Fifty Years of Transformer Problems

Teshmont

Gas Cushion Transformers

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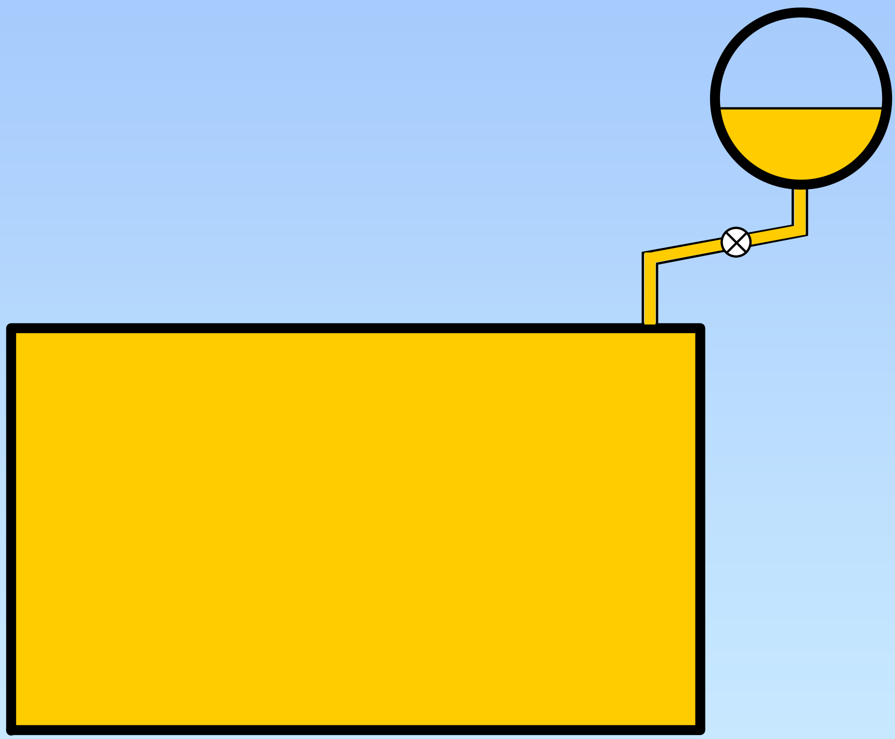
Transformers Oil Preservation (2)

The "Standard" Oil Conservator

Function:

less O_2 and H_2O in Oil



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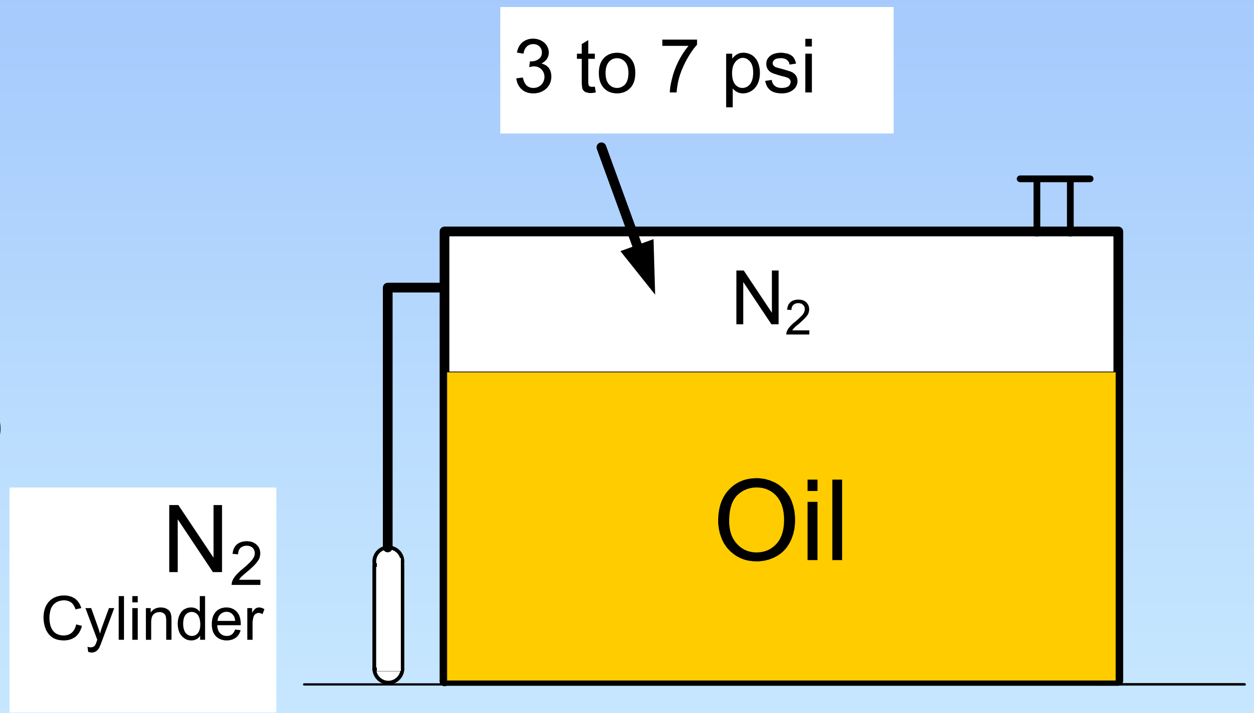
“Gas Cushion” Oil Preservation (3)

Used mainly in the United States

Aim: almost no O_2 in Oil



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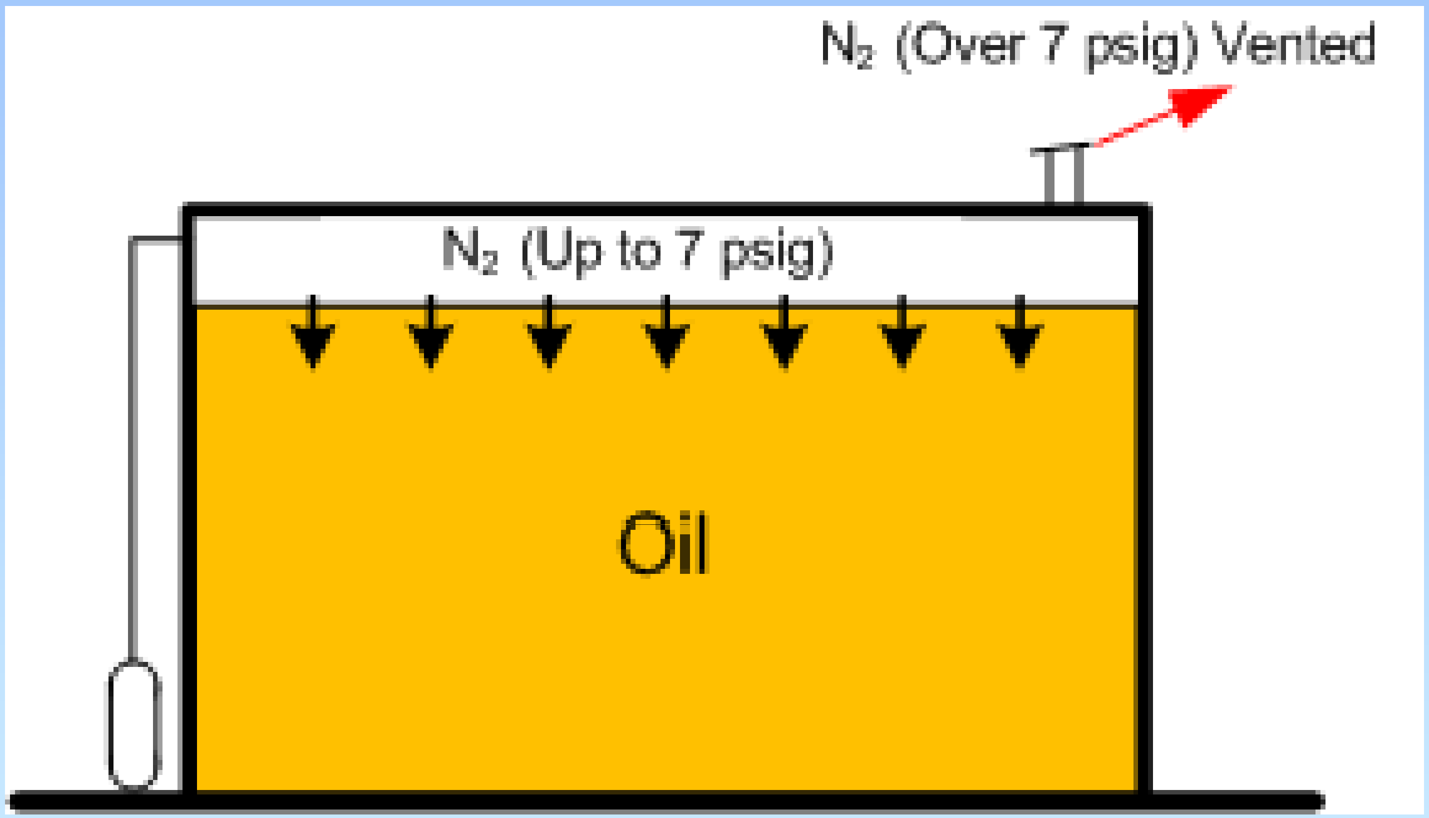
Gas Cushion (High Pressure) (4)



With load the N_2 pressure goes up to 7 psi

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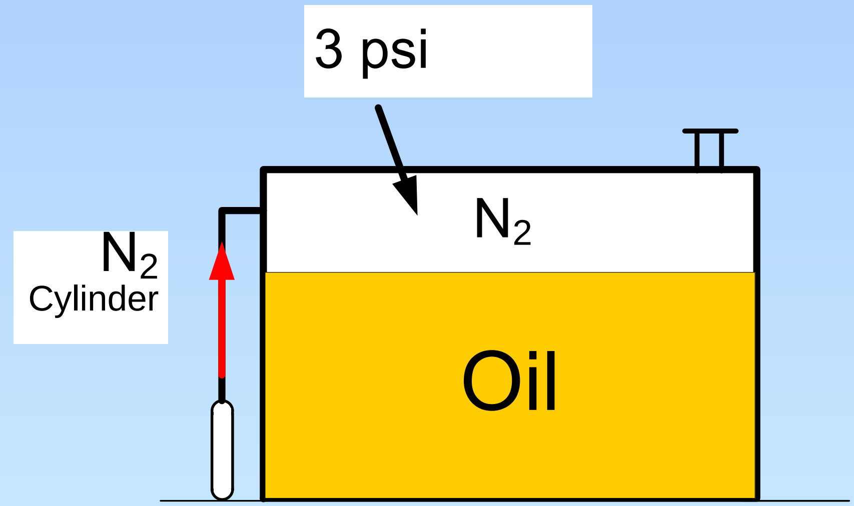
Gas Cushion pressure Change (4)

With lower Load, as the oil falls, the N_2 pressure also fall and at 3 psi. the N_2 is pressure is held by supplying fresh N_2 from the “bottle”.



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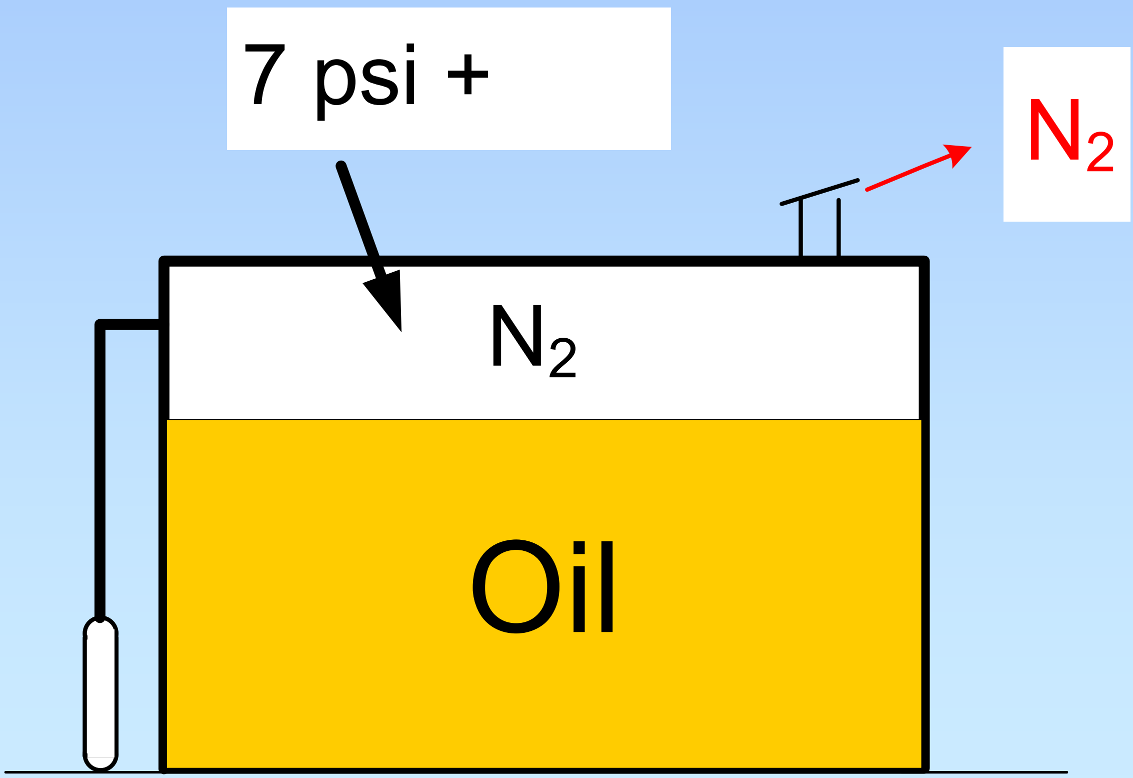
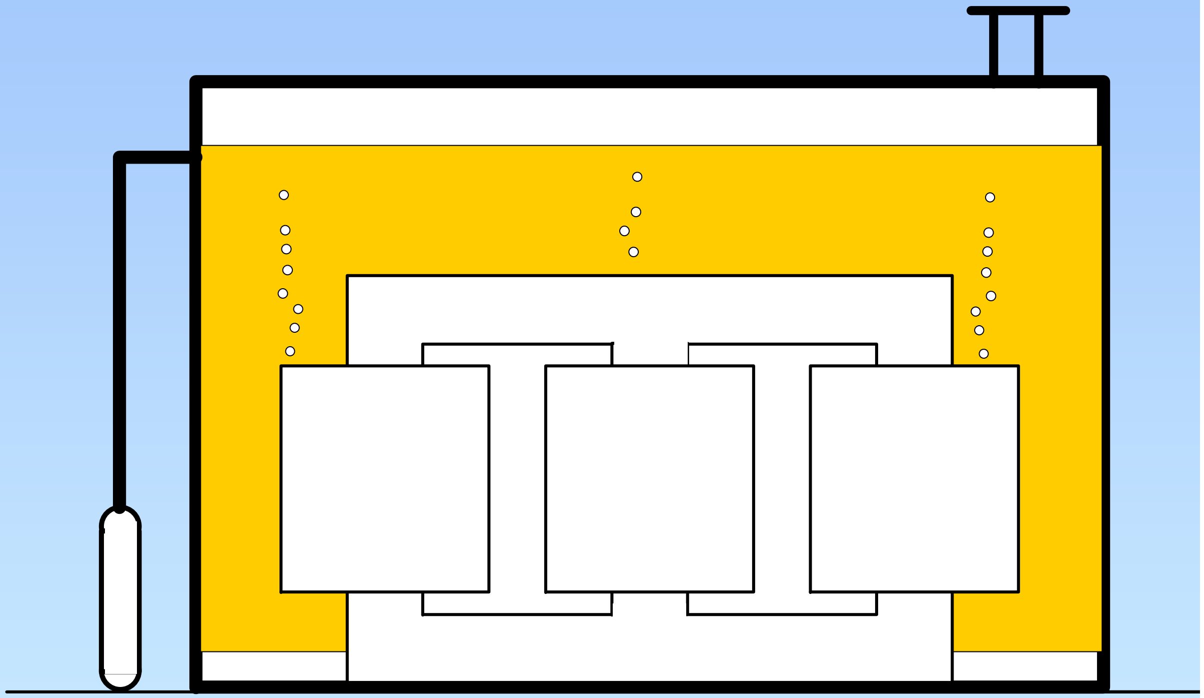
Gas (High Pressure (2)) (5)

Above 7 psi Nitrogen vented to atmosphere



Transformers Oil Preservation (6)

We found that an over saturated oil by about 2 psi or more, N_2 can come out of solution, in the form of bubbles.



