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Automotive Engineering Research at Czech Technical University

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The Czech Technical University in Prague (established 1707) and the Mechanical Engineering Faculty of the CTU

8 faculties - Civil Eng, MechEng, ElEng, Informatics, NucEng, TranspEng, BioMedEng and Architecture/Styling

21 000 students (mostly MS level, partially BS and PhD)
1 550 academic staff

Faculty of MechEng: 2 500 students (6-8 semesters Bc, 5 semesters MS studies, 4 years PhD studies)

300 academic staff

Automotive Eng. (incl. ICE, electric powertrains - 50 MS (Dipl.-Ing.) graduates/year, currently 20 active PhD. students. 50 academic-research staff

http://bozek.cvut.cz **www.vtp-roztoky.cz** **www.cvum.eu**
jan.macek@fs.cvut.cz

Josef Božek - the Head of Mechanical Engineering Labs 1806 - 1825,

the designer of a steam car 1815 and a steam boat 1817

Josef Božek Research Centre Overview - Competences

Josef Božek Centre of Vehicles for Sustainable Mobility is a part of Faculty of Mechanical Engineering. It provides research and development of vehicle powertrains and complete vehicles, namely

- **spark ignition engines** (gasoline, gas, alternative fuels) and **diesel engines** (including heavy fuels): **thermodynamics, aerodynamics, turbo/supercharging and chargers**, emissions, **cooling**, engine/powertrain control **(mechatronics, model-based predictive and adaptive control)**,
- alternative thermal engines,
- vehicle transmissions design and optimization (mechanical, hydraulic, **electrical powertrains, hybrids**),
- vehicle body/chassis design (including NVH and **active mechatronic elements** and their control).

Centre Overview – Organisation, National and European Projects

Josef Božek Centre of Vehicles for Sustainable Mobility is a part of t Czech Technical University in Prague (CVUT). It links by **common project Božek Competence Center for Automotive Industry granted by Technological Agency of Czech Republic** relevant research workers and postgraduate students from **Faculties of Mechanical, Electrical and Transport Engineering of CVUT**, Technical University in Brno, Technical University of Liberec, School of Mines in Ostrava, TÜV Süd Czech (the member of TÜV Süddeutschland Group), Ricardo Prague, Škoda Auto, TATRA Trucks, CZ a.s., Honeywell, spol. s r.o., Brano a.s., Motorpal, ADW .

CVUT members of JBRC have elaborated 8 **European projects of FP6 and FP7:**

- New Integrated Combustion system for future car Engines NICE,
- Roads to Hydrogen Communities Roads2HyCOM,
- GREen Heavy Duty ENgine GREEN,
- **VEhicle COncept Modelling VECOM (Marie Curie ITN Project),**
- **Integrated Gas Engine Powertrain InGAS,**
- **Large-Eddy and System Simulation to Predict Cyclic Variability LESSCCV**
- **POWERtrain of FUture Light-duty vehicles POWERFUL**
- **Integration and Management of Performance and ROad Efficiency of Electric Vehicle Electronics IMPROVE**

Josef Božek Centre Overview - Current European Projects FP7 and H2020

Josef Božek Centre of Vehicles for Sustainable Mobility is a member of European Automotive Research Partners Association EARPA and European Green Vehicle Initiative Association EGVIA. It takes part in activities of technological platform European Road Transport Advisory Committee ERTRAC.

All of them are more and more taken into account during European strategies planning.

CVSM members are linked to **European projects of FP7 and approved projects of H2020, focused on powertrains and control:**

- **Integration and Management of Performance and ROad Efficiency of Electric Vehicle Electronics IMPROVE (FP7)**
- **REWARD (future ICE based powertrains for passenger cars) – H2020**
- **GasOn (EGVIA project for use of NG in passenger vehicles) – H2020, PPP EGVI**

- **other 4 projects of H2020 in preparation**

Josef Božek Centre Overview – Current Goals, Topics and Tools

Current Important Goals

- in-time assessment of innovative concepts and short time-to-market of selected feasible configurations

- design of vehicles, power trains and prime movers of reduced fossil fuel consumption and CO2 emissions (Well-To-Wheels) and environment-friendliness (EURO 6+)
  - offering top level of safety, comfort and fun2drive for users of different age and habits,
  - reacting to changing demands in a flexible way and at being competitive even at emerging markets.

Josef Božek Centre Overview – Current Goals, Topics and Tools

Research Topics

- power train downsizing – optimization of turbo/supercharging,
- exhaust emissions aftertreatment
- alternative fuel usage (both renewable and unconventional) for ICE
- lightweight design,
- electric powertrains including hybridization,
- integrated predictive/adaptive vehicle control,
- ICT for cheap cars
- improved vehicle safety.

Tools

- simultaneous engineering, based on integrated use of modeling by simulation and experiments combined with knowledge storage and re-use
- seamless interactions between experts of mentioned science domains, especially engineering mechanics, thermodynamics, power electrical engineering, control engineering, ICT, microelectronics, mechatronics and traffic engineering.

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

EVROPSKÁ UNIE
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
INVESTICE DO VAŠÍ BUDOUCNOSTI

2007-13
OP Výzkum a vývoj pro inovace

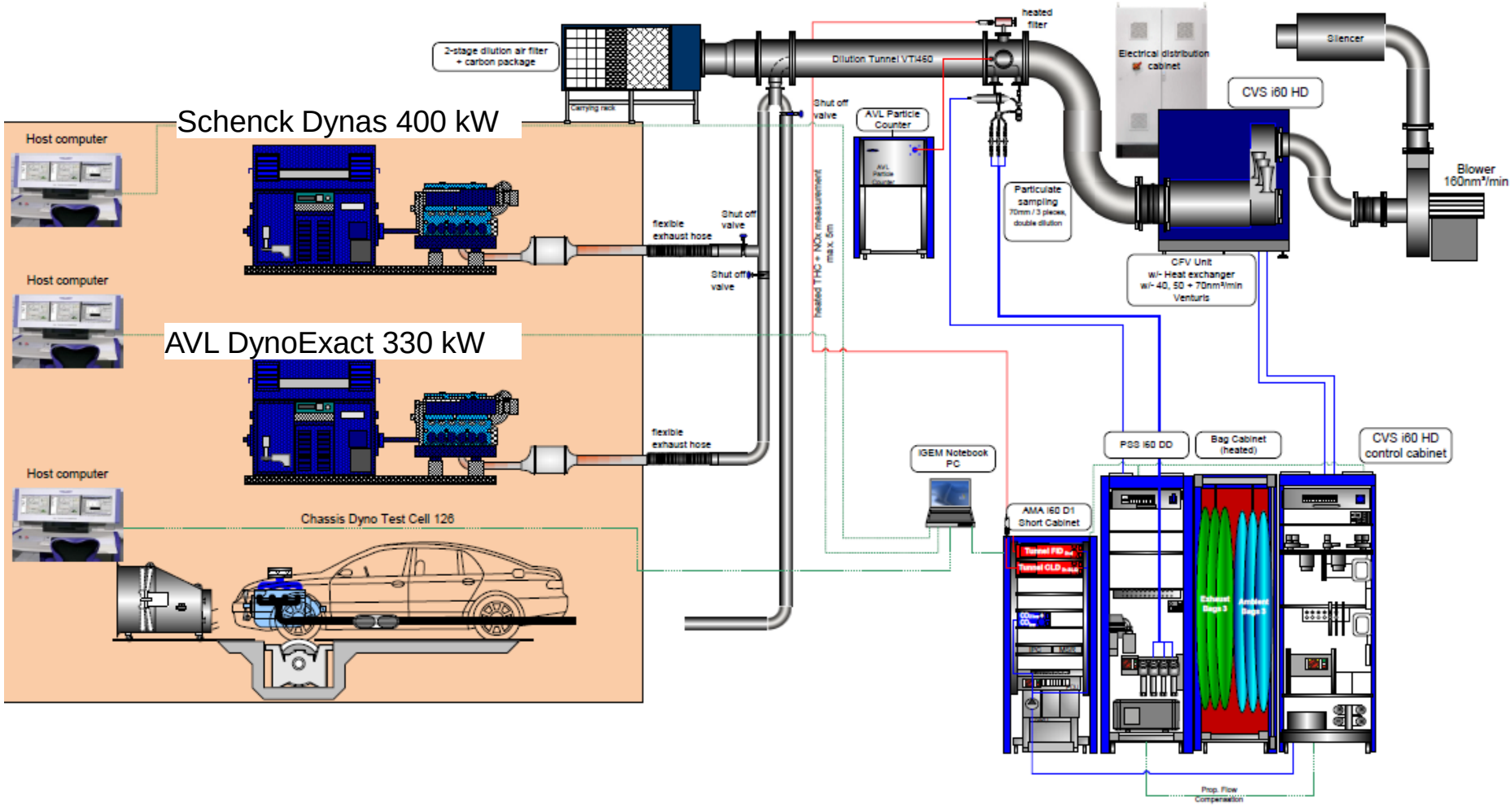
VTP ROZTOKY A.S.

