FIBRE REINFORCED PLASTICS IN HIGH VOLTAGE APPLICATIONS

Volker Bergmann, Reinhausen Power Composites GmbH
OVERVIEW

1. Introduction
2. Hollow core composite insulators and their application
3. Dielectric and mechanic requirements
4. FRP material solution
5. Product testing: design, sample and routine tests
INTRODUCTION

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- Technology & Development, Electrical Applications
- Reinhausen Power Composites GmbH, Regensburg

Curriculum Vitae

- Study of Electrical Engineering, TU Berlin
- Research Scientist, High Voltage Engineering, TU Berlin
- R&D Engineer, HV Circuit Breaker, Siemens AG, Berlin
- Area Sales Manager Asia, Reinhausen Power Composites GmbH, Regensburg

Committees

- Member of DKE/K 451: Isolatoren
- Member of IEC TC 112: Evaluation and qualification of electrical insulating materials and systems, WG 3: Electrical Strength
- Guest in IEC TC 36, DKE/K 183
HOLLOW CORE COMPOSITE INSULATORS

Structure:
- FRP tube: mechanical strength
- Aluminum end fittings: interface
- Shed profile of silicone rubber: protection and electrical performance

Applications:
- Transformers-, Wall- & GIS-Bushing
- Circuit Breaker – Dead Tank & Live Tank
- Cable Termination
- Instrument Transformer – CT, VT & CVT
- Arrestor
- Disconnecting Switch
- Post Insulator
- Capacitor
- Wind Coupling
WHY HOLLOW CORE COMPOSITE INSULATORS?

DIMENSIONS

- Porcelain insulators available up to a length of 3 m
  - For larger porcelain insulators:
    - Only a few producers with sufficient capability
    - Brittleness $\rightarrow$ damages during production
    - Broad tolerances (> 1 cm) $\rightarrow$ large number of rejections
- For composites almost no limitation in length

[http://www.hnhddc.com/encp.htm]
Porcelain-Insulator: Explosion

[Dan Windmar, Anders Holmberg, Mattias Lundborg: Production & Application of Hollow Composite Insulators on HV Apparatus; in 2009 World Congress on Insulators, Arresters and Bushings]
WHY HOLLOW CORE COMPOSITE INSULATORS?

SAFETY

Composite Insulator: Bullet hole

[Dan Windmar, Anders Holmberg, Mattias Lundborg: Production & Application of Hollow Composite Insulators on HV Apparatus, in 2009 World Congress on Insulators, Arresters and Bushings]
WHY HOLLOW CORE COMPOSITE INSULATORS?
SEISMIC WITHSTAND

Seismic test of transformer bushing
WHY HOLLOW CORE COMPOSITE INSULATORS?

ADVANTAGES

- Large dimensions
- Improved seismic withstand
- No shivers (safety)
- Adjustable material characteristics
- Weight: about 40% less than porcelain
APPLICATIONS

Wall Bushing for 800kV HVDC

- Horizontal
- Connects indoor and outdoor side in an HVDC yard, e.g. valve hall.
- Operation in high polluted areas results in long creepage distances
- Outdoor side:
  - Length: 9 m
  - Weight: 850 kg (insulator)
  - Specified bending moment: 500 kNm
Applications

Tapered bushing on 500kV SF6 circuit breaker

- Arcs in breaking chamber produce hot gases and aggressive byproducts
- Short circuit currents result in high dynamic forces
- Tapered design to save insulation media SF6 up to 45%
- Expected life time: 30 years and more, minimum service (e.g. no cleaning)
- Length: 4.5 m, weight 200 kg, specified bending moment 150 kNm
APPLICATIONS

Post insulator for 800 kV HVDC coils

- Coils weigh up to 40 t
- Withstand to earthquakes
- Length: >10 m, weight: 1100 kg, specified bending moment: 400 kNm
APPLICATIONS

Oil-gas bushing insert for 800 kV power transformer

- Barrier between inner oil side and outer SF6 bushing side
- Immersed in SF6 results in high electric stresses and temperatures
- Protection of the surface against used insulating gases and liquids
- Length about 2 m, weight about 50 kg
**Dielectric requirements for FRP:**

- Resistance to chemical and physical degradation by water
- Volume resistivity > $10^{10} \Omega m$
- Breakdown field strength $\approx 30$ kV/cm