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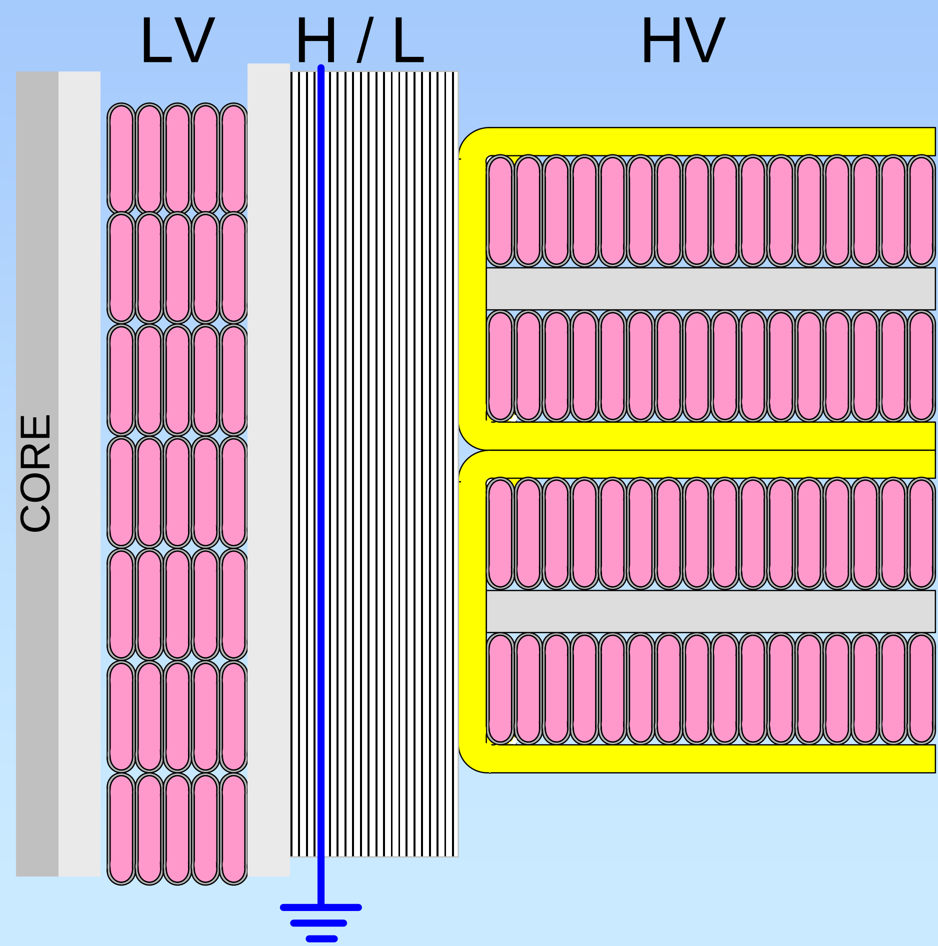
Winding Arrangement (7)

The transformer used the traditional winding arrangement working radially outwards from the core to the HV. The unusual part was the “solid” H / L insulation.



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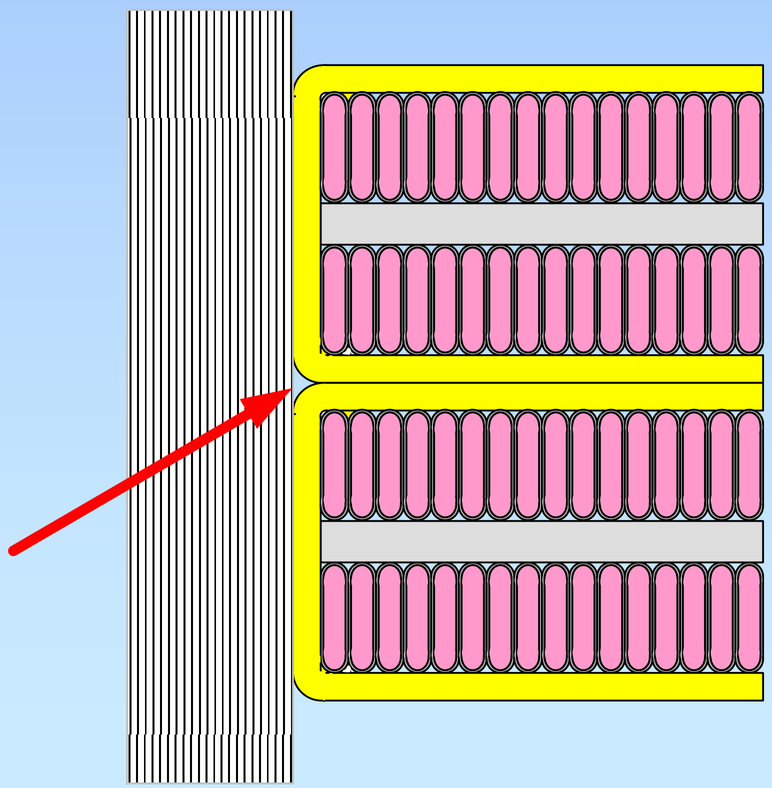
HV Winding with ‘extra insulation’ (8)

The “solid” H / L insulation resulted in a high stress occurring on the inside of the HV, so additional crepe tape (yellow) was applied.

Partial discharge in N_2 occurred at the back of the coil (red arrow). & black staining was found.

HV



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Insulation (9)

The black stain was copper oxide.

Lab work reveled that the partial discharge in the N_2 produced an amine compound, which is a derivative of Ammonia, and can dissolve copper oxide from the HV conductors.

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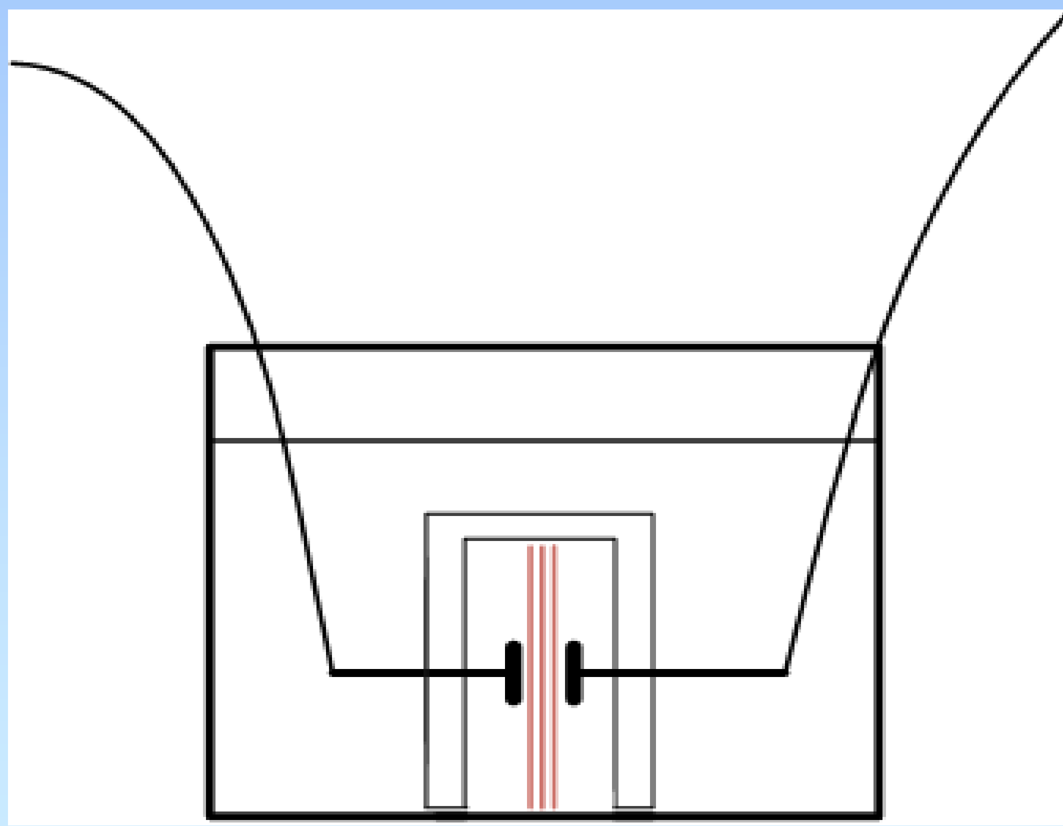
Model for tests



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Insulation (10)

The amine with Copper Oxide migrated though the crepe paper, and once diluted with the bulk oil, promptly deposited the Copper Oxide on the outside of the coils.

Not a good idea!

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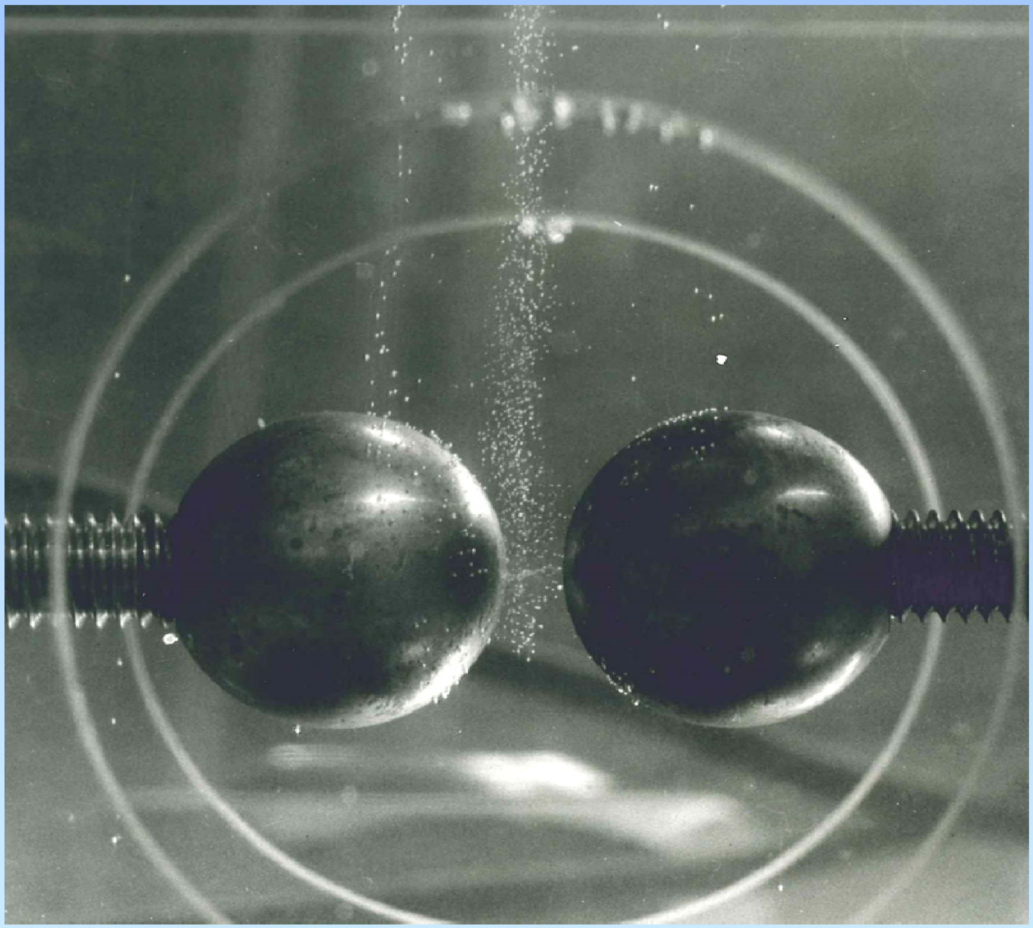
Bubbles in Oil (11)

12 mm dia spheres with 10 kV applied, in oil super-saturated with N_2..

Bubbles created spontaneously



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“Solid”: HV to LV Insulation

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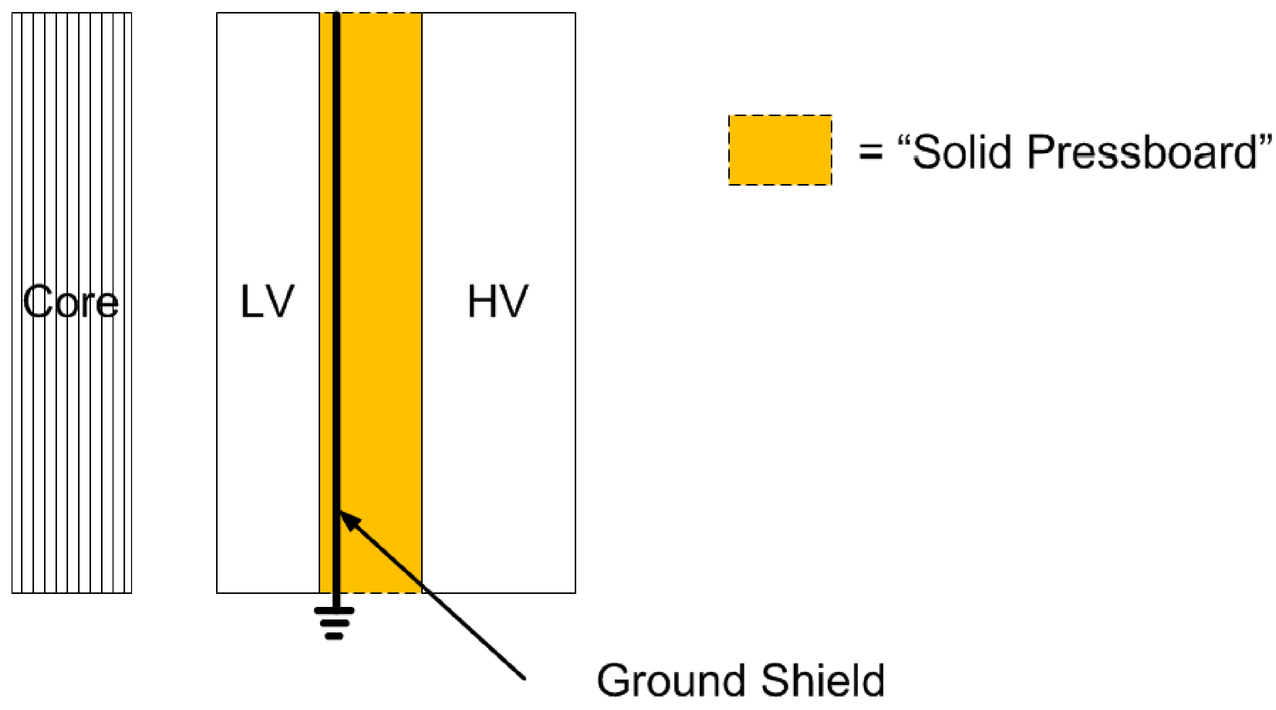
Grounded Shield to reduce impulse transfer to the LV



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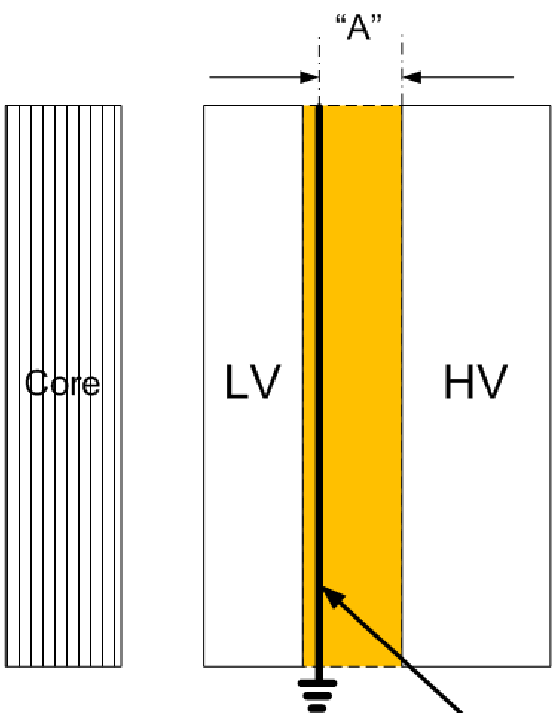
EE Major Insulation Design circa 1960



System Voltage (kV)	"A"
132 kV	1 "
275 kV	2¼ "

