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Dielectric Water Determination of Transformers

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Dielectric Water Determination of Transformers



Dielectric Water Determination of Transformers

Martin Anghuber



Agenda

- **Water in transformers**
 - Water content in the life of a transformer
 - Dielectric Water Determination
 - Case Studies





Dielectric Water Determination of Transformers

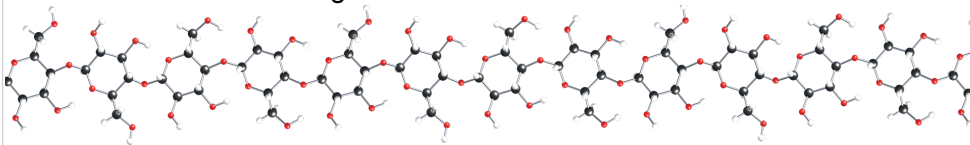
The problem of water in oil paper insulations

Water in oil paper insulations:

- Reduces the breakdown voltage of oil
- Can lead to bubbling at hot spots
- Accelerates the aging of paper

Cellulose and aging

- Cellulose: Built of glucose chains



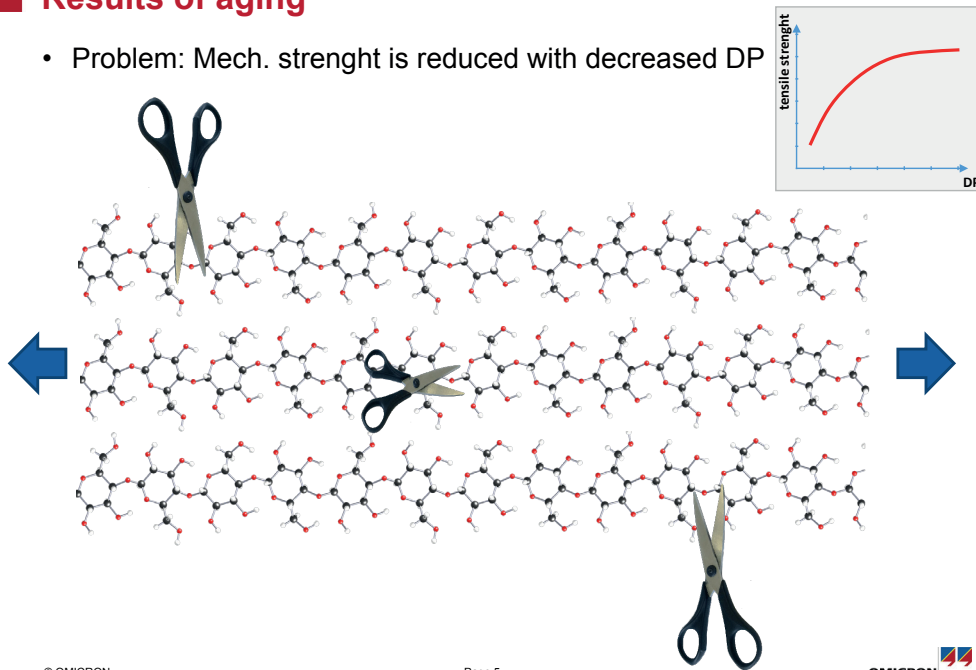
- Degree of polymerization (DP): Average number of glucose rings in a chain
 - New paper: DP: ~ 1200
 - End of life: DP: ~ 200
- Water splits the chains (Hydrolysis)
 - Water is a byproduct of the hydrolysis
 - Self-accelerating process
 - The higher the water content, the faster the aging



Dielectric Water Determination of Transformers

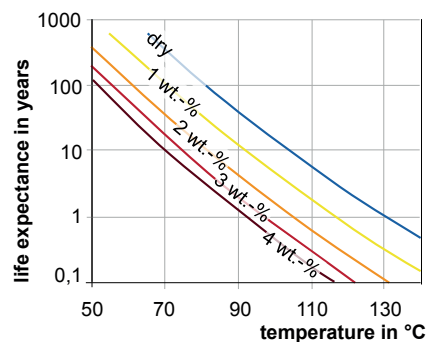
Results of aging

- Problem: Mech. strenght is reduced with decreased DP



Aging by Water and Temperature

- Temperature accellerates aging
- Water accellerates aging
- „Rule of thumb“:
 - Each 8 K \uparrow : half life expectance
 - Each 1 wt.% \uparrow : half life expectance



