gives comprehensive information about the discharge and its evolution by providing electron and ion distribution functions for any given time point. The complete numerical solution of Boltzmann equations for multi-component gas discharge plasma is quite challenging even for one-dimensional problems due to the mathematical complexity. That is the reason why gas discharges are usually described in terms of simplified moments models with drift-diffusion approximation or particle-in-cell (PIC) models including Monte-Carlo collisions. Here we represent novel hybrid theoretical approach for simulation of discharges. It bases on both plasma hydrodynamics and kinetics methodologies simultaneously describing the dynamics of different discharge plasma components. Particularly, we solve Boltzmann equation for electron distribution function self-consistently with ion equation of continuity coupled with electromagnetic field equations. The efficiency of the proposed approach has been shown on the example of one-dimensional coaxial relativistic gas diode. Our model accurately provides the electron power spectrum containing a group with the so-called "anomalous" energies (above the maximal applied voltage value) that were not theoretically predicted before, but do exists it various experiments. Hybrid model is also opens up the possibility to describe discharges initiated mainly by runaway electrons.</p>
10:45	<p>[89] PRELIMINARY EXPERIMENT ON SHOCK WAVES GENERATED BY UNDERWATER ELECTRICAL EXPLOSION OF WIRES <i>Presenter: LI, Liuxia</i></p> <p>It is well-known that underwater electrical wire explosion (UEWE) is accompanied by generation of strong shock waves (SSW) with fast front and short duration, which makes it attractive for various scientific and technological purposes. In this paper, a device for UEWE was developed and composed of pulse capacitors (200μF, 1~6kV), a spark gap switch, and a metal wire immersed in a chamber filled with water. The total inductance of circuit is 1.2μH and resistance is 14mΩ, while the pulsed current is 1.4kA/μs in rise rate and 2kA to 50kA in amplitude depending on the charging voltage of the capacitors and wires used. A Rogowski coil and a voltage divider were used for the measurements of the current and the voltage on the wire load, respectively. The shock waves were recorded by a piezoelectric pressure probe (model: PCB138A11). The amplitude of the shock waves was measured to be 82.4MPa at 50mm from the exploding wire. The effects of the experimental parameters (including the wire diameter, the storage energy in capacitors, the energy deposition into the wire) on the shock waves were investigated. The transfer rate from the storage energy to the deposition energy was calculated for different conditions. It was shown that the thicker copper wires would generate the stronger shock waves and the amplitude of shock wave was approximately proportional to the energy deposition into the wire. For the potential application in the oil exploitation, the destruction of the concrete cylinders with a thickness of 75mm by the shock wave was studied. The storage energy of 0.9 kJ is high enough to break the concrete cylinder into pieces. At a position of 75mm from the exploding wire, the shock wave measured in the concrete cylinder attenuates to 43.5% in amplitude of that measured in water without the cylinder.</p>
11:00	<p>[92] Space Plasma Generator for Controlled Enhancement of the Ionosphere <i>Presenter: KIM, James</i></p> <p>We are presenting an innovative space plasma generator, using explosive-driven flux compression generators to convert explosive chemical energy to electromagnetic energy. We will then use a Joule heating to heat up light metallic load in a sub millisecond time scale to transform the load from a solid metallic state to a first ionization plasma state going through multi-phase transitions to generate an artificial man-made plasma cloud in the ionosphere. The target plasma cloud will be composed of 10²⁵ ion-electron pairs of fully-ionized plasma with a few eV temperature propagating initially as a plasma disk jet, cylindrical jet, or linear jet depending on the choice of load material and geometry. This is the required amount of plasma to control enhancement of the ionosphere over the wide area of application zone. We also present analytical/computational studies of the generated plasma and plasma cloud interacting with the ionosphere and the geomagnetic field. Major mechanisms of plasma generation and initial plasma disk jet formation have been identified during parametric studies of plasma liner simulations. We used the ALEGRA-MHD code with the multi-phase equation of state and conductivity models to study multi-phase transition, plasma formation, and initial plasma evolution. Many interesting plasma physics phenomena in later time scales will be discussed, including ambient geomagnetic flux compression dynamics, high kinetic beta plasma evolution, and dense plasma recombination. We studied the dispersal of the injected artificial plasma clouds, their interaction with the ambient particles and magnetic field as a function of the injection altitude, ambient ionospheric parameters and energy and mass of the injected artificial plasma over several hours. A sounding rocket can be utilized to demonstrate the device performance in ionospheric test environments.</p>

11:15	<p>[133] The research on the design method and pre-arcing characteristic of the pulsed discharge fuse <i>Presenter: JIN, Chaoliang</i></p> <p>In the capacitive pulsed power supply, several or even hundreds of capacitors are in parallel to provide energy. If internal short circuit occurs in one of the capacitors, the others will inject a lot of energy into the fault one, which may cause a severe accident. By taking a shunt capacitor bank composed of ninety-six 33kJ-capacitors as the research object, a scheme which tries to protect shunt capacitors through current limiting fuse is evaluated. The paper describes the fusing process and puts forward a design method of pulsed discharge fuses' sectional area. A multi-field coupled model of circuit, current, structural heat transfer is developed by using COMSOL. The model is used to analyze the pre-arcing time, temperature distribution and resistance of the fuse. Due to the extremely short pulse width(about 200μs) of pulse current, the fusing process is assumed as an adiabatic process. The latent heat of fusion and resistivity–temperature relationship are also taken into account in the model. When the fuse isn't added to the circuit, the short-circuit discharge current peak value can reach 300kA. After adding fuse to the circuit, the simulation results show that the fuse starts to evaporate in 99μs when the voltage decreases from 10.8kV to 8.9kV, and the current value is 193kA at this moment. At last, a pulse circuit is constructed to verify the above results. The tests show that the fuse cuts off the current in 95μs, and the capacitor voltage, current is respectively 7.9kV, 200kA at this moment.</p>
11:30	<p>[142] Testing High Voltage (200kV) DC cable and feed-through designs in rep-rated modes* <i>Presenter: MAZARAKIS, MICHAEL</i></p> <p>Michael G. Mazarakis, Mark L. Kiefer, Joshua J. Leckbee, Sandia National Laboratories Albuquerque, NM 87185</p> <p>Del H. Anderson, Frank L. Wilkins, Robert J. Obregon National Security Technologies</p> <p>We have constructed a Component Test Stand (CTS) to test various high voltage components to be utilized in near future pulsed-power devices. In addition to cable and oil feed-through design voltage hold off, different types of high voltage switches will be evaluated. The system contains two switches connected in series separated by a ~50 ns worth of high voltage cable. The configuration is such that triggering the first switch enables the triggering of the second switch. This way we can evaluate the performance of two switches at a time and study the influence of one switch on the other. A software system similar to LabView is designed and built to operate and collect data in a rep-rated mode. The two switches are immersed in transformer oil tanks and pressurized with dry air. The present paper will mainly present a cable-oil feed-through design evaluation as a function of repetition rate. The rep-rate will be adjusted to not affect the cable voltage hold-off as well as switch performance. The rep-rate is necessary in order to obtain component lifetime results in a reasonably short time. Apparently the transformer oil in a high voltage DC environment behaves much differently than in AC. Its behavior is similar to a weak electrolyte, and space charge effects seriously affect the current through it as well as the field distribution.</p> <p>-----</p> <p>* Sandia is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract No. DE- AC04-94AL85000</p>
11:45	<p>[173] Effects of Contamination Accumulation on The Surface Temperature Distribution of a Glass Insulator String <i>Presenter: ILOMUANYA, Chibuike</i></p> <p>A study is carried out on a uniformly contaminated cap and pin insulator string consisting of 10 glass discs, using a Finite Element Analysis software. A CAD design of the insulator is such that a thin conductive water layer covers the entire glass region. This water layer represents acid rain. 150μS/cm conductivity is applied to the water layer to represent an approximate 5% concentration of sulphuric acid at -1\circC. The insulator is energized by applying 100kV to its High Voltage end. The highest temperatures were observed at the edges of the insulator and can be attributed to higher power dissipation in these regions. This causes dry band formation on the insulator surface and possible partial discharge (pd) activities. The temperature at the glass and metal component junction remains lower than those at the edges, but high enough to cause an expansion and contraction activity in this region which could lead to an insulator failure due to thermal stress. The percentage concentration of the acid was varied by varying the conductivity of the water layer. While similar results were obtained, the temperatures of the narrow edges increased with increase in conductivity and decreased when the conductivity was reduced. A simulation was carried out without the conductive layer and a uniform temperature was observed across the insulator. The distribution of the electric field on the insulator's surface is also calculated. The regions of the insulator surface having the highest electric field intensity are the points susceptible to pd activities. As conductivity of the water layer in this work is determined by the percentage concentration of the acid, which in turn explains the level of contamination on the insulator, it is evident that monitoring of pollution severity of HV insulators in harsh environments will provide necessary information for prevention of insulator failure.</p>

12:00	<p>[360] Initial Experiments with the LANL “Ranchero-S” Flux Compression Generator <i>Presenter: HAROZ, Erik</i></p> <p>Initial experiments have been conducted with a new model of the LANL Ranchero magnetic flux compression generator (FCG) that has been introduced as the Ranchero-S configuration. The design overcomes a weakness in the earlier versions related to possible flux pocketing near the output glide plane when currents become very high. In addition to employing an armature that is sculpted to match a contoured stator, the high explosive (HE) is pressed, machined, and glued PBX 9501 pieces instead of a single PBXN-110 casting. PBX 9501 provides higher armature velocity, but presents unique assembly challenges. This first test uses a capacitor bank to supply a 3.5 MA seed current to the 87 nH FCG. Peak current is ~40 MA as measured by Rogowski coils and Faraday rotation loops (including development of an improved Faraday rotation configuration). Peak current is applied into an imploding 100-gram aluminum liner load capable of exceeding velocities of 1 cm/μs and with an initial inductance of 2.5 nH and a peak inductance of 3.5 nH at peak current. Liner performance, including liner velocity and liner/glide plane interaction effects, is monitored via an array of photon Doppler velocimetry probes positioned about the central measuring unit. Our experimental results are compared with our MHD calculation predictions.</p>
12:15	<p>[137] Partial Discharge in High Voltage DC Cables <i>Presenter: MORRIS, Euan</i></p> <p>This paper is concerned with use of partial discharge monitoring to provide information about the condition of the insulation of electrical cables used for HVDC transmission systems. Electrical cables are among the most fundamental components of any electrical grid, from large subsea international interconnectors, to the ‘last mile’ providing consumers with their electrical supply. The size, cost and current carrying capability are the main considerations when designing and selecting a cable, and in this regard the insulation of these cables is as fundamental as the conductor. Partial discharge (PD) measurement is becoming increasingly vital in monitoring the condition of cable insulation, providing valuable information about the health of the insulation, and predicting when insulation is likely to fail. The majority of this PD monitoring is performed on cable operating under AC conditions, however, with the increasing use of high voltage DC links, for subsea, or long land-based connections provides motivation for the increased use of PD monitoring on cables operating under HVDC. However, despite the increased intensity of research into PD in HVDC cables, there are significant knowledge gaps, preventing the practical application of PD monitoring techniques to HVDC cables. This paper seeks to partially address these gaps in knowledge, by presenting results obtained from PD measurements on artificial voids created in polymeric cable insulation under both AC and DC conditions. From this, recommendations on the use of PD monitoring for HVDC cables may be provided, as well as potentially recommendations for future research at both an academic and industrial level.</p>

Oral session 14 - High-Current Accelerators - Session Chair: Frédéric Bayol - Room Stanmer (10:00-12:30)

10:00	<p>[256] Status of the 1st Radiographic Axis of the Epure Facility <i>Presenter: GEORGES, Alain</i></p> <p>Epure is a shared French and British hydrodynamic experiment facility, in use since 2014 with one radiographic machine, previously called Airix and installed in a former French facility.</p> <p>This linear induction accelerator has been moved and refurbished over the course of years 2013-2014, and operated with success and reliability since then. Special care has been given to maintenance optimization and quality to achieve these results.</p> <p>Of particular notice are the good performances obtained with different developed operating points in terms of dose and focal spot characteristics, which enabled a series of successful hydro experiments.</p> <p>Betterments are envisioned as a way of careful control of all parameters involved in radiographic performance and in preparation of multi-axis operation.</p>
10:15	<p>[457] Investigations on Dual Pulse technologies for future upgrade of CEA flash X-rays LIA <i>Presenter: VERMARE, Christophe</i></p> <p>X-Ray flash radiography is a useful diagnostic to investigate the structural response of matter under impulsive loading during hydrodynamic experiments. In addition to multiple axis capability, multiple pulses design for future upgrade of LIA machine(s) is under investigation at CEA. The major design changes of a dual-pulse LIA compared to the existing and operational one at EPURE (ex-AIRIX) are: the injector, the HV generators driving the induction cells and the electron / X-rays conversion target. CEA has developed a dual-pulse HV generator using coaxial water lines connected in series. This design has been successfully tested and reliability evaluation is ongoing. About the injector, CEA choose to investigate an induction push-pull design. Preliminary design is in progress and the main validation steps to reach a complete feasibility demonstration are identified. Finally, studies on the target material behavior under strong energy density deposition have started using numerical models and simulations tools. A complete experimental programme has been established along the coming years to gain and confirm understanding required for an optimized design. Overall coherence of those studies and several recent achievements will be presented.</p>

10:30 **[375] Scorpius: The development of a new multi-pulse radiographic system**

Presenter: CRAWFORD, Mark

One of the original drivers behind the development of pulsed power was the need for short-pulse (flash) x-ray sources for hydrodynamic tests. These systems continue to be an important diagnostic for the evaluation of hydrodynamic phenomena. In the United States, three primary facilities provide this function: Flash X-Ray (FXR) at Lawrence Livermore National Laboratory (LLNL); the Dual Axis Radiographic Hydrodynamic Test (DARHT) Facility at Los Alamos National Laboratory (LANL); and Cygnus at the Nevada National Security Site (NNSS). FXR and DARHT provide highly penetrating radiographic capabilities but are limited in the types of hydrodynamic experiments that can be performed, while Cygnus can support a larger range of experiments, but does not provide the same penetrating capability.

To fill this gap in hydrodynamic experimental capability, the National Nuclear Security Agency (NNSA) has recently issued a set of high-level requirements describing a radiographic capability similar to that of DARHT, but located in a facility similar to Cygnus. In response to these requirements, a project called Scorpius has been developed as a joint partnership between LANL, LLNL, Sandia, and NNSS.

A key requirement is the ability to deliver multiple (2 or more) radiographic images along a single axis in a short time scale. This requirement effectively limits the possible system choices to a linear induction accelerator (LIA). However, there are several families of multi-pulse LIA architectures from which to choose.

This paper describes the high-level system requirements for Scorpius as well as the evaluation of technologies and systems that might meet those requirements. In addition, the current preferred option and the associated technology maturation activities are discussed.

*This work supported by the US National Nuclear Security Agency and the US Department of Energy under contract DE-AC52-06NA25396

10:45 **[13] The MERLIN Induction Voltage Adder Radiographic Accelerator**

Presenter: THOMAS, Ken

The MERLIN accelerator being commissioned at AWE in a new Technology Development Centre will provide one of the flash radiographic sources at a joint UK/French facility for hydrodynamic testing in support of the two nations' nuclear deterrents. The ten module Induction Voltage Adder (IVA) has been designed to provide a 60 ns long TerraWatt pulse to drive a Self Magnetic Pinch (SMP) electron beam diode at 7.5 MV. The design work for MERLIN was carried out by L3 Pulse Sciences in San Leandro, California and builds on previous IVA experience in the USA. Prototyping of sub-systems was also carried out by L3 to confirm that the performance and reliability requirements for the overall accelerator can be met. However, it is only now that all the components of the accelerator have been brought together and its overall function can be characterised and compared with predictions. Commissioning of the accelerator has involved setting to work the ancillary systems which provide and control oil, de-ionised water, sulphur hexa-fluoride gas, vacuum, control and instrumentation, diagnostics and data acquisition. With these operating satisfactorily testing of the pulsed power systems was able to commence.

Commissioning of the pulsed power systems started with a run up of the Marx generator into a resistive load to its operating voltage of 2.5 MV, including characterisation of the trigger systems and the diverter switches. These are intended to short the Marx output after it reaches peak voltage, or if a pre-fire occurs, in order to reduce the risk of electrical breakdowns. The waveforms produced during factory tests in the US were successfully reproduced and the jitter of the trigger systems shown to meet specification. This allowed the commissioning programme to proceed to the active commissioning phase where an X-ray output is generated.

Active commissioning is enabled by the Marx generator being connected via an oil insulated transfer line to the Pulse Forming Lines (PFLs). Each module of MERLIN comprises an induction cell driven by one of these PFLs. The upstream section of each PFL receives its 2.5 MV charge from the Marx generator on a microsecond timescale before its pulse forming action is initiated by a laser triggered gas switch. The laser triggering should provide nanosecond order synchronisation, and hence excellent pulse reproducibility, when the pulses are combined in the adder. The 60ns duration, 1.1 MV outputs of the PFLs are fed to their corresponding induction cells which act to perform voltage addition along a 28 metre long 80 Ohm MITL. This delivers an 11 MV forward going wave to the e-beam diode.

The pulsed radiographic source driven by MERLIN will be a SMP diode developed in an AWE led research programme in collaboration with US National Laboratories. This diode operates at approximately 40 Ohms with the result that re-trapping of the MITL sheath current occurs transforming the 11 MV forward wave down to ~ 7.5 MV while increasing the load current to ~ 200 kA. The PFL's configuration tailors the output pulse to compensate for the SMP diode's intra-pulse impedance droop and hence generate a relatively constant voltage during the X-ray flash. Since the SMP diode is a single shot device (due to the energy density incident at the anode/X-ray converter) a Large Area Diode (LAD) of similar impedance is utilised to allow repeated testing of the pulsed power systems. By mid-2017 the testing of the Pulsed Power systems and MITL with the LAD is due to have been completed and the optimisation of the SMP diode should be in progress.

11:15	<p>[128] Design of compact and repetitive pulsed e-beam source <i>Presenter: SONG, Fa-lun</i></p> <p>We report on the design of a compact and repetitive pulsed e-beam source. This pulsed e-beam source, which can work stably for long time, was built based on Marx technology. The designed output voltage, current, pulse width and repetition frequency of this e-beam source is 1 MV, 20 kA, 180 ns and 1~50 Hz, respectively. In contrast, the volume and weight of this source is limited to 2.5 m³ and 2.2 ton. The energy density of a pulse forming network model in this source attains 23 kJ/m³. When working at single shots, this e-beam source gives an output voltage of 0.98 MV, current of 18 kA and power of approximate 20 GW. On the other hand, this e-beam source realizes an output voltage of 0.9 MV, current 18 kA and power 16 GW at a repetition frequency of 30 Hz. The source works very stable, with a jitter of 6 ns.</p>
11:30	<p>[194] Generation of Intense Pulsed X-ray and Repetitive Pulsed X-rays <i>Presenter: YUAN, Jianqiang</i></p> <p>Both intense pulsed X-ray and repetitive pulsed X-rays play an important role in the investigation of various physical processes in hydrodynamic experiments.</p> <p>In order to generate intense pulsed X-ray, 1.2 MV pulsed power generator and rod-pinch diode are designed and constructed at Institute of Fluid Physics, CAEP. The generator is composed of a Marx generator, an upstream oil line, a pulse forming line, an oil switch, a transfer line and a load. As the working ratio is kept at 70%, the jitter of Marx generator is less than 6 ns, the jitter of the pulsed power generator is less than 18 ns when a copper-sulphate resistive load was used. The X-ray dose of 1.4 R at 1 m in the forward direction and the spot size of 1.47 mm are achieved.</p> <p>In order to generate repetitive pulsed X-rays, a stacked Blumlein line (SBL) type pulsed power source (220 kV, 1 kA, 1 kHz) based on high power photoconductive semiconductor switches (PCSSs) and industrial cold cathode diode have been constructed at Institute of Fluid Physics, CAEP. Metal-ceramic surface flashover cathodes (spoke-shaped or not) are employed to enhance electron emission and improve the diode performance. ICCD images show that the spoke-shaped metal-ceramic surface flashover cathode has more uniform electron emission than metal foil cathode. Repetitive pulsed X-rays with dose of 25 mR, FWHM of 40 ns and repetition rate of 1 kHz were generated.</p> <p>*This work was supported by National Natural Science Foundation of China (51007085, 51207147, 51407170, 51477185)</p>
11:45	<p>[386] Analysis and improvement of a folded gigawatt intense electron-beam accelerators <i>Presenter: YIN, Yi</i></p> <p>Long pulse intense electron-beam accelerators (IEBA) are of great interesting in many regions. In this paper, a folded IEBA is introduced. The pulse forming section of the IEBA is made up of two pulse forming lines (PFL) and a curving transition section to joint two PFLs together. This type of IEBA is compact in structure. The flat voltage of the main pulse on the load of IEBA is one of the important factors which affect the quality and characteristic of the output beam current of IEBA. Effect of the transition section on the output voltage of IEBA is analyzed in theory. A formula which is used to calculate the output voltage of IEBA is obtained. Wave impedance and transmission time of the transition section are major factors that influence the output pulse voltage waveform at the load. Experiments are performed on IEBA with different transition sections. The results show that to get flap top voltage at the load wave impedance of transition section should match the impedance of PFL. At the gas breakdown voltage of ~740 kV, a square shape pulse with voltage ~370 kV and pulse width 288 ns was obtained at the load. The experiments results are in good agreement with theoretical analysis.</p>
12:00	<p>[383] Multi-Pulse Diode-Isolated-Blumlein Induction-Cell Drivers <i>Presenter: ROSE, Chris</i></p> <p>The Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility at Los Alamos National Laboratory (LANL) uses two, linear-induction accelerators (LIAs) for flash, x-ray radiography of hydrodynamic tests. The Axis-I LIA uses a single, beam pulse of 60 ns, 20 MeV, and 2 kA. The Axis-II LIA uses a long beam pulse, and a kicker to generate four radiation pulses.</p> <p>The National Nuclear Security Agency (NNSA) is planning a new, multi-pulse, single-axis, electron LIA for hydrodynamic experiments. One method for generating multiple, beam pulses on a single axis, without a kicker, is to multi pulse the injector and each accelerator cell. Diode-isolated Blumleins are being considered as the pulsed-power drivers for the accelerator cells.</p> <p>On DARHT Axis-I, the Blumleins are dc connected to the cells such that when they are charged, the connected cells' magnetic cores are also preset. With diodes in the circuit, this dc path is not available. This paper describes the 300-kV, diode-isolated Blumlein concept, performance requirements, Blumlein charging options, core preset methods, and circuit simulation results.</p> <p>Work supported by the US National Nuclear Security Agency and the US Department of Energy under contract DE-AC52-06NA25396</p>

12:15	<p>[408] Testing and Evaluation of High Voltage Diode Stacks for multi-pulse Linear Induction Accelerators <i>Presenter: DIGHE, Kalpak</i></p> <p>The Department of Energy has tasked a few of the national laboratories to design and develop a new linear induction accelerator (LIA) capable of multi-pulse operation. This LIA would be different from the DARHT Axis II design in that, instead of multiple pulses being 'kicked' out of a single long pulse, the multiple pulses will be delivered independent of each other by the pulsed power system. In order to successfully do so, the pulsed power systems need to be isolated from each by inserting high voltage diode stacks in the pulsed power paths.</p> <p>Los Alamos National Laboratory is currently testing and evaluating a few different designs of such diodes stacks capable of withstanding voltages of ~300 kilovolts. Preliminary test results of high voltage pulses from Blumleins - capable of 300 kV pulses - fired into dummy (resistive) loads will be presented in this talk.</p> <p>Comparison of these data with SPICE simulations of the circuit models, as well as, preliminary testing of dual pulsing results will be presented in companion papers.</p>
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Oral session 15 - Prime Power and Power Systems - Session Chair : Brett Huhman - Room Preston (10:00-12:30)

10:00	<p>[119] Integrated Module Based on Reversely Switched Dynistor (RSD) and Its Stress Analysis <i>Presenter: LIANG, Lin</i></p> <p>Based on the controllable plasma layer turn-on principle, RSD(reversely switched dynistor) has low dissipation and high di/dt capability. It is a special kind of semiconductor devices applied in the pulsed power area. Due to the advantages of small volume, low parasitic parameters and high reliability for the integrated modules, similar to the power electronic area, the integration trend has also appeared in the pulsed power area in recent years. The integrated module based on RSD is proposed and designed in this paper and its stress is analyzed.</p> <p>The secondary packaging integrated module of PCB level based on RSD is proposed for the first time, and by establishing the electrical-thermal-mechanical multi-physical fields coupling finite element models, the distributions of the electromagnetic and thermal stress in the module are discussed. The electromagnetic stress increases with the increase of the amplitude of the current. The thermal stress increases with the increase of the amplitude and the frequency of the current. Taken the pull-out force of pads as a standard, the limiting current is determined by the electromagnetic stress at low frequency and by the thermal stress at high frequency. In the practical module, with the double-layer routing, and RSD as the boundary, the anode network of RSD is on the bottom layer of PCB while the cathode one is on the top. In the turn-on experiments of the module, the temperature is measured by the infrared thermal imager and the magnetic field is measured by the near field probe. Some contents of the model analysis are verified preliminarily.</p>
10:15	<p>[249] Solid-State Pulsed Power System with GaAs-PCSS for Dielectric Wall Accelerator <i>Presenter: LIU, Yi</i></p> <p>Benefiting from solid-state pulsed power system with GaAs-PCSS, dielectric wall accelerator (DWA) as a new kind of high acceleration gradient accelerator has a compact construction that makes it quite suitable for some certain applications, such as proton tumor treatment and industrial inspection. The solid-state pulsed power system is made up of several groups of pulsed power units. Each group contains 2 to 4 units, and each unit is set up as a 2-stage Blumlein line. It is constituted by GaAs-PCSS(Photoconductive Semiconductor Switch) and plate pulse forming lines, which are made of high-performance dielectric ceramic. The GaAs PCSS triggered by a high power laser diode driver works in nonlinear mode and its bias voltage and conduction current can be up to 20 kV and 800 A respectively. In the experiments, the 2-BL unit can provide a 34 kV, 10 ns pulse. Several groups have been used to load accelerating tubes at different intervals so as to accelerate the proton beams which are just passing through. Until now, the solid-state pulsed power system has performed well and a system with 6 groups (14 units in total) can accelerate proton from 40 keV (after the kicker) to 460 keV with 80.5 mA beam intensity.</p>
10:30	<p>[251] Research on a novel high-power semi-insulating GaAs photoconductive semiconductor switch <i>Presenter: XIAO, Jinshui</i></p> <p>To enhance the optical absorption efficiency, a novel GaAs Photoconductive semiconductor switch (PCSS) with reflecting film and antireflecting film has been made. When triggered by a 1064nm laser pulse with an incident optical energy of 5.4 mJ, an optical pulse width of 25 ns and a bias voltage of 6 kV, the calculated on-state resistance of the PCSS with reflecting film and antireflection film was only 0.61 Ω. To increase the photocurrent of the PCSS, a PCSS with interdigital electrode has been made, at a bias voltage of 2 kV, the on-state resistance can be reduced 0.35 Ω. In this condition, the lifetime of GaAs PCSS can be further improved.</p>

