INSULATION IN TRANSFORMERS

13TH MAY 2016

WEIDMANN

ELECTRICAL TECHNOLOGY

WEIDMANN ELECTRICAL TECHNOLOGY, INC.
A Member of the **WICOR** Group

WEIDMANN

Agenda

1. **Introduction**
2. Insulation
    1. Liquid Insulation
    2. Solid Insulation (Cellulose)
        1. Paper
        2. Board
    3. Insulation Life
3. Dielectric Stress/Design

WEIDMANN ELECTRICAL TECHNOLOGY

WEIDMANN is a leading specialist for high voltage insulation and world-wide technology partner for manufacturers and users of transformers.

We develop and produce insulation materials, components and systems and advise our customers in all aspects of transformer design and operation.

WICOR
WEIDMANN INTERNATIONAL CORPORATION

•Founded in 1877

•Employees 4000

•Worldwide supplier for engineered products in ELECTRICAL TECHNOLOGY and PLASTICS TECHNOLOGY

•Privately held

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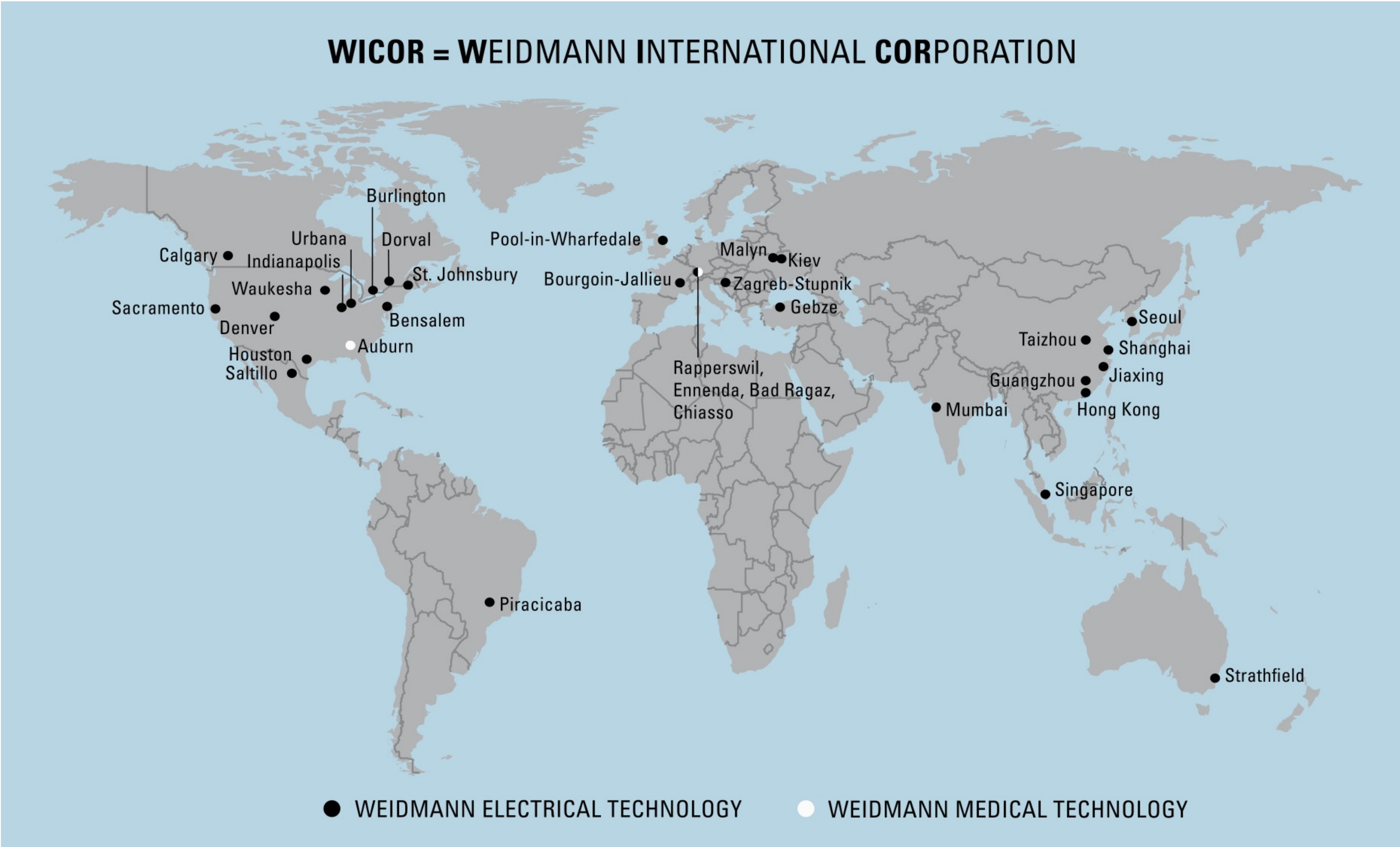
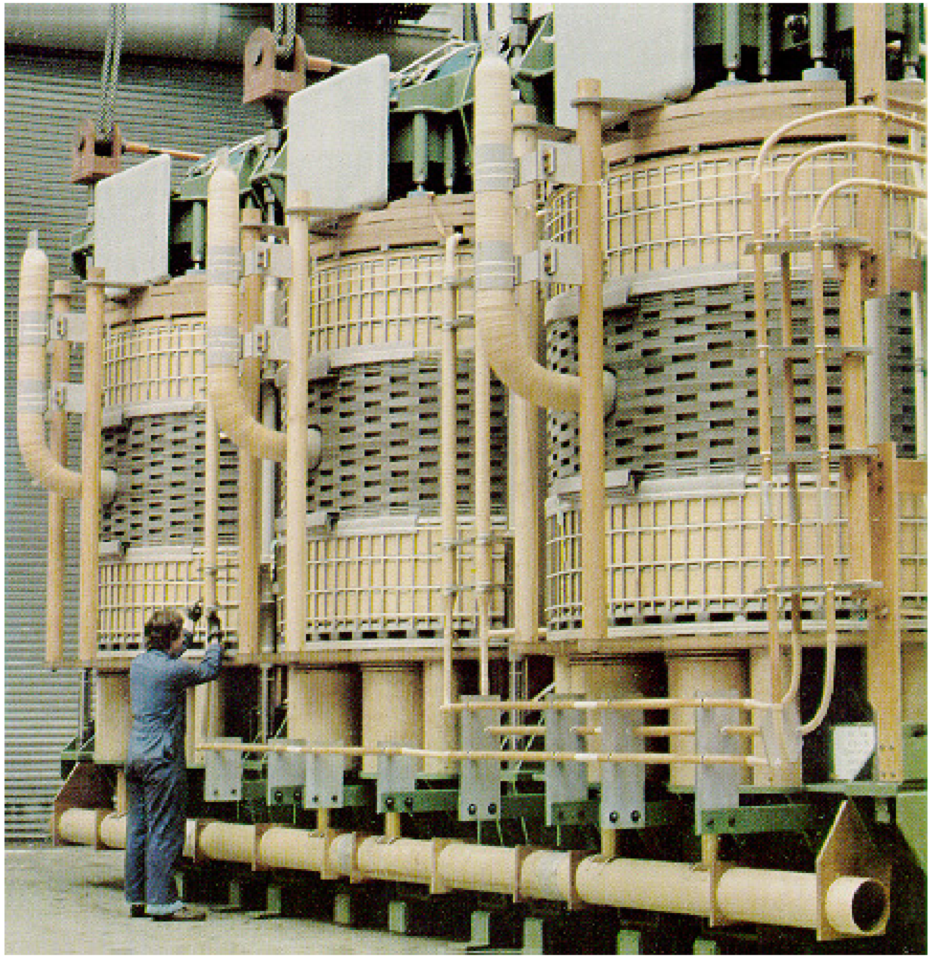
Locations



Modern Power Transformer

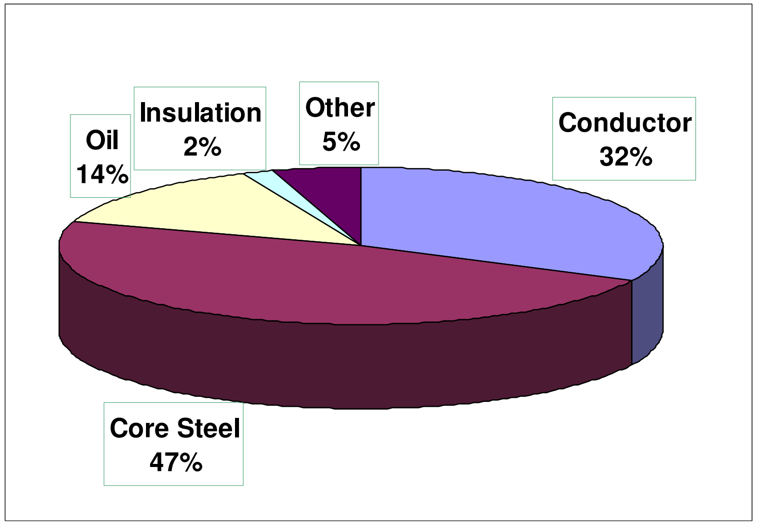
Insulation Systems

- Transformerboard
- Insulating Paper
- Laminated PB
- Laminated Wood
- Enamel – Wire
- Epoxy Coatings
- Paper Phenolic
- Dielectric Fluid



Cellulose insulation in transformers

- Cellulose insulation in transformers comprise just a small percentage of total transformer costs, yet have tremendous leverage over design, size & weight.
- It is the weakest link in the transformers and has the most influence during the ageing process



Large Power Transformer Materials

(reference 250 MVA Transformer)

Material	Weight (kg)	%
Core Steel	67165	34
Sheet Steel	45573	22
Copper Wire	24228	12
Transformer Oil	48000	24
Kraft - Cellulose		
Pressboard	5294	3.0
Paper	1479	1.0
Total	200,000	100%

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Purpose of the Dielectric Fluid

- Provide Sufficient Dielectric Strength
- Provide Sufficient Cooling/Heat Transfer
- Preserve the Core and Coil Assembly
  (By filling the insulating material voids)
- Minimize the contact of oxygen with cellulose and other materials susceptible to oxidation

Insulation Fluids

- Mineral Oil
    - Naphthenic
    - Paraffinic
    - High Molecular Weight
- Silicone Fluid
- Synthetic hydrocarbons
    - E.g. Polyalphaolefins
- Polyol Esters
- Natural Esters (seed oils)
    -BioTemp®, FR3®

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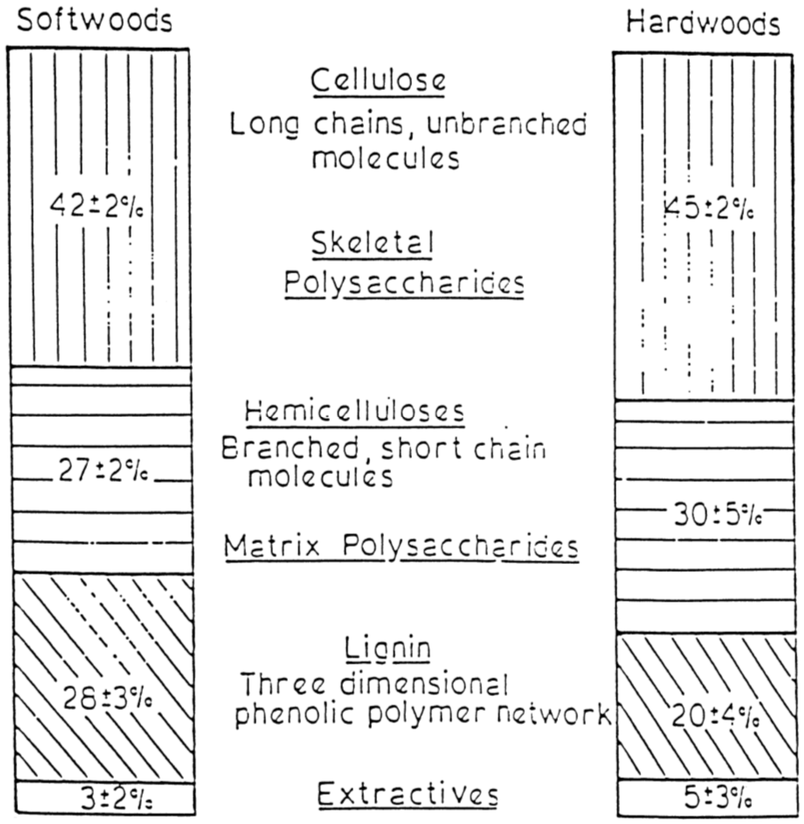
Role of Transformberboard in the Transformer‘s Insulation Subsytem

