WEBINAR

# Insulation concepts to optimize the design of liquid-filled transformers

March 26th | 15:00 CET | 10:00 EST

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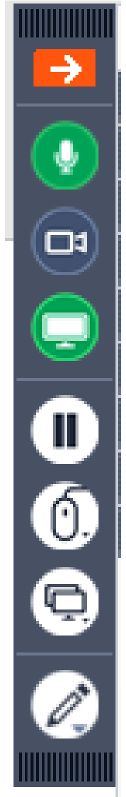
# HOW TO ASK A QUESTION?

Minimized GoToWebinar panel

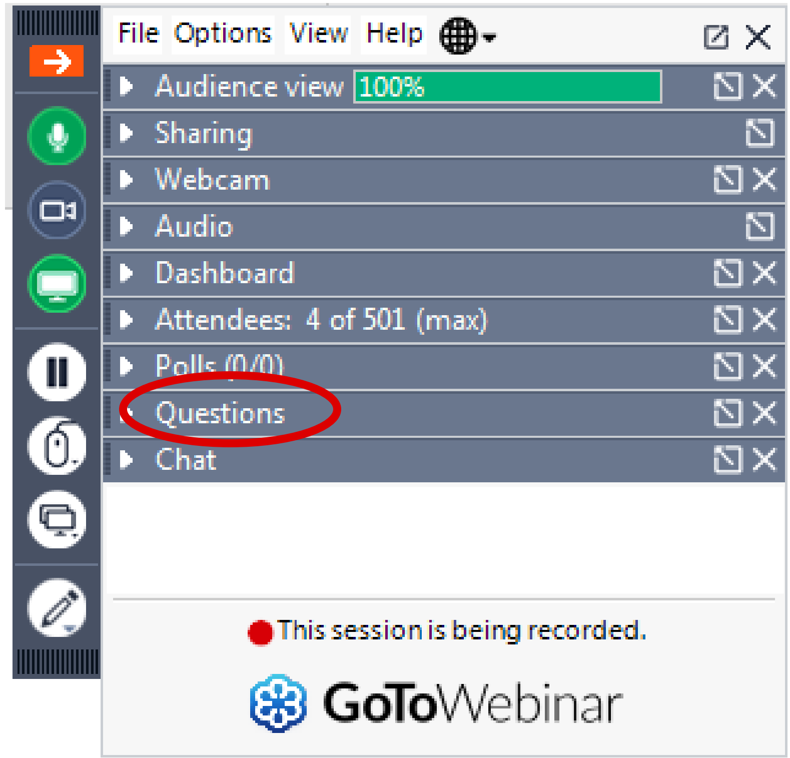
→ Click arrow to enlarge



Enlarged GoToWebinar panel

→ Expand the field Questions

→ Type your question and send to Organizers or to All



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# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

THOMAS PREVOST, BRAD GREAVES, & JASON BEAUDOIN

# INSULATION DESIGN CONCEPTS

**01** **Optimized Ingredients for Solid Transformer Insulation**

**02** Optimized Space Factor In The Windings

**03** Optimized Short Circuit Resilience

**04** Optimized Stress Distribution By Understanding Material Permittivity

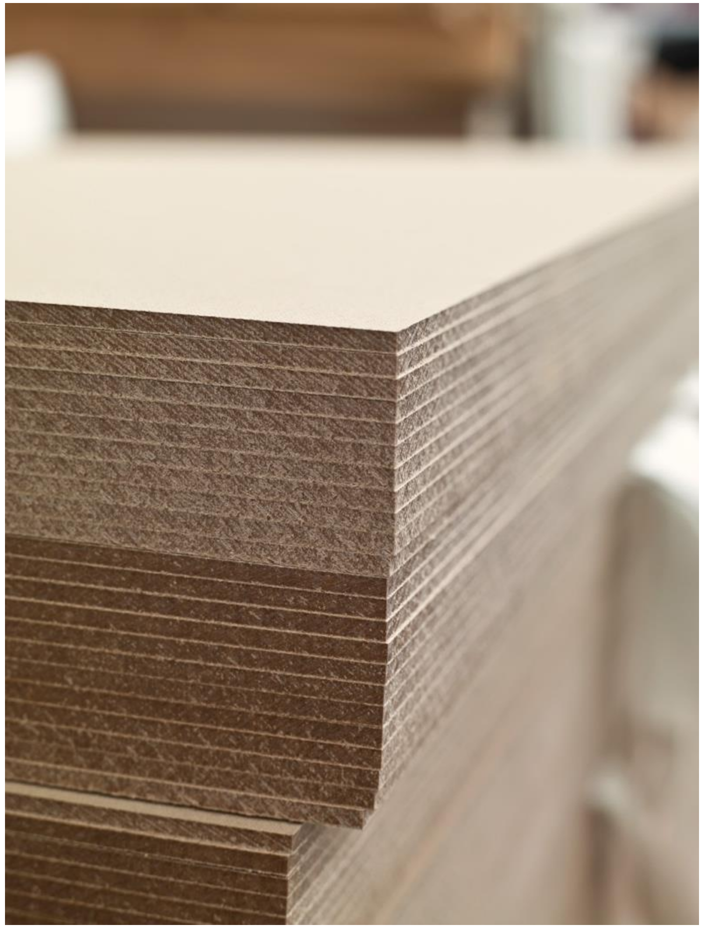
**05** Optimized Dielectric Clearances By Use Of Barrier System

**06** Optimized Surface Stress Using Contoured Insulation

# OPTIMIZED INGREDIENTS FOR SOLID TRANSFORMER INSULATION

## PERFORMANCE REQUIREMENTS

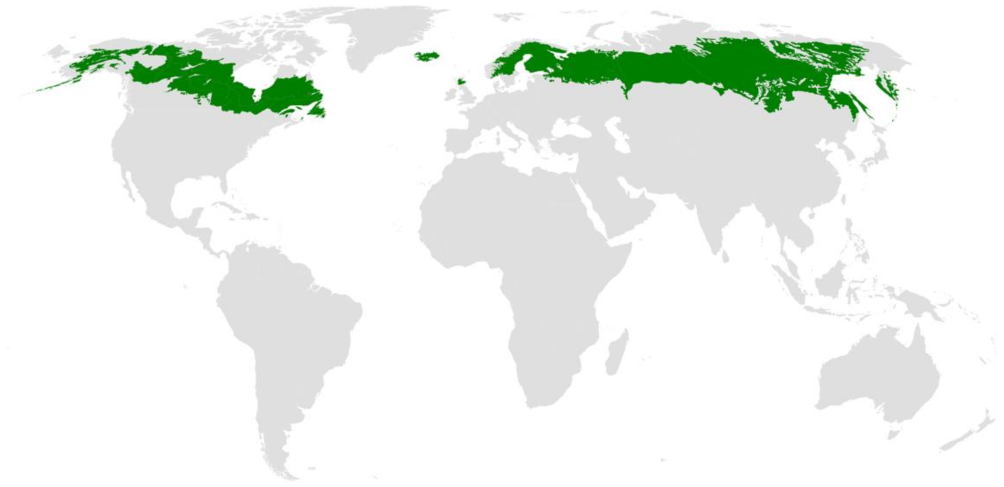
- Dielectric
  - High Breakdown Voltage
  - Low Dissipation Factor
- Mechanical
  - High Tensile Strength
  - High Flexure Strength
  - Low Compression
- Thermal
  - High Thermal Class
  - High Degree of Polymerisation



Superior performance is achieved by using optimized ingredients……

# OPTIMIZED INGREDIENTS FOR SOLID TRANSFORMER INSULATION

## CELLULOSE FIBERS DERIVED FROM KRAFT PROCESS



Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 2001

- Trees
  - Softwood
  - From Boreal Forest
  - Sustainable
    - Forest Stewardship Council
- Pulp
  - Kraft Process

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# OPTIMIZED INGREDIENTS FOR SOLID TRANSFORMER INSULATION

## WATER

- Raw material for Transformer Insulation
  - Cellulose Fibers from Kraft Process
  - Water

- Water must be clean with low conductivity
  - Low chlorides
  - Neutral pH
  - Low conductivity

# INSULATION DESIGN CONCEPTS

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04 Optimized Stress Distribution By Understanding Material Permittivity