Source: L. E. Lundgaard, "Aging of oil-impregnated paper in power transformers", IEEE Transactions on Power Delivery, Jan. 2004



Dielectric Water Determination of Transformers

Agenda

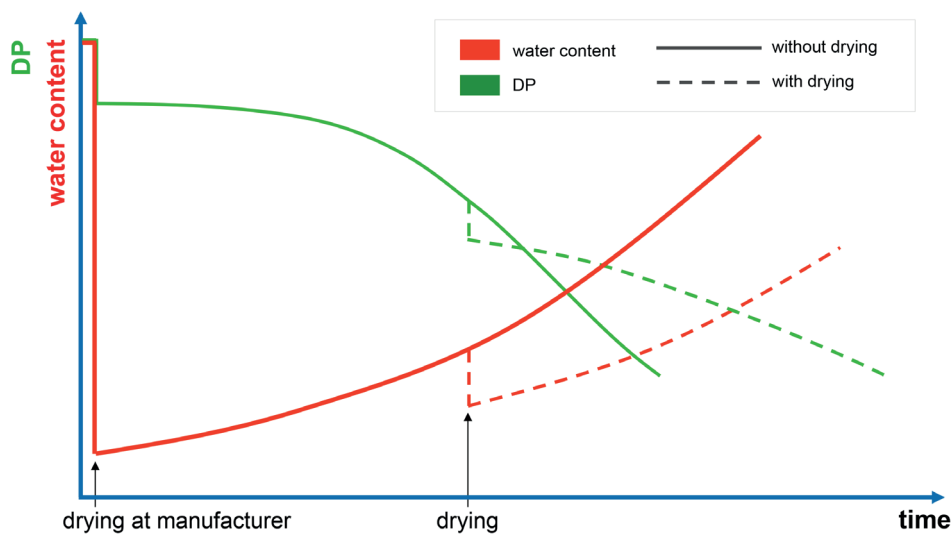
- Water in transformers
- **Water content in the life of a transformer**
 - Dielectric Water Determination
 - Case Studies

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Water content in the life of a transformer (schematic)



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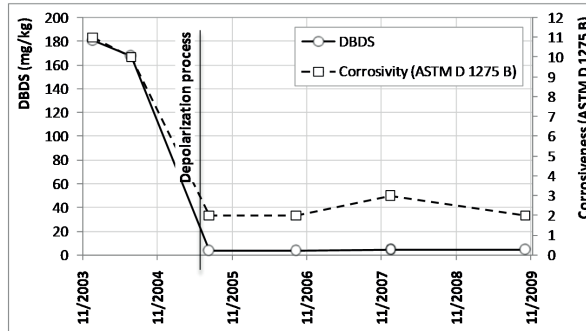
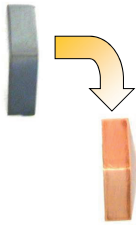
Dielectric Water Determination of Transformers

Transformer Life Management 2014
Corrosive Sulfur in Transformer Insulating Mineral Oil

Selective Depolarization

Real case of Selective Depolarization – survey of oil's parameters after the treatment

Parameter	Units	Value
Power	MVA	15
Rated voltage	kV	15
Oil type	-	Nynas Nytrafo 11
Year of installation	-	2000
Cooling mode	-	ONAF
Segregation	-	Breathing