10:45	<p>[270] A Modularized High Power Solid-State Switch for Pulsed Electric Fields (PEF) Applications <i>Presenter: CHEN, Xiaotian</i></p> <p>Pulsed electric fields (PEF) technology is an innovative non-thermal pasteurization method by using the high electric field (more than 20 kV/cm) and short duration (ns to ms) pulses to inactivate microorganisms and enzymes with only a small increase in temperature. In accordance with the aforementioned working principle of PEF application, a repetitive high power solid-state switch with high voltage and current capacity is designed and implemented, based on series and parallel connection of discrete 1200V IGBTs. The proposed switch is composed of ten IGBT stacks formed with four series-connected IGBT function units, and each unit is made up of one gate driver and four parallel-connected IGBTs. On this basis, a digital signal processor (DSP) is utilized as the control unit of the system, which monitors the state of the switch and produces the gate driving signal. This paper investigates the causes and solutions of unequal sharing of voltage and current happened in IGBT series-parallel topology. A snubber circuit with optimized parameters is suggested to ensure the synchronization of IGBTs switching. To solve the problem of unbalanced sharing current in the parallel circuit, all of devices on IGBT stacks are arranged annularly and placed on an integrated circular printed circuit board (PCB) to diminish the parasitic effect, and IGBTs with close electrical characteristics are screened to use for reducing the difference sharing of current among parallel branches. Furthermore, a protection circuit has been developed to shut down the IGBT stacks when the load is shorted. Applying the switch to the high-voltage pulse generator for PEF processing, the test shows that the generator could produce high voltage square wave pulses with steep edge stably, which achieves the pilot-scale processing capacity. And the protection circuit responds effectively to prevent the switch damaged when short circuit occurs.</p>
11:00	<p>[283] A 100kV, IGBT switched, spark gap trigger generator <i>Presenter: SMITH, Paul W.</i></p> <p>The lack of availability of small, fast, switches such as krytrons (e.g. EG&G KN 6) and thyratrons (e.g. E2V FX2530) makes the design of high voltage spark gap trigger units problematic. This paper will describe a 100kV trigger generator which is switched using a high voltage, high current IGBT switch. A capacitor, charged up to 5kV, is discharged with the IGBT into the primary of a high gain autotransformer, the secondary of which is connected to the output of the generator. The transformer is wound with copper and mylar foils on to an amorphous metal glass core which is carefully gapped to avoid core saturation.</p> <p>One of the advantages of this all-solid-state generator is that it can easily be triggered by a TTL input pulse and the throughput delay and jitter of the generator is well characterised. Hence it is then very easy to synchronise a pulsed power system, triggered by this generator, to any diagnostic measurements that may need to be made.</p> <p>Output pulse rise-times from the trigger generator are typically below 150 ns and a simple pulse sharpening circuit can added to the output circuit of the pulse transformer which can reduce the rise-time to durations which are short enough to promote multi-channelling in rail-gaps. Basic circuit and transformer calculations will be described which explain the trade-off between voltage gain from the primary to the secondary circuits of the transformer and the rise-time of the output pulse.</p> <p>*paul.smith@firstlightfusion.com</p>
11:15	<p>[378] OPTICAL NONLINEAR ABSORPTION PROPERTIES OF 4H-SiC—EXPERIMENT AND MODEL <i>Presenter: MEYERS, Vincent</i></p> <p>Intensity-dependent nonlinear light absorption in bulk 4H-SiC at the above-bandgap energy of 3.49 eV ($\lambda=355$ nm) is studied. Characterization and understanding of such nonlinear optical behavior in 4H-SiC forms the basis of efficiency improvements and design of optoelectronic SiC devices, including photo-conductive semiconductor switches. It is noted that previous research performed elsewhere had focused primarily on nonlinearities at below-bandgap energies, while little had been explored above-bandgap. In this study, absorption of short laser pulses with fluences ranging from 1 mJ/cm² to 30 mJ/cm² incident on 160 μm-thick high purity semi-insulating 4H-SiC samples of varying recombination lifetimes is addressed. Sample bulk recombination lifetimes vary from 0.5 ns to 100 ns displaying the range of effects from growth, electron irradiation, and annealing. The effective absorption coefficient varies significantly within this range as an apparent function of bulk recombination lifetime. A four-level time- and space-dependent finite difference time domain (FDTD) model taking into account electron trapping, interband absorption, and free-carrier absorption was constructed that yielded further insight into the absorption dynamics. For instance, the importance of free carrier absorption and deep-level trapping in the nonlinear absorption behavior is elucidated.</p>

11:30	<p>[310] Current progress on a fast semiconductor-based Marx generator for a pulsed electron beam device <i>Presenter: HOCHBERG, Martin</i></p> <p>A fast semiconductor-based Marx-generator is currently under development at the Institute for Pulsed Power and Microwave Technology (IHM) as driving pulse power source for a pulsed electron beam device (GESA). Its design addresses the challenging requirements of multipoint explosive emission cathodes such as fast voltage rise times below 100 ns together with flat top pulse amplitudes of 120 kV \pm 1% at currents ranging from 200 A to 600 A for pulse length of up to 100 μs. Guided by economic considerations, 6 parallel 1.2 kV IGBTs are employed as switching elements. Fast current rise time is achieved using an effective gate-boosting circuit and a quasi-coaxial design of the generator. To guarantee a flat top voltage pulse at varying load conditions due to the dynamic impedance of the device at moderate stage capacitance, approximately 150 stages are required. As result challenges arise considering the distribution of supply and charging voltage as well as synchronous triggering. This contribution presents selected aspects of the generator design and first measurements on a small-scale setup.</p>
12:00	<p>[379] Toward the Development of an Efficient Bulk Semi-Insulating GaN Photoconductive Switch <i>Presenter: MEYERS, Vincent</i></p> <p>Photoconductive semiconductor switches (PCSS) made from bulk, semi-insulating GaN have been fabricated and tested under pulse-charged conditions. Switching response and photocurrent efficiency of GaN PCSSs triggered by sub-10 ns, 355 nm laser pulses is reported. It is shown that fast rise time (<300 ns) voltage pulses can be used to charge a GaN PCSS to fields well beyond the DC breakdown field strength of GaN and improve switching performance. GaN's wide band gap, breakdown field strength, and electron mobility make it a material superior to SiC and far superior to GaAs for PCSS applications, though historically these materials have dominated PCSS research due to their relative ease of fabrication. Recent improvements to crystal quality and wafer size have allowed GaN and more recently semi-insulating GaN to play an increasing role in high-power and high-voltage solid state devices.</p>
12:15	<p>[385] Impulsive Dielectric Performance of HFO-gas Mixtures <i>Presenter: YAO, Yuan</i></p> <p>There is a strong demand in the power and pulsed power industries for environmentally friendly insulating gases and liquids with advanced dielectric properties as a replacement for SF₆ due to environmental concerns. Recently several novel dielectric fluids have been proposed for potential use as insulating materials. 3M has developed the fluoroketone Novec™ 5110 dielectric fluid as a possible alternative to sulphur hexafluoride, [1]. Based on the Novec™ 5110 molecule, General Electric has developed a novel gas mixture, g3 (Green Gas for Grid described in [2]), with a low, 98% less compared to SF₆, green house potential for switch-gear and grid applications. Other potential alternatives to SF₆ include gases such as CF₃I [3, 4] and hydrofluoroolefin, [5] mixed with buffer gases, typically with carbon dioxide or nitrogen. However, the breakdown properties of these fluids are not well understood and required further investigation in order to establish potential practical applications of these gases and gas mixtures.</p> <p>The present work is aimed at investigation of the impulsive dielectric breakdown properties of the hydrofluoroolefin HFO1234ze in combination with other buffer gas(es) such as CO₂. The triggered switching topology developed for this research project was used to characterise the switching performance, i.e. jitter and breakdown voltage spread of the gas mixtures stressed with high voltage impulses with rates of voltage rise in ns and μs ranges. In pulse power applications in order to minimise the switch inductance and electrode's erosion rate, it is desirable to achieve multi-channelling operation of the plasma closing switch. Investigations into potential multi-channeling operation of the switching topology filled with different proportions of hydrofluoroolefin and buffer gas(es) has therefore been conducted. Based on the obtained results, the paper provides recommendations for potential applications of the hydrofluoroolefin HFO1234ze gas mixtures for plasma closing switching operations.</p>

Poster session III - High Power Electronics - Hall 4 / Cambridge (13:30-15:00)

board

[472] A Novel Active Soft-Switching Converter with loss-less Snubber for MTEM Electromagnetic Transmitter

1

Presenter: WANG, Xuhong

Multi-channel transient electromagnetic (MTEM) is an artificial source electromagnetic detection method, the transmitter injects the high-power pseudo-random binary sequence (PRBS) signals with different coding frequencies into the earth to obtain the geological structure and the mineral resources. A novel active soft-switching converter with loss-less snubber for MTEM transmitter is presented in this paper. In contrast to the conventional DC/DC converter, the main switches, auxiliary switches and rectifier diodes of the proposed converter can achieve soft-switching from nearly zero to full load. According to the change of the load power, the proposed converter can operate in the passive soft-switching or the active soft-switching. Under the action of the cut-off diodes and auxiliary windings coupled to the main transformer, the auxiliary switches achieve soft-switching without increasing the electric stress of the devices. In addition, the conduction loss and switching loss are greatly reduced than the ordinary auxiliary circuits. The loss-less snubber in the output rectifier is composed of a controlled switch, a capacitor and two diodes, which ensures the soft-switching for the rectifier diodes. So the voltage ringing across the output rectifier is clamped. The transmission efficiency and power density of the proposed converter are significantly improved than the conventional converter. Firstly, the topology of the proposed converter and the timing diagram of control signals are described. Secondly, the working principle of the converter is analyzed in detail. And then, the relationship between the operating modes and the load power is given. Finally, the Saber simulation and experimental results verify the feasibility and validity of the converter, and a 60kW prototype is implemented.

[466] DESIGN AND IMPLEMENT CONTROL SYSTEM OF HIGH VOLTAGE PULSE POWER SUPPLY

2

Presenter: LI, WEIBIN

The high voltage pulse power supply is the important components in HL-2A tokamak device which provide the direct-current (DC) energy to auxiliary heating system. The high voltage pulse power supply is build based on pulse step modulation (PSM) in HL-2A. The performance of the PSM power supply control system will directly affect the result of the auxiliary heating system, including the study of the physical characteristics of the plasma. The alternative-current (AC) voltage is provide by pulse motor generator set which have many loads operating at different times, so when a loads is running output AC voltage of the pulse motor generator set will be disturbed. In order to obtain good control performance pulse width modulation (PWM) control technology is adapted to control PSM power supply. The whole control system of PSM power supply is consists of programmable logic controller (PLC), close loop feedback control system which is realized based on NI software and hardware, RT operation system (OS), fault detecting system and measurement. Except of PLC all signals are transmitted by optical fiber to ensure the reliability and anti-interference ability of the control system. The new control system has been used in the experiment; the results show that pulse step modulation, high efficient frequency of the output, short protection time (less 5ms), high output power and high reliability can be achieved.

[421] Evaluation of High Frequency Solid State Switches for Pulsed Power Applications Using a 12 kW Variable Voltage Testbed

3

Presenter: BAYNE, Stephen

Field Effect Transistor (FET) controlled devices, such as MOSFETs and IGBTs, exhibit some desirable characteristics over other solid-state devices; benefits include high frequency switching, voltage control, and compact control circuitry. This paper details a testbed for evaluation of FET controlled devices used in inductive pulsed power systems as well as the diagnostics used to characterize the devices under test (DUT). The testbed operates in two modes: (1) High energy pulsed mode, with charge voltages up to 300 V, pulse width of 3 seconds and up to 18 kJ total stored energy (2) Continuous pulse-train mode, with charge voltage up to 300 V, up to 18 kJ total stored energy and average current output up to 40 A. Both of these modes utilize a 396 mF capacitor bank to store energy. A fast, custom, gigabyte-memory-depth data acquisition oscilloscope records voltage and current waveforms at a 60 Mega-Sample/second rate. Due to the frequency regime (3-30 kHz), high current levels (up to 100 A peak) and wide voltage range of these experiments, making these measurements, reliably, is a non-trivial effort. Several methods of making each measurement were examined. Calibrated voltage, current, energy, and power waveforms quantify the DUT's turn-on / conduction / turn-off characteristics. Measurements of interest in these experiments are device current and device voltage; energy dissipated in the DUT is extrapolated from these measurements.

[400] Design of Time Sequence Discharging Control System for Pulse Power Supply Modules

4

Presenter: LIU, Kun

As the development of pulse power technology, the pulse power supply modules (PPSM) are widely used in areas of scientific research, medical treatment, industry, military, and geological prospecting. In these areas, more and more energy is needed and the number of PPSM is increasing rapidly, and the accurate pule discharging waveforms are required in some applications. How to control so many PPSM to discharge in precise time sequence effectively to obtain the waveform becomes one of the key in the pulse power technology.

According to the requirements of a pulse discharging velocity source, a time sequence discharging control system is designed, which can control 30 PPSMs to discharge in a precise time sequence. In this control system, the digital signal processor (DSP) is used as the main control chip and the high speed photoelectric converters and optical fibers are used as the trigger signals transmission system. The time sequence can be set by using the upper computer software and the accuracy of the trigger pulses can reach to microsecond level. This control system is used in the actual experiments of the speed source and the results proved that the control system is effectively.

<p>[366] Optimization of High Frequency Transformer Based on Advanced Genetic Algorithm <i>Presenter: YANG, Zhiting</i></p> <p>Traditional transformer design optimization is obviously inadequate, the main content of this paper that we should consider the high-frequency loss model, using the improved genetic theory, to achieve a fast and efficient multi-objective optimization method, and compared the result of the classic multi-objective optimal method and the NSGA II to get the most effective method which will open up new ways to design of high-frequency high voltage and high power transformer.</p>	5
<p>[321] Zero average flux tracking algorithm for high frequency transformers used in long pulse applications <i>Presenter: COLLINS, Max</i></p> <p>High voltage long pulse klystron modulators typically use pulse transformers, where the length of the pulse dictates the size of the transformer. Recent advancements in power electronics applied to modulator technology have, in order to facilitate multi-millisecond long pulse generation, instead suggests use of high frequency transformers in a high frequency pulse modulation/demodulation scheme, eliminating the size-pulse length dependency.</p> <p>The stacked multi-level (SML) topology is built around this technique, where a cascaded power converters chain inverting, amplifying, rectifying and filtering the voltage following a capacitor bank charging stage to generate high voltage pulses. In a modulator built to European Spallation Source requirements, six such stages are connected in series at respective output, reducing stress on each module and increasing output ripple frequency, limiting the need of filtering, i.e. further reducing size, pulse rise time and stored energy.</p> <p>While use of this topology has demonstrated reduction in modulator footprint and cost for typical long pulse applications, use of high frequency switching obliges strict transformer core flux control to avoid transformer saturation due to undesired dc voltage components generated by the inverter without transformer oversizing, hence maintaining high pulse-to-pulse accuracy and reproducibility.</p> <p>Several methods implementing similar modes of control already exist, but commonly require additional sensors which may not be available or practical for inclusion in high voltage environments. Furthermore, available methods assume constant operation whereas the pulse-forming stage needs to systematically switch off completely between pulses, creating an additional problem related to remanent core flux and consequent inrush current; it must be ensured that flux is reset before the following pulse is to be generated, otherwise pulse-to-pulse flux accumulation will entail transformer saturation.</p> <p>This paper describes the above problems in detail and outlines a practical algorithm, assessing its capability to control flux independent of pulse duration while maximizing rise time.</p>	22
<p>[278] Solid state thyatron replacement switch feasibility <i>Presenter: RAVIDÀ, Gianfranco</i></p> <p>The CERN CTF3 facility is being used to test and demonstrate key technical issues for the CLIC (Compact Linear Collider). Pulsed RF power sources are essential elements in this test facility. Klystrons at S-band (3GHz), in conjunction with pulse compression systems, are used to power the Drive Beam Accelerator (DBA). Most of the modulators that provide the electrical power to the klystrons use a 'line' type modulator consisting of a resonant charging system to charge a pulse forming network (PFN) up to a maximum voltage of 50kV. The stored energy in the PFN is then discharged at a repetition rate of 50Hz via a pulse transformer using a thyatron switch (model CX1836A from E2V technologies) giving a resultant voltage and current on the klystron of 300kV and 290 A, with a pulse width of 8µs at full width half height (FWHH). Pulse rise time is approximately 1µs. A 12 stage series connected prototype solid state switching unit (each stage consisting of two parallel thyristors) that can be retro fitted as a replacement for the thyatron in the existing modulators has been built and already tested up to 30kV, 50Hz for initial evaluation. Upcoming tests are foreseen to reach nominal voltage on the klystron in order to complete the evaluation of the feasibility to replace a thyatron by a semiconductor switch technology in a 'line' type high power modulator. This paper will describe the results and performance of this switch.</p>	19

<p>[262] A new synchronization method based on compensation of phase deviation for pulsed generator power supply</p> <p><i>Presenter: XU, Yun</i></p> <p>At Wuhan National High Magnetic Field Center, a 100 MVA/100 MJ pulsed generator and two 67.5 MW converter modules have been installed as power supply for pulsed magnets. This power supply can energize magnets alone or with other power supplies. Long-pulsed magnetic field with 50 T/100 ms flat-top has been produced, and 100 T pulse magnetic field is under commissioning. In those high power occasions, the three-phase voltages undergo serious harmonics, large notches, amplitude variation, rapid frequency fluctuation and phase jump simultaneously. In order to guarantee the security operation of the system and quality of magnetic field wave, synchronization method with both fast dynamics and excellent harmonics rejection is expected, which is difficult for conventional synchronous reference frame PLL (SRF-PLL). Therefore this paper presents a new open-loop synchronization method based on compensation of phase deviation. In this method, the phase of three-phase voltages, which is achieved by summing filtered phase deviation and phase of a given d-q rotating reference frame, is open-loop computed directly. The phase deviation would be determined through making the division of v_d and v_q and a subsequent arctangent, while the v_d and v_q are obtained by applying given d-q rotating reference frame for Park's transformation. Then the phase deviation is filtered by a designed fourth-order filter to reject the influence of harmonics and estimate the frequency. Due to direct computation of phase, dynamics of this synchronization method is independent of voltages amplitude, meanwhile the specialized filter contributes to faster dynamics and better harmonics rejection. Experimental results in comparison with SRF-PLL are used to validate the better performance of the proposed method. Finally the proposed method has been applied to the pulsed generator power supply, a magnetic field wave with 40 T/100 ms flat-top is produced, and the ripple during the flat-top is less than 0.2%.</p>	17
<p>[230] Improving low power (30W to 250W average) pulsed power performance and reliability by improving High Voltage power quality</p> <p><i>Presenter: BYFIELD, Gary</i></p> <p>**Introduction:**</p> <p>When researching improvements to low power (30W to 250W average) pulsed power systems knowledge of High Voltage power quality terms, specifications, and key performance factors can be essential to selecting or improving the best available technology or for working with suppliers on specific needs. Examples of key High Voltage Power Supply elements resulting in performance & reliability gains are outlined. This material can enable system researchers & designers to identify key observations, facilitate change, and ultimately deliver better performance, accuracy, and repeatability.</p> <p>**Methods:**</p> <p>Test stand configuration diagram along with unique test fixture requirements will be outlined. Commercial High Voltage and Low voltage test equipment used for control & measurement will be listed with accuracy data. Overall accuracy and repeatability of HV measurement will be established with data & graphs. High Voltage devices evaluated for performance will be identified.</p> <p>**Preliminary Data (Abstract):**</p> <p>High Voltage power source quality terms will be defined. Data presented for High Voltage charge rates, overshoot, settling, stability (drift over time, temperature, pulse-to-pulse), and response time measurements (Tables & Graphs) from example high power density / high voltage density modular High Voltage devices. Key observations will be outlined with conclusions and will illustrate key parameters of High Voltage power quality.</p> <p>**Novel Aspect:**</p> <p>High Voltage power quality specifications, device selection, and performance verification can directly improve pulse power system performance & reliability.</p>	16
<p>[186] Research of distributed charge based on magnetic self-balance</p> <p><i>Presenter: ZHOU, Qianyu</i></p> <p>This paper describes the principle and design of a high-voltage high repetition frequency solid-state pulse power modulator(SSPPM) which can operate at an output voltage of tens of kilovolts and a repetitive frequency of tens of kilohertz. Charging circuit of traditional Marx generator is generally based on DC power with series resistor or inductance to charge the capacitors, and it leads to low efficiency, small output pulse duty cycle and other issues. However, this new SSPPM operates in series resonant mode and uses series of magnetic ring, which effectively solve the above issues. Due to voltage difference between load capacitors, the compensating third wind is used to make the voltage balanced. Through principle, software simulation and physical comparison, the compensating third wind is introduced in detail.</p>	15

<p>[182] Wide Injection Range OCVD System for Lifetime Spectroscopy Techniques</p> <p><i>Presenter: LACOUTURE, Shelby</i></p> <p>To continually increase the voltage and current capabilities of power semiconductor devices, whether pushing older materials such as Si to its' intrinsic electrical limits or by employing newer substances like SiC or GaN, a thorough understanding of the entire device is required, from the basic physics of the material and its interactions with defects and passivation, up to the complete device structure, including terminal performance and device - level limitations. Of the fundamental parameters that affect device performance, the most complex and malleable is the carrier lifetime. Carrier lifetime has a profound effect on power devices designed for high voltage applications and power devices relying on conductivity modulation. This parameter cannot be given as a ball – park figure unlike mobility (and hence diffusion coefficients) as it is affected by nearly every processing step a device undergoes: a final device can have carrier lifetimes that differ drastically from the starting bulk material. The work herein utilizes a relatively new set of techniques collectively known as Lifetime Spectroscopy (LS) methods to extract fundamental material parameters relating to recombination activity: τ_{n0}, τ_{p0} and ΔE_t. These LS methods directly measure recombination activity of defects and hence acquire characteristic data of defects and dopants that is complimentary in nature to the information gleaned about them from more orthodox methods such as Deep – Level Transient Spectroscopy (DLTS). The Open Circuit Voltage Decay (OCVD) method is used along with improved data manipulation algorithms to extract the effective carrier lifetime as injection and temperature are swept. A complete stand – alone system has been constructed that allows a very wide range of current injection (~1mA to > 200A) and built – in OCVD waveform acquisition. The first complete Temperature – Injection Dependent Lifetime Spectroscopy (T-IDLS) studies are carried out on a small signal PiN commercial diode.</p>	14
<p>[135] Application of current charged pulse forming lines for generation of high voltage nanosecond pulses</p> <p><i>Presenter: LYUBLINSKY, Alexander</i></p> <p>Pulse forming networks (PFN) and charging lines are widely used in pulse power techniques for high voltage pulses generation and shaping. Usually PFN should be precharged to the double voltage (energy is stored in electric field) and is used in combination with high voltage closing switch. A lot of theoretical and experimental researches with different types of PFN-based circuit design have been made.</p> <p>Alternative circuit design with current charged PFN (energy is stored in magnetic field) in combination with fast opening switches is described. The main benefits of new approach are nanosecond and subnanosecond rise/fall times as well as high voltage output pulse generation with using of low voltage power supplies only. Therefore, compact and effective pulse generators can be made. As an example, the description and output pulse oscillograms of square-like high voltage pulse generator are presented.</p>	13
<p>[132] Analysis and Design of a Series-Parallel Resonant Converter without Inductor Filter for use in High Voltage Capacitor Charger Applications</p> <p><i>Presenter: BAE, Youngseok</i></p> <p>A huge inductor filter becomes essential when capacitor charger which has capacitive characteristics is implemented based on the series-parallel resonant converter. This paper described analysis, design and test results of the series-parallel resonant converter which operates as a constant current source on above resonance without inductor filter for use in high voltage capacitor charger applications. Voltage gain and current gain of the series-parallel resonant converter in terms of the load variation, series-to-parallel capacitance ratio and normalized switching frequency are derived and the voltage and current stresses of each resonant component are calculated using the Fundamental Harmonic Approximation (FHA) analysis. The resonant current and *kVA/kW* rating are considered for the optimal design of the resonant parameters and a 3 *kJ/s* constant current source type series-parallel resonant converter prototype is assembled with 6 *kΩ* resistor of 100 *kJ*, 10 *kV* energy storage capacitor. Design results based on the FHA analysis are verified by resistive load and high voltage capacitor charging experiments.</p>	12
<p>[131] Design and Experiment of a 3-phase Series-Parallel Resonant Type High Voltage Capacitor Charger</p> <p><i>Presenter: BAE, Youngseok</i></p> <p>Design, implementation and experimental results of a 3-phase series-parallel resonant type high voltage capacitor charger which is operating as a constant current source at a specific switching frequency are described. The operating principle of the capacitor charger as the variation of an input-to-output voltage gain is explained. Several current gain curves as the variation of series-parallel capacitance *(k)* and normalized switching frequency using an AC analysis method are derived and are used to decide an optimal resonant tank parameter to minimize the power density of the capacitor charger. A 12 *kV*, 24 *kJ/s* prototype charger of which three single-phase high-frequency transformers are wye-connected in primary side and three voltage doubler rectifiers are connected in series in secondary side is implemented. The measurement results about the efficiency and power factor of the implemented capacitor charger as the variation of the charging power by the resistive load are described. The basic charging performance of implemented capacitor charger is verified by the capacitor charging experiment using 600 *kJ*, 10 *kV*, and 12 *mF* capacitor bank. The reliability of the capacitor charger in the malfunction of the load side is verified by the experiments concerning misfiring of the discharge switch and shorting of the output terminal during the charging operation. The implemented 3-phase capacitor charger's electrical characteristics are additionally compared with those of a single-phase capacitor charger of the same size.</p>	11

