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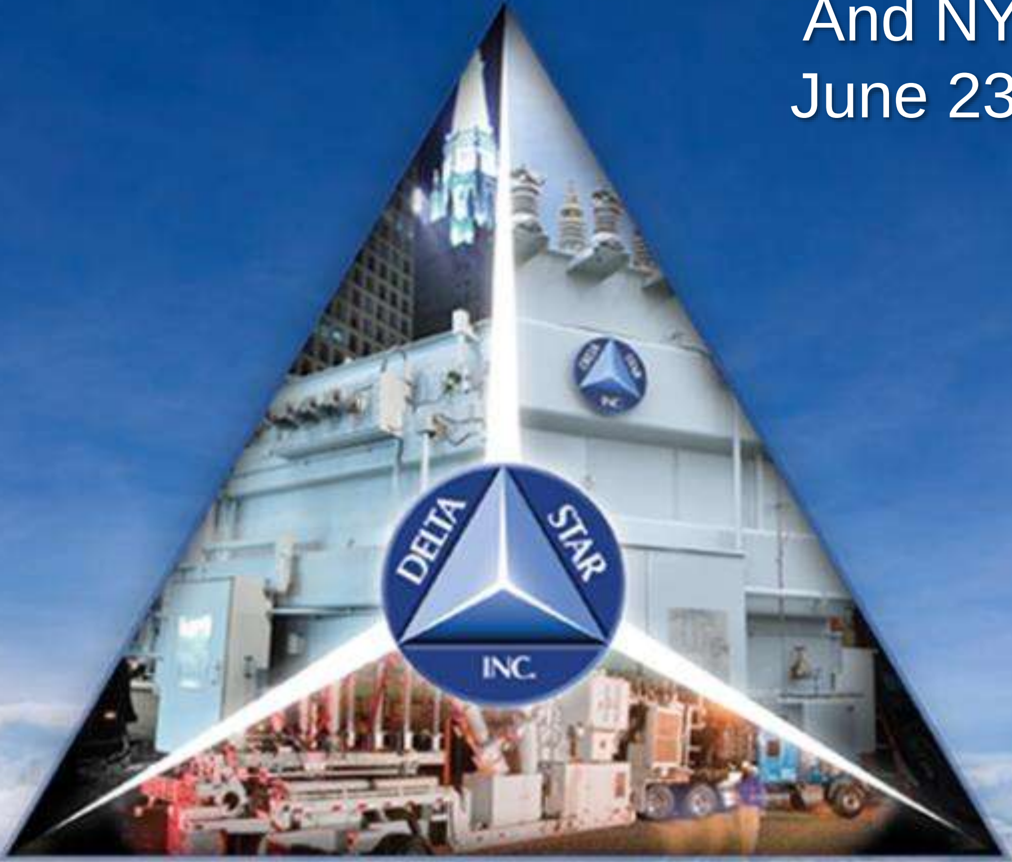

Transformers ▲ Mobile Substations ▲ Quality Since 1908

High Temperature Insulation Systems and their use in Mobile Transformers

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Delta Star, Inc.

June 23rd 2015

Introduction

History of Delta Star

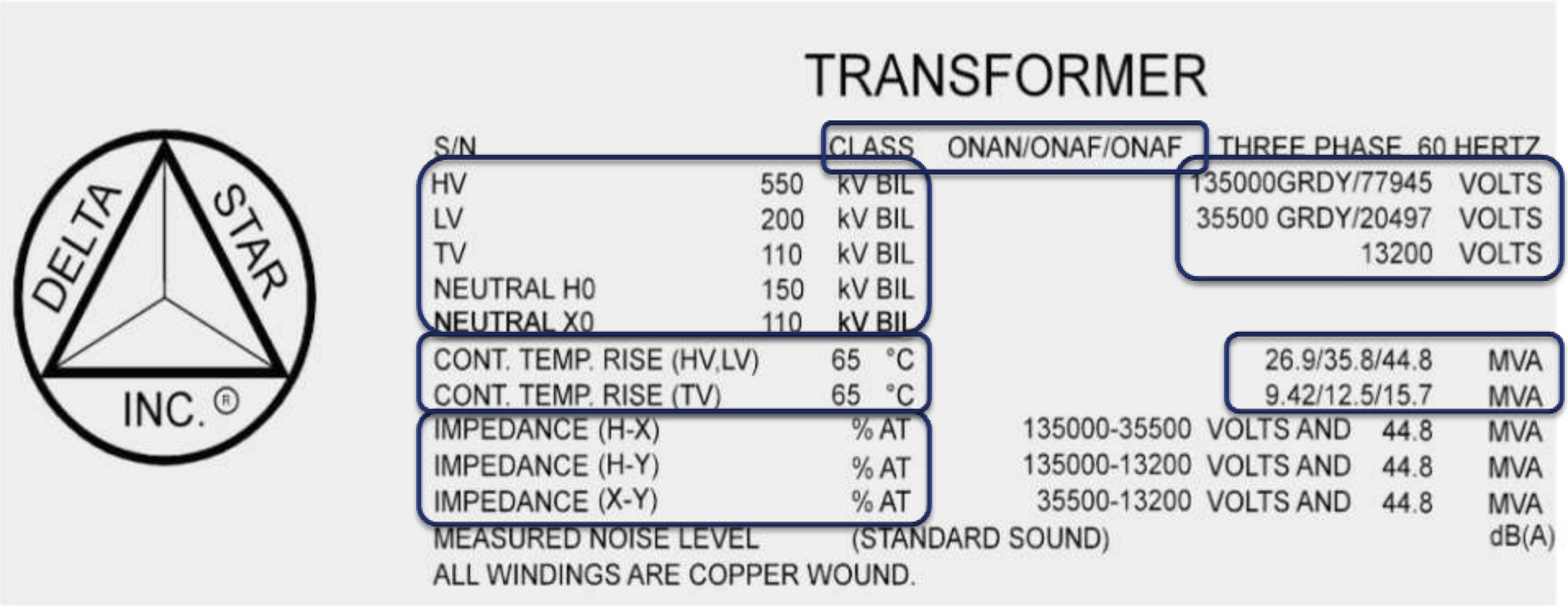
- **1908** – Delta Star founded in Chicago
- **1950** – Purchased by H.K. Porter and named Delta Star Electric Division
- **1959** – Delta Star purchased Hill Transformer located in San Carlos, CA
- **1961** – Built our Lynchburg, VA manufacturing facility
- **1976** – First mobile substation built for Withlacoochie Electric Coop
- **1988** – Delta Star became an Employee Owned Company (ESOP)
- **2003** – Delta Star received ISO 9001:2008 standing
- **2005** – Delta Star chosen by Congress to provide military mobile transformers
- **2008** – Delta Star celebrating 100 years in business
- **2009** – Delta Star plant modernization complete
- **2013** – Delta Star completes hi-bay expansion
- **2014** – Delta Star completes second vapor phase
- **2015** – Delta Star increases capacity.

Agenda

- Basic Transformer Design Variables
- Mobile Transformer Design vs. Power Transformer Design
- Thermal Limits of Conventional Insulation
- Affects of Heat on Conventional Insulation Systems
- Definitions from C57.154-2012 IEEE Standard
- Hybrid Insulation Thermal Limits
- Factory Thermal Testing
- Purpose of C57.154-2012 IEEE Standard
- Mobile Transformer construction and setup
- Summary
- Examples of mobile solutions
- Q&A

Basic Transformer Design

- **Nameplate Ratings**



TRANSFORMER

S/N		CLASS ONAN/ONAF/ONAF	THREE PHASE 60 HERTZ	
HV	550	kV BIL	135000GRDY/77945	VOLTS
LV	200	kV BIL	35500 GRDY/20497	VOLTS
TV	110	kV BIL	13200	VOLTS
NEUTRAL H0	150	kV BIL		
NEUTRAL X0	110	kV BIL		
CONT. TEMP. RISE (HV,LV)	65	°C	26.9/35.8/44.8	MVA
CONT. TEMP. RISE (TV)	65	°C	9.42/12.5/15.7	MVA
IMPEDANCE (H-X)		% AT	135000-35500 VOLTS AND 44.8	MVA
IMPEDANCE (H-Y)		% AT	135000-13200 VOLTS AND 44.8	MVA
IMPEDANCE (X-Y)		% AT	35500-13200 VOLTS AND 44.8	MVA
MEASURED NOISE LEVEL		(STANDARD SOUND)		dB(A)

ALL WINDINGS ARE COPPER WOUND.

Basic Transformer Design

- **Details, details, details**
  - Electric and Magnetic Fields
  - Current Density
  - Radial and Axial short circuit forces
  - Flux Density
  - Turns Ratio
  - Winding Resistance
  - Ampere turns

Basic Transformer Design

- **Items to consider**
  - What does the customer need?
  - Are there size limitations?
  - What is the intended usage?
- **Items most critical**
  - Voltage Ratio
  - Phase Angle
  - Impedance
  - MVA

Basic Transformer Design

- **Forces:**
  - Vectoral components, in axial and radial directions, seen by the windings.
  - These forces are the mechanical stresses on the transformer.

Force ∝ Flux Density X Current Density

$$\vec{F} \propto \vec{B} \text{ x } \vec{J}$$

Basic Transformer Design

- **Forces:**

$$\vec{F} \propto \vec{B} \ \mathrm{x} \ \vec{J}$$

$$\vec{B} \propto N\vec{I}$$

$$\vec{J} = \frac{\vec{I}}{\text{area}}$$

Flux Density

Ampere Turns

Current Density

By association

$$F \propto \frac{1}{\text{area}}$$

$$F \propto I^2N$$

Basic Transformer Design

- **Forces:**

$$F \propto I^2 N$$

  - Current is already determined by MVA and Voltage ratings.
  - Now we need to determine the number of turns
  - What do turns affect, other than ratio?

Basic Transformer Design

- **Impedance:** $\%Z$

- **Impedance is affected by 2 main things.**

1. Geometry – Height and gap. Typically taller units will have a lower impedance.

   *Assuming the same number of turns.

2. The # of turns – Impedance varies with the **square** of the turns.

Basic Transformer Design

- **Once we know our turns**
- We can calculate our volts/turn

  Exactly as it sounds. The voltage drop across each turn in the windings.

  Once established, this value is the same for all windings in the transformer. i.e. HV, LV, TV, RV, etc.

Basic Transformer Design

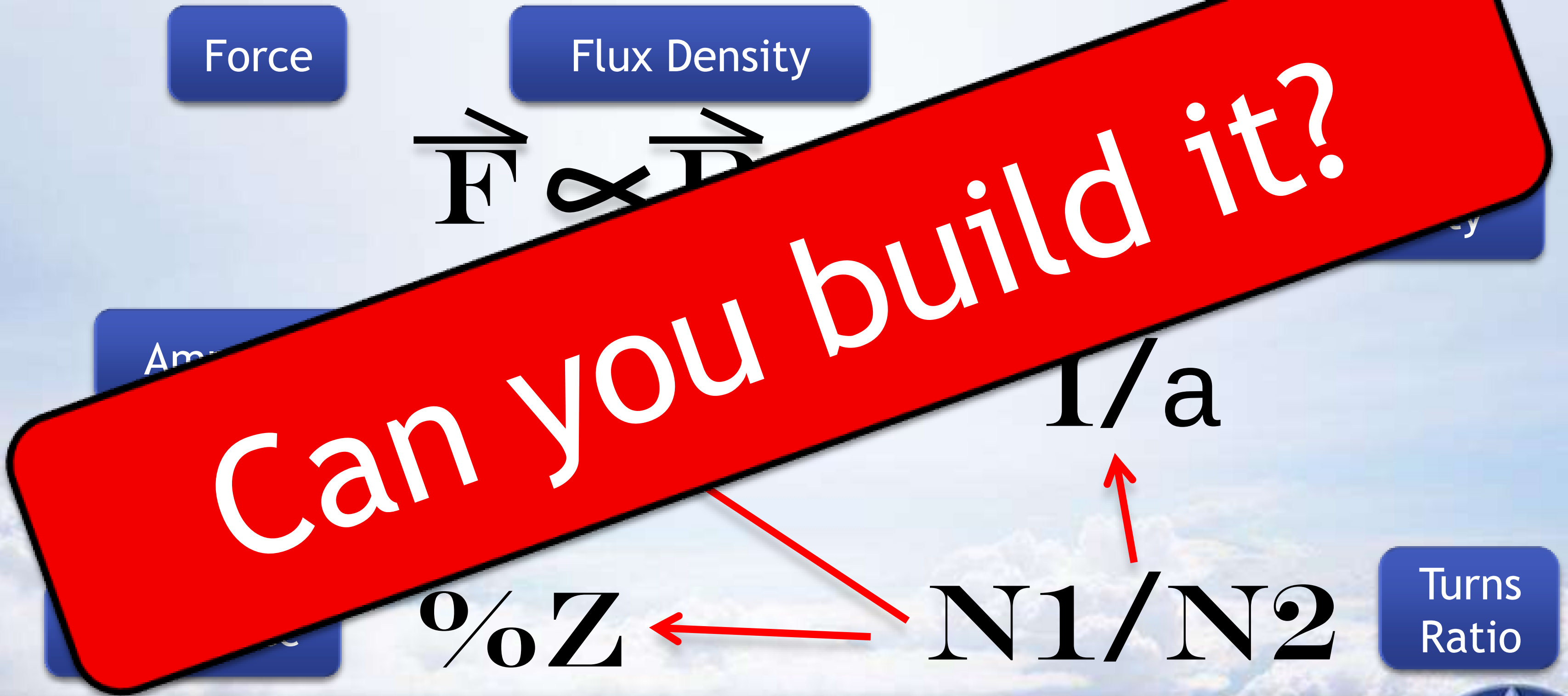
- **Example:**
  - 138,000 volts across an HV winding having 1380 turns equates to 100 volts/turn.
  - 72 turns on the LV winding will produce (72)X(100) = 7200 volts
  - What about a regulating winding?
  - ****The lower the volts/turn, the smaller the iron core can be for a given flux density.**

Basic Transformer Design

- **Now we know Turns, Impedance, Volts/Turn, and Flux Density**
  - The last item we need for our basic design is **Current Density**.
  - Remember, our forces are proportional to current density. A smaller conductor means a smaller coil, but higher forces and higher resistance.
  - What does a larger conductor do?