- Only Two Components
  - Water
  - Cellulose
- Mechanical
- Dielectric
- Thermal Cellulose determines life and loading
  - Class “A” Insulation - 105ºC class

Cellulose

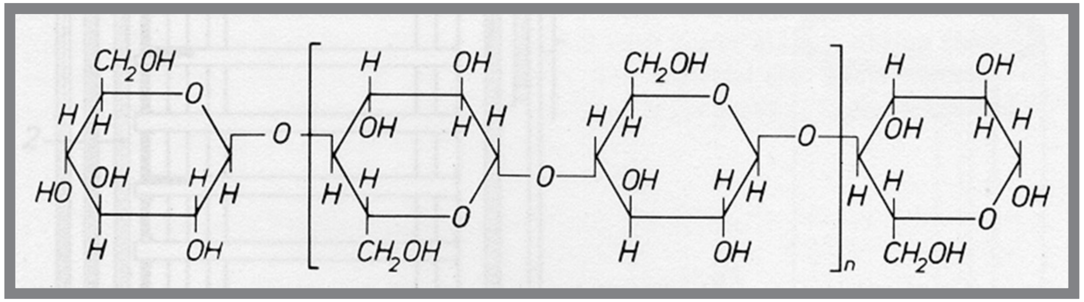


Average compositions of softwoods and hardwoods.

Northern Softwood Conifer: long, thin fiber (3-6mm)

Electrical-Grade (kraft process) Paper and Pressboard

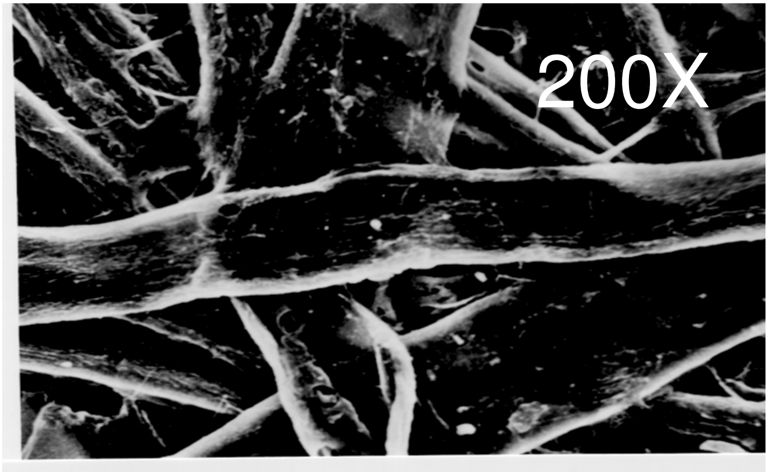
- **Most electrical-grade pressboard and papers used in oil-filled apparatus are made from wood cellulose refined using the "kraft" process. ("kraft" = German word for "strong".)**
- **The usual pulp furnish for electrical grade papers is unbleached, kraft-process pulp made from spruce, fir, and pine tree species from northern latitudes. Why? → cold climate = slower tree growth → long fiber length = higher strength.**

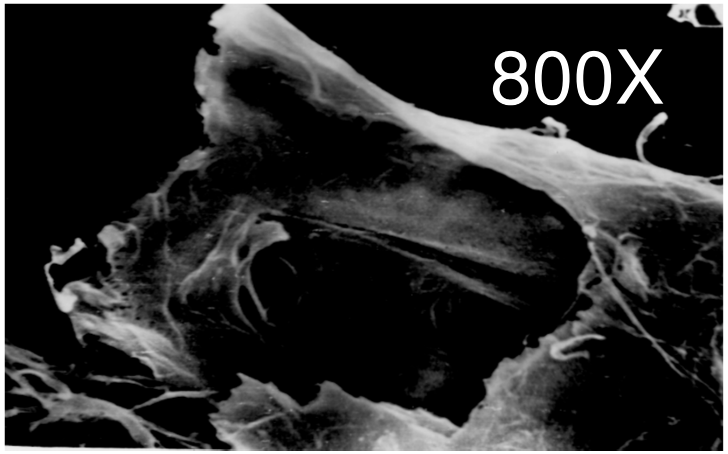


Cellulose Macromolecule

Transformerboard Production

Cellulose



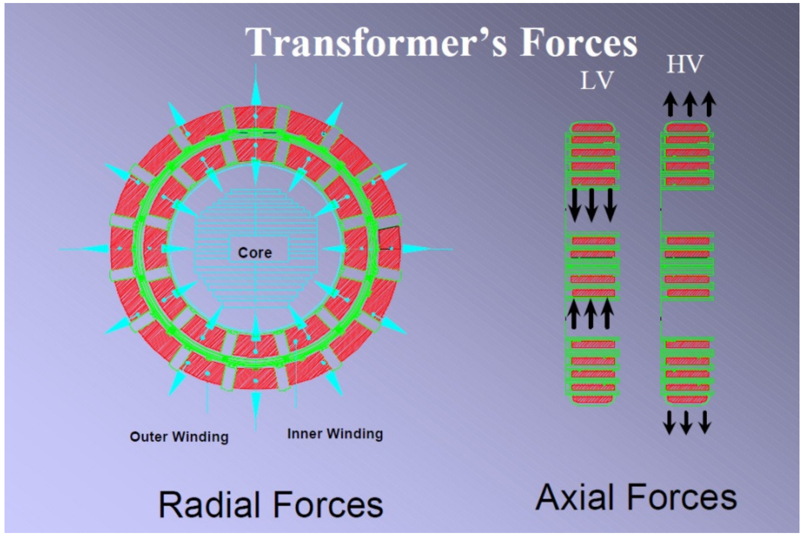


Cellulose Enlargements

Purpose of Solid Insulation in Transformers

Mechanical

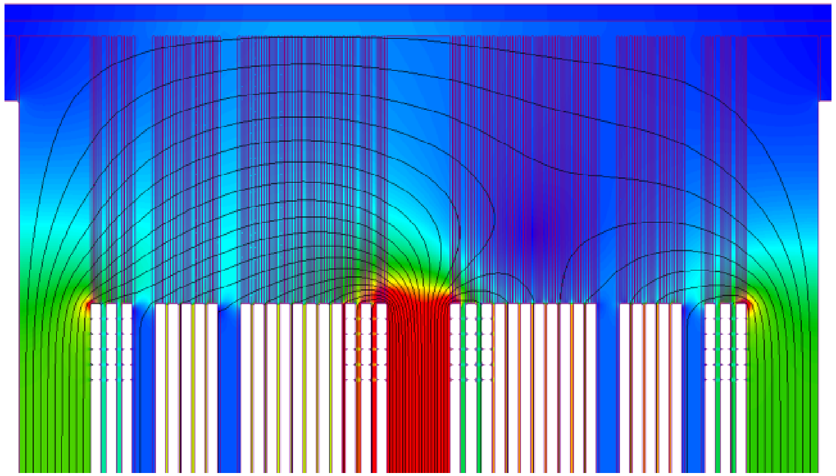
- Winding tool
- Support the windings during short circuit
- Deal with axial and radial forces
- Maintain sufficient tensile, elongation, tear and compression strength during ageing of insulation
- Maintain dielectric clearances
- Support leads and auxiliary equipment



Purpose of Solid Insulation in Transformers

Dielectric

- Insulation should be able to deal with various dielectric stresses
  - Oil gap stresses
  - Creep Stresses
  - Stress in solid insulation



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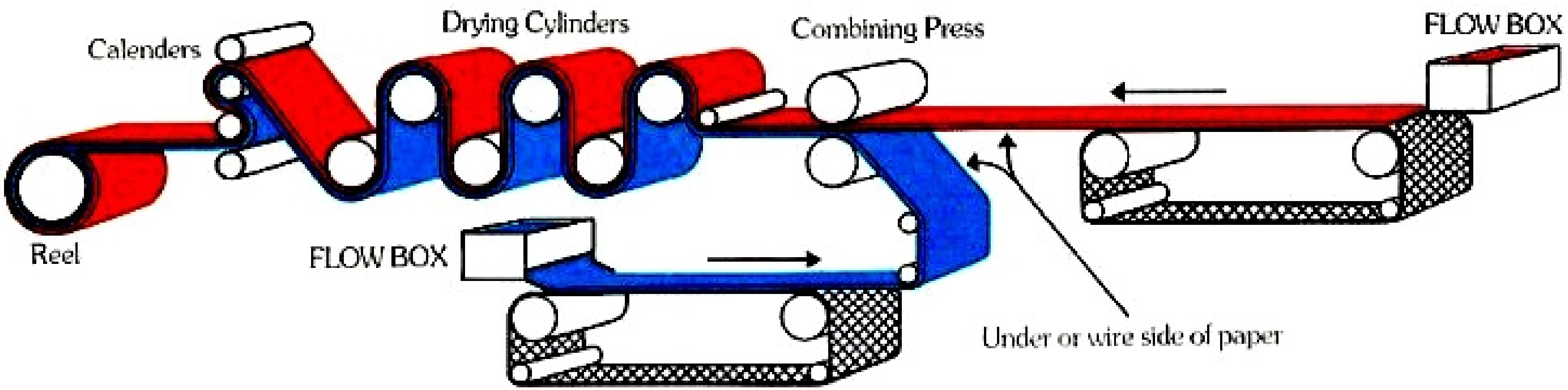
Paper Production

