Stator Insulation Aging and Design for Reliability

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William Chen

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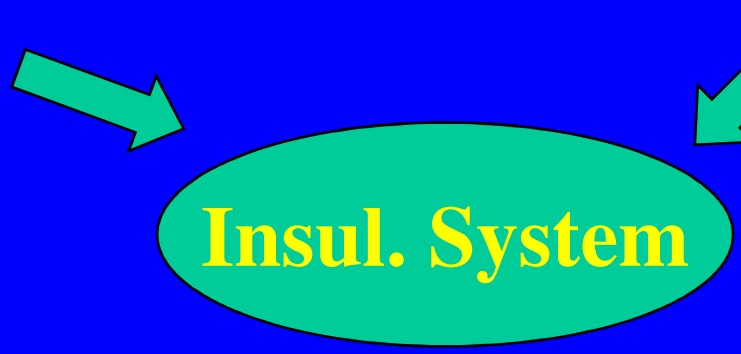
Insulation Stresses and Machine Service Life

- Mechanical

Cracking
Tension
Vibration

- Electrical

PD
Overvoltage
Tracking



- Thermal

Oxidation
Hydrolysis

- Chemical

Gas, Acids
Radiation

not easy to predict
not easy to test

Service Proof Methods

Motor Efficiency & Service Life
vs.
Insulation Design

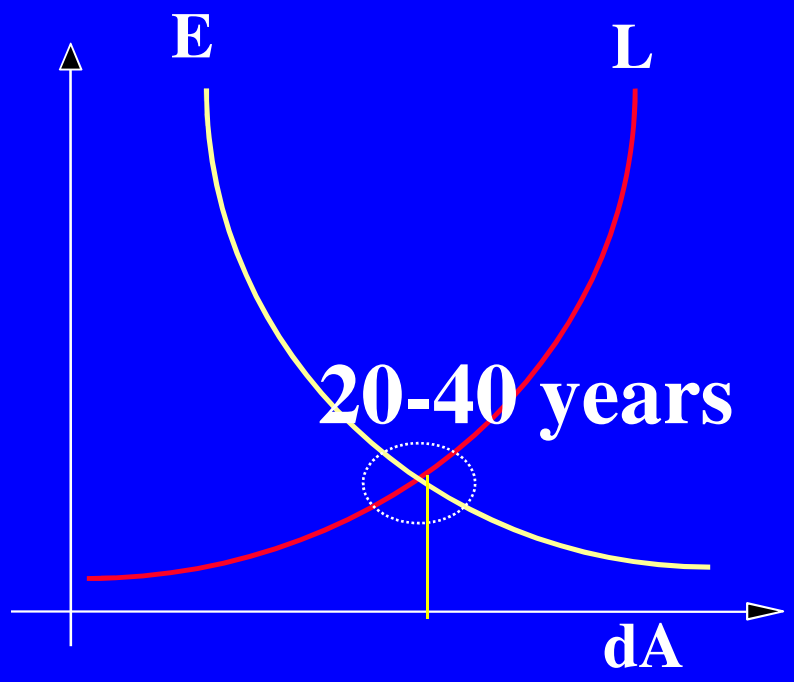
- **Design Quality**

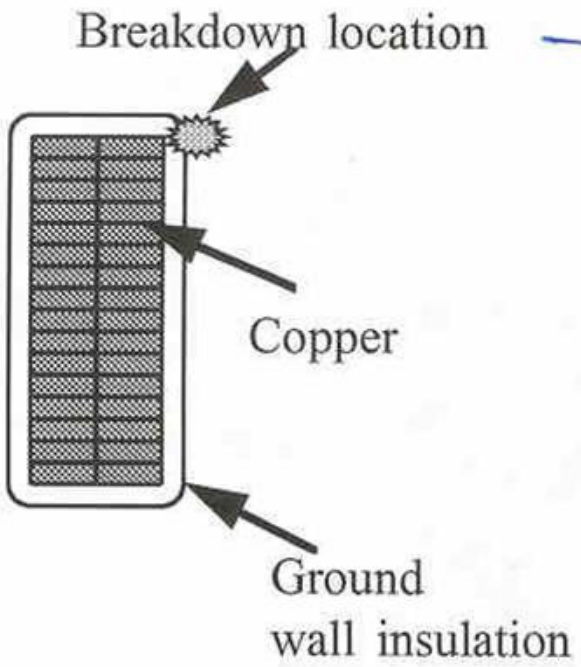
$$Q = \frac{Ac}{As}$$

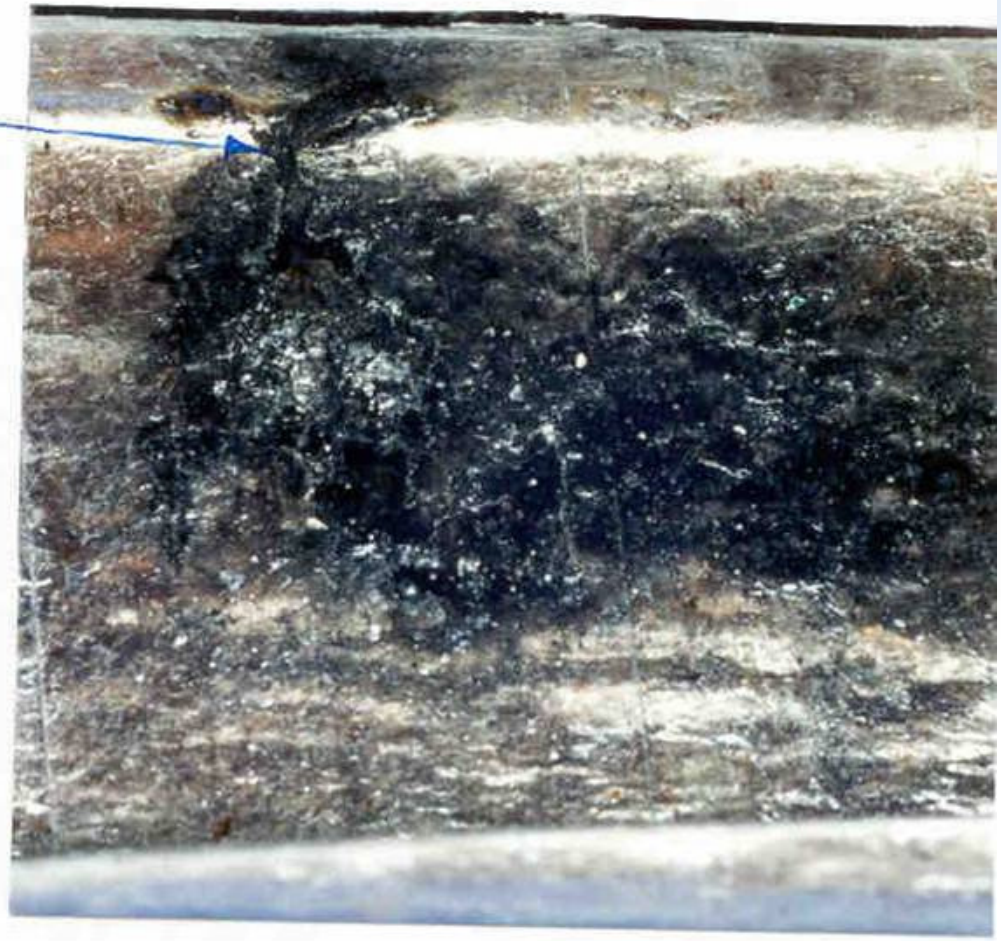