Basic Transformer Design

- ☐ Adjustments to one variable typically affects other variables.



$$\vec{F} \propto \vec{B}$$

$$I/a$$

$$\%Z \leftarrow N1/N2$$

Can you build it?

Basic Transformer Design

- **Are you bored yet?**

- How is this related to high temperature insulation?
- What causes higher temperatures in transformers?

Heating

- **Heating:**
  - Generally caused by high losses, or reduced cooling. How are losses calculated?
  - Losses are split into three categories, with the third having two subcategories.
    1) I^2R Losses from the copper in the winding
    2) No-Load losses for the iron in the core
    3) Stray losses consisting of Eddy and Hysteresis losses in the stray fields.

Losses

- **I^2R, or Copper Losses**

  Simple mathematic equation, the product of I^2R. The resistance of the winding multiplied by the square of the current.

  These losses vary as the square of the MVA or current. Once measured, they can be scaled to any MVA for a given unit.

- What did we discuss that affects the resistance?

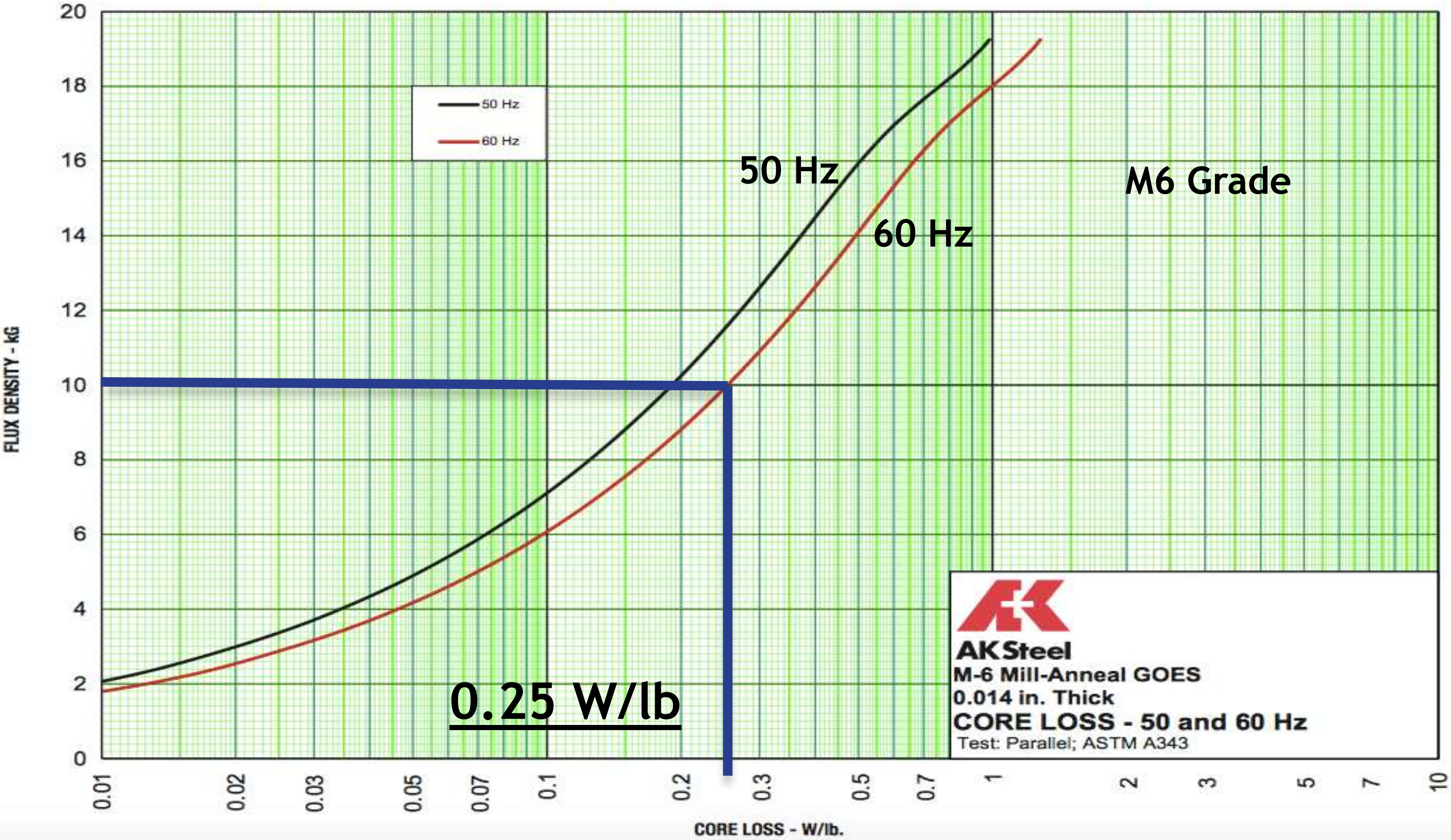
Losses

- **No-Load Losses or Iron Losses**

By using our core diameter and window height, we calculate the core weight. Also knowing the flux density allows us to calculate the no-load losses from performance curves of the electrical steel being used for the core.

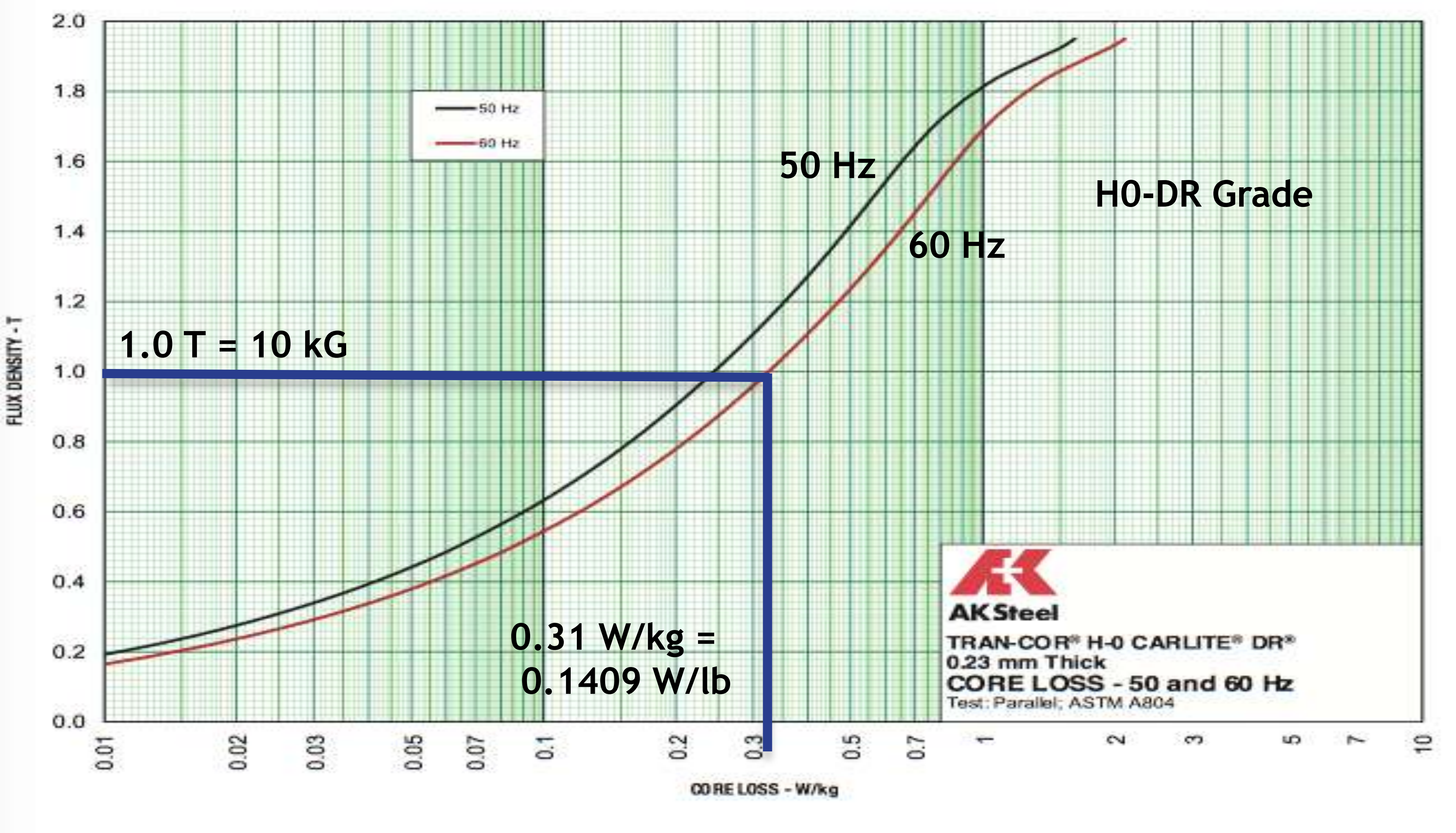
Losses

- No-Load Losses:



Losses

- ☐ **No-Load Losses:**



50 Hz

60 Hz

H0-DR Grade

1.0 T = 10 kG

0.31 W/kg =
0.1409 W/lb

Losses

- **No-Load Losses:**

From this example, by changing core steel grades from M6 to H0-DR, our loss values at the same flux density went from:

0.25 Watts/pound for M6 to

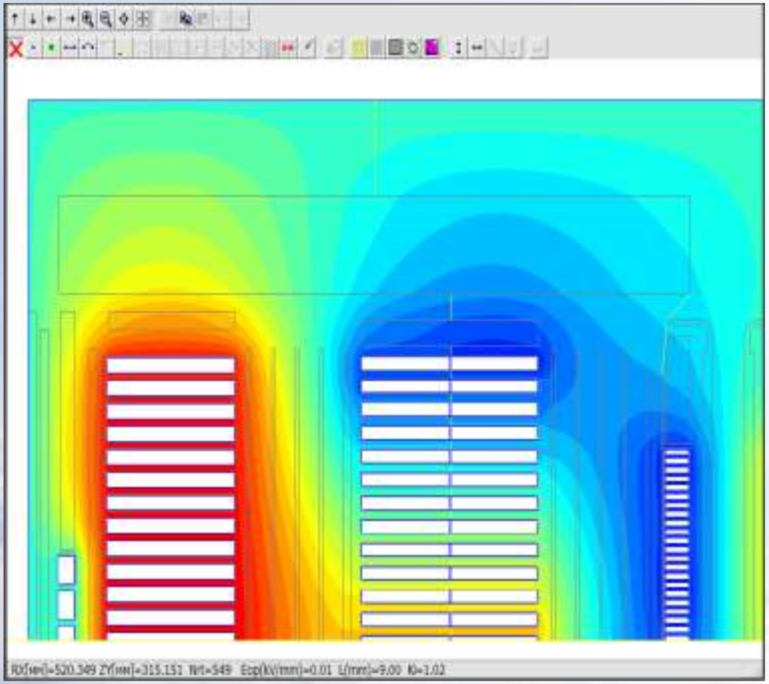
0.141 Watts/pound for H0-DR

Nearly 44% decrease!!!!!

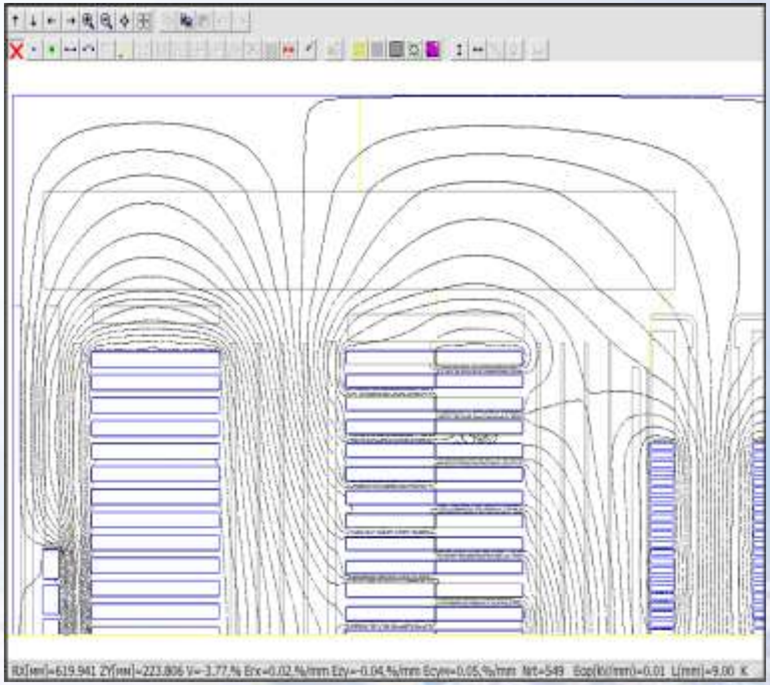
Losses

❑ **Stray Losses:**

These losses are calculated by evaluating finite element field plots for the design.



RX[мм]=520.349 ZY[мм]=315.151 Nrt=549 Eop(kV/mm)=0.01 L(mm)=9.00 Ki=1.02



RX[мм]=619.941 ZY[мм]=223.806 V=-3.77,% Erx=0.02,%/mm Ezy=-0.04,%/mm Ecym=0.05,%/mm Nrt=549 Eop(kV/mm)=0.01 L(mm)=9.00 K

Cooling

- Now that we know our losses, how are we going to cool the unit?