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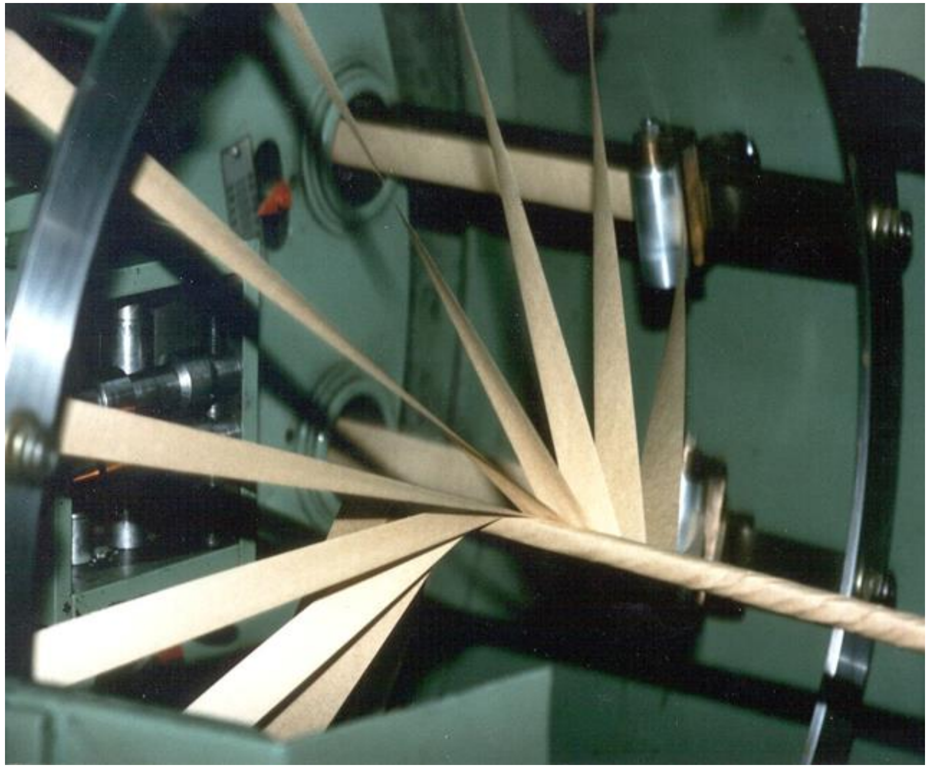
# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## OPTIMIZED SPACE FACTOR IN THE WINDINGS

Conductor Insulation

- High Dielectric Strength
  - Determined by thickness and number of layers
- Turn to Turn Thickness optimized by wrapping paper as tightly as possible.
  - High tension on conductor insulation
- Strength of paper
  - Tensile
  - Elongation
- Best Conductor Insulation has High Tensile and High Elongation

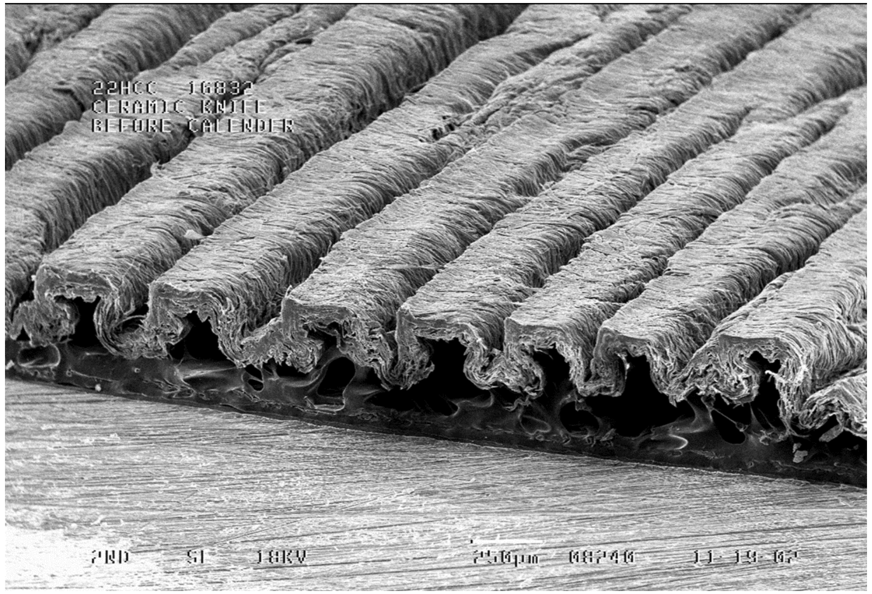


# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## OPTIMIZED SPACE FACTOR IN THE WINDINGS

Conductor Insulation

| Type | % Elongation | Use |
|---|---|---|
| Non-Creped | 2-4 | Winding Cu |
| **Calendered Crepe** | **8-12** | **Winding Cu** |
| Crepe | 50-200 | Leads |

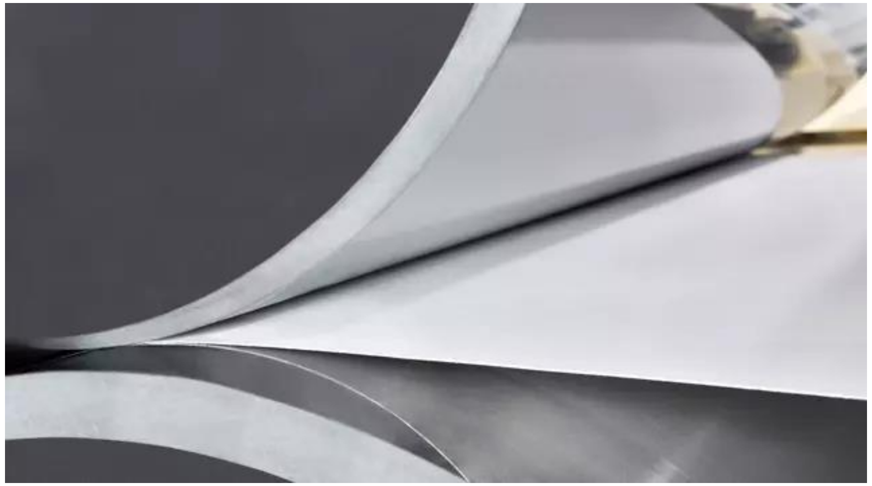



22 HCC is equivalent to “Dennison Crepe”

Known as “Calendered Crepe”

Crepe paper densified through calendering

Get thickness tolerance of Non-creped with strength of creped.



# INSULATION DESIGN CONCEPTS

01 Optimized Ingredients for Solid Transformer Insulation

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03 **Optimized Short Circuit Resilience**

04 Optimized Stress Distribution By Understanding Material Permittivity

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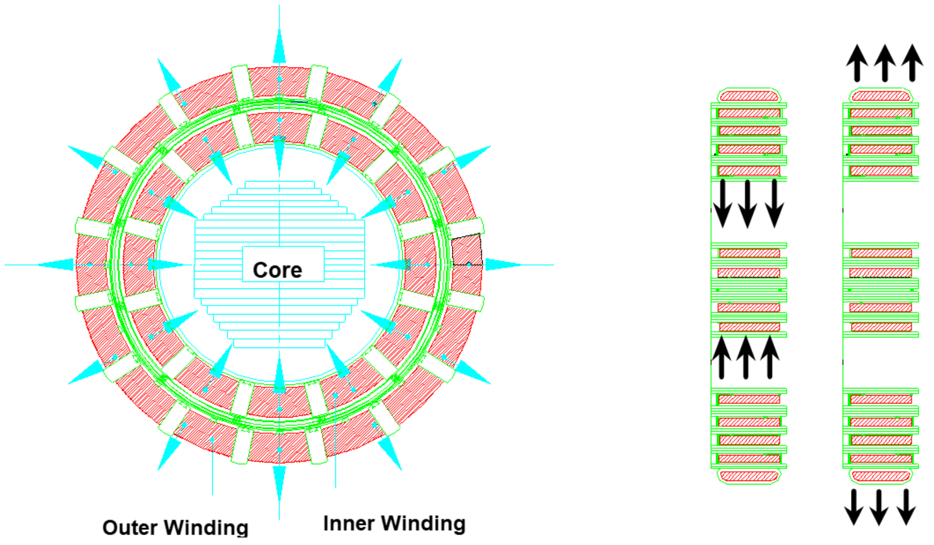
# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## OPTIMIZED SHORT CIRCUIT RESILIENCE