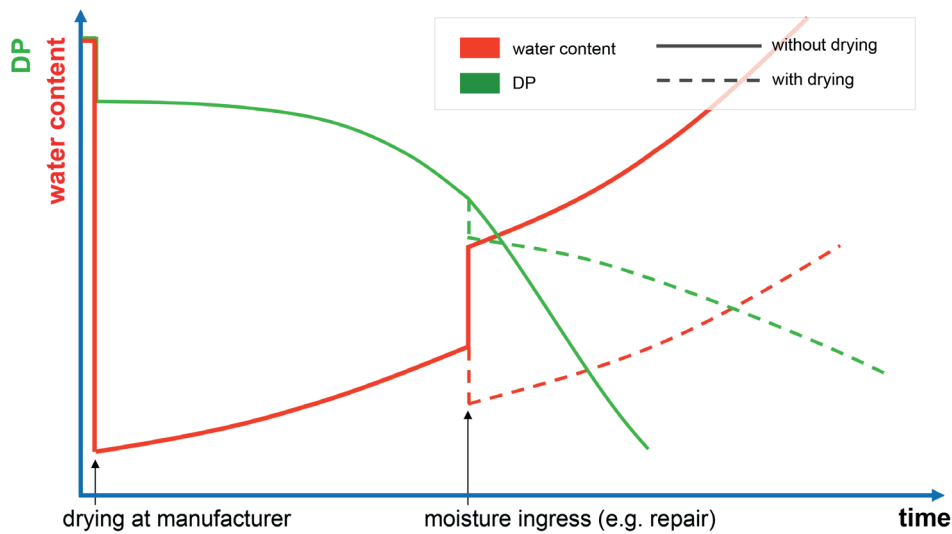
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Radisson Royal Hotel- Dubai – 2014 October 28-29

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Water content in the life of a transformer (schematic)



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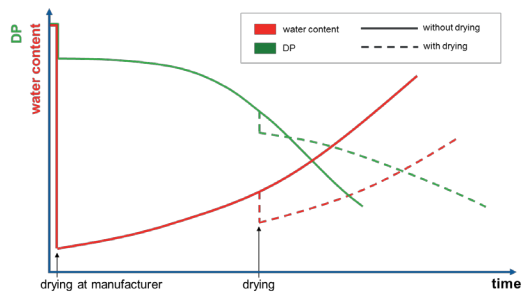




Dielectric Water Determination of Transformers

Water content in the life of a transformer (schematic)

- The water content increases steadily with the life of a transformer
- Time is dependent on temperature (\leftrightarrow load)
- Drying slows down the aging but can't reverse the aging
- Knowing the water content can tell you if drying is necessary



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Agenda

- Water in transformers
- Water content in the life of a transformer
- **Dielectric Water Determination**
- **Theory**
 - Measurement setup
 - Case Studies

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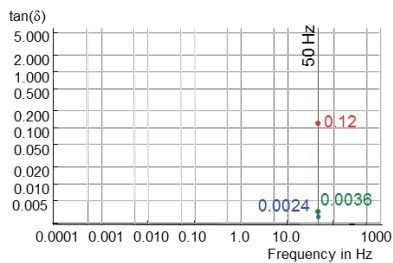


Dielectric Water Determination of Transformers

Dielectric measurements

Common “types” of dielectric measurements at low voltage:

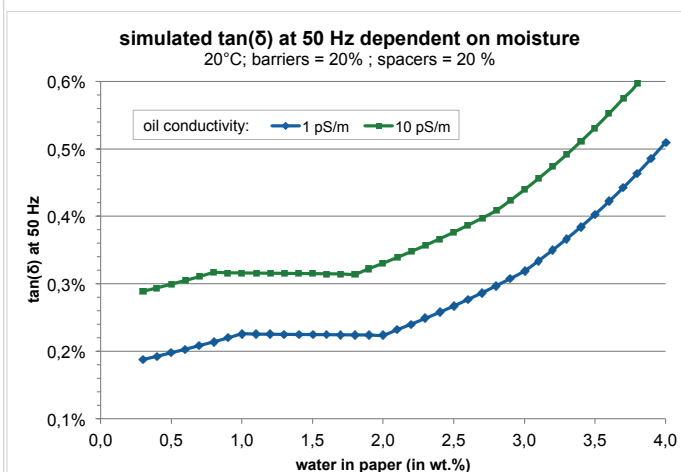
$\tan(\delta)$, C at 50 Hz:



- No separation of effects
- Very rough statement of overall condition

Dielectric measurements at 50 Hz

- $\tan(\delta)$ around 50 Hz usually insensitive to moisture < 2%
- Dependency on oil conductivity and temperature