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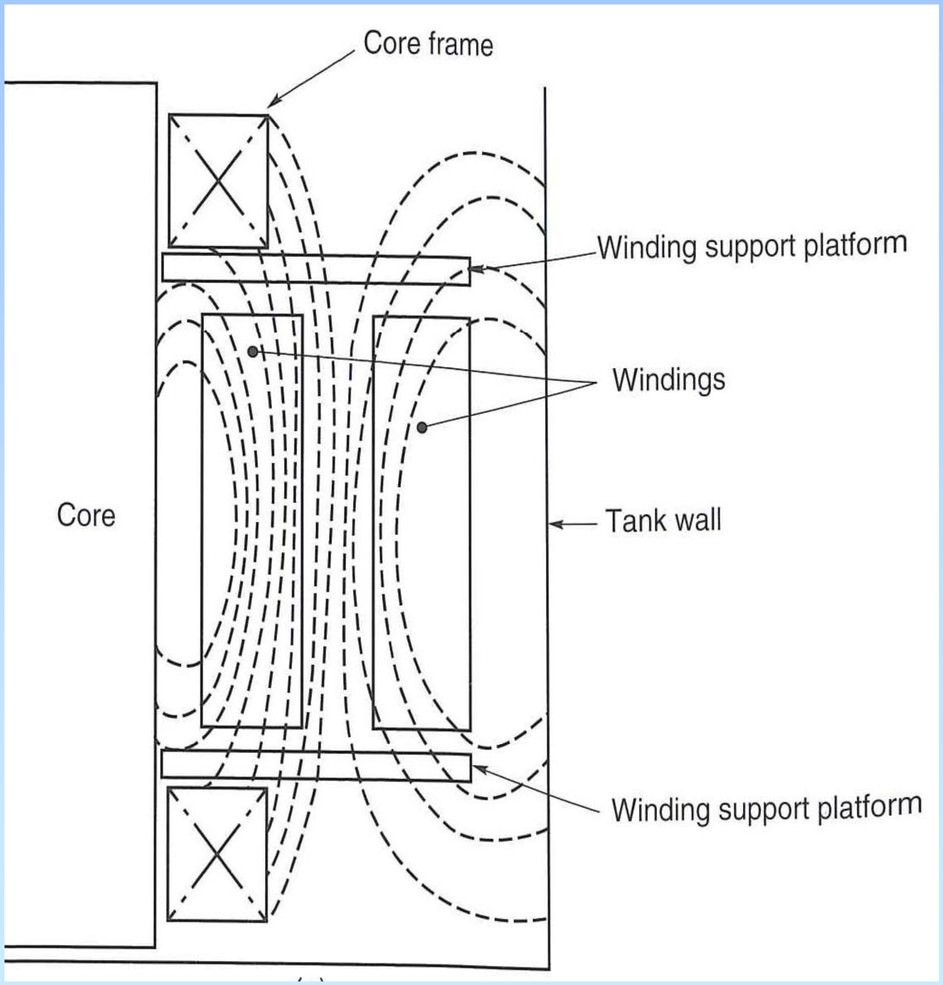
Leakage Flux (13)

A leakage flux plot from the J & P transformer book.

As transformer sizes increased, radial fluxes became more significant.



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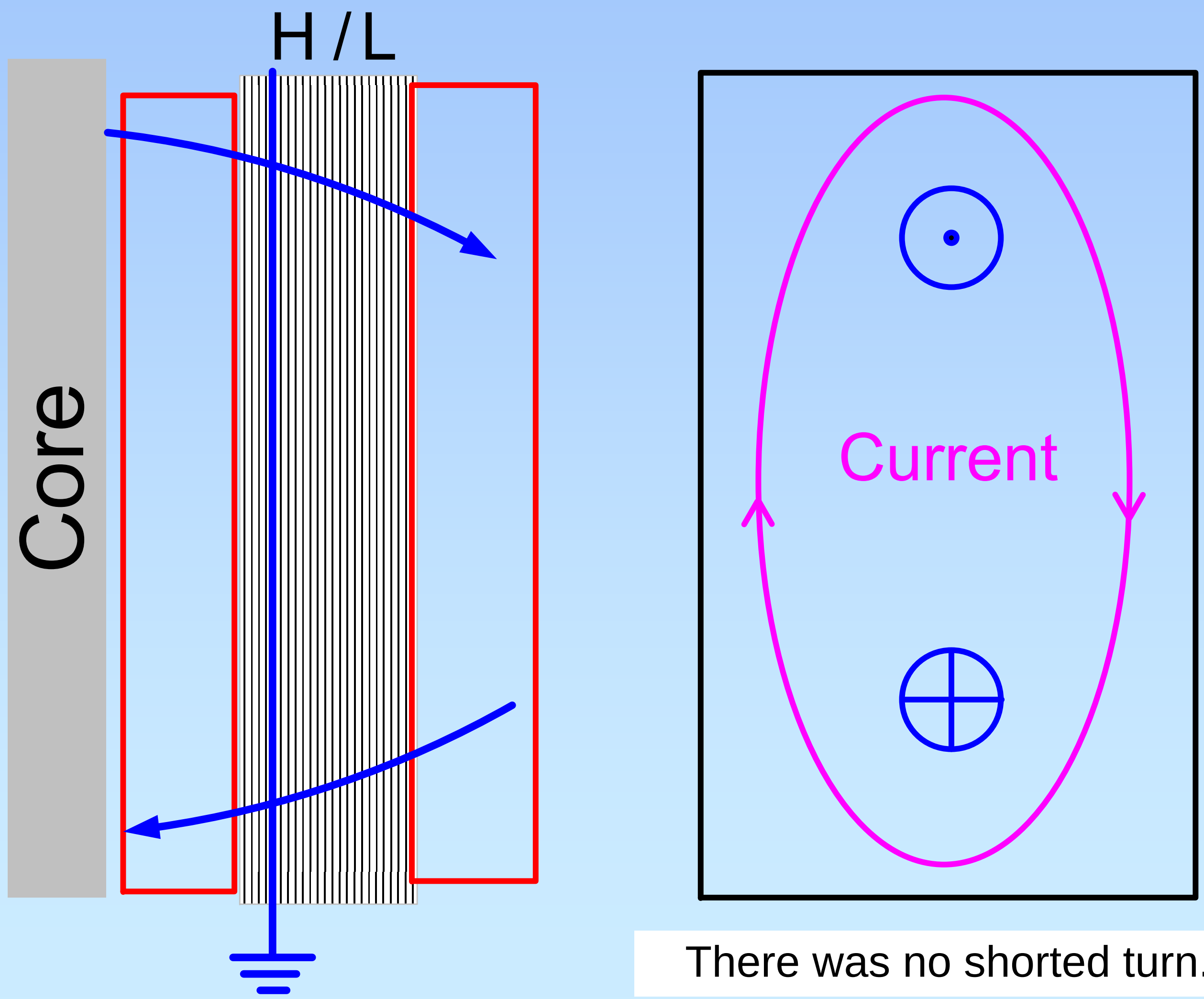
Leakage Flux (12)



There was no shorted turn.

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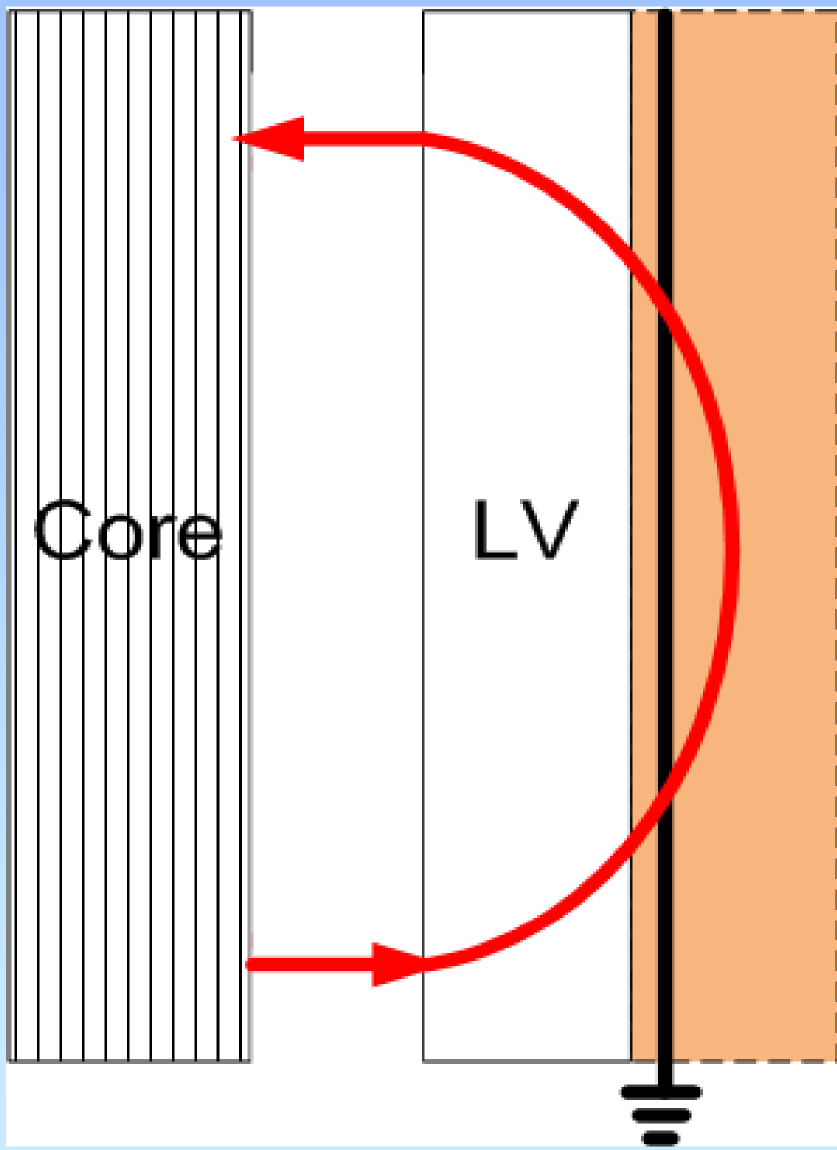

As the leakage flux “cuts” the shield

Hence the shield has a “gap”

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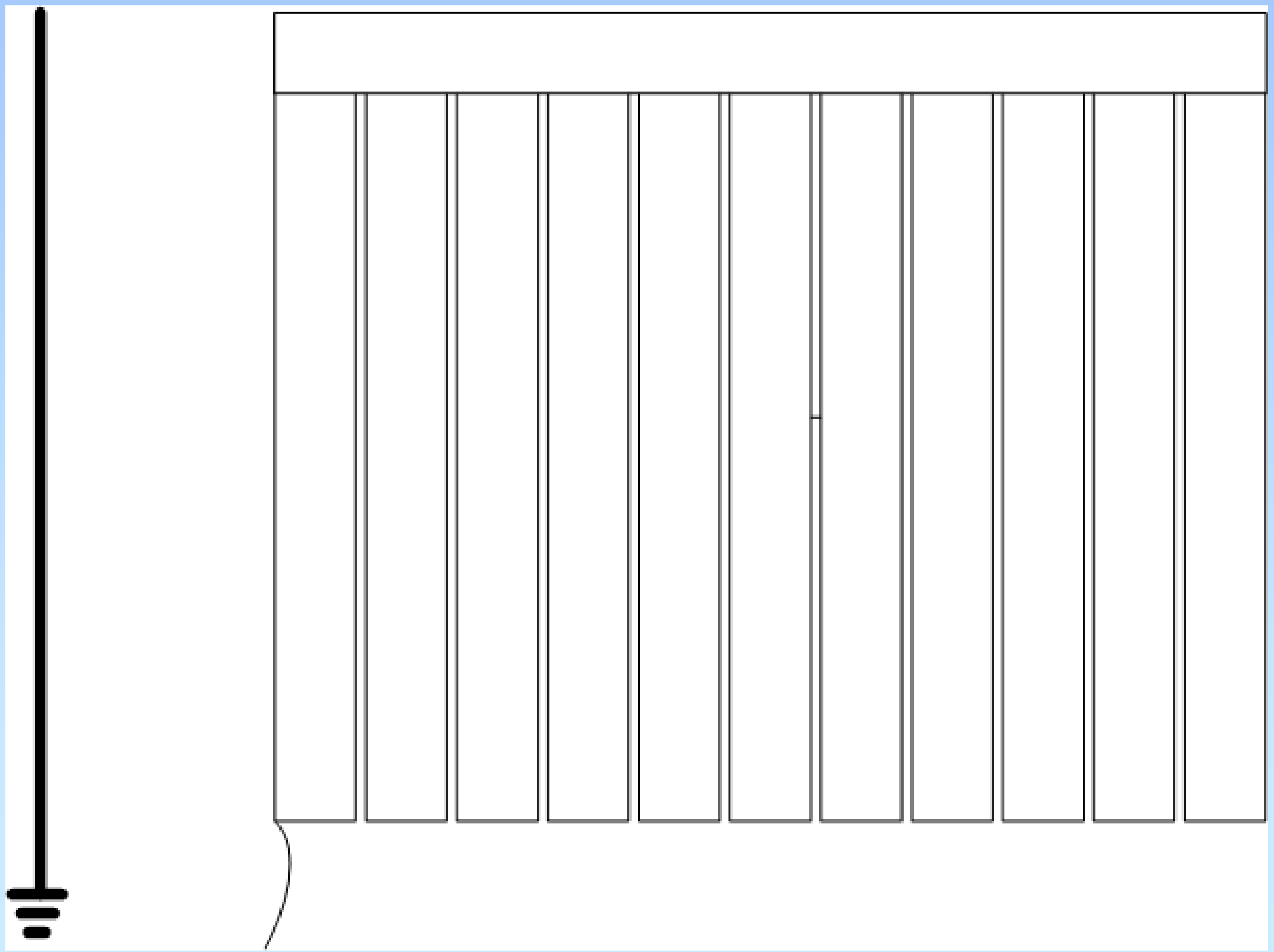
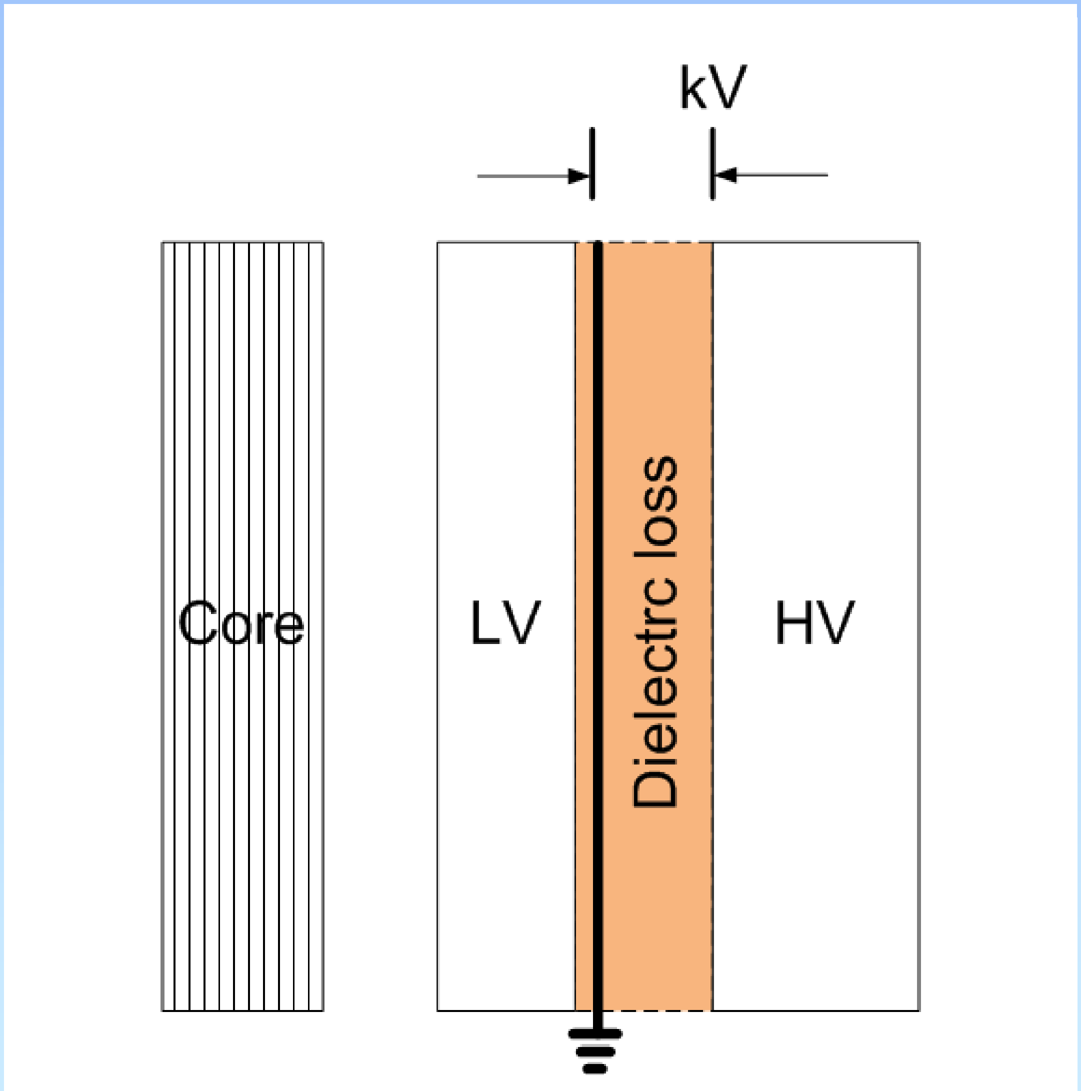
Developed view of the shield made using <u>nickel-silver</u> sheet, soldered as necessary