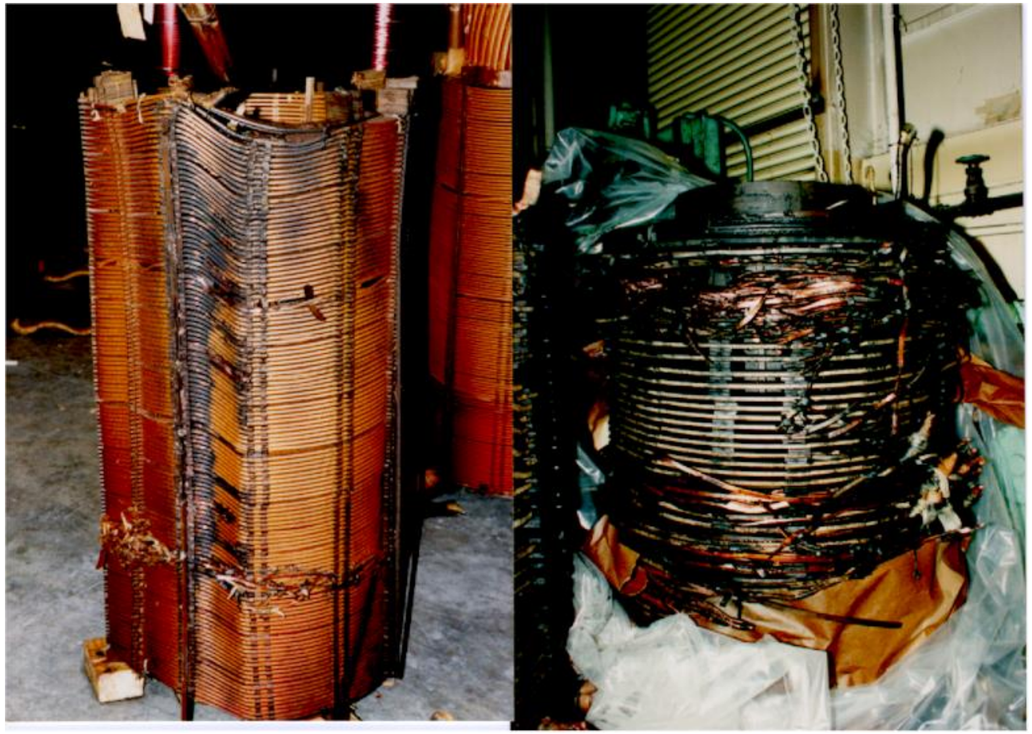
- A major aspect of insulation is for mechanical stability of the windings
- Specifically, to support the windings during short circuit events

**Transformer's Forces**




Radial Forces

Axial Forces



- One way to ensure windings are sufficiently supported axially is by selecting the correct radial spacer material with the optimal compressibility characteristics

# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## OPTIMIZED SHORT CIRCUIT RESILIENCE

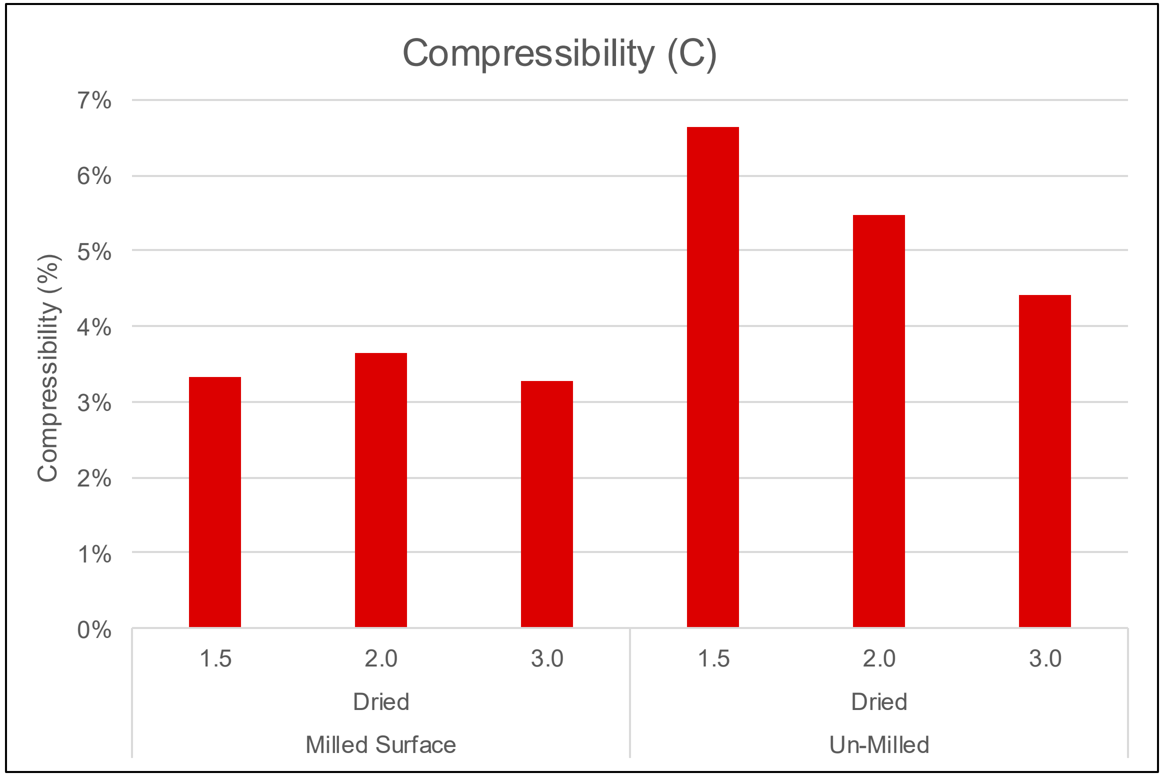
- Compressibility can be affected by multiple properties with most significant being surface condition; milled surface vs. un-milled surface (with screen pattern intact).

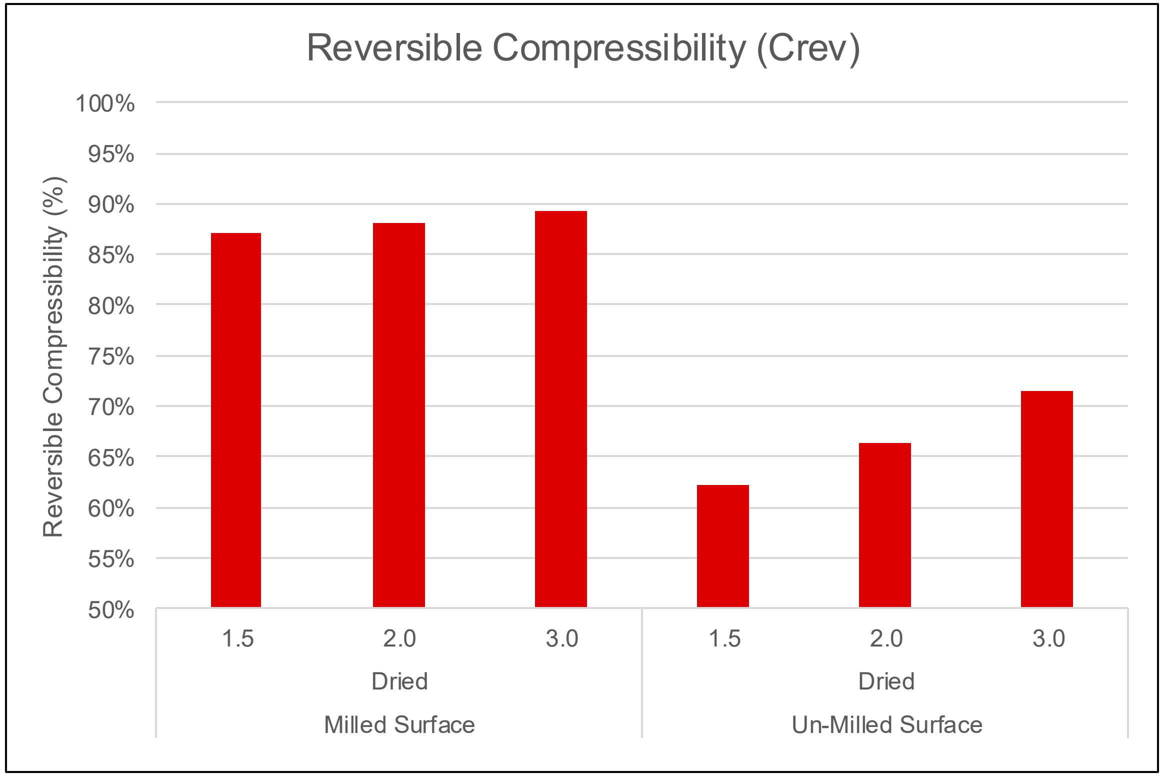
- Modifying the surface of the HD PB by removing the screen pattern allows for more consistent thickness and, more importantly, compression characteristics

# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## OPTIMIZED SHORT CIRCUIT RESILIENCE

- Laboratory testing of various spacers showed the following:
  - Un-milled surface has higher compressibility and lower reversible compressibility than milled
  - Un-milled surface is largely dependent on thickness




Note: Testing completed per IEC 60641-2 section 10. Bedding pressure = 1 MPa, Compression pressure = 20 MPa.