Pulp – Paper Flow

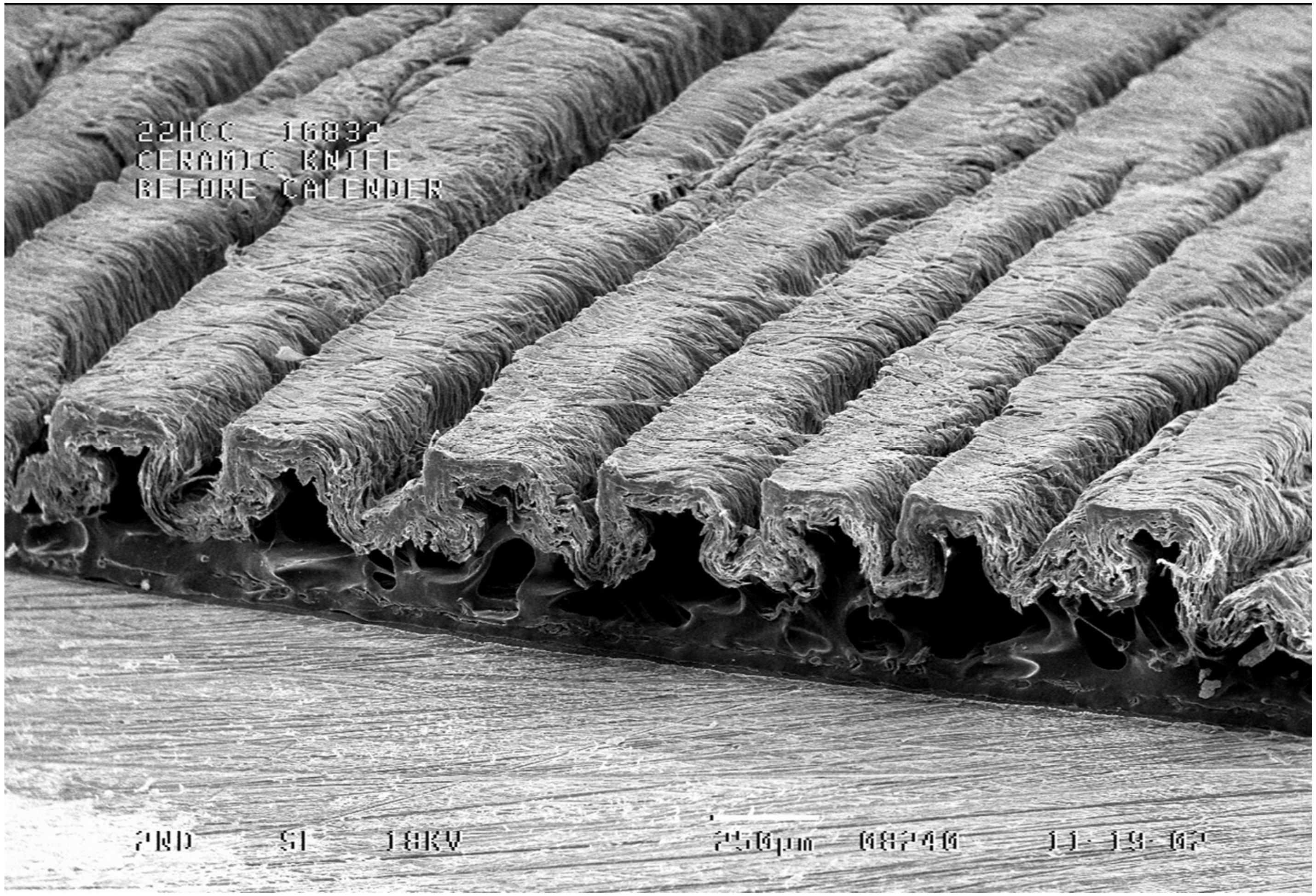


•Multiple wire-mesh assemblies allows for thicker material

•Paper is continually processed whereas Transformerboard is made one sheet at a time

Paper

Creped Material



Paper

Creped Paper

- Provides extensibility (stretch) to the product
  - Allows the paper to fit tightly over curved surfaces without wrinkles or gaps
  - Resists tearing during coil winding
  - Low **T**ensile **E**nergy **A**bsorption (toughness)
- Can be calendared
  - Control thickness of creped material
  - Adds some TEA

Paper

Adhesives

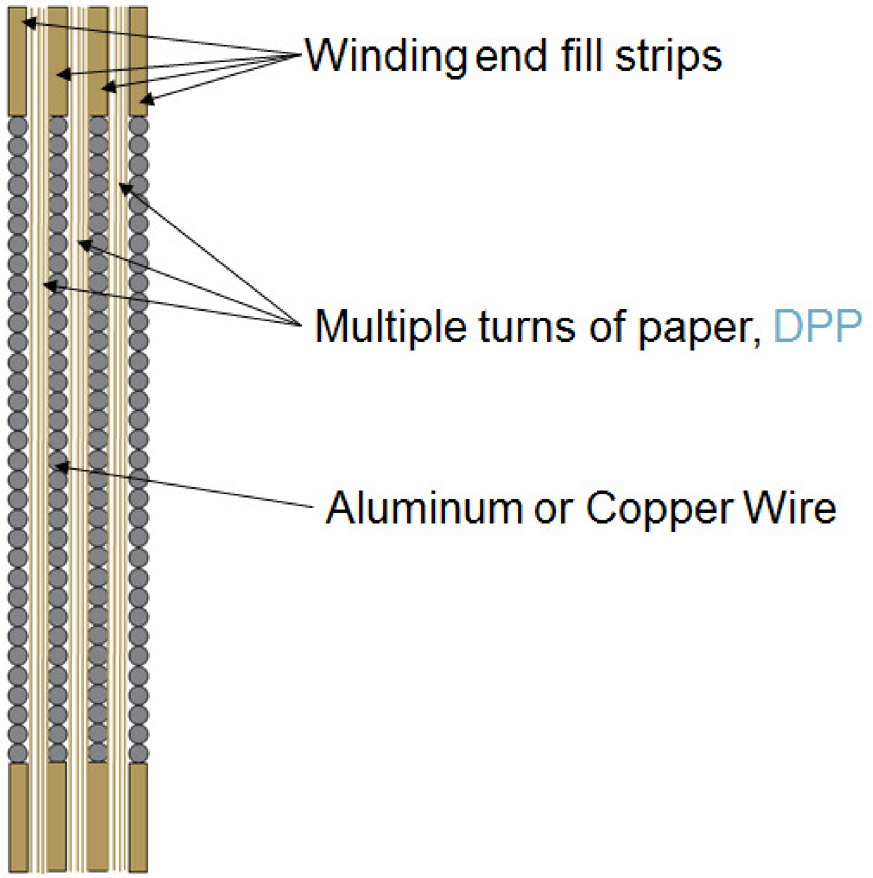
- Single or double sided application
- B-stage epoxy creates a rigid structure after heat treatment
- Diamond pattern creates a small oil duct to allow for impregnation

Paper

Thermal Upgrading

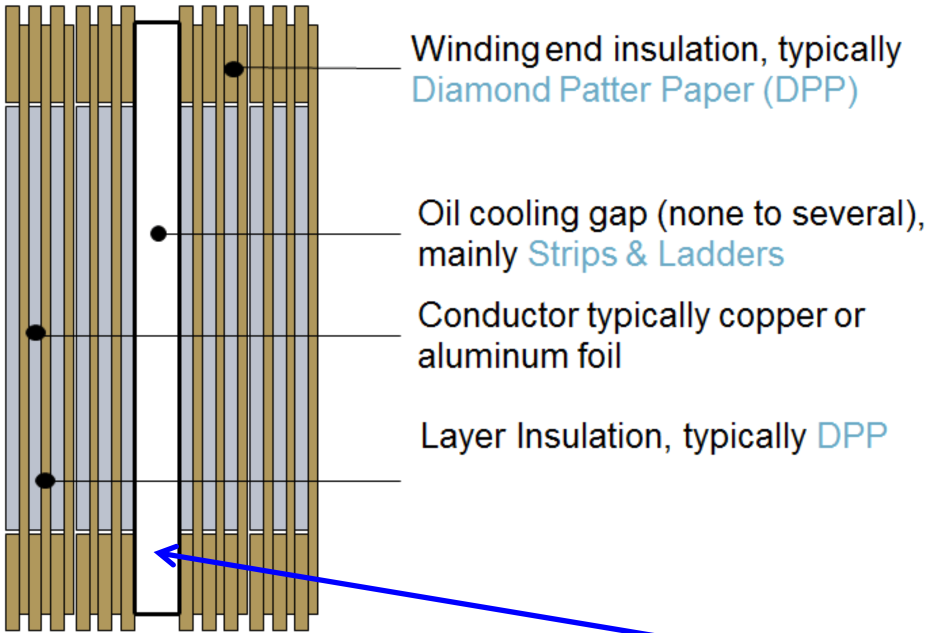
- All insulations degrade, changing chemical composition and properties over time. Dielectric, Mechanical, and Chemical strength dissipates.
- This process is greatly accelerated by heat.
- If we increase the paper's maximum "normal operating " temperature to a higher level, we can:
    - Run the transformer at a higher temperature, without degradation, and thus raise its capacity and productivity.
    - Run the transformer at the prior normal temperature, and extend its life.
- Normal paper is designed for a 55º "rise" (40º ambient + 55º rise = 95º total.)
- Thermally Upgraded paper can operate at a 65º "rise" (40º ambient + 65º rise = 105º total.)

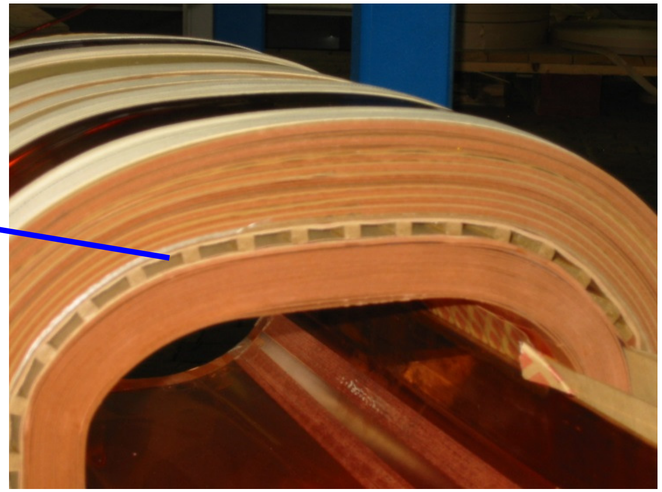
HV Layer Type Windings



LV Layer Type Windings

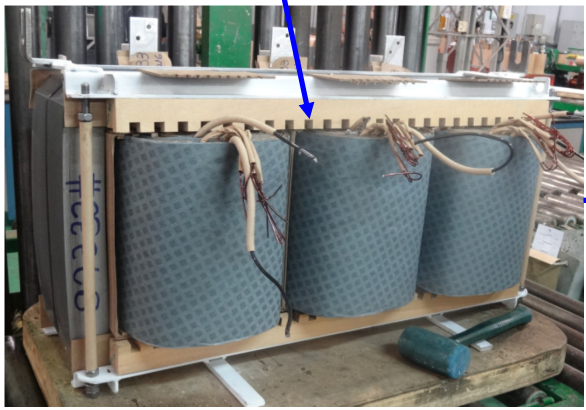
LV Winding



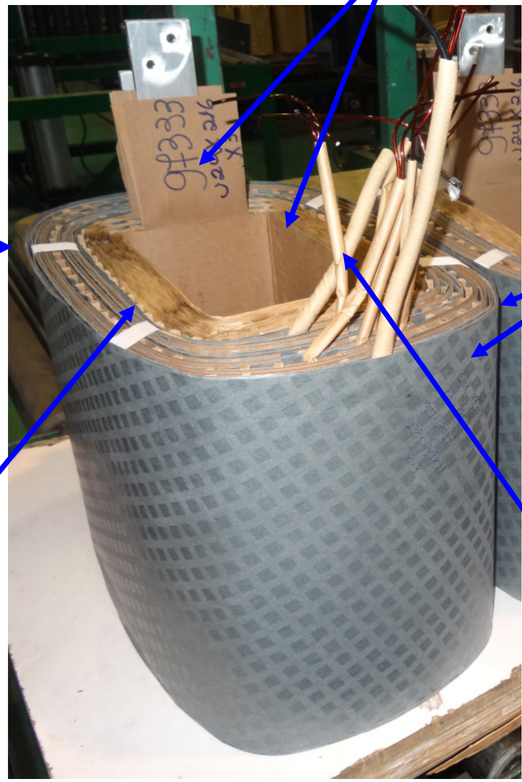


Other Insulation Products

Fixation Elements such as clamps and blocks



Transformerboard



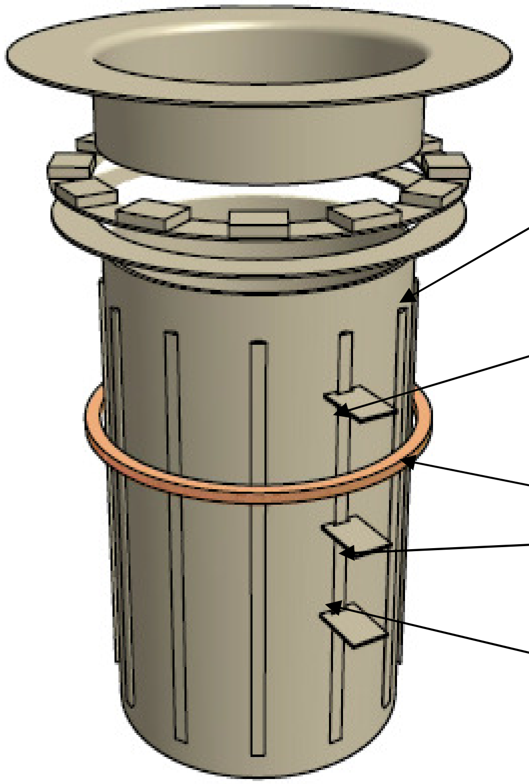
Various paper products: DPP, Kraft paper, Crepe paper…