A_c: total copper cross section

A_s: total slot cross section

$dA = A_s - A_c$ Insulation filling







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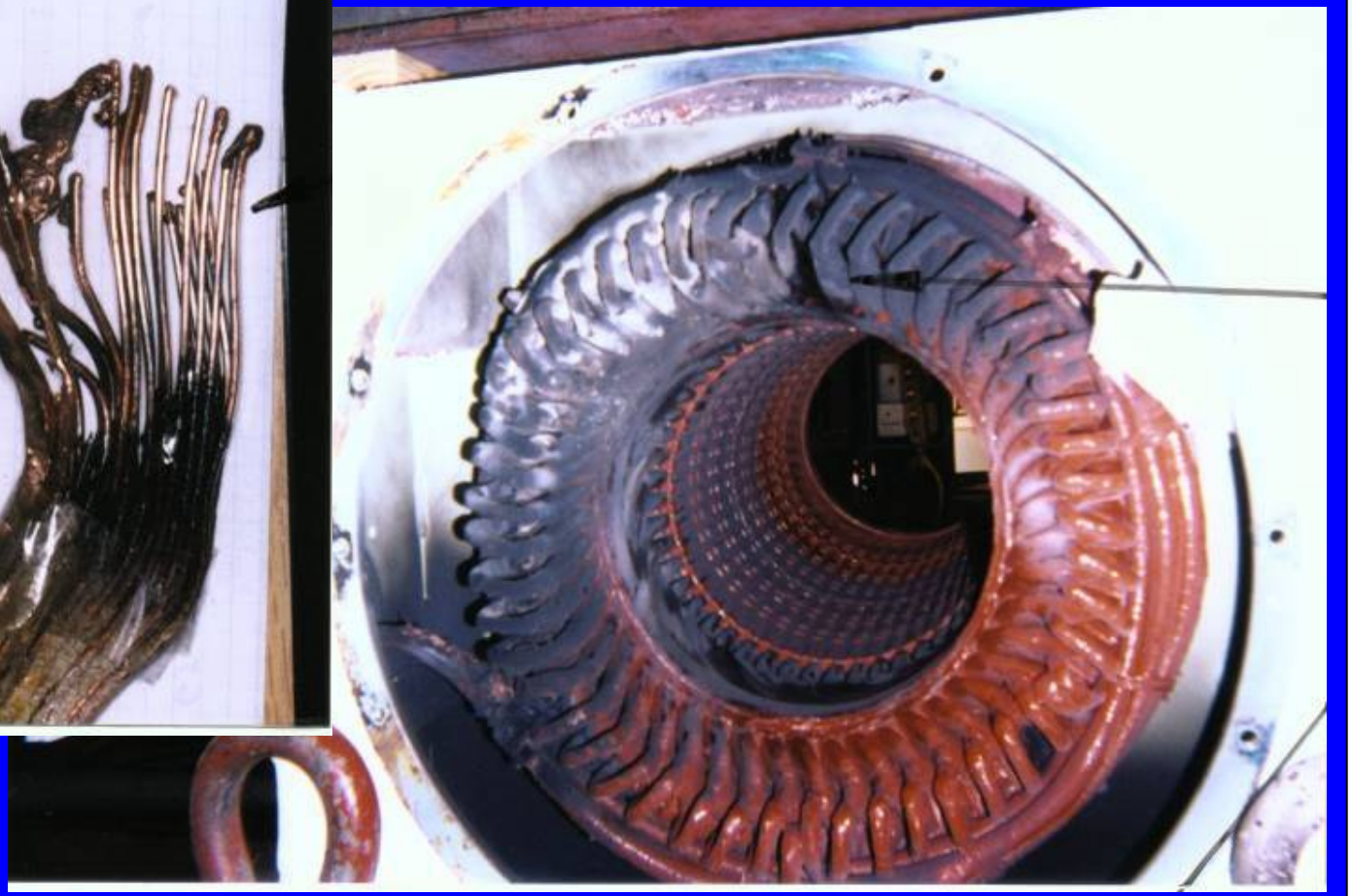
Turn To Turn Failure



Poor Design

Surface PD damages due to poor stress grading system

Design/Manufacture for Reliability to Minimize the Winding Aging Processes

- Electrical
- Thermal
- Mechanical (Vibration, Movement)
- Environment (Contamination: oil, dirt, water, chemical, salt, radiation….)
- Manufacturing Process Issues
- VFD operation

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Basic Insulation Components in Large Form Wound Motor Stator Windings