Teshmont



Dielectric losses were present because of poor impregnation

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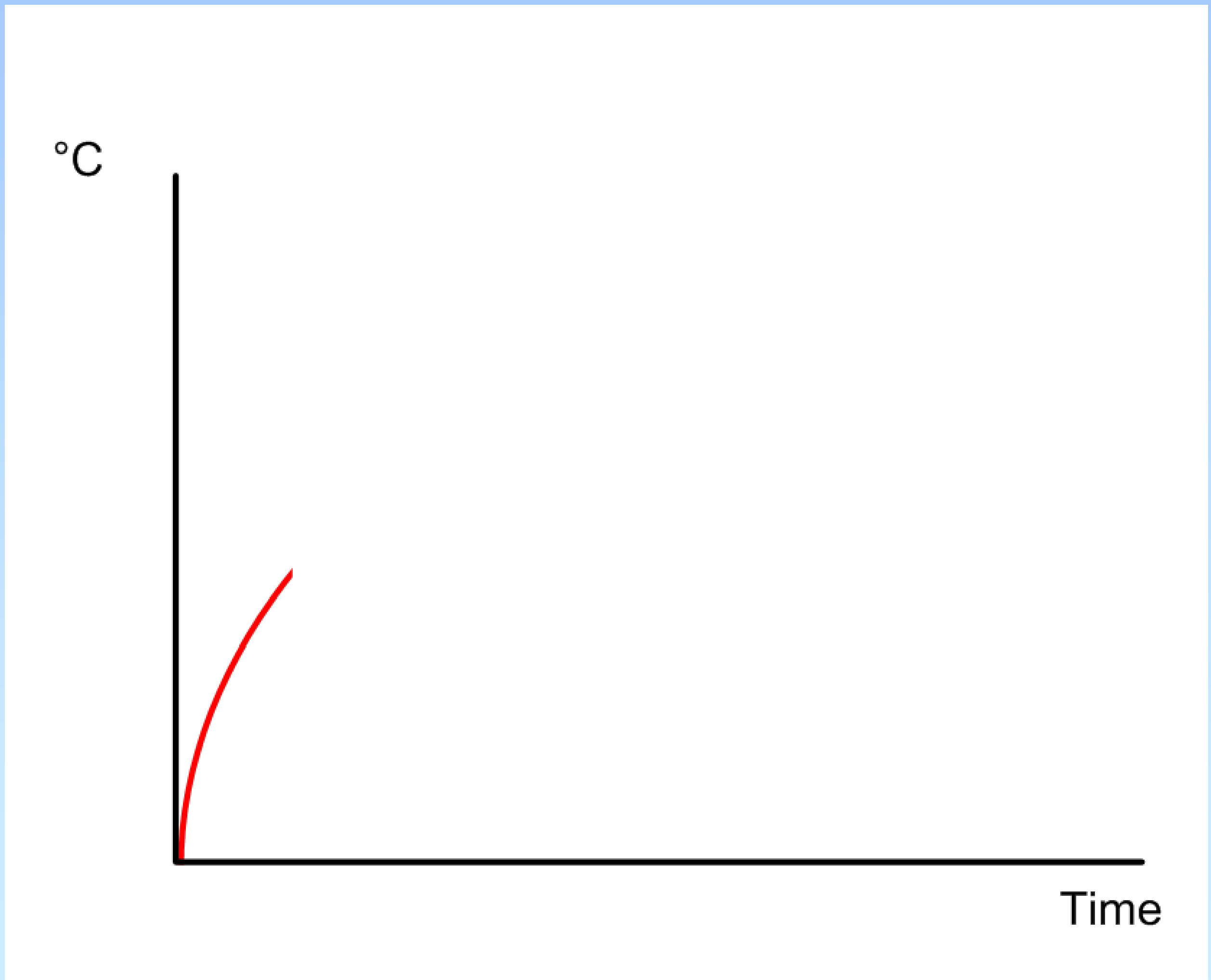
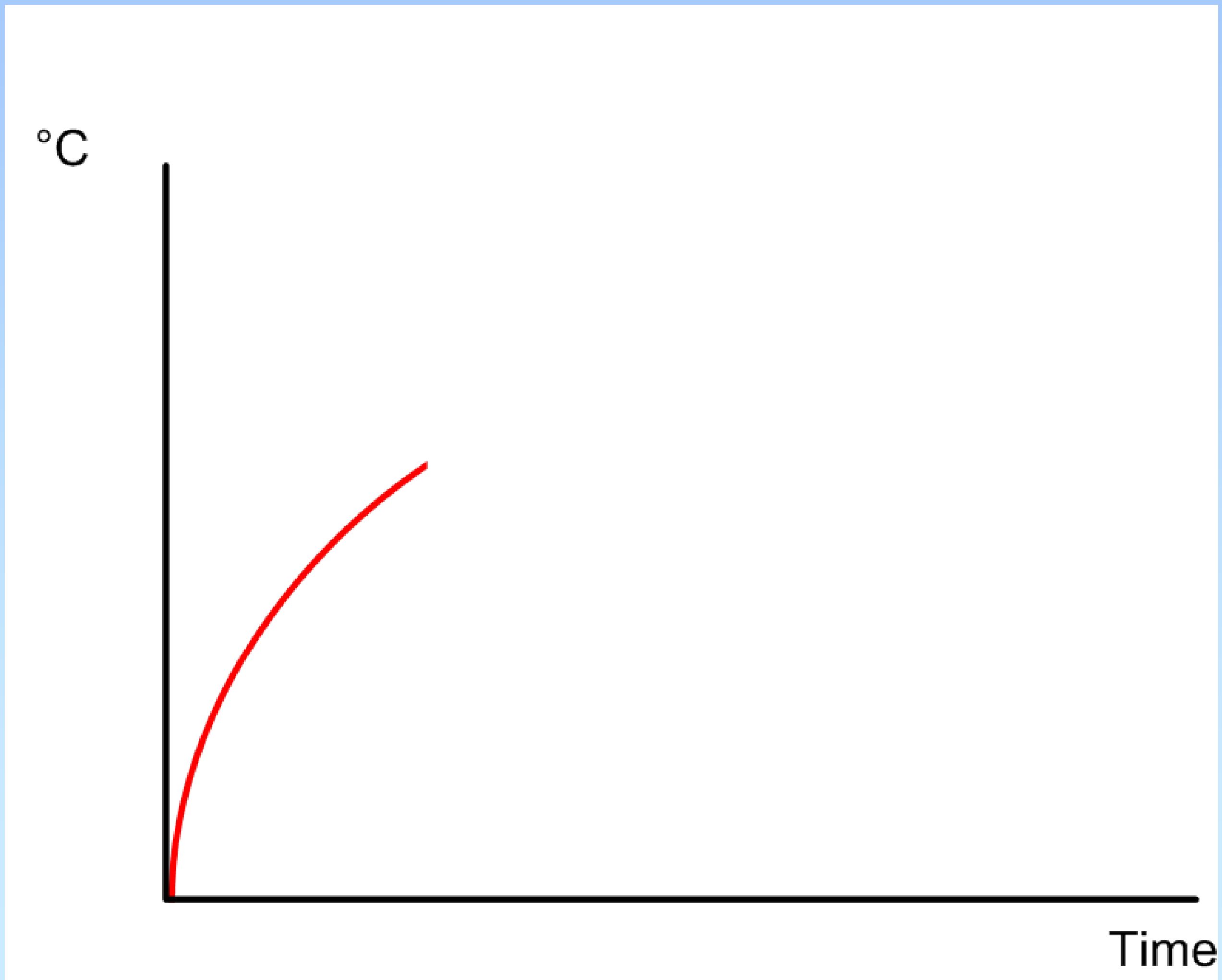
Model confirmed that if dielectric loss high, very high temperatures possible



Teshmont



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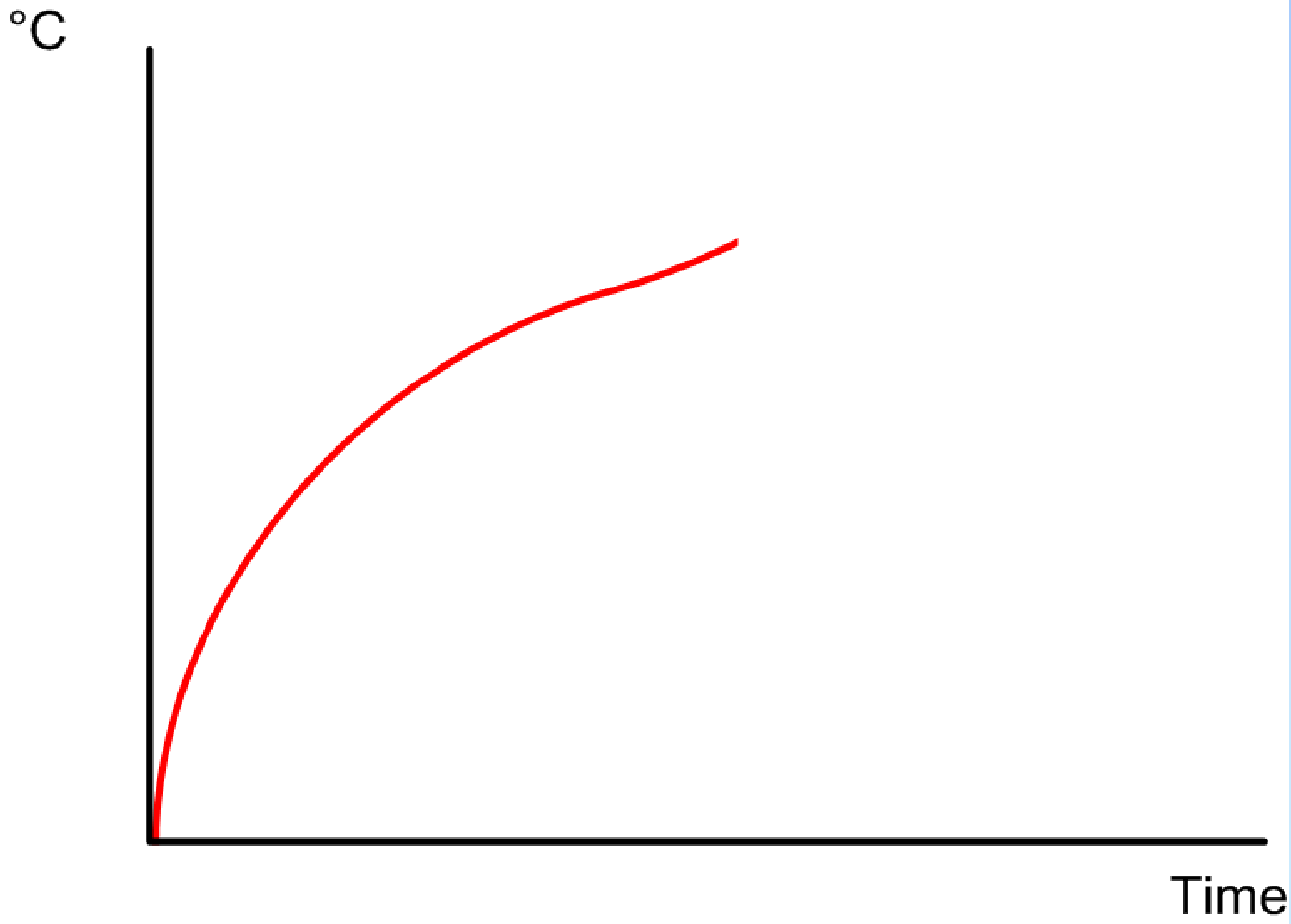

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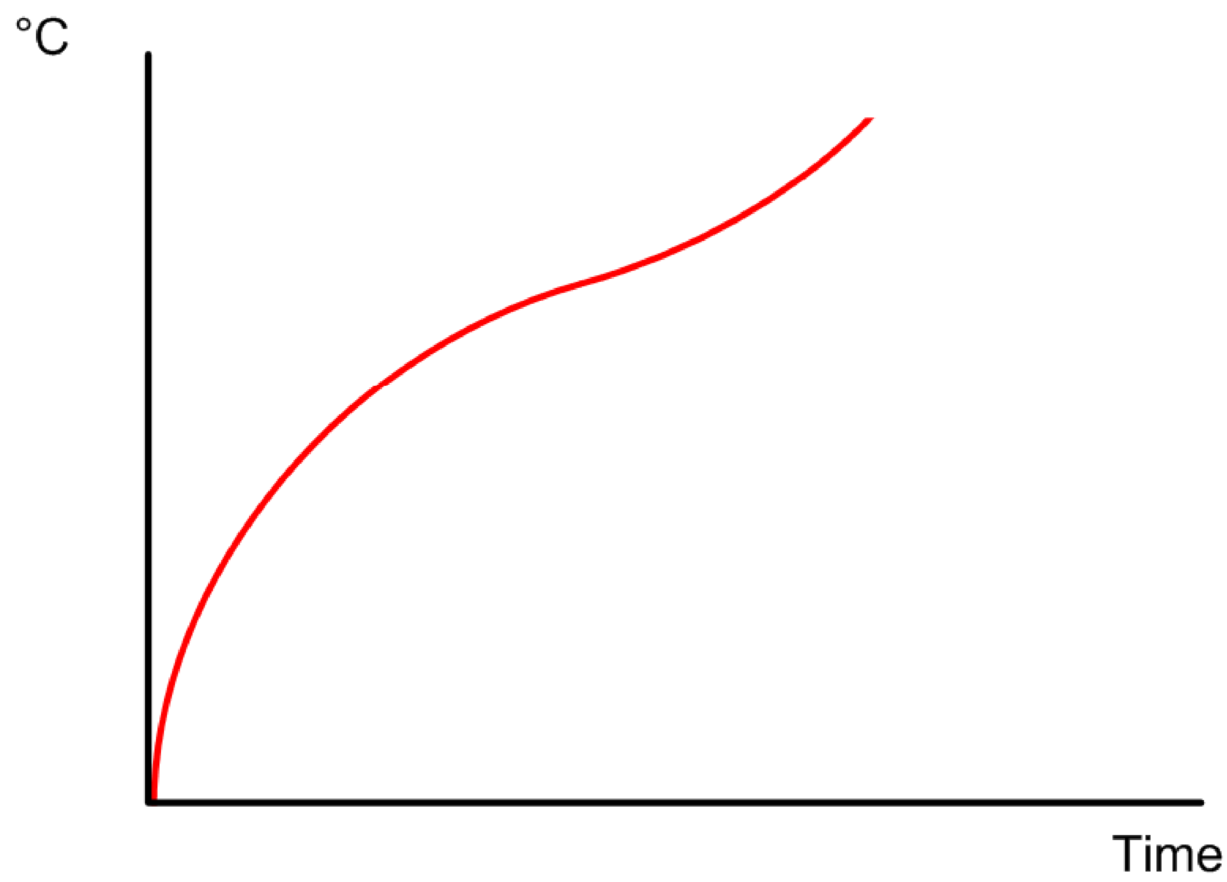