Duct Strips for oil flow

Copper conductor insulated by crepe paper tubes

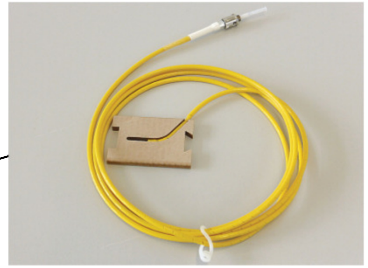
SMART INSULATION™ – DIRECT MONITORING APPROACH

Insulation System
with Embedded Sensors

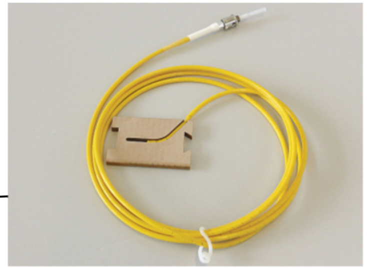


Winding Cylinder

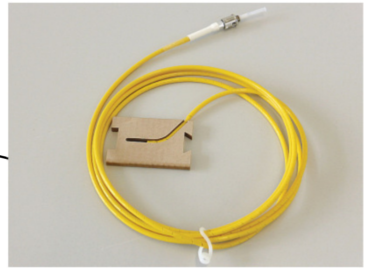
Conductor



SmartSpacer® T
Temperature



SmartSpacer® M
Moisture in Paper
(in development)



SmartSpacer® F
Clamping Force
(in development)

Sensors are integrated with
eNameplate software.

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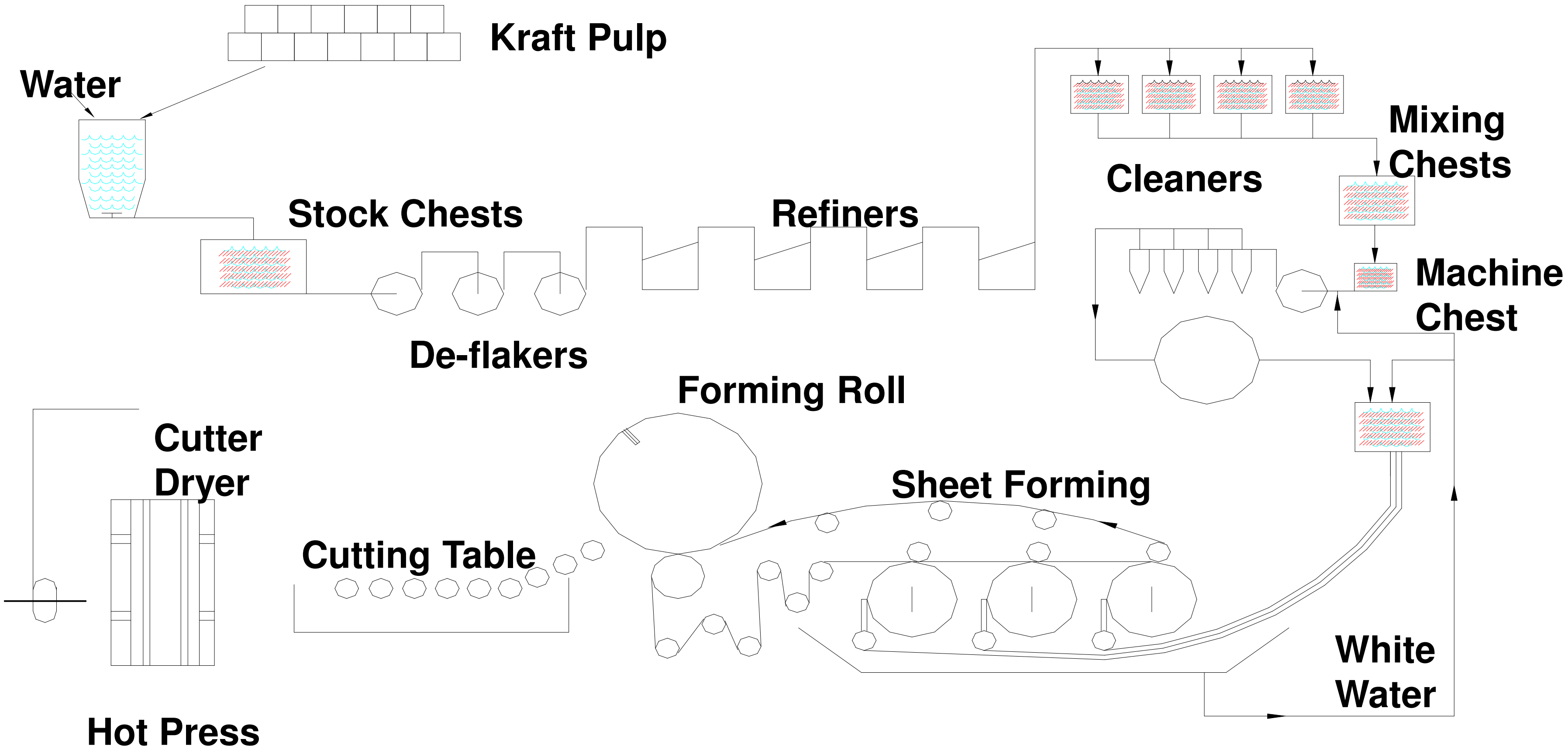
Transformerboard Production

Pulp - Transformerboard Flow



(Machine diagram for production of Transformerboard precompressed.)

Transformerboard Production

BM#1 – Low Density

BM#2 – High Density

Transformerboard Production

Types of Transformerboard

*Difference is due to final drying process

Pre-compressed – High Density

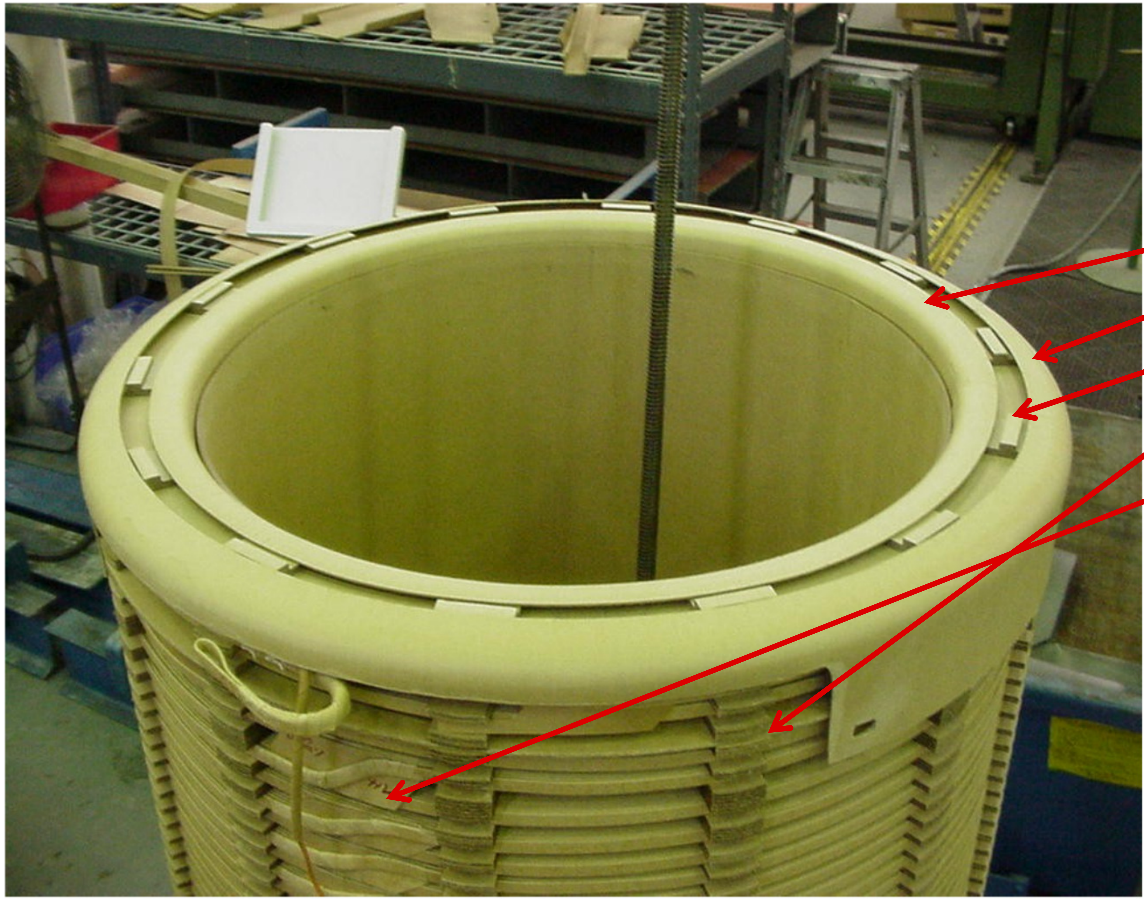
- Dried Under Pressure and Temperature
- Restrained between screened platens – PEEK wires

Calendared – Low Density, Formable

- Dried Unrestrained – no pressure
- Circulating Air Over ~ 100m long
- Calendared – roll press to obtain final density