<p>[18] HIGH CURRENT PULSED POWER SUPPLIES FOR ST-40 SPHERICAL TOKAMAK</p> <p><i>Presenter: EIKELBOOM, Bas</i></p> <p>The ST-40 tokamak is a Spherical Tokamak designed and under construction by Tokamak Energy to reach the goal of producing clean energy by means of nuclear fusion. The tokamak machine consists of several high power magnets to confine and control the plasma inside the fusion chamber. These electro-magnetic magnets require very high currents, however the existing power infrastructure doesn't permit this and thus a pulsed power supply with ultra-capacitor energy storage is used. The ST-40 will produce the highest magnetic field ever in a spherical tokamak.</p> <p>In total 3 types of pulsed power supplies have been designed and developed by Jema Energy for the ST-40 machine;</p> <ul style="list-style-type: none"> - Toroidal Field Power Supply (100kA 120ms flat top, upgradable up to 250kA) - Central Solenoid Power Supply (+/-17kA 100ms flat top) - Poloidal Field BvU Power Supply (12,5kA 50ms flat top) <p>The design of the power supplies is a modular concept based on IGBT. The power supplies control system will be integrated under the Tokamak Energy Control and will be current or voltage managed. The total stored energy in the power supplies is 108MJ.</p>	6
<p>[23] Design of a 30MJ capacitor-based pulsed power supply for EML</p> <p><i>Presenter: LI, Zhenxiao</i></p> <p>We are developing a 30MJ high power pulsed power supply (PPS) system with 10kV operation voltage for EML research. The PPS system can be divided into several functional subsystems: pulse forming subsystem, control subsystem, charging subsystem, and measurement subsystem. Matrix type structure and modular architecture are adopted in the design of the PPS. The PPS is assembled in two 40' general purpose containers in order to meet the requirements of field experiments and transportation.</p> <p>The pulse forming subsystem consists of 30 parallel pulse power modules. Each module includes three 334kJ pulse forming units in parallel. The pulse forming unit mainly includes a 6680μF metallized film capacitor, a 35μH foil type inductor, a 200kA high power thyristor stack and a 200kA high power diode stack. The control subsystem has a two-level control structure. The primary level control device is a remote master controller and the second level is a pulse power module controller. With optical fiber synchronous network, the remote master controller sends synchronous clock signal of pulse discharging to each pulse power module to achieve an accurate sequential discharging control. The charging subsystem is composed of 30 high voltage capacity charging power supplies (CCPS). Each pulse power module is configured with one CCPS. The core component of CCPS is a series resonance converter based on IGBT bridges. The measurement subsystem adopts a PXI bus based data collection system and a master-slave network structure with optical fiber synchronous communication.</p> <p>With electrical parameters of the PPS and railgun being assumed, numerical studies of the railgun launch process have been down with Matlab/Simulink platform. At present, 2 PFU and 1 CCPS have been built and debugged successfully. The 30MJ PPS is expected to be built soon after and will be used for EML research.</p>	7
<p>[24] Silvaco-based electrothermal simulation of 10 kV 4H-SiC p-i-n diode under pulsed condition</p> <p><i>Presenter: PUSHPAKARAN, Bejoy</i></p> <p>Power p-i-n diodes are well known for their high-voltage and high-current capability which makes it a viable candidate for pulsed power circuits. The breakdown mechanism of a p-i-n diode enables high blocking voltage capability whereas, conductivity modulation due to high level injection drastically reduces the ON-state resistance during high forward current. Even though it is possible to develop silicon-based p-i-n diode with very high blocking voltage, the device characteristics, both steady state and transient, are adversely affected primarily due to the large drift region thickness which is in the order of several hundred microns. The application of silicon carbide technology in p-i-n diode has facilitated the development of p-i-n rectifiers up to several kV blocking voltage with a much thinner drift region thickness as compared to its silicon counterpart. This research is focused on the 2D electrothermal simulation of a 10 kV 4H-SiC p-i-n diode model developed using Silvaco ATLAS TCAD software. The p-i-n diode structure was designed for 100 A/cm² forward current density with a cell pitch of 16 μm and an active area of 10 μm². Physics-based models were included to account for low-field mobility, carrier-carrier scattering, carrier generation-recombination, avalanche breakdown, and lattice heating. The device model was simulated under steady state and transient conditions. Pulsed simulation of the p-i-n diode was carried out using an RLC ring down circuit to generate a 5 μs wide pulse with peak current densities up to 5000 A/cm². The reverse recovery characteristics of the diode was analyzed for a forward current density of 100 A/cm² and varying turn-off di/dt to assess the limitation on usable switching frequency. Thermal profile of the p-i-n diode was generated by including heat generation models during transient simulation to identify thermal hot spot formation and areas of possible failure during pulsed operation.</p>	8

<p>[30] Heavy Pulse Currents LTT Switch Unit <i>Presenter: FRIDMAN, Boris</i></p> <p>The results of research of heavy pulse current switches built on Light Triggered Thyristors (LTT) and pulsed diodes are presented. Transients in a semi-conductor switch are analyzed at a capacitor discharge in a Pulse Forming Network (PFN), which incorporates an inductor and crowbar diodes. Maximal currents for a semiconductor structure, at which thermo-generation peaks appear on oscillograms of forward voltage drop, have been determined. The switch-on process of LTT has been investigated and the need for application of speed-up R-C circuits for a fast and stable transition of the LTT semiconductor structure to the conducting state has been shown. The current switching into the crowbar diodes and pulse over-voltage generation at a reverse recovery of LTTs has been analyzed, and the snubbers for suppression of these over-voltages have been chosen. The results of testing performed at switching of a pulse current up to 100 kA with a voltage up to 6 kV confirm the validity of the accepted technical solutions.</p>	9
<p>[44] Skin-parameter of massive conductors and transients in electrical circuits of pulse power facilities <i>Presenter: FRIDMAN, Boris</i></p> <p>For massive conductors in case of sharp skin-effect it is possible to define the skin-parameter, which does not depend on time and frequency and effects on transients in electrical circuits with massive conductors. In the paper the peculiarities of transients with massive conductors are described, the definition and justification of skin-parameter are presented, the methods of calculation and measurement are given, and the algorithms of calculation of transients in electrical circuits with massive conductors are offered.</p>	10
<p>[265] Design of Active Voltage Droop Compensator for Solid-State Long Pulse Modulator <i>Presenter: JANG, Sung-Roc</i></p> <p>This paper describes the design of an active voltage droop compensator for solid-state long pulse modulator. For generating long pulse with low voltage droop, the active droop compensation technique provides advantages in terms of the high power density and low cost. The proposed droop compensator required to generate triangular waveform consists of the resonant converter and the flyback converter. The resonant converter at DCM operation allows linear charging of the compensation capacitor owing to its pure current source characteristic. The flyback converter recovers the charged energy from the compensation capacitor to input and provides fast falling of compensator output voltage. Based on the proposed topology, a compensator that has 1 kV and 26 A of the maximum voltage and current specifications is developed for a 40 kV, 20 A, 300μs, 200Hz, 0.5% droop solid-state pulsed power modulator. Finally, it was experimentally verified that the proposed compensator can be effectively used for achieving low voltage droop by means of the series operation with the existing solid-state pulsed power modulator.</p>	18
<p>[281] A High Power Charging Power Supply for Capacitive Pulsed Power System <i>Presenter: ZHOU, Jun</i></p> <p>High pulsed magnetic field, particle accelerator, strong laser, electromagnetic emission and other pulsed power system require capacitive energy with short duration and high density. It is necessary to recharge the capacitor to specific voltage by capacitor charging power supply after the discharge of energy stored in the capacitor. Charging power supply applied in high power capacitive pulsed power system has the characteristics of high voltage, large charging current and high efficiency, and such characteristics provide opportunities and challenges to its research and development. At Wuhan National Magnetic Field Center (WHFMC), a scheme of large power charging power supply applied in capacitive pulsed power system for high pulsed magnetic field is proposed with parameters of 35 kV rated voltage, 1020 A maximum current and 11.2 MW peak power. Multiple BUCK circuit topology is employed to reduce charging current ripple and each BUCK circuit operates reliably in critical continuous current mode to eliminate the overvoltage caused by reverse recovery of fly-wheel diode. Charging switch consists of 10 IGBT connected in series directly while snubber circuit ensures the effectiveness of average voltage distribution. The control strategy combining current limited control and power limited control is adopted to reduce the original capacity requirements of DC power supply and increase the charging efficiency. Simulation model of the proposed charging power supply is established that simulation result shows the validity and feasibility of the scheme. Details of the charging power supply prototype is demonstrated in this paper. According to experimental result, the charging power supply has been proven to be effective in high power capacitive pulsed power system.</p> <p>Acknowledgements: The National key research and development program of China (2016YFA0401702) and the Program for New Century Excellent Talents in University.</p>	20

<p>[299] Improving high power precision Electron Beam and Ion Beam performance and reliability by improving High Voltage power quality</p> <p><i>Presenter: BYFIELD, Gary</i></p> <p>**Introduction**</p> <p>When researching improvements to high power precision Electron Beam and Ion Beam performance power systems knowledge of High Voltage power quality terms, specifications, and key performance factors can be essential to selecting or improving the best available technology or for working with suppliers on specific needs. Examples of key High Voltage Power Supply elements resulting in performance & reliability gains are outlined. This material can enable system researchers & designers to identify key observations, facilitate change, and ultimately deliver better performance, accuracy, and repeatability.</p> <p>**Methods**</p> <p>Test stand configuration diagram along with unique test fixture requirements will be outlined. Commercial High Voltage and Low voltage test equipment used for control & measurement will be listed with accuracy data. Overall accuracy and repeatability of HV measurement will be established with data & graphs. High Voltage devices evaluated for performance will be identified.</p> <p>**Preliminary Data (Abstract)**</p> <p>High Voltage power source quality terms will be defined. Data presented for High Voltage energy storage, slew rates, overshoot, settling, stability (drift over time, temperature, load), and arc management (response time, technique) measurements (Tables & Graphs) from example High Voltage devices up to 10kW. Key observations will be outlined with conclusions and will illustrate key parameters of High Voltage power quality.</p> <p>**Novel Aspect**</p> <p>High Voltage power quality specifications, device selection, and performance verification can directly improve Electron Beam and Ion Beam power system performance</p>	21
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Poster session III - Particle Beam and Accelerator Technologies - Hall 4 / Cambridge (13:30-15:00)

board

<p>[244] AUTOMATIC DATA PROCESSING AND DATA DISPLAY SYSTEM FOR THE HERMES III ACCELERATOR</p> <p><i>Presenter: COFFEY, SEAN</i></p> <p>This paper describes the software changes made to the data processing and display system for HERMES III accelerator at the Simulation Technology Laboratory (STL) at Sandia National Laboratories, New Mexico. The HERMES III accelerator is a gamma ray simulator producing 100kRad[Si] dose per shot with a full width half max pulse duration of ~25 nanoseconds averaging six shots per day. For each accelerator test approximately 400 probe signals are recorded over approximately 65 digitizers. The original data processing system provided the operator a report summarizing the start of probe signal timings for groups of probes located within the power flow conductors. This timing information is indicative of power flow symmetry allowing the operator to make necessary adjustments prior to the next test. The report also provided data overlays concerning laser trigger light output, x-ray diode currents and x-ray source output. Power flow in the HERMES III accelerator is comprised of many circuit paths and detailed current and voltage information within these paths could provide a more thorough understanding of accelerator operation and performance, however this information was either not quickly available to the operators or the display of the data was not optimum. We expanded our data processing abilities to determine the current and voltage amplitudes throughout the power flow conductors and improved the data display abilities so data plots can be presented in a more organized fashion.</p> <p>We detail our efforts creating a software program capable of processing the ~ 400 probe signals together with an organized method for displaying the dozens of current and voltage probes. This process is implemented immediately after all digitizer data has been collected so the operator is provided timing and power flow information shortly after each accelerator shot.</p>	23
<p>[236] SNS PROTON POWER UPGRADE REQUIREMENTS FOR MAGNET AND KICKER SYSTEMS</p> <p><i>Presenter: SAETHRE, Robert</i></p> <p>The Spallation Neutron Source (SNS) Proton Power Upgrade (PPU) will double the beam power from 1.4 to 2.8 MW by adding cavities in the superconducting linear accelerator (SCL) which will increase the beam energy from 0.97 to 1.3 GeV and by increasing the average Linac beam current from 26 to 38 mA. Provisions for an accelerator power increase were made in the original SNS project, and these are being leveraged to provide a cost-effective means of doubling the beam power. The magnet systems were originally designed for the higher beam energies with the exception of a few in the injection and extraction regions of the accumulator ring. Three injection region magnets will be redesigned. The eight injection-bump kicker power supplies will be upgraded to permit higher current operation and two additional extraction kicker power supplies and magnets will be added. This paper will review the requirements and options for the magnets and power supplies for the injection and extraction regions.</p>	24

<p>[464] CSNS Pulse Klystron High Voltage Power Supply System Overview and Performance Test</p> <p><i>Presenter: LI, Jian</i></p> <p>The China Spallation Neutron Source (CSNS) accelerator is designed to accelerate proton beam pulses to 1.6 GeV at 25 Hz repetition rate, striking a solid metal target to produce spallation neutrons. The accelerator provides a beam power of 100 kW on the target in the first phase [1]. The linac is designed with beam energy of 81 MeV and a peak current of 15mA. It consists of RFQ, two bunchers of medium energy beam transmission (MEBT) line, four DTL tanks, and one debuncher of linac-to-ring beam transmission (LRBT) line. So far, rf power source mass production and equipment installation have been completed. Equipment commissioning are still under way. In this paper, a description of overview of the klystron high voltage power supply system and the key equipments' performance test, such as 400 Hz ac series resonance high voltage power supply, modulator and crowbar, will be briefly presented.</p>	25
<p>[458] Status of the 3rd axis flash X-rays LIA of the EPURE facility</p> <p><i>Presenter: VERMARE, Christophe</i></p> <p>Under the UK and France Treaties related to "Defence and Security Co-operation" and to "joint radiographic / hydrodynamics facilities", the joint Hydrodynamics Research Facility known as EPURE is under construction at CEA VALDUC in France. At present, this facility is fully operational using a single radiographic axis configuration. By 2022, two others high performance X-ray machines will be added and jointly operated between France and UK. One of those two additional sources will be an LIA similar to the existing 1st axis accelerator. This presentation will propose an overview of the procurement of this LIA including the several validation phases planned. A focus on required design updates will be also detailed.</p>	26
<p>[454] Measurement of intense continuous and flash radiographic sources with Compton spectrometers</p> <p><i>Presenter: GEHRING, Amanda</i></p> <p>Our team at Los Alamos National Laboratory has successfully employed Compton spectrometers to measure the x-ray spectra of intense radiographic sources, both continuous and flash. In this method, a collimated beam of x-rays incident on a converter foil ejects Compton electrons. A collimator may be inserted into the entrance of the spectrometer to select the angular acceptance of the forward-scattered electrons, which then enter the magnetic field region of the spectrometer. The position of the electrons at the magnet's focal plane is proportional to the square root of their momentum, allowing the x-ray spectrum to be reconstructed. Two spectrometers have been fielded since 2013; a neodymium-iron permanent magnet with an energy range of 500 keV to 20 MeV, and a new samarium-cobalt magnet with an energy range of 50 keV to 4 MeV. The measured spectra were produced by x-ray generating machines of various intensities (~5 rad at 1 m per 50 ns pulse to >2000 rad/min at 1 m) and different endpoints (range of 2.25 to 20 MeV). A survey of these results will be presented with emphasis on our recent, low-energy experiments.</p>	27
<p>[409] A new radiographic source using a plasma opening switch and plasma-filled rod-pinch diode</p> <p><i>Presenter: WEBER, Bruce</i></p> <p>We are testing a new radiographic source that uses a Marx bank with a one microsecond discharge time, coupled through a plasma opening switch (POS) to a plasma-filled rod-pinch diode (PFRP). The Hawk generator at NRL contains four Marx banks connected in parallel with an erected voltage of 640 kV and an output current of 700 kA with 1.2 microsecond quarter period into a short circuited 600 nH load. A POS configuration developed on Hawk in the 1990s [1] is utilized to conduct (in vacuum) for 900 ns then rapidly open, switching a fraction of the current to a downstream PFRP load [2]. The POS on Hawk works best when the center conductor is negative, generating up to -2 MV, therefore the PFRP must be operated in negative polarity also. The PFRP utilizes a cable-gun plasma source located inside the center conductor to inject plasma in the axial direction through a tube toward an on-axis 1 mm diameter rod that is connected to a grounded end plate. The injected PFRP plasma envelops the rod, with higher density near the rod tip and lower density near the end plate. The switched current is conducted through the PFRP plasma which pinches onto the rod and zippers toward the tip, quickly forming an electron beam that is focused at the tip, creating an x-ray source that could be useful for flash radiography. Several geometry variations have been tested to determine the potential of this novel type of radiographic source.</p> <p>1. P. J. Goodrich, et al., in Proc. IEEE Pulsed Power Conf., 511 (1993). 2. B. V. Weber, et al., IEEE Trans Plasma Sci. 36, 443 (2008).</p>	41

<p>[382] Large area plasma electron emitter: Emission behavior in long pulse electron accelerator</p> <p><i>Presenter: AN, Wladimir</i></p> <p>Different diagnostic tools were installed at the facility GESA-SOFIE in order to investigate the plasma behavior in the cathode-grid gap. A high-resolution fast CCD camera was used to monitor the formation and evolution of the cathode and grid plasmas. A streak camera with high dynamic range delivered information on the characteristics of the plasma motion. A complex modification of the cathode block enabled admission and versatile circuiting of the plasma adjacent components. In order to keep the beam parameters constant over the pulse duration of several tens of microseconds, it is required to prevent the expansion of the cathode plasma. This is possible in the direction of the electric field, if the plasma front reaches emission saturation prior to breakdown of the electrode gap. Several approaches were tested to reduce the excessive generation of plasma and thus to stabilize the emission front: an active voltage control to tune the emission current; manipulation of the plasma decay by offering additional contact areas; relief of the emission tips by rerouting the current. In spite of the various measures, an influence on the continuously rising perveance of the facility was hardly achieved. The most severe issue is the expansion of the cathode plasma in the transversal, weak field direction: the increase of the effective emission area leads to a decrease of the facility impedance, which results in a more intense plasma generation. Additionally, the uncontrolled transversal expansion leads to a natural pulse duration limit – the breakdown occurs outside the acceleration gap.</p>	39
<p>[330] Spectroscopic Comparison of Cable-Gun and Marshall-Gun Opening Switch Plasmas*</p> <p><i>Presenter: JACKSON, S. L.</i></p> <p>The characteristics of opening switch plasmas initialized by two methods—cable guns and gas-fed Marshall guns— were compared spectroscopically, as part of an effort to understand the effect of multi-species plasma composition on opening switch performance. Anecdotal observations of slower switching with single-species plasma sources compared to multi-species sources have led to the hypothesis that multi-species composition plays a role in fast switching. Studies of the underlying physics in multi-species plasmas have resulted in observations of fast magnetic field penetration; the work reported here is an assessment of the differences between multi-species and single-species sources that might affect this fast field penetration. A time-gated spectrometer was used to diagnose opening switch plasmas driven by NRL's Hawk pulsed-power generator, with a peak current of up to 700 kA and a quarter-cycle time of 1.2 μs. The cable-gun initialization method is commonly used in plasma opening switches and produced an inherently multi-species plasma from the ionization of Teflon, composed of carbon and fluorine. The Marshall-gun initialization method allowed for more control of the initial plasma composition through adjustment of the gas mixture feeding the gun, typically pure argon, pure helium, or a mixture of both. The constituent plasma ions resulting from each initialization method were identified spectroscopically and compared, both prior to and during the application of the main Hawk pulse.</p> <p>*This work was supported by the Naval Research Laboratory Base Program and the Office of Naval Research under Grant # N62929-16-1-2192.</p>	33
<p>[253] Using a full-sine septum power supply to study the top-up orbit disturbance at Taiwan light source</p> <p><i>Presenter: LIN, Ke-Kang</i></p> <p>Observation shows that the electron orbit of the TLS (Taiwan light source) storage ring was greatly disturbed during the top-up injection process, both from BPM readings and profile monitor. The distortion duration exceeds the pulse lengths of both injection kickers and septum. It was speculated that one of the possible causes would be due to the eddy current effect induced by the leak field of septum magnet. For clarification purpose, a full-sine septum power supply has been constructed and field implemented in order to eliminate the said eddy current effect. The study shows that both pulse shape matching among four kickers and septum leakage field play major influence on the causes. The experimental results will be presented in this report.</p>	28
<p>[274] The L-3 Pulserad flash X-ray system simulation with LSP and CST PS code</p> <p><i>Presenter: HAN, Seung Ho</i></p> <p>We performed computerized analysis of the L-3 Communications Pulserad flash X-ray system (Model 42710A) for explosion analysis in our laboratory. As a Site Acceptance Test, X-ray generation experiments have been carried out to collect data on dose measurements according to distance and azimuthal angle. Based on the X-ray measurement data, the computational analysis of diode and the Bremsstrahlung X-ray photon is performed to find the optimal simulation method by LSP/MCNP code combination. The electron data impinging on the tungsten target was generated from diode simulation with LSP code and input to the MCNP code to simulate the X-ray generation using electron data converting tool from LSP to MCNP code.</p>	29

<p>[285] Modelling the mechanism of multipactor suppression through novel laser engineered structures</p> <p><i>Presenter: SMITH, Jonathan</i></p> <p>Electron multipactor is a major problem in accelerators, both in accelerating cavities associated with dark current and beam induced e-cloud problems, and in RF distribution systems leading to catastrophic damage or in mild cases performance decrease and phase shifting. In many scenarios passive mitigation techniques are preferred. Multipactor may be completely avoided if the effective SEY is less than unity. Recently, grooved micron-size structures using laser processing have been shown to give dramatically improved response. This result prompted effort to understand the mechanism responsible for this reduction. This paper presents simulation work aimed at gaining improved understanding of the fundamental processes causing reductions in the secondary electron yield due to geometric effects, enabled by the VSim software suite. We identify constituent models and conclude that significant reduction in multipactor can be achieved through geometric modification. We discuss some potential applications and limitations of the new technology.</p>	30
<p>[301] Status of a 140 keV electron source for high current linac</p> <p><i>Presenter: CASSANY, Bruno</i></p> <p>LEETCHI is an electron source designed to produce 140 keV, 5 A, 140 μs beams at a repetition rate of 50 Hz. The shot to shot and flat top current stability of this drive beam injector for CLIC has to be better than 0.1 % and a normalized emittance of 14 mm.mrad is expected. A test stand has been build which allows to diagnose and dump the beam produced by a thermionic cathode. The thermionic cathode is equipped with a grid which will allow us to control the current and eventually to have a feedback on the flattop shape.</p> <p>Results with few μs pulses lengths are presented. The analysis shows a very good stability of the LEETCHI experiment. OTR measurements with short pulses are compared with Particle In Cells and tracking simulations. These comparisons are used to estimate the emittance of the beam.</p> <p>First results at 5 Amperes, 140 μs pulse duration and low repetition rate, show the capability of this gridded cathode to resist to the thermal constrains.</p>	31
<p>[323] Upgrade of the Power Triggering System of the LHC Beam Dumping System</p> <p><i>Presenter: ALLONNEAU, Lorane</i></p> <p>The beam dumping system of CERN's Large Hadron Collider (LHC) is equipped with fast solid state closing switches composed of a stack of ten series connected Fast High Current Thyristors (FHCT).</p> <p>The triggering circuit of these switches consists of a 10:1 trigger transformer, with stray inductance of 5μH, powered by two redundant Power Trigger Modules (PTM) delivering 500 A peak gate current with rate of rise of 350 A/us.</p> <p>Operational experience gained since the commissioning of the system in 1998 has identified performance limitation of the LHC Beam Dumping System (LBDS) that could be solved by increasing the triggering current.</p> <p>In view of the operation of the LHC with higher luminosity beams in the coming years, an upgrade of the LBDS triggering system is proposed. The objective is an increase of the FHCT gate current to 2 kA peak with a rate of rise of 3 kA/us, which will increase the FHCT lifetime and reduce the switching time and losses. These new performances will be obtained by the design of a faster low inductance trigger transformer, an optimization of the present PTM electrical circuit and a reduction of the trigger cable inductance.</p> <p>This paper will present the different modifications proposed for the PTM. First encouraging results obtained with a slightly modified PTM and new prototype trigger transformer will also be discussed.</p>	32
<p>[342] Development of Bipolar Pulse Accelerator for High-Purity Intense heavy Ion Beam</p> <p><i>Presenter: HONOKI, Taro</i></p> <p>Recently pulsed ion beam technology has been widely used for materials surface properties modification by the methods of ion implantation, ion plasma coatings deposition, and high energy ion beam energetic impact. For those materials processing applications, it is very important to develop the accelerator technology to generate ion beams with various ion species and high purity.</p> <p>In order to improve the purity of the intense pulsed ion beam, a new type of a pulsed ion beam accelerator named "bipolar pulse accelerator" has been proposed. In order to confirm the principle of the accelerator, a double coaxial type bipolar pulse generator and a prototype of the experimental system were developed. The bipolar pulse generator consists of a Marx generator and a pulse forming line (PFL) with a rail gap switch on its end. The system utilizes a magnetically insulated acceleration gap and was operated with the bipolar pulse. A coaxial gas puff plasma gun was used as an ion source, which was placed inside of the grounded anode. Source plasma was injected into the acceleration gap. When the bipolar pulse with voltage with the first pulse with a voltage of -138 kV and the second pulse with a voltage of +102 kV was applied to the drift tube, the ions were successfully accelerated from the grounded anode to the drift tube in the 1st gap by the negative pulse of the bipolar pulse. The pulsed ion beam with current density of 24 A/cm² and pulse duration of 50 ns was obtained at 50 mm downstream from the anode surface. The ion energy was in reasonable good agreement with the acceleration voltage, i.e., 1st pulse (negative pulse) voltage of the bipolar pulse. We are doing experiments on the two-stage acceleration of pulsed ion beam in the bipolar pulse accelerator.</p>	34

<p>[327] A New Modification for RHIC Abort Kicker System <i>Presenter: MI, Jianlin</i> Pre-fire problem in the abort kicker system have been last for a long time during the past 17 years of operation in RHIC. In order to limit the number of pre-fire events, a new system is implemented, installed and tested pre start of Run 17. We have installed two new Relay Control Units into the RHIC abort kicker system, one in Blue Ring and one in Yellow Ring. The scheme is included a simple replay connected in series with PFN discharging thyatron. The electronics and modified block diagram will be described in this paper. Both Relay Control Units have been tested in place within blue ring and yellow ring PFN circuit. The PFN test voltage range is from 4kV to 30kV.</p>	35
<p>[344] Electrical and X-ray diagnostics on the NSTec 2-MA dense plasma focus system <i>Presenter: SAVAGE, Mark</i> National Security Technologies (NSTec) is developing dense plasma focus systems as intense pulsed neutron sources. Sandia National Laboratories participated in a limited number of experiments on an NSTec plasma focus. In collaboration with NSTec, Los Alamos National Laboratory, and Lawrence Livermore National Laboratory, we implemented additional electrical and X-ray image measurements in parallel with normal operation of the system.</p> <p>Dense plasma focus neutron sources have been studied for decades, but much of the experimental interest has been on neutron and X-ray yield. The primary goal for the present work was to deliver high-fidelity and traceably-calibrated current and voltage measurements for comparison to computer simulations. The secondary goals were to utilize the current and voltage measurements to add general understanding of vacuum insulator behavior and current sheet dynamics, and conduct initial scoping of soft X-ray diagnostics. We will show the electrical diagnostics and the techniques used to acquire high-fidelity signals in the difficult environment of the 2 MA, 6 μs plasma focus drive pulse. We will show how we measure accreted plasma mass non-invasively, and the sensitivity to background fill density. We will also show initial results from filtered X-ray pinhole images and spectroscopic data from the pinch region.</p> <p>*Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.*</p>	36
<p>[362] Monolithic Aluminum Nitride High Gradient Vacuum Insulators <i>Presenter: POUNCEY, Jon</i> In the design of pulsed relativistic accelerators, high power electrical pulses are generated in a volume that is filled with either high pressure gas or an oil to manage the high electric fields. However, the beam generating diode must operate in vacuum. The two sections, then, require an insulating barrier between them which is subject to very high electric fields. The vast majority of interface insulators are made from polymers such as acrylics, polystyrenes, and epoxies because they are easy to machine and have well characterized high voltage performance. These materials create problems in achieving high-quality vacuum due to outgassing and the temperature limitations that prevent baking. Polymers also limit the ability to operate at high repetition rates due to poor thermal conductivity and low maximum temperature limits. Ceramic vacuum insulators are widely used in construction of conventional vacuum electronic devices, but have not found extensive use in relativistic pulsed accelerators. Aluminum nitride (AlN) is a covalently-bonded unique dielectric ceramic that combines high thermal conductivity with high bulk breakdown strength and resistivity. High gradient insulators (HGIs) are electrical insulating structures for vacuum applications composed of thin alternating layers of metal and dielectric. The HGI was originally conceived in the early 1980s and follows from the observation that the threshold electric field strength for surface flashover increases with decreased insulator length. Thus, by breaking up the total length into small segments, the breakdown mechanism scales with the shorter length, resulting in an overall increase in the vacuum flashover voltage compared to conventional insulators of the same length. The University of New Mexico has partnered with Sienna Technologies, a US company that specializes in the fabrication of high technology ceramic materials, to develop and test AlN high-gradient insulators for application in high power pulsed vacuum electronic devices.</p>	37
<p>[377] Emitted electron beams from velvet cathodes <i>Presenter: COURTOIS, Laurent</i> Velvet cathodes are widely used in field-emission electron diodes, in particular in induction accelerators used for flash X-ray radiography. The emission from velvet could be different from pulse to pulse in multi-pulse operation. As a consequence, we are revisiting the beam homogeneity and the emittance of the electron beam produced by velvet cathodes. First, we used a single-pulse diode connected to a 100 ns, 400 kV, 1-4 kA Blumlein generator. Various cathode-anode configurations were tested and we present here the analysis of the emitted beam along with numerical simulations performed both with MAGIC2D and CST-PS3D. The Cerenkov emission produced by the beam in a fused silica target is observed with fast cameras. A Pepper pot was installed in order to measure the emittance whose value is compared to the predictions of PIC simulations. Planned studies with the M12 double pulse injector prototype will be discussed.</p>	38