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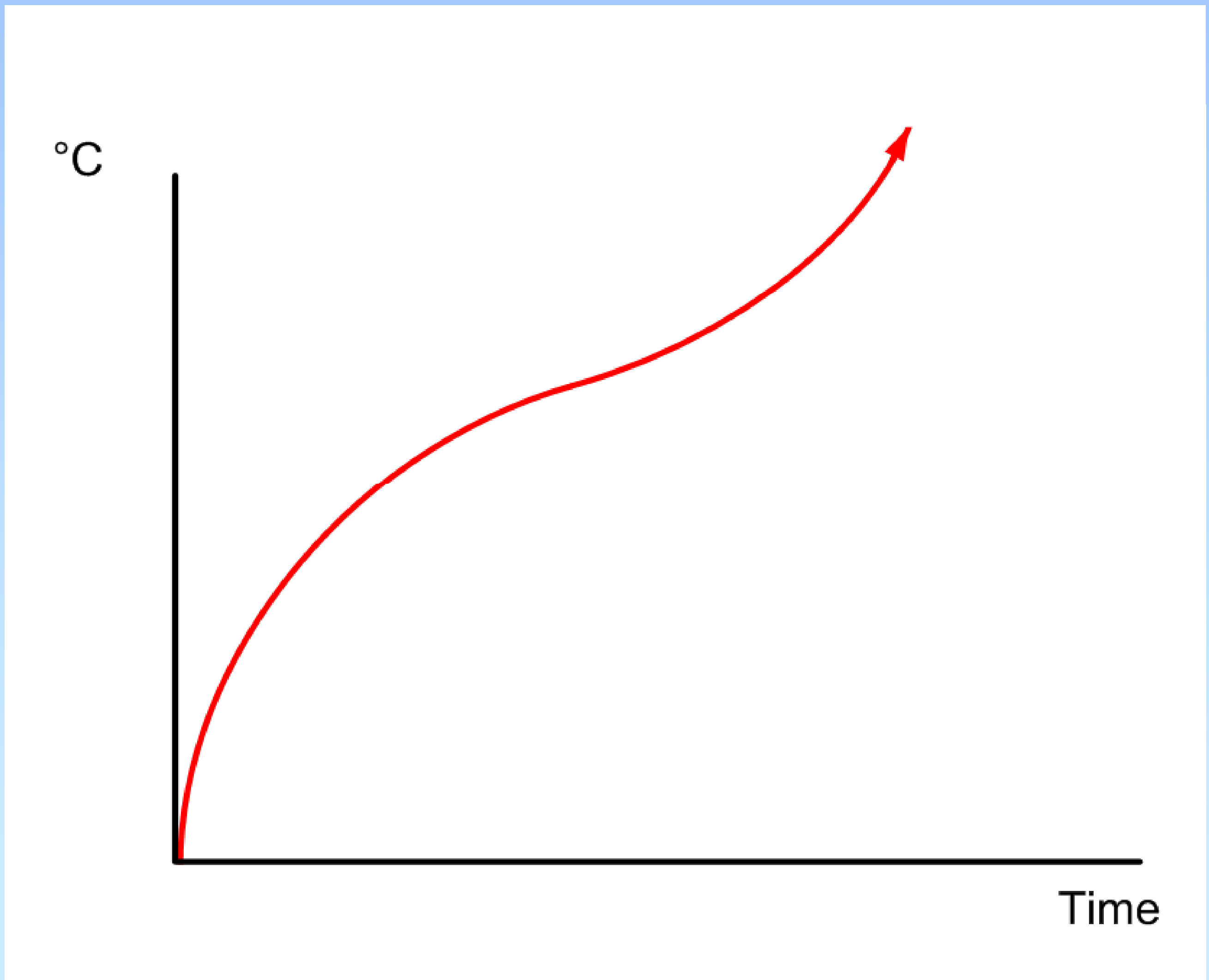
Nickel Silver melts at 1600 °C



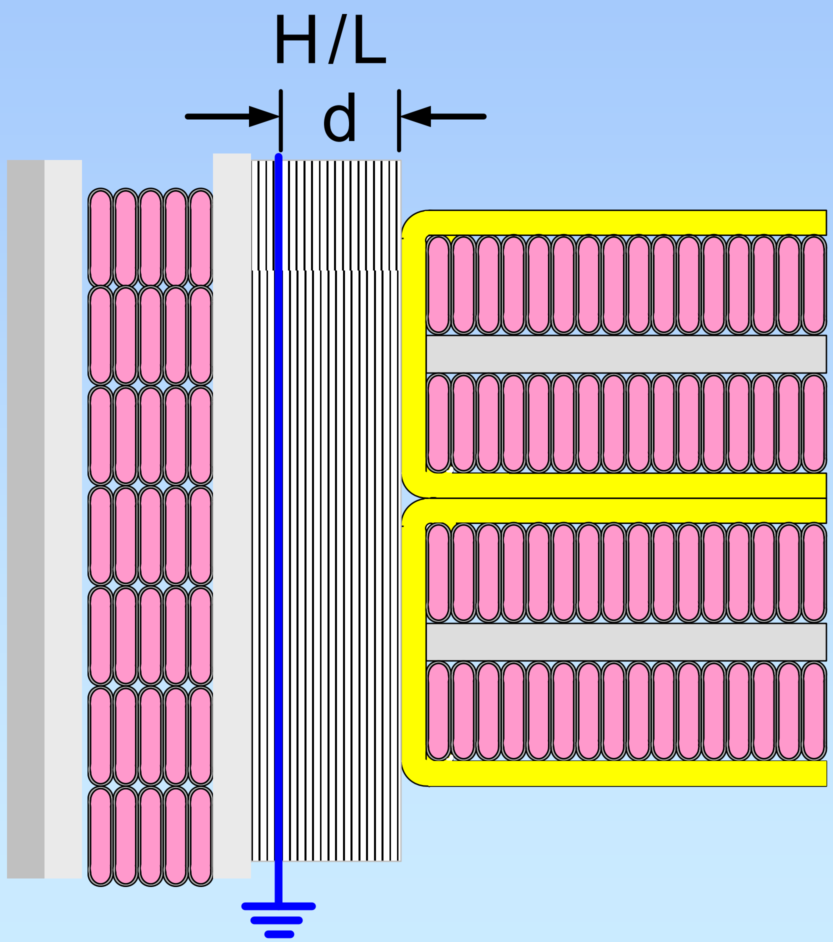
High to Low Insulation Design (14)

The design the Company used at that time consisted of a ”solid” wrap of pressboard:-

For 132 kV d=1”

For 275 kV d = 2¼ “

For 400 kV d = ??



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High to Low Insulation Design (16)

The cause of the high power factor was found to be due to inadequate processing at site.

So we carried out RIV tests, using an ERA equipment, on all the Companied 275 kV transformers in the country.

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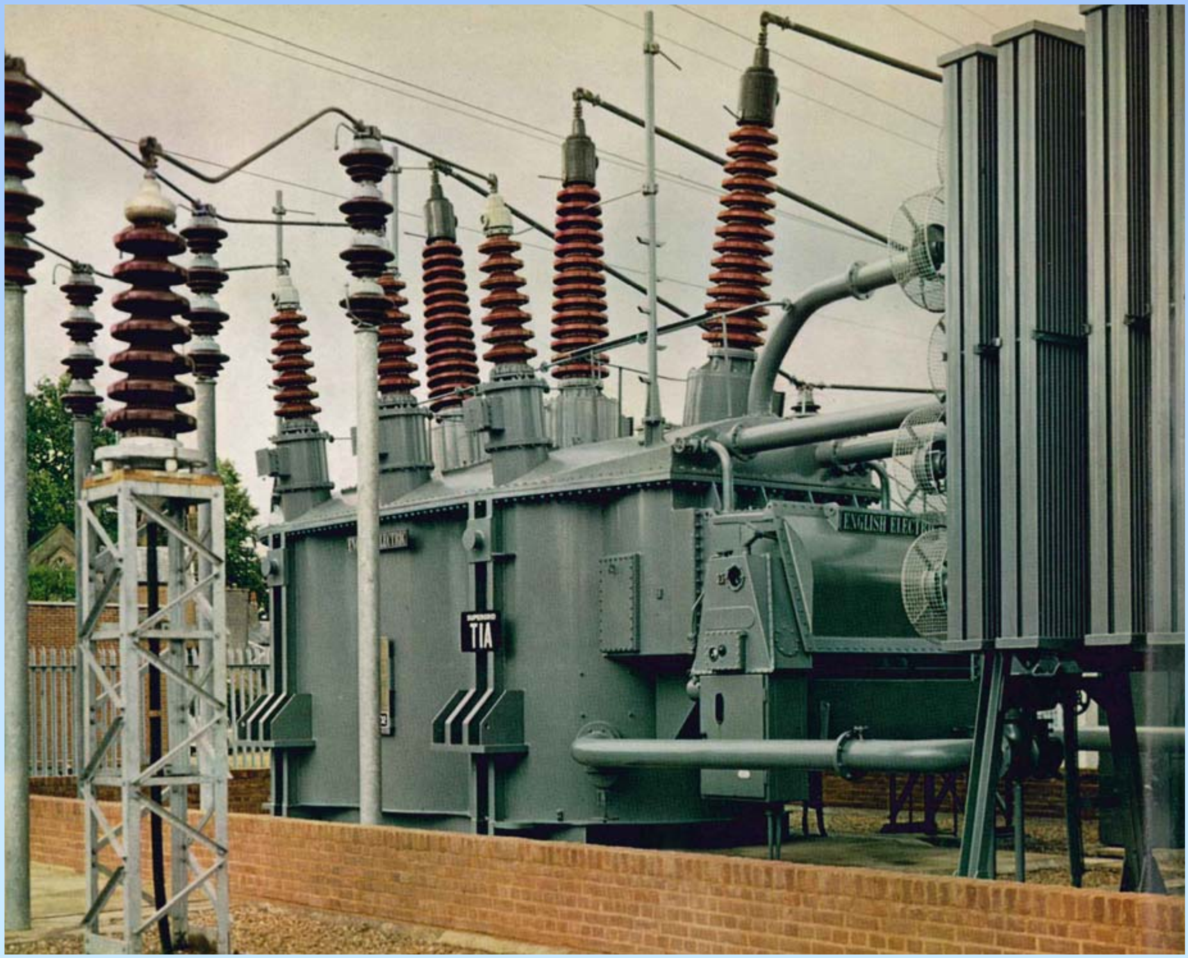
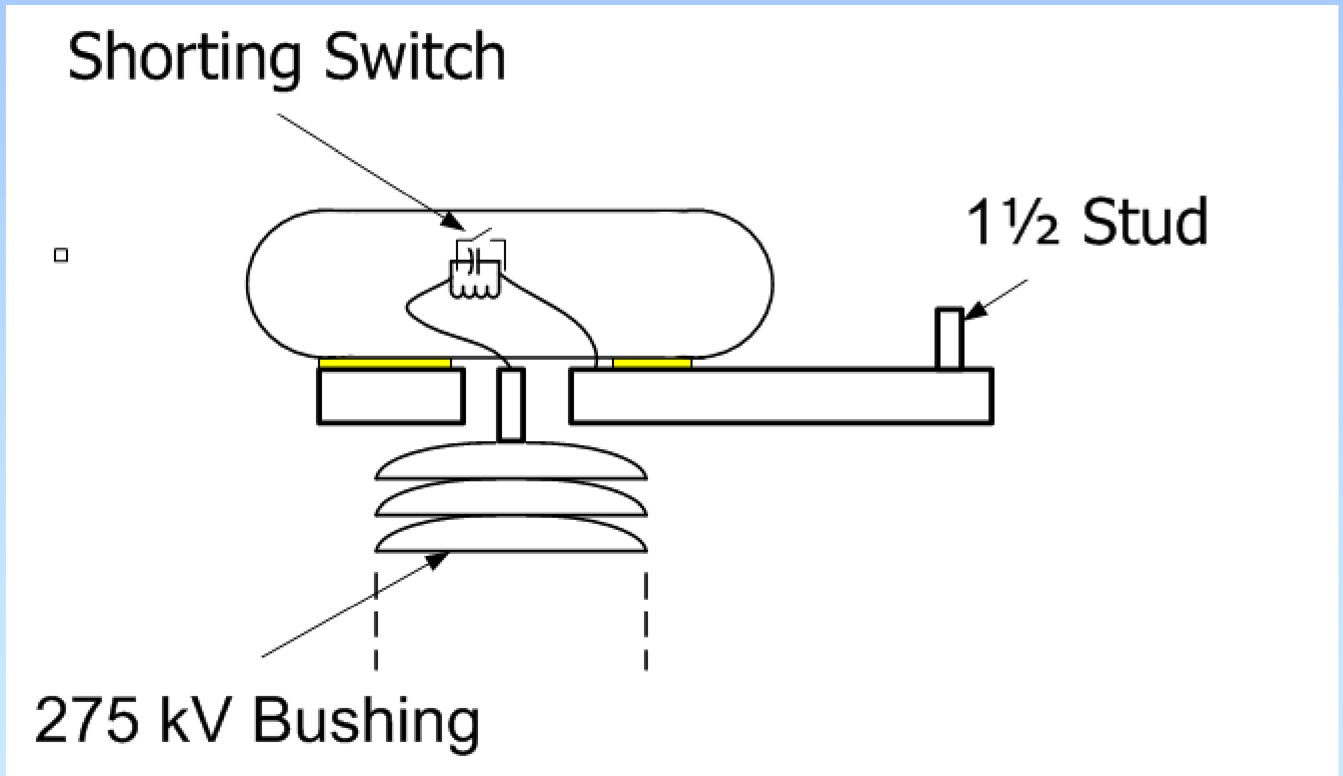
275/132 kV Autotransformer at Iver Station (Buckinghamshire)



HF Filter on HV Bushing



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High to Low Insulation Design (17)

Where the ERA system detected Partial Discharge (PD), the transformer was taken out of service, the oil drained, high vacuum applied and the unit refilled with de-gassed oil. Then PD testing repeated.

In each and every case the repeat test the PD was not detectable.

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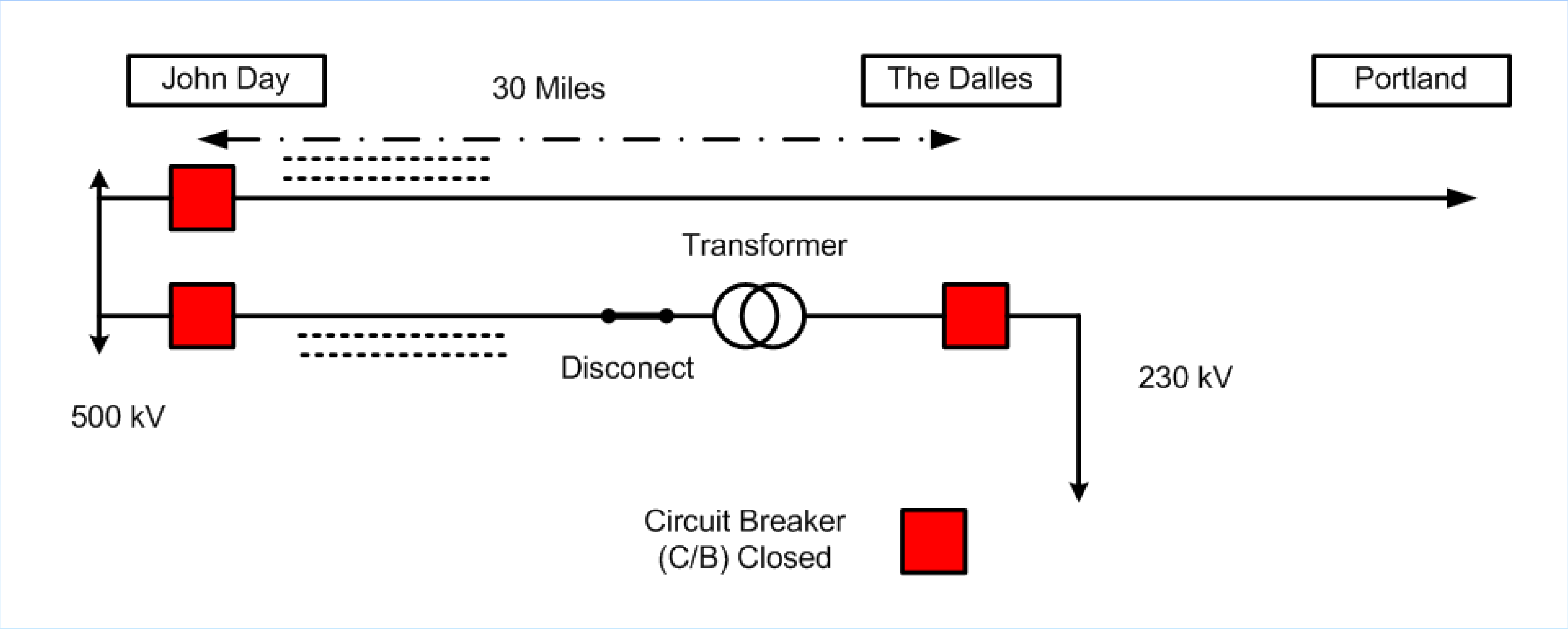
Bonneville Power, WA
Ferro-resonance at 500 kV