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# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## OPTIMIZED STRESS DISTRIBUTION BY UNDERSTANDING MATERIAL RELATIVE PERMITTIVITY

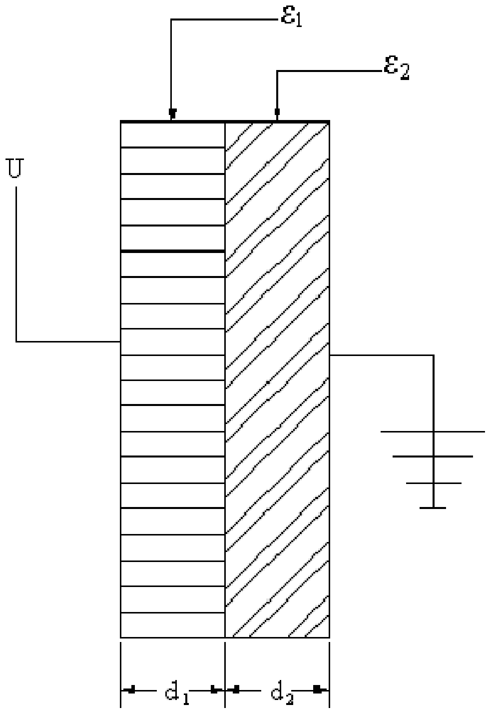
- Relative permittivity (dielectric constant) relates the effect of the material on the capacitance of an object compared to air.
- Air = 1.0
- Transformer Oil = 2.2
- Theoretical Pure Cellulose = 6
- Typical cellulose materials (impregnated with mineral oil) have a relative permittivity ranging between 3.8 and 4.6

| Material | Density ($g/cm^3$) | Relative Permittivity | Oil Absorption (%) |
|---|---|---|---|
| Hi-Val | 0.95 | 3.8 | 24 |
| T4 | 1.2 | 4.6 | 12 |
| Transformer Oil | 0.88 | 2.2 | --- |

# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## OPTIMIZED STRESS DISTRIBUTION BY UNDERSTANDING MATERIAL RELATIVE PERMITTIVITY

- Dielectric stress distributes inversely proportional to the material permittivity




$\varepsilon_1$=permittivity mat. 1
$\varepsilon_2$=permittivity mat. 2
$Z=(d_1/\varepsilon_1) + (d_2/\varepsilon_2)$

$E_1 = U/(\varepsilon_1 * Z)$

$E_2 = U/(\varepsilon_2 * Z)$

U= Applied Voltage
$E_1$= Stress in material 1
$E_2$= Stress in material 2

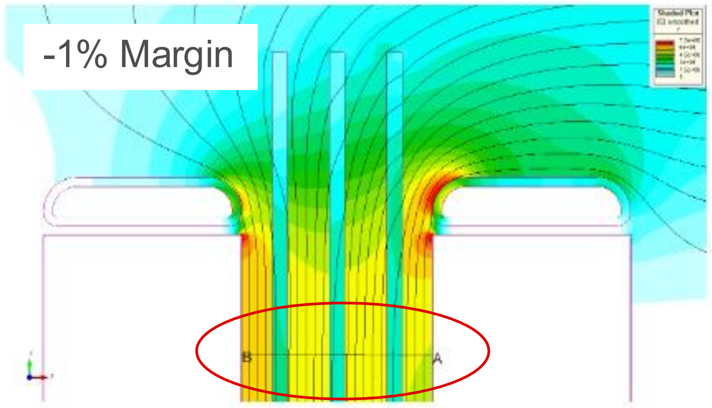
| HD PB & MO | LD PB & MO |
|---|---|
| $\varepsilon_1 = \varepsilon_{PB} = 4.6$ | $\varepsilon_1 = \varepsilon_{PB} = 3.8$ |
| U=100kV | U=100kV |
| $\varepsilon_2 = \varepsilon_{oil} = 2.2$ | $\varepsilon_2 = \varepsilon_{oil} = 2.2$ |
| $d_1 = d_2$=5mm | $d_1 = d_2$=5mm |
| **$E_1 = E_{PB}$= 6.5 kV/mm** | **$E_1 = E_{PB}$= 7.3 kV/mm** |
| **$E_2 = E_{oil}$=13.5kV/mm** | **$E_2 = E_{oil}$=12.7kV/mm** |

- By exchanging HD with LD board, bringing the relative permittivity of the solid closer to the relative permittivity of the liquid, the stress in the liquid was reduced by ~6%

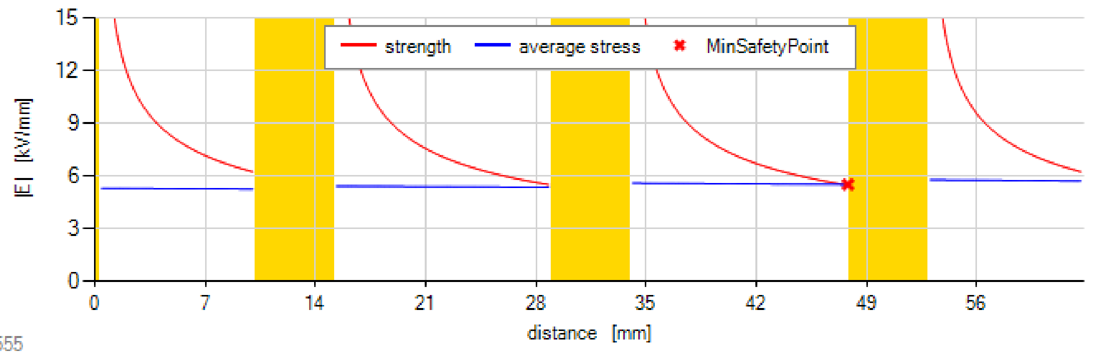
# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## OPTIMIZED STRESS DISTRIBUTION BY UNDERSTANDING MATERIAL RELATIVE PERMITTIVITY

- Replacing Hi-Lo barriers from HD PB (T4) to LD PB (Hi-Val) results in a shift of the dielectric stress into the liquid and an increase in the percent margin during IDA.




Field Plot (RZ Model)



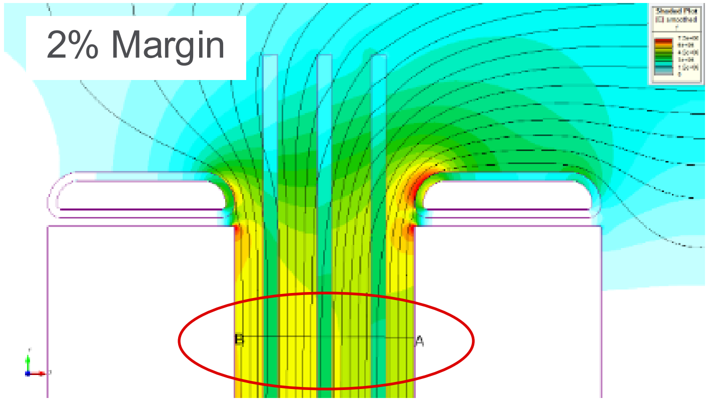

Comparison of max. averaged field and oil curves in function of the respective gap length