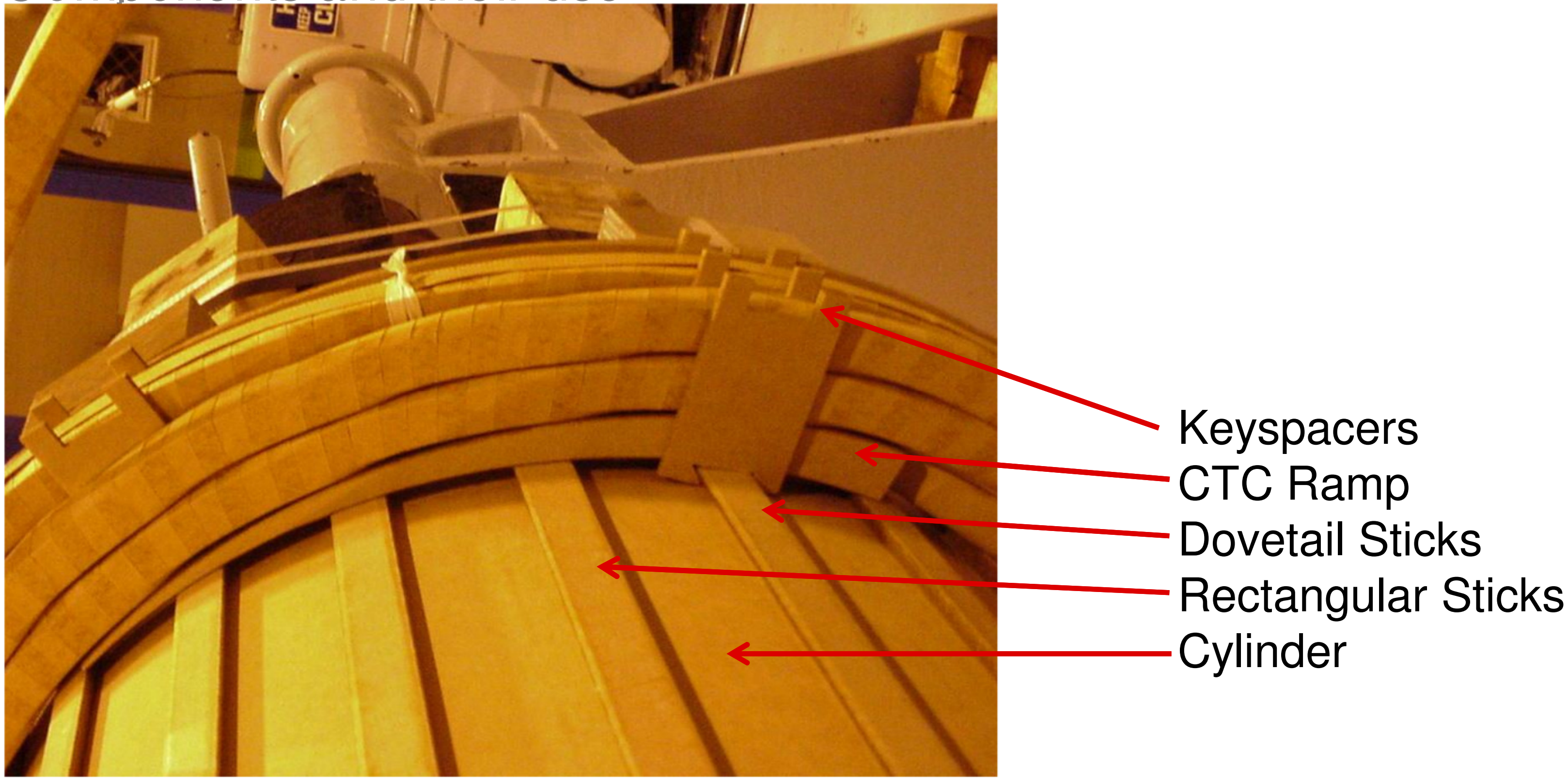
Function

Components and their use

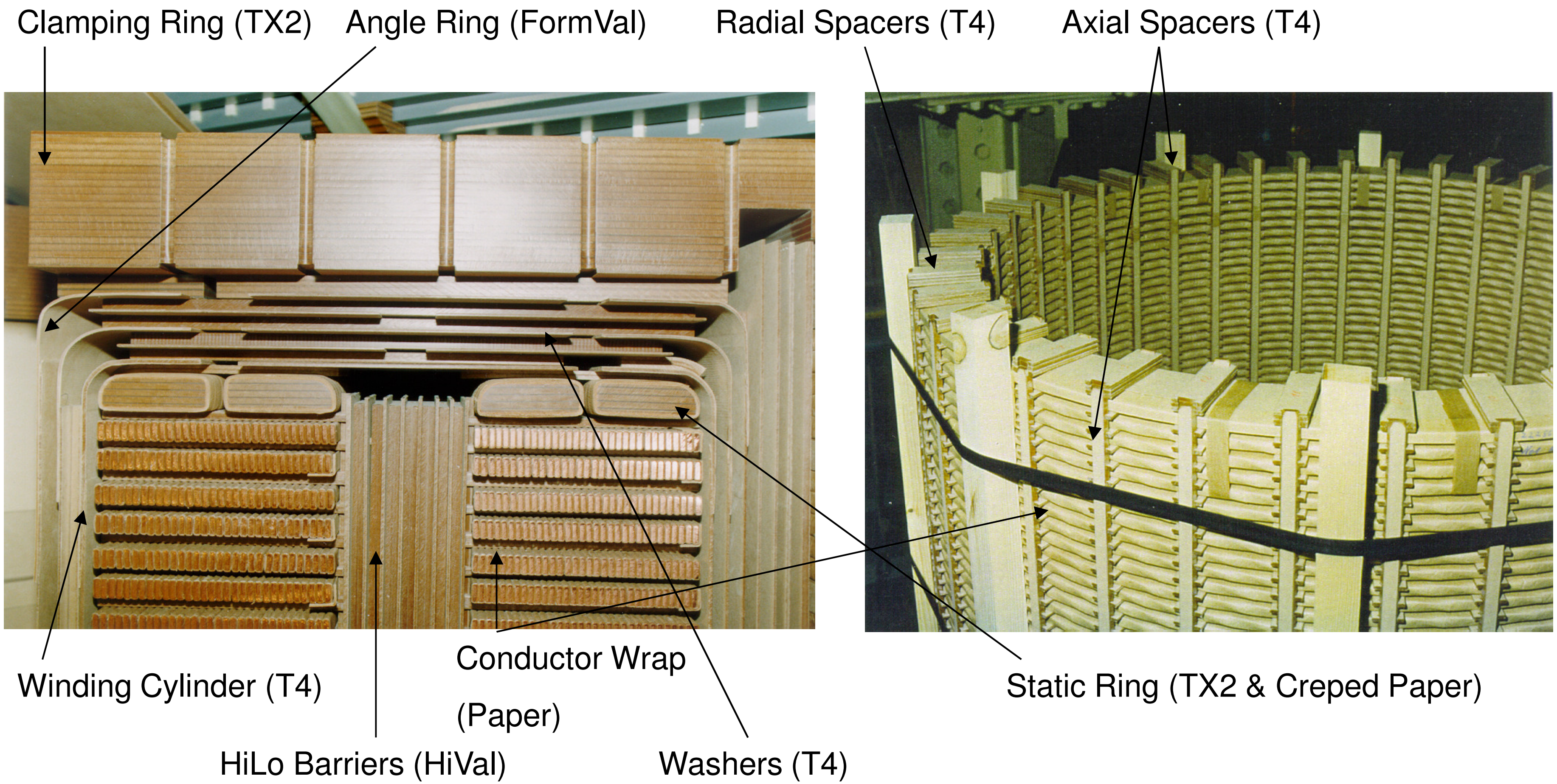


Function

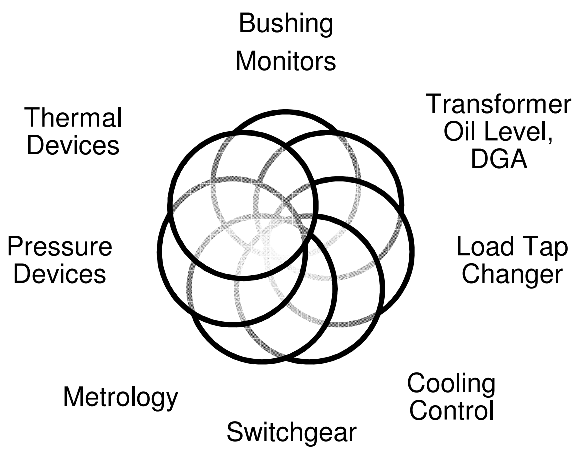
Components and their use

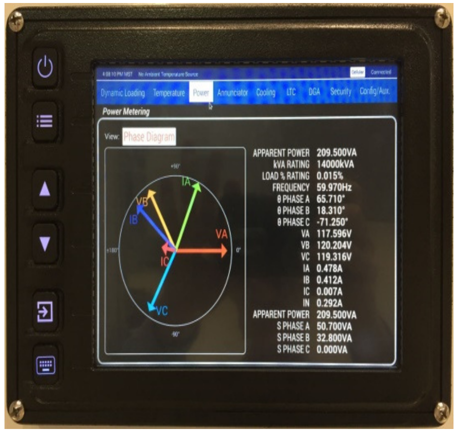


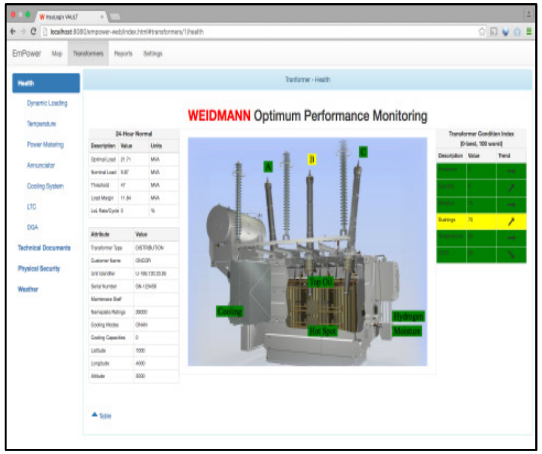
How is Pressboard used?

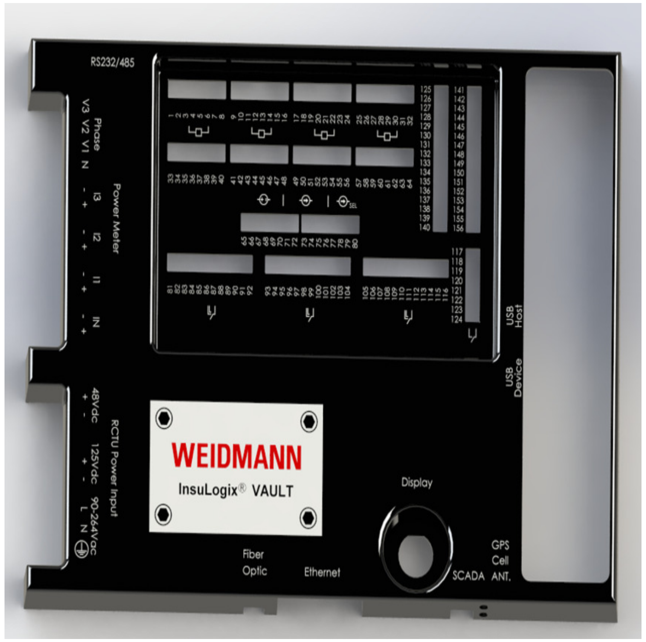


WEIDMANN InsuLogix® Vault - the next step in SMART INSULATION™







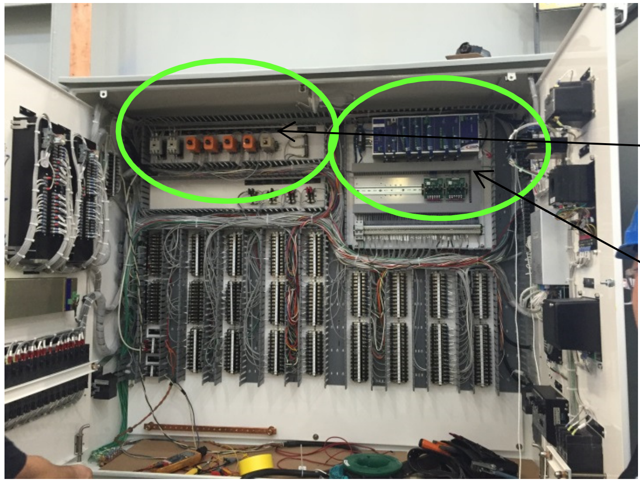


Control Panel components that can be replaced with the VAULT

Annunciator

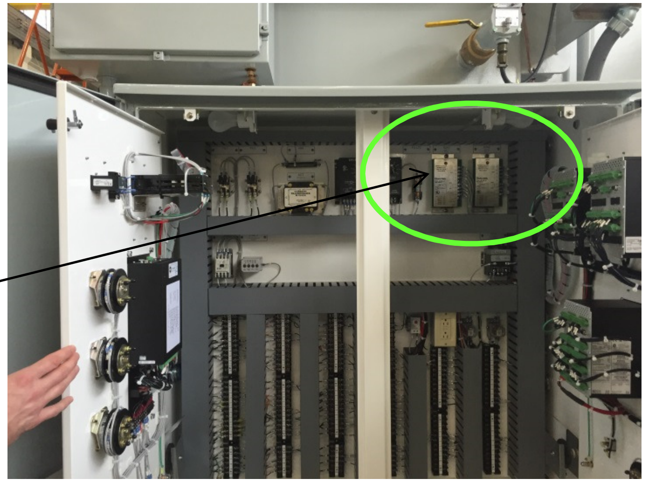
Tap counter

Monitor



Relays

Monitor Modules



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Insulation Life

The thermal limit of transformer windings is the insulation on the conductor at the winding hot spot. The average winding rise is calculated as follows:

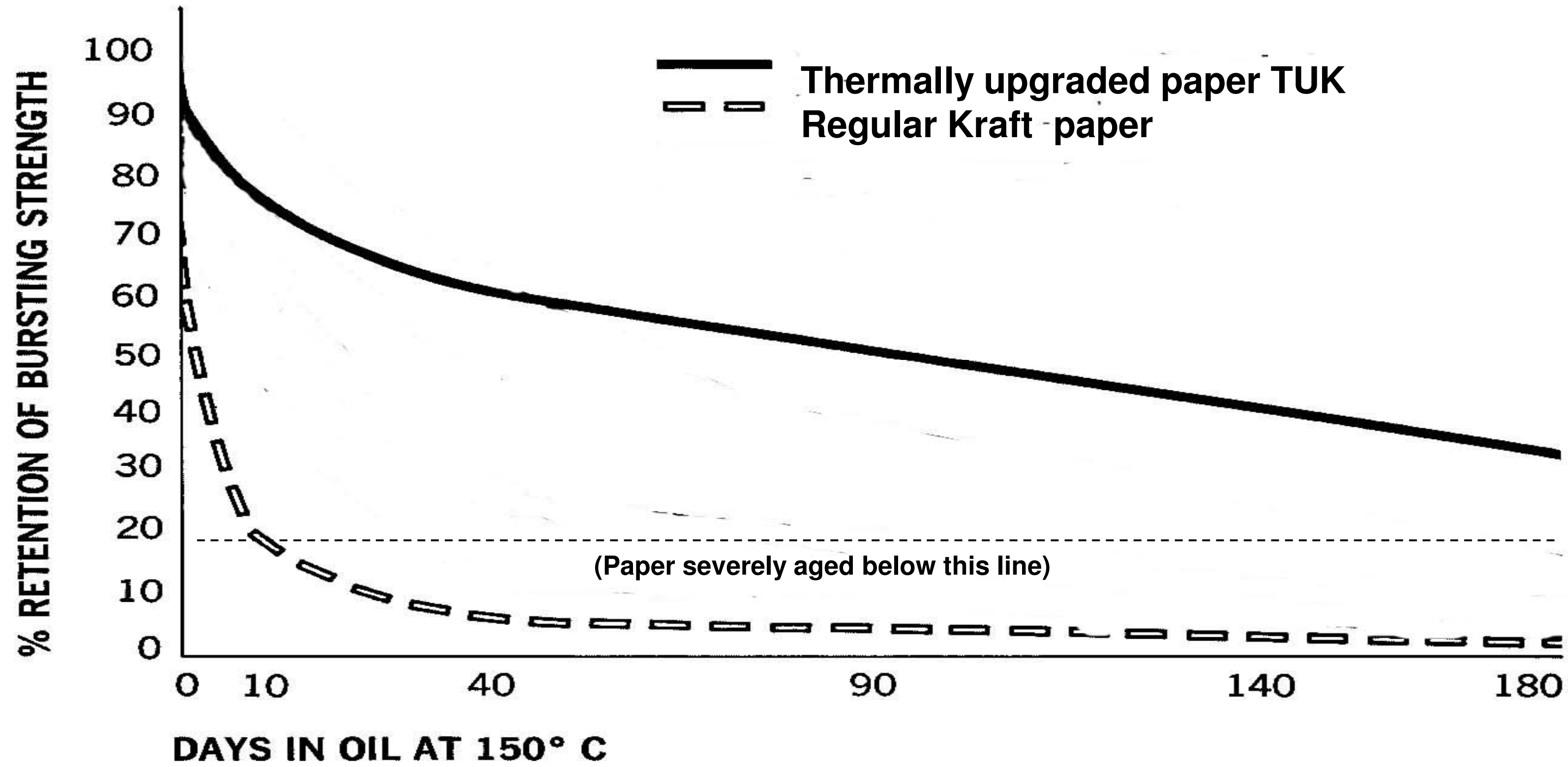
	55° C Rise	65° C Rise	75° C Rise
Ambient (max ave.)	30°	30°	30°
Average Winding Rise	55°	65°	75°
Hot Spot Differential	10°	15°	15°
Hot Spot Temperature	95°	110° *	120° **

*Only attainable with thermally upgraded insulation.
** Only attainable with specialty cellulose insulation.

+10º C ≈ 12% Increase in Transformer MVA

Insulation Life

Aging Curves



Source: Westinghouse/ABB Brochure on Insuldur®

Insulation Life

Degree of Polymerization

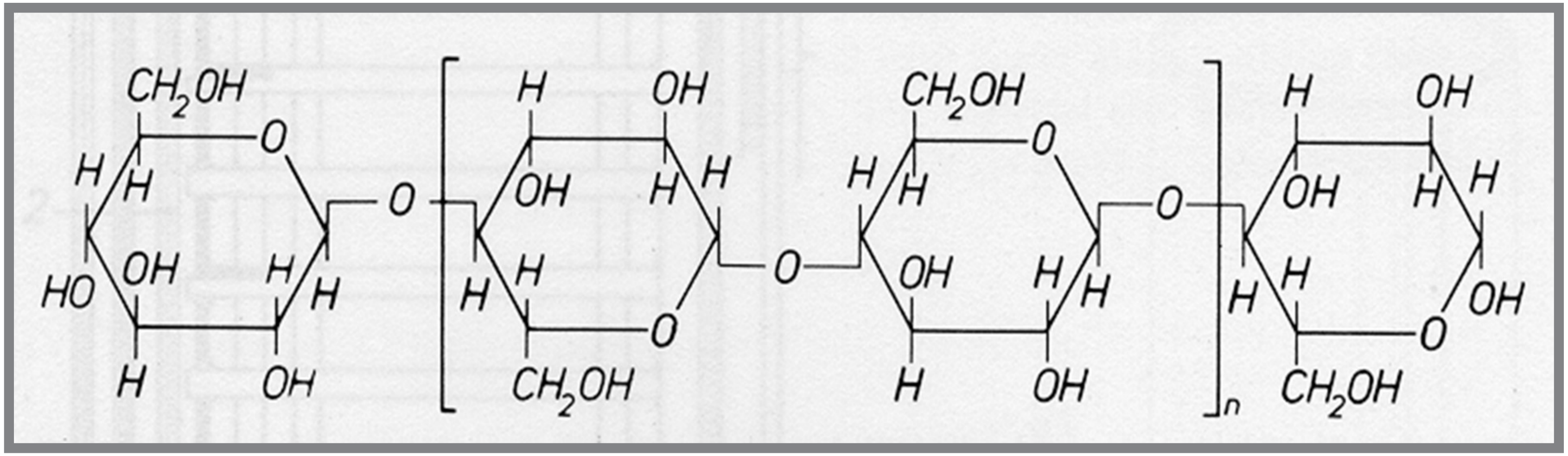
Measurement of intrinsic viscosity after dissolving the cellulose in a specific solvent.

Gives an average measurement of the number of glucose units per molecular chain = Average fiber length

• DP Incoming Kraft Pulp	~1400
• DP of Insulation Components prior to processing	~1200
• DP of Insulation Components following processing	~1000
• DP level considered as “over-processed”	~800
• DP level considered end of life	~200

Insulation Life

Degree of Polymerization



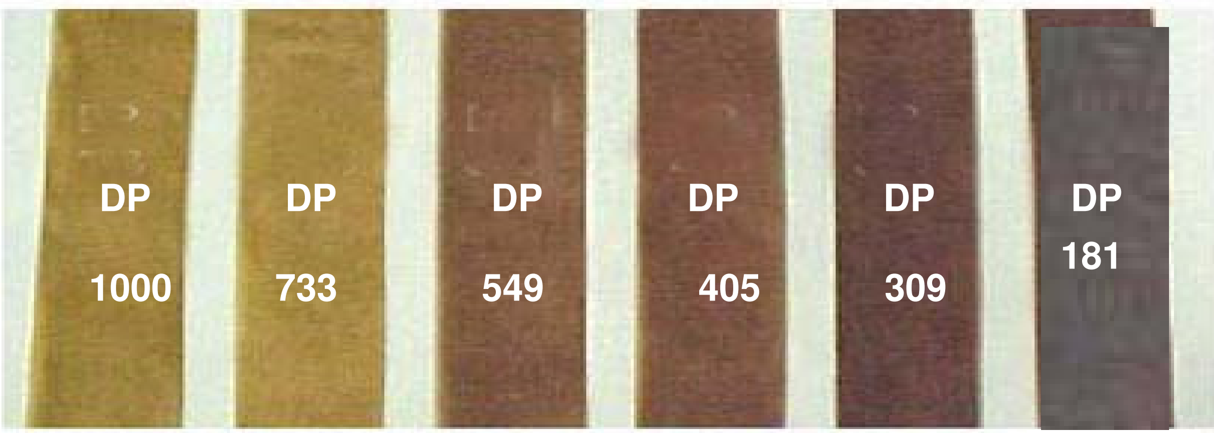
Degree of Polymerization = measurement of “n”

Quantity of uninterrupted molecules is indicative of structural stability

Insulation Life

Degree of Polymerization

Paper Insulation Aging in Mineral Oil



Progressive aging with time **End of mech str.** **Brittle & dark**

<u>Effects of aging:</u>

- **darkening of color**
- **loss of electrical and mechanical strength; trans. Failure**
- **shortening of cellulose chains – DP lowered**
- **paper becomes wetter, and acidic**
- **by-products contaminate the oil**

Source ABB Power Technologies, Inc.