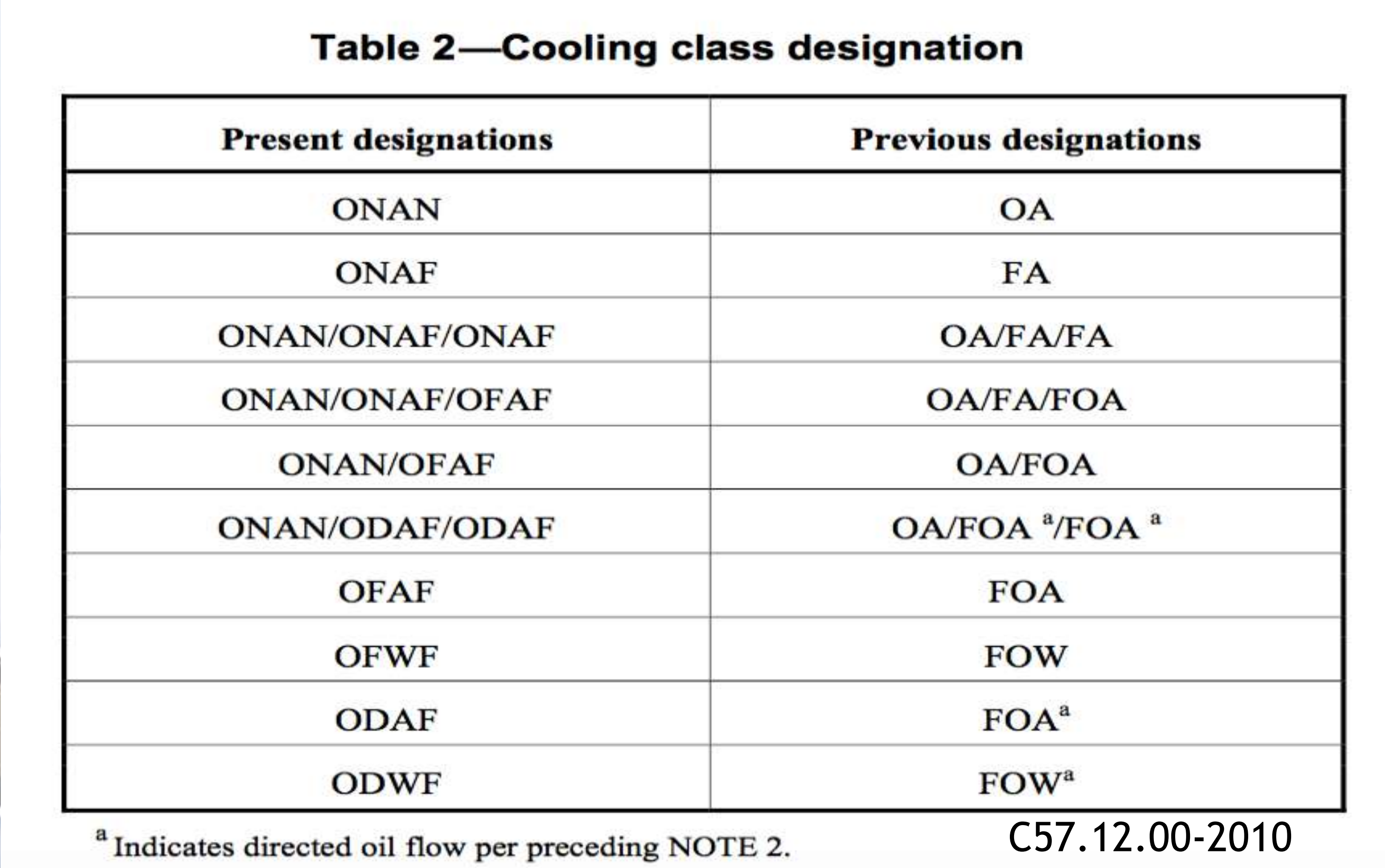


Table 2—Cooling class designation

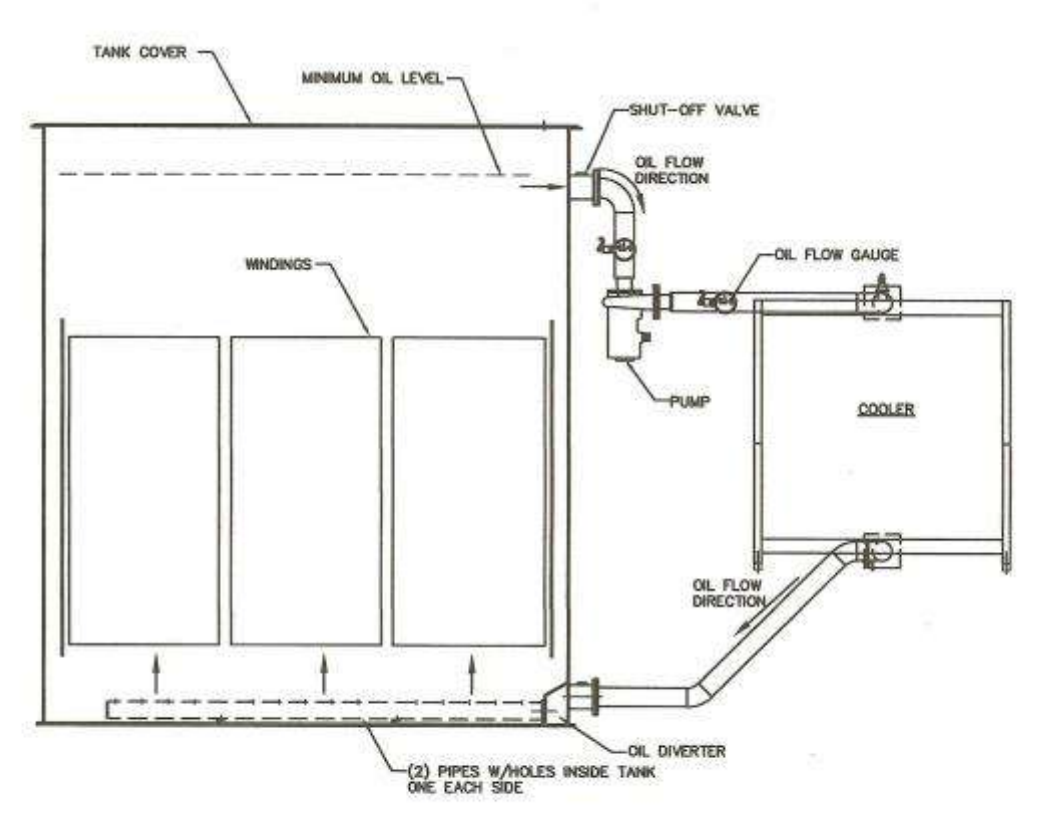
Present designations	Previous designations
ONAN	OA
ONAF	FA
ONAN/ONAF/ONAF	OA/FA/FA
ONAN/ONAF/OFAF	OA/FA/FOA
ONAN/OFAF	OA/FOA
ONAN/ODAF/ODAF	OA/FOA[a]/FOA[a]
OFAF	FOA
OFWF	FOW
ODAF	FOA[a]
ODWF	FOW[a]

[a] Indicates directed oil flow per preceding NOTE 2.

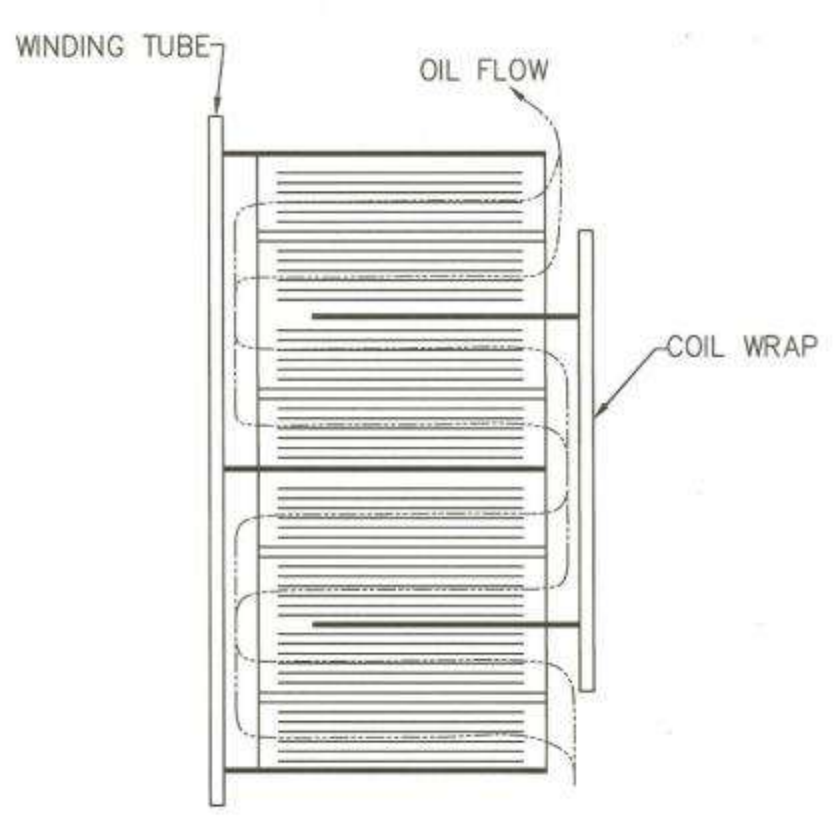
C57.12.00-2010

Cooling - ODAF

Oil flow – 2 parallel systems



Oil flow within the winding



Mobile Units

Applications

- **Transformer failure - Emergency**
  - Natural causes
  - Vandalism/Sabotage
  - Terrorism
  - EMP/GIC
- **Routine maintenance**
- **Temporary power supply**
- **Power for a seasonal load**

Types of mobile units

- **Mobile transformer**

Types of mobile units

- Mobile transformer
- **Mobile substation**

Types of Mobile Units

- ☐ Mobile Transformer
- ☐ Mobile Substation
- ☐ **Portable Transformer**

Types of mobile units

- ☐ Mobile transformer
- ☐ Mobile substation
- ☐ Portable transformer
- ☐ **Skid mounted**

Types of mobile units

All of these have something in common.

The need to be compact for the amount of MVA they deliver, in order to be quickly transported

Mobile versus Power unit

Mobile versus Power Unit

- Smaller size
- Lighter
- Delivered fully assembled to the site
- Short set up time
- Self contained - auxiliary power supply
- Must comply with DOT regulations
- May be equipped with HV and LV protection
- May be used outside substation if properly equipped

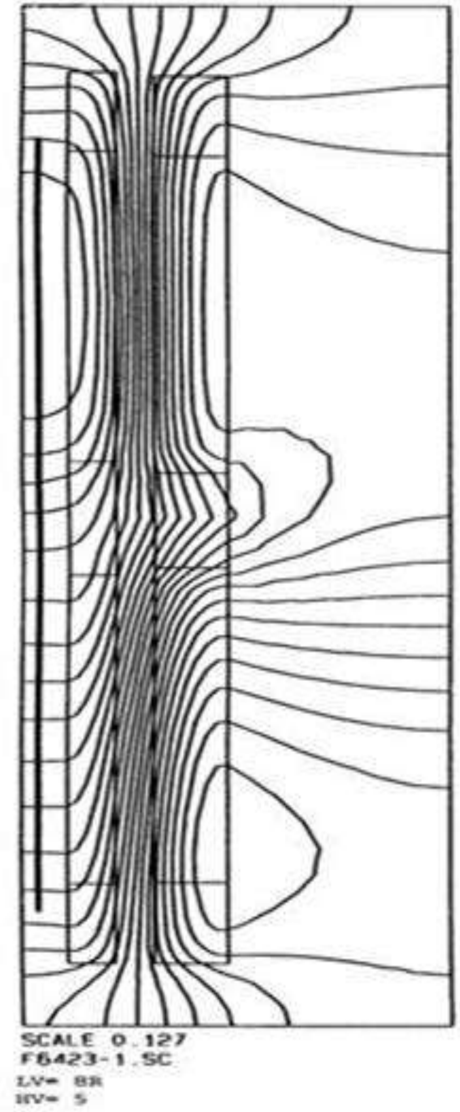
How to achieve it?

Mobile versus Power Unit

- High current densities and temperature rises – limited by short circuit withstand
- Insulation – hybrid for 75, 95 and 95/115 C ratings
- Impedance voltage specified at maximum rating
- Core – high permeability steel
- Oil preservation system – sealed tank, N2 system
- Cooling – ODAF, sound pressure level and source
- Tank – High strength steel
- Switches instead of boards
- Auxiliary power supply – external or internal
- Accessories and trailer design

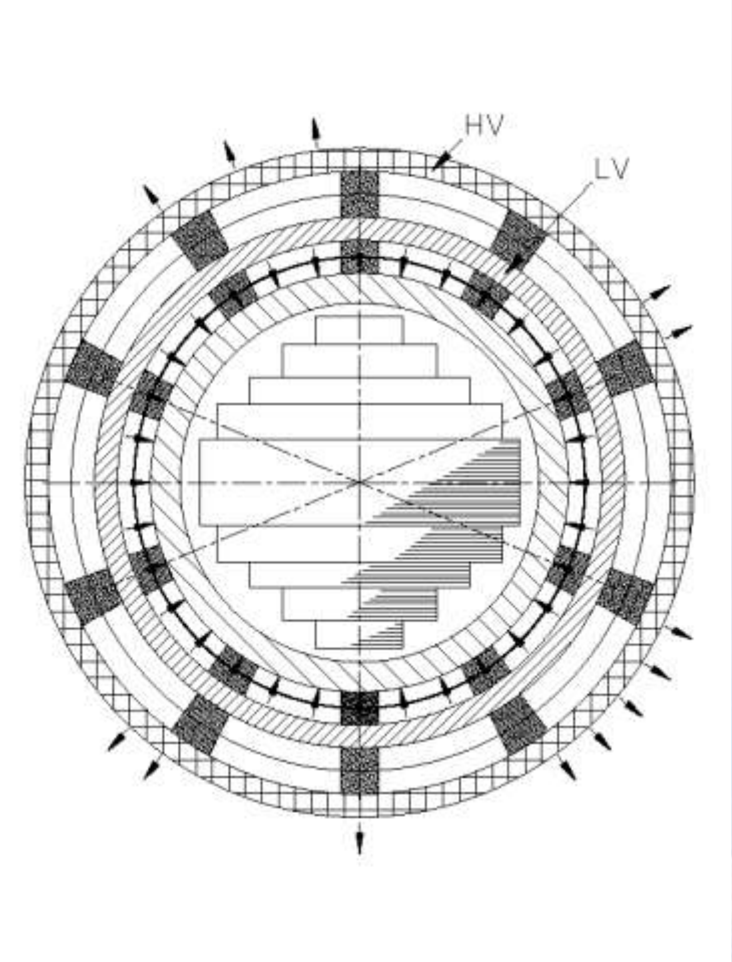
Short Circuit Withstand

- Current densities for mobiles
  - Restricted by short circuit withstand
  - Higher losses
- The unit protected by its own impedance only
- Impedance restraints
  - Regulation – affected by power factor
  - Stray losses – affected by stray flux
- Radial forces
  - Compressive (buckling) on inner winding
  - Outward force on outer winding
- Axial forces
  - Forces within the winding and on end structures
  - Pre-compressing windings