Test Voltage [kV]: 300

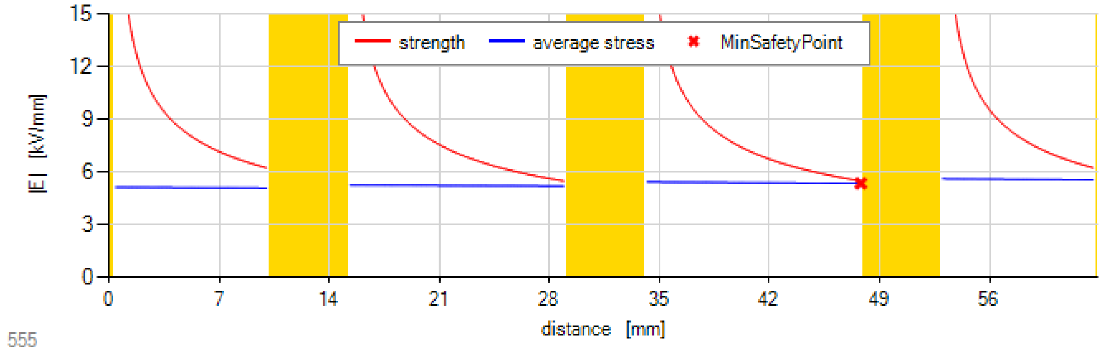
Starting Point [mm]: X=506.5; Y=1570.7; Z=0.0

Max|E| [kV/mm]: 5.8

Minimum DL [%]: 99 Percent Margin [%]: -1




Field Plot (RZ Model)




Comparison of max. averaged field and oil curves in function of the respective gap length

Test Voltage [kV]: 300

Starting Point [mm]: X=506.5; Y=1571.3; Z=0.0

Max|E| [kV/mm]: 5.6

Minimum DL [%]: 103 Percent Margin [%]: 2

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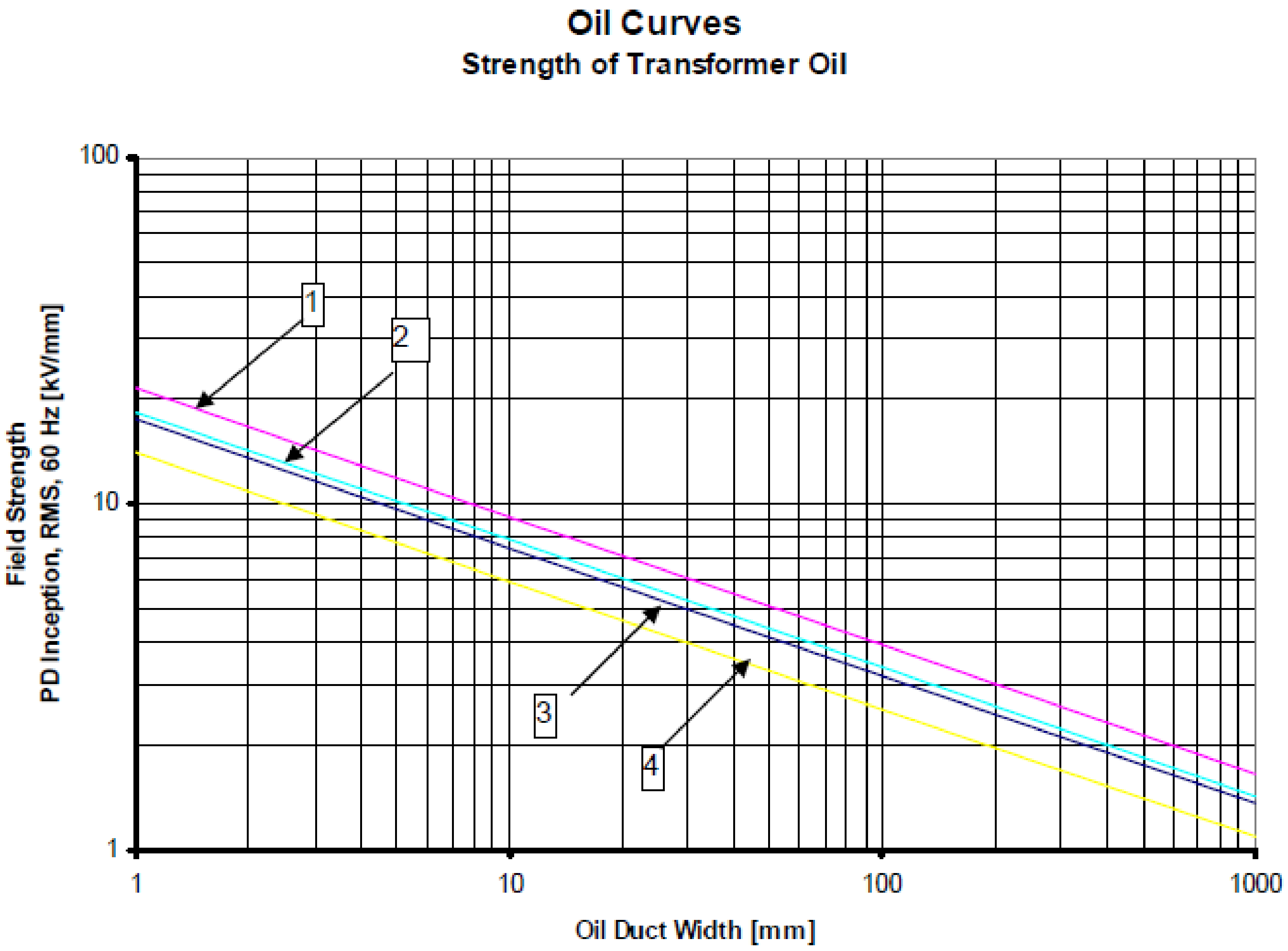
# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

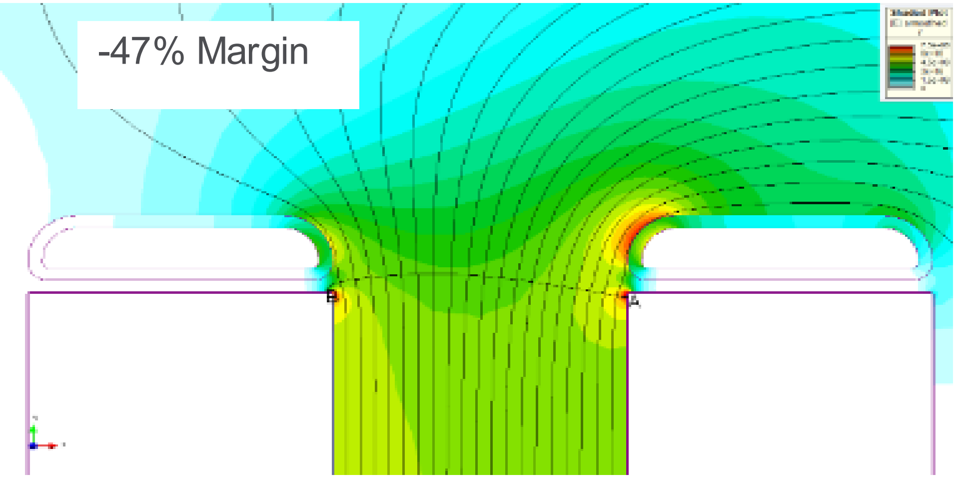
## WEIDMANN REFERENCE CURVES

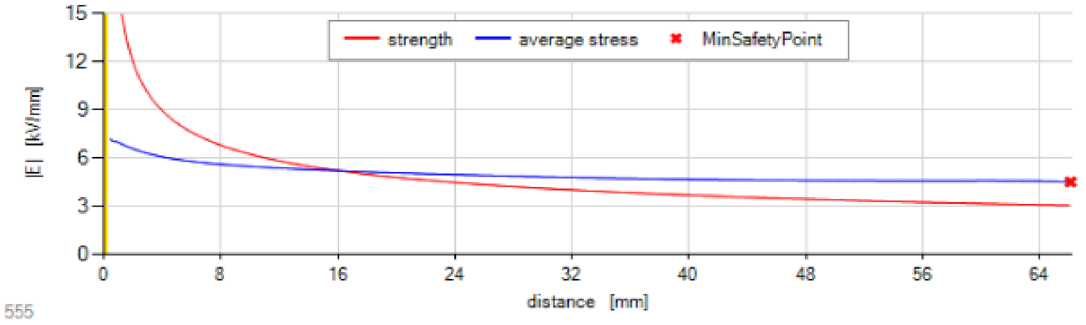



- The strength of the dielectric liquids decrease as the length of the gap increases
- The inverse is also true!

# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## GAP WITHOUT BARRIERS VERSUS GAP WITH 3 BARRIERS



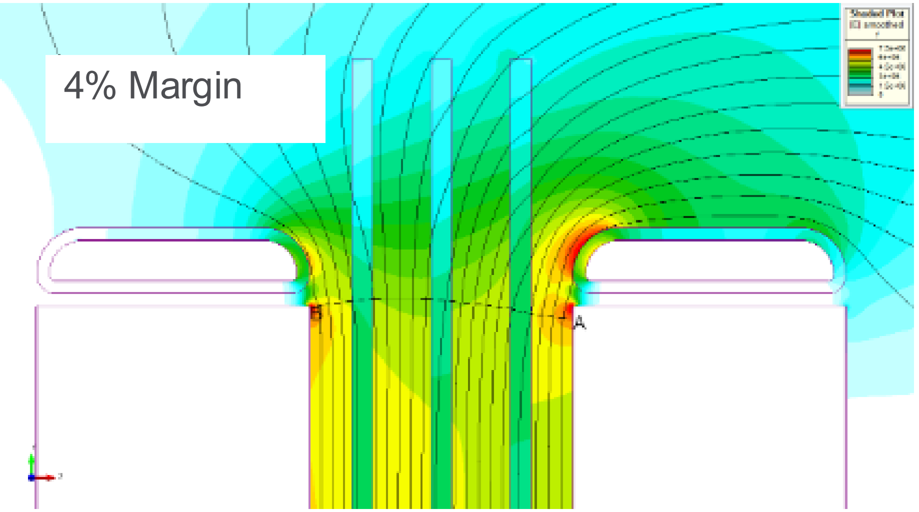

Comparison of max. averaged field and oil curves in function of the respective gap length

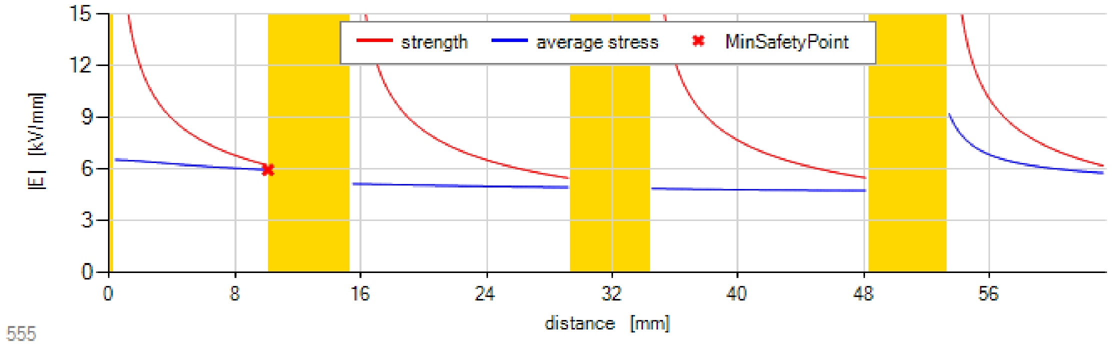
Test Voltage [kV]: 300

Max|E| [kV/mm]: 7.3

Starting Point [mm]: X=506.5; Y=1609.0; Z=0.0

Minimum DL [%]: 68    Percent Margin [%]: -47




Comparison of max. averaged field and oil curves in function of the respective gap length

Test Voltage [kV]: 300

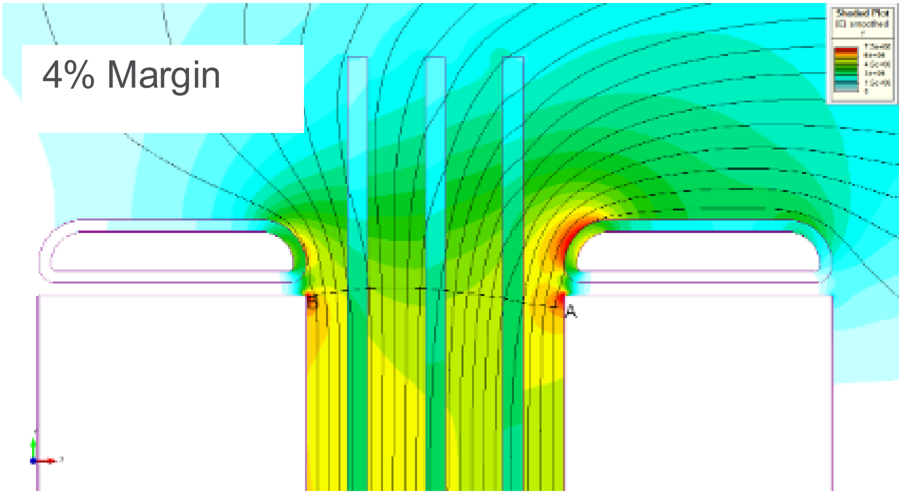
Max|E| [kV/mm]: 9.4

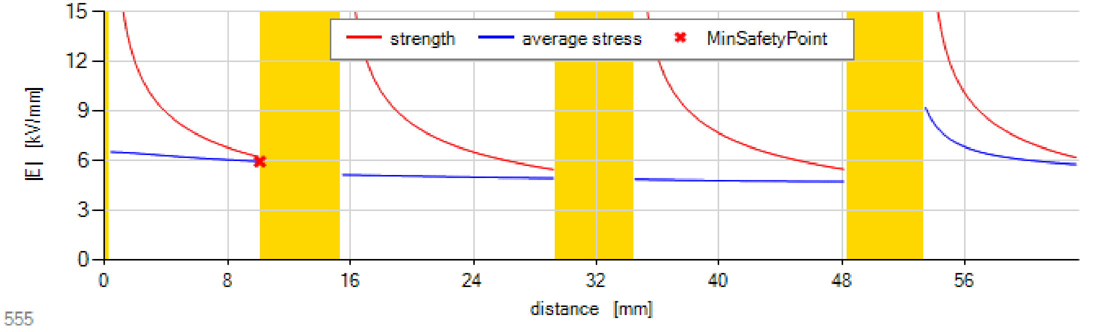
Starting Point [mm]: X=506.5; Y=1607.0; Z=0.0

Minimum DL [%]: 104    Percent Margin [%]: 4

# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## GAP WITH 3 THICK BARRIERS VERSUS 5 THIN BARRIERS

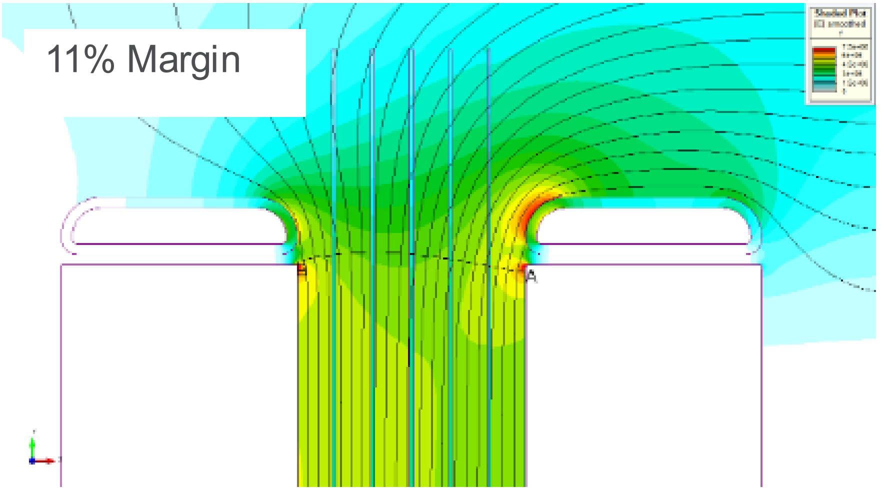


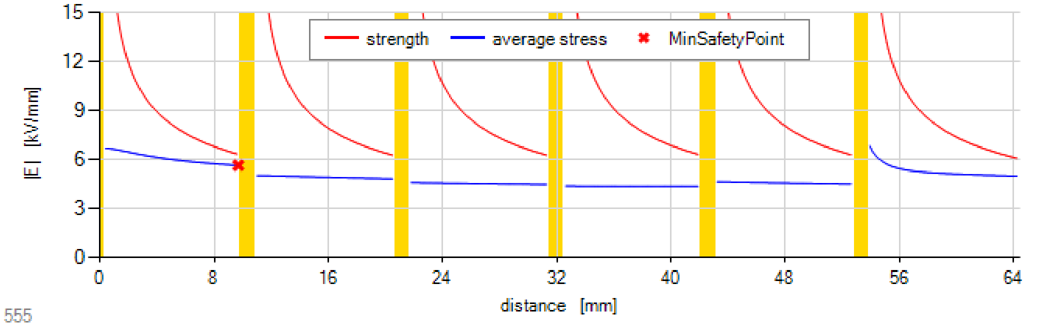




Comparison of max. averaged field and oil curves in function of the respective gap length