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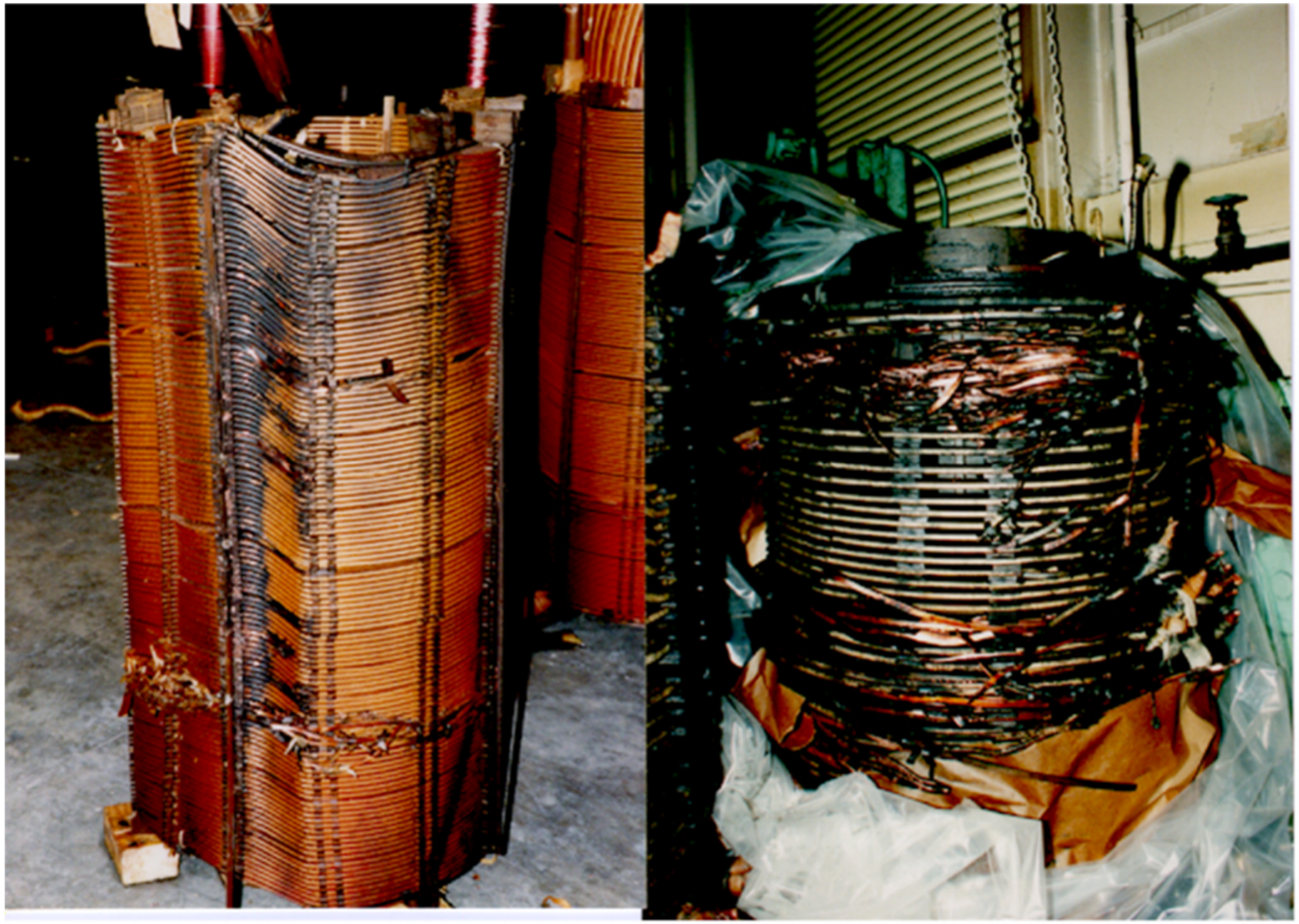
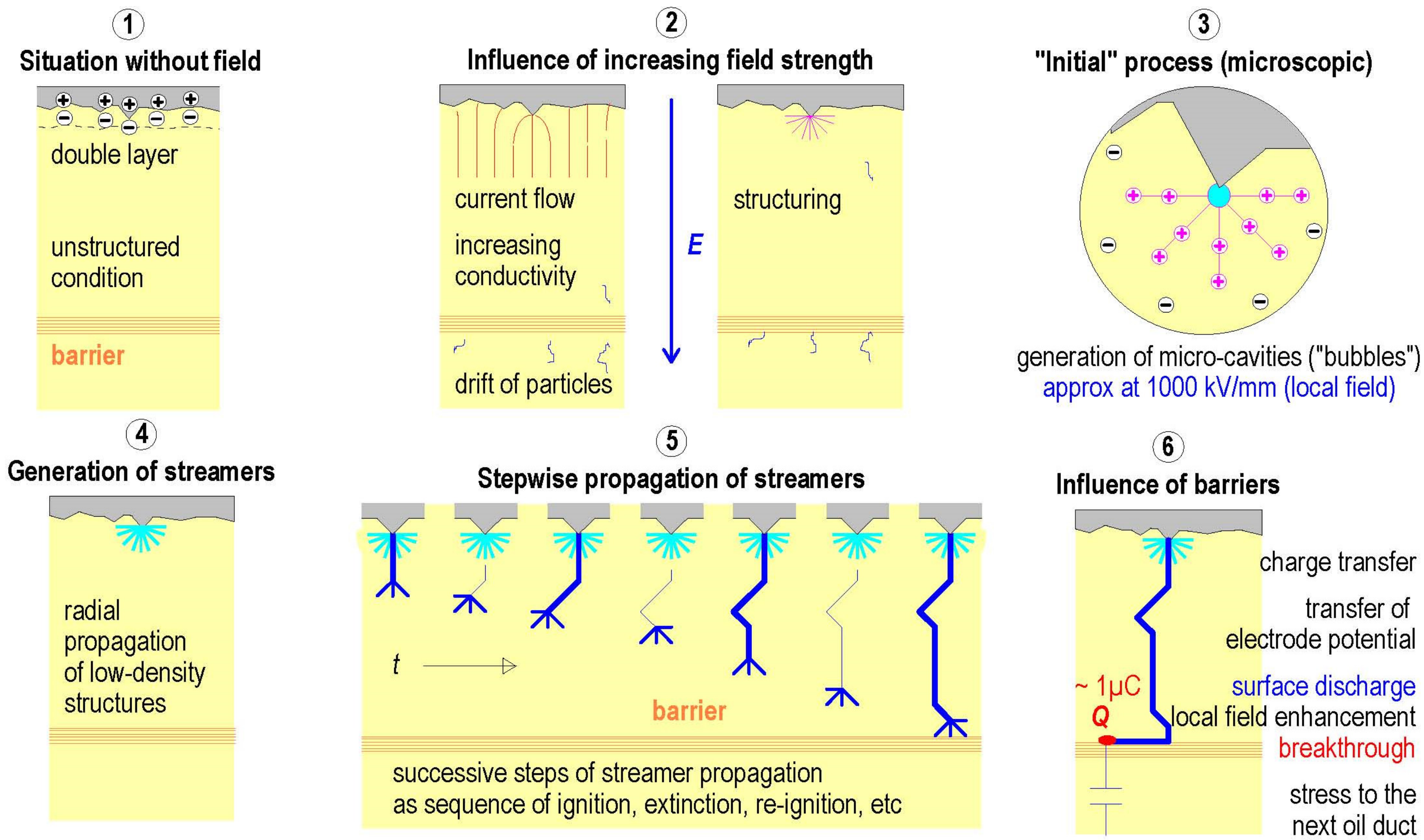
FAILURE!



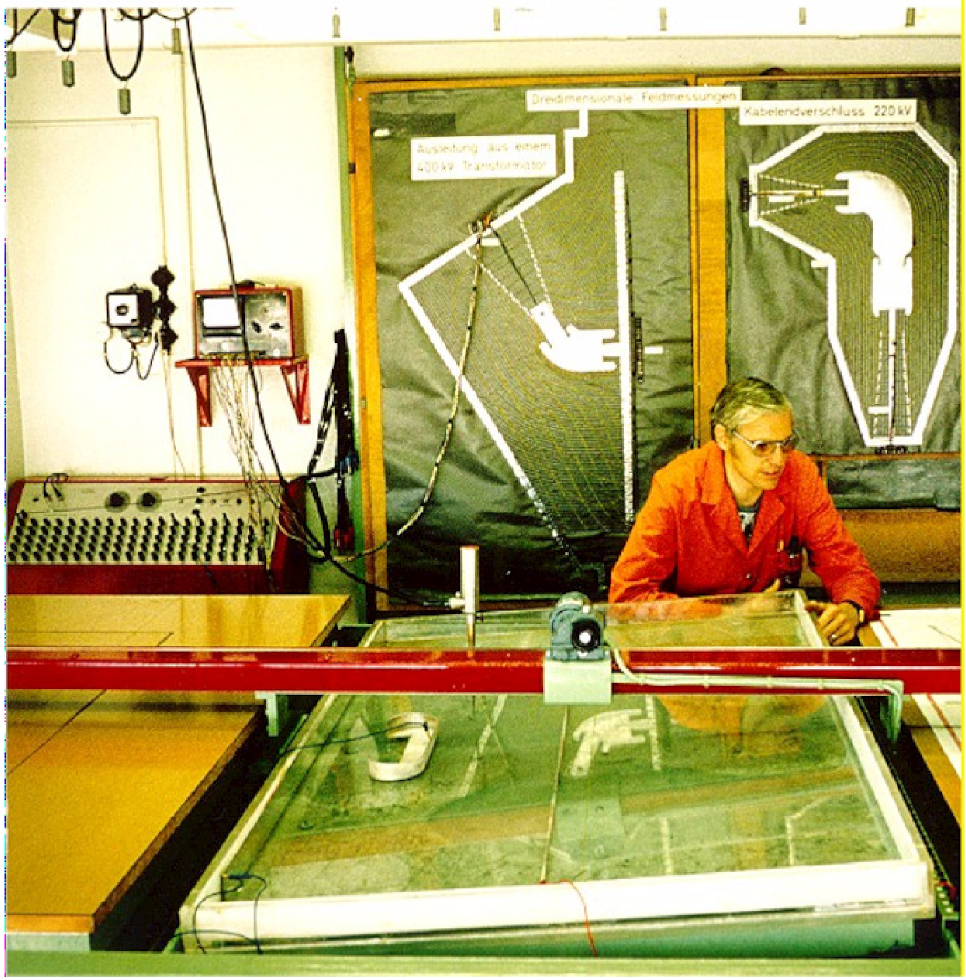
Dielectric Stress

Theoretical Failure Model



Dielectric Stress

Predicting Failures

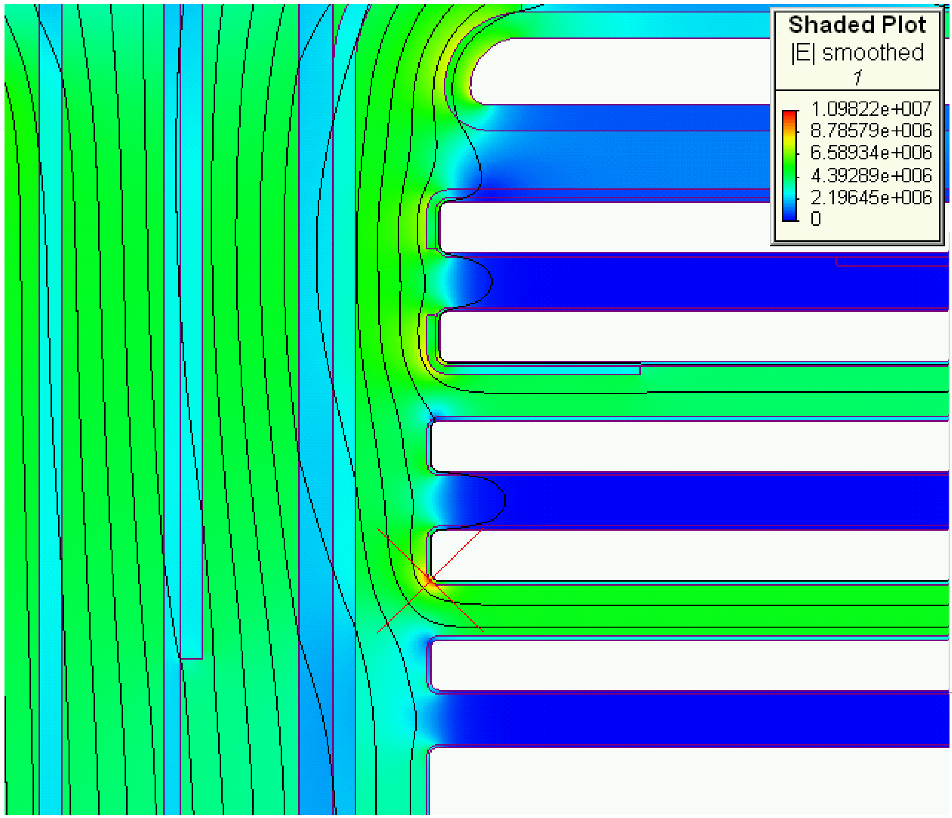


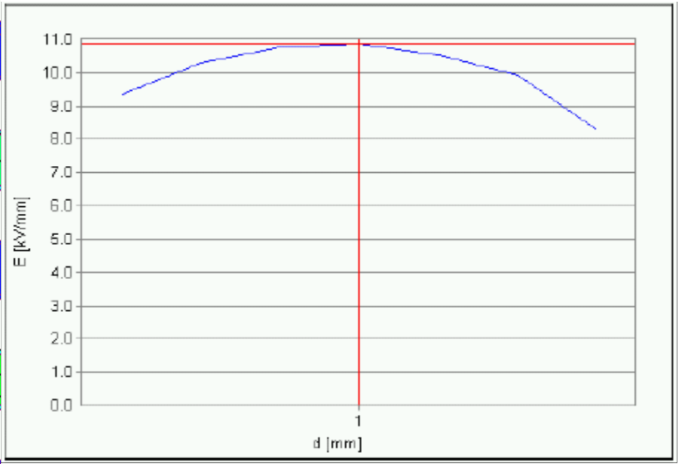
Finite Element Analysis (FEA) allows us to predict where areas of high dielectric stress could occur. We can then arrange Transformerboard in a manner that reduces the likelihood of discharges propagating.