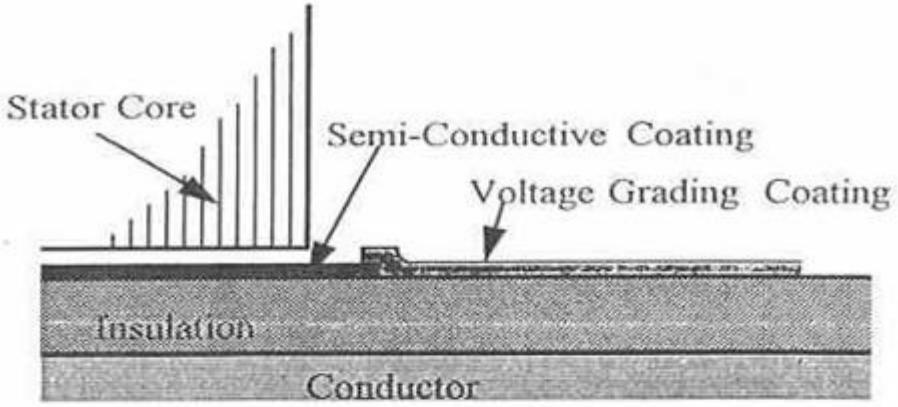
COIL INSULATION

Strand/Turn Insulation

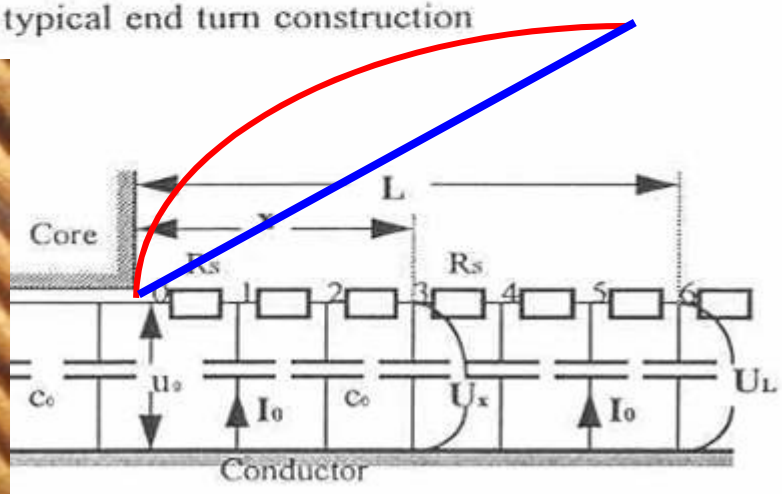
Dedicated Turn Insulation

- **Strand Insulation**
  Daglass, Enamel, Kapton, Mica tape
- **Turn Insulation**
  Mica tape, or same as strand insulation
- **Ground Wall Insul.**
  Mica tape
- **Stress Grading System**
  Conducting coating; Semi-conducting coating

High Voltage Coil Voltage Stress Grading System



a) typical end turn construction



equivalent circuit of typical end turn

Function

To smooth the voltage distribution along the coil endturn (from HV to GND)

Design Considerations

- Non-Linear V-I characters for grading coating
- Compatible between conducting/grading layers;
- Proper design of the length and overlapping between two layers;
- Solid electrical contacts between two layers
- Mechanical fatigue stress

Insulation Materials Systems

Vacuum Pressure Impregnation (VPI)

- Mica tapes with low binder resin content (6-10%)
- Solventless VPI resin (Epoxy or Polyester)

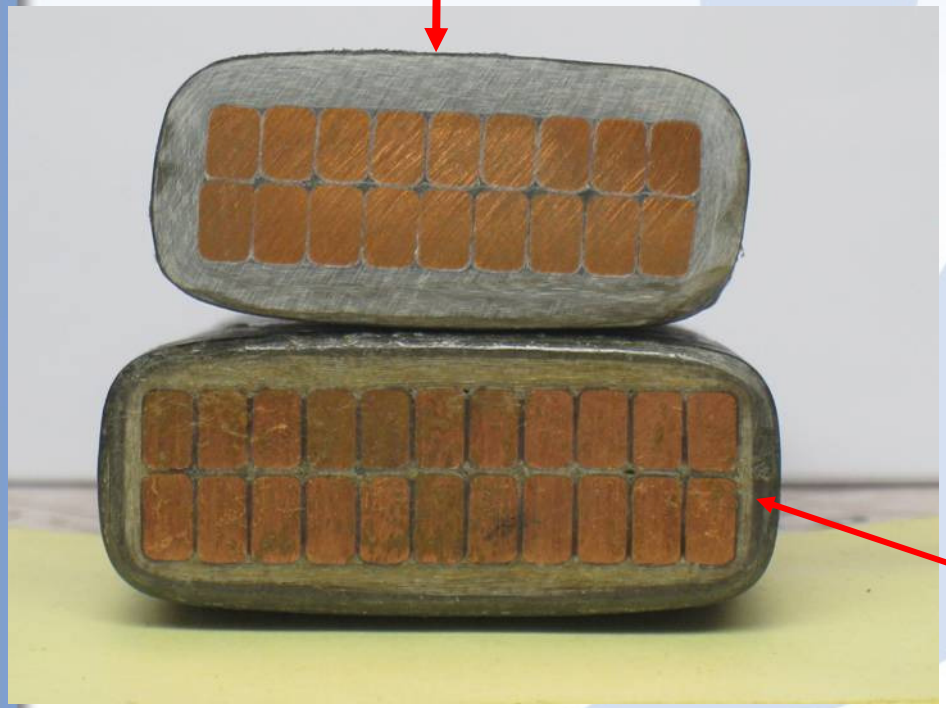
Resin-Rich RR

- Mica tapes with high binder resin content (37 -45%)

TABLE 2: Advantages and disadvantages of RR and VPI coil manufacturing techniques

	RR	VPI
advantages	• high dielectric strength (= absence of voids in the pressed slot part) • control of the flexibility in the end-turn region • complete electrical testing of the coils is possible before assembling them • low capital investment • easy to service (easily removable) • negligible expenditure for resin control measurements, etc.	• sealing of the complete stator, good thermal and electrical coupling between the coil and the core • with large numbers: lower costs as compared to RR-t to RR-w • short overhang possible with high rated voltage ➢ smaller frame sizes
disadvantages	• increased number of process steps • with RR-W: discontinuous insulation - lower surge voltage strength - longer overhang at higher voltages ➢ larger frame sizes - no automation • with RR-t: - high cost compared to VPI for large numbers	• removal of coils after impregnation is difficult • high capital investment • final electrical testing of the individual coils is not possible before assembling and impregnating them • sophisticated laboratory tests (resin quality control)