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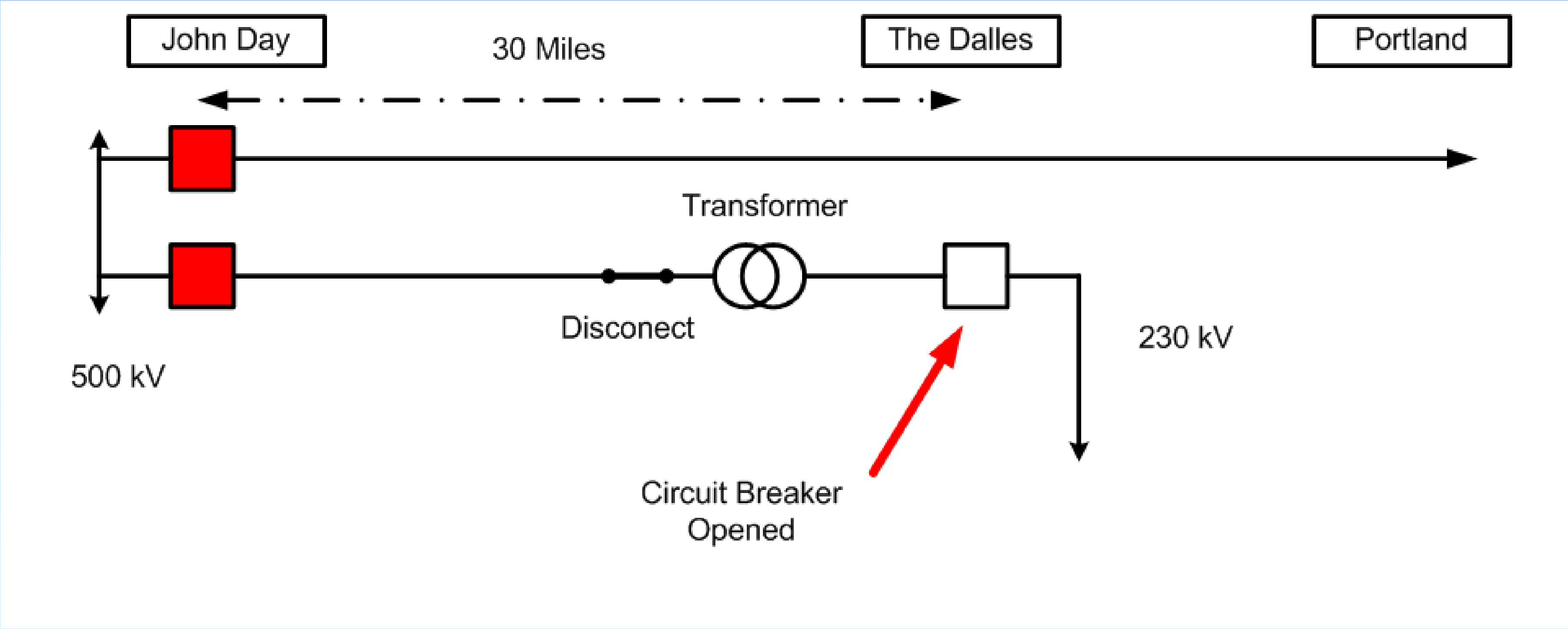
[1] 230 kV C/B at The Dalles opened



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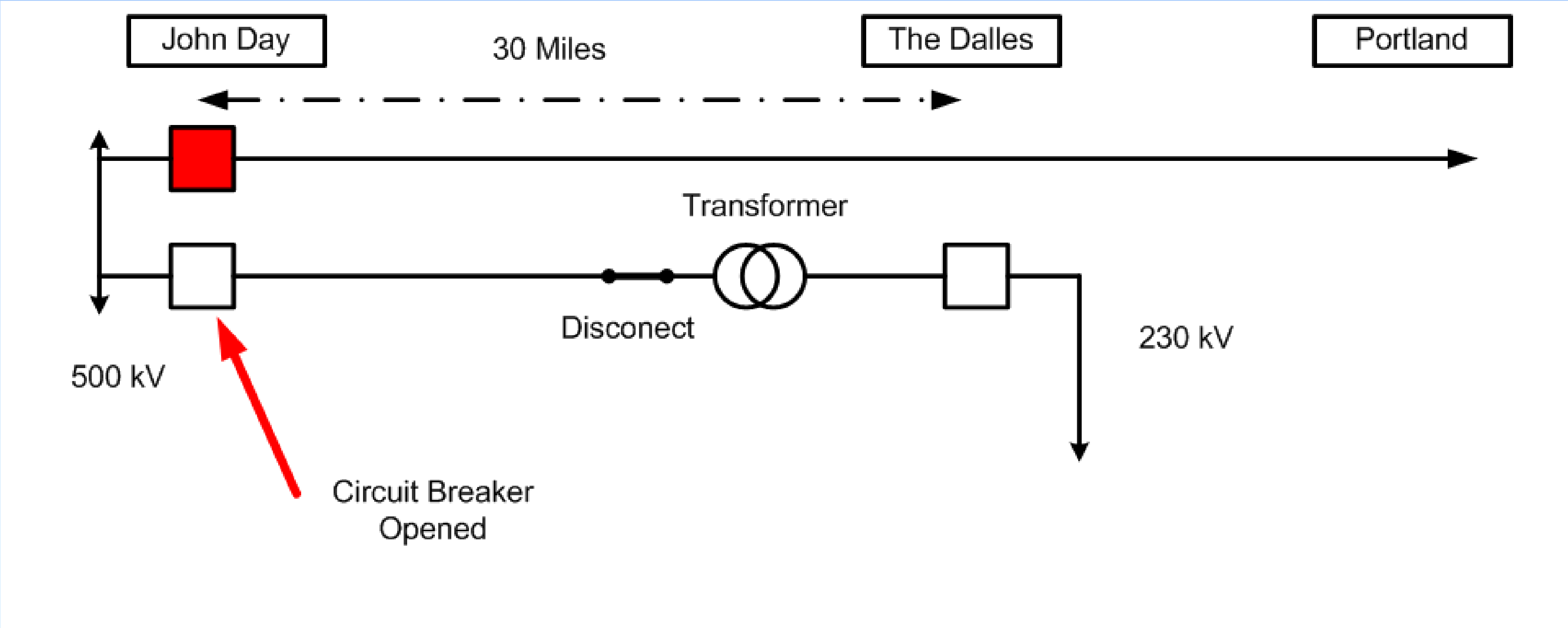
[2] 500 kV C/B at John Day opened



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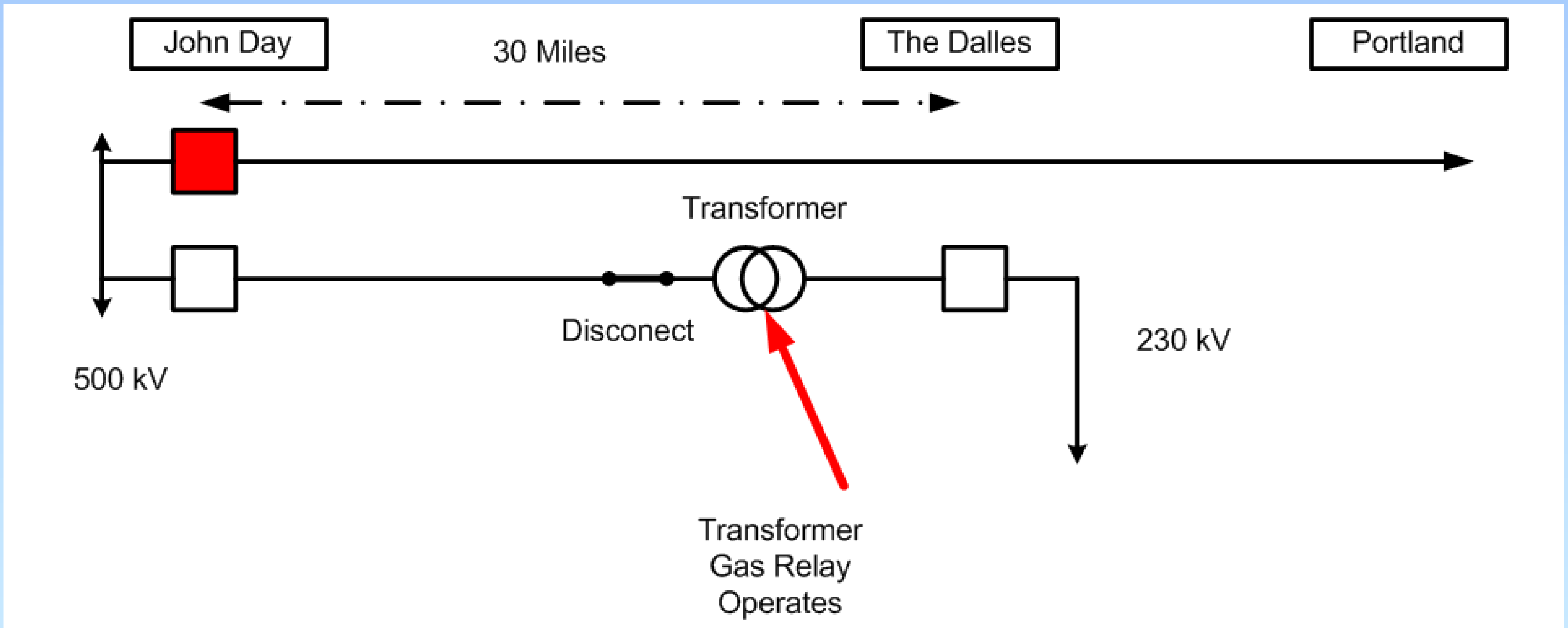
[3] After 8 minutes GAS relay operates



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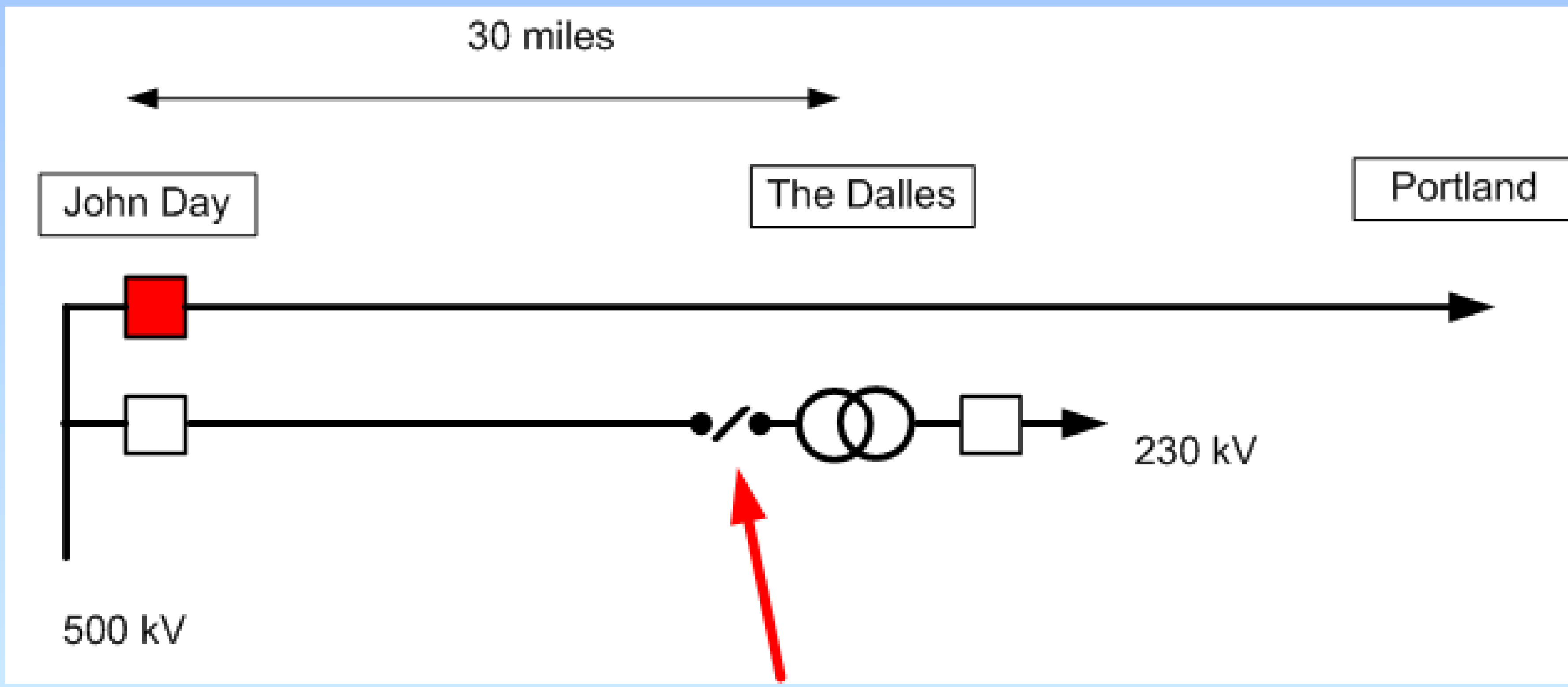
[4] After another 8 minutes



500 kV Disconnect arced when opened!

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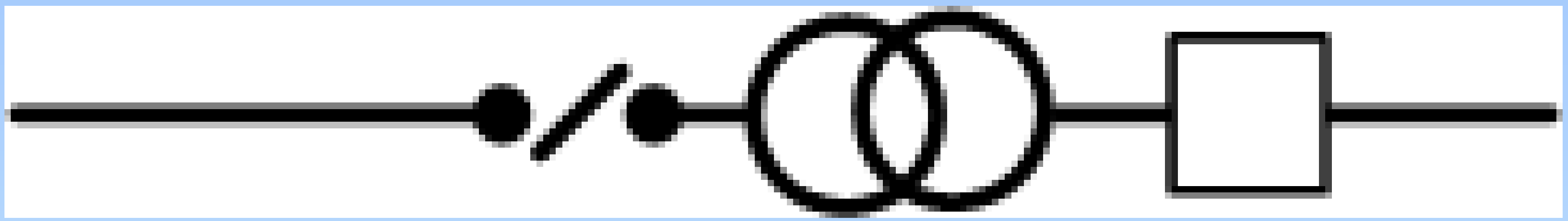
Site tests on Transformer



Site tests on Transformer

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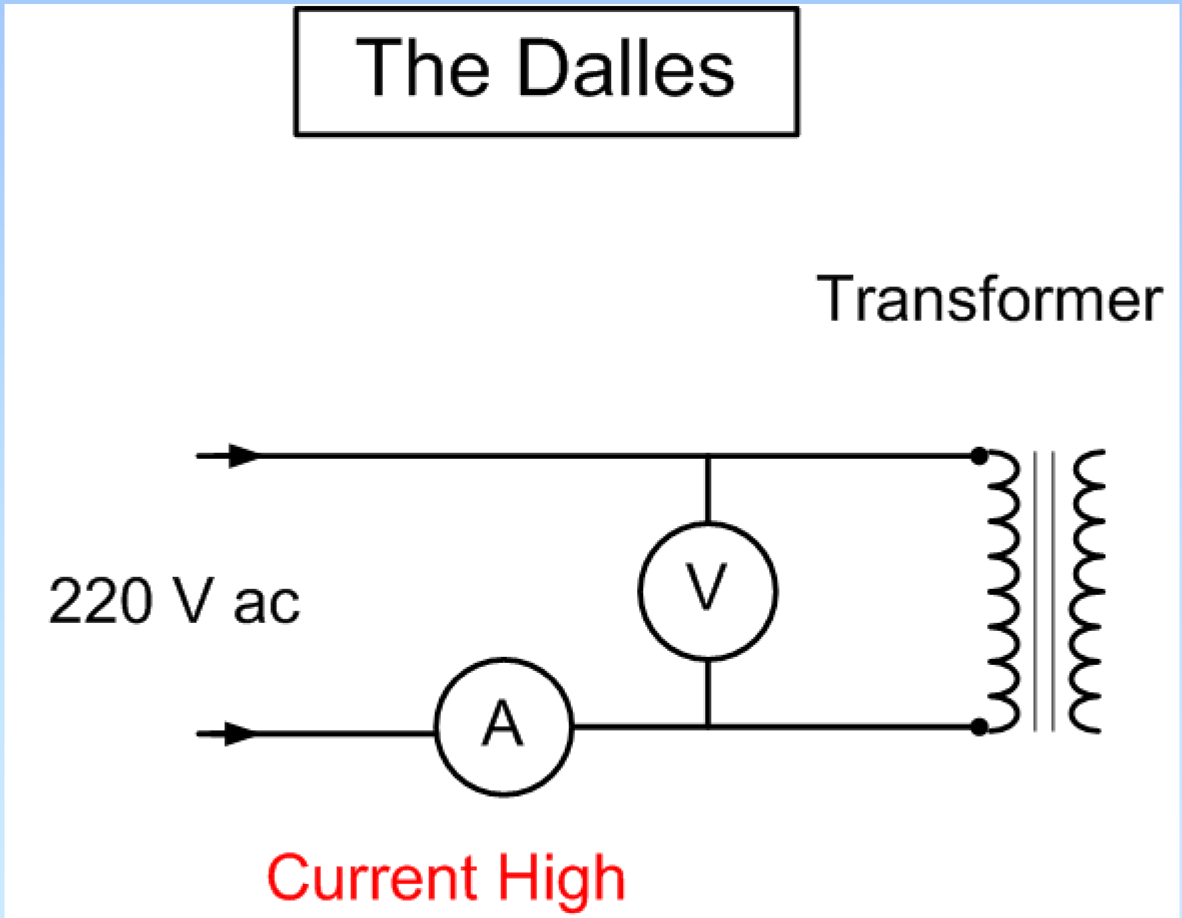
Mag. Current High