trigema

CHASSIS DYNO 4WD and Emission Measurements

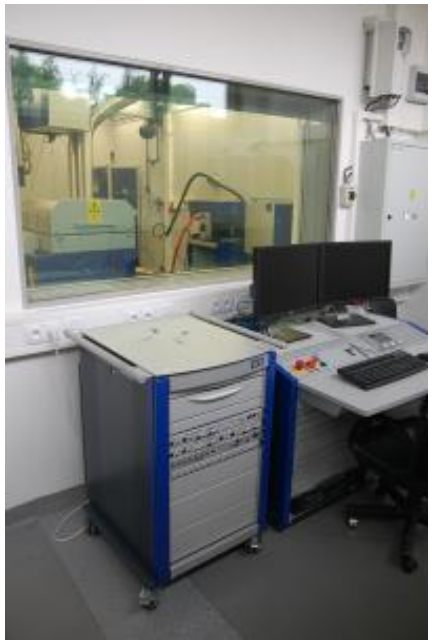
Producer: MAHA-AIP GmbH & Co. KG
Model: AIP-ECDM 48L-4mot

EAMPLE OF EMISSION EQUIPMENT - CVS OVERVIEW



ENGINE TEST CELL EXAMPLE - NO.1 and NO.4 – TECHNICAL DESCRIPTION

AVL List GmbH. has supplied two engine test cells equipped with:



- **The DynoExact** - robust high accuracy cradled-mounted AC Dynamometers with squirrel cage rotor especially designed for engine testing under harsh conditions equipped with hydrostatic bearings. High accuracy torque measurement (**<±0,1% F.S.**)

- **Automation System PUMA Open Software & Hardware**
  - Drive-by-Wire 400 / E-Gas Potentiometer Simulation
  - Vehicle, Driver and Road Simulation including Manual Transmission Simulation
  - Engine and Dynamometer Controller EMCON
  - Safety Module compliant to safety standards ISO 13849-1 and IEC 62061

- **Testbench is ready to operate in transient mode based on UN ECE 49 and UN ECE 85**
  - Testcell no.4 (330 kW) is connected to CVS (full flow dilution)

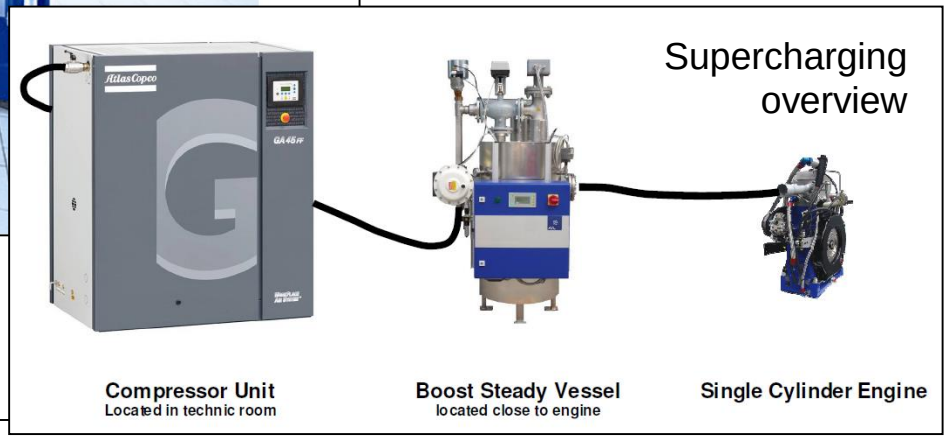
ENGINE TEST LABORATORY – SINGLE CYLINDER RESEARCH ENGINE

Compact Single Cylinder Engine Test Bed, system supplied by: AVL List GmbH.

in-house data acquisition and full-size engine simulation system

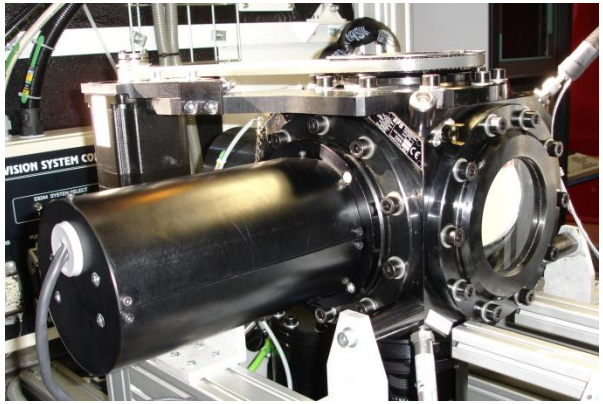
alternative fuels and LTC dual fuel system

preparation for CI/SI conversion

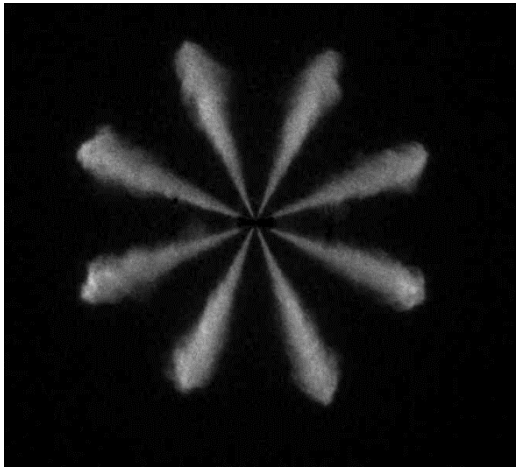


FIE LABORATORY

ITB 240 RC–V injection system test bench - INJETVISION

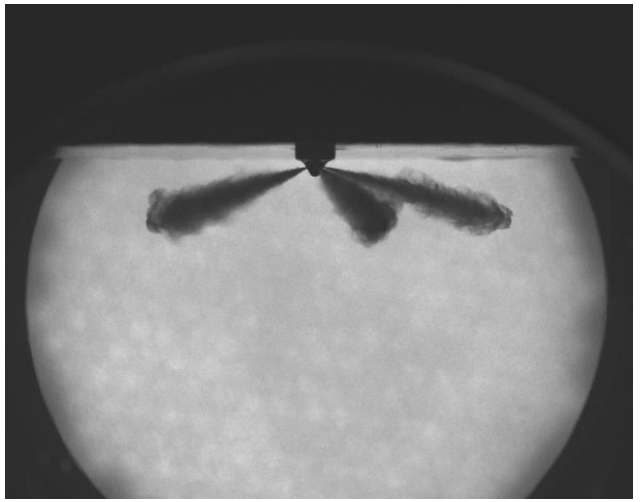


- **InjetVision System**
  - possibility to observe and study jets from high pressure diesel injectors
  - alfa and lambda view
  - inert atmosphere (N_2 or CO_2) up to 50 bars
  - fog extraction