<p>[384] Multiple-Pulse High-Voltage Diode Isolation Testing for a Linear Induction Accelerator (LIA)</p> <p><i>Presenter: MCCUISTIAN, B Trent</i></p> <p>Multiple pulse flash radiography has been implemented worldwide utilizing various methods for many years. In the past decade, the method for achieving multiple pulse flash radiography has focused on utilizing a Linear Induction Accelerator (LIA) as the source. Various techniques, including diode isolation^[1], have been used to accomplish the multiple pulse function.</p> <p>Los Alamos National Laboratory is evaluating the use of diode stacks for multiple pulse capabilities. Experimental results of diode performance isolating multiple high-voltage pulses into a resistive load will be presented in this paper. Diode stack SPICE simulations as well as various diode stack evaluations for single pulses will be presented in companion papers.</p> <p>[1] Chen, et. al., Nuclear Instruments and Methods in Physics Research A 579 (2007) 941–950</p> <p>* This work supported by the US National Nuclear Security Agency and the US Department of Energy under contract DE-AC52-06NA25396</p>	40
<p>[422] The ELI-NP Gamma Beam System: a New Facility for Nuclear Physics Research – Current Status</p> <p><i>Presenter: TRACZ, Piotr</i></p> <p>The Gamma Beam System – the future user facility – is being built in the framework of the Extreme Light Infrastructure–Nuclear Physics (ELI-NP) project in Bucharest/Magurele, Romania. This is an advanced source of gamma rays based on Compton back-scattering. By collision of a visible laser beam and a high brightness relativistic electron beam, an intense (~10¹¹ γ/s), brilliant γ beam (<0.5% bandwidth) with E_γ up to 19.5 MeV will be obtained.</p> <p>A warm RF linac operated at the C-band mode with S-band photo-injector will deliver electron beams of energy up to about 720 MeV. The photo-injector laser system will produce a sequence of trains made of 32 laser pulses at 100Hz repetition rate with a ~10ps pulse duration in the UV range. For the Interaction Points (IP) other lasers will produce pulses with energy of 0.2J, at 515nm and 3.5ps duration at a repetition rate of 100 Hz. The collision of the interaction laser pulses with the 32 electron micro-bunches every 10 ms will be ensured by an optical cavity – multi-pass re-circulator – that will recirculate 32 times each IP laser pulse. Appropriate collimators to filter out the energy spectrum and a γ-beam characterization system will be used.</p> <p>The Gamma Beam System will be a state-of-the-art machine, capable to produce gamma beams with extremely advanced features. It will pursue advanced applications in the field of national security, nuclear waste treatment, nuclear medicine, as well as fundamental studies in nuclear physics.</p> <p>Currently building construction as well as acceptance procedures of linac system components corresponding to a gamma beam energy of minimum 1 MeV are completed (Project Stage I), and installation of accelerator is being started. The current status of building and RF linac for the Gamma Beam System will be presented.</p>	42
<p>[424] Beam Breakup Simulation and Optimization for Induction Accelerator</p> <p><i>Presenter: WU, Yuan Hui</i></p> <p>Beam breakup instability (BBU) is an important factor dominate the design of induction cell for high intensity linear induction accelerator. In this study, we optimize a magnetic tune for a conceptual induction accelerator. By using BREAKUP code and optimization algorithm, we estimate how BBU would affect the final beam spot size.</p>	43
<p>[426] Design Optimization for 2kA, 2MeV Diode Injector</p> <p><i>Presenter: WU, Yuan Hui</i></p> <p>The performance of induction accelerator relies greatly on the design of the diode injector. By using TRAK (ray tracing code) and AMBER (slice PIC code), we designed a 2KA/2MeV diode injector and beam transportation from position of cathode to accelerator exit. We will present some design optimization strategies for diode injector and simulation results from TRAK and AMBER, particle loading and different capabilities between two codes will also be discussed.</p>	44
<p>[447] Fast Magnetization of Amorphous Metallic Cores</p> <p><i>Presenter: TACCETTI, Martin</i></p> <p>Due to their high saturation flux density, amorphous metallic alloys play a key role in linear induction accelerators that require ferromagnetic cores with sufficient volt-seconds to support multiple pulses. As both the shape of the material hysteresis curve and the core losses depend on the magnetization rate, dB/dt, measurements at various rates are necessary in any system model involving these alloys. We present the characterization of two candidate materials, Metglas 2605CO and HB1M, at magnetization rates ranging from 1-7 T/μs. We also compare our results to published data [1].</p> <p>[1] Smith, C. H., and L. Barberi. "Fast Magnetization Reversals in Tape-Wound, Square-Loop Amorphous Alloy Cores." In Proceedings of the Soft Magnetic Materials Conference, p. 329. 1985.</p>	45

<p>[449] Combination of Ferrite and Amorphous Metal Cores in an LIA Cell <i>Presenter: MCCRADY, Rod</i> Ferrites have not only been used as the principal core material in linear induction accelerators (LIAs), but also as rf absorbing material to impede beam-breakup instability growth. For this reason, they are also present in multi-pulse accelerators that use amorphous metallic cores to achieve the required volt-seconds. If they are located in the leakage current path along with the latter, differences in magnetic behavior of the two materials can result in high electric fields between the ferrite and the cell outer housing. Segmenting of the ferrite core alleviates this issue. We present experimental measurements obtained by combining these two materials inside of a conducting cavity meant to represent an LIA cell, for both the solid and segmented ferrite core cases.</p>	46
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Poster session III - Pulsed Power Industrial and Bio-Medical Applications - Hall 4 / Cambridge (13:30-15:00)

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<p>[348] A comparison of the effects of RF and pulsed DC nonthermal plasma jets on melanoma cell viability <i>Presenter: THOMPSON, Kyle</i></p>	47
<p>Nonthermal plasma has been used as a successful treatment method for melanoma cancer cells. There are a number of power sources used to generate the high voltage signal required to create nonthermal plasma. The RF plasma jet uses a resonance transformer to generate a low frequency sinusoidal voltage. The pulsed DC plasma jet uses a high voltage pulse circuit to generate a low frequency square pulse. A comparison of the effects of melanoma cell viability using a low frequency RF power source and a pulsed DC power source for plasma generation are presented.</p>	
<p>[349] Nanosecond Electric Pulses for Lipid Extraction from Microalgae <i>Presenter: MULLIGAN, Mary</i></p>	48
<p>The continued increase in overall energy demand and the desire to mitigate environmental hazards of emissions continues to motivate alternative energy source development. Initial studies focused on developing plant biofuels; however, this approach is expensive and used foodstuffs, raising food costs. Microalgae provide an alternative source of liquid fuels that is not involved in the food supply. The most common lipid extraction method, Bligh & Dyer [1], is costly and toxic. Treating microalgae with electric pulses (EPs) permeabilizes the cell membranes which can lyse the cells to increase the extraction efficiency of safer, greener biofuels [2]. Thus, EPs can intensify biological effects to provide a safer and less expensive renewable solution than the Bligh & Dyer method. In this study, we assess the impact of using nanosecond duration EPs with different numbers of pulses and electric fields on lipid extraction. We compare these results to extraction using conventional electroporation pulses with the same energy [2] and to extraction without EPs [3]. The implications of these results on lipid extraction and ideas for future parametric studies of EP parameters will be discussed.</p> <p>[1] E. G. Bligh and W. J. Dyer, "A rapid method of total lipid extraction and purification," <i>Can. J. Biochem. Phys.</i>, vol. 37, no. 8, pp. 911-917, 1959.</p> <p>[2] C. Joannes, C. S. Sipaut, J. Dayou, S. M. Yasir, and R. F. Mansa, "The potential of using pulsed electric field (PEF) technology as the cell disruption method to extract lipid from microalgae for biodiesel production," <i>Int. J. Renew. Energy Res.</i>, vol. 5, pp. 598-621, 2015.</p> <p>[3] J. O'Grady and J. A. Morgan, "Heterotrophic growth and lipid production of <i>Chlorella protothecoides</i> on glycerol," <i>Bioprocess. Biosyst. Eng.</i>, vol. 34, pp. 121-125, 2011.</p>	

<p>[359] Preparation of thermo-sensitive poly(N-isopropylacrylamide) film using KHz alternating current pulsed discharge</p> <p><i>Presenter: TANG, Xiaoliang</i></p> <p>Dielectric barrier discharge (DBD) is an effective way of producing homogeneous plasma. Plasma, a quasi-neutral gas, is referred to as the forth state of matter. Plasma surface treatment consists of plasma surface modification, plasma polymerization and plasma surface grafting. It is very applicable to modern continuous mass production of industry, and has a very broad prospect. Dielectric barrier discharge consists of infinite microdischarges, which distribute irregularly the whole discharge space both in time and in space. Homogeneous dielectric barrier discharge looks like the glow discharge in vacuum and is very necessary to the surface modification of some special materials. And it has become one focus of plasma physics. The paper explains the mechanism of dielectric barrier discharge and favorable conditions for homogenous DBD discharge using KHz alternating current pulsed discharge. The self-made equipment of atmospheric pressure plasma vapor deposition of poly (N-isopropylacrylamide) (PNIPAm) was used in the environment of argon and the suitable discharge gap. PNIPAm is a new type of smart thermo-sensitive macromolecule material that is characterized by a sudden precipitation on heating, switching from a hydrophilic to a hydrophobic state. The samples were characterized by scanning electron microscopy (SEM), x-ray photoelectron spectroscopy (XPS) and water contact angle. It was revealed from the results of SEM analysis that the poly PNIPAm coatings were formed on the surface of the smooth glass slides, according to XPS, it was found that there exists PNIPAm and the wettability was significantly modified by changing the temperature above and below the lower critical solution temperature (LCST) from the data of the water contact angle test.</p>	49
<p>[365] Pulsed Ultraviolet Light Decontamination of Artificially-Generated Microbiological Aerosols</p> <p><i>Presenter: TIMOSHKIN, Igor</i></p> <p>Airborne transmission of infectious organisms is a major public health concern, particularly within healthcare and communal public environments. Methods of environmental decontamination utilising pulsed ultraviolet (UV) light are currently available, however it is important that germicidal efficacy against airborne contamination is established. This study demonstrates evidence of the dose-response kinetics of airborne bacterial contamination when exposed to pulsed UV-rich (PUV) light.</p> <p>Bacterial aerosols (*Staphylococcus epidermidis*) were generated using a 6-Jet Collison nebuliser, and introduced into a custom-designed aerosol chamber which enabled prolonged airborne suspension and circulation. Bacterial aerosols were exposed to short duration pulses (~20 μs) of UV-rich light emitted from a xenon-filled flashlamp. The lamp was operated using a 1 kV solid-state pulsed power source, with a pulse frequency of 1 Hz, and output energy of 20 J/pulse. Post-treatment, air samples were extracted from the chamber using a BioSampler liquid impinger, and the surviving fraction was enumerated using standard microbiological culture methods.</p> <p>Results demonstrate successful aerosol inactivation, with a 66.4% reduction achieved with only 10 pulses of UV-rich light ($P < 0.0002$). Inactivation using continuous UV light was also investigated in order to quantify the comparative efficacy of these antimicrobial light regions. In addition to determining the inactivation kinetics, the spectral outputs of the pulsed and continuous UV sources were captured and compared in order to assess their comparative UV-C content, and subsequently assess how this UV content relates to their germicidal efficiency.</p> <p>Overall, results provide evidence of the dose-response kinetics of bacterial aerosols to PUV-rich light. As with continuous UV light, safety restrictions limit its application to unoccupied environments, or within sealed enclosures such as air handling units, however the reduced treatment times with PUV provides operational advantages over continuous light treatment.</p>	50
<p>[376] Control System and Diagnostic Tools of Pulsed Power Supply for TPS Pulsed Magnets</p> <p><i>Presenter: LIN, Ke-Kang</i></p> <p>Taiwan Photon Source (TPS) is the latest-generation 3-GeV synchrotron light source. Pulsed power supplies to control injection and extraction of the TPS pulsed magnets have been designed and implemented. The experimental physics and industrial control system (EPICS) embedded programmable logic controllers (PLCs) were developed to control the pulsed power supplies. The control interface is remotely accessible with EPICS client tools. The timing system provides synchronous trigger signals for pulsed power supplies. Data acquisition system with EPICS support are employed to observe the output current of the pulsed power supplies. The control system of these pulsed power supplies satisfies complete system integration, rich graphical user interfaces and useful diagnostic tools. It has been running with no down time since mid-2014, which indicates high reliability. A detailed description of control system, operational interfaces, real-time monitoring system and diagnostic tools for the pulsed power supplies is presented in this paper.</p>	51

<p>[388] Improved High Voltage Pulse Generator for Automated Insulator Fault Detection</p> <p><i>Presenter: SANDERS, Howard</i></p> <p>Insulators that have suffered invisible damage can cause catastrophic system failure. Detection of the fault through visual inspection is not possible. An automated non-destructive test method is preferred. We have developed a system capable of a peak pulse voltage > 50 kV with fast rise time and limited pulse energy coupled with a high speed FPGA processor to analyze the output voltage and current for potential insulator faults. This paper will discuss the design and test results of this high-voltage pulse generator with automated fault detection.</p> <p>This pulse generator has been improved using a new high-voltage solid state switch based on thyristors capable of >100 A/ns and >300 V/ns. Using this switch increased the efficiency by 25% versus an IGBT based switch. This paper will also discuss the design and test results of this new switch.</p>	68
<p>[430] Effect of Current Rising Rate on Ablation and Plasma Bulk Velocity in a Pulsed Plasma Thruster</p> <p><i>Presenter: HAN, Ruoyu</i></p> <p>Pulsed plasma thrusters (PPTs) have vast potential for application in small satellites. Capillary discharge, which produces high density and relative low temperature plasma, has a great interest in space propulsion devices. Based on the capillary discharge, PPTs make full use of electrothermal acceleration mechanism to promote the overall efficiency in low energy level.</p> <p>In this paper, a capillary discharge based pulsed plasma thruster has been designed, the main discharge circuit was compact, and the circuit inductance was low. With the change of the main capacitor capacitance and charged voltage, the current rising rate could be adjusted from 3A/ns to 20A/ns. Under the given dimensions of discharge cavity, the effect of different current rising rates on the ablation and plasma bulk velocity was studied.</p> <p>With an electronic balance, the ablated mass per 1000 shots was measured. As the result showed, the ablated mass increased with increasing the current rising rate. It has been proved that the current rising rate has an effect on the ablation and ionization of propellant, affecting the relative content of products. This effect was studied with a spectrometer. A reduction of the current rising rate decreased the emission spectrum intensity of plasma with a similar composition.</p> <p>With the PMT array, the plasma bulk velocity was measured based on the time-flight method. Result showed that increasing the current rising rate would accelerate the plasma bulk to a higher velocity. Meanwhile, the light-emission intensity showed the same tendency as the plasma bulk velocity.</p>	61
<p>[473] NON -DESTRUCTIVE COILS AND FIELD SHAPERS FOR HIGH MAGNETIC FIELDS INDUSTRIAL APPLICATION, Yuri Livshitz, Amit Izar, PULSAR Ltd ISRAEL</p> <p><i>Presenter: LIVSHITZ, Yuri</i></p> <p>Keywords: Coil, Design, Alloys, Service life, Magnetic Pulse</p> <p>Abstracts</p> <p>High magnetic field pulse, despite it's proven advantages, has still not been widely adopted in industrial applications-mainly because of critical parameter of work-coil's service life.</p> <p>PULSAR's R&D works aimed to create suitable work-coils (Solenoids) for industrial use are reported here. The material and geometry considerations are addressed.</p> <p>I-turn coils with or without power-pulse transformers were designed, manufactured and tested at a wide range of both dimensions and work regimens, including water cooling and air cooling system. A contact system for the coil at peak current about 1MA has been developed and tested too. Magnetic field distribution has been checked as well and the one-turn water cooled solenoid tested to 50000 pulses lifetime at 25 Tesla and 4 pulse /minute</p>	52
<p>[471] Multi-pulse Current Source for Highly Inductive Load</p> <p><i>Presenter: GUO, Bing</i></p> <p>With the low cost, high resolution, good traffic and other characteristics, Helicopter Transient ElectroMagnetic (HTEM) system has gradually become a hot topic of Airborne ElectroMagnetic (AEM) survey. The multi-pulse large magnetic moment transmitting is one of its key technologies. However, a few topologies have been reported in the literature. The high-power multi-pulse current source circuit suitable for HTEM transmitter system is presented in this paper. Through the switch matrix composed by IGBT, the circuit uses the LC resonance principle to achieve the release and recovery of transmitting energy, thus producing the main pulse of the large current and secondary pulse steep edge. The charging circuit is designed with constant power control and soft switching technology to replenish the capacitor energy gap. The formula of the circuit parameters is deduced by the analysis of the circuit working process. In order to evaluate the performance of the proposed circuit topology, the circuit simulation is carried out by using Matlab/Simulink software and a prototype circuit is built. The results show that the proposed circuit can realize multi-pulse current waveform output under inductive load, and it has the characteristics of simple structure and flexible control.</p>	53

<p>[446] Ethylene treatment using nanosecond pulsed discharge</p> <p><i>Presenter: TORIGOE, Yasuaki</i></p> <p>Ethylene is a gas released from fruits and vegetables and has the effect of promoting their growth. Today, fruits and vegetables of various types are transported together by container ship. However, ethylene release amount and product sensitivity toward ethylene depend on product type; thus, if product with high ethylene release such as apples are mixed with that with high ethylene sensitivity such as persimmons, the latter will ripen excessively. Non-thermal plasmas (NTP) such as dielectric barrier discharges (DBD) and corona discharges have been investigated as a way to decompose ethylene. The nanosecond (ns) pulsed discharge is one of NTP and is known that generate O₃, treat exhaust gases and decompose VOCs with higher energy efficiency. However, many issues still remain prior to industrial implementation, including increasing energy efficiency for the removal of residual HCOOH, CO, and O₃ as byproducts; there are also decomposition limitations in areas of low ethylene concentration. Overcoming these limitations is the purpose of this work.</p> <p>The output voltage of the ns pulse generator was 30 kV – 50 kV in amplitude, 10 pulse/s – 100 pulse/s in repetition rate, and 5 ns in pulse width. The 100 ppm ethylene which was diluted with dried air was employed as simulated gas of the transportation container. The gas mixture was fed into the coaxial cylinder type reactor for the evaluation of the decomposition efficiency. Ethylene concentration decreased to less than 0.1 ppm after ns pulsed discharge treatment at 30 J/L in input energy density. O₃, CO, N₂O, HCOOH, HNO₃ were generated as byproducts; byproduct concentrations were measured.</p>	446
<p>[444] Nanosecond pulsed discharge type ozonizer with cooling structure</p> <p><i>Presenter: IKOMA, Daichi</i></p> <p>Dielectric Barrier Discharge type ozonizers has been used in water treatment, sterilization and deodorization for many years. However, the yield in ozone generation leaves a room to expand its utilization. On the other hand, ozone generation using nanosecond pulsed discharge has attracted attention as a high-yield ozonizer. However, maximum ozone concentration remains lower value than that required for further industrial applications. A main cause of ozone concentration saturation is assumed to be gas temperature rise near the H.V. central electrode of the coaxial cylindrical electrodes. Our previous study showed that gas temperature rises more near the center electrode. This paper describes the effects of center electrode cooling on ozone concentration.</p> <p>In this study, a tube-cylinder reactor was used. The center electrode, with an inner diameter of 6 mm and outer diameter of 8 mm, allowed coolant to flow inside of it. Results show the possibility of high voltage application by increasing the diameter of the center electrode and suppressing gas temperature rise in the vicinity of the center electrode. Furthermore, higher ozone concentrations could be produced compared with conventional wire-cylinder reactors. These results suggest that suppression of gas temperature rise near the center electrode is efficient for suppressing ozone decomposition in ozone production using nanosecond pulsed discharge.</p>	55
<p>[439] Development of Pulse-Operated Penning Plasma Source for High-Speed Physical Vapor Deposition</p> <p><i>Presenter: TAKAKI, Koichi</i></p> <p>A pulse-operated penning plasma source has an instantaneous power of several tens of kilo-watts and an order of the current density of A/cm² class, of which characteristics are similar to so-called HiPIMS glow plasma. The magnetic field is perpendicular to the target surface thoroughly and the plasma generation can be set arc-free and no-droplets. These characteristics are superior to the conventional magnetic sputtering system. The parallel magnetic field line would be easy to know plasma characteristics by using a global simulation based on the electron-collision dominant reactions. We are aiming the pulse-operated Penning plasma generation system to apply a small scale PVD system for semi-conductor manufacturing system such as minimal fab system. This plasma generation system is also featured to be easily for scaling up the PVD deposition system. From these two points, we believe that the Penning glow plasma source is promising the new deposition system. In this study, we obtained the fundamental plasma characteristics by a simulation model. After that, we prepared aluminum thin film on silicon substrate with 1.5 micro-meter/h high-deposition rate.</p>	56
<p>[436] Temporal Profile of 100-200 kHz Band High-Power Inductively Coupled Impulse Sputtering Glow Plasma</p> <p><i>Presenter: TAKAK, Koichi</i></p> <p>Plasma source of an inductively coupled impulse sputtering (ICIS) driven by high voltage burst pulse has been developed to generate high density plasma. In this study, the electrical characteristic of the ICIS driven by high voltage burst pulse was obtained using double probe measurements. The experimental apparatus consists of two electrodes immersed in an ICP driven by high voltage burst pulse. The plasma source consists of an inductor consisted of a solenoid coil (42 turn, length 64 mm, 64 μH) wound on the glass tube. A 500 μs wide burst of 157 kHz power supply is employed to generate ICP with repetition rate of 1 Hz. The capacitor (16 nF) is used to consist resonance circuit with the inductor and the power supply. The argon gas is supplied at gas flow rate of 35 sccm into the chamber. The gas pressure is fixed at 15 Pa by a mass flow controller. The coil voltage and current are monitored by a high voltage probe and a current probe. The plasma density and the electron temperature of the produced plasma were evaluated using a double probe measurement. The electric power consumed in the plasma exceeded 7.2 kW. The time-averaged electron temperature was obtained as 6 eV. The maximum plasma density was obtained as $4 \times 10^{19} \text{ m}^{-3}$ at 40 mm apart from the coil edge.</p>	57

<p>[434] Influence of Oxygen Concentration on Ethylene Removal Efficiency</p> <p><i>Presenter: TAKAKI, Koichi</i></p> <p>Ethylene (C₂H₄) gas promotes the aging of some kinds of fruits and vegetables. Decomposition of C₂H₄ using non-thermal plasma is effective for keeping freshness of fruits and vegetables. In this paper, the influence of O₂ concentration to C₂H₄ decomposition using a dielectric barrier discharge (DBD) was evaluated. The dual polarities pulsed voltage was generated using a pulse transformer driven by a full-bridge type pulse modulator using MOS-FETs. The bipolar pulse width are set as about 50 μs and the pulse repetition rate is fixed at 1 kHz. C₂H₄ gas was diluted by 200 ppm with N₂ and O₂ gas mixture and was fed into the DBD reactor at a gas flow rate of 3 L/min. The C₂H₄ and O₃ concentrations are determined using a FT-IR spectrometer. C₂H₄ concentration decreased with increasing input energy density for all the O₂ concentrations. C₂H₄ removal was improved by decreasing the O₂ content from 20% to 2%. O₃ concentration linearly increased with input energy density. Since the reaction rate of C₂H₄ with O is much higher than that with O₃, O primarily decomposes C₂H₄ in the DBD reactor. Therefore, the O₃ concentration with C₂H₄ is lower than that without C₂H₄. O₃ concentration in the case of O₂ concentration of 2% is approximately 2 times lower than that of 20% at same input energy density, which indicates that production of O decreases in the same proportion. However, the reaction between O and O₂ is suppressed by the decrease of O₂ concentration, which promotes the reaction between O and C₂H₄. Therefore, C₂H₄ removal was improved by the decrease of the O₂ content from 20% to 2%.</p>	58
<p>[433] Inactivation of Ralstonia solanacearum Using Pulse Discharge under Culture Solution in Hydroponics</p> <p><i>Presenter: TAKAKI, Koichi</i></p> <p>A discharge plasma under water is a promising candidate to reduce the risks of bacterial infection in a hydroponics culture system. In addition, the discharge plasma provides nitric acid into the solution, which promote plant growth rate. We developed a system using plasma under solution and the performance of the developed system was evaluated using tomato seedlings in the recirculation system and Ralstonia solanacearum which causes wilt disease, followed by a serious crop loss. The discharge reactor consisted of a wire high-voltage electrode in the cylinder and a grounded electrode on cylinder outside. The reactor was sunk under the culture solution. Atmospheric air gas was injected into the cylinder and released through holes. Holes of the cylinder were 0.5 mm in a diameter and 2.0 mm separation one another. Repetitive nanosecond pulses are applied to the wire electrode, using a magnetic pulse compression (MPC) pulsed power generator. The applied voltage was 10 kV with 150 ns pulse width and 2,000 pps repetition rate. The 15 L culture solution was heavily contaminated with R.solanacearum. After that, the discharge plasma treatment was continued for 100 min. We prepared another experimental section that was a control. The culture solution in control was contaminated with R.solanacearum without plasma treatment. Seedlings were monitored and disease severity was evaluated. The result shows that the disease severity of discharge group increased on the 6th day, and was 20 % on the 8th day and after. In contrast, the disease severity of control increased on the 4th day and continuously increasing to be 100 % on the 8th day. The density of R. solanacearum of control was above 10⁷ CFU/mL, in contrast, that of discharge group was below 10² CFU/mL on the initial day.</p>	59
<p>[432] Propagation characteristics of plasma bullet in laminar gas-fed atmospheric pressure plasma jet using double coaxial glass tube</p> <p><i>Presenter: ITO, Hiroaki</i></p> <p>An atmospheric pressure plasma jets (APPJs) have been used for several years in a wide field of applications. APPJs are driven by sinusoidal wave of several tens of kilohertz. We have developed a surrounding gas-fed type APPJ to improve the selectivity of various feeding gases expecting production of ROS and RNS with a shielding effect from the ambient air condition. A newly developed APPJ consists of a double coaxial glass tube. Two gases can introduce independently into the tube and the gas and plasma flows form a laminar flow and then interact outside of the glass tube. We report the characteristics of laminar flow atmospheric pressure plasma jets. Although the effect of laminar flow APPJ to the surface is very interested, the characterization of the laminar flow APPJ itself is more important for applications. In the case of helium (He) as an inner gas flow with an outer nitrogen (N₂) gas flow, emission lines of nitric oxide, the first negative and second positive system bands of N₂ were observed, while only the second positive system band was observed in the case of argon (Ar) as the inner one. Considering the Penning effects of each excited state, the metastable state of He have a higher energy than that of Ar resulting in energetic nitrogenous productions in the former case. The excited state in the core plasma is one of the important condition to determine the characteristics of the APPJ produced with a double coaxial glass tube. In this study, we evaluated the effect of core plasma dependence of the laminar flow APPJ by comparing the emission spectra of different core plasma APPJs. In addition, the properties of spatio-temporally localized luminous effects, i.e. "plasma bullet" in laminar APPJs were explored with an intensified video camera by comparing with conventional single APPJ.</p>	60