Test Voltage [kV]: 300 Max|E| [kV/mm]: 9.4

Starting Point [mm]: X=506.5; Y=1607.0; Z=0.0 Minimum DL [%]: 104 Percent Margin [%]: 4




Comparison of max. averaged field and oil curves in function of the respective gap length

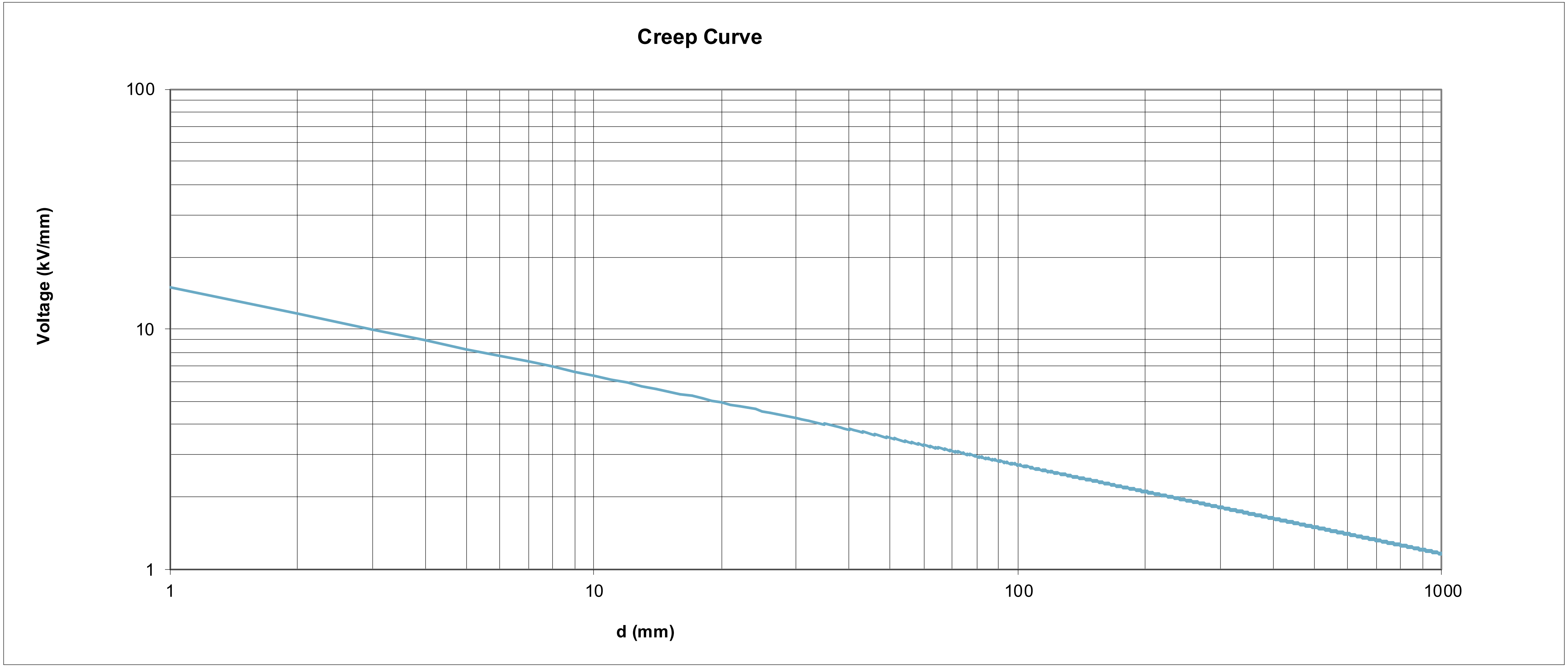
Test Voltage [kV]: 300 Max|E| [kV/mm]: 7.1

Starting Point [mm]: X=506.5; Y=1608.3; Z=0.0 Minimum DL [%]: 112 Percent Margin [%]: 11

# INSULATION DESIGN CONCEPTS

# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

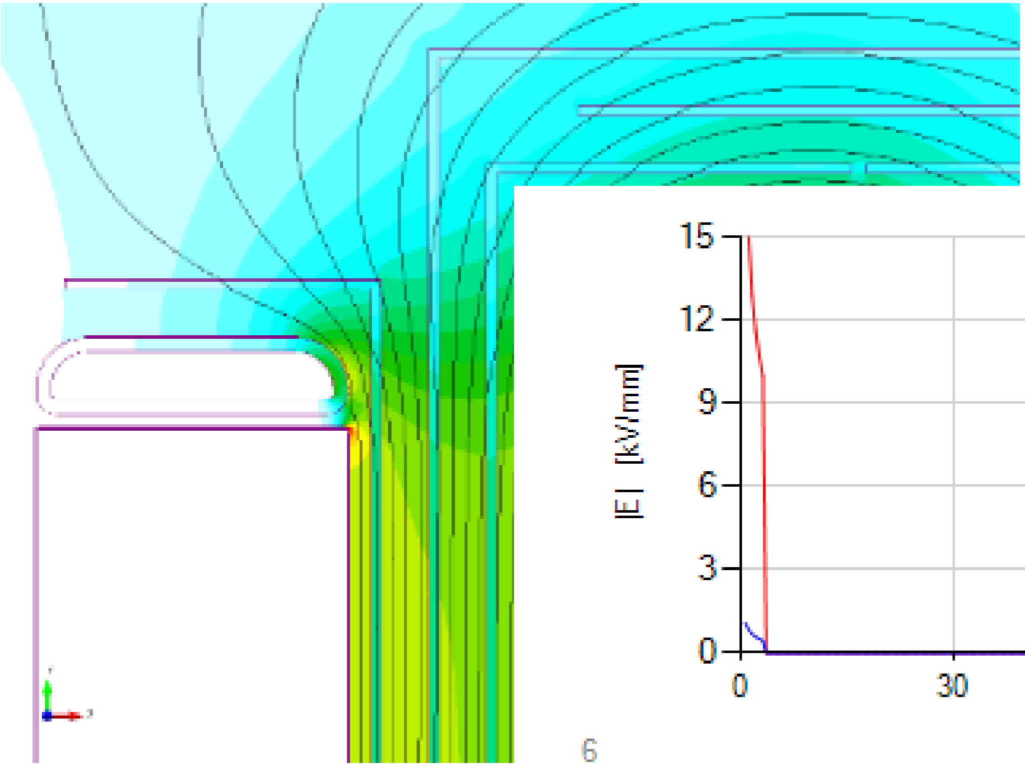
## OPTIMIZED OIL/TRANSFORMERBOARD SURFACE STRESS USING CONTOURED INSULATION

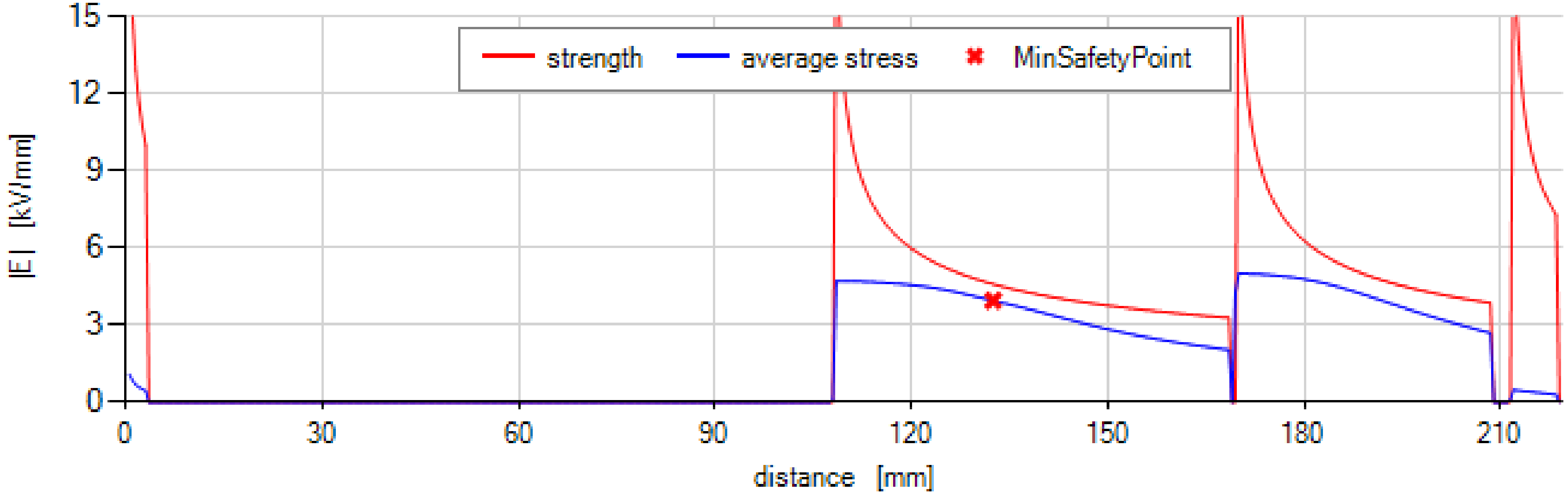


# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## OPTIMIZED OIL/TRANSFORMERBOARD INTERFACE WITHOUT CONTOURED BARRIERS