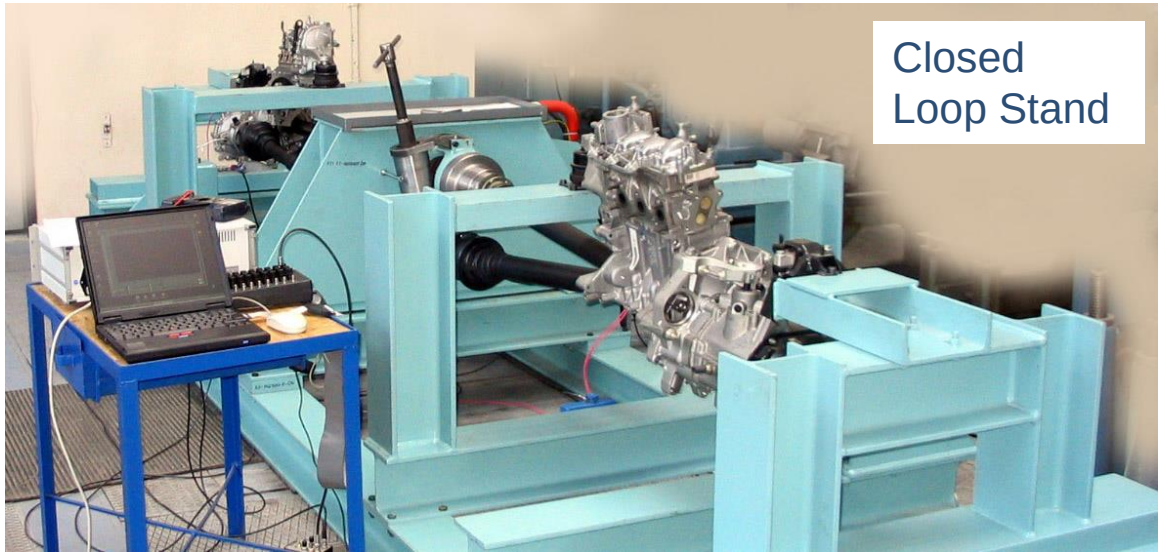


Example results

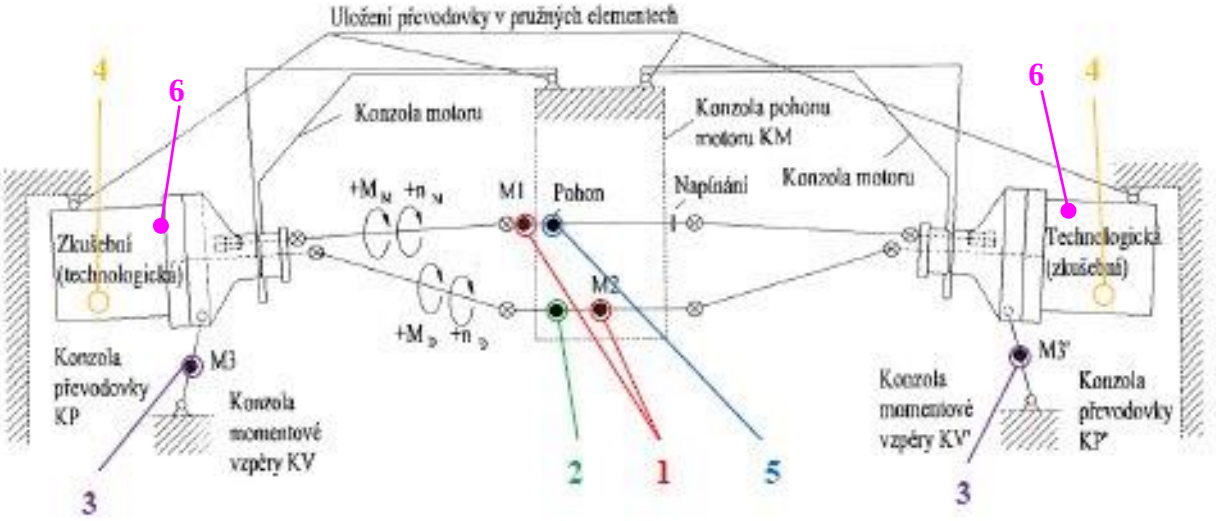
- Jet penetration percentage
- Jet opening angle
- Jet surface
- Jet volume
- Symmetry
- Spray cone angle in lambda view
- Angle λ of a jet in lambda view
- Statistical analysis



GEARBOX LABORATORY – CLOSED LOOP TEST STAND



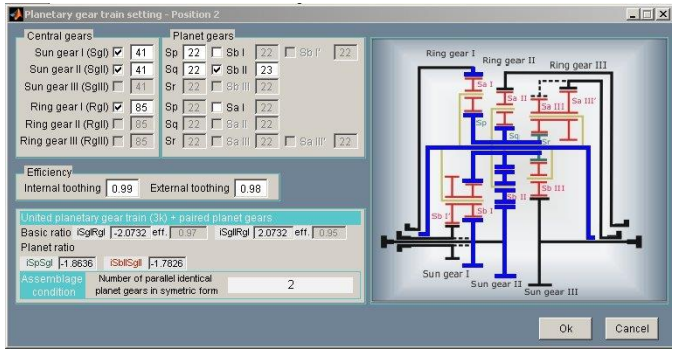
Strain-gauge flange for constant torque measurements

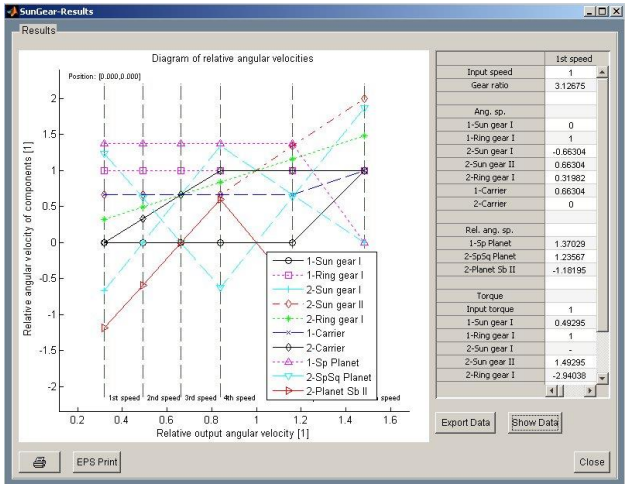


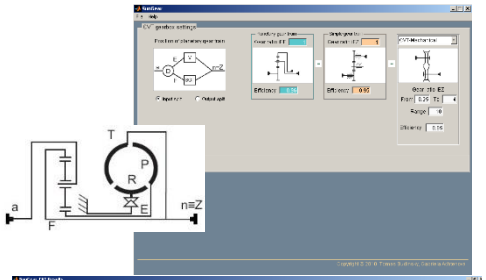
1 – Torque strain gauge measurement
2 – RPM capture
3 – Strain gauge measurement of reactive force
4 – Temperature measurement
5 – Electromotor
6 – Vibration monitoring with help of Brüel&Kjaer equipment

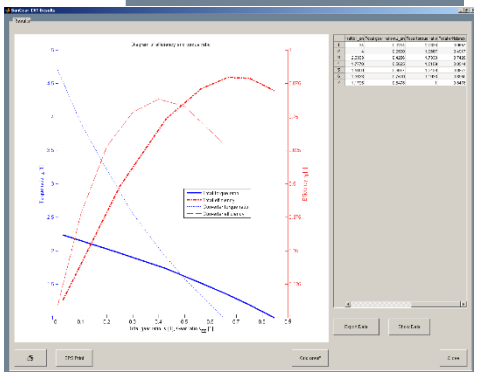
Analysis and synthesis of planetary gear sets

Summary of achievements









Program for complete analysis of morestep planetary gearboxes consisting of maximally 4 single planetary sets of arbitrary type.

Synthesis of chosen type of step planetary gearbox.

Set of rules for design of efficient powersplit CVT mechanism

Methodology of tests of nonstandard shift mechanisms

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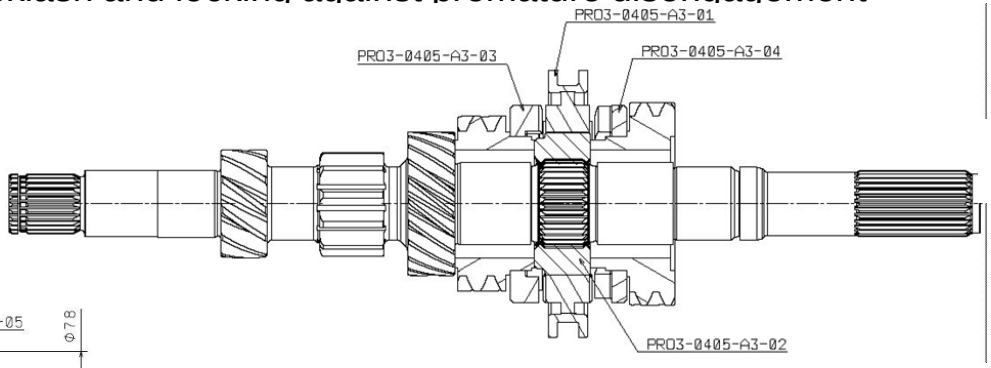
Important for electric vehicles for improvement of efficency at low speeds