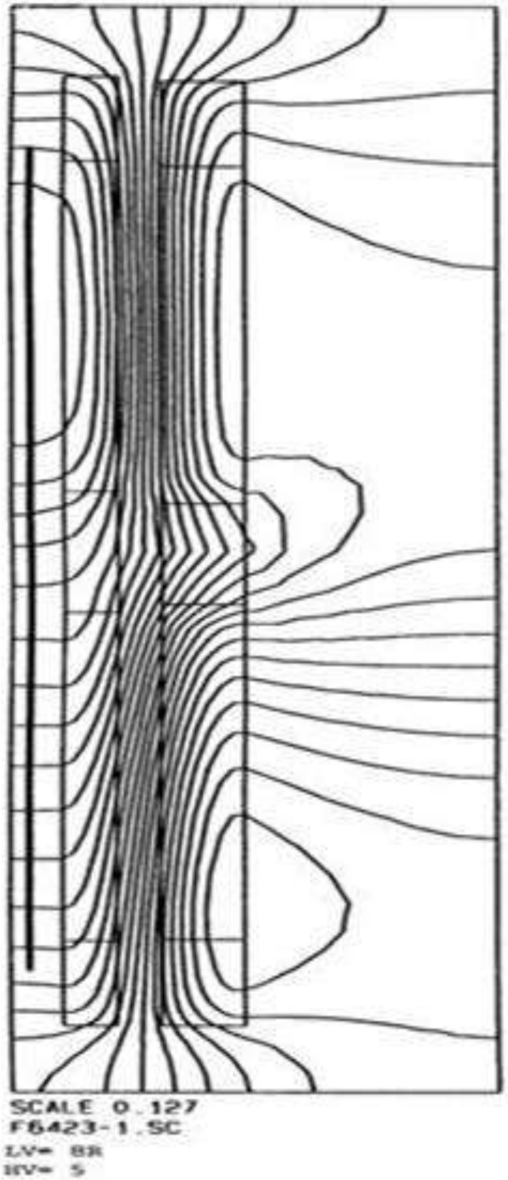


Radial Forces

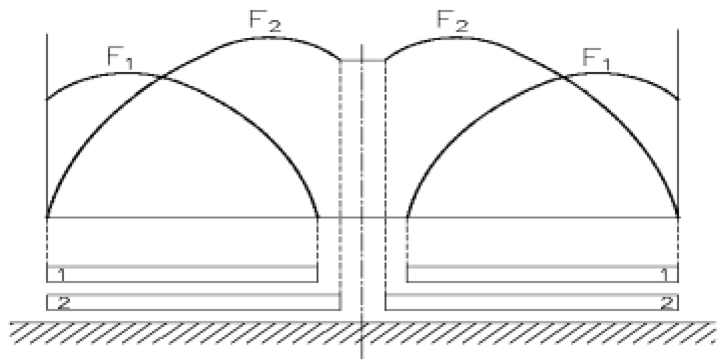
- Compressive (buckling) forces on the inner winding (usually LV)
- Self supporting winding
- Outward forces on the outer winding (usually HV)
- Forces try to increase the main duct



Axial Forces

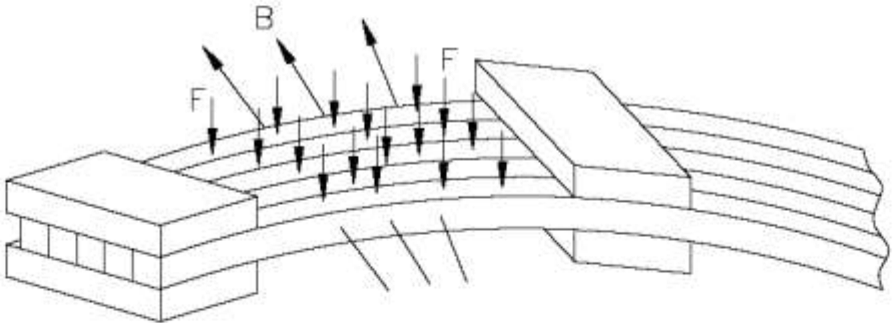


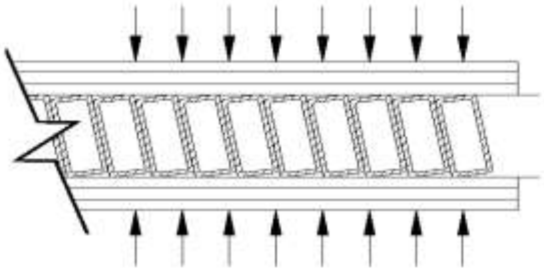
- Forces at the ends of windings
- Forces within windings created by taps
- Balancing windings



Axial Forces

- Forces within the windings
  - Bending forces
  - Pressing key spacers
  - Tilting forces
- Pre-compressing windings
- Pressing beams, rings and end insulation





3D Models

Model

- As Built

Heat Generated from Mobile Design

- **Mobiles typically generate 30%-50% more heat as a comparative power transformer, given the same MVA.**
  - Due to:
    - Higher current density, flux density, and impedance.
    - Smaller tanks
    - Less oil

Factory Temperature Test

Meant to measure actual temperature for average winding and top oil during full load simulation. Hot spot can also be measured, if fiber optics are installed, if not, hot spot is calculated using the measured winding gradient and an empirical multiplier generated by the manufacturer.

Proving of the design!

Factory Temperature Test

- No-load and Load Losses are measured independently for the top rated MVA. We already discussed what affects these values
- These losses are summed together and this simulated “Load” is forced upon the unit in test.
- Monitored variables include: Top Oil temp, Bottom and Top radiator temp, ambient temp, hot spot (if possible), Actual sourced kW, and actual sourced current.

Factory Temperature Test

- Continues until the top oil rise over ambient changes by less than 2.5% or 1°C for 3 consecutive hours.
- Load is reduced to rated current for the associated MVA for 1 hour.
- Source power is disconnected and winding resistance is measured for a 10 minute period in 15 second intervals.

Factory Temperature Test

- These resistance values are then plotted in a spreadsheet to extrapolate the resistance value at the time the source was disconnected, “time zero”
- This resistance value, when compared to the winding resistance at an ambient reference temperature, allows us to calculate the average winding temperature and winding gradient at the associated MVA.

Thermal Test results

Simplified formula according to

IEC 60076-7 (old IEC 354):

Hot Spot = Top oil + $H*g*K^y$

H=Hot-Spot Factor (empirical value of the transformer maker),

g= Gradient (calculated by the transformer maker)

K= Load factor (actual load/nominal load)

y= Winding exponent (depending on the cooling mode ONAN, ONAF;…)

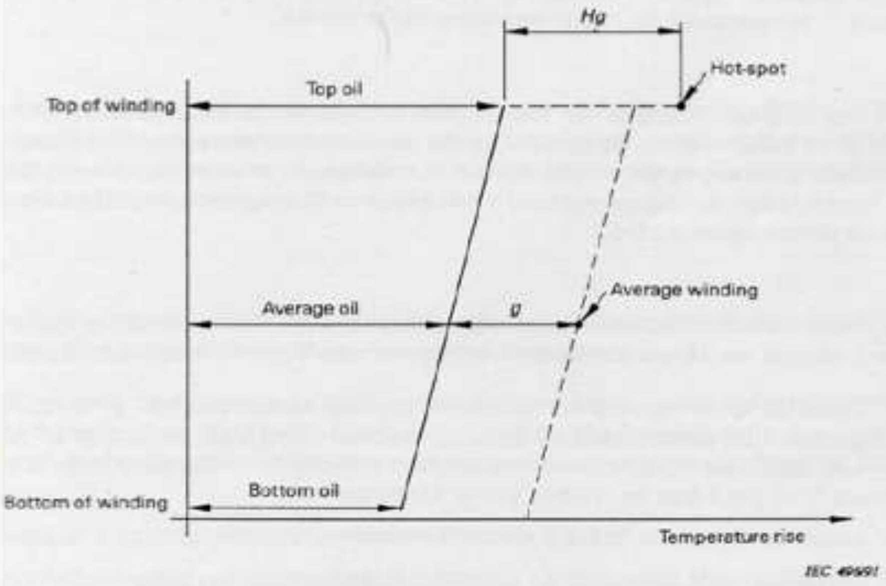
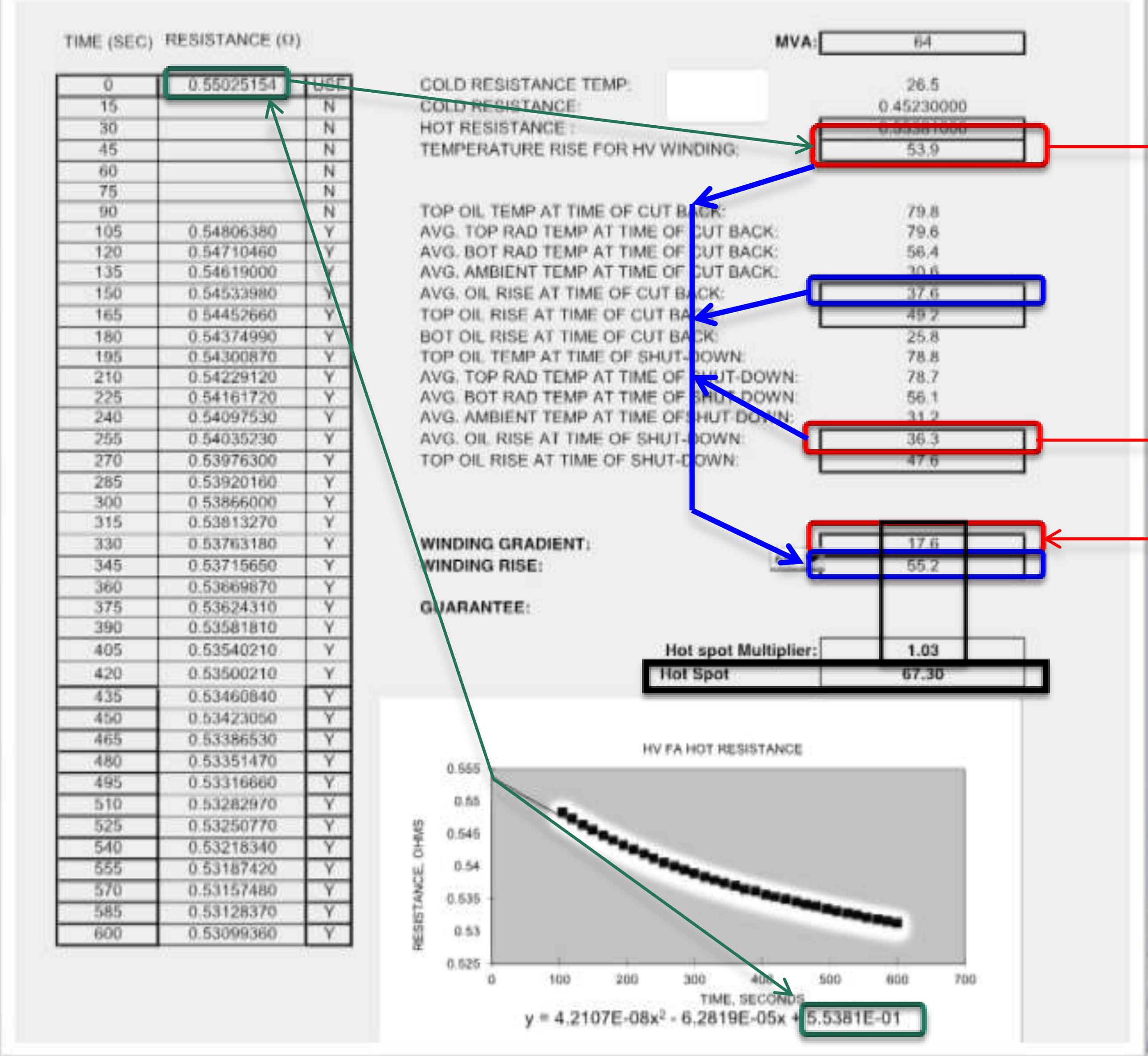


Figure 1 – Thermal diagram



TIME (SEC)	RESISTANCE (Ω)	USE
0	0.55025154	USE
15		N
30		N
45		N
60		N
75		N
90		N
105	0.54806380	Y
120	0.54710460	Y
135	0.54619000	Y
150	0.54533980	Y
165	0.54452660	Y
180	0.54374990	Y
195	0.54300870	Y
210	0.54229120	Y
225	0.54161720	Y
240	0.54097530	Y
255	0.54035230	Y
270	0.53976300	Y
285	0.53920160	Y
300	0.53866000	Y
315	0.53813270	Y
330	0.53763180	Y
345	0.53715650	Y
360	0.53669870	Y
375	0.53624310	Y
390	0.53581810	Y
405	0.53540210	Y
420	0.53500210	Y
435	0.53460840	Y
450	0.53423050	Y
465	0.53386530	Y
480	0.53351470	Y
495	0.53316660	Y
510	0.53282970	Y
525	0.53250770	Y
540	0.53218340	Y
555	0.53187420	Y
570	0.53157480	Y
585	0.53128370	Y
600	0.53099360	Y

MVA: 64

COLD RESISTANCE TEMP:	26.5
COLD RESISTANCE:	0.45230000
HOT RESISTANCE :	0.55381000
TEMPERATURE RISE FOR HV WINDING:	53.9
TOP OIL TEMP AT TIME OF CUT BACK:	79.8
AVG. TOP RAD TEMP AT TIME OF CUT BACK:	79.6
AVG. BOT RAD TEMP AT TIME OF CUT BACK:	56.4
AVG. AMBIENT TEMP AT TIME OF CUT BACK:	30.6
AVG. OIL RISE AT TIME OF CUT BACK:	37.6
TOP OIL RISE AT TIME OF CUT BACK:	49.2
BOT OIL RISE AT TIME OF CUT BACK:	25.8
TOP OIL TEMP AT TIME OF SHUT-DOWN:	78.8
AVG. TOP RAD TEMP AT TIME OF SHUT-DOWN:	78.7
AVG. BOT RAD TEMP AT TIME OF SHUT-DOWN:	56.1
AVG. AMBIENT TEMP AT TIME OFSHUT-DOWN:	31.2
AVG. OIL RISE AT TIME OF SHUT-DOWN:	36.3
TOP OIL RISE AT TIME OF SHUT-DOWN:	47.6

WINDING GRADIENT: 17.6

WINDING RISE: 55.2

GUARANTEE:

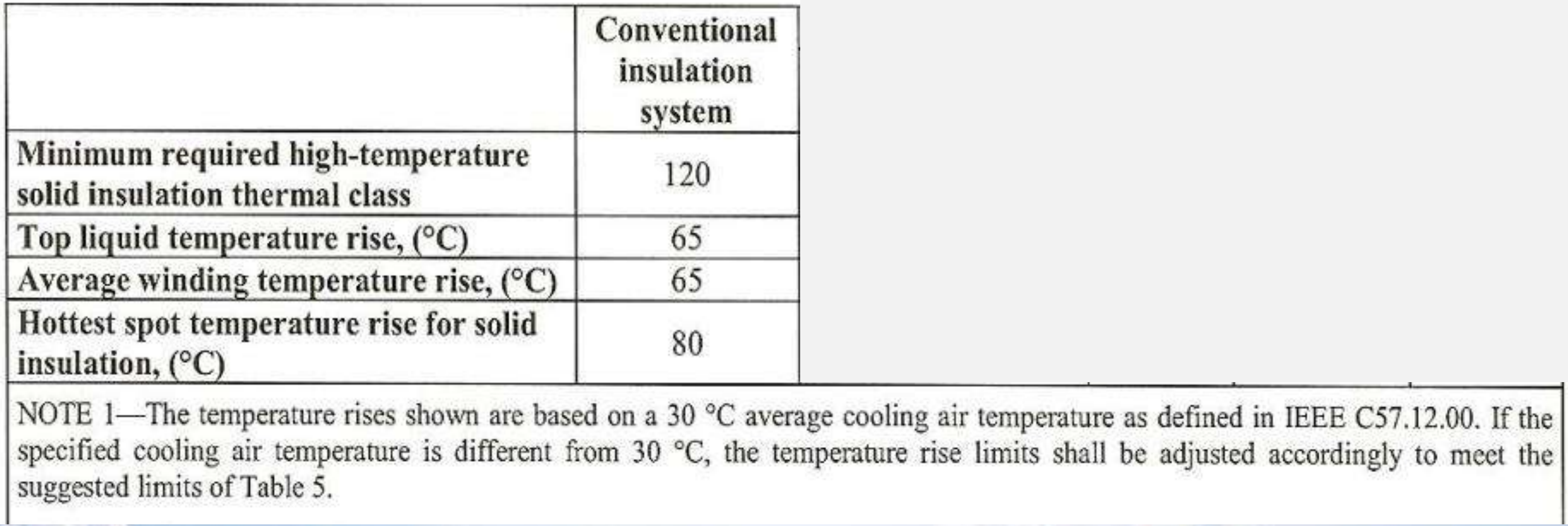
Hot spot Multiplier: **1.03**

Hot Spot **67.30**

$y = 4.2107E-08x^2 - 6.2819E-05x + 5.5381E-01$

Conventional Insulation limits

Table 3—Maximum continuous temperature rise limits



	Conventional insulation system
Minimum required high-temperature solid insulation thermal class	120
Top liquid temperature rise, (°C)	65
Average winding temperature rise, (°C)	65
Hottest spot temperature rise for solid insulation, (°C)	80

NOTE 1—The temperature rises shown are based on a 30 °C average cooling air temperature as defined in IEEE C57.12.00. If the specified cooling air temperature is different from 30 °C, the temperature rise limits shall be adjusted accordingly to meet the suggested limits of Table 5.

How to meet the limits using paper?

- **ONAF?**

Radiators would be too big for a mobile application

- **ODAF?**

More efficient and smaller than rads, but just not enough oil to keep the windings cool

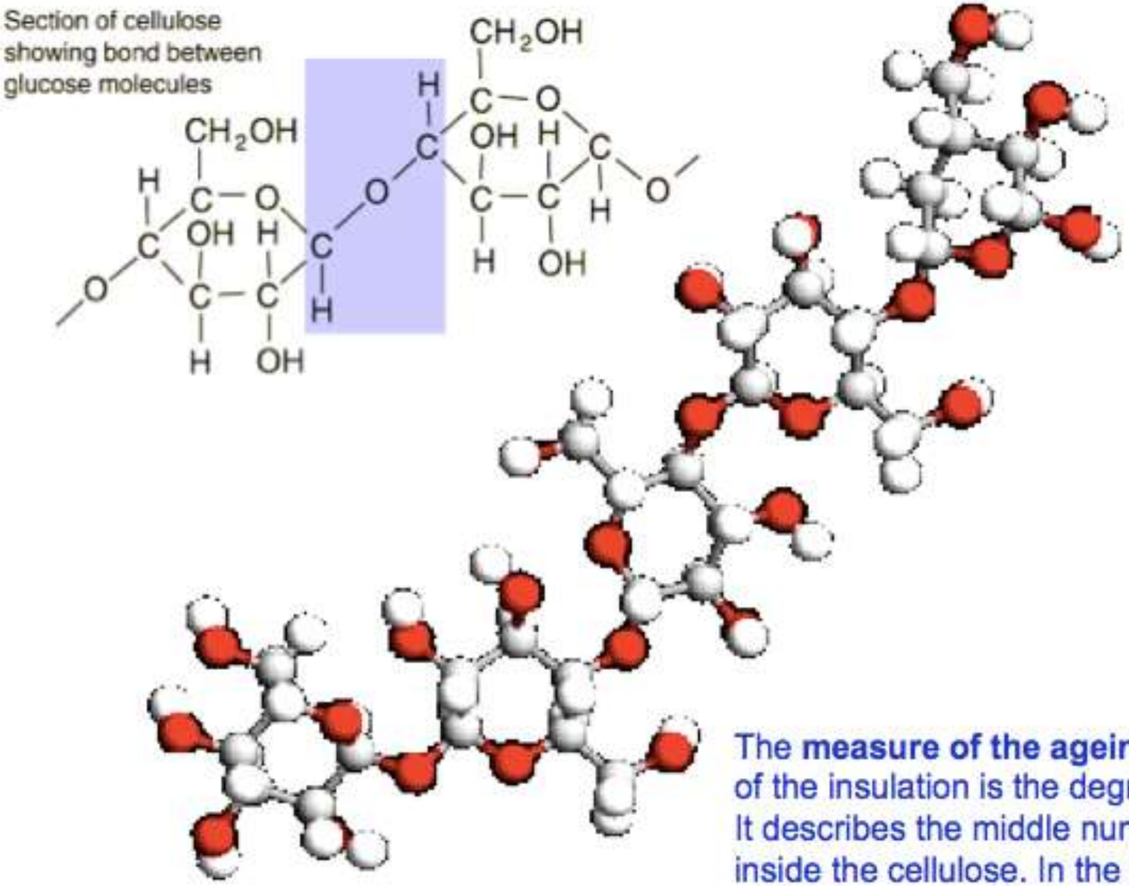
What happens when paper overheats

- Insulation in a transformer has two properties; mechanical and electrical

- Overheating conventional insulation results in lowered degree of de-polymerization (mech), and decreased dielectric properties (elect).

- **Decreased life, eventual failure!**

What happens when paper overheats



Section of cellulose showing bond between glucose molecules

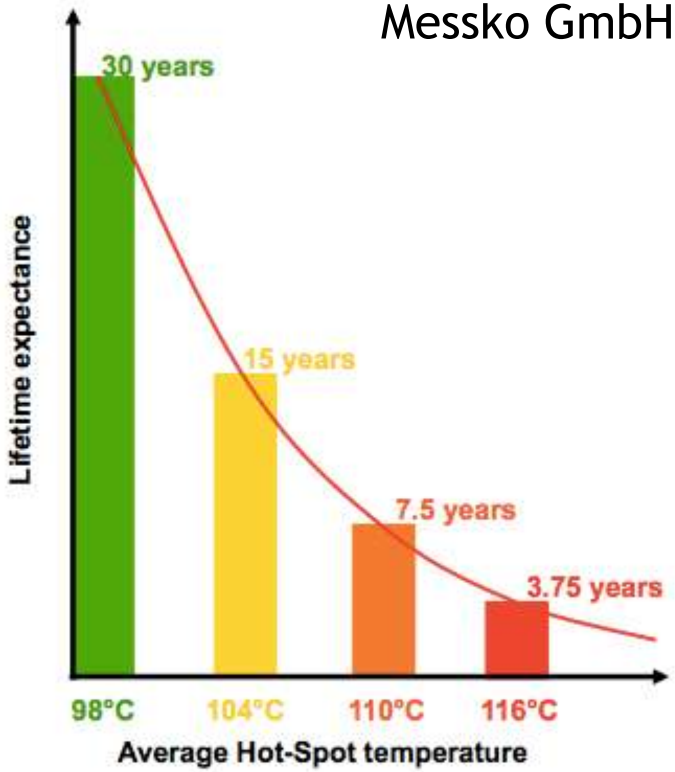
*Ansgar Hinz
Messko GmbH

The **measure of the ageing** of cellulose-containing parts of the insulation is the degree of ***de-polymerisation (DP)***. It describes the middle number of combined glucose-rings inside the cellulose. In the unaged state the cellulose has a **DP of approx. 1200.**

What happens when paper overheats

Ageing of a transformer according IEC 60076-7 (old IEC 354)

*Ansgar Hinz
Messko GmbH



C57.154 Definitions

- **Conventional** – temp rise limits, insulation materials or insulation systems operating at temperatures within normal thermal limits of IEEE C57.12.00
  - 65°C avg winding rise, 80°C Hot Spot Rise, 110°C Hotspot temp, and 65°C top oil rise
- **High Temperature** – A description applied to temp-rise limits, insulation materials or insulation systems operating at higher temps than conventional
- **Hybrid Insulation System** – High temp solid insulation operating above conventional temps, combined with conventional solid insulation.
- **Mixed Hybrid Insulation Winding**– A winding composed of conventional solid insulation with high temp insulation **used only selectively to allow higher than conventional hottest spot temps**, with conventional avg temps.
- **Full Hybrid Insulation Winding** – A winding composed of conventional solid insulation with high temp insulation used **in areas in contact with the winding conductor** to allow higher avg winding and hot spot temps.

High Temp Insulation

The Primary High-Temperature Insulation used in the United States in Nomex® by Dupont

- Aramid based material
- Suitable for continuous operation at 220°C
- Retains dielectric strength from 0 - 95% relative humidity
- Once oil impregnated, significantly better dielectric strength than kraft paper of the same thickness

Temperature Rises (from IEEE C57.154)

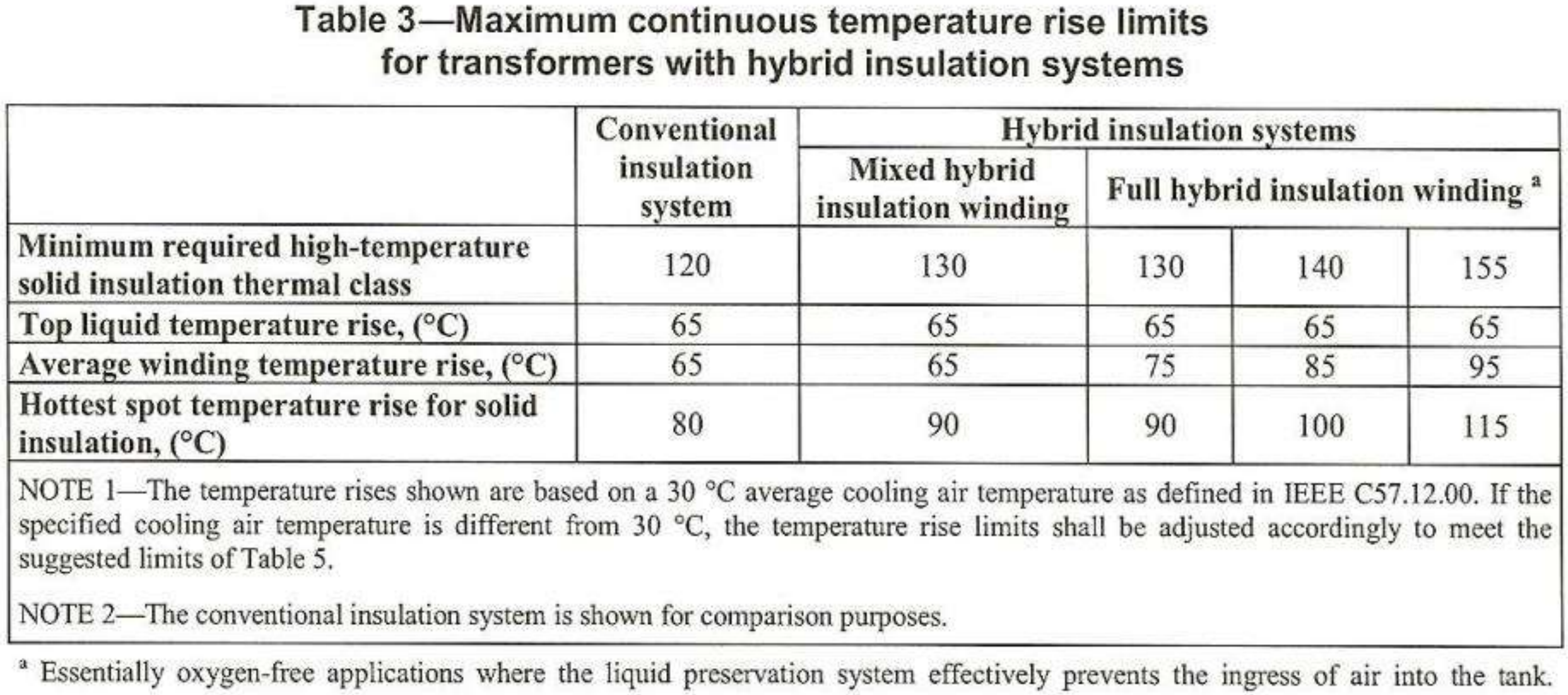


Table 3—Maximum continuous temperature rise limits for transformers with hybrid insulation systems

	Conventional insulation system	Hybrid insulation systems			
		Mixed hybrid insulation winding	Full hybrid insulation winding [a]		
Minimum required high-temperature solid insulation thermal class	120	130	130	140	155
Top liquid temperature rise, (°C)	65	65	65	65	65
Average winding temperature rise, (°C)	65	65	75	85	95
Hottest spot temperature rise for solid insulation, (°C)	80	90	90	100	115

NOTE 1—The temperature rises shown are based on a 30 °C average cooling air temperature as defined in IEEE C57.12.00. If the specified cooling air temperature is different from 30 °C, the temperature rise limits shall be adjusted accordingly to meet the suggested limits of Table 5.