**Mechanic requirements for FRP:**

- Glass transition temperature
  $T_g > T_{max} + 15K$
- Temperature $-60^\circ C .. +110^\circ C$ (typical)
- Pressure
- Bending
Further criteria for resin systems in high voltage application

- Ageing behaviour
- Compatibility to insulating media (e.g. oil, SF₆)
- Moisture absorption
- Gas permability
- Tracking resistance
- Arc resistance
- Dielectric characteristics (e.g. $\varepsilon_R$, loss factor)
- Conductivity $\kappa$ (important for DC) ...
SOLUTION

- Reinforcement: E-glass
- Matrix system: epoxy resin
  - Superior electrical properties
  - Good chemical resistance
SOLUTION

Designation: BFW tube
Criss-Cross fiber reinforced matrix
30° winding angle
Suitable for high bending load (high stiffness)

Designation: PFW tube
Criss-Cross fiber reinforced matrix
54° winding angle
Suitable for high internal pressure stress

Designation: TFW tube
Criss-Cross displacement
45° winding angle
Suitable for high torsional load

Designation: PBFW tube
Criss-Cross, Axially reinforced matrix
25° and 54° winding angle
Suitable for bending and internal pressure stress
Housing material: silicone rubber SiR

- Chemical structure: \(-\text{Si} - \text{O} - \text{Si} - \text{O} -\)

- High bonding energy: 444 kJ/mole

<table>
<thead>
<tr>
<th>Shed material</th>
<th>Chemical structure</th>
<th>Bonding energy</th>
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<tr>
<td>SiR</td>
<td>(-\text{Si} - \text{O} - \text{Si} - \text{O} -)</td>
<td>444 kJ/mol</td>
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<tr>
<td>EVM/EPR</td>
<td>(-\text{C} - \text{C} -)</td>
<td>345 kJ/mol</td>
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- High resistance against:
  - UV-radiation
  - Chemical attack
  - High temperatures

- Hydrophobicity

PRODUCT TESTS ACCORDING IEC 61462

Design Tests
- Excessive material, electrical and mechanical tests on samples and sample insulators to ensure suitability of design, materials and manufacturing technology

Type Tests
- Mechanical tests to validate the customized insulator type properties

Sample Tests
- Tests on samples from the batch to verify characteristics, which depend on manufacturing quality and materials used

Routine Tests
- Eliminate insulators with manufacturing defects
MATERIAL TEST

Performed tests on cutted samples of winding tube

- High voltage test (IEC 60243-1)
  - Immersed in insulating tempered mineral oil
  - Short term electrical withstand and thermal breakdown

- Dye Penetration Test (IEC 62217)
  - Put in colourant bath
  - Color penetrates through capillars and other imperfections

- Water Diffusion Test (IEC 62217)
  - Boiled in water with defined salinity (100 h)
  - Current and electrical withstand
  - Withstand against degradation by water
DESIGN TEST

IEC 61462 §7.2

- Thermal mechanical prestress (bending at low and high temperature)
- Water immersion pre-stressing

Verification of performance by

- AC flashover test
- Steep-front impulse voltage test
- 30 min AC withstand test
- Visual examination

[IEC 61462:2007]
BENDING, PRESSURE AND TIGHTNESS TEST

Acceptance criteria:
- No permanent deformation after 1.5 x MML and 2 x MSP
- No visible damage after 2.5 x MML and 4 x MSP
- Tightness according customer agreement

Design is mechanically specified by
- MML: maximum mechanical load in service
- MSP: maximum service pressure

Bending of insulator: force applied to top fitting
- Type test: up to 2.5 x MML
- Sample test: up to 1.5 x MML
- Routine test: 1 x MML

Inner pressure test of insulator:
- Type test: up to 4 x MSP
- Sample test: 2 x MSP
- Routine test: 2 x MSP

Tightness test of insulator:
- Pressure loss test with air or
- Accumulation bag test with helium at 1 x MSP
CONCLUSION

Hollow core composite insulators

- Have advantages against porcelain
- Performance / safety / dimension
- Have mechanical and dielectric requirements
- Expected lifetime >30 years, also in harsh environment
- High testing requirements (100% mechanical routine tests)