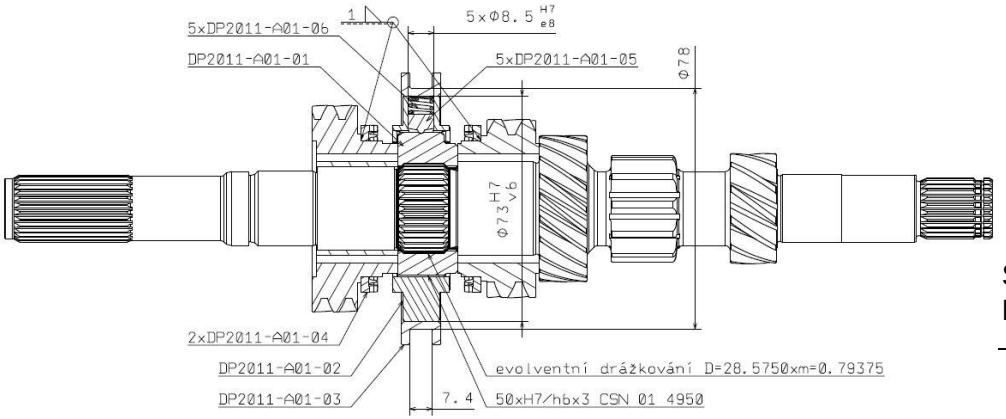
Summary of achievements

1) Design and construction of shift robot for tests of internal shift mechanisms. Usage for test of synchronisers and nontraditional shift mechanisms.
2) Design of Maybach clutch with shaped fronts
3) 3) Design of dog clutch with shaped fronts ensuring zero radial backlash and locking against premature disengagement

Pelc M.:
DP 2011

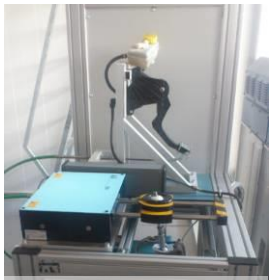


Miller P.:
DP 2010

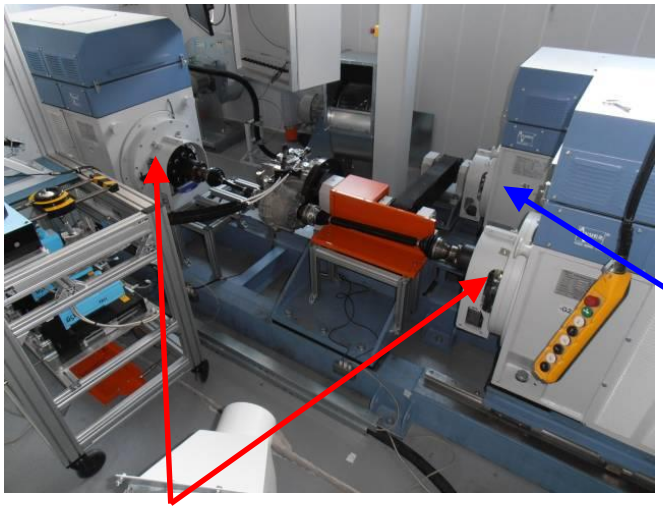


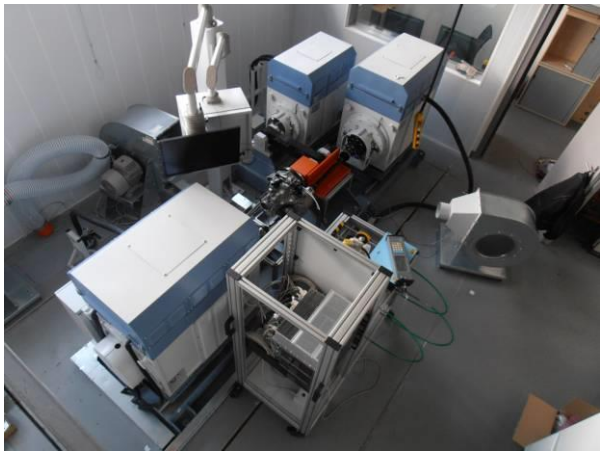
Sikora M.:
DP 2011

GEARBOX TEST STAND – OPEN SYSTEM FOR VEHICLE DRIVELINE

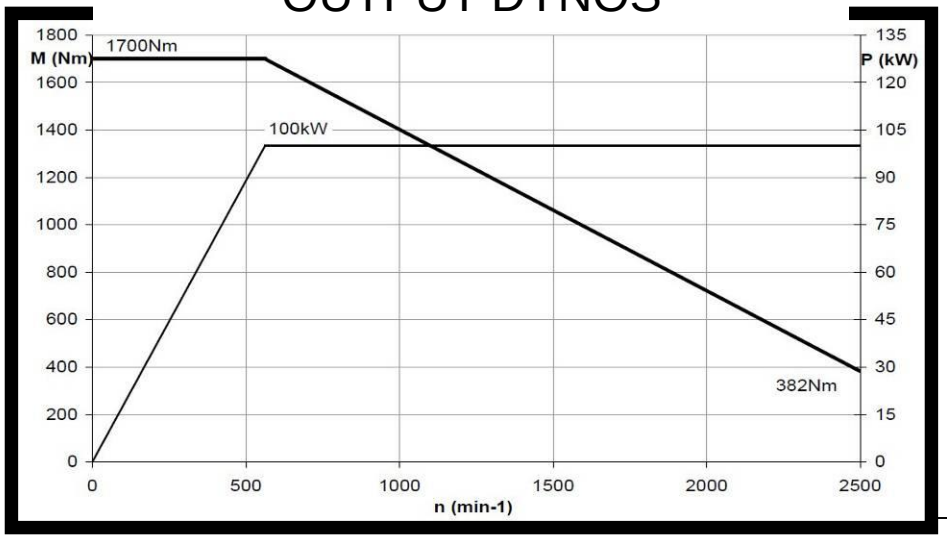


SHIFTING AUTOMAT and CLUTCH ACTIVATION

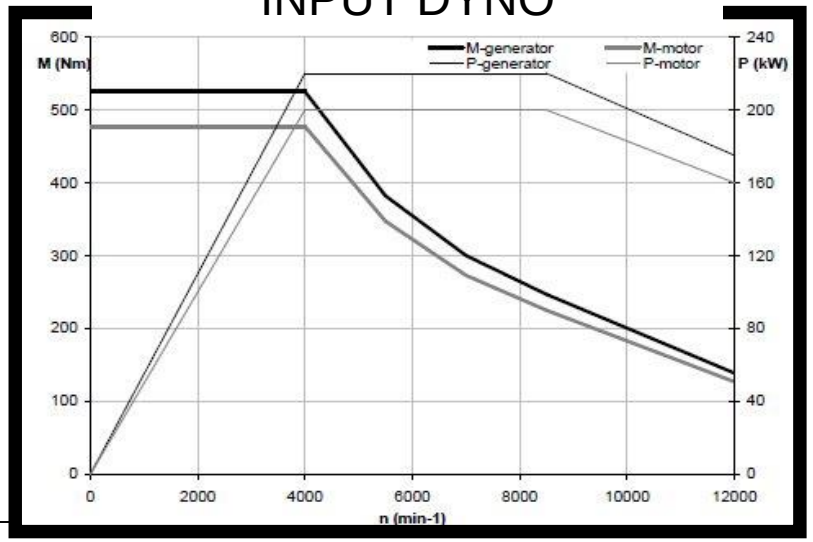




OUTPUT DYNOS



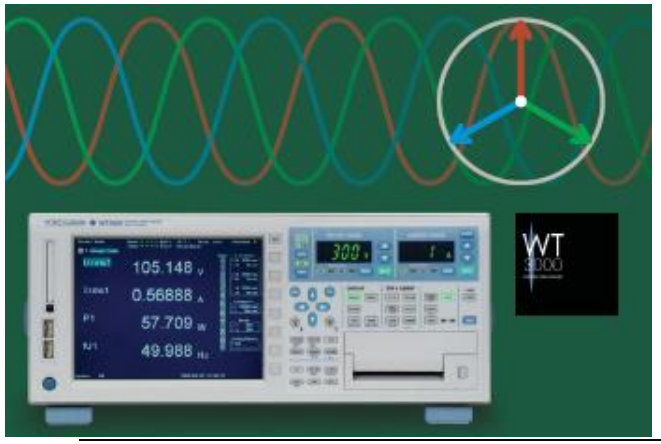
INPUT DYNO

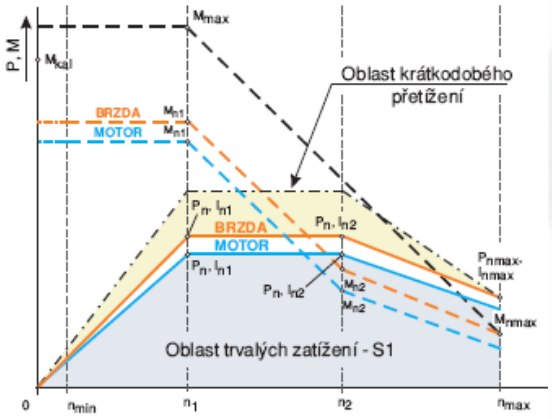


ELECTRIC DRIVES LABORATORY

Testing bench for electric cars powertrains characteristics measurement

- automated dynamometric testing bench for torque characteristics of electric machines measurement. Maximal revolutions 6000 rev./min
- automated data logging and plotting
- Testing of advanced electric energy storages for EV applications (chemical accumulator, super-capacitor, fuel cell)
- possibility of electric energy recuperation to the network
- working bench for high-revolutions electric machines (up to 80000 rev./min)