<p>[425] Study on nitrogen oxide treatment by pulsed dielectric barrier discharge</p> <p><i>Presenter: KIYAN, Tsuyoshi</i></p> <p>Selective catalytic reduction (SCR: selective catalytic reduction) is currently the mainstream as a method of treating nitrogen oxides (NOx) in exhaust gas. Originally it was a technology of fixed sources such as thermal power plants, but in recent years it has been diverted to diesel cars. Ammonia is mainly used as a reducing agent, and it shows high removal rate of NOx. On the other hand, problems such as reduction in removal rate at low exhaust temperature, leakage of unreacted ammonia and poisoning of the first stage oxidation catalyst by carbon monoxide and hydrocarbons have been reported. Also, since it is necessary to secure a catalyst volume corresponding to the maximum flow rate of exhaust gas, the SCR catalyst is wasted at low load.</p> <p>Many researches have been conducted on treatment of exhaust gas by pulse discharge plasma. However many problems still remain for mobile sources such as diesel cars. Its apparatus is desirable to be smaller in size for the movement source compared to stationary one. Many researchers have reported that removal efficiency and removal rate depend on specific energy density (SED) with regard to NOx treatment. It means that there is no difference in efficiency if SEDs are aligned according to frequencies even though the discharge energy per pulse (Ep) is different. On the other hand, there is also a report that Ep changes the NO removal efficiency.</p> <p>In this research, emphasis is placed on removing exhaust gas with a small-scale processing equipment, and NOx was treated by pulsed dielectric barrier discharge. Experimental studies were investigated by the change in the processing efficiency depending on the gap length, electrode shape and NOx removal rate by Ep. We will report that Ep affects both of the removal rate and removal efficiency in the same SED.</p>	62
<p>[423] Investigation of pulsed discharge plasma in supercritical fluids by optical emission spectroscopy for material synthesis</p> <p><i>Presenter: KIYAN, Tsuyoshi</i></p> <p>Research of electric discharge plasma in high pressurized fluids including supercritical state has been growing to attract attention as a new reaction process in chemical reaction engineering by using pulsed power technology. It is able to be focus on applications of synergy effect which would be expected by the combination of discharge plasma and supercritical fluids. Application of the electric discharge plasma to the reaction process which aimed at reality-based fusion in a supercritical fluid will be fostered new reaction process, with few environmental impacts such as materials synthesis, chemical reaction and so on. In this respect, the characteristics of the electric discharge plasma in the supercritical state which consists of the point of view with a monoatomic molecule become important. Otherwise, a variety of active species generated by electrical discharge plasma may contribute to a reaction intricately.</p> <p>For application to material synthesis, it is an important task to investigate pulse discharge characteristics in high pressure nitrogen including supercritical state. In order to evaluate plasma characteristics by applied pulsed voltage, we developed a high pressure apparatus with optimized pulse power generator which consists of magnetic pulsed compression method. Experimental studies were conducted by applying a high pulse voltage to the point-to-point electrode placed in a high pressure vessel filled with supercritical nitrogen.</p> <p>In this research, we will report the experimental results of pulse discharge plasma characteristics of high pressurized nitrogen including supercritical state by optical emission spectroscopy and Laser interferometry.</p>	63
<p>[419] Application of Repetitive Pulse Power Supply in Rock Fracturing</p> <p><i>Presenter: FU, Rongyao</i></p> <p>The rock fracturing technology can effectively enhance the permeability, the flow conductivity, and the production of oil and gas. Hence, in order to research the fracturing effect caused by the high voltage large current, a repetitive pulse power supply (RPPS) is developed. The RPPS is mainly composed of a repetitive charging power supply, energy storage capacitor, discharging switch and discharging electrode. The power of repetitive charging supply is 20 kW/20 kV. The maximum discharging energy of RPPS is 40 kJ. The experiment of rock fracture is completed with the RPPS and the size of cement rock is $\phi 200 \text{ cm} \times 60 \text{ cm}$. The fracture result shows that cracks are in a state of symmetry. With the increase of fracture frequency and fracture number, the width and length of the crack become larger.</p>	64

<p>[403] Assessment of microbial inactivation on fruit juices by nanosecond electric pulses</p> <p><i>Presenter: GARNER, Allen</i></p> <p>Food process engineering aims to create new products with improved quality to satisfy increasing consumer demand for fresh and healthy products [1,2]. To fulfill the expanding consumer demands for foods with higher nutritional value and “fresh-like” taste, novel technologies, such as pulsed electric fields (PEFs), are currently under investigation to replace conventional thermal processes [3]. Short duration PEFs permeabilize microorganism membranes [4] to inactivate them with minimal loss of food quality [3]. Thus, PEFs have great potential as an alternative to conventional thermal treatments for fruit juice sterilization [3]. Most PEF studies use microsecond to millisecond pulses with repetition rates on the order of hundreds of Hertz. The present study explores the potential of using nanosecond PEFs (nsPEFs) with lower repetition rates to inactivate microorganisms and retain fruit juice quality by minimizing PEF induced heating. This study reports the eradication of various microbial pathogens, such as <i>E. coli</i> O157:H7 and <i>Salmonella</i> Typhimurium. The implications of this study on the potential application of nsPEFs for microbial inactivation to generate safe and high quality fruit juices will be discussed.</p> <p>[1] J. Mosqueda-Melgar, et al., “Non-thermal pasteurization of fruit juices by combining high-intensity pulsed electric fields with natural antimicrobials,” <i>Innov. Food Sci. Emerg. Technol.</i>, vol. 9, pp. 328–340, 2008.</p> <p>[2] S. Bubler, et al., “Impact of thermal treatment versus cold atmospheric plasma processing on the techno-functional protein properties from <i>Pisum sativum</i> ‘Salamanca.’” <i>J. Food Eng.</i>, vol. 167, pp. 166–174, 2015.</p> <p>[3] V. Heinz, et al., “Overview of Pulsed Electric Fields Processing for Food,” In: Sun, D. <i>Emerging Technologies for Food Processing</i>. 2nd ed. Academic Press, pp. 93-114, 2014.</p> <p>[4] N. Yang, et al., “Pulsed electric field technology in the manufacturing processes of wine, beer, and rice wine: A review,” <i>Food Control</i>, vol. 61, pp. 28–38, 2016.</p>	65
<p>[395] Effects of Nanosecond Pulse Electric Discharge Underwater Shock Waves on the Proliferation of Histiocytic Lymphoma Cells</p> <p><i>Presenter: IKEBE, T.</i></p> <p>The effects of underwater shock waves induced by nanosecond pulse electric discharge on the proliferation of human histiocytic lymphoma cell line U937 are investigated. Extracorporeal shock waves (ESW) have been successfully applied for non-invasive disintegration of kidney stone in urology and for bone formation in orthopedic surgery. The present research aims to extend the medical application of shock waves to possible treatment of lymphoma cancer.</p> <p>Underwater shock waves were generated by electric discharge using a magnetic pulse compression circuit (MPC) and point to point electrodes. Pressure profiles of shock waves were measured by a fiber optic probe hydrophone. Underwater shock waves were applied to U937 human histiocytic lymphoma cells through an innovative experimental setup. A variety range of number of shock waves ranging from 100 to 500 shots with 10 to 30 MPa over pressures was applied. The effects of shock waves on the U937 cells growth were observed by a fluorescent microscope. Propidium iodide (PI) and “annexin V” were used to investigate the effects of shock wave on the cancer cells membrane and to detect apoptotic cells. After shock waves application, depending on the shock dosage and pressure, a clear reduction or complete block of the growth of U937 cells was observed. The extents cells of damage were increased by increasing the shock wave numbers.</p>	66
<p>[392] Study of Oil Extraction from Microalgae by Pulsed Power as a Renewable Source of Green Energy</p> <p><i>Presenter: HOSSEINI, Bahareh</i></p> <p>Biofuel production as a sustainable source of green energy is considered as promising complements to petroleum in order to prevent environmental problems such as global warming. In this regard, microalgae can be one of the best options since other plant resources may be used for human consumption, using them for producing biofuel may cause an increase in their price. However, there are several challenges to extract oil from microalgae, e.g., high energy consumption, chemical solvents, and algae culture destruction; which should be addressed by new approaches. This study suggests two pulsed power based physical methods for hydrocarbon extraction from microalgae: nanosecond pulse electric fields (nsPEF) and underwater shock waves. <i>Botryococcus braunii</i> with high hydrocarbon production potential was used as microalga model. For nanosecond pulse electric fields (nsPEF) experiments, 20 to 65 kV/cm electric fields with 80 ns pulse duration, with different pulse repetition frequencies and pulse numbers were applied. Underwater shock waves experiments were conducted by applying 500 to 1000 shock waves, generated by nanosecond pulse electric discharge in water. Fluorescence microscopic observation and image and chemical assessments were performed for analysing the samples, understanding the extraction mechanisms, and comparing the outcomes. According to the results, both pulsed power approaches can be used as high-efficiency physical methods for extracting oil from <i>Botryococcus braunii</i>.</p> <p>Keywords: Biofuel, Microalgae, <i>Botryococcus braunii</i>, Oil extraction, Pulsed power</p>	67

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board

[453] STUDY OF OUTPUT CHARACTERS OF PULSE TRANSFORMER WITH DIFFERENT CLOSED MAGNETIC CIRCUIT

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*Presenter: CHATTERJEE, SAIBAL***ABSTRACT:**

Pulse Transformers are used in pulse power generating system when Output Voltage is to be raised, to invert the polarity and provide a DC isolation between discharging source and Load with minimum loss of energy and maximum transformation efficiency. Among different kinds of high-voltage pulse transformers, Authors have studied Pulse Transformer with closed magnetic core. Studies are made with pulse transformer with different geometric structure of transformer windings and considerable impacts on the output characteristics has been observed. Authors also studied the effect of auxiliary windings on the pulse shape of a closed magnetic circuit -type high-voltage pulse transformer. Source pulse signal with different repetition rate , pulse widths, and rise times are applied on the Pulse transformer with closed magnetic circuit and both the time and the frequency response has been observed.

Key words:

Pulse Transformer, Pulsed Power, Fast Rising Voltage, Magnetic Circuit, Frequency Response.

Acknowledgement:

NERIST TEQIP II

NEO TELE-TRONIX PVT. LTD.(NTPL)

[452] Design and simulation of magnetic switch and reset circuit for non-thermal water sterilize use

70

Presenter: AMIRBANDE, Masoume

Unlike other types of switches can be used in pulsed power, magnetic switch has not control gate. This means that the switching time is a function of load conditions, the source of the initial pulse, switch terminal voltage waveforms caused by these two and the switch design parameters. Considering the fact that the switch should be designed to suit the load and source and not vice versa, we can conclude that the only determinant of switch on time is its design parameters. Considering the importance of the specially designed of magnetic Switches, design trends of this switch and its core magnetic reset circuit has been developed. The Material and core structure, material and coil structure, the cross-section of conductors, cross-section of the core and the number of winding turn included in the design process. In this article, design of reset circuit design and magnetic Switches is investigated and design sample for the use of non-thermal Water disinfection has taken place and the results of the simulation are presented.

[448] Optimized Solid-State Bipolar Marx Modulador with Resonant type Droop Compensation

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Presenter: CANACSINH, Hiren

Nowadays there are many topologies based on the Marx concept using power semiconductor devices as switches that are capable to generate unipolar or bipolar high voltage pulses. In some industrial applications such as water decontamination or liquid food processing, the use of bipolar pulses instead of unipolar pulses, has demonstrated an enhanced final product or industrial process. Generally high voltage bipolar modulators require additional switches, which may allow fault tolerance capability but requires a complex triggering circuit. Alternatively, optimized bipolar topologies [1] using reduced number of semiconductors per cell create additional stress in some semiconductors during various operating modes, which increase losses. Thus, in addition to semiconductors characteristics, the design of the Marx modulator has to consider the pulse energy and the required pulse voltage droop in order to determine the capacitance of the capacitors. Considering this last point, in various applications, the used value for the capacitors is very high, making the design of a compact Marx modulator unaffordable. For this reason voltage droop compensation techniques must be considered [2, 3].

Considering the optimized solid-state bipolar Marx modulator, a voltage droop compensation technique based in resonant circuit will be proposed in this paper.

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<p>[441] STUDY OF TRANSFORMER AND MOTOR WINDING UNDER PULSED POWER APPLICATION</p> <p><i>Presenter: BASURAY, ARIJIT</i> Arijit Basuray1, Saibal Chatterjee2</p> <p>1.NEO TELE-TRONIX PVT. LTD.(NTPL), Kolkata,India email: abasuray@gmail.com 2.DEPARTMENT OF ELECTRICAL ENGINEERING, NERIST (Deemed University),Arunachal Pradesh,India email: saibalda@ieee.org</p> <p>ABSTRACT: Pulsed Power in the form of Recurrent Surge Generator (RSG) can be used for testing various parameters of Motor or Transformer windings including inter turn, interlayer insulation and many other winding defects. In motor and dry type transformers insulation has many interfaces and undesirable defects and these defects can be exposed under this non destructive testing methodology. With the development of power electronics, variable frequency drives (VFD), Dry Type or cast resin Transformers used with PWM Sine wave inverters for solar power are being widely used. Solid insulation system used nowadays are shifting more and more to high frequency applications. To probe the integrity of the Electrical insulation system as well as winding defects we have used the recurrent surge generator for testing winding integrity as well as Partial Discharge(PD) at fast rising voltage enabling PD measurement at closer situation under which the insulation system is supposed to work. We have discussed test results on different system with recurrent surge voltages of different rise time. Key words: Fast Rising Voltage, Partial Discharge, Pulsed Power, Recurrent Surge Generator, Solid Insulation.</p> <p>Acknowledgement: NERIST TEQIP II NEO TELE-TRONIX PVT. LTD.(NTPL)</p>	72
<p>[440] Increasing the Voltage Droop Compensation Range in Generalized Bipolar Solid-State Marx Modulator</p> <p><i>Presenter: CANACSINH, Hiren</i></p> <p>The Marx generator, also known as switched capacitor voltage multipliers, is one of the most used topology to generate high-voltage unipolar or bipolar pulses. The Marx generator is composed of n capacitors, charged by a parallel connection to the power supply and discharged to the load by a series connection. The connections are enabled using switching power semiconductors. Current semiconductors allow high pulse repetition rate, duty cycle adjustment and are capable to deal with different type of loads. Among various characteristics of the solid-state Marx modulators, the flatness of the output voltage is an issue for applications such as biological or food industry that requires high energy and long pulses (i.e. dozens of microseconds), as the capacitors voltage droops. Several authors have presented different droop corrections for unipolar Marx type circuits [1, 2], based on auxiliary stages or “bouncer” circuits. The author [3] has developed a scheme of resonant type voltage droop compensation for solid-state bipolar Marx modulator. However, this compensation scheme is limited to a certain percentage of bipolar pulse voltage droop. The increase of the compensation of the voltage droop of the bipolar pulse, based on resonant circuit is evaluated for generalized solid-state bipolar Marx modulator, using low cost circuitry, design and control.</p> <p>[1] Cassel, R.L.: “Pulsed Voltage Droop Compensation for Solid-State Marx Modulator”, in Proceedings of the IEEE International Power Modulators and High Voltage Conference, May 2008, pp. 117 – 119. [2] Tang, Tao; Burkhart, Craig P.; Nguyen, Minh N.: “A vernier regulator for ILC Marx droop compensation”, in IEEE Pulsed Power Conference, pp. 1402-1405, June 2009. [3] Hiren Canacsinh, Luis M. Redondo, J. Fernando Silva, Beatriz Borges: “Voltage Droop Compensation Based on Resonant Circuit for Generalized High Voltage Solid-State Marx Modulator”, in IEEE Applied Power Electronics Conference and Exposition, Long Beach, California, USA, 20-24 March, 2016.</p>	73

<p>[406] Magnetic Field Diffusion into Hollow Conductors with Walls on the Order of the Skin Depth</p> <p><i>Presenter: BUNTIN, Tyler</i></p> <p>Transient magnetic diffusion through conductors of thickness comparable to the skin depth is investigated. Since an analytical solution is unavailable in this case, such magnetic diffusion results must be determined via simulation or experimentation.</p> <p>In the experimental approach a sinusoidal current with peak values in the range of 20-30 kA (approx. 7 kHz ringing frequency) is pushed through a two turn coil generating a sinusoidally varying magnetic field. A hollow structure with metallic walls of controlled thickness is placed roughly 10 cm away from the exciting coil. The focus of this investigation is on the transient skin depth, which occurs during the first half-wave of the signal, as that is most relevant for pulsed power applications. A calibrated B-dot probe placed inside the structure facilitates measurement of the diffused field. Experimental data shows that magnetic field diffusion across the wall is not instantaneous, causing a delay before the diffused field is measured inside the test structure. The impact of cracks and holes in the conductor on the speed and magnitude of the magnetic field diffusion is elucidated. For instance, for a 30 cm long aluminum pipe (3.125 mm wall, 31.25 mm diameter), the addition of a 6.35 mm diameter hole facing the coil did not change the magnitude of the peak of the first half-wave response. However, for the hole oriented ninety degrees away from the coil face, the measured radial dB/dt peak magnitude decreases by a factor of 0.86 from 46.1 to 39.7 mT/s. This unexpected reduction is believed to be due to the superposition of magnetic field diffused through the wall and directly penetrated through the hole. Results for materials of different conductivities are compared and analyzed for the transition between thin and medium walled cases.</p>	83
<p>[371] Development of a Multiple Megaampere, Pulsed Power Lab</p> <p><i>Presenter: SCHREIBER, Adam</i></p> <p>Of general interest to the scientific and engineering community is the development of facilities for testing, validation, and qualification of pulsed power systems, components, and assemblies. Naval Surface Warfare Center Dahlgren Division (NSWCDD) has a long history of designing and implementing facilities for testing pulsed power systems capable of generating, transmitting, and sinking multiple megaamperes of peak electrical current at world record energy levels. Of general interest to the electric ship and weapon communities are the processes used to develop requirements for, and verify the capabilities of, these facilities. NSWCDD is developing a new laboratory within an existing facility using resident legacy pulsed power capabilities that can provide a wide range of electrical actions and peak currents. The new laboratory will be able to test and qualify pulsed power components in a number of test fixtures, as well as scaled and full size assemblies utilizing these components.</p> <p>In this paper, the authors will discuss the requirements development process and how different portions of the laboratory meet or exceed the basic requirements to provide for future growth. Additionally, the paper will discuss how the existing legacy pulsed power system influenced these requirements, limits future capability of the laboratory, and how these limits may be overcome. A phased construction and facility qualification plan will be presented.</p>	81
<p>[468] The characteristics of the bus-bar of electromagnetic rail launcher</p> <p><i>Presenter: YING, Zhao</i></p> <p>Electromagnetic rail launcher (EMRL) is one of the new propulsor based on impulse discharge with high current technique. In recent years, the research of EMRL has attracted the attention of domestic and foreign institutions, such as China, the United States Navy Laboratory, the French German Joint Laboratory, and has made great progress. In order to solve the fracture problem between bus-bar and rail connections caused by strong recoil in experiments, base on the study of mechanical properties this paper studied a bus-bar structure with high flow capacity, long life, and operational characteristics. The high current causes the bus-bar to be subjected to a strong recoil, in order to weaken the influence of the recoil, geometric design and simulation analysis are done according to the different angle between the bus-bar and the track. A high reliability, easy to operate bus-bar optimization structure is obtained through the force analysis and initial velocity calculation. This structure can be used in the laboratory.</p>	76

<p>[470] A Greater Than 6 MV Laser Triggered Gas Switch Used on Z</p> <p><i>Presenter: WEMPLE, Nathan</i></p> <p>The Z pulsed power driver at Sandia National Laboratories is used for a wide range of high energy density physics experiments in areas such as inertial confinement fusion, radiation effects, and dynamic material properties. Experimental demands are pushing for the highest energy attainable with more reliability and precision in timing and pulse compression. A previous version of the laser-triggered gas switch had been made reliable at voltages up to 5.7 MV, allowing 5 nanosecond load accuracy. The desire for higher energy and higher precision dictated a new laser-triggered switch design. In Z, 36 DC-charged Marx generators pulse-charge a water-insulated capacitor in 1.5 microseconds. The laser-triggered gas switch commutes the energy stored in the water-insulated capacitor to subsequent pulse compression stages that utilize self-closing water switches. The laser-triggered switch is the last command triggered switch in the chain, and largely determines the time accuracy of the total load current. Both switches consist of a laser triggered section and a self-closing cascade section. The previous design required a trigger plate to provided support for compressing the cascade section. With fixed laser energy, it was impossible to increase the triggered fraction of the switch. Because of the trigger support plate, establishing an operating pressure that provides a reliable balance between low pre-fire rate and low jitter becomes difficult, and more so at higher voltage. The new switch uses a cantilevered design that increases the electric stress in the self-closing section after triggering, even with a slightly-reduced trigger gap. It was required that the new design work within the same operating space and infrastructure as the previous. We will show details of the design and features necessary for reliable operation in the extreme electrical and mechanical environment presented by daily operation on Z.</p>	74
<p>[469] Study of electrical breakdown properties of liquid dielectrics for compact pulsed power applications</p> <p><i>Presenter: GAJULA, Veda Prakash</i></p> <p>Liquid dielectric breakdown properties are studied towards the development of efficient intermediate storage devices for pulsed power applications. A Tesla based pulse generator along with suitable voltage (V-dot) and current (self-integrating Rogowski coil) sensors are indigenously developed. The experiments are performed by applying few 100 KV with few tens of nanosecond pulse under uniform electric field conditions. Preliminary experiments are carried out on deionized water ($\epsilon_r = 78$, $\sigma < 1 \mu\text{S/cm}$), the experimental parameters being different electrode materials (brass and stainless steel), inter electrode gaps (3, 6, 8 mm). Subsequently, the experiments are extended to understand the suitability of heavy water for compact pulsed power applications. In addition to the electrical diagnostics, optical measurements i.e. absorption spectroscopy and emission spectroscopy are also used for understating the breakdown properties. Further, the discharge initiation and evolution is studied using a fast camera (4 PICOS ICCD). The observations indicate significant charge holding capability in case of stainless steel compared to brass, suitability of water in comparison to heavy water for compact pulsed power applications. The experimental details and important outcomes will be presented.</p>	75
<p>[467] Lifetime Prediction Testing of High Energy Density Metalized Film Capacitors</p> <p><i>Presenter: MILLER, Seth</i></p> <p>ABSTRACT</p> <p>High energy density metalized film capacitors can be an enabling technology for pulsed power systems. High electric field stress (i.e. high voltage) is known to limit shot life on these capacitors from breakdowns through the thin film which reduces the capacitance. This is commonly referred to as the "self-healing" property of metalized film caps. Much research has been done to observe this trait of metalized film capacitors and is fairly well understood. However what is not well understood is the fracturing of electrodes which is different than a breakdown through the dielectric but a breakdown between the film metallization and the electrode end treatment. These types of failures are observed in high current discharges which can be even more detrimental than clearings, meaning the lifetime and robustness is inversely proportional to peak current. This fracturing appears to be the dominating failure mode for very high current metalized film capacitors. A test is being developed at Sandia to measure this Electrode Fracture Discharge or EFD using radiated emissions to see how these measurements correlate to lifetime. Lifetime is defined as being the number of shots until 10% loss in capacitance compared to a figure of merit from the lifetime prediction test.</p>	77
<p>[462] Transient Simulation of a High Voltage SiC Bipolar Power Device under High Action Operation</p> <p><i>Presenter: HINOJOSA, Miguel</i></p> <p>This research details the high action pulse evaluation and corresponding modeling and simulation of a high voltage bipolar silicon carbide power device. A model of a high power bipolar device was developed in the Silvaco Atlas software to better understand the extreme electro-thermal stresses in the power device when subjected to an elevated-pulse current at a very unique time scale. Simulation of the on-state pulse current, device forward voltage drop, and lattice temperature profile of the pulsed power device will be presented in this research. The current density distribution through the bipolar device was analyzed and areas of localized very high current density were identified.</p>	78