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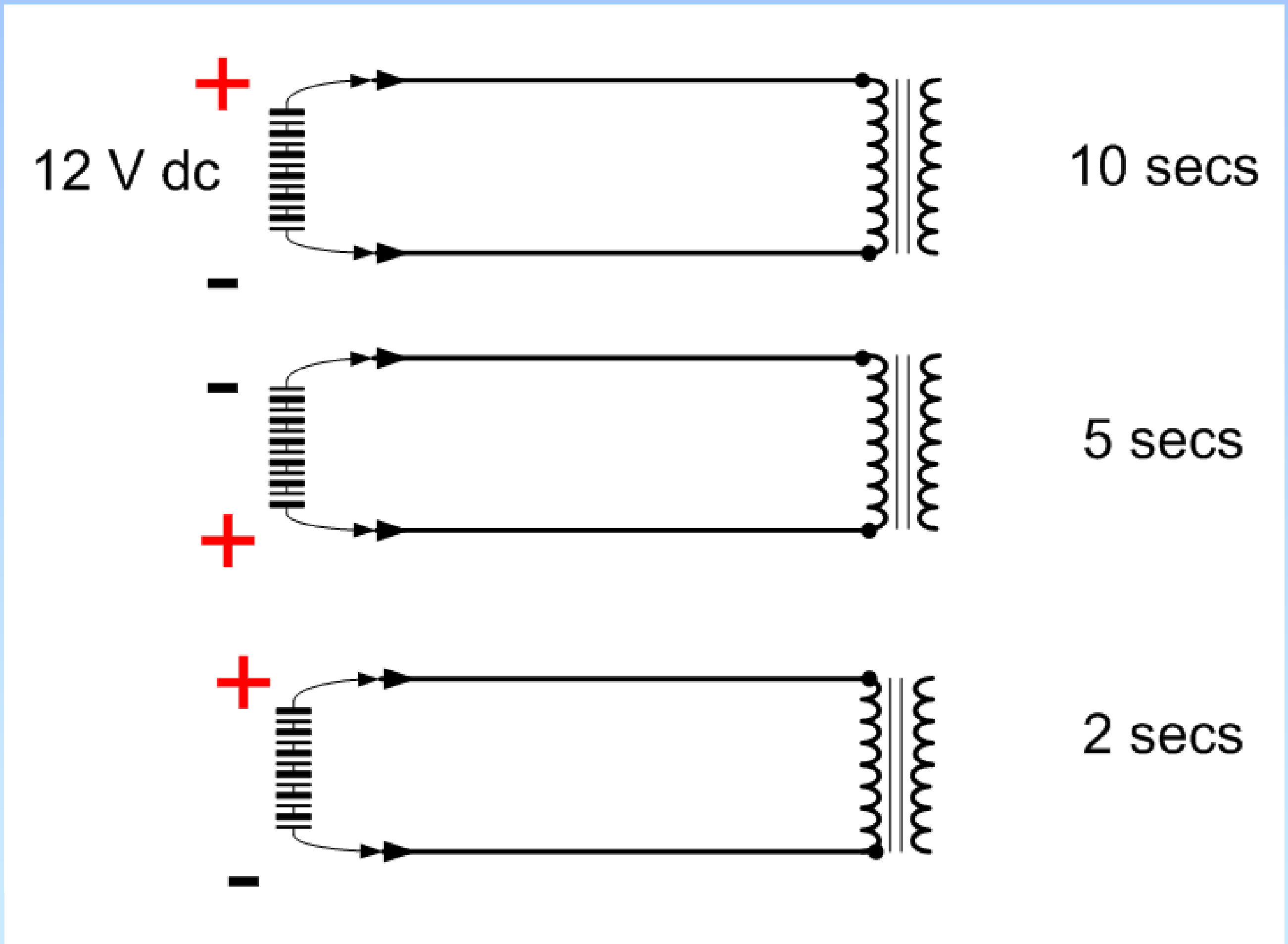
Core de-magnetized with battery



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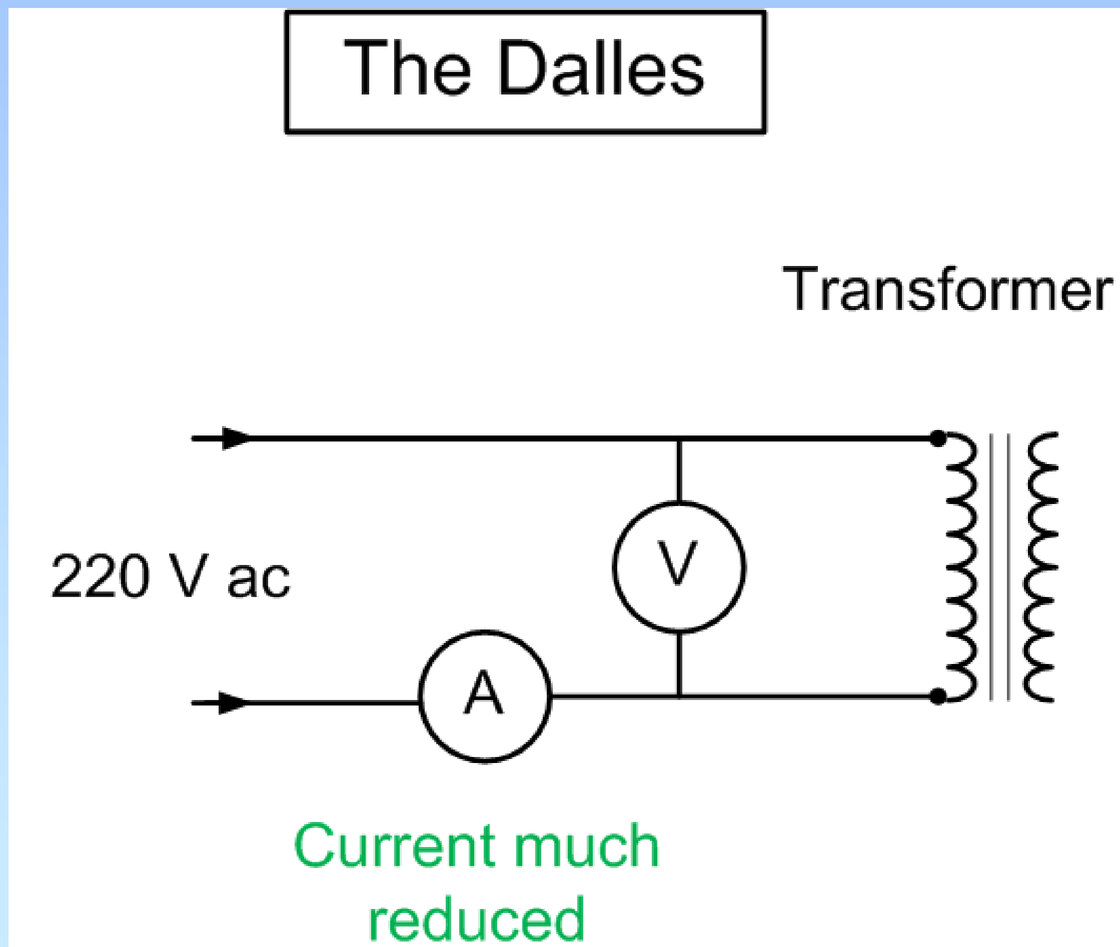
Mag. Current much reduced



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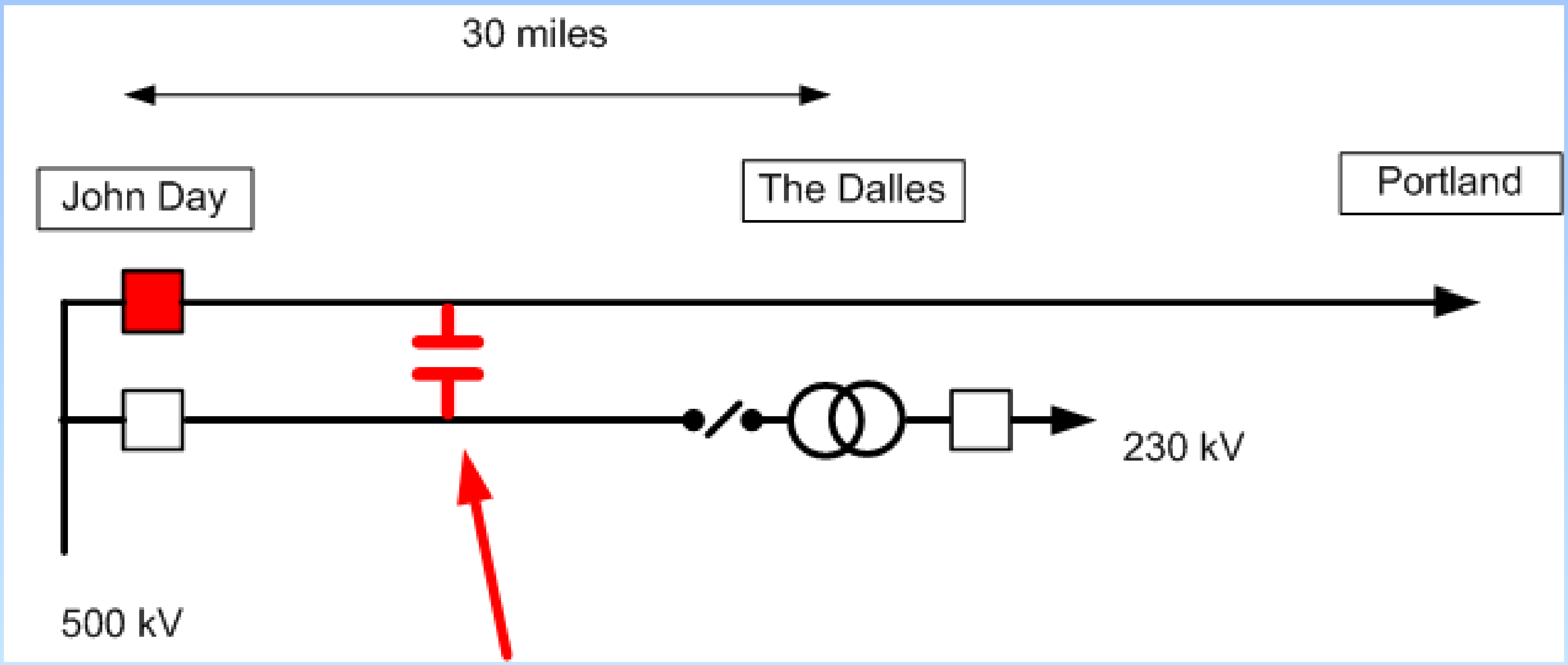
Problem solved !



Problem due to ferroresonance between parallel 500 kV line conductors

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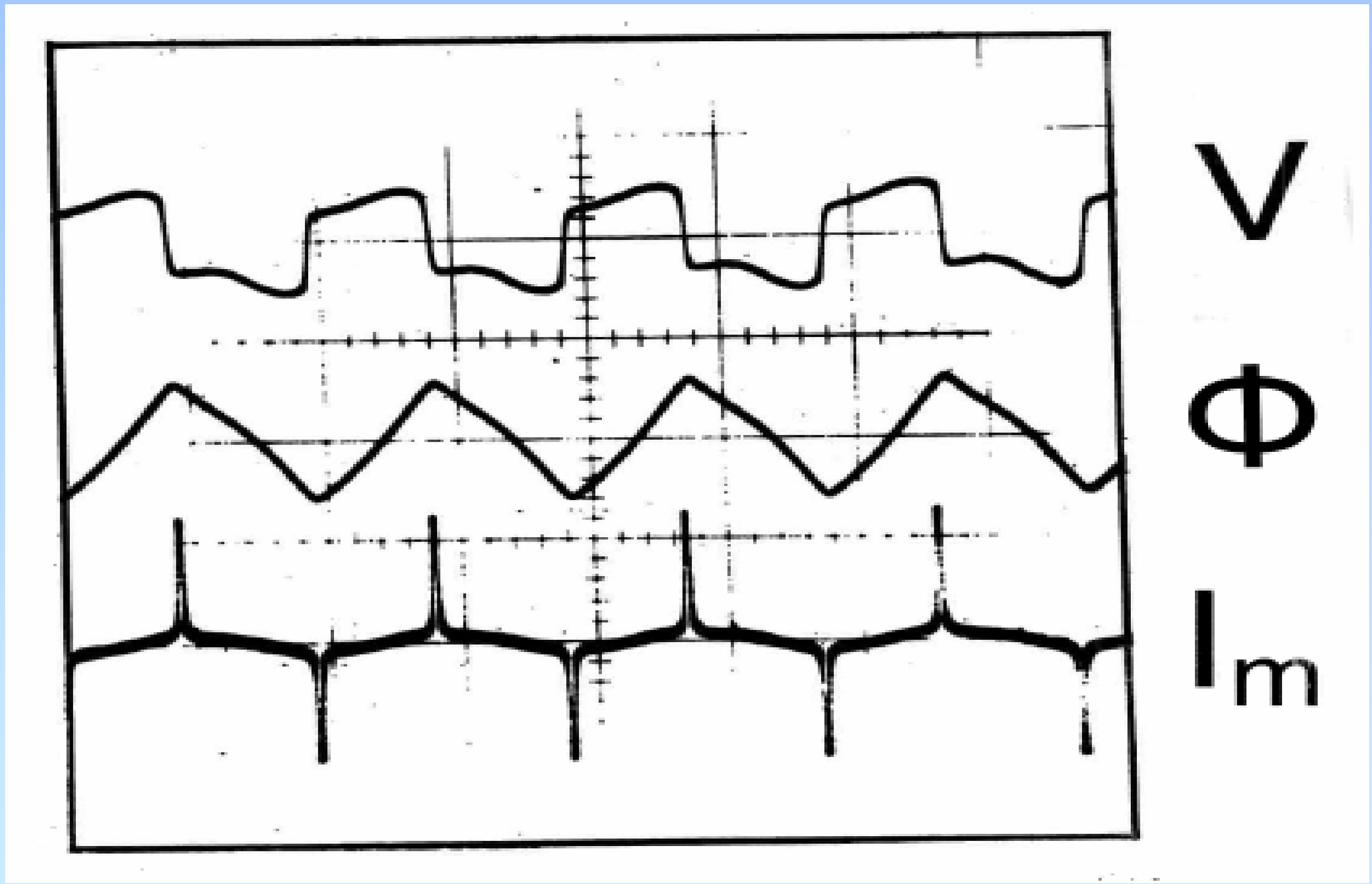
Plots of Voltage, Flux & Mag. Current



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EE Co Transformer replaced with Oerlikon unit

Ferroresonance would not occur, because Oerlikon transformer had higher no-load loss!

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Bonneville Power had to change their switching procedures

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- Refer to IEEE PES paper by Dolan, Gillies & Kimbark included in High Power Symposium on High Power Testing, Portland Ore, July 1971

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Ferrybridge
High Current LV problem.

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High Current Lead Problem (18)

The Company had supplied the 570 MVA 275 / 13.8 kV Generator Transformers for Ferrybridge Power Station.

The LV current on the LV of these transformers was 22,000 Amps.