LABORATORY OF MICROELECTRONICS

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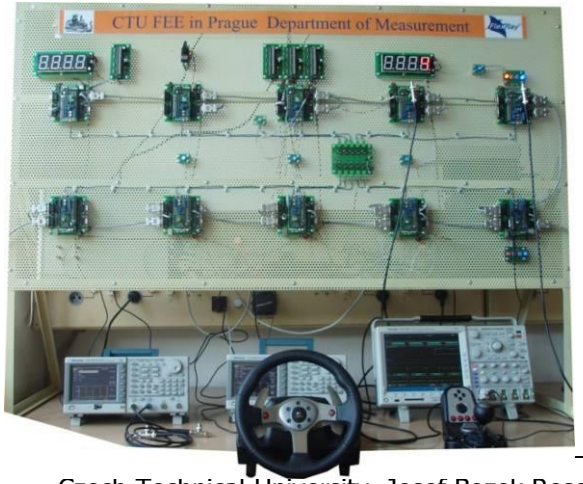
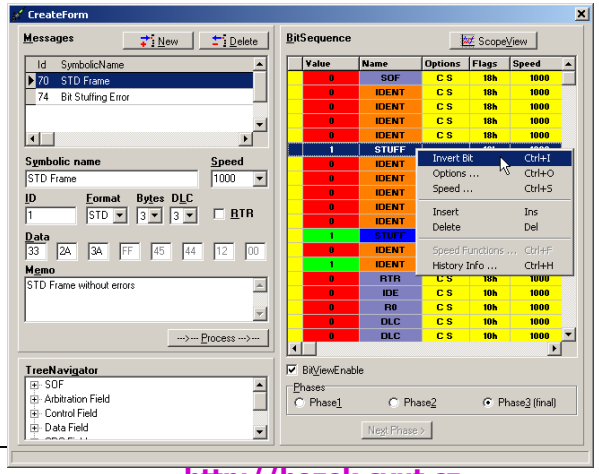
- R&D of test methods for vehicle distributed systems (CAN, LIN FlexRay based).
- EMC of distributed systems, fault-tolerant systems.
- X-by-Wire systems.
- Research and development of robust test methods, that:
  - are performed on precisely defined conditions,
  - provide repeatable results with known uncertainty,
  - minimally affect the test objects.





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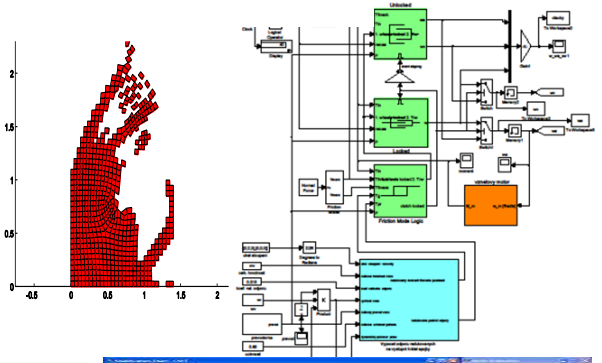
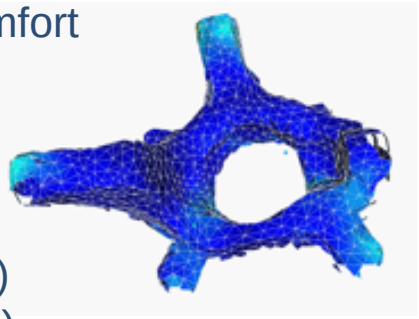
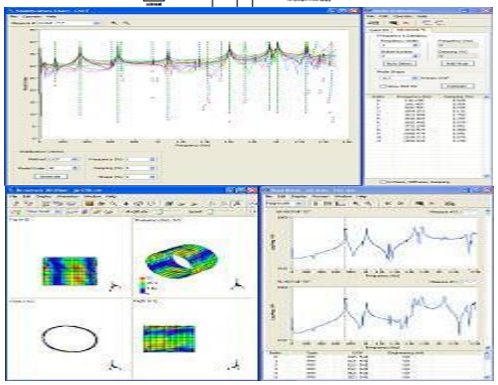
MECHATRONIC LABORATORY - OVERVIEW

- Vehicle Integrated Control Development (Controlled Suspension, ABS, ESP, synergy of all the systems)
- Combustion Engine Predictive Control
- Noise and vibration (NVH) problem solution based on
  - Solid powerful experimental equipment (EMA, ODS, OMA)
  - Theoretical experience and tools (FEM modelling, analyses, optimization (PENOPT), experiment-model correlation)
- Objective evaluation of the vehicle vibration comfort
- HIL and SIL experiments







Equipment

- RapidPrototyping platform:
  - General purpose (CompactRIO, PXI, dSpace)
  - Combustion engine (ETAS ECU and software)
- Software: LabView, ModalView, Matlab, Simulink, Ansys, PENOPT, …
- Electromechanic, hydraulic excitation, strain gauge technology, accelerometers, eddy currents sensors
- MIMO multichannel vibration analyzer
- Laser scanning vibrometer
- Acoustic camera – spatial acoustic field measurement

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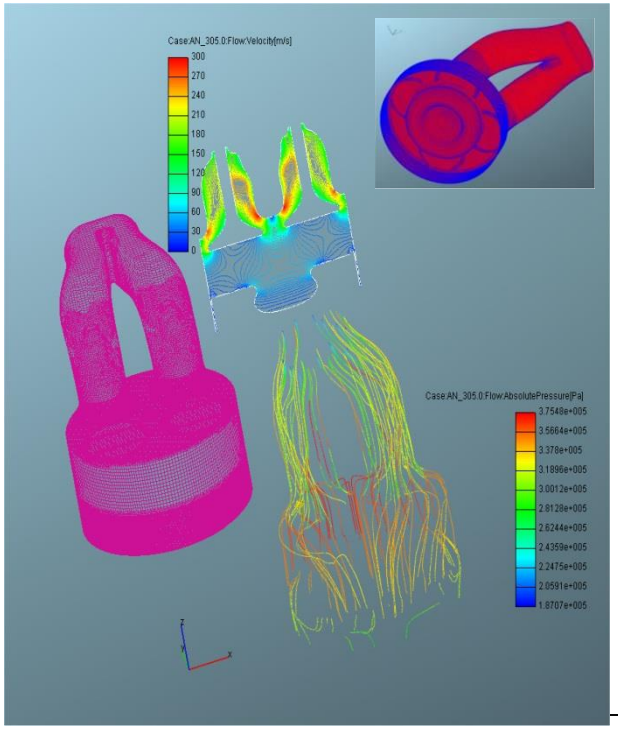
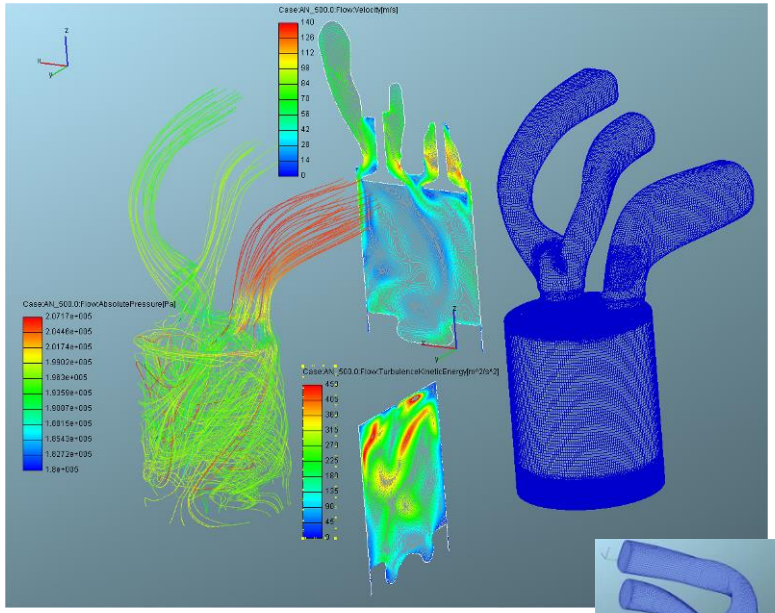
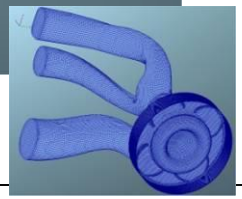
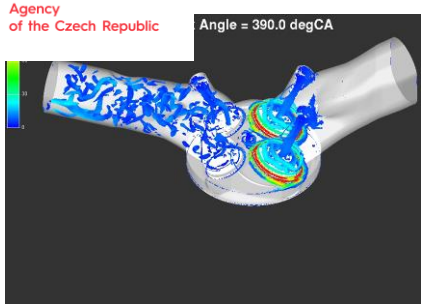
SIMULATION CENTRE