<p>[358] Development of low-impedance, variable pulse-width, high repetition-rate, 400 kV modulator</p> <p><i>Presenter: CHAPARRO, Jordan</i></p> <p>A low impedance modulator made up of ceramic-loaded parallel-plate transmission line sections in a Marx configuration has been developed as a test bed for high power microwave sources. The generator has configurable impedance between 15 and 25 ohms, pulse-width between 50 and 200 ns, and can operate at repetition rates up to 100 Hz with a 200 kW high voltage power supply. The energy stored in the lowest impedance and longest pulse width setting is 2 kJ. A low inductance, 18 mm thick center-plane triggered rail switch has been developed around an SLA 3D printed pressure vessel. The generator design, implementation, and initial experimental results are discussed.</p>	79
<p>[363] Exploring current loss mechanisms on the Z accelerator using PIC/DSMC methods</p> <p><i>Presenter: FIERRO, Andrew</i></p> <p>Initial optimization of the Sandia National Laboratories Z accelerator has enabled the delivery of tens of MA's of current to various load types. However, plasma formation in the vacuum magnetically insulated transmission lines (MITLs) is seen as one of the limiting factors in improving machine performance. It is believed that severe heating of the electrode surfaces, due to a combination of Joule heating and ion-impact processes, can cause neutral desorption from the surface. This desorbed neutral layer, combined with field emission of electrons from the cathode, can lead to plasma formation which can break the magnetic insulation of the power flow architecture (i.e. current loss). Simulations of the highest electric field regions (e.g. convolute post-holes and radial transmission lines) are challenging due to geometric complexity, the transient behavior of the plasma, and the detailed chemistry involved in the plasma formation. Here, an electro- and magneto- static kinetic approach is employed to investigate the early-time underlying plasma formation that may contribute to subsequent current loss.</p> <p>A one-dimensional model of the post-hole convolute ($d = 1.22$ cm) is constructed. Water desorption is assumed from both anode and cathode. A realistic time-varying voltage pulse is enforced as a boundary condition on the anode and a time-varying magnetic field is introduced consistent with that measured on the Z accelerator. Known electron-neutral collision cross sections for H₂O, O, and H are included into the model to track the creation, flow, and loss of these neutrals and their associated ions. This kinetic approach allows for detailed analysis of the underlying physics that lead the plasma formation.</p> <p>Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.</p>	80
<p>[405] Surface flashover behaviour of insulating materials under impulsive electric fields in environmentally friendly gases</p> <p><i>Presenter: MERMIGKAS, Athanasios</i></p> <p>The insulating level of a pulsed-power system is usually limited by the voltage that initiates flashover over the surface of its solid insulators, rather than by the bulk solid breakdown strength. Due to environmental concerns, the use of SF₆ is being reduced and it is therefore imperative to investigate the surface flashover performance of various commonly used solid insulating materials, in conjunction with the use of more environmentally friendly gases for compact pulsed power systems. Gases like nitrogen and carbon dioxide, that are proven to have desirable dielectric strength under pulsed conditions, are being considered as potential insulating gases for pulsed power systems and applications. Such gases can potentially be mixed with 4th generation refrigerants that exhibit high dielectric strength while having low global warming potential, approximately 5 orders of magnitude lower than that of SF₆.</p> <p>In this work, the flashover characteristics of solid dielectrics in a gaseous CO₂ environment were studied. Disc shaped solid dielectric samples (20 mm diameter and 2 mm thickness) were subjected to high voltage impulses in the gas pressure range of 1-5 atm (absolute). HV impulses with positive and negative polarities and with rise times in both ns and μs regimes were applied. PVC, Tufnol, Nylon 66, glass reinforced Nylon and Perspex were used as insulating materials. The HV electrode was a 1.6 mm radius tungsten rod, located at the centre of the samples.</p> <p>It was observed that flashover strength increases with increasing gas pressure. It was also found that some insulating materials consistently show higher flashover voltage, especially at elevated pressures. Based on the obtained results, recommendations for the use of different solid dielectrics in conjunction with environmentally friendly gases are provided, contributing to insulation coordination for pulsed power systems.</p>	82

<p>[407] Magnetic Field Diffusion in Medium-Walled Conductors Using Finite Element Method (FEM)</p> <p><i>Presenter: COLLIER, Landon</i></p> <p>The diffusion of a magnetic field through the walls of a hollow conductor is a problem that eludes analytical description with a few exceptions only. For instance, some solutions exist for cylindrical geometries in the limiting cases that the skin depth is much larger than or much smaller than the wall thickness. However, in pulsed applications, where the transient skin depth may be similar to conductor thickness, the underlying simplifications to the thin wall solution begin to breakdown. Electromagnetic simulations using the finite element method (FEM) are conducted for various 2-D and 3 D geometries focused on the medium-walled case, which is considered to be of great importance in a variety of pulsed power applications, from shielding sensitive electronics to obtaining accurate diagnostics.</p> <p>Even in simplified geometries, the development of complex eddy current distributions gives rise to a finite delay time observed in the diffused field inside the shielded volume vs. the applied field. Further, for transient sinusoidal excitation, the dB/dt magnitude at its first half-wave peak decreases initially over-exponentially with the wall thickness. This dependence changes to a simple exponential relationship for wall thicknesses beyond the skin depth. For instance, for a wall thickness equal to about one transient skin depth, simulation reveals a reduction in dB/dt magnitude by roughly one order of magnitude over the unshielded case (skin depth ~ 0.86 mm for Al T6061 at the given frequency of 7.1 kHz). However, to achieve an additional order of magnitude reduction in dB/dt peak magnitude, a wall thickness of approximately seven times the skin depth (~ 6 mm) is required.</p> <p>In more detail, the effects of material parameters such as conductivity and permeability on the diffusion process are examined. Simulation accuracy is verified through comparison with simple-geometry, high-frequency-limit analytical solutions and results from pulsed high-magnetic field experiments.</p>	84
<p>[413] Dynamics of Audio Square Wave Plasmas: Insights for Plasma Cleaning of Vacuum Diode Electrodes</p> <p><i>Presenter: TANG, Ricky</i></p> <p>The Z machine is a high-current pulsed-power generator located at Sandia National Laboratories capable of delivering 100-ns, 30-MA current pulses to a variety of targets. Under certain conditions, however, a significant fraction of the current does not reach the load but is shunted across the inter-electrode vacuum gap that leads to the load. That undesirable current loss is believed to be due to neutral desorption from the heated electrodes that are then ionized, forming an electrode plasma that flows into the vacuum gap. Much past work on vacuum diodes have shown positive effects of various in-situ conditioning techniques in improving diode performance, including cryogenically-cooled electrodes, surface coatings, discharge cleaning, and electrode heating.</p> <p>Due to the operation and scale of Z, an in-situ discharge cleaning approach was chosen for electrode conditioning. Implementation focuses on cleaning the convolute and final feed regions where majority of current loss is observed to occur. A novel approach of generating the cleaning plasma using a bipolar audio square wave (ASW) was developed and compares favorably with the conventional method of radio-frequency (rf) generation. Optical emission spectroscopy of the two plasmas reveals higher-intensity emission in the UV/visible range for the ASW plasma comparing to the rf plasma at comparable powers. Data suggest that the electron energy is higher for the ASW plasma leading to higher ionization, resulting in increased ion density and ion flux to surfaces. Laser absorption and laser-induced fluorescence (LIF) measurements reveal intriguing dynamics for the ASW plasma and provide insights for further optimization. Preliminary modeling efforts suggest that the low-frequency polarity switch causes a much more abrupt potential variation to support interesting transport phenomena, generating a "wave" of higher temperature electrons leading to more ionization, as well as "sheath capture" of a higher density bolus of ions that are then accelerated during polarity switch.</p>	85
<p>[414] Study on aerodynamic characteristics of electromagnetic rail launcher</p> <p><i>Presenter: ZHAO, Weikang</i></p> <p>The efficiency of the electromagnetic launch system depends on the electromagnetic energy which is converted into the kinetic energy of the projectile. The energy loss of electromagnetic rail launch system mainly includes electromagnetic loss, friction loss and aerodynamic loss. The aerodynamic loss may reach up to 10% of the system energy, and the higher the projectile velocity, the higher the proportion of total energy consumption. At the same time, this will lead to a rapid rise in total energy consumption. Under normal circumstances, the aerodynamic drag is proportional to the square of velocity. However, there is a gap between the armature and the two sides of the insulating plate, which makes the flow field in the launching process more complicated. In order to understand the influence of the flow field on the aerodynamic drag of projectile and the performance of the electromagnetic rail launcher, in this paper, the aerodynamic characteristics of the interior ballistics of the electromagnetic launcher are analyzed by theoretical analysis and numerical simulation.</p>	86

<p>[416] Secondary electron emission yield of Fluorinated Crosslinked Polystyrene <i>Presenter: SONG, Bai-peng</i> With the development of high power microwave (HPM) technology and its transmitted power increasing from the level of MW to GW, dielectric window, as an important part of transmission and radiation system, is suffered with high gradient electric field, resulting in phenomena of surface flashover. Secondary electron emission yield (SEY) is an important parameter determining build up of multipactor and final flashover. This paper is focused on SEY measurement of fluorinated crosslinked polystyrene, a potential window material, to investigate influences of fluorination on multipactor suppression. An instrument for dielectrics SEY with incident energy range from 50eV to 2000eV is established based on the classical electron-collector method. The hemispherical collector with two grids is used to collect secondary electrons, biased to +100V positive voltage. Experimental results indicate that fluorination can produce fluoride groups on the surface, C-Fn, after replacement reaction of C-H bonds. New introduction of C-F bonds change chemical energy structure and potential barrier of materials surface, resulting in decreasing of SEY. Additionally, the treatment methods of fluorination involving fluorinated gas proportion and applied time have significant influences on SEY. The decrease of SEY can suppress multipactor formation and thus finally lead to increase of flashover threshold. These results are effective to illuminate theoretical mechanism of fluorination suppression and optimize the treatment process.</p>	87
<p>[420] Study on Surface Flashover Properties of PTFE by Ion Implantation <i>Presenter: ZHAO, Weikang</i> The surface flashover across the insulators is the major limitation of the performance for the high voltage system. Surface flashover voltage is mainly affected by the surface properties of the materials. Therefore, it has become an important technical means to improve the surface flashover voltage of insulation materials by a series of surface treatment technology. As a new material surface treatment technology, ion implantation can change the surface roughness, resistivity and adsorption. In this paper, the surface morphology and dielectric properties of PTFE were studied by nitrogen ion beam implantation. The ion implantation experiments were carried out by changing the injection time and energy density. The surface flashover experiments were carried out in a vacuum chamber. In order to find the influencing factors on surface flashover properties modified by ion implantation, the simulations on ion implantation was completed by using SRIM software. The experimental results show that the insulation properties and microstructure of PTFE are changed after ion implantation, and the ion implantation technique can improve the vacuum surface flashover voltage of PTFE.</p>	88
<p>[427] Design and Calibration for High-Frequency Magnetic Probe <i>Presenter: WU, Yuan Hui</i> To eliminate the common mode signal, the new magnetic probe (B-dot) is employed with balance design with two loops wired at opposite direction. The magnetic probe is capable of measuring signal up to 150Mhz, we will present the design details and calibration procedures.</p>	89

Oral session 16 - Solid State Modulators and Pulsed Magnets for Accelerators, Electromagnetic Launchers

- Session Chair : Michael John Barnes - Room Stanmer (15:00-17:30)

15:00	<p>[157] Power Supply Options for a Naval Railgun <i>Presenter: HUNDERTMARK, Stephan</i> Railguns allow to accelerate military payloads to large muzzle velocities and large muzzle energies. This enables the design of range enhanced artillery systems. These systems would allow to cover target distances of more than 100 km. As modern naval ships do have electrical power generation capabilities of the order of 10s of megawatts, it is reasonable to think of electrical, heavy naval deck guns. Some preliminary parameters of such a gun were developed in recent studies [1,2]. To further investigate the electrical behavior of the proposed 25 MJ muzzle energy railgun, simulations with two different pulsed power supply units (PSU) were performed and compared. The more conventional approach uses a capacitor based PSU, the other investigated option is an inductive PSU. The simulations allow a detailed comparison of these two different approaches to meet the huge power requirements in the gigawatt scale of such a railgun. In addition the electrical aspects, aspects like safety, size, weight, cost efficiency and maintenance are of high interest for a ship-board PSU. This study will give support for the selection of the most suited pulsed power supply for a naval based railgun artillery system.</p> <p>[1] S. Hundertmark, D. Lancelle, "A Scenario for a Future European Shipboard Railgun", IEEE Transactions on Plasma Science, Vol. 43, No. 5, May 2015.</p> <p>[2] O. Liebfried, P. Frings, "Parameter study of an inductively powered railgun", 18th Int. Symp. Electromagn. Launch, Oct 24-28, Wuhan, China</p>
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15:30	<p>[27] Overview of Circuit Topologies for Inductive Pulsed Power Supplies <i>Presenter: LIU, Xukun</i></p> <p>The pulsed power supply is one of the most important components in the electromagnetic launch system. The IPPS (Inductive Pulsed Power Supply) has attracted researchers' attentions with its major advantages of high energy storage density (over capacitive pulsed power supply) and easy control (over rotating mechanical pulsed power supply). Since the circuit topology of the basic IPPS module will directly determine the comprehensive performance of the whole IPPS system, circuit study has been an important focus in the field of IPPS.</p> <p>This paper reviews the present circuit topologies for IPPS, including the XRAM (MARX spelt backwards) with GTO (Gate-Turn-Off thyristor), the XRAM with ICCOS (Inverse Current COmmutation with Semiconductor devices), the XRAM with MFCE (Magnetic Flux Compression Effects), the CMIS (Current Multiplier by Inductive Storage), the STRETCH (Slow TRansfer of Energy Through Capacitive Hybrid) meat grinder, the STRETCH meat grinder with ICCOS, the meat grinder with SECT (SElf-charged Capacitor and Thyristors), and the meat grinder with CPFU (Capacitive Pulse Forming Unit).</p> <p>To be specific, as for these circuit topologies, historical development timeline and spectrum structure are illustrated; circuit structure and working principles are introduced; module performances including volume, energy storage level, energy storage density, peak output current, energy delivery efficiency, and money cost, are compared; major strengths and weaknesses are summarized.</p>
15:45	<p>[222] Armature Shape Optimization of an Electromagnetic Launcher Using Genetic Algorithm <i>Presenter: CEYLAN, Doga</i></p> <p>Barrel side and pulsed power supply module are two crucial parts of an electromagnetic launcher, which affects the efficiency. The most important feature in the barrel side is the shape of the armature.</p> <p>In this study, the shape of the armature is optimized by using independent variables to define the exact geometry of the armature. The main goal is to maximize the muzzle kinetic energy of the armature.</p> <p>In the literature, most of studies put emphasis on C-shaped armature geometry including most of the commercial products. However, detailed analysis on the geometry of the armature is not available in the literature. In this paper, armature geometry is divided into pieces which are used in the optimization algorithm as independent variables. Then, discrete armature shape is interpolated and used for calculation of fitness function. The fitness function results of different armature geometries are compared in the genetic algorithm. Stationary, time dependent and frequency domain analysis are implemented with this method. In the analysis of current pulse excitation of barrel, skin and proximity effects are also taken into account in the optimization algorithm.</p> <p>However, developing an analytical fitness function for armature shape is a difficult problem, because of the complexity and the non-linearity of the system. Hence, using finite element method (FEM) in evaluation of fitness function is a more accurate approach in the optimization algorithm. Although, using FEM increases computational cost of the optimization.</p> <p>In this paper, detailed analysis of the effect of the armature shape to the muzzle kinetic energy is investigated. In the analysis, MATLAB is coupled with COMSOL, and a genetic algorithm optimization is implemented to compare the performance of different armature geometries. As a result, the best shape will be presented as well as the validation of FEM and optimization results with analytic study and discussion.</p>
16:00	<p>[95] Design strategies for a SiC Marx generator for a kicker magnet <i>Presenter: REDONDO, Luis</i></p> <p>Kicker magnets are specialised elements of the beam transfer system of particle accelerators, used to inject and extract beam from an accelerator. The deflection field produced by kicker magnets must rise/fall within the time period between the beam bunch trains; hence they typically produce rectangular field pulses with fast rise- and/or fall-times. In addition, the field must not significantly deviate from the flat top of the pulse or from zero between pulses. Typical field rise/fall-times range from tens to hundreds of nanoseconds and pulse widths range from tens of nanoseconds to tens of microseconds.</p> <p>Most existing kicker systems at CERN rely on established technologies, which include thyatron switches and pulse-forming networks/lines (PFN/PFL). For thyatrons, long-term availability is a concern: hence alternate fast-switch technologies, based on high power semiconductor devices, such as the Marx generator are being actively pursued. A Marx generator topology would also potentially resolve problems associated with pulse forming: PFNs are complex devices built of many discrete components, difficult to adjust for optimisation of pulse-shapes, and PFLs rely on difficult-to-source cable for the highest voltage ($\approx 80\text{kV}$) kicker systems.</p> <p>This paper presents design strategies and preliminary test results for a Marx generator with specifications of 40kV, 3.2kA, 3microseconds pulse width, 30ns rise and fall-times, and 1Hz repetition rate, for possible replacement of an existing kicker thyatron/PFL system. The proposed topology will use 50 stages, each 800V stage comprising 24 SiC MOSFETs in parallel, each MOSFET conducting almost 140A pulses. First tests using single and parallel SiC MOSFETs will be described and results discussed in light of the proposed topology. Also the structure of the complete system will be discussed, as the parasitic inductances are a key issue in this application.</p>

16:15	<p>[332] Prospects for an optical Re-Triggering System for the LHC Beam Dumping System at CERN <i>Presenter: RODZIEWICZ, Janusz Pawel</i></p> <p>The LHC beam extraction kicker system, composed of 15 fast kicker magnets per beam, is used to extract the particles in one turn from the collider and to dispose of them, after dilution, on an external absorber. Each of the 15 magnets is powered by a separate pulse generator, all of which are simultaneously triggered when a beam extraction from the machine is requested. Spontaneous firing of a single generator will create undamped beam oscillations that are likely to exceed the accelerator aperture resulting in beam losses and potential damage to the machine. In order to protect against occurrence of such events, a Re-Triggering System (RTS) has been implemented to redistribute, as fast as possible, a trigger request issued from the spontaneous-firing generator to the remaining 14 generators. Due to the architecture of the system an avalanche mechanism is started after a detection of a spontaneous firing. Since there is no stored energy in the system itself it is difficult to create spurious triggers; neither a disconnected cable nor a defective trigger source could cause triggers. Nevertheless, such a system has demonstrated potential electro-magnetic immunity weaknesses due to common coupling between generators.</p> <p>A prospect for a RTS based on passively generated and transmitted optical power to all others generators has been studied in order to overcome this limitation. This can be accomplished by coupling light from a number of diode laser bars at re-trigger sources of one generator to bundles of optical fibres subsequently dispatched the remaining 14 generators. At each generator control stage we foresee a photoconductive semiconductor switch which ensure the conversion of the light signal into isolated electrical triggering pulse. The system can provide electrical power to the generator stacks of switching circuits through an optical link and therefore excluding common mode failures of interconnected re-triggering segments.</p>
16:30	<p>[438] Launch efficiency and muzzle velocity accuracy enhancement with a 24MJ DES railgun <i>Presenter: DAL, Ling</i></p> <p>It is proved by many researchers that the distributed-energy-store (DES) railgun can provide higher launch efficiency. This paper takes a 24MJ pulsed power system and an 8.5m long railgun as the simulation example, and analyzes the launch efficiencies and muzzle velocity accuracies from DES and breech-fed railgun. 24MJ pulsed power modules consisted of 234 pulsed forming units (PFUs) are divided into five groups. And we set five energy feed-in points along the length of gun with different spacing distance. The peak current value with DES mode is 2.25MA, the residual current is 1.2MA, and the efficiency is 31.5%. While the breech-fed railgun just obtains an efficiency of 22.3%, though the peak current of 2.46MA is higher and the residual current of 0.59MA is lower. The method of increasing muzzle velocity accuracy from DES railgun is also studied in this paper. We add an energy feed-in point located in 2.5m away from gun muzzle. 20 PFUs are linked to this point. According to the armature real time velocity, PFUs of appropriate numbers are triggered and discharge energy into railgun. By this way, the dispersion of muzzle velocity are decreased from ■2.5% to ■2.5%. If more energy compensation points are adopted, the muzzle velocity accuracy can be improved furthermore.</p>
16:45	<p>[196] Study on the Isolation of Multiple STRETCH Meat Grinder Modules <i>Presenter: LIU, Hui</i></p> <p>The STRETCH meat grinder, put forward by IAT (Institute for Advanced Technology), is a typical inductive pulsed power supply (IPPS) unit for electromagnetic launch systems. When multiple STRETCH meat grinder modules supply one railgun load together, the currents flowing among these modules might cause them being coupled with each other. In order to promote the modularization of IPPS modules and diminish the current coupling effect, two STRETCH meat grinder modules are selected to analyze. We find that, by increasing the ratio of the first inductance value to the second inductance value and the ratio of the second inductance value to the load inductance value, the current coupling among these modules can be reduced. More than 98% of the module current will be supplied to the load when the ratio of the second inductance value to the load inductance value reaches 50. To verify the above theory, the prototype experiment and simulation are carried out with two modules feeding one load in the case that the two modules are triggered at different times. In order to compare the effect of the isolation, one criterion is defined as taking the root mean square (rms) of the current values of 10k points on the load current waveforms and the corresponding points on the standard load current waveforms with the discharge time range from 7.55 to 11ms. The smaller value means the better isolation. By analyzing the above criterion, the consistency of the theoretical results and the experimental results are approved. So by increasing the ratio of the first inductance value to the second inductance value and the ratio of the second inductance value to the load inductance value, the modules can reduce the coupling current among them. This result also provides certain theoretical guidance for the practical engineering applications.</p>

17:00	<p>[45] Pulsed Power Considerations Relating to EM Space Launch <i>Presenter: ANDERSON, Michael</i></p> <p>Recent studies have evaluated whether a ground-based electromagnetic (EM) acceleration system could provide a useful reduction in launch-to-orbit costs compared with the large chemical boosters currently used. Potential advantages of the EM launch approach include increased launch frequency, safety and reliability as well as cost reductions. There is a growing market for launch of small satellites that are commonly referred to as nanosatellites or microsatellites, especially, but not exclusively, for missions in low Earth orbit (LEO). The most common systems presently being studied are based on cubesats which may operate in multi-satellite constellations; each individual cubesat typically has a mass of a few kilograms. The study reported here has evaluated the launch of a two-stage-to-low-Earth-orbit projectile, with the initial velocity being provided electromagnetically using a railgun and the orbit insertion via a rocket motor in a second stage that would carry the payload into low-Earth orbit.</p> <p>Electromagnetic launch systems of this type will be governed by the same fundamental principles as tactical railguns but a major difference is that the EM accelerator track—which may be tens or hundreds of meters in length—cannot be powered only from the “breach” as in a tactical railgun, since electrical resistive losses will become unacceptably large. To overcome this, a distributed energy feed system (DES) is required.</p> <p>One of the major differences between EM launch and present rocket launch systems is the acceleration load that the payload will have to tolerate. Present cubesats and similar satellites are designed only to tolerate accelerations of a few Gees, as encountered in conventional rockets. In contrast, as tactical railgun designs show, the EM launcher is capable of very high accelerations. The development of future novel pulsed power concepts and/or low-cost manufacturing approaches could help the EM system to become economically attractive and options for such approaches are discussed.</p>
17:15	<p>[91] Experimental Study On The Plasma Development For Pulsed Inductive Thruster <i>Presenter: LI, Xiaokang</i></p> <p>The pulsed inductive thruster (PIT) is a promising space-propulsion method of long working life, better propellant compatibility and the accessibility to high-power application, because of its unique electrodeless feature. In a PIT, the electric energy stored in a capacitor is inductively transferred to the kinetic energy of the plasma, at the same time the impulse for propulsion is gained. In this paper, a discharge system operated in vacuum was set up, including a specially-designed driving coil. Using Argon as the propellant, a bright puff of circular plasma is obtained in the experiment, with a typical life of 20 microseconds. The image sequences of the plasma developing process acquired by an ultra-high speed camera were analyzed, combined with the current curves of the discharge circuit. The results indicate that the breakdown always arises near the zero-crossing point of the current. Once the plasma is generated, the load characteristic of the driving circuit is obviously changed. Sequentially, the plasma experiences an intensity oscillation, during which the energy in the circuit is inductively absorbed by the plasma.</p>

Oral session 17 - High Voltage Switching technology - Session Chair : John Dolan - Room Preston (15:00-17:30)

15:00	<p>[368] Hydrogen spark gap performance after long-term storage under various gases <i>Presenter: WHITE, Paul</i></p> <p>The performance of hydrogen insulated, triggered 3-electrode spark gaps after long-term storage in argon, hydrogen and nitrogen has been investigated. 15 spark gaps were characterised and for each of the 3 different gases, 5 of those sparkgaps were stored for periods between 1 & 5 months. Those spark gaps with a storage period of 1 & 2 months were subjected to repeat tests. Before each testing point the sparkgaps were flushed and refilled with hydrogen. This paper presents data comparing the number of self-break events and non-trigger events after each storage period. In order to understand the influence of the storage gases upon the spark gap performance, the trigger voltage and the charge voltage were measured for each pulse. The effect of storage time on the amplitude of the required trigger voltage for each storage gas is also presented.</p> <p>This work was sponsored by MOD under contract number DSTL/AGR/00282/01.</p>
15:15	<p>[369] Performance characteristics of spark gaps with hydrogen-nitrogen & hydrogen-argon gas mixtures <i>Presenter: WHITE, Paul</i></p> <p>This paper describes an investigation into the performance of sparkgaps with hydrogen-nitrogen, argon-hydrogen mixtures and a hydrogen only gas fill. The spark gap was operated in both self-breaking and triggered modes of operation to quantify the voltage hold-off and trigger voltage requirements as a function of gas mixture and gas recovery time. An un-triggered spark gap was operated and the self-break voltage measured over a range of pressures and pulse repetition rates from 1Hz to 1,000Hz for each of the different gases. For operation in a triggered mode, the required trigger voltage was measured for different pressures across a range of pulse repetition rates for the different gas mixtures.</p> <p>This work was sponsored by MOD under contract number DSTL/AGR/00282/01.</p>