NOTE 2—The conventional insulation system is shown for comparison purposes.

[a] Essentially oxygen-free applications where the liquid preservation system effectively prevents the ingress of air into the tank.

C57.154 standard

IEEE Standard for the Design, Testing, and Application of Liquid-Immersed Distribution, Power, and Regulating Transformers Using High-Temperature Insulation Systems and Operating at Elevated Temperatures

C57.154 standard

The purpose is to **standardize** the development of liquid-immersed transformers that use high-temperature insulation and operate at temperatures that exceed the normal thermal limits of C57.12.00 under continuous load, in the designed ambient, and at rated conditions.

Create rules that apply to all manufacturers for using insulation above conventional levels.

Avg Winding temp : Conventional Limits
Winding Hot Spot temp : Higher than conventional

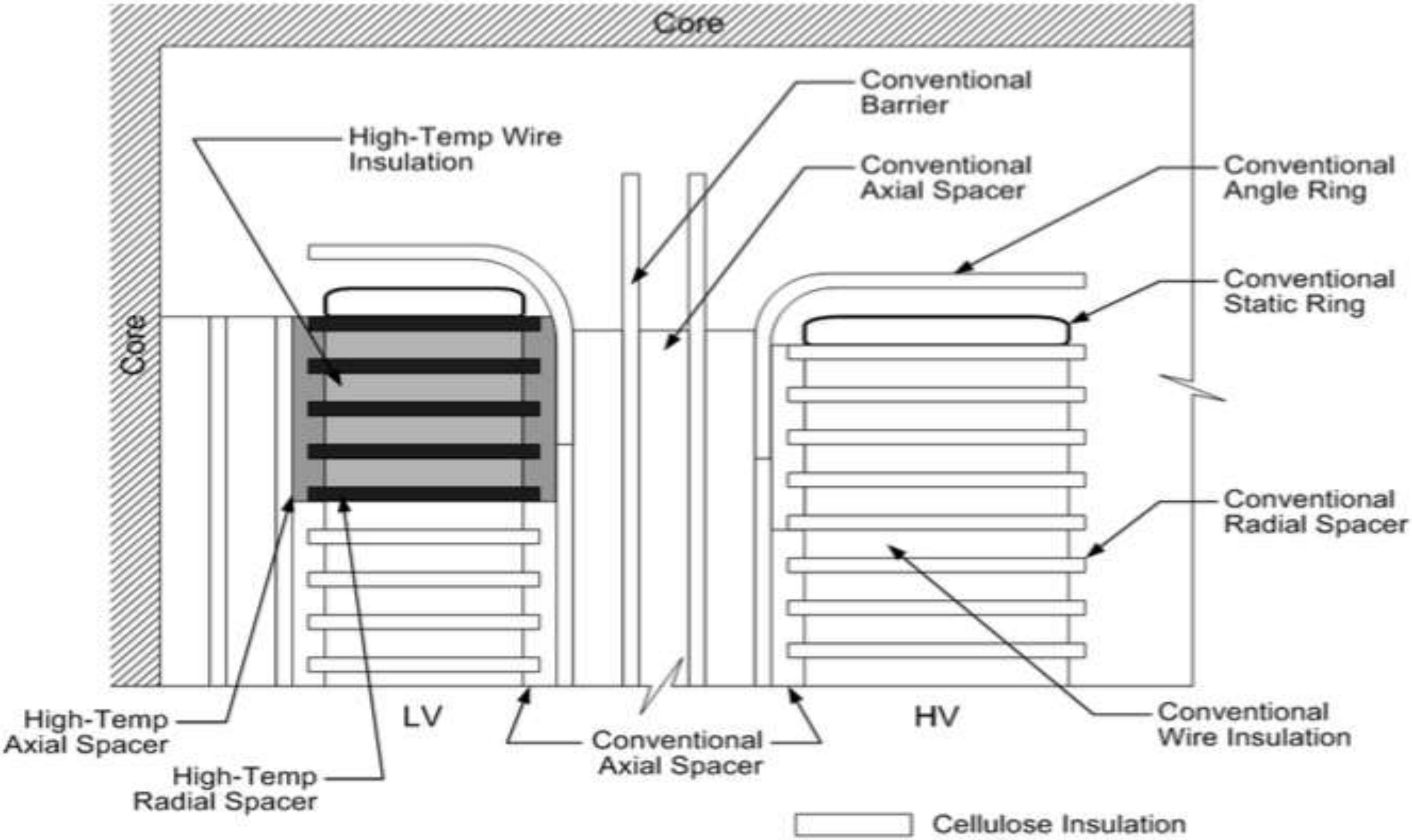


Figure 1—Illustration of a mixed hybrid insulation winding

Avg Winding temp : Higher than conventional
Winding Hot Spot temp : Higher than conventional

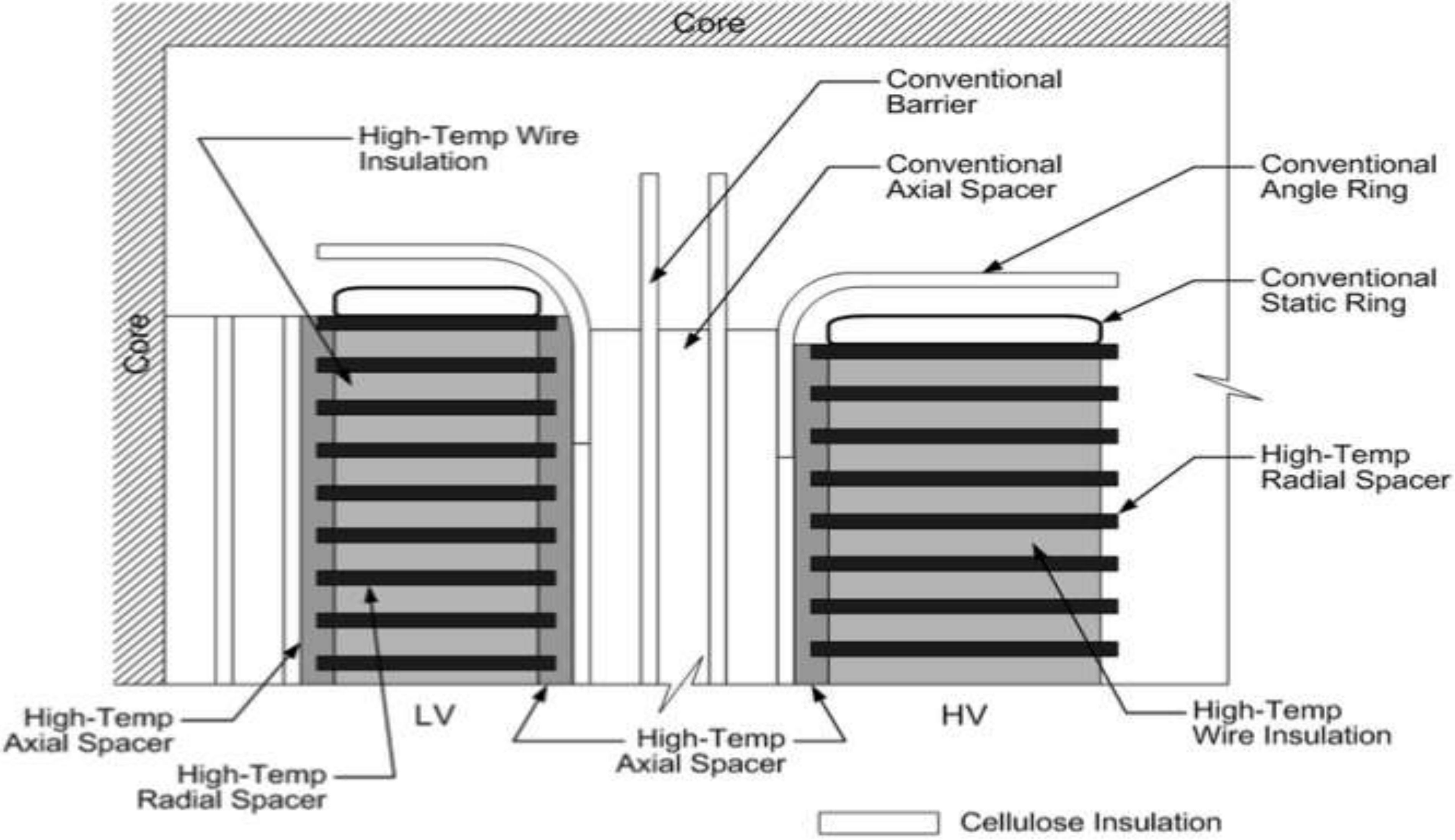


Figure 2—Illustration of a full hybrid insulation winding

C57.154 standard

What's This?

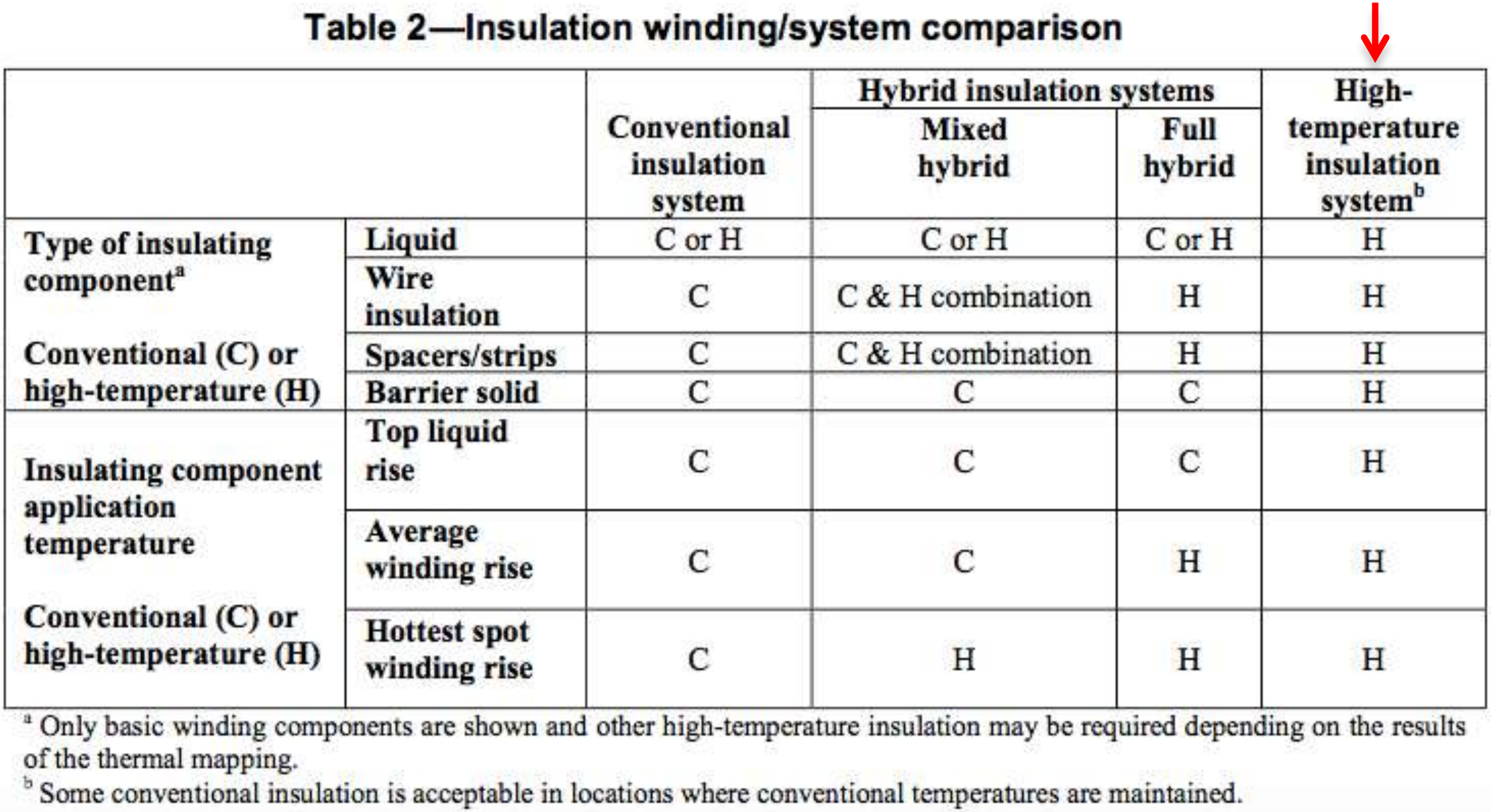


Table 2—Insulation winding/system comparison

		Conventional insulation system	Hybrid insulation systems		High-temperature insulation system[b]
			Mixed hybrid	Full hybrid	
Type of insulating component[a] Conventional (C) or high-temperature (H)	Liquid	C or H	C or H	C or H	H
	Wire insulation	C	C & H combination	H	H
	Spacers/strips	C	C & H combination	H	H
	Barrier solid	C	C	C	H
Insulating component application temperature Conventional (C) or high-temperature (H)	Top liquid rise	C	C	C	H
	Average winding rise	C	C	H	H
	Hottest spot winding rise	C	H	H	H

[a] Only basic winding components are shown and other high-temperature insulation may be required depending on the results of the thermal mapping.

[b] Some conventional insulation is acceptable in locations where conventional temperatures are maintained.