Good VPI'ed Coil



Poor VPI'ed Coil

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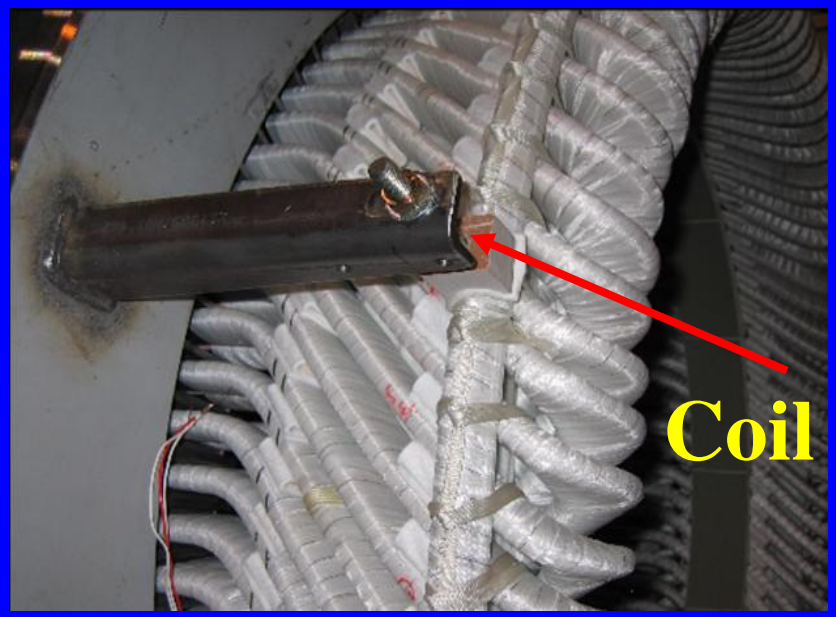
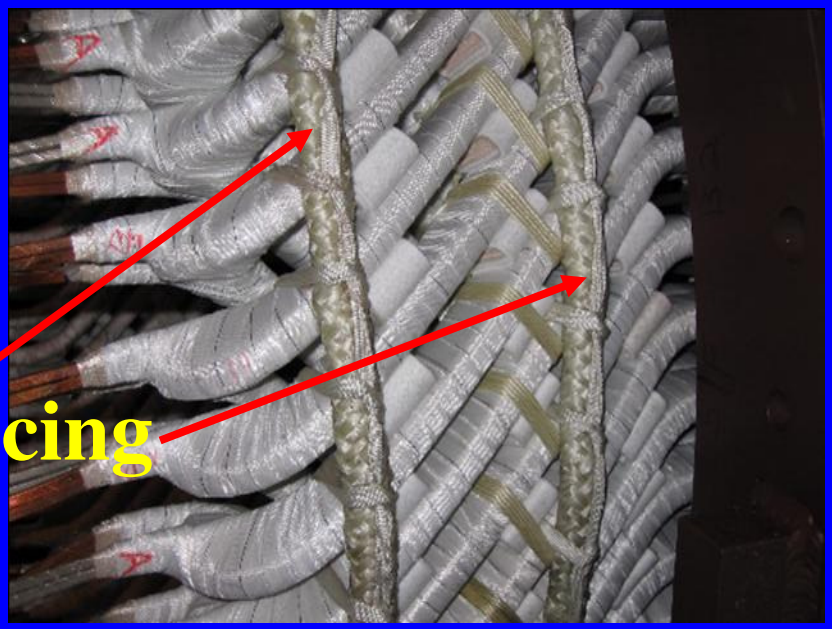
Basic Insulation Components in Large Form Wound Motor Stator Windings

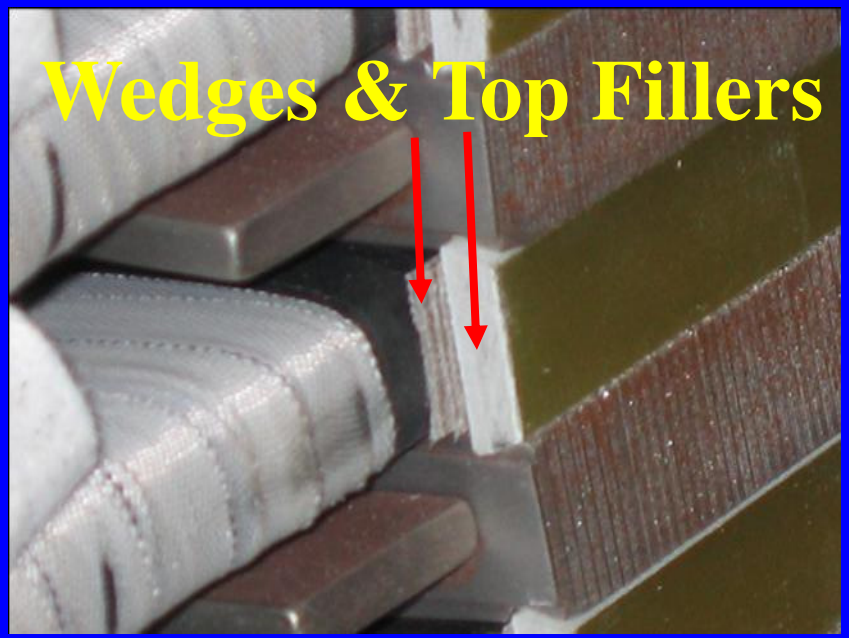
WINDING INSULATION

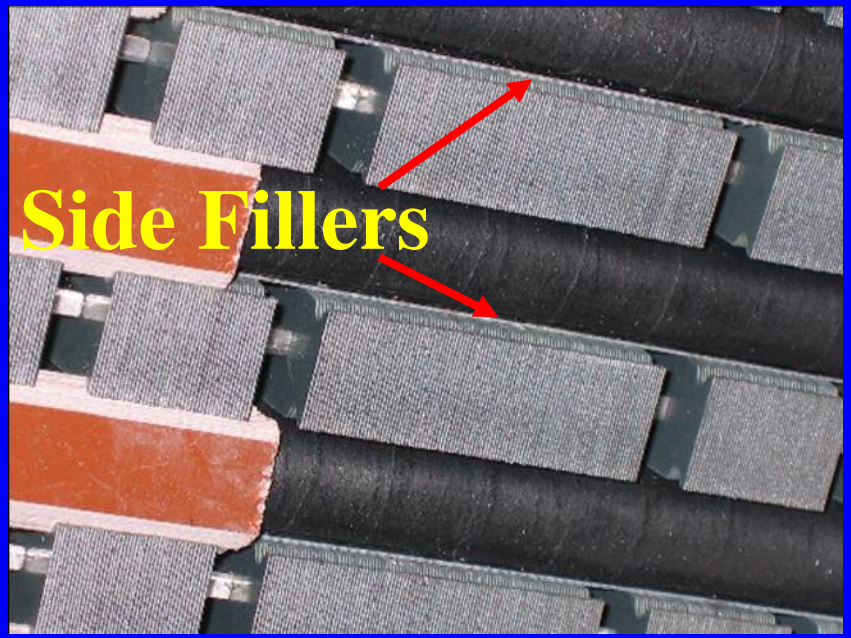
- Coil lead joints insulation
  Mica Tape
- Main lead (cable) insulation
  Silicon Rubber
- Leads & cable spacers
  Felt & Micarta



Coil Bracing







Design Limits of Winding Insulation Allowance

- Strand Insulation: Withstand 120 V AC test voltage;
- Turn Insulation: Based on actual winding electrical design and operating voltage stress at Surge Voltage Condition: NEMA std./IEEE std. 522:
  - Typical: 2 p.u.
  - Severe: 3.5 p.u.
- Ground Wall Insulation:
  - Typical: 50 – 70 Volts/Mil (single side)
  - Some designs: 100 Volts/Mil