15:30	<p>[370] Characterisation of a triggered mid-plane spark gap with UV illumination <i>Presenter: WHITE, Paul</i></p> <p>This paper describes the results of a study into the performance of a triggered three electrode, uv illuminated spark gap. A test cell containing the 3-electrode triggered spark gap and a separate two electrode spark gap (to provide the UV illumination) was developed initially. UV from the two electrode gap was produced by breaking the gap with an independent HV pulse generator, which allowed UV timing and intensity to be varied easily. The effects of intensity and timing of the UV illumination on the trigger voltage required to initiate the closure of the spark gap were measured. Subsequently the trigger circuit for the 3-electrode spark gap was modified to simultaneously provide the trigger pulse and the HV pulse for the UV illuminator.</p> <p>This work was sponsored by MOD under contract number DSTL/AGR/00282/01.</p>
15:45	<p>[410] Triggering of a High Pressure Air-filled High Voltage Spark Gap Switch Using Laser Induced Plasmas Resulting in Sub-nanosecond Jitter at Low Percentages of Self-Break* <i>Presenter: SIMPSON, Sean</i></p> <p>We demonstrate a high pressure, air-filled, spark gap switch with small gap geometries of 1.5 - 3.5 mm triggered using a laser induced plasma between the electrodes with laser energies as low as 500 uJ resulting in jitter from 350 ps to 2.2 ns when operated between 70% - 30% of self-break for voltages >100 kV. Switches of this design can be used for near-synchronous firing of 100's to 1000's of switches while maintaining low impedance and low inductance.</p> <p>In this work, we will present our most recent results for our prototype switch in terms of gap geometry, DC hold-off voltage, operating pressure, switch run-time, laser energy, and jitter.</p> <p>*Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.</p>
16:15	<p>[390] Pulse-Sharpening Circuit for High Current Explosive Emission Cathode Driver <i>Presenter: KALLAS, Nicholas</i></p> <p>Explosive Emission Cathodes (EEC), used for the generation of relativistic electron beams, require short rise-time high voltage pulses in order to reduce the extraction of off-energy electrons. To this end a rise-time sharpening circuit has been developed at the Los Alamos National Laboratory. The circuit consists of a ~7nF water filled peaking capacitor with an integrated self-breakdown switch designed to operate up to 300kV. This unit is intended to reduce the rise time of a 4-stage type E PFN Marx Generator and was used to study the operational characteristics of a planar carbon fiber velvet cathode with respect to varying voltage turn-on time. Simulations of the peaking circuit in situ show a reduction in voltage rise-time from over 100ns to roughly 20ns. This paper details the simulation, design, and testing of the peaking circuit.</p>
16:30	<p>[393] Comparative study of laser triggered pressurized spark gaps <i>Presenter: MAYSONNAVE, Thomas</i></p> <p>The UV laser triggering of high pulse power switches has been quite extensively studied over the past decades. This tool gives generally access to a reliable triggering with low jitter. New generations of lasers allow now to work with other wavelengths available at higher energy. How these two parameters interplay in the triggering mechanism? How could they be optimized to increase the triggering efficiency?</p> <p>In this context, we have developed an experimental setup in order to make a triggering comparative study with a pressurized spark gap on which a static potential was applied. We have used a Nd:YAG laser allowing to work with three different wavelengths and energy range: 1064nm (<850mJ), 532nm (<430mJ) and 266nm (<150mJ). Our capacity to initiate the breakdown at low voltage (relative to its self-break voltage) was investigated depending on the wavelength, the energy and the focal distance of the laser, as well as the pressure (≤ 3bar) and the gap [5; 6.5; 8cm] of the switch.</p>
16:45	<p>[415] Pulsed Power Generators Based on Solid-State LTD Technology <i>Presenter: JIANG, Weihua</i></p> <p>Linear transformer driver (LTD) is an alternative pulsed power generation scheme to traditional pulse compression methods. Solid-state LTDs are being developed for industrial applications. They have advantages in system modularity and output flexibility. In addition, they are also featured by compactness and stress distribution.</p> <p>Semiconductor power devices have been used as switches for the LTDs. The output voltage and current of an LTD system are determined by the number of modules and the number of switching devices in each module. The rise-time and pulse-width depend on the specifications of the switch and the circuit inductance.</p> <p>Experimental studies have been carried out on the development of hybrid LTD, bipolar LTD and smart LTD. The hybrid LTD uses both MOSFETs and IGBTs as switches so that the system output can benefit from the merits of both devices. The bipolar LTD can generate bipolar output with arbitrary combination. The smart LTD is characterized by waveform variation and feedback control.</p>

17:00	<p>[435] Development of trigger circuit applied in high temperature of triggered vacuum switch <i>Presenter: XIANG, Lingfeng</i></p> <p>Pulse power systems applied in oil well stimulation device are required to work under circumstances of high temperature while the maximum working temperature is over 120°C. In traditional trigger devices, the capacitor discharges via the trigger surface when a high power thyristor closes the circuit, releasing enormous energy but the high power semiconductor devices and the drive circuits cannot operate normally under high temperature. In order to insure normal work against high temperature, a new trigger system without any high power semiconductor elements is designed. In the three-stage switch operated trigger device, the single chip microcomputer switches on the relay while a small capacitor discharges through the relay, triggering a three-electrode spark gap then and another capacitor discharges through the spark gap, triggering the triggered vacuum switch (TVS) at the final stage. In this paper, double thresholds examining the main current twice are set and the method of examining the voltage level in a period of time is adopted to prevent spurious trigger caused by white noise. In addition, a small pulse transformer is introduced in case of insulation breakdown between the voltage measure circuit and trigger circuit when the voltage difference is large enough (The voltage difference can be as large as 15kV when the main voltage reaches 30kV). Based on the design, a prototype is developed and it is tested to trigger a TVS under the temperature of 120°C. The results show that the trigger device can switch the TVS 100% reliably.</p>
17:15	<p>[437] Effects of voltage rise rate on pulsed streamer discharge <i>Presenter: FUJITA, Ryo</i></p> <p>Pulsed streamer discharge plasma, a type of non-thermal plasma, is known to generate various chemically active species therefore widely applied to many fields such as water quality improvement and ozone generation. However, detailed physical properties of streamer discharge remain unclear. Thus, basic research on pulsed streamer discharge is necessary. Some studies report the streamer discharge observation, but mostly based on the unfixed peak voltage. In this study, discharge propagation phenomena were investigated at a fixed peak voltage under various voltage rise rates using an ICCD camera.</p> <p>In the experiment, a pulsed voltage with a duration of 100 ns was created using Blumlein lines generator and applied to a needle-hemisphere electrodes. The applied peak voltage was about 71 kV with the electrode gap set at 24 mm as measured from the top of the needle to hemisphere surface.</p> <p>To adjust the voltage rise rates, an inductor was employed in the generator with changing its winding number. A decrease in the number of winding from 5 to 0 resulted in a pulsed voltage rise rate increased from 0.61 to 1.21 kV/ns. Important results are as follows: (1) The ending time of streamer head propagation was delayed, and the voltage at that time increased from 53.1 to 61.0 kV; (2) Streamer head velocity on average increased from 0.45 to 0.58 mm/ns; (3) Brightness value increased at the end of streamer head propagation.</p> <p>The experimental results elucidate the relationship of pulsed voltage rise rate to various streamer discharge parameters. It can be concluded that pulsed voltage rise rate has a great influence on the physical characteristics of streamer discharge.</p>

Oral session 18 - Intense Electron and Ion Beams, Plasma, Ion and Electron Sources - Session Chair : Jacob Zier - Dukes Suite (15:00-17:30)

15:00	<p>[374] PREDICTIVE MODELLING OF THE MERLIN SMP DIODE PERFORMANCE <i>Presenter: GOUDE, David</i></p> <p>AWE conducts hydrodynamic trials as part of its continual mission to maintain the UK nuclear deterrent. The trials utilise flash x-ray radiography as a key diagnostic for studying explosively driven experiments. Future trials will use a Self-Magnetic Pinch diode on the Merlin Inductive Voltage Adder as one of the radiographic sources.</p> <p>This body of work presents predictions of the radiographic performance of a Self-Magnetic Pinch diode on Merlin, which have been made for anticipated optimal and sub-optimal diode geometries. The predictions are made using an ensemble of codes including: the transmission line code, Bertha; the Particle-in-Cell code, LSP; the Monte-Carlo code, MCNP; and the Bayes Inference Engine. The methodology of sequentially linking predictions from a circuit model through to dose measurements on a radiograph will be illustrated. Specific attention will be given to how the electron beam focussing within a Self-Magnetic Pinch diode is modelled.</p> <p>This represents the first attempt to make such a broad range of predictions of a flash radiographic diode ahead of experimental data at AWE. Together with the results a number of strengths and weaknesses identified in the simulation methodology will be presented, which suggest how future models can be developed for better accuracy and speed.</p>
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15:15	<p>[101] Simulation and experimental characterization of a high power electron diode for linear induction accelerators <i>Presenter: J.M., Plewa</i></p> <p>X-Ray flash radiography is a useful diagnostic for investigating the structural response of matter during hydrodynamic experiments. Intense pulsed X-ray sources are required to freeze the motion during these experiments and hence, produce sharp images. For this purpose, Linear Induction Accelerators (LIA) provide high flux X-rays pulses [1-2]. In order to optimize the electron beam transport, a good knowledge of e-beam characteristics and its dynamics out of the injector is required. Studying and predicting the beam dynamics in various regions, including within the injector, is critical for improving the radiographic spot size [3] and the dose for existing and future accelerators. This work describes the numerical model developed in order to assess the beam dynamics. The computational model is based on the LSP particle-in-cell code [4]. The simulation setup will be presented and results will be discussed. This model was used to increase the beam intensity from 2 kA to 2.5 kA on the first axis at the EPURE facility. The good agreement between the simulation and the measurements on the first axis validates this simulation tool for designing novel high power electron diodes.</p> <p>[1] A. Georges et al, "Status on AIRIX restart", Proceedings of LINAC 2014, Geneva, Switzerland. [2] C. Ekdahl, "Modern electron accelerators for radiography," IEEE Trans. Plasma Sci., vol. 30, n°. 1, pp. 254-261, 2002. [3] N. Pichoff et al, "Contributors to AIRIX focal spot size", Proceedings of EPAC 2006, Edinburgh, Scotland. [4] LSP is a product of Mission Research Corp., Albuquerque, 417 NM.</p>
15:30	<p>[93] Validation of gas-chemistry models for intense electron-beam induced gas breakdown* <i>Presenter: SWANEKAMP, Stephen</i></p> <p>Experiments have been carried out at the Naval Research Laboratory to measure the air response to an intense electron beam created using a 4 kA, 100 kV, 50 ns pulsed-power source. The electron beam is extracted through a pair of thin foils and injected directly into an 11-cm-long, 17.8-cm-diameter, gas-filled chamber. The properties of the plasma produced by the rapidly varying electron-beam pulse are characterized with an array of diagnostics including laser interferometry to measure the line-integrated electron density and plasma spectroscopy to measure important molecular and atomic nitrogen lines. The measurements are being used to validate gas chemistry and plasma dynamics models. A weakly-ionized-gas model can be used when the electron-neutral collision frequency is small compared to the electron-electron collision frequency. This translates into a rough condition for the validity of the weakly-ionized model given by $n_e/n_{gas} < 0.01$. In the opposite limit, other collision processes must be considered. An important collision for molecular nitrogen is dissociative recombination which can be a significant source of atomic nitrogen during the beam pulse. This significantly complicates the gas chemistry model. In addition to the gas chemistry model, the plasma electron dynamics can be modeled either as a fluid or fully kinetic. A fluid model can be used at high pressure when the collisional mean free path is small compared to the gradient scale length. A kinetic model is needed at low gas pressures where the mean-free-path becomes comparable to the gradient scale length. Modeling of the experiments has begun and progress toward the validation of both the gas chemistry and the plasma dynamics models will be presented.</p> <p>*Work supported by DTRA</p>
15:45	<p>[238] Development of Uniform Electron-Beam Sources for Materials Study* <i>Presenter: HINSHELWOOD, David</i></p> <p>We are pursuing the development of 0.5-4 MV, 40-120 J/cm² electron beams to benchmark and validate models of dynamic material response. Large-area sources at low impedance can be achieved using multiple parallel ring diodes, whose multiple current returns keep the local self-magnetic field below the threshold for pinching, thus alleviating the need for an external magnetic field. We report here on development of single and double ring-diode sources on the Gamble II generator at NRL. The Gamble II parameters (~1 MV, ~800 kA, 50-ns FWHM) provide an excellent test-bed for ring-diode-source development. In parallel, we are developing a source on the EROS generator at AWE. EROS, with its lower current (~100 kA), longer pulse (~120-ns FWHM) and higher voltage (2-4 MV) is very useful in stretching the parameter space for model benchmarking. The lower current should allow a simple, large-area diode that avoids pinching by operating below the energy-deposition threshold for anode plasma formation. In both cases, the beam passes through the anode foil and then through low-pressure gas to the target. The beam profile at the target is affected both by scattering in the foil and by self-field effects during transport. Both sources are modeled using an integrated chain comprising a circuit model, particle-in-cell modeling of the diode, Monte-Carlo scattering in the anode foil, and transport through low-pressure gas to the target. The latter employs a new gas-chemistry model developed at NRL[1]. The resulting electron beams are diagnosed using calorimetry and thermal imaging of the target plane, with a common diagnostic arrangement used on both generators. Interferometry and spectroscopy have also been applied to the transport region in Gamble II experiments to validate the gas-chemistry model. This talk will describe both modeling and experimental results.</p> <p>*This work funded by AWE through NNSA</p> <p>[1] Angus, et al., PhysPlas. 23, 053510.</p>

16:00	<p>[224] Electrons Loss Characteristics Study on Bremsstrahlung Reflex Triode <i>Presenter: HUANG, Zhongliang</i></p> <p>Experimental study of system-generated electromagnetic pulse effect requires large area hard x-ray source with the average energy of photons less than 100 keV and few electrons. Compared with the single diode, the bremsstrahlung reflex triode can generate hard x-ray more efficiently to meet the demand of experiment. Reflex triode applies two face-to-face cathodes to reflex the electrons. The electron makes multiple passes through the foil, so the generate efficiency of hard x-ray is improved. But some electrons lose energy in the foil holder without producing useful x-ray. So the study of the electrons loss characteristics is very important for the bremsstrahlung efficiency. In the paper, the electrons loss characteristics of the reflex triode were discussed by using PIC code and theory analysis. The influences of the foil size, cathode size and foil thickness on the electrons loss characteristics were considered, which provided references to reduce the loss of electrons.</p>
16:15	<p>[161] Characterisation of the plasma filled rod pinch diode operation <i>Presenter: MACDONALD, James</i></p> <p>The plasma filled rod pinch diode (aka PFRP) offers a small radiographic spot size and a high brightness source. it operates in a very similar way to plasma opening switches and dense plasma focus devices - with a plasma prefill supplied by a number of simple coaxial plasma guns, being snowploughed along a thin rod anode before detaching at the end. The aim of this study is to model the PFRP and understand factors that affect its performance.</p> <p>Given the dependence on the PFRP on the prefill, we are making detailed measurements of the density ($10^{15} - 10^{18}$ /cm³), velocity, ionisation and temperature of the plasma emitted from the guns. This information will then be used to provide initial conditions to the Gorgon 3d MHD code, and the dynamics of the PFRP operation will then be studied.</p>
16:30	<p>[143] Repetitively Pulsed Cold Cathode Research in the NRL Plasma Physics Division <i>Presenter: HEGELER, Frank</i></p> <p>A large selection of materials have been investigated as electron beam producing repetitively pulsed cold cathodes. The cathodes were tested at 200 kV to 500 kV, 100 A to 110 kA, with cathode cross-sections ranging from 5 cm² to 3000 cm², and pulse widths from 50 ns to 300 ns. Cathode turn-on time and emission uniformity were measured, and cathode longevity was estimated for the following materials: solid carbon, carbon fiber flock with and without cesium iodide (CsI) coating, velvet with different fiber lengths and fiber densities, glass fiber, carbon fiber cloth, bundles of carbon fibers, carbon foam, ceramic honeycomb, ceramic/metal configurations, silicon carbide, and diamond-like carbon.</p> <p>This paper provides a summary of two decades of cold cathode research, discusses the advantages and limitations of each cathode material, and it covers other topics relevant for rep-rated operation, such as cathode holding structures and vacuum chamber pressure considerations.</p> <p>Work was supported by the Naval Research Laboratory Base Program</p>
17:00	<p>[197] Influence of Target Plasma on Electron Beam Focusing in LIA <i>Presenter: SKOVORODIN, Dmitriy</i></p> <p>Performance of flash radiography system requires high spatial resolution. To produce point-like source of x-ray radiation electron beams focused on high-Z material are used. The target material is strongly heated by an electron beam with power deposition about of 1 kJ/mm³. Dense plasma is formed that affects the beam via neutralization by fast ions and ionic instabilities. In this work we present theoretical and experimental study of beam defocusing by target plasma in LIA [1].</p> <p>[1] Starostenko, D. A., et al. Results of operating LIA-2 in radiograph mode// Physics of Particles and Nuclei Letters, 11.5, 660-664 (2014).</p>
17:15	<p>[397] Effects of anode and cathode surface treatments on vacuum breakdown between metal electrodes with 50-ns high voltage pulses* <i>Presenter: ALLEN, Raymond</i></p> <p>Well diagnosed measurements of electrical breakdown between metal electrodes in vacuum have been made using a 1-MV, 50-ns pulse-generator-based test stand [1]. Results with bare, as-machined electrodes showed that cathode surface finish and material have little to no effect on the breakdown electric field. However, changing the AK gap did affect the breakdown field level, suggesting that the anode is involved in cathode turn on. Further tests showed that applying a carbon coating to the anode can dramatically decrease the breakdown field [2]. Here, we report on other anode and cathode surface treatments and how they can enhance or suppress breakdown. Polishing of the anode can prevent breakdown at certain field strengths and decrease the breakdown current at higher fields. Marring a small spot on a polished anode is shown to initiate cathode turn on at a location opposite that spot. The effects of other surface treatments such as metallic and dielectric coatings on anode and cathode surfaces will also be discussed.</p> <p>* Work supported by the Naval Research Laboratory Base Program</p>

Thursday 22 June 2017

Memorial session in the memory of Magne 'Kris' Kristiansen - Chair: Andreas Neuber, Oxford hall (08:00-09:00)

Plenary Session 4 - Invited Plenary Speaker : Jane Lehr - Chair: Ray Allen, Oxford hall (09:00-10:00)

09:00	<p>[475] Multi-Scale Pulsed Power <i>Presenter: LEHR, Jane</i></p> <p>In the last two decades, pulsed power technology has undergone a transformation from its nuclear roots to widespread application as specialized power conditioning in many diverse technical areas. Along the way, the field expanded to incorporate a wide variety of auxiliary competencies, fueled by its inherent multidisciplinary nature. These include the physics of ionized gas phenomena, advanced computational techniques and high energy density physics and high power electromagnetics. In this historical context, I will describe the variety of endeavors with an emphasis on the parallel themes across the variety of voltage scales and emerging vistas.</p>
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Oral session 19 - Numerical Modelling - Session Chair : Bryan Oliver - Oxford hall (10:30-13:00)

10:30	<p>[176] Ion Cyclotron Resonance Heating Transmitter Opening Switch Upgrade <i>Presenter: KEMPKE, Michael</i></p> <p>Diversified Technologies Inc. (DTI) has installed a high-power solid-state opening switch upgrade package to replace the mercury ignitron crowbars in the Ion Cyclotron Resonance Heating (ICRH) Transmitters at MIT Plasma Fusion Science Center's (PFSC) Alcator C Mod, a Tokamak-type fusion experimental device. The anode plate switch is rated for 30 kV, 200 A. The speed of the series opening switch avoids the large fault currents on the transformer and power feed inherent with a crowbar. This improvement enables re-optimization of the Transformer/Rectifier (T/R) set, ultimately allowing increased power output and increased tetrode reliability.</p> <p>The ratings of the prior high voltage power supply are a compromise between high output power (lower impedance required from the T/R set) and crowbar reliability (higher impedance required from the power supply to limit fault current). DTI's opening switch upgrade safely allows the use of significantly reduced transformer impedance and lower droop, giving increased power as well as improved tube protection. DTI's opening switch kit can readily be adapted to any similar transmitters as an upgrade from a crowbar.</p>
11:00	<p>[8] Circuit-PIC Coupled Model of 3D Simulation for Magnetically Insulated Transmission Line <i>Presenter: LUO, Wei</i></p> <p>In this paper, a circuit-PIC coupled model for 3-D electromagnetic (EM) PIC simulation is developed and introduced, which can be used in pulsed power system with magnetically insulated transmission line (MITL). The circuit-PIC coupled algorithm consists of an external circuit algorithm and a coupling algorithm. The external circuit algorithm based on BERTHA treats circuit elements as 1-D transmission line elements, and the coupling algorithm makes the external circuit and PIC simulation coupled with each other to form a self-consistent model. This circuit-PIC coupled model has been demonstrated and implemented in a 3-D conformal finite-difference time-domain PIC code, UNIPIC. Moreover, a coupled model of 2-D simulation and 3-D simulation for 10-stage LTDs driven MITL with a helical support have been developed. Simulation results agree well with experimental results, especially for the 3-D circuit-PIC coupled model, as asymmetric power flow can be modelled though 3-D simulation. The integrated simulation model provides an effective approach to simulating MITL system which is azimuthal asymmetry in power flow or structure.</p>

11:15	<p>[97] A 2-D Numerical Model for the Estimation of the Time Varying Inductance of an Explosively-Driven Helical Flux Compression Generator <i>Presenter: SHARMA, Ashish</i></p> <p>There is a considerable interest worldwide in the development of compact and single-shot expendable pulsed power sources for various applications. Explosively-driven helical magnetic flux compression generators (HFCGs) are natural contenders to provide the high power requirement for such applications. They consist of a hollow cylindrical metal tube called the armature filled with high energy explosives, placed within a helical coil that forms the stator. The explosives when detonated cause the armature to expand leading to the compression of the magnetic flux present within the space between the armature and the stator. This flux is initially set up by the seed current flowing in the circuit using a separate current source. These can be used to achieve very high magnetic fields accompanied with very high currents.</p> <p>The present interest in the use of HFCGs brings about the need for a fast computer code for use in the preliminary design stage which can provide results with good accuracy. Using these codes, the performance of the generator can be analyzed before conducting actual experiments, which are difficult to conduct. The electrical equivalent circuit of HFCG can be represented by a first-order series R-L circuit with time-varying elements. During armature expansion, equivalent resistance and inductance of the generator tend to vary with time and geometry. A 2-D numerical model described in this paper presents an approach to evaluate the time-varying inductance of the generator by simulating the chemical explosion occurring within the armature using a commercially available package (AUTODYN) and using these results, a numerical code has been developed to model the time-varying inductance of the generator. The results obtained using the numerical model are compared with the ones available in the literature to validate the code developed. The results will be presented and discussed in detail in the final manuscript.</p>
11:30	<p>[275] Simulation and experimental study on thermal effect of electromagnetic pulse forming <i>Presenter: ZHOU, Yan</i></p> <p>Abstract: Electromagnetic pulse forming is one of the most widely used pulse power techniques, thermal effect of electromagnetic pulse forming technology has been studied in this paper. The thermal effect is produced by the joule heat generated by the high current and the deformation of the sample in the process of electromagnetic pulse forming. The whole process is showed by simulation based on COMSOL Multiphysics, which coupling the electromagnetic field, plastic mechanics, heat transfer and thermal. The relationship between sample's parameters and the thermal effect has been analyzed by comparing different material and thickness of samples. The simulation results show that the temperature change because of the thermal effect. And a high-current pulse generator has been developed for the experiment of electromagnetic pulse forming to verify the simulation results. The high-current pulse generator has been designed and fabricated for maximum operating voltage of 25kV, peak current of 200kA. The experimental results verify that the materials and thickness affect thermal effect in the process of electromagnetic pulse forming. This work presented here extends the state of the art in the area of electromagnetic pulse forming.</p>
11:45	<p>[352] HV Pulse transformer generalized equivalent circuit identification based on detailed mechanical structure <i>Presenter: CANDOLFI, Sylvain</i></p> <p>The dynamic behavior of High Voltage pulse transformers used in klystron amplifiers cannot be accurately represented with a standard low order lumped equivalent circuit because the distributed parasitic capacitances and leakage inductances are highly dependent of the detailed mechanical structure. A methodology based on generalized high order equivalent circuits identified from 2D and 3D FEA simulations of the detailed transformer structure is presented.</p> <p>With this methodology, it is possible to derive from the detailed structure and dimensions of an existing transformer an accurate equivalent circuit model that can be used to design the power stage and control system of high performance modulators or to diagnose transient internal winding overvoltages. The method can also be used in an optimal design process of pulse transformers to be used in modulators with tight specifications in terms of output pulse overshoot, rise and settling time.</p> <p>Generalized high order equivalent circuits of an existing transformer can be identified by splitting the main windings in an arbitrary number n of elementary windings. Each elementary winding is considered as a lumped element with its own capacitance and capacitive influence coefficients with the other elements, and with its own inductance and magnetic couplings with the other elements. Skin and proximity effects in the conductors are also represented by subcircuits with additional mutual inductances and resistances. The generalized equivalent circuit order n can be chosen according to the transformer size and the operational frequency range. The minimal elementary winding is a single coil turn. The elementary capacitance, inductance and coupling factors are derived from specific identification techniques based on 2D or 3D FEA simulations of the detailed mechanical structure.</p> <p>The identification methodology has been validated on two transformers with a rated output voltage of 9.8kV and 180KV respectively that have been designed and tested at CERN.</p>

12:00	<p>[147] High Voltage Crowbar for Protection of Marx Trigger Generator (MTG) Systems on Z <i>Presenter: WHITE, William</i></p> <p>Triggering of high voltage Marx generators generally involves multiple stages, with the lower voltage signals associated with control systems being amplified to higher voltages to ensure operation with: high reliability, low jitter, and low probability of pre-fire. At the Sandia National Laboratories Z Machine, the trigger chain for the thirty-six Main Marxes includes a primary 100 kV laser triggered switch initiated by the Z control system (LTS100); which drives an array of nine Marx Trigger Generators (MTG); each of which triggers four of the Main Z Marxes. Each MTG consists of twelve capacitors which are themselves arranged in a Marx configuration to be able to produce an output pulse of 600 kV at full charge.</p> <p>The advantages of the staged trigger scheme described above are considerable, but introduce the possibility of a failure mode where higher voltage systems can deliver energy back into the lower voltage trigger components. This failure mode has been observed on Z, with subsequent damage to both MTG capacitors and spark gaps. One way to prevent this failure mode would be to add a protection circuit, or crowbar, between the MTG output and the Main Marx trigger input. Such a circuit would need to prevent the nearly 6 MV maximum voltage on the Main Marxes from propagating back along the trigger line into the MTG(s).</p> <p>A review of the available crowbar options/technologies for installation on Z will be discussed, along with subsequent tradeoffs and advantages of each type. Solid state, gas/vacuum switches, and liquid (oil) filled switches will be considered for the final design. The crowbar switch selected must not interfere with the normal trigger operation of Z, and must still be able to divert energy away from MTG components on a time scale relevant to the output risetime of the Main Marxes (~1.5 μsec).</p>
12:15	<p>[150] Experimental Research on The Operating Characteristics of Vacuum Surface Flashover Switch <i>Presenter: ZENG, Bo</i></p> <p>Vacuum surface flashover switch is a promising technique scheme of high repetitive frequency fast closing switch applied in pulsed power system. In this paper, the operating characteristics of vacuum surface flashover switch are experimentally investigated with organic materials and ceramics as the flashover dielectrics. The closing time of the switch is comprised of inductance time and resistance time. The former can be calculated from the flashover channel length and the electric parameters of the discharge circuit by Martin empirical formula. The experimental results show that, the latter is inversely proportional to the flashover electric field, which can be calculated by . The coefficient for different dielectric materials obtained from the experiments is in the range of 100~300ns*kV/cm. High voltage pulse with 2.02ns effective rise-time and 400kV amplitude is obtained in the experiments. According to the experiments, the conductive resistance of the switch is basically in direct proportion to the length of the flashover channel, and it decreases with higher conductive current. When the current reaches to kA level, the resistance is in 1Ω/cm~0.1Ω/cm range. Switches with different dielectric materials show different insulation recovery rate. Pulse string mode is applied to investigate the switch insulation recovery time. The results show that tens of milliseconds are needed for organic material flashover switch to recover, and the data for ceramics flashover switches is hundreds of microseconds. Observation under the microscope shows that flashover results in erosion grooves in the surface of organic dielectrics, where carbon is deposited. Flashover traces are also observed on ceramics surface, and XPS (X-ray photoelectron spectroscopy) measurement indicates that metal is formed along the traces.</p>
12:30	<p>[181] CALCULATION OF BREAKDOWN VOLTAGE OF GAS GAPS WITH ARBITRARY GEOMETRY ON EXAMPLES OF SPHERES AND TOROIDS <i>Presenter: POKRYVAILO, Alexander</i></p> <p>Breakdown voltage (BDV) is calculated for two electrode structures, namely sphere and donut gaps, operating in air at atmospheric pressure. The calculation is based on the streamer breakdown criterion. Comsol software is used for field analysis and calculation of critical number of electrons by assessing integrals of the efficient ionization coefficient along field lines. Thus, also lengths of critical avalanches that can propagate from both electrodes were obtained. First, simulations were performed for sphere gaps at standardized by IEEE conditions to derive critical number of electrons for highly reliable experimental data. It was shown that that these numbers deviate greatly from the widely accepted 10^8 number, and that clear tendencies for the deviations exist depending on the gap to sphere diameter ratio. This guided us in the second part of this work, which is a description of a spark gap (SG) formed by two unequal concentric toroids (donuts). Only low-potential electrode has a support to ground; the HV electrode is mounted on the low-voltage one. Thus, SG is compact compared to sphere ones. It can serve as a closing switch, and as a crude HV measurement means. The toroidal SG was tested with the capacitor charger described in an accompanying paper. BDVs were calculated and compared to experimental results in the voltage range up to 200kV. These two examples illustrate a convenient method of BDV calculation in arbitrary geometries with weakly non-uniform field; it can be used with industry-standard software in daily HV practice.</p>