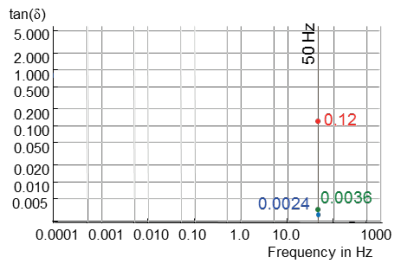


Dielectric Water Determination of Transformers

Dielectric measurements

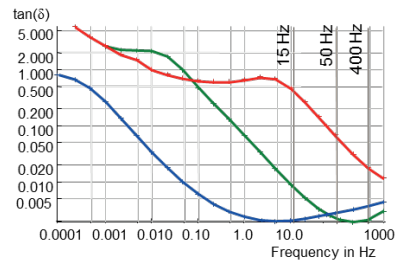
Common “types” of dielectric measurements at low voltage:

$\tan(\delta)$, C at 50 Hz:



- No separation of effects
- Very rough statement of overall condition

dielectric response: ($\tan(\delta)$, C at kHz...μHz)

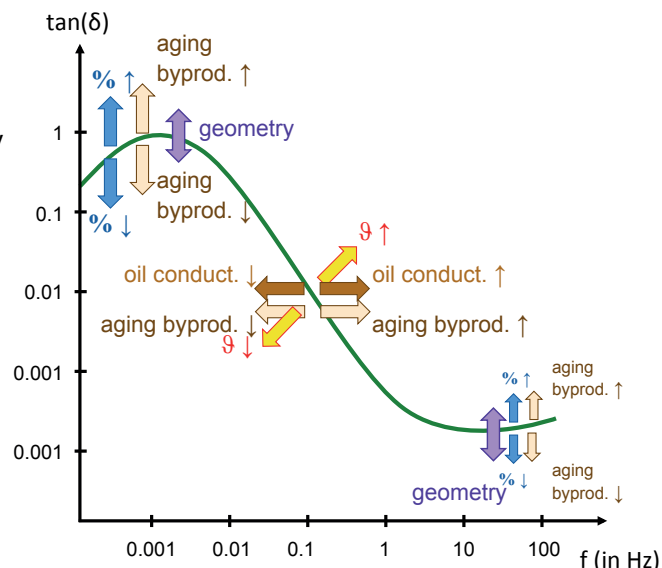


- Separation of effects due to large frequency range
- Moisture assessment in paper

Factors influencing the dielectric response

Influence factors:

- Temperature
- Moisture
- Insulation geometry
- Oil conductivity
- Aging byproducts

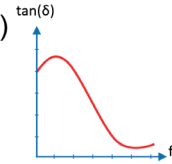




Dielectric Water Determination of Transformers

Water determination using dielectric response

- Dielectric response: dielectric properties ($\tan(\delta)$, C' , C'' ...) dependent on frequency



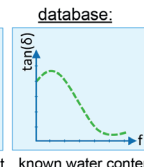
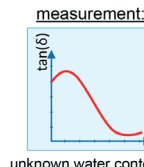
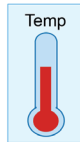
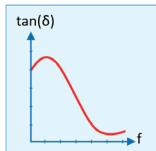
- Moisture determination:

dielectric response

+ temperature

→ comparison with database

→ water content

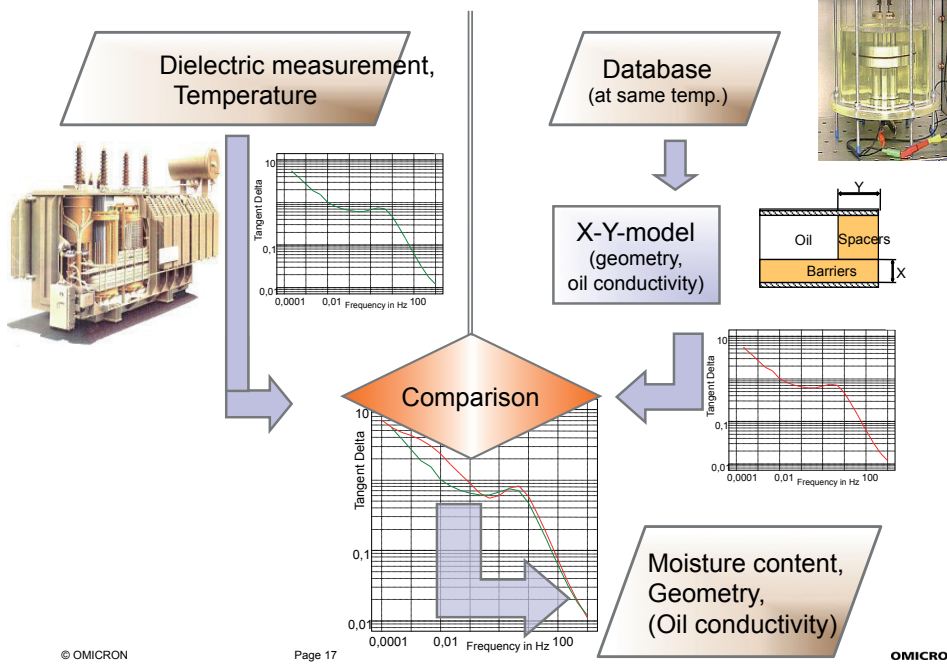


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Water determination using dielectric response



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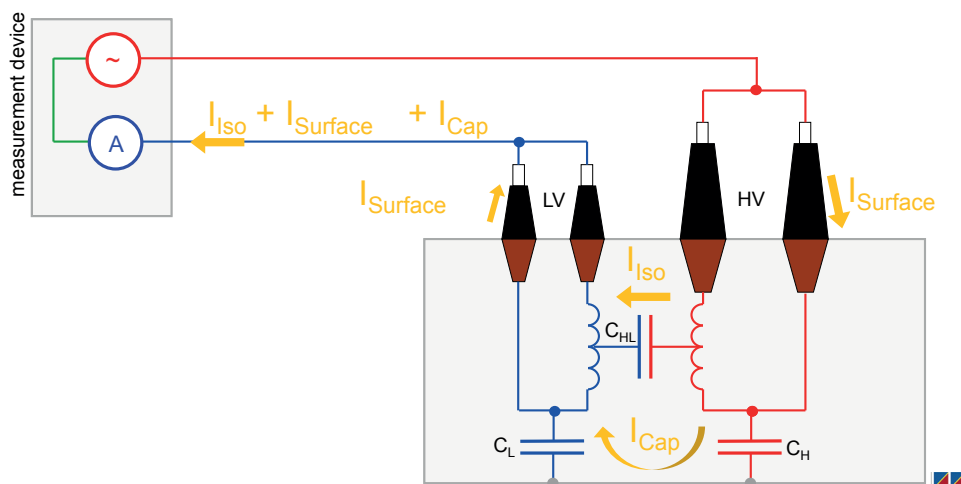
Dielectric Water Determination of Transformers

Agenda

- Water in transformers
- Water content in the life of a transformer
- **Dielectric Water Determination**
 - Theory
- **Measurement setup**
 - Case Studies

Dielectric measurement setup:

- Measurement of CHL for moisture determination

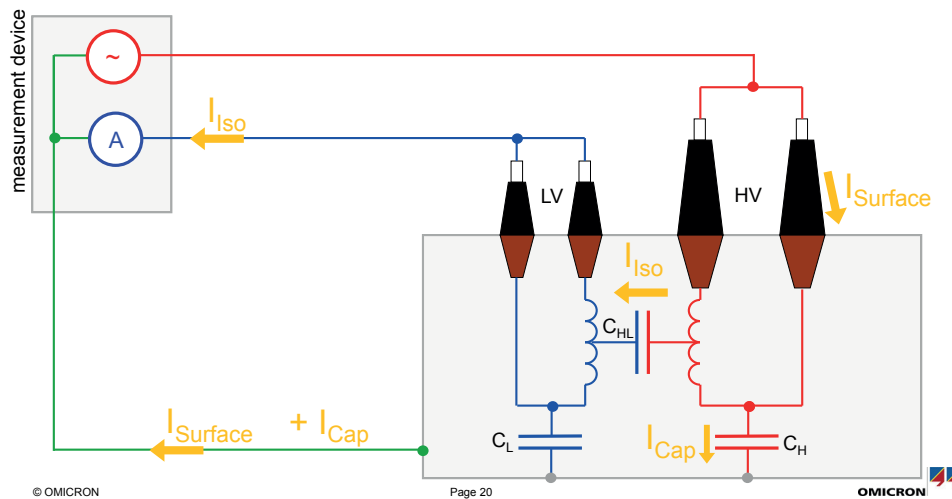




Dielectric Water Determination of Transformers

Dielectric measurement setup:

- Measurement of CHL for moisture determination
- Guard eliminates disturbances and the influence of CH and CL and the bushings



Advantages of dielectric moisture determination

- Simple measurement, fast results
- Water content of paper/pressboard is determined
- No invasive method
- No equilibrium required (oil ↔ paper)
- Suitable for onsite measurement or drying
- Influence of aging byproducts can be compensated
- Applicable for all transformer sizes and types



Dielectric Water Determination of Transformers

Agenda

- Water in transformers
- Water content in the life of a transformer
- Dielectric Water Determination
- **Case Studies**
- **Single measurements**
- Drying monitoring

Case Study I

- Transformer 133 MVA
- 230 kV / 115 kV / 48 kV
- Manufactured 1967
- Dielectric measurements:
 - HV-LV: 2,5 wt. %
 - LV-TV: 3,8 wt. %
 - tertiary winding was not used
- After 1,5 years of online drying:
 - HV-LV: 1,5 wt. %
 - LV-TV: 2,8 wt. %
- Additional lifetime





Dielectric Water Determination of Transformers

Case Study II

- Aged transformer (manufactured 1965)
 - Water-in-oil test: 2 wt.% moisture in paper insulation
 - Dielectric test: 5.4 wt.% moisture („extremely wet“)
 - Oil has been replaced recently
 - Dielectric results confirmed by other measurement
- Replacement unit could be ordered before failure occurred

Agenda

Water in transformers
Water content in the life of a transformer
Dielectric Water Determination

- **Case Studies**
 - Single measurements
- **Drying monitoring**



Dielectric Water Determination of Transformers

The problem with drying transformers

- **Drying too short**

- Moisture content too high
- Accelerated aging
- Reduced lifetime

- **Drying too long**

- Energy costs, production speed
- Paper too long at hot temperature
- additional Loss of DP
- Reduced lifetime

➔ **Optimal drying time is essential**

➔ **Monitoring of moisture content necessary**

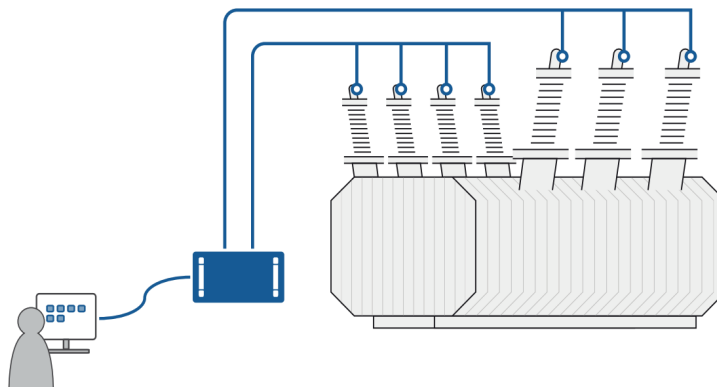
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Case study IV – hot oil spray drying

- Sample: used transformer, 50 MVA after repair
- Drying using hot oil spray & vacuum
- Drying and measurement in tank via bushings



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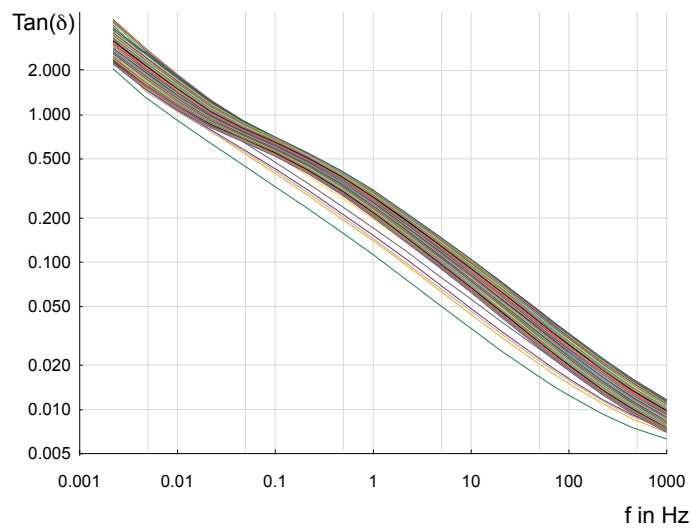
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Dielectric Water Determination of Transformers