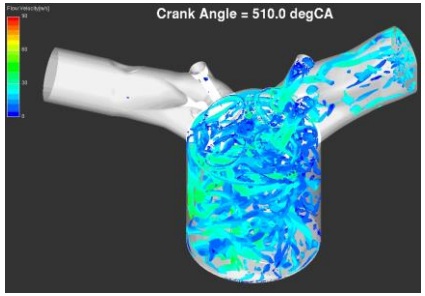
- 3-D CFD (AVL FIRE) – detailed modeling of in-cylinder thermodynamics including combustion and pollutant production
- 3-D FEM (ABAQUS) – detailed modeling of stresses caused by mechanical/thermal load
- vehicle-to-infrastructure interaction

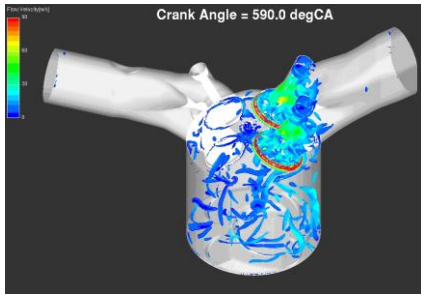




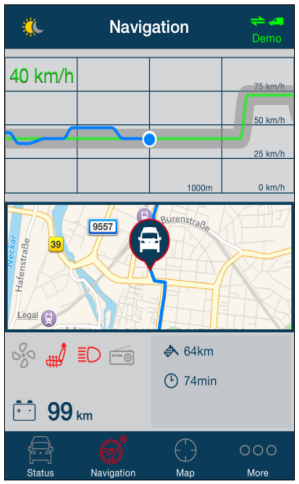




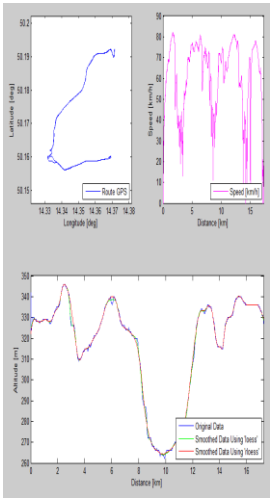




Optimization of Energy Management – EU FP7 IMPROVE Project



Route planning



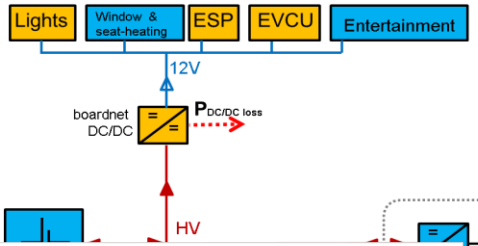
Route data preprocessing

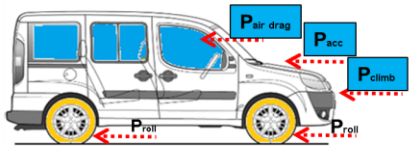
Prediction based on general parameters

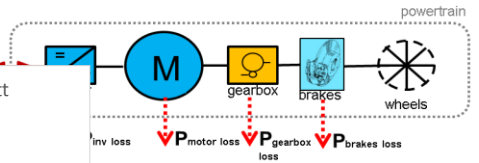
- route planning and description of driving resistance parameters (maximum velocity, recommended velocity, slope, charging possibilities, …)
- vehicle description – driving resistance parameters and accessory input parameters
- **data generalized from operation history**
  - route – influences of date and time, traffic and weather impacts, charging times
  - vehicle – battery SoH

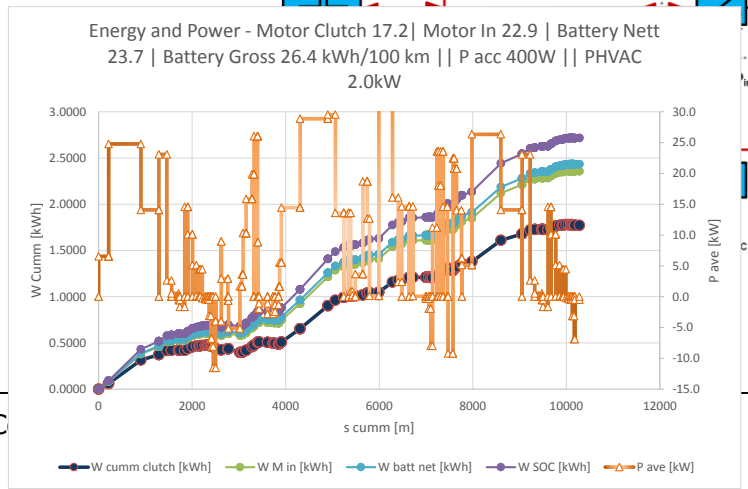
Adaptiveness based on up-dated route and vehicle parameters

- route – **traffic intensity (additional stop-and-go features)**
- vehicle – battery SoC, **current and predicted load**, **up-dated HVAC** demands and their **coverage**









Autonomous Driving Tested on Models since 2007

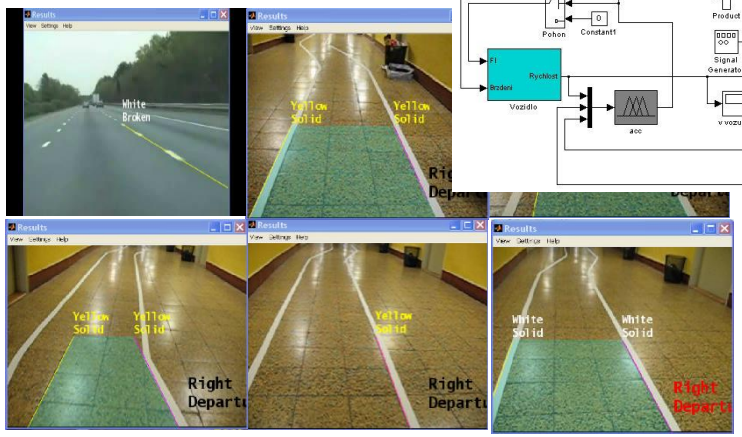
Prepared algorithms – vehicle to intelligent transport systém interaction

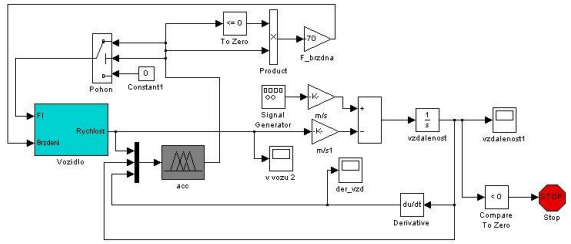
Functional revised scaled vehicle model of articulated vehicle capable to test the algorithms of vehicle control systems for lateral dynamics control (within limited margin) and to test the algorithms of superior transport systems, included the autonomous vehicle drive.