Mfg Process and Material Dependent

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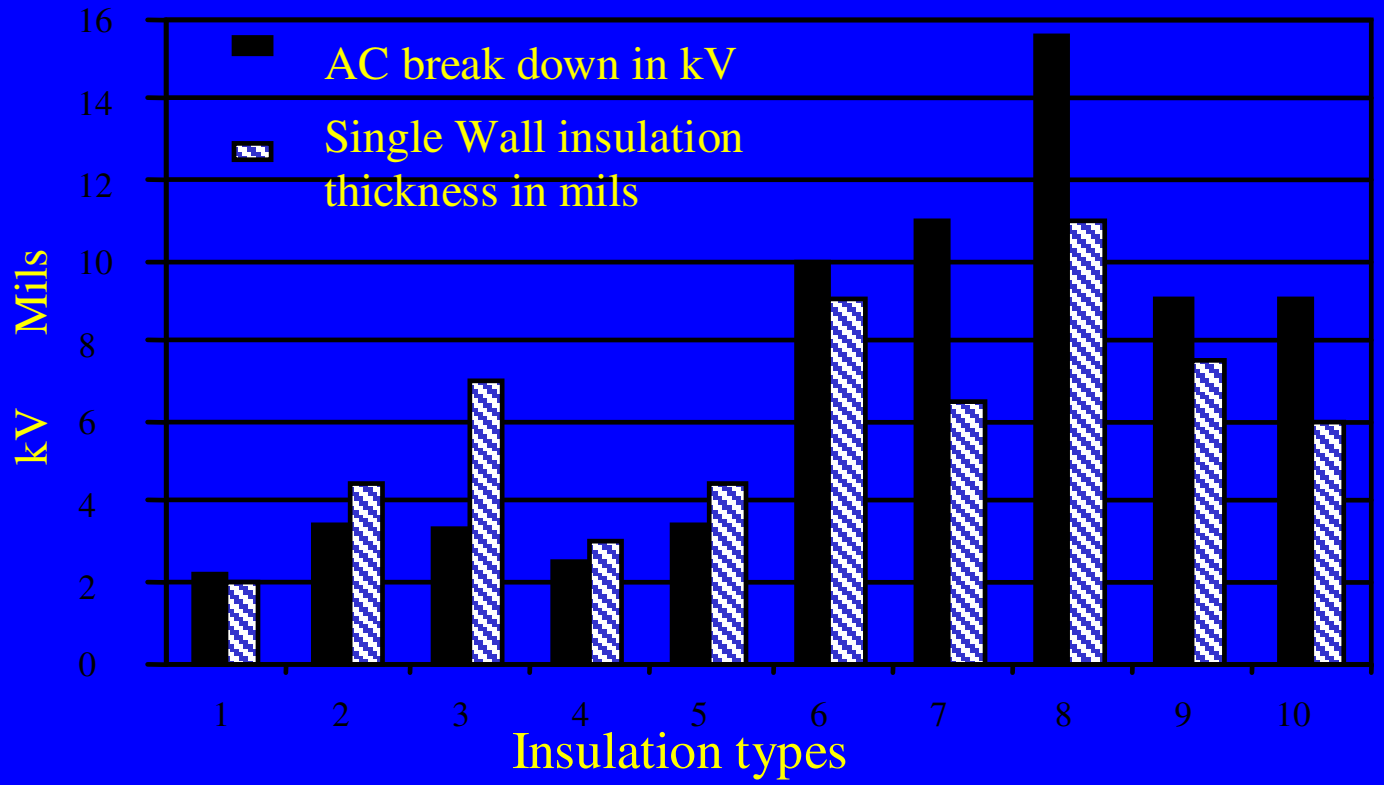
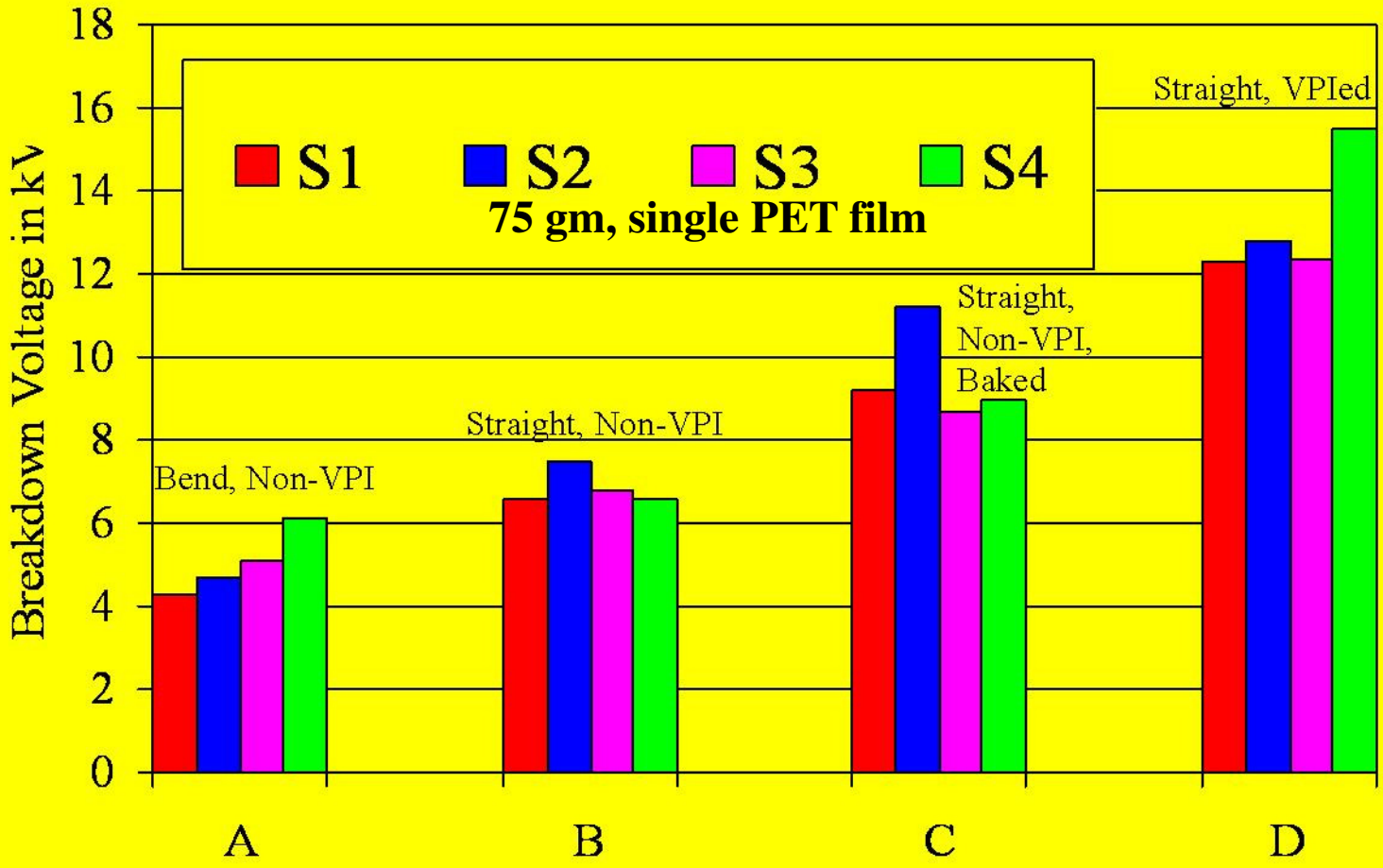