Case study IV – hot oil spray drying

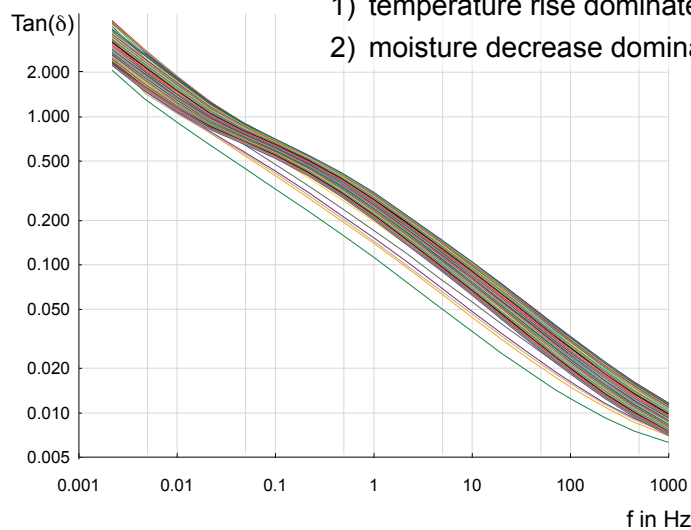


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Case study IV – hot oil spray drying



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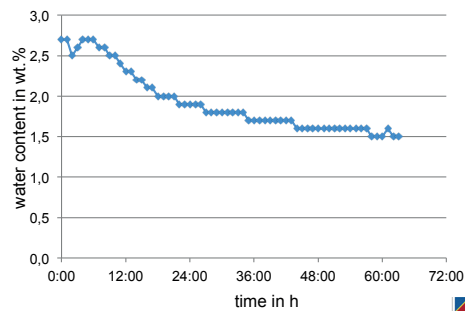
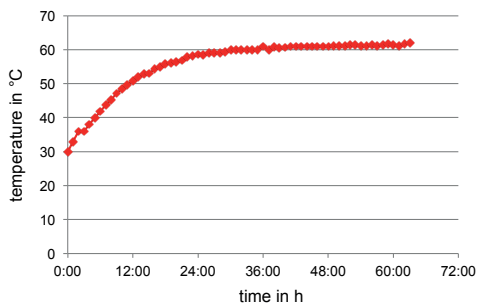
Case study IV – hot oil spray drying

Temperature:

- Low temperature (~ 60°C) used for low loss of DP

Moisture:

- Before drying: ~ 2,7 %
- After 60 h drying: 1,5 %
- Further drying would barely have an effect
- Drying to lower moisture would require higher temperatures



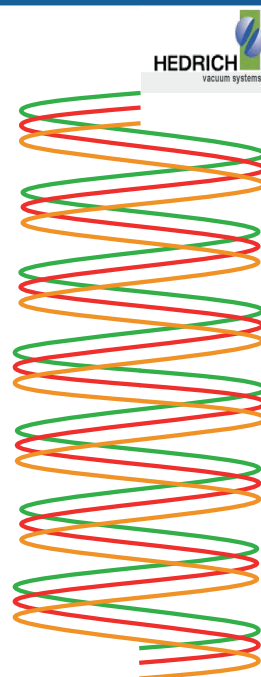
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Case study V – Coil drying

- Sample: Coil with 3 separated windings (each ~ 40 turns)
- Tests were done at Hedrich Vacuum systems
- Hot air & vacuum
- Paper insulation: only a thin layer of paper around the conductors
→ very fast drying, compared to a transformer
- Paper not oil impregnated
- Drying and re-moisturization was monitored