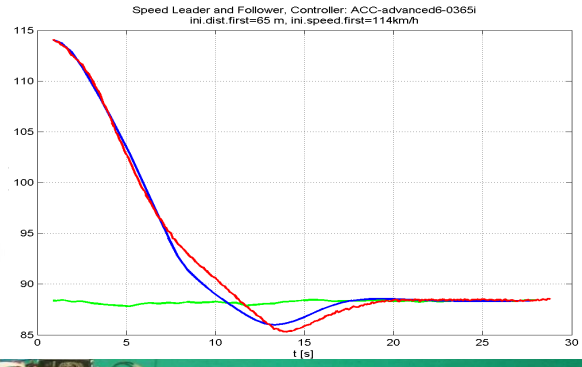
Model-based driving using vehicle dynamics models.

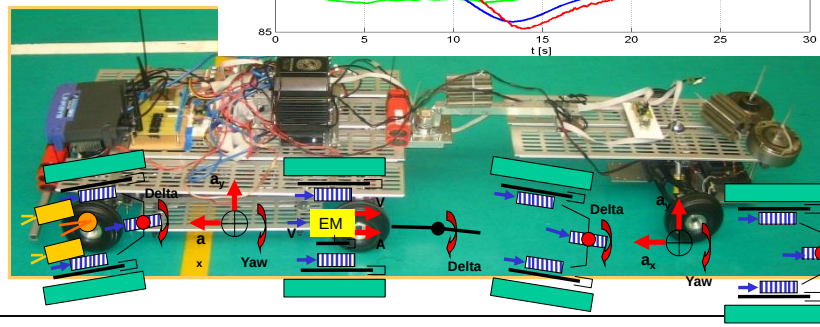
Lane keeping, adaptive cruise control, predictive control, etc.

FISITA Island of Excellence 2014









Integrated safety of vehicles and transport systems for future transport systems – Cooperation with TÜV SÜD CZECH

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Main outputs 2012-2014

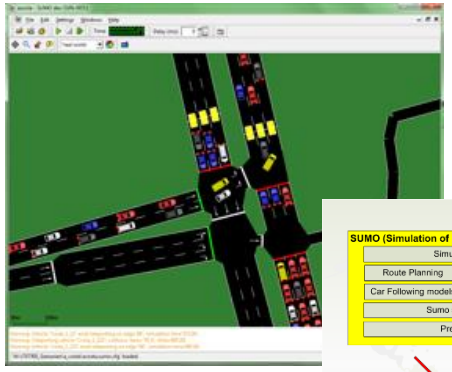
ADAS:

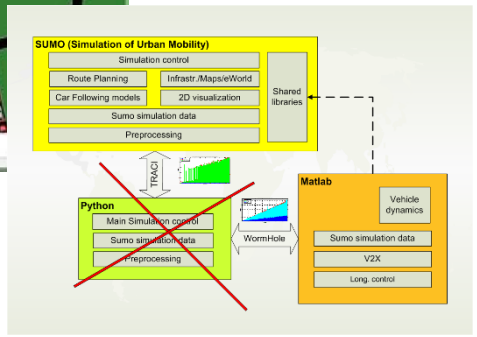
- draft test method of ACC systems designed
- 2 test campaigns of vehicles with ADAS
- whole vehicle soft target realized
- long-term monitoring of ADAS system in service started

- technology for ROP testing realized
- 2 test campaigns, various ROP set-ups

v2x communication, traffic stream simulation:

- recherche of available SW tools, SW tool based on SUMO and Matlab developed
- analysis of influence of ACC-equipped vehicle penetration on track capacity and emissions
- driver simulation model and ACC simulation models realized





Integrated safety of vehicles and transport systems for future transport systems

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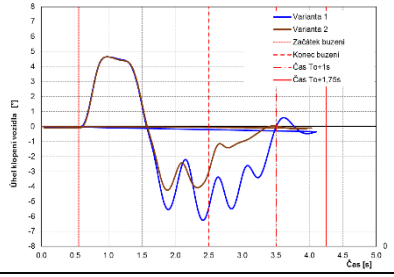
Main outputs 2014

ADAS:

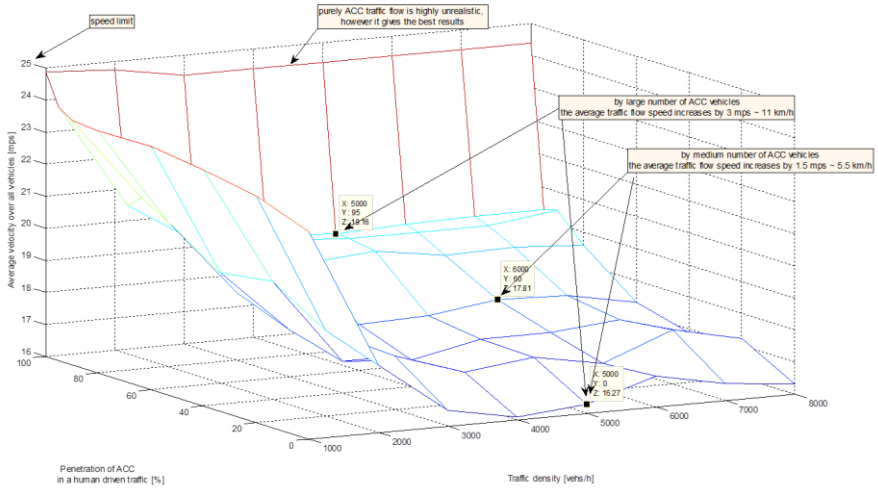
- 2013 tests evaluation
- long-term monitoring of ADAS system in service started
- development of the measurement system based on NI CompactRIO in progress

- 2nd test campaign – various ROP set-ups
- data analyzed, key points of further test method set



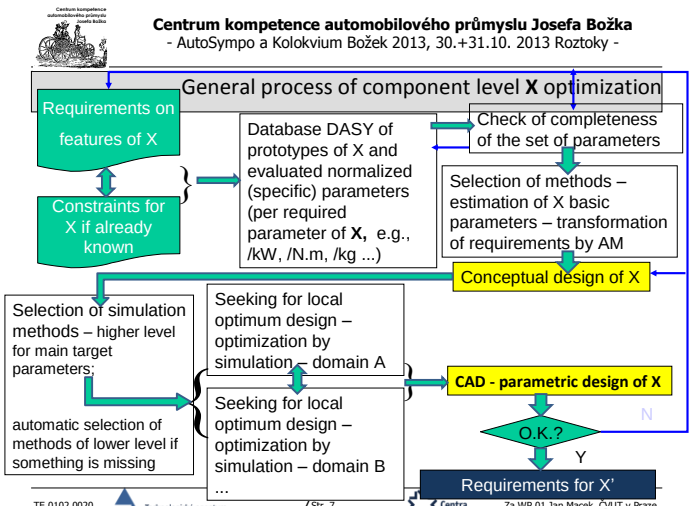
v2x communication, traffic stream simulation :

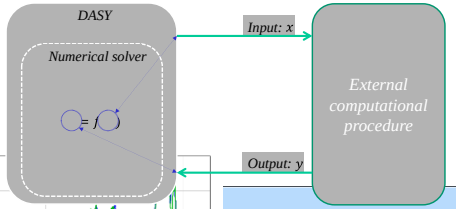
- analysis of influence of ACC-equipped vehicle penetration on track capacity and emissions
- driver simulation model and ACC simulation models realized

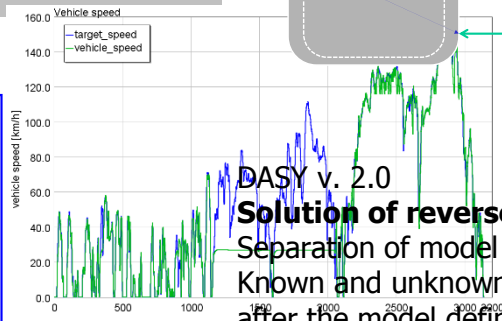


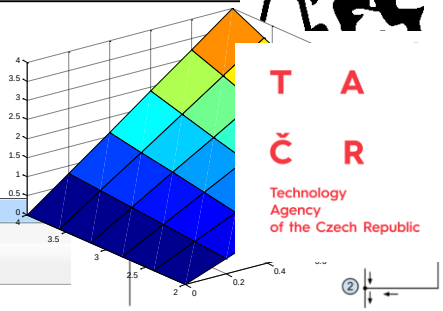
- possibilities of Jízda-SUMO interface analyzed

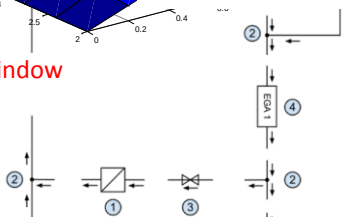
Examples of Results: Design Assistance SYstem – DASY – Holistic View