In order to save oil the tanks were what we referred to as “form fit”

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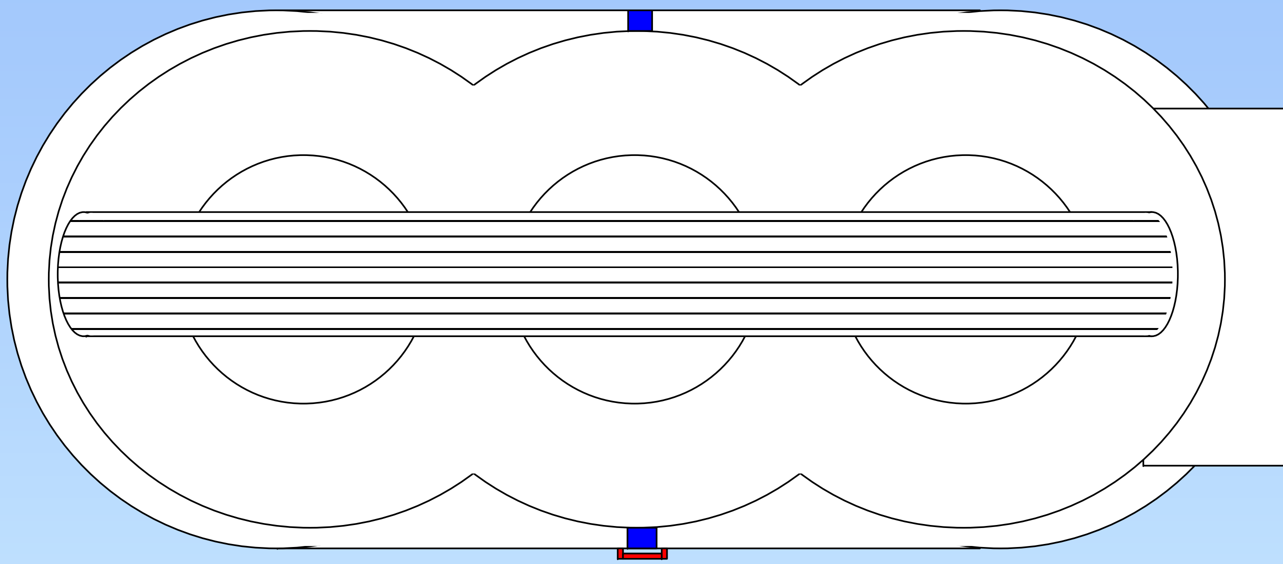
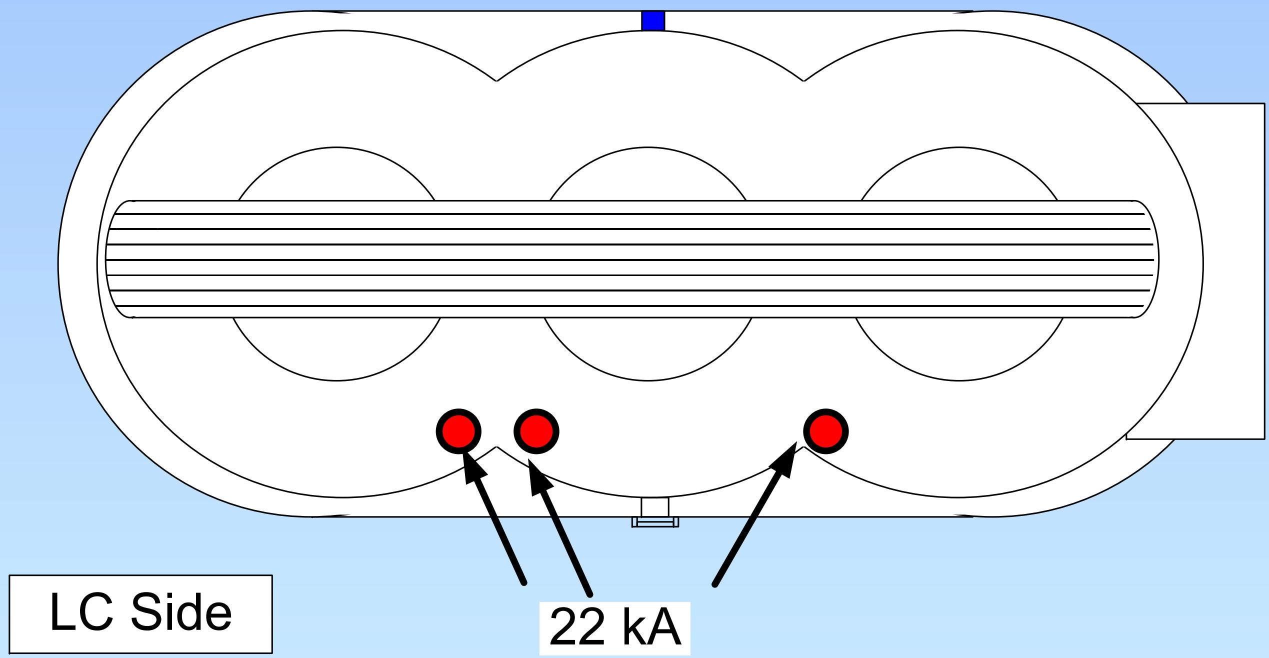
“Form Fit” Transformer Tank (19)



570 MVA Generator Transformer

High Current Lead Problem (20)



570 MVA Generator Transformer

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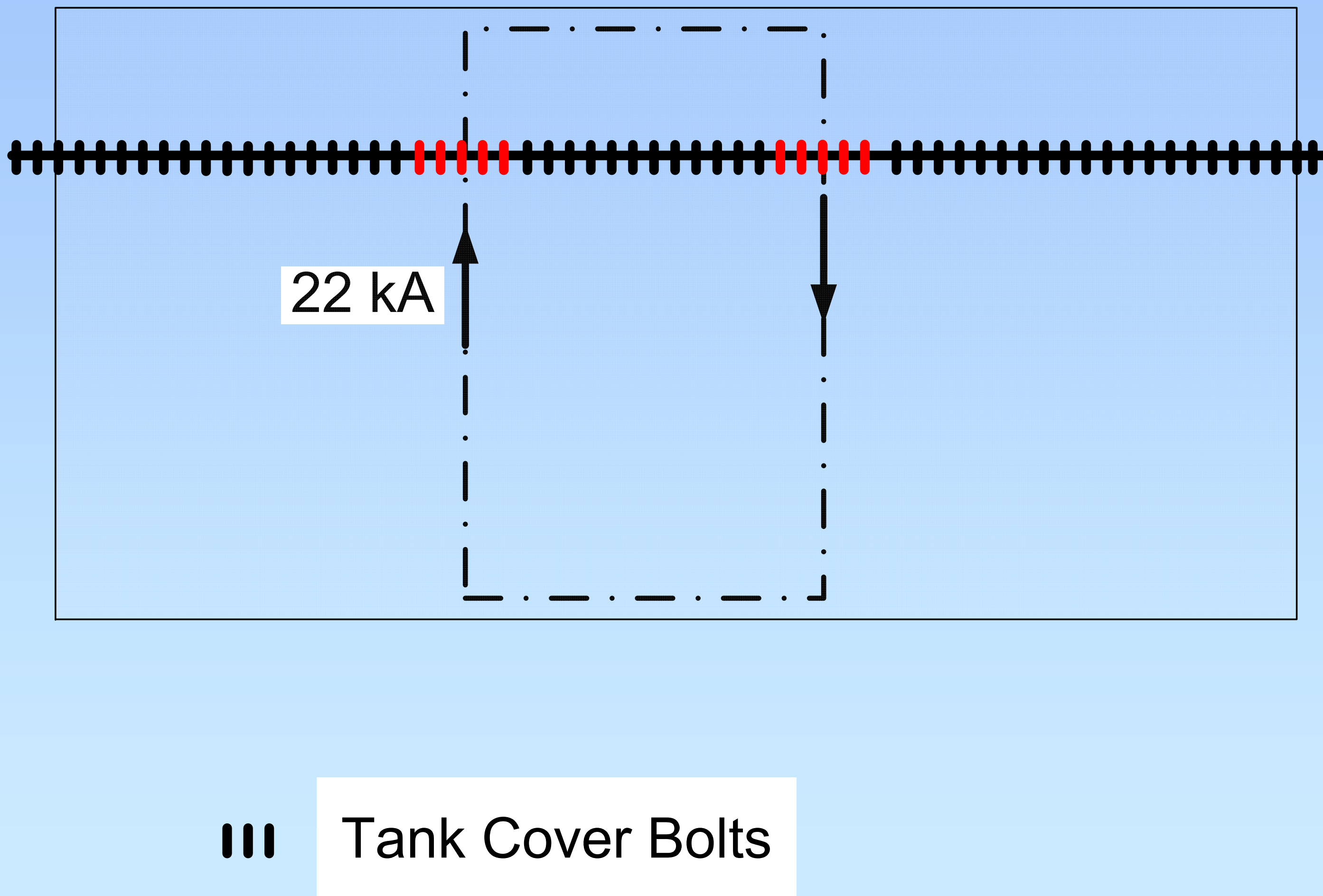
High Current Loop caused a current to circulate round the tank (21)



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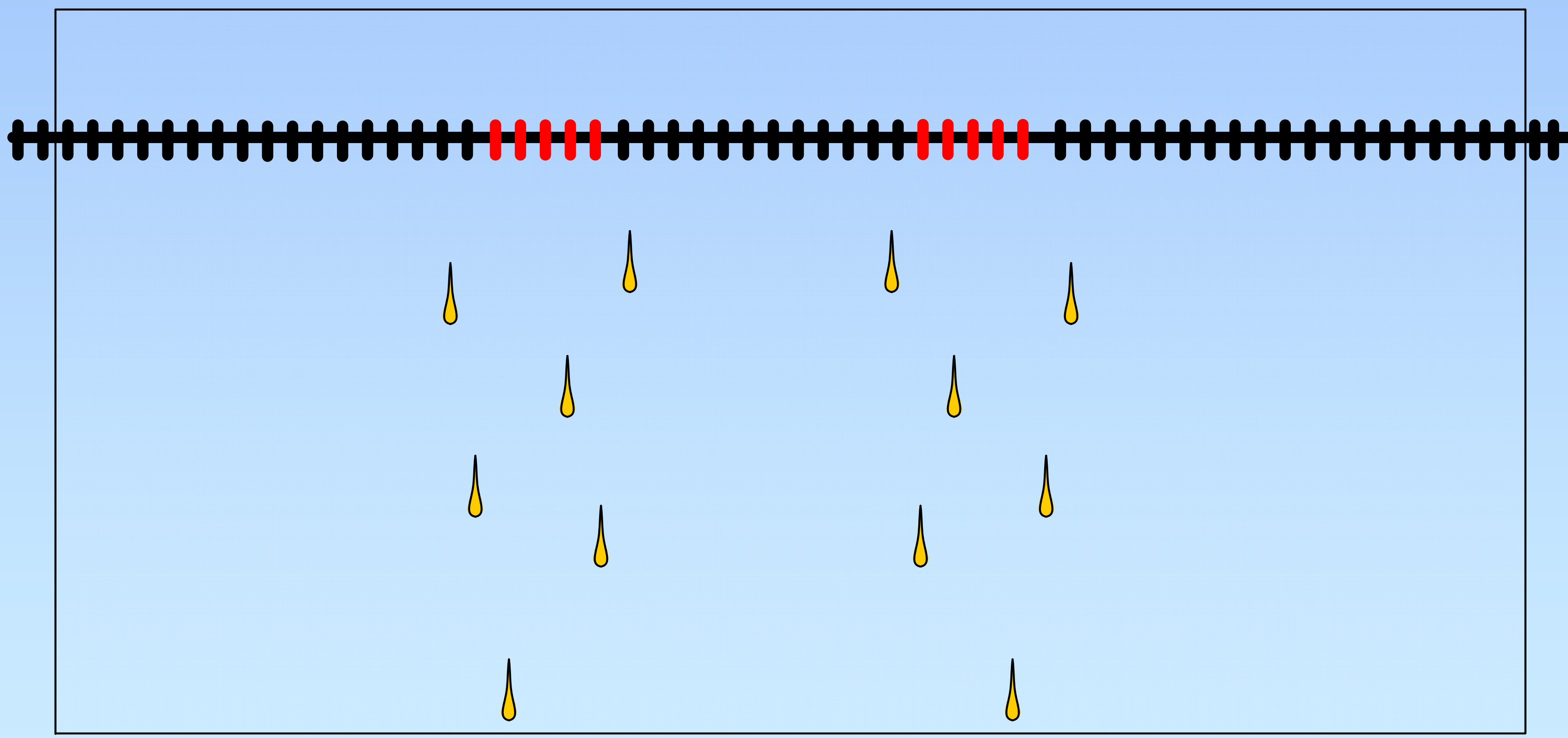
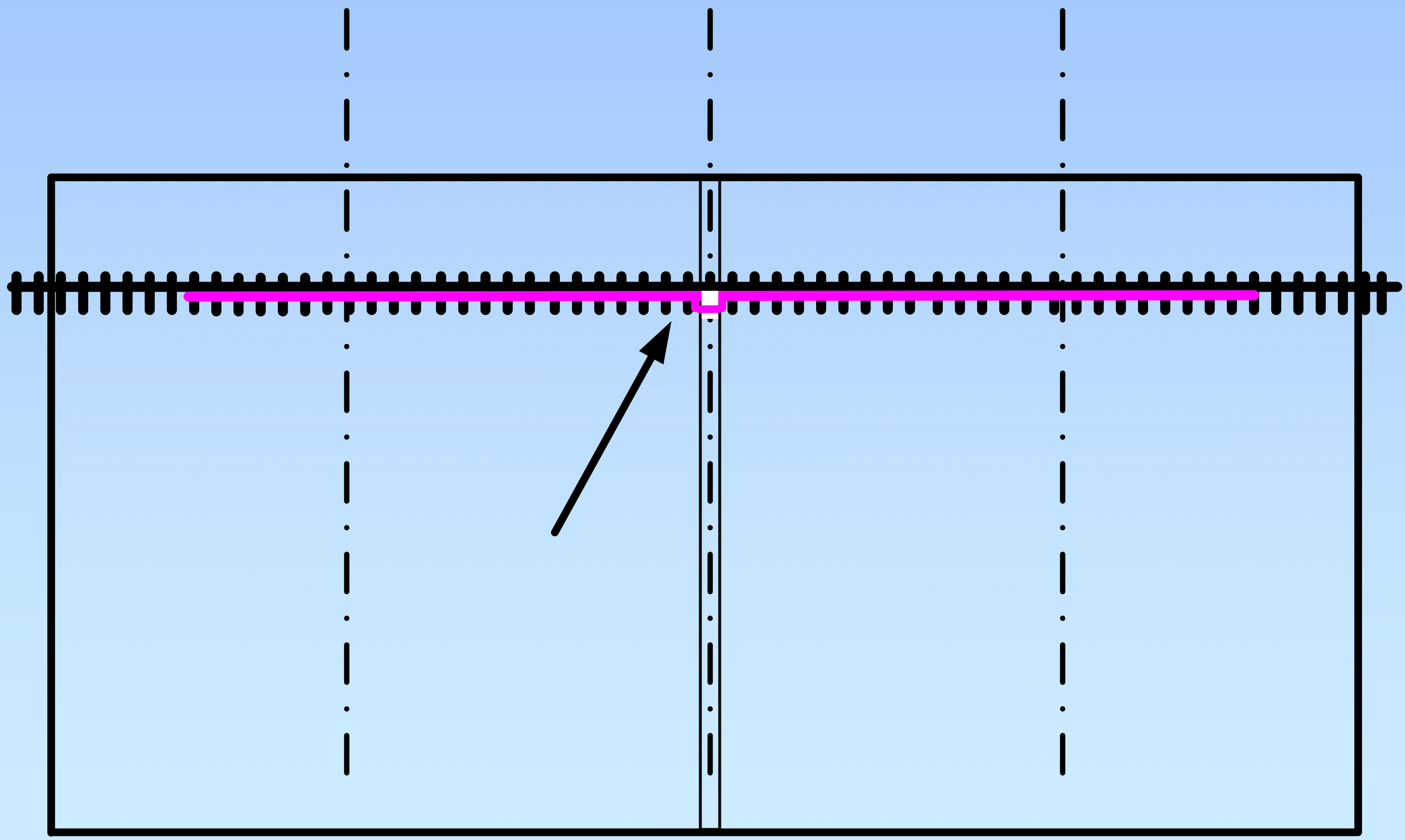
The Cover Bolts became so hot the tank / cover gasket burnt, and oil ran down the side of the tank! (22)



Even with the bolts insulated, the tank flange was still too hot. So a copper bar was bolted to the underside. This bar had to go round the stiffener at the mid point. (Arrow). (23)



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