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- **High Temp Insulation System** – An insulation system used throughout the transformer, except for some minor insulation in lower temp areas, **together with high-temp insulating liquid** operating at higher than conventional levels

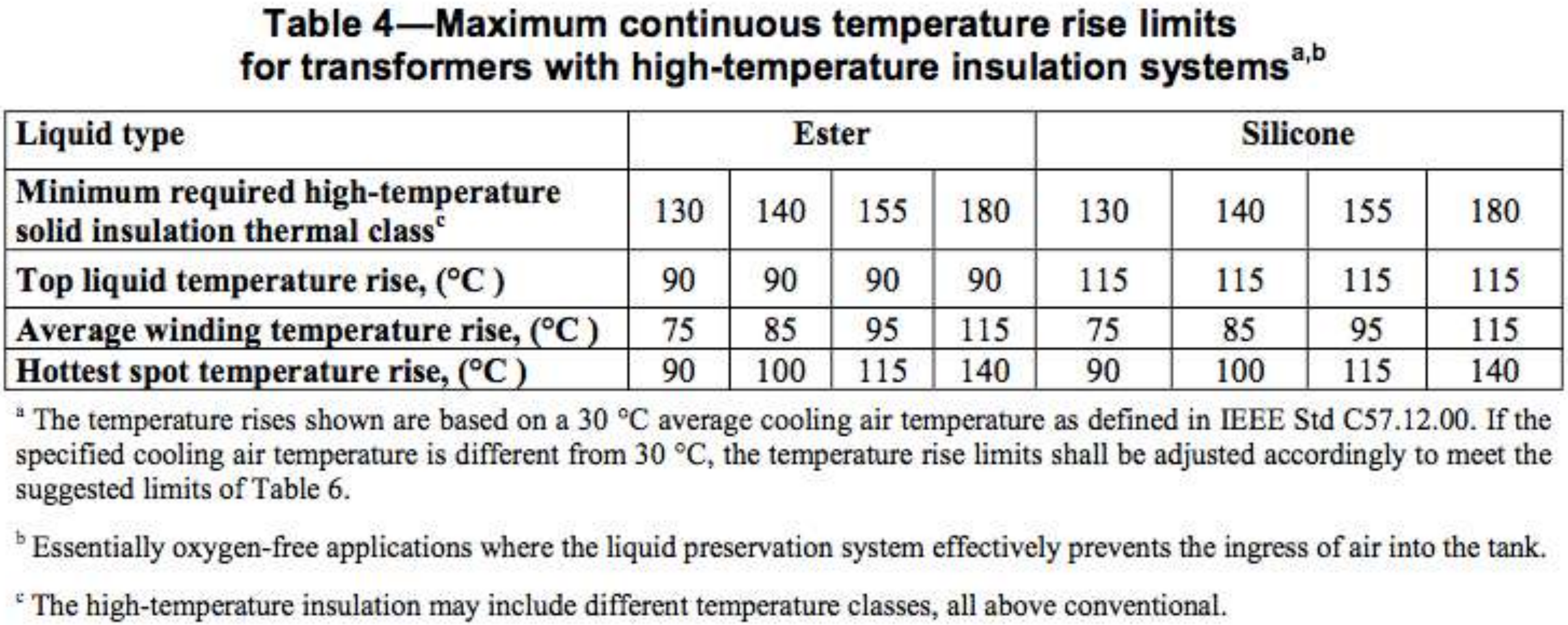

Table 4—Maximum continuous temperature rise limits for transformers with high-temperature insulation systems[a,b]

Liquid type	Ester				Silicone			
Minimum required high-temperature solid insulation thermal class[c]	130	140	155	180	130	140	155	180
Top liquid temperature rise, (°C)	90	90	90	90	115	115	115	115
Average winding temperature rise, (°C)	75	85	95	115	75	85	95	115
Hottest spot temperature rise, (°C)	90	100	115	140	90	100	115	140

[a] The temperature rises shown are based on a 30 °C average cooling air temperature as defined in IEEE Std C57.12.00. If the specified cooling air temperature is different from 30 °C, the temperature rise limits shall be adjusted accordingly to meet the suggested limits of Table 6.

[b] Essentially oxygen-free applications where the liquid preservation system effectively prevents the ingress of air into the tank.

[c] The high-temperature insulation may include different temperature classes, all above conventional.

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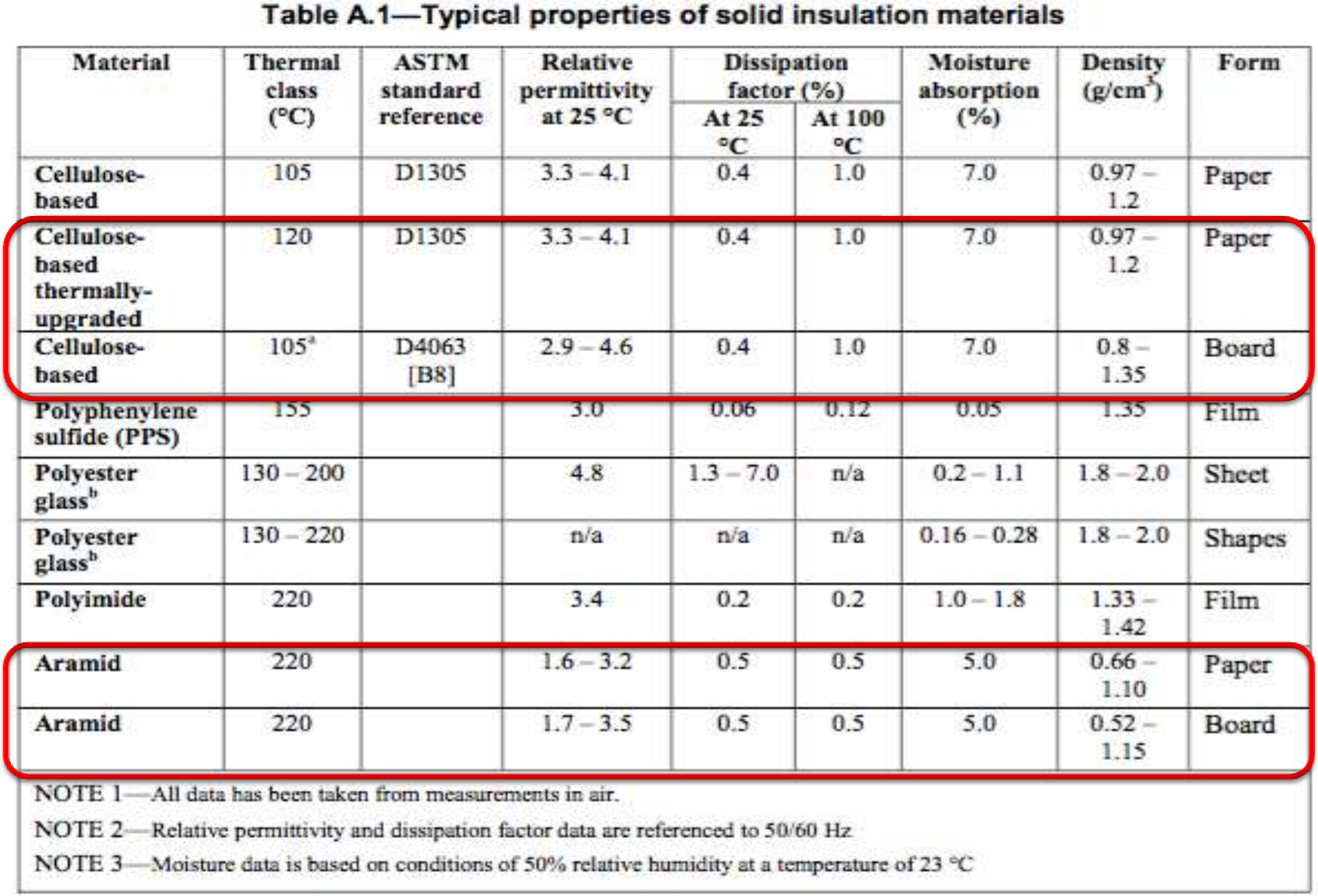


Table A.1—Typical properties of solid insulation materials

Material	Thermal class (°C)	ASTM standard reference	Relative permittivity at 25 °C	Dissipation factor (%)		Moisture absorption (%)	Density (g/cm^3)	Form
				At 25 °C	At 100 °C			
Cellulose-based	105	D1305	3.3 – 4.1	0.4	1.0	7.0	0.97 – 1.2	Paper
Cellulose-based thermally-upgraded	120	D1305	3.3 – 4.1	0.4	1.0	7.0	0.97 – 1.2	Paper
Cellulose-based	105[a]	D4063 [B8]	2.9 – 4.6	0.4	1.0	7.0	0.8 – 1.35	Board
Polyphenylene sulfide (PPS)	155		3.0	0.06	0.12	0.05	1.35	Film
Polyester glass[b]	130 – 200		4.8	1.3 – 7.0	n/a	0.2 – 1.1	1.8 – 2.0	Sheet
Polyester glass[b]	130 – 220		n/a	n/a	n/a	0.16 – 0.28	1.8 – 2.0	Shapes
Polyimide	220		3.4	0.2	0.2	1.0 – 1.8	1.33 – 1.42	Film
Aramid	220		1.6 – 3.2	0.5	0.5	5.0	0.66 – 1.10	Paper
Aramid	220		1.7 – 3.5	0.5	0.5	5.0	0.52 – 1.15	Board

NOTE 1—All data has been taken from measurements in air.

NOTE 2—Relative permittivity and dissipation factor data are referenced to 50/60 Hz

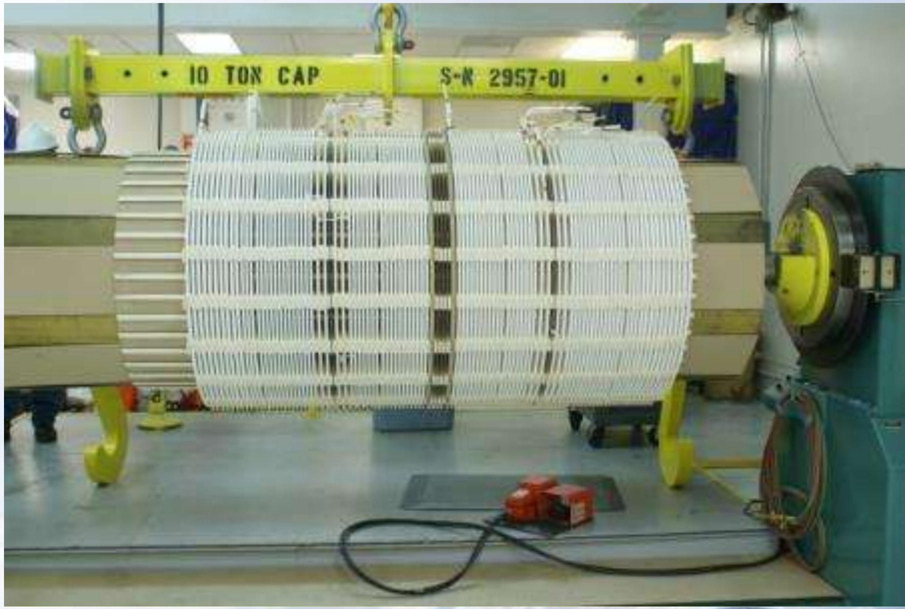
NOTE 3—Moisture data is based on conditions of 50% relative humidity at a temperature of 23 °C

Typical Mobile Transformer construction

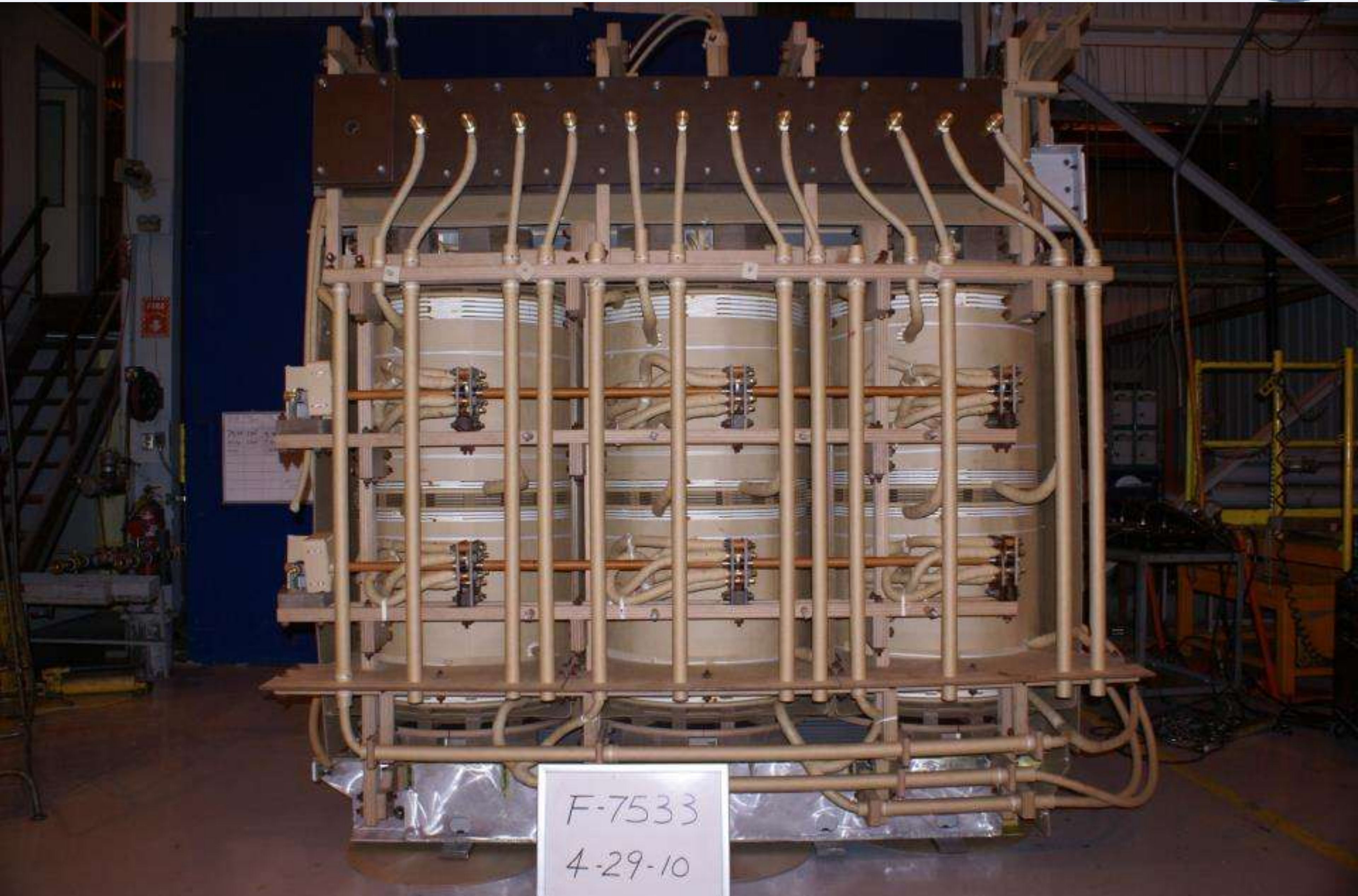
❑ High temperature material minimum 155 °C