AC breakdown strength in kV and single wall insulation thickness in mils for different turn insulation systems

1. **Heavy film enamel**
2. **SDG & heavy film enamel**
3. **DDG & heavy film enamel**
4. **Single layer half lapped Kapton**
5. **Single layer half lapped mica tape**
6. **Double layer of edge lapped mica tape**
7. **Single layer edge lapped mica tape over heavy film enamel**
8. **Double layer edge lapped mica tape over heavy film enamel**
9. **Single layer half lapped mica tape over single layer half lapped Kapton**
10. **Double layer half lapped Kapton**



Comparison of AC breakdown voltage of mica taped wires tested at various conditions (4 suppliers)

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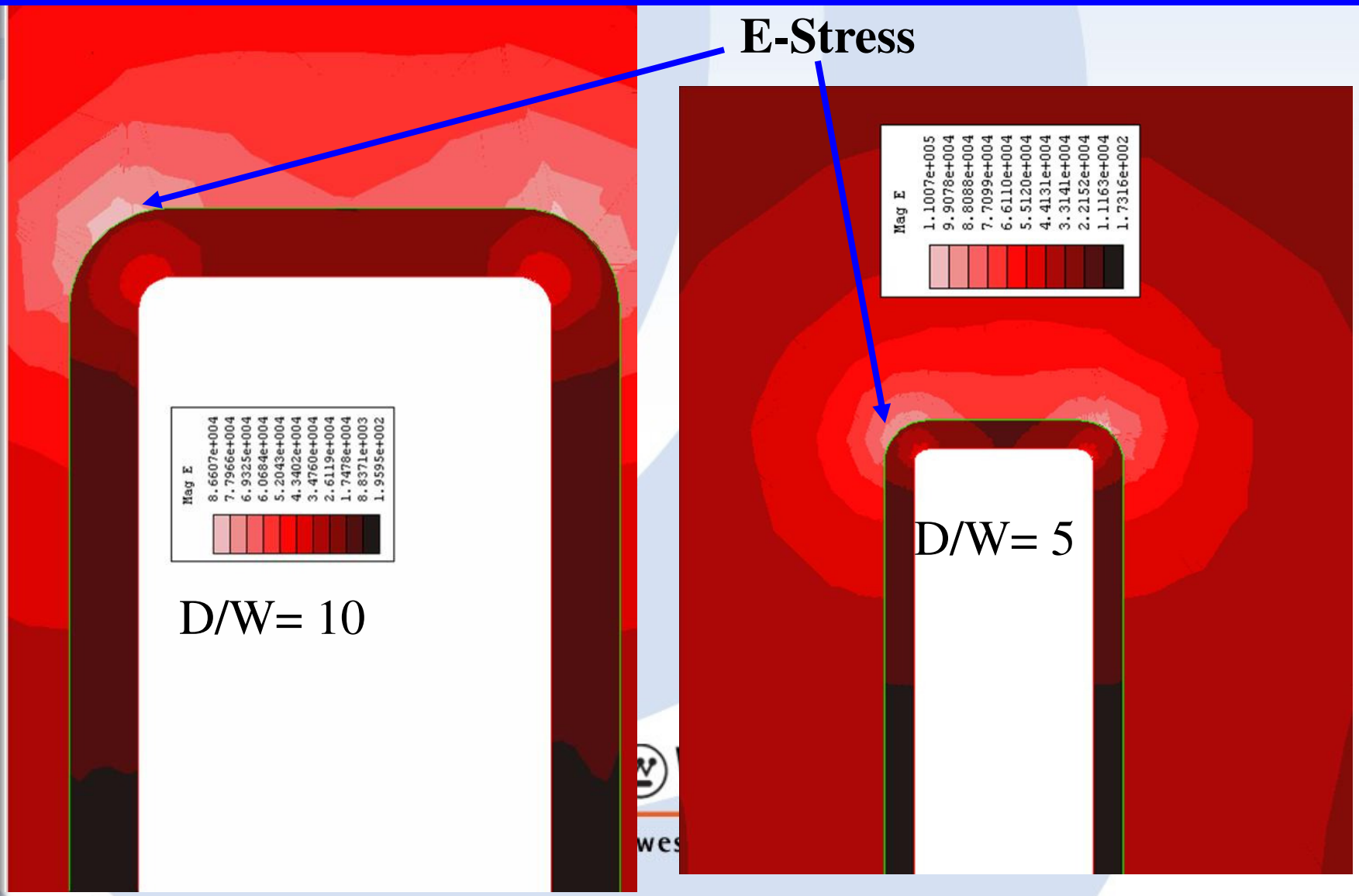
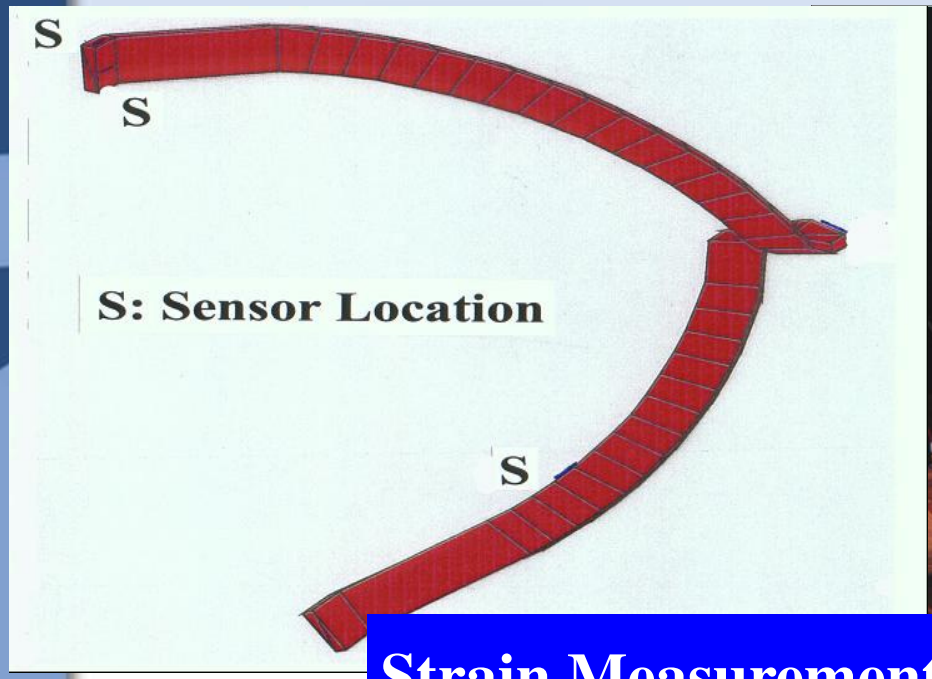
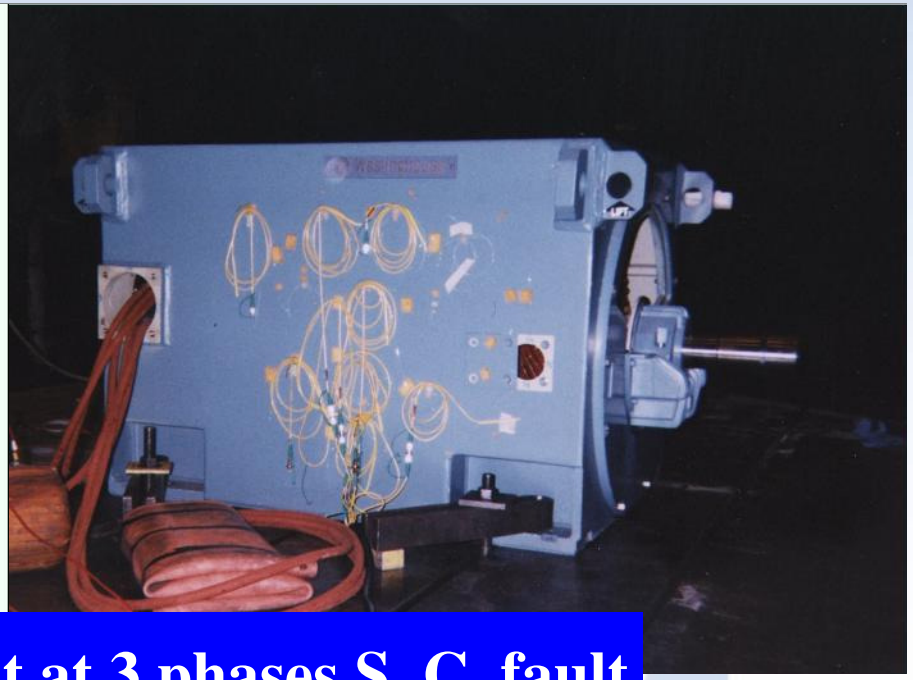
Effect of Coil Shape Design (Aspect Ratio) on the Insulation Stress



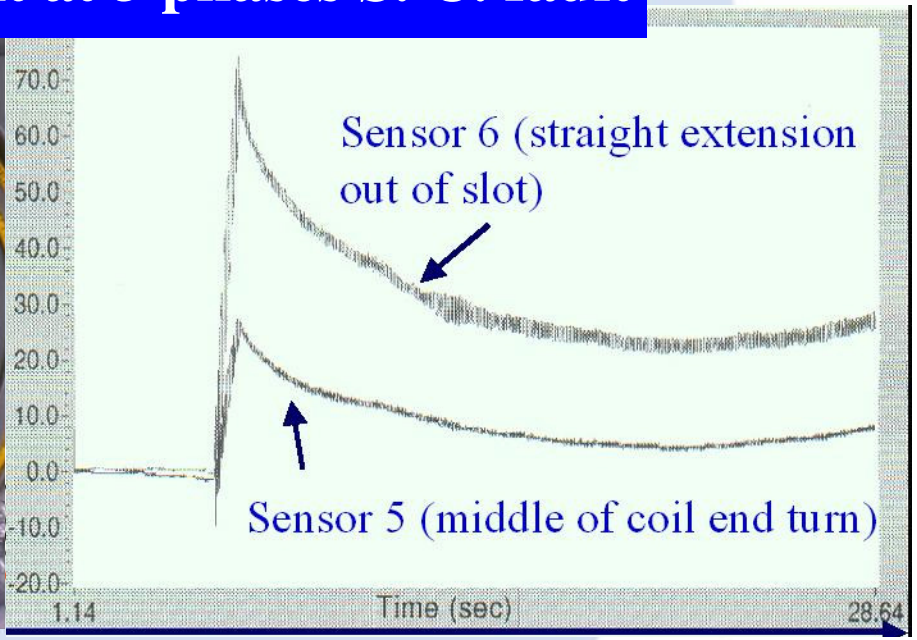
Various Insulation Qualification Tests

- IEEE 275 & 429 (new 1776) for thermal classification.
- IEEE 1043 & 1553 for high voltage (> 4 kV) endurance.
- IEEE 1310 for thermal cycling.
- IEEE 1434 for PD (partial discharge).
- Thermal and voltage endurance.
- Darkness test for stress grading materials.
- Water immersion test for moisture resistance.
- IEEE 286 for power factors tip-up test.
- IEC 60034-18-41,42 for inverter drive application.
- Other IEC standards.

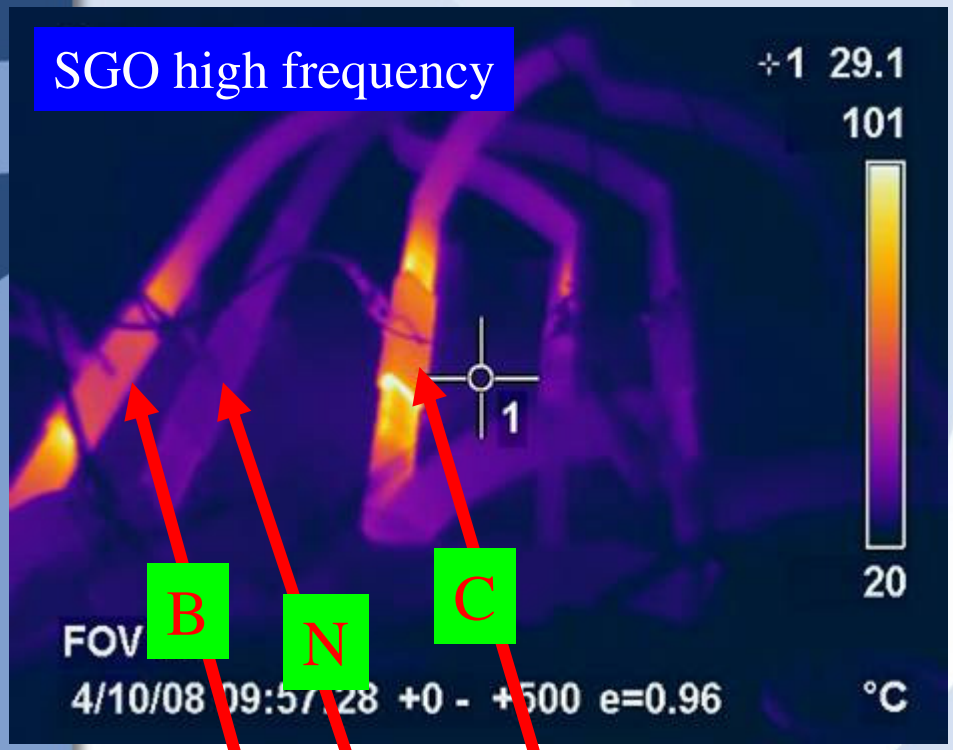




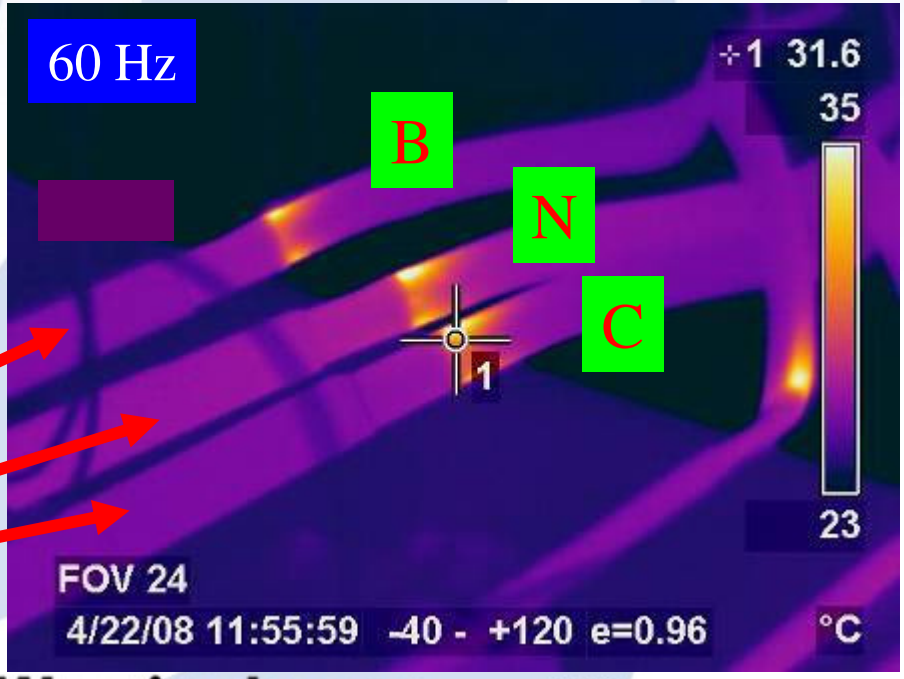
Strain Measurement at 3 phases S. C. fault



Thermography of Stress Control System Evaluation



Same Peak voltage = 20.1 kV



Grounding plates

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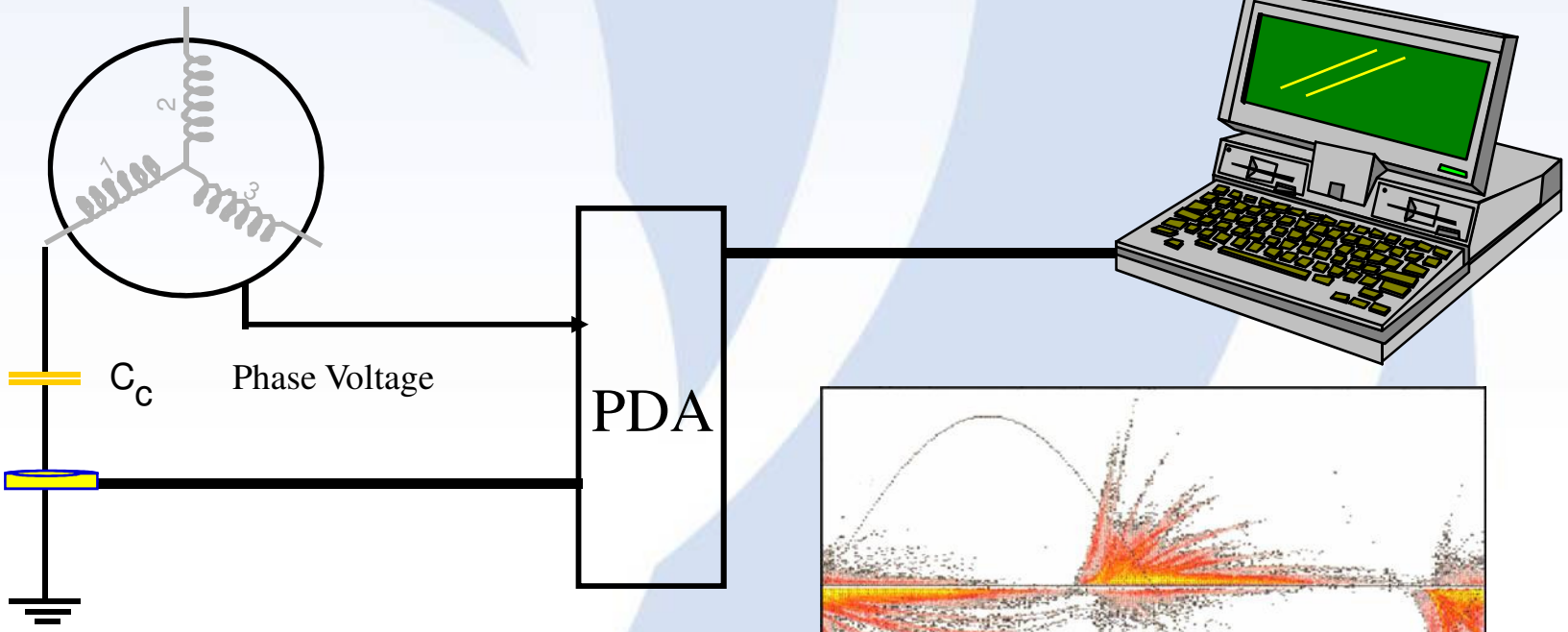
Partial Discharge Analysis

6 kV and above machines



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Conclusion

Advanced Materials/Designs and Manufacturing Technologies

Help

to Improve the Stator Winding Insulation Quality and Service Life

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Questions?

Comments?

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