14% margin along the edges of the components closest to the winding






Comparison of max. averaged field and oil curves in function of the respective creep length

Test Voltage [kV]: 600

Max|E| [kV/mm]: 5.0

Starting Point [mm]: X=498.5; Y=1469.9; Z=0.0

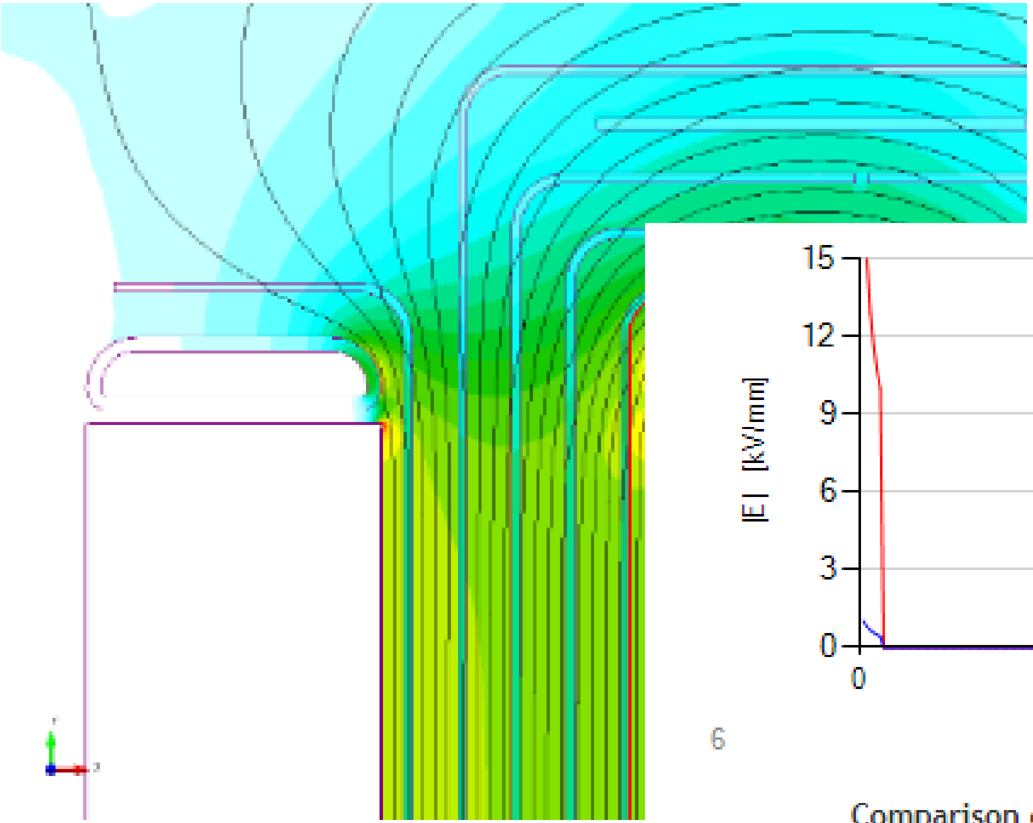
Minimum DL [%]: 116

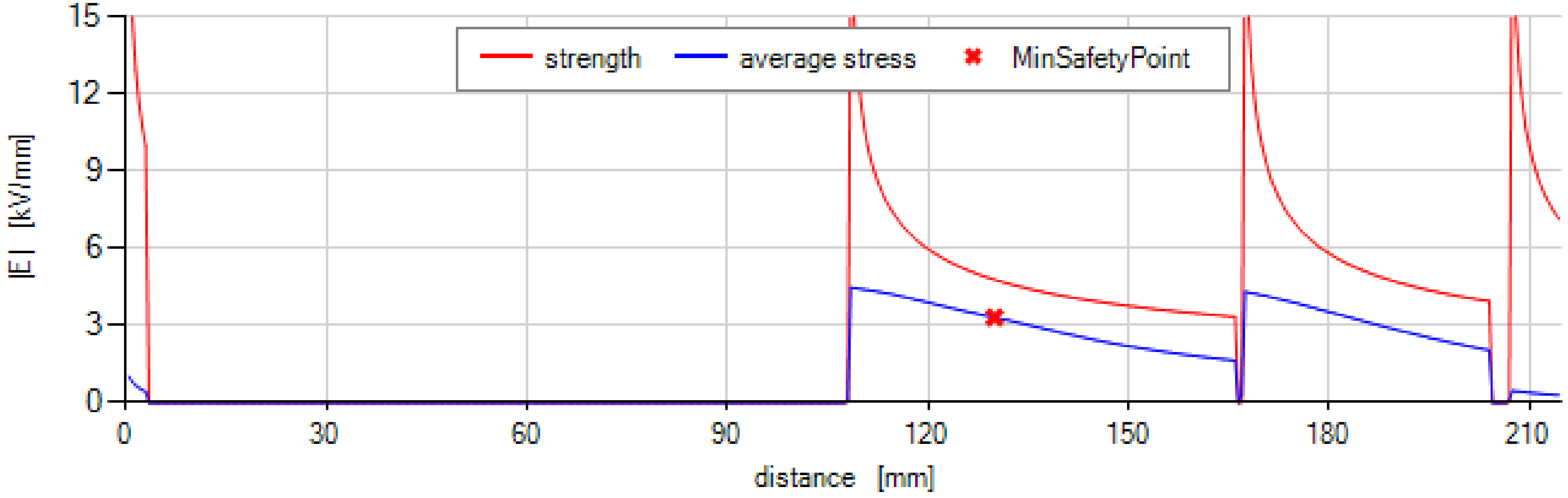
Percent Margin [%]: 14

# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED TRANSFORMERS

## OPTIMIZED OIL/TRANSFORMERBOARD INTERFACE WITH CONTOURED BARRIERS

31% margin along the edges of the components closest to the winding






Comparison of max. averaged field and oil curves in function of the respective creep length

Test Voltage [kV]: 600

Max|E| [kV/mm]: 4.5

Starting Point [mm]: X=498.5; Y=1469.9; Z=0.0

Minimum DL [%]: 144

Percent Margin [%]: 31

# INSULATION CONCEPTS TO OPTIMIZE THE DESIGN OF LIQUID-FILLED

## SUMMARY

- Kraft Pulp from Boreal Forest with quality water are essential raw materials for high dielectric, mechanical, and thermal performance.
- By creping and then calendaring conductor insulation the strength and elongation is significantly improved allowing for high tension during the wrapping process which provides improved space factor.
- By removing the screen pattern on the surface of high-density pressboard the compression characteristics are significantly improved which improves the ability to withstand axial short circuit forces.
- Utilizing pressboard barriers with lower relative permittivity lowers the dielectric stress in the liquid, allowing for smaller oil gaps.
- Dividing the liquid dielectric gap into smaller sub-gaps through the introduction of Transformerboard barriers allows for a smaller overall clearance.
- Using contoured Transformerboard insulation can reduce the surface tangential stress on barriers, allowing for a reduction in clearances or improvement in safety margin.
- Weidmann engineers utilize these concepts as well as many others to provide Optimized Insulation Design Analysis Services.

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# Q&A

# REFERENCES


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