- Wire insulation on all designs
- Key spacers on 95°C rise units
- Vertical strips on 95°C rise units
- Insulation in contact with metal parts temperature over 120°C

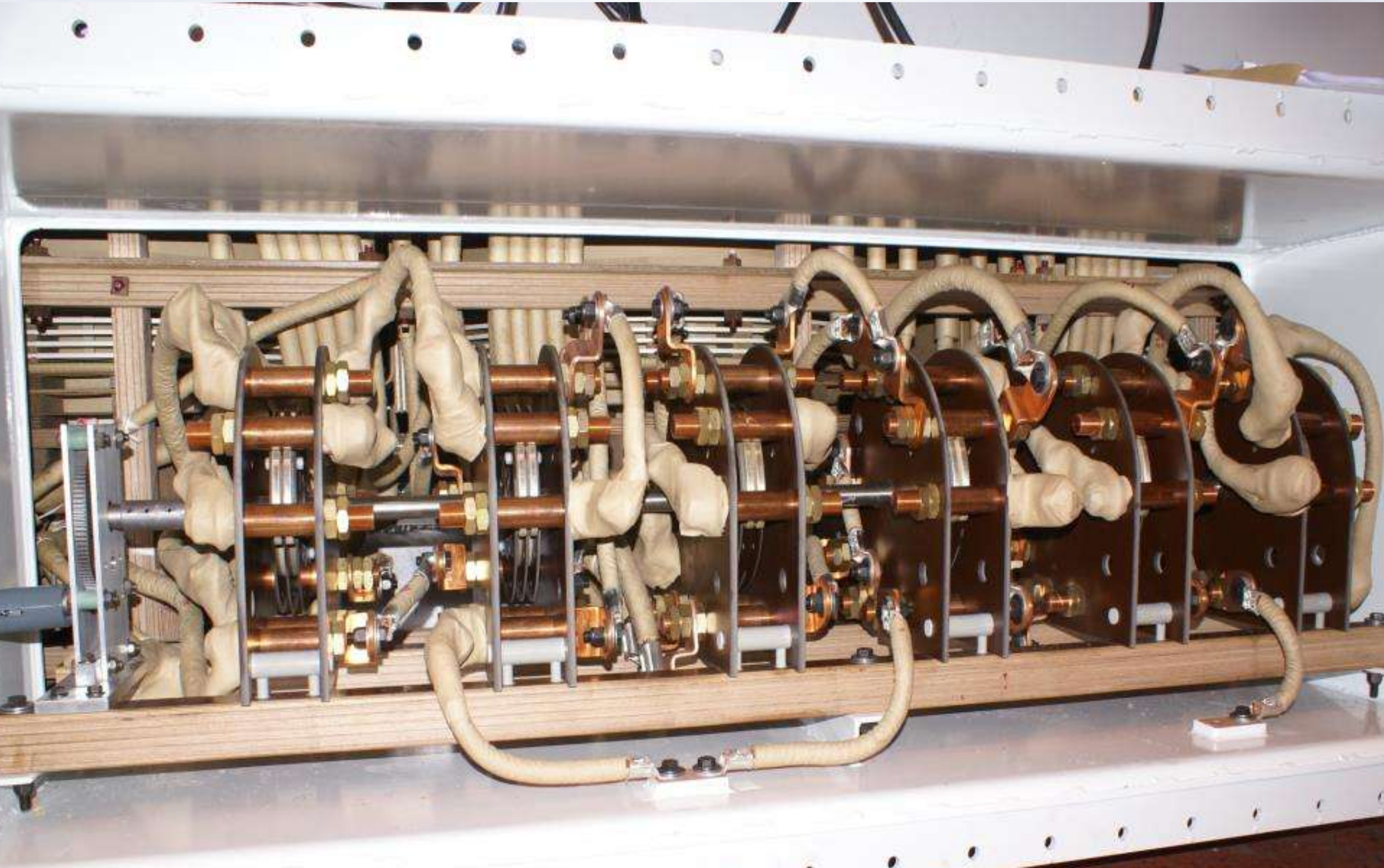
❑ Pressboard (low- and high density) for areas in contact with oil only where temperature is up to 105°C



HV Switch



LV Switch



Setting up mobile units

Setting up units

Power	Mobile
☐ Unit in storage	☐ Unit in storage
☐ Move on truck with crane	☐ ------
☐ Move to location	☐ Move to location
☐ Move to pad with **crane**	☐ ------
☐ Set on pad	☐ Set mobile
☐ **Install rads., bushings, SA**	☐ ------
☐ Wire control cabinet	☐ ------
☐ Check and set controls	☐ Check and set controls

Setting up units

Power

- ☐ Vacuum fill unit
- ☐ Waiting time after filling
- ☐ Test unit
- ☐ Energize unit
- ☐ DGA
- ☐ Load unit
- ☐ DGA
- ☐ Set up time – 4-6 days longer than for mobile unit

Mobile

- ☐ ------
- ☐ ------
- ☐ Test unit
- ☐ Energize unit
- ☐ DGA
- ☐ Load unit
- ☐ DGA

Summary

- Transformer Design is FUN!
- Changes to one variable affects others
- Substantial differences in Mobile vs. Power
- High temperature insulation has made it possible to push more MVA out of smaller size
- Read IEEE C57.154 for more detailed information

Examples of Mobile Substations and Mobile Products

Enclosed 10 MVA 34400 – 4800 x 2400

Enclosed 7 MVA, 25 kV Class Substation


DELTA STAR, INC.

HV 69 kV on the Gooseneck

70 MVA, 230 kV – 34.5 kV

50 MVA, 230 kV – 69 kV

45 MVA, 115 kV – 12 kV

40 MVA, 115 kV – 69 kV

30 MVA, 138 kV – 13 kV

HV PASMO Breaker

HV Transrupter

Transformer + LV
and
HV Breaker Trailer

Conservator Type

Portable Autotransformer

TURN_TABLE

Skid with Removable Wheels

Skid mounted Substation

Ready for transport

JUN 23 2006

Under the test

Visible shock absorbers

JUN 22 2006

Skid Unit

With LV switchgear, HV breaker, cooling

Transrupter with Switch Trailer

LV Breaker Trailer

Switchgear Trailer


DELTA STAR, INC.

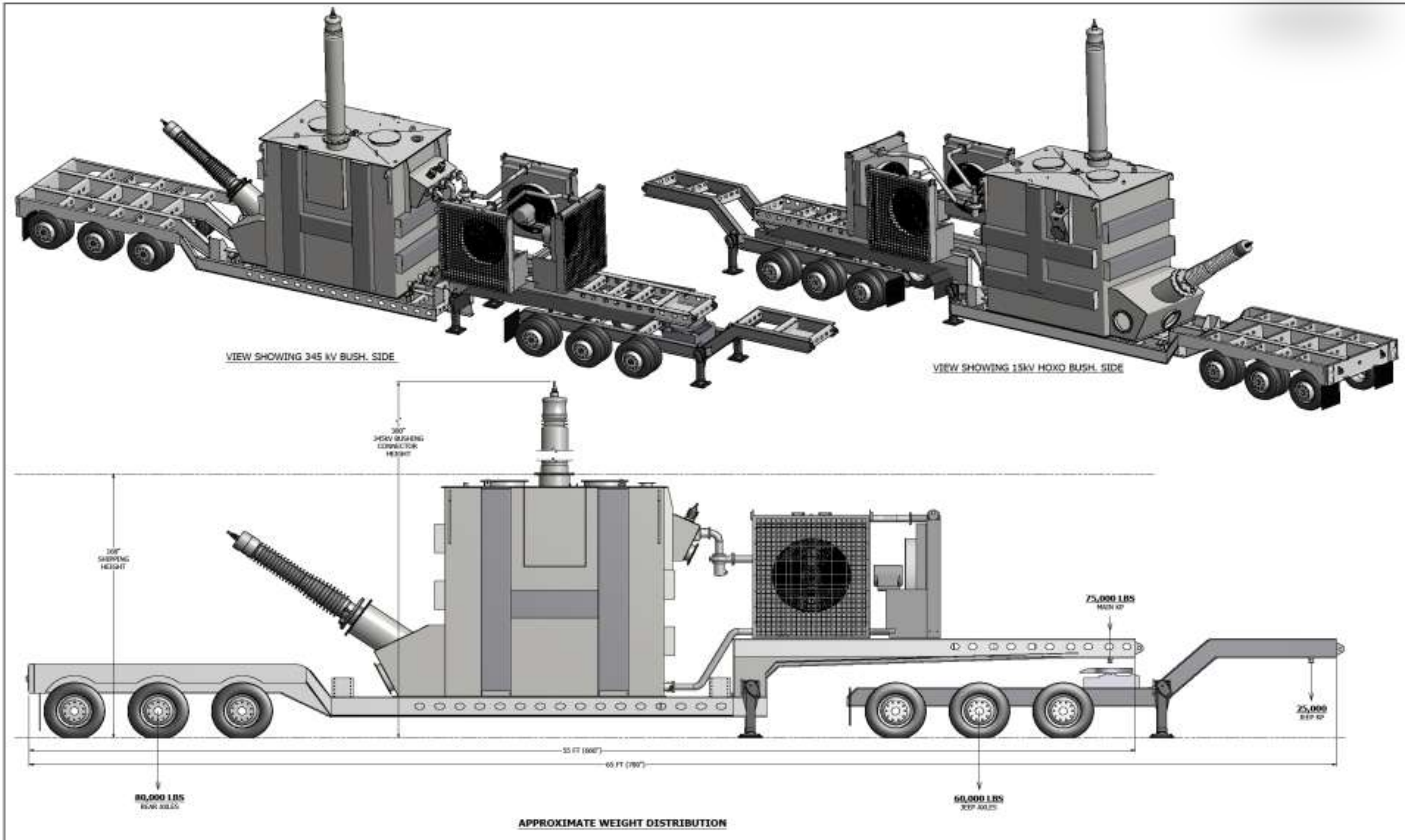
Cable Trailers

E7405

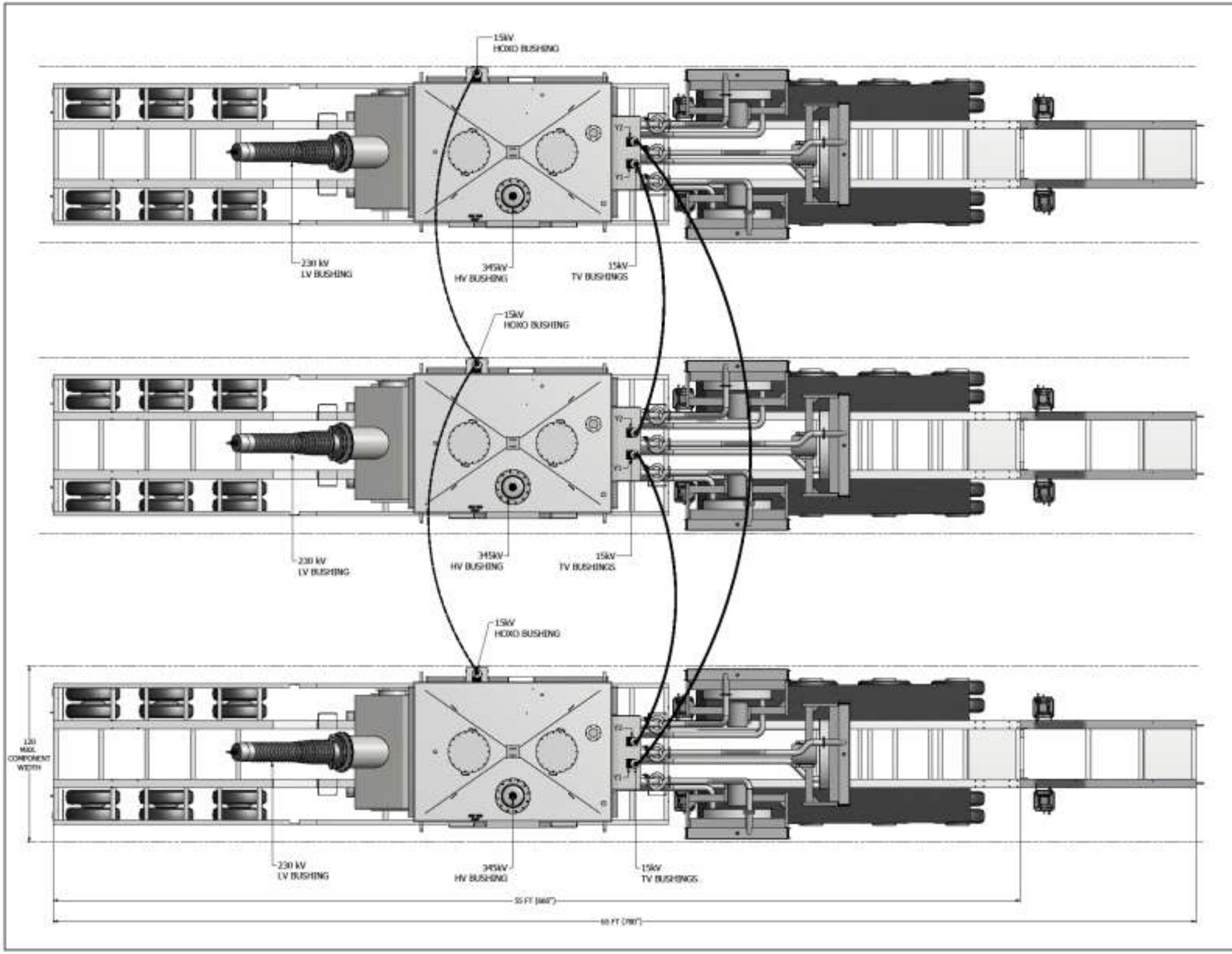

DELTA
STAR
INC.

Conceptual Design
of
400 MVA Autotransformer
345 kV – 230 kV, 15 kV TV
on three trailers

Single Phase Auto 133 MVA
345 kV - 230 kV



Connections and Weights



APPROXIMATE WEIGHTS	WEIGHTS [LBS]
UNTANKING (CORE & COIL)	45,000
OIL - MAIN TANK (6000 GAL)	45,000
TANK & FITTINGS	25,000
PUMP & COOLERS	10,000
ACCESSORIES AND MISC.	5,000
TRAILER	25,000
JEEP	10,000
TOTAL (6000 GAL)	165,000

THANK YOU