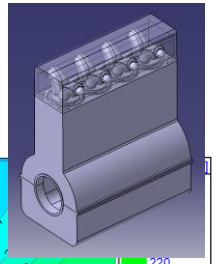


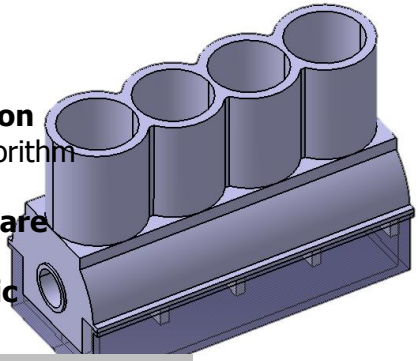


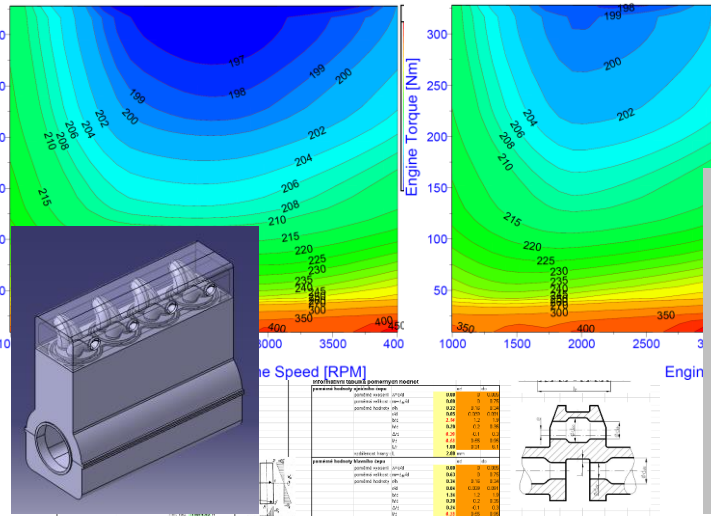


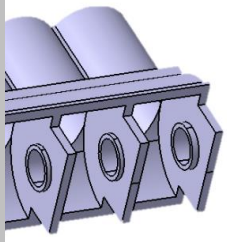


DASY v. 2.0
Solution of reverse (or any other) task.
Separation of model and task definition.
Known and unknown parameters are defined after the model definition. Link to external procedures.
Gauss-Newton algorithm and response surfaces.
Advanced **multi-objective optimization algorithm** based on SPEA2 genetic algorithm with support of constraints.
Interaction with any existing software packages - data to/from files.
Interaction simulation ⇒ parametric CAD with optimized changes.









DASY links components, parameters and methods: simulation (input from CAD), CAD (input of results from simulation) and experiments (calibration inputs for simulation).

It enables the holistic approach to powertrain optimization starting at early stage of design by combining previous experience condensed to empirical algebraic relations with virtual engine models.

Examples of Results: Design of Cost-effective Engines for Developing Markets and Range Extenders

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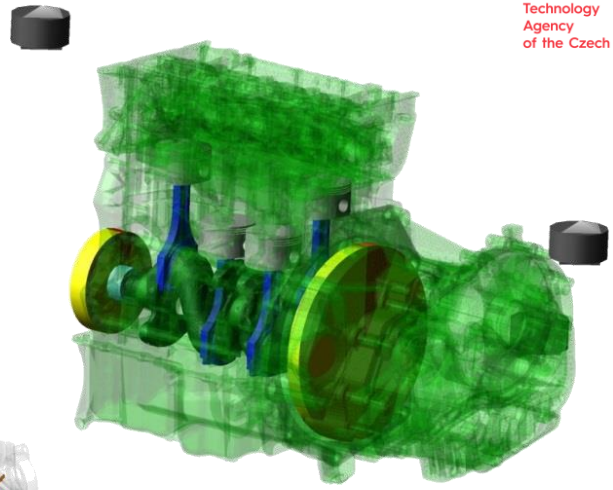
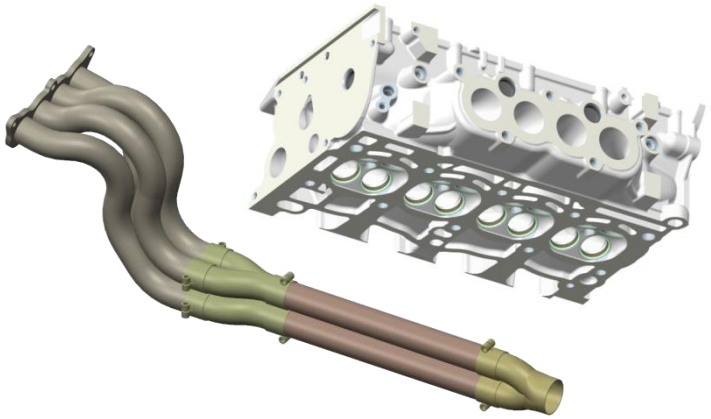
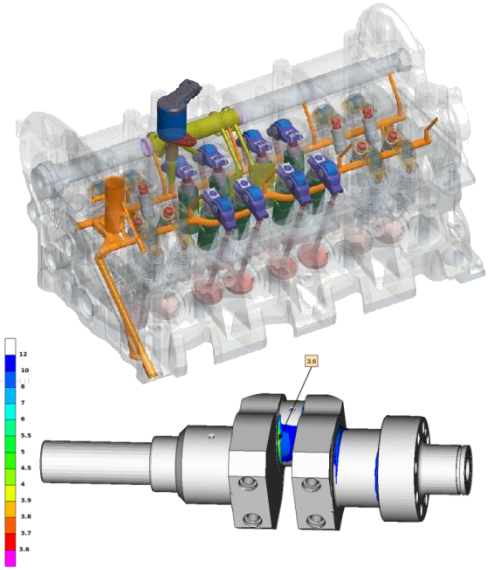
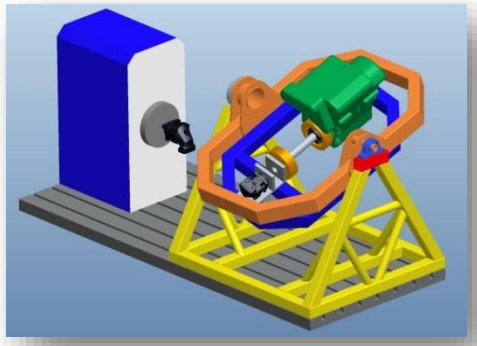
Current Main Results 2014

- Complex computational model of a low-friction-losses-engine – virtual engine (BUT)
- Complex solution of inside engine aerodynamics (Škoda Auto, a.s.)
- Commissioning and modifications of Single Cylinder Research Engine (ČVUT Prague)
- Design of two axis engine tilting test stand (ČVUT Prague)









Josef Božek Centre Overview – Current Goals, Topics and Tools

Active since 2013

Turnover 2 500 k€, 15% education, 15 % industrial contracts

Equipment is important but competent and motivated team is decisive for good results

- 50 FTE researchers (65 persons)
- combination of experienced senior researchers with young postdocs and PhD. students (average age of researchers 40 years)
- selection of future researchers based on projects during master studies
- international experience based on Europen projects and contractual research worldwide
- collaboration with Czech branches of research companies is based on direct research contracts and sharing of **students education in projects** (3 half-year projects at Master level + diploma thesis) and **during PhD education**.

Innovative educational activities of CTU FMEch Automotive FORMULA STUDENT/SAE TEAM at CTU in PRAGUE

Engagement of the students since 2008; 2011 - 2014 gasoline (3 races per year, currently 20th position in global 450 teams' competition) and electric cars

Design

Rám

Josef Božek Research Centre Overview – Industry-based Activities

Current or past contract-based collaboration with VW, Škoda Auto, Daimler, Renault, Ford Motor Company, John Deere, Ricardo, **Gamma Tech. Inc. (official partner for GT Suite/GT Power)**, Michigan Technological University, University of Michigan etc.

Member of EARPA (European Automotive Research Partners Association).

Activities at SAE - SAE Int. - Czech branch established 2006.

Collaboration with AVL List Graz, IFPEN Paris, FEV Aachen, **TÜV-Süd Czech, Ricardo Prague, mbTech Bohemia, Porsche Engineering Services Praha**.

You can be the next partner to this list (if you wish).

Thank you for your interest

…we are looking forward to our future cooperation

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