12:45	<p>[242] 30-100kV PLASTIC CASE CAPACITORS FOR LTD'S, MARX GENERATORS, AND OTHER PULSE POWER APPLICATIONS</p> <p><i>Presenter: ENNIS, Joel</i></p> <p>Abstract</p> <p>Plastic case capacitors have been developed that offer compact, economical, low inductance solutions for a variety of high voltage pulse power applications. Both extended foil and tapped foil configurations, combined with rail terminals, have been designed for fast discharge ($\leq 1\mu\text{s}$ pulse width) low inductance and low capacitance units. For the highest rep rates and RMS currents, all-polypropylene dielectrics and extended foils are used, while for lower rep rates, mixed Kraft/polypropylene dielectrics may be utilized, as they offer additional resistance to degradation from voltage reversal. For maximum specific energy, dielectrics based on high density Kraft paper or mixed Kraft and polyester (PET) films were utilized to take advantage of the higher permittivities of these materials. Specific liquid impregnants are used with the different combinations of film and paper materials to achieve the best combined dielectric properties.</p> <p>When inductance is not as critical, a different internal geometry lends itself to the use of standardized winding materials that can satisfy a very wide range of capacitances and voltages used in repetitively pulsed applications such as in PFN modulators for particle accelerators. Such designs have capacitively graded voltage between their axial terminals. For relatively slow pulse ($>50\mu\text{sec}$ discharge time) applications, self-healing metallized film has been successfully integrated into plastic cases. When not required for utmost performance or undesirable for the application, the liquid dielectric oil has been eliminated, and both it and the thermoplastic case replaced with a molded thermosetting encapsulating and insulating resin.</p> <p>This paper will describe the performance characteristics and different ranges of application of these different types of plastic case capacitors.</p>
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Oral session 20 - High-Voltage Power Supplies Thermal and Power Conditioning - Session Chair : Christopher Yeckel - Room Stanmer (10:30-13:00)

10:30	<p>[180] A compact 210-kV, 10-kJ/s capacitor charger for industrial applications</p> <p><i>Presenter: POKRYVAILO, Alexander</i></p> <p>A compact 210-kV, 10-kJ/s heavy-duty capacitor charger is described. One possible application is solids fragmentation. The charger has universal three-phase input. Pulse repetition rate (PRR) can be from single shot to 250 Hz, depending on the storage capacitance. Energy dosing (ED) topology [1] was chosen. It facilitates high wall-pug efficiency of typically 92% at switching frequency of up to 55 kHz while using low-cost standard IGBTs with low static losses.</p> <p>Minimizing energy stored in the multiplier, Ems, was one of the major focuses of the development because Ems does not reach the load. It is dissipated mostly in the arc-limiter circuitry. Hence, the multiplier is center-fed, which minimizes Ems. Circuit simulations show zero-current switching at variable frequency during the charge, which was also evidenced by experiments. A reduction of peak power drawn from the primary source compared to conventional series-resonant chargers is observed.</p> <p>Another main design challenge was insulation design. Criteria of choice of permissible electric stress for complex voltage waveshapes are given. Insulation design was guided by subsystems tests and assisted by electrostatic field analyses performed in both 2D and 3D. Field plots of the HV transformer as the most stressed part are shown. Magnetic field simulations and eddy current 3D analyses helped in magnetics design.</p> <p>Multiple tests were executed. Custom test accessories, e.g., a precision, high-impedance, fast HV divider were developed. The charger was successfully tested with stored energy of up to 550 J at discharge via a compact custom-designed spark gap at PRR up to 50 Hz (in bursts).</p> <p>The charger was tested also at a customer site. Future work will focus on customization for different applications and collecting field data.</p> <p>[1] A. Pokryvailo et al., "High Power, High Performance, Low Cost Capacitor Charger Concept and Implementation", IEEE Transactions on Plasma Science, Vol. 38, No. 10, 2010.</p>
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10:45	<p>[340] Design of a resonant DC-DC Converter for High Voltage Applications <i>Presenter: MOTTA, Claudio</i></p> <p>This work reports on theoretical studies for an isolated CLC resonant DC-DC converter to generate high voltage regulated including of a control system. The converter is based on a full bridge structure using Mosfets as switching devices. The output stage of the DC-DC converter is built using series-connected lower voltage modules. The proposed topology is based on DC-DC converter operating and controlled with PWM modulation, active clamping and zero voltage switching. The PWM-Phase-Shift together with a proportional and integral controller is used to control the converter in closed loop. A high voltage transformer is used to step up AC voltage and its intrinsic capacitance and leakage inductance are utilized to obtain soft-switching zero voltage and zero current switching providing loss reduction, improving efficiency and increasing the power density. The theoretical equations of the circuit operations are studied in detail and an expression for average current in load is presented. The theoretical converter efficiency operating at the nominal output power is almost 94%. The controller proposed is being experimentally used control the output voltage of a 2.2 kW prototype, fed into 400V, which biases a pulsed TWT with voltages of 400V in the grid electrode, 11 kV in the one stage depressed collector and 24 kV in the cathode.</p>
11:00	<p>[333] Compact Power Supply with Integrated Energy Storage and Recovery Capabilities for Arbitrary Currents up to 2 kA <i>Presenter: LAMPASI, Alessandro</i></p> <p>PROTO-SPHERA can be considered as the first tokamak with a simply connected configuration, namely without external components (as the central coil) inside the plasma volume. The tokamak-like shape is obtained by the self-organization of a plasma arc (pinch) in a cylindrical vacuum vessel, resulting in a minimal aspect ratio with a high confinement efficiency. The first PROTO-SPHERA experiments suggested to introduce further external coils to adjust the internal magnetic field. Even though the coil power supply (PS) would require currents up to 2 kA with peak powers higher than 400 kW, it operates with a low duty cycle (≈ 2 s every 600 s) and with a limited net energy.</p> <p>This is a typical situation in nuclear fusion and plasma facilities: the PSs are oversized to sustain short peak demands. On the other hand, the new PS developed for PROTO-SPHERA exploits an integrated energy storage system (ESS) to deliver all the output power, requiring a very low (and tuneable according to the situation) input power (<1 kW) and only when the other PSs are not operating. In some cases, a portion of the injected power can be recovered in the ESS. The voltage available for the ramps is ± 200 V, but a different compromise among voltages, currents and times can be obtained by rearranging the ESS configuration (mainly based on supercapacitors).</p> <p>The final scope of the research is to develop standard and general-purpose PS and ESS modules to achieve higher currents and voltages without significant (compared with the output) demands from the power distribution systems and from the national grid. The modular topology would simplify the PS maintenance and would reduce the overall costs.</p> <p>The possibility to extend this approach to many PSs of a large facility, as a tokamak, will be discussed showing interesting prospects and open issues.</p>
11:15	<p>[314] A constant power capacitor charging structure for flicker mitigation in high power long pulse klystron modulators <i>Presenter: COLLINS, Max</i></p> <p>In order to generate high voltage high pulsed power, klystron modulators necessarily contain at least one capacitor bank charging structure supplying the energy to be released during the pulse. Conventional charging structures are based on AC/DC front-end units typically based on diode rectifiers combined with on/off power charging as a second stage, producing prohibitive levels of grid flicker and harmonic contents on the AC grid side while operating at suboptimal power factor; problems usually corrected by both costly and spacious external grid compensators.</p> <p>Today, increased demand on both accelerator peak power and pulse length (translating into average power), in conjunction with stricter regulations and standards on flicker as well as generated harmonics augment these problems, representing additional challenges in modulator design.</p> <p>To cope with this, an alternative method for capacitor bank charging implying use of a combination of a grid connected active rectifier and a dc/dc buck converter is proposed. This combination allows, first, the active rectifier to control the AC line current to be sinusoidal (reducing harmonic content) and in phase with the AC line voltage (minimizing reactive power). Second, the dc/dc buck converter is regulated in current mode for instantaneous constant power charging by measuring capacitor bank voltage droop, adjusting the current reference to match the exact average power consumed by the load, i.e. complete reduction of grid flicker is possible despite heavily pulsed loading.</p> <p>This paper explains in detail the working principle behind the proposed control methodology, and provides successful power quality results detailing modulator AC grid side quantities obtained both in simulation and from experiments carried out on a klystron modulator prototype delivering long (3.5 ms), high voltage (115 kV), and high power pulses (peak power > 2 MW).</p>

11:45	<p>[396] Different Control Techniques for Active Power Filter for Harmonic Elimination & Power Quality Improvement <i>Presenter: ALI, IRFAN</i></p> <p>Power electronic loads are being connected to the distributed power plants through power electronic converters and these power electronic converters and loads are the source of harmonics and reactive power which affects the performance of the power system network. Switching compensators called Active filters or active power line conditioners brings an effective alternative to the conventional passive LC filters as they can compensate for several harmonic orders, and are unaffected by major changes in network characteristics, avoiding the risk of resonance between the filter and network impedance and are compact and robust compared with traditional passive compensators.</p> <p>The aim of this work is to design shunt active filter to mitigate and alleviate the harmonics and reactive power issues with controller based on different theories under unbalanced and distorted regimes. In this paper a control method for active power filter using Space Vector Pulse Width Modulation (SVPWM) is compared with other control techniques.</p>
12:00	<p>[398] Incorporating Saturation in Permanent-Magnetic Synchronous Generator Modeling for All-Electric Ship Applications <i>Presenter: OKOU, Francis</i></p> <p>Increasing ship-board power demand coupled with environmental sustainability initiatives has created interest in pursuing all-electric ships (AES) for both commercial and military applications. AES can be equipped with power electronic components, loads, machines, and cables. Many electric generator topologies can be used for AES. Permanent-magnetic synchronous generator (PMSG) is the most attractive solution because it is characterized by low maintenance levels, high compactness, and quiet operation. To evaluate, provide information, and guide technology selection, modeling and simulation of AES is required. This paper proposes an accurate PMSG model to analyze the dynamic characteristics of the generation system and to support system critical operations in the event of dynamic load change or component failure. Saturation in PMSG is modeled by means of analytical expressions, which can be easily embedded in equivalent-circuit models and which has some distinct advantages over look-up tables. The proposed model can be used in real-time control applications and in computer simulations. Four case studies are investigated through computer simulations with Simulink. From the simulations, it is found that the PMSG model has accurate performance as the variations of voltages and currents within acceptable ranges.</p>
12:15	<p>[456] Operation Independent Spark – Combined Source Region Electromagnetic Pulse (SREMP) Effects Investigation on Operational Transmission-Distribution Power Substation and Components <i>Presenter: ANDERSON, Charlie</i></p> <p>Operation Independent Spark was a successful collaborative test between the Defense Threat Reduction Agency (DTRA) and the UK Ministry of Defense Science and Technology Laboratory (Dstl) in June 2016 at Sandia National Laboratories' High-Energy Radiation Megavolt Electron Source (HERMES III). The test was designed to investigate the survivability of transmission-distribution level power grid components and a 69 kVAC operational substation to the effects of a simulated Source Region Electromagnetic Pulse (SREMP) environment with a dose rate environment of 106 rad(Si)/s to 109 rad(Si)/s.</p> <p>The testing, completed in two phases, was designed to obtain detailed information on the response of modern grid technology to an SREMP environment. The first phase consisted of grid component tests. High-voltage grid elements such as lightning arrestors, suspension and post insulator and grid control equipment were exposed to an ionizing radiation pulse to determine radiation induced effects. The second phase subjected an operational 69kV substation with distribution level output voltages (i.e. 2400VAC and 480VAC) to the simulated threat SREMP environment.</p> <p>Operation Independent Spark marked the first evaluation of a modern operational substation subject to an SREMP environment. In addition, it was the first test to synchronize the SREMP gamma radiation pulse (30ns FWHM) with a 5kA fast transient electromagnetic pulse. This coupled physics environment emulates the effect a substation might be subjected to on the survivability boundary from nuclear blast, shock and thermal effects. The experimental results found that the ionizing radiation and fast electromagnetic drive effects can be treated separately. This paper discusses the experimental setup and results from both phase of the experiment. In particular, details regarding the co-timing of the ionizing radiation pulse and the fast electromagnetic pulse will be discussed.</p>

12:30	<p>[411] Applications in High Power Solid-State Switching at High Peak Power Level and Nanosecond Rise-Times <i>Presenter: ZIEMBA, Timothy</i></p> <p>Eagle Harbor Technologies, Inc. has developed new solid-state switching capability that has been utilized in a wide range of pulsed power applications. These systems can operate at very high pulsed power levels (> 1 MW) at high switching frequency (~ 1 MHz). Average continuous power levels of over 10 kW have been demonstrated. The technology has been configured in various topologies including high current power supplies that can switch up to tens of kiloamps at high frequency. High voltage nanosecond pulsers that can produce tens of kilovolts with rise times less than 10 ns at variable pulse widths and variable pulse repetition frequencies. Power systems that can provide bi-polar or rectified floating output at high voltage (> 10 kV) for arbitrary pulse generation from 100s kHz to DC output. The power systems have been used for DBD and plasma creation, high power microwave generation, high current PWM control of electromagnets, plasma sterilization, ion and electron accelerators, strip-line and magnetic kicker systems and high power current drive schemes. Eagle Harbor will present examples of individual power systems, associated power supply topologies and output waveforms for each system.</p>
12:45	<p>[178] 400 kV, 400 mA Power Supply <i>Presenter: KEMPKE, Michael</i></p> <p>Diversified Technologies, Inc. (DTI) recently completed and delivered a 400 kVDC, 400 mA power supply for a commercial client. The 160 kW average power supply is comprised of 16 25 kV modules arranged in a vertical, air-insulated stack. Electrically, the system is a Cockcroft-Walton cascade multiplier fed by a standard DTI high power, high voltage inverter.</p>

Oral session 21 - High Voltage Techniques - Session Chair : Adrian Cross - Room Preston (10:30-13:00)

10:30	<p>[463] High voltage characteristics of novel 3-D printing techniques and materials <i>Presenter: SHANNON, John</i></p> <p>Recent progress in a variety of 3-D printing technologies that include various materials and much improved layer refinements have led to novel capabilities in rapid prototyping. NSWCCD has specifically incorporated this rapid prototyping ability for the design and testing of high voltage pulse power components that are relevant for high power radio frequency (HPRF) systems. Complex geometries that are non-conductive, have high breakdown strength, and hold high pressure is essential in high voltage pulse power designs. This paper will test and evaluate the high voltage properties of various Formlabs resins used in several HPRF projects. Testing and evaluation will include the measurement of dielectric constants using cavity loading techniques and determination of dielectric strengths while varying resins, print resolution, material thickness, and print orientations.</p>
10:45	<p>[287] Failure Mechanism for Metallized Film Capacitors under Pulsed Current <i>Presenter: LI, Liwei</i></p> <p>For pulsed metallized film capacitors, the pulsed current would lead to the electrode fracture, which could further cause the decrease of capacitance, and the process could be accelerated when repetitive pulsed current passes. The pulsed current would further lead to the failure of metallized film capacitors, and shorten the lifetime of capacitors. Besides, the anatomical results of metallized film capacitors show the existence of electrode fracture. This paper analyzes the failure of metallized film capacitors when bearing large pulsed current, the criteria and the threshold value of the current density of electrode fracture are also studied. Moreover, experiments are carried out to study the electrode fracture when capacitors bear single pulsed current and repetitive pulsed current respectively, the experimental results indicate that the threshold value of the electrode fracture is 1.07×10^{11} A/m² when the single pulsed current passes, and 1.39×10^{10} A/m² when the repetitive pulsed current passes. Theoretical results are also derived based on the theory of Joule effect and the phase transition of metal, indicating that the threshold value of the electrode fracture is 1.30×10^{11} A/m² when the single pulsed current passes, and 2.65×10^{10} A/m² when the repetitive pulsed current passes. The theoretical results match the experimental results, indicating that the pulsed current would cause the electrode fracture, which would further result in the failure of metallized film capacitors.</p>

11:00	<p>[445] Development of High Voltage IES Pulse Chargers Using SI-Thyristor and IGBT <i>Presenter: YAMAGUCHI, Takehiro</i></p> <p>Studies in recent years of pulsed power technology have led to applications in various fields such as medical, environmental, and agriculture. For practical applications, both energy efficiency and system simplicity are important. The nanosecond pulse discharge system developed by our research group generates pulsed power with a rise time of 5 ns and a peak voltage over 60 kV, resulting in low heating loss of discharge and enabling highly efficient gas treatments. The system consists of a DC charger, microsecond pulse generation circuit, nanosecond pulse forming line, transmission line and a load. Current problem which should be solved is the large size and complexity of this system. In this study, it was focused on the microsecond pulse generation circuit in order to solve this problem. Current microsecond pulse generation circuits are based on capacitive energy storage (CES); conversely, use of inductive energy storage (IES) would both reduce and simplify the system. Fortunately, the technology of power devices has developed dramatically in recent years, and semiconductor devices that enable interruption of large currents in the high speed region have also been developed. This enables development of pulse voltage sources based on induced energy storage instead of capacitive energy storage. Here, we introduce two compact and low-cost microsecond pulse generation circuits based on IES using SI-Thyristor and IGBT as opening switches. The comparison and evaluation of these circuits with current CES microsecond pulse generation circuits were also carried out.</p>
11:15	<p>[443] Performance of a Low Impedance Nanosecond Pulse Generator <i>Presenter: SHIMOTSU, Ryusei</i></p> <p>A nanosecond pulse generator (NS-PG) which can generate high voltage pulses with duration of 5 ns and fast rise and fall times of 2 ns enables higher energy efficiencies of plasma processing. To enable development of a high-power generator for high processing capacity in the applications such as ozone generation and exhaust gas treatment, a low impedance NS-PG with higher output current was investigated.</p> <p>The NS-PG consists of a microsecond-pulse generation circuit as a charging unit, and a nanosecond pulse forming line based on a Blumlein line configuration. This study focused on the nanosecond pulse forming line, consisting of a spark gap switch (SGS) as a self-closing switch, a triaxial Blumlein line as a pulse forming line, and a transmission line from the Blumlein line to load. SF6 gas filled the SGS, and the output voltage of the generator was regulated by varying the pressure of the gas. The Blumlein and transmission lines were filled with silicone oil; which changed with ethylene glycol in this study to reduce characteristic impedance of the NS-PG. In addition, the length of the Blumlein line and the structure of the SGS were also varied to improve the performance of the low impedance NS-PG.</p> <p>This paper presents both the performance of several types of NS-PGs made in the development process of the low impedance NS-PG and switching performance of the new low inductance SGS. All of experiments carried out using a matched resistor as load for each generator. Results show that peak current of the low impedance NS-PG with the new SGS was 3 times higher than that of the previous NS-PG; also, the new SGS showed different switching characteristics from the conventional one in both pressure and frequency characteristics.</p>
11:30	<p>[401] Design and Improvement of a Pulse Shaping Inductor for a Pulsed Power Supply <i>Presenter: CIVIL, Anil</i></p> <p>Pulsed power supplies (PPS) deliver high currents in a short period of time. Designing a pulse shaping inductor (PSI) requires major effort because of the electromagnetic forces exerted on the windings due to high pulse currents. A pulse shaping foil inductor is simulated with the help of finite element software COMSOL Multiphysics. Two different mechanical structures are designed in order to increase the strength of the inductor. The PSIs are manufactured and tested as a component of a 200 kJ PPS module. Test results show that the final PSI prototype can operate without any significant damage when the PSI current reach to 160 kA. Improvement process still continues to make the PSI more enduring.</p> <p>Keywords: Pulsed Power Supply; Pulse Shaping Inductor; Foil Inductor; Finite Element Method</p>

11:45 [266] Study on Nanosecond Pulse Discharge in Upstream and Downstream Flow*Presenter: DESHENG, Zhou*

Recently, the widely application of nanosecond pulse discharge, such as flow control, enhance combustion, etc., has led to much more attention to the research of discharge under airflow.

Nanosecond pulse discharge under airflow is a typical multi-field coupling model, which contain a variety of time scales.

Pulse discharge has a nanosecond time scale for a single pulse, as well as the PRF of the millisecond time scale; the charged particles in the space have a certain time of generation and extinguish. For a fixed flow field structure, the transport time of airflow is controllable. In our research, a multi-electrodes structure is designed to explore the multi-scale coupling characteristics of nanosecond pulse discharge under airflow.

The schematic diagram is shown in Fig.1, which includes a subsonic air wind tunnel (with a maximum value of up to 250m/s), a nanosecond pulse generator (pulse width:5ns and the max PRF:3kHz), discharge systems, and measurement systems.

The details are shown in Fig.1.

Fig.1 Experimental Setup

As shown in Fig.2, the amplitude of upstream decreased from 46A to 33A, and for the downstream discharge, the amplitude of discharge current increased from 33A to 46A, And with the increase of airflow speed, the discharge mode transferred from the filamentary to diffuse discharge, and for a specific speed, the mode of upstream is a typical diffuse discharge, however, the downstream illustrate a filamentary mode.

Fig.2 Experimental Results

For pulse discharge, the electrons transferred from cathode to anode by the applied electric field. With applying of airflow, the charged particles transport from upstream to downstream discharge area, and influence the distribution of charged particles. For a specific airflow speed, the transport effect of airflow is much more obvious, revealing a specific coupling relationship.

[1] Tang J.F., PST, 18,3.

[2] Ren C.S., POP, 23,053509.

12:00 [461] Electrical Breakdown Model and Partial Discharge in Ceramic Dielectrics*Presenter: HEIDGER, Susan*

The Air Force Research Laboratory has been studying ceramic dielectric materials for high voltage pulsed power capacitor applications. As part of this effort, we have been developing an electric breakdown model for ceramic dielectrics using AFRL's massively parallel 3-dimensional electromagnetic particle-in-cell code, ICEPIC. First a method to generate randomly shaped polyhedral utilizing Voronoi tessellation was developed to simulate the ceramic material. Since electrical breakdown occurs when the local electric field exceeds the threshold electrical strength of the dielectric, breakdown was initially modeled as individual cells in the grid changing from an insulating state to a conducting states as an electric field is applied that exceed the local breakdown strength. It was also assumed that the grain boundaries of the ceramic have a lower breakdown strength that of the ceramic crystal. Details developing the electrical breakdown model of ceramic dielectrics and current progress is described. In addition, partial discharge (PD) measurements of high breakdown strength ceramic dielectrics has been performed using a Haefely Hipotronics model 750-10A6-EX-B partial discharge detector. This detector is capable of performing PD measurements with up to 50 kilovolts of applied voltage. PD measurements are presented on ceramic dielectrics before and after applying multiple pulses of increasingly higher electrical stresses. Relationships between the electric breakdown, partial discharge measurements and structure of the dielectric ceramic are discussed. This work was funded by the Air Force Office of Scientific Research through Laboratory In-house Research Program, LIR 16RDCOR281.

12:30	<p>[356] Kilo-Hertz alternating current pulsed discharge in insulated liquid <i>Presenter: TANG, Xiaoliang</i></p> <p>Discharge in liquid has been researched for about half century since the 1960s, but the theories of discharge in liquid are of great variety. We can simply classify those researches into direct current discharge in liquid, radio frequency (RF) discharge and microwave discharge in liquid and pulse discharge in liquid according to the frequency of the power source. We can also classify those researches into insulated liquid discharge and uninsulated liquid discharge. And the mostly used liquid in those researches is water at recently. Liquid nitrogen and liquid helium are also used in 60s of the last century. The mechanisms of discharge in liquid are concluded into field ionization theory, heat generated bubble and field ionization with heat generated bubble.</p> <p>This article mainly study the discharge in insulated organic mixed liquid such as oxalic acid dissolved ethanol and ethanol-water with an alternating current of 8 kilo-Hertz in room temperature. The electrical parameters and discharging spectrum were logged while discharging to optimize the discharge process. The products of discharging were Raman spectra analyzed to identify the components. Then the processes of the discharging were analyzed according to the spectrum and the electrical parameters and the probably chemical reaction were listed according to the characteristic absorption band in the spectrum.</p> <p>The power source is an alternating current power source whose frequency can be changed between 6 to 20 kilo-Hertz and the insulated liquid used are oxalic acid dissolved ethanol and ethanol-water. Different electrical parameters were measured in different concentration to find the best discharge parameters. Possibly chemical reactions were listed according to the characteristic peaks of spectrum and discharging electrical parameters.</p> <p>The mechanism of discharge in liquid concluded according to the experiments is that the discharge is generated due to the asynchronously vibration of electron and molecule in time varying electric field.</p>
12:45	<p>[367] Research on an adjustable magnetic switch <i>Presenter: LI, Song</i></p> <p>Military and industrial applications have stimulated intense interests in pulse generators with high power level, high repetitive rate achievability and long life time reliability. As an important component, the magnetic pulse compressor, being able to steadily modulate electric pulses, can be widely employed in high power microwaves (HPMs), environmental protection, plasma science, and material surface treatment. However, the unchangeable operating parameters are currently one of the crucial limitations for the device and generators based on it. In this paper, an adjustable magnetic pulse compressor is investigated both numerically and experimentally. Dominate parameters including saturation time, peak voltage, and even compression ratio can be adjusted continuously, which significantly expands the applicable area of the device and generators based on it. Specifically, an optimized GW level adjustable magnetic pulse compressor is designed with varying compression ratios. Pre-pulse of the magnetic switch is studied theoretically, and key parameters which influence the amplitude pre-pulse are analyzed. Structure of the magnetic cores is also optimized to decrease the volume and weight of the device. Based on the conclusion, an adjustable compressor was setup and studied experimentally in both the single shot mode and repetitive rate mode. Pulses with peak voltage of 100kV and energy of 500J/pulse were achieved. The rise times of the pulses were compressed at repetitive rate of 20Hz with good repeatability. Experimental results show reasonable agreement with analyses.</p>