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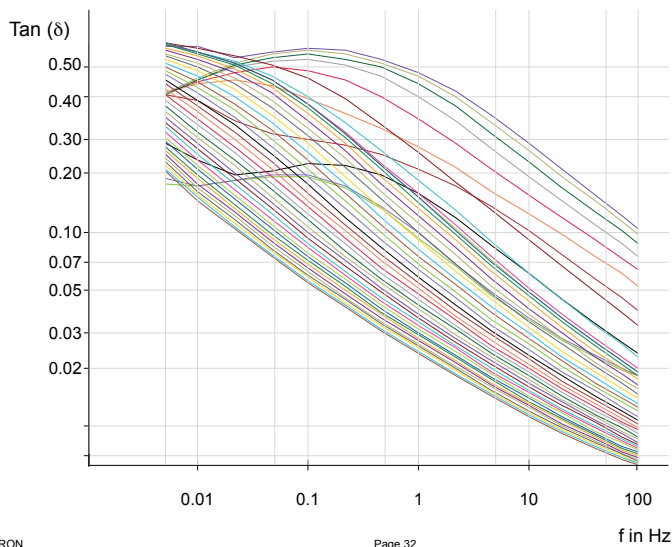




Dielectric Water Determination of Transformers

Case study V – Coil drying

- **Dielectric:** $\tan(\delta)$ curve first increases (temperature increase), then decreases (moisture decrease)



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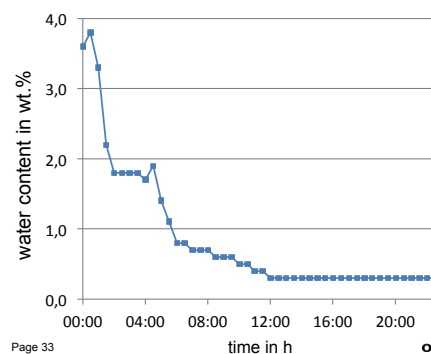
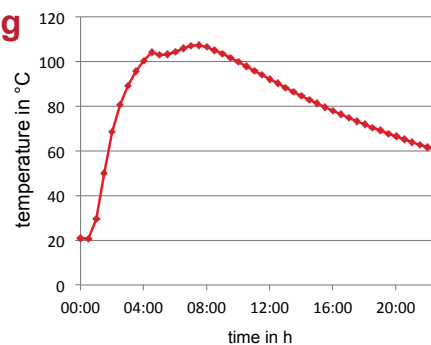
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f in Hz



Case study V – Coil drying

- **Temperature:**
Stable results even at very low resistance changes (only 0,068 mΩ/K)
- **Moisture:**
Rapid decrease at the beginning, fast drying due to thin insulation (~13 h to 0,3 %)



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time in h



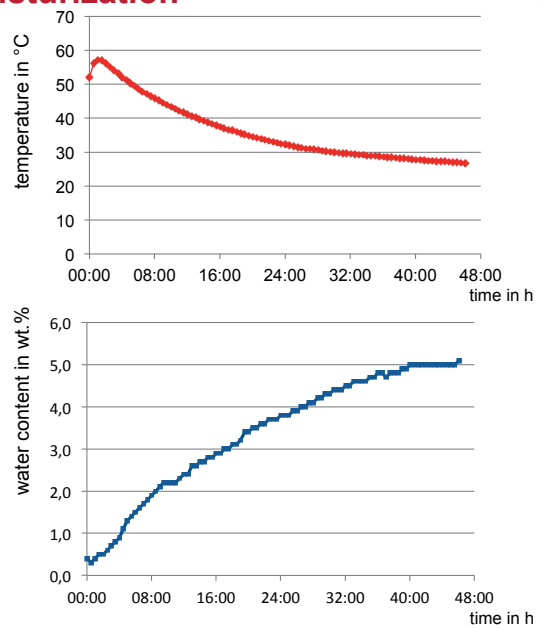


Dielectric Water Determination of Transformers

Case study V – Coil remoisturization

Remoisturization

- **Temperature:**
- **Moisture:**
0,3 % to 5 % in 40 hours



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Thank you!

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