Dielectric Stress

Predicting Failures – Local Stress

New FEA tools allow us to simulate designs and stresses much quicker

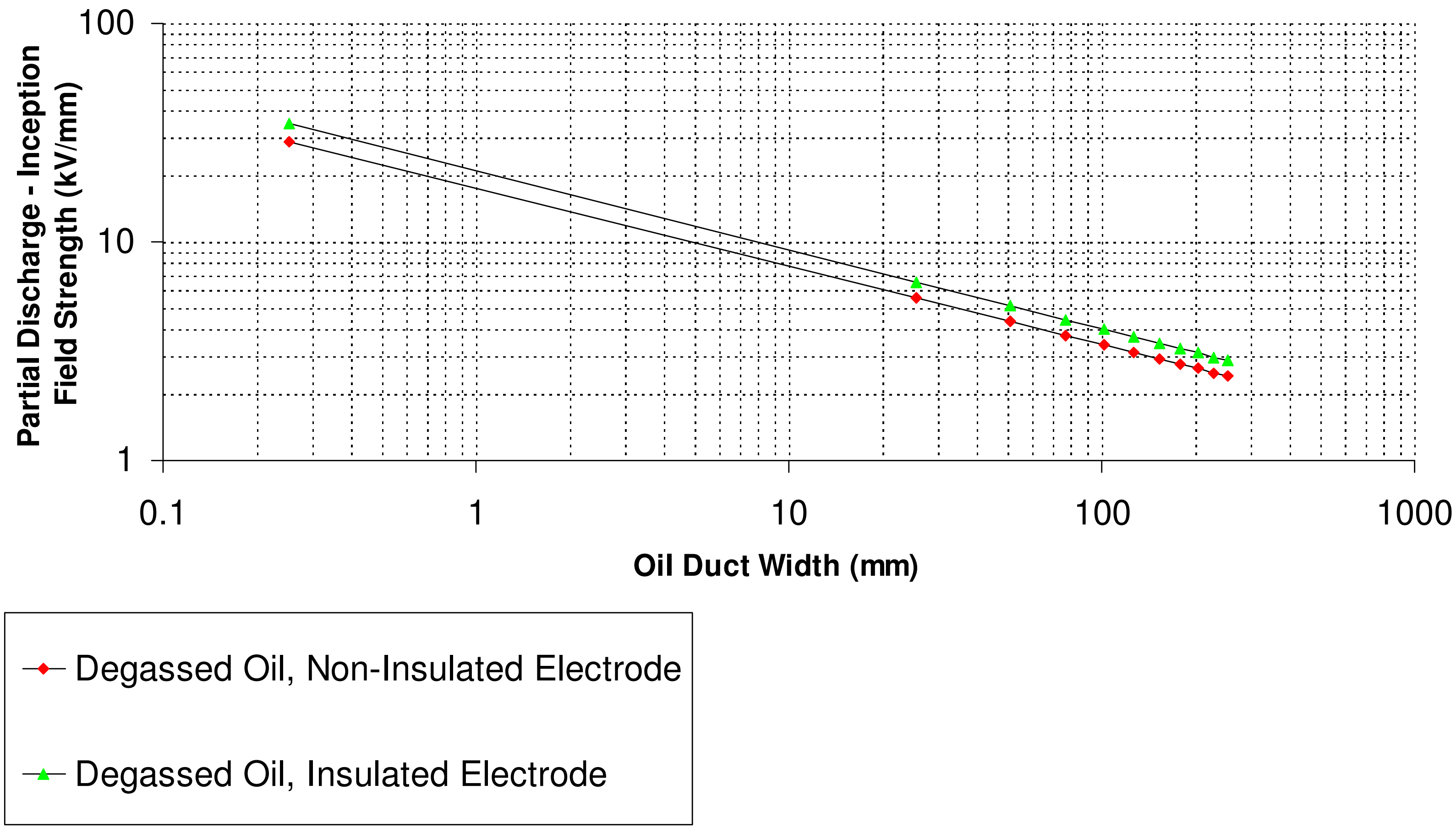




Stress Profile Between 4th & 5th Top HV Sections = 10.9 kV/mm.

Dielectric Stress

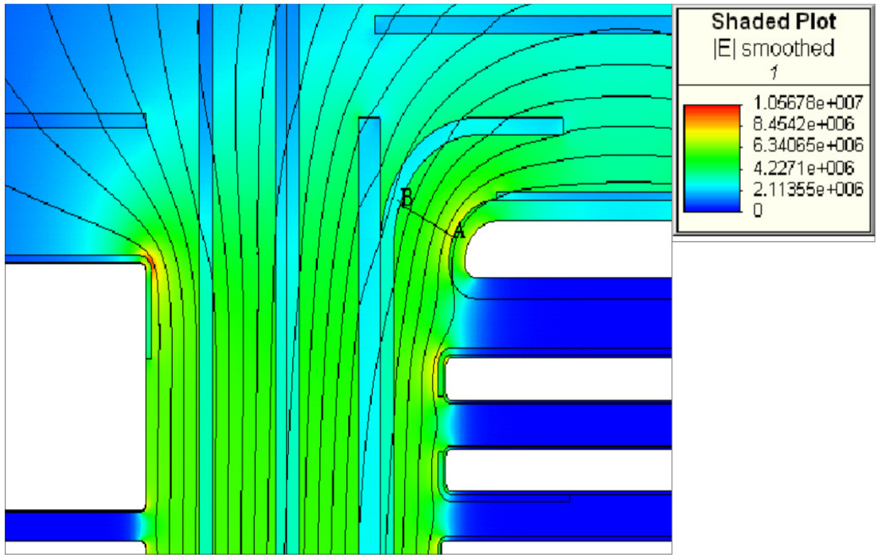
WEIDMANN Reference Curves - Oil

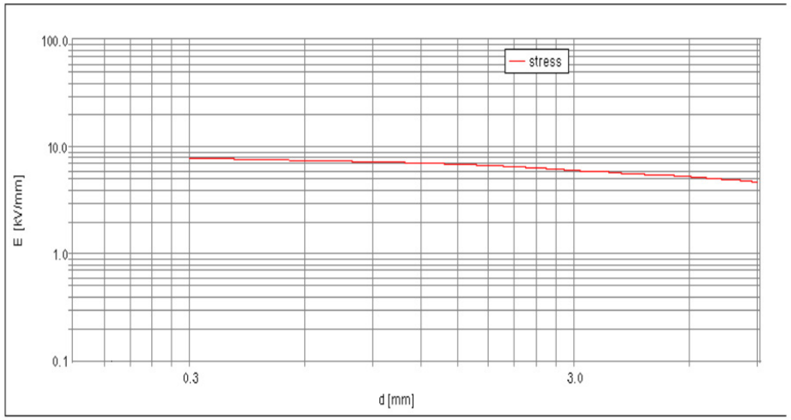


Dielectric Stress

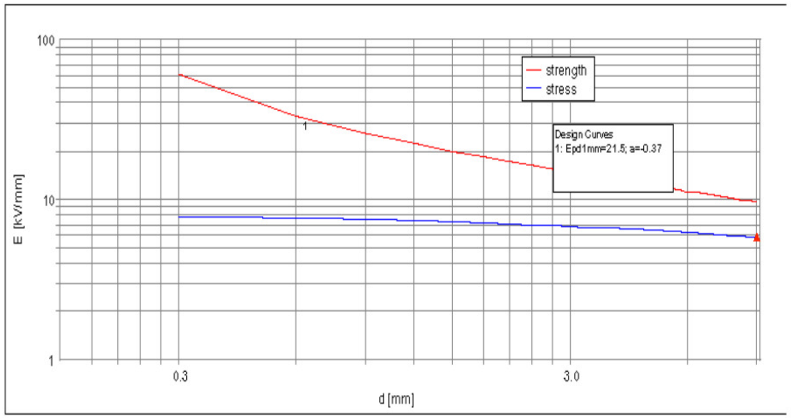
Predicting Failures – Oil Gaps

Using the WRCs we're able to determine a "safety margin" for the oil based on a Weibull distribution





Absolute value of the local field vector stress profile along the field line (from A to B)



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

Test Voltage : 230.kV Percent Margin : 40

INSULATION SPECIFICATION GUIDE

WHY DID WE CREATE IT?

- Overall lack of concern in transformer specifications related to insulation requirements
- If insulation is specified, typically the verbiage is very general or outdated
- WEIDMANN Guide provides support/data for specifying insulation materials
- Ultimately provides an important barrier to potential offshore suppliers
- Bring awareness about differences in insulation materials currently available on the market and its effect on transformer performance, reliability and longevity

INSULATION SPECIFICATION GUIDE

WHY TRANSFORMER OWNERS SHOULD SPECIFY INSULATION MATERIALS

	Transformer Manufacturer	**Transformer Owner / End User**
Insulation Cost	2-8% of Transformer Selling Price	Negligible % of Cost of Substation or Generating Plant where the transformer is located
Risk	Test Floor or In-Service Failure within Warranty	In Service Failure & Resulting Cost
Capital at Risk	Cost of rework or replacement	Partial or total loss of Substation or Generation plant 7 – 10 X Transformer Cost
Duration of Risk	Transformer Production and Warranty Period 1 – 5 years	Transformer operational life 20 – 30 years

INSULATION SPECIFICATION GUIDE

WHAT IS IT?

Example 1: Solid Insulation Transformerboard

Solid Insulation Transformer-board	General	Solid insulation within the windings and clamping structure shall be of a suitable cellulosic or aramid material and shall comply with current applicable industry standards for dielectric integrity, short circuit, thermal requirements, loss of life, and emergency loading.
	Directed	Solid insulation within the windings and clamping structure shall be of a suitable cellulosic or aramid material supplied by a manufacturer with a proven history (15 or more years experience supported by technical development and testing) and shall comply with current applicable industry standards for dielectric integrity, short circuit, thermal requirements, loss of life, and emergency loading.
	Specific	Transformer to be manufactured using only WEIDMANN Transformerboard for solid, non-paper insulation components.

THANK YOU!

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