Stator Insulation Aging and Design for Reliability

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Insulation Stresses and Machine Service Life

- Mechanical
  Cracking
  Tension
  Vibration

- Thermal
  Oxidation
  Hydrolysis

- Electrical
  PD
  Overvoltage
  Tracking

- Chemical
  Gas, Acids
  Radiation

not easy to predict
not easy to test

Service Proof Methods
Motor Efficiency & Service Life

vs.

Insulation Design

- Design Quality

\[ Q = \frac{A_c}{A_s} \]

\( A_c \): total copper cross section
\( A_s \): total slot cross section
\( dA = A_s - A_c \) Insulation filling

20-40 years
Higher corner E-Stress will cause lower PD Inception Voltage or earlier E-Failure.

Breakdown location

Copper

Ground wall insulation
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
Basic Insulation Components in Large Form
Wound Motor Stator Windings

**COIL 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

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

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

Good 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

Wedges & Top Fillers

Side Fillers
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
AC breakdown strength in kV and single wall insulation thickness in mils for different turn insulation systems.
Comparison of AC breakdown voltage of mica taped wires tested at various conditions (4 suppliers)
Effect of Coil Shape Design (Aspect Ratio) on the Insulation Stress

D/W = 5

D/W = 10
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

Sensor 6 (straight extension out of slot)

Sensor 5 (middle of coil end turn)
Thermography of Stress Control System Evaluation

Same Peak voltage = 20.1 kV

Grounding plates

SGO high frequency
Partial Discharge Analysis

6 kV and above machines

Phase Voltage

PDA

Phase-Resolved PD Analysis

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Conclusion

Advanced Materials/Designs and Manufacturing Technologies Help to Improve the Stator Winding Insulation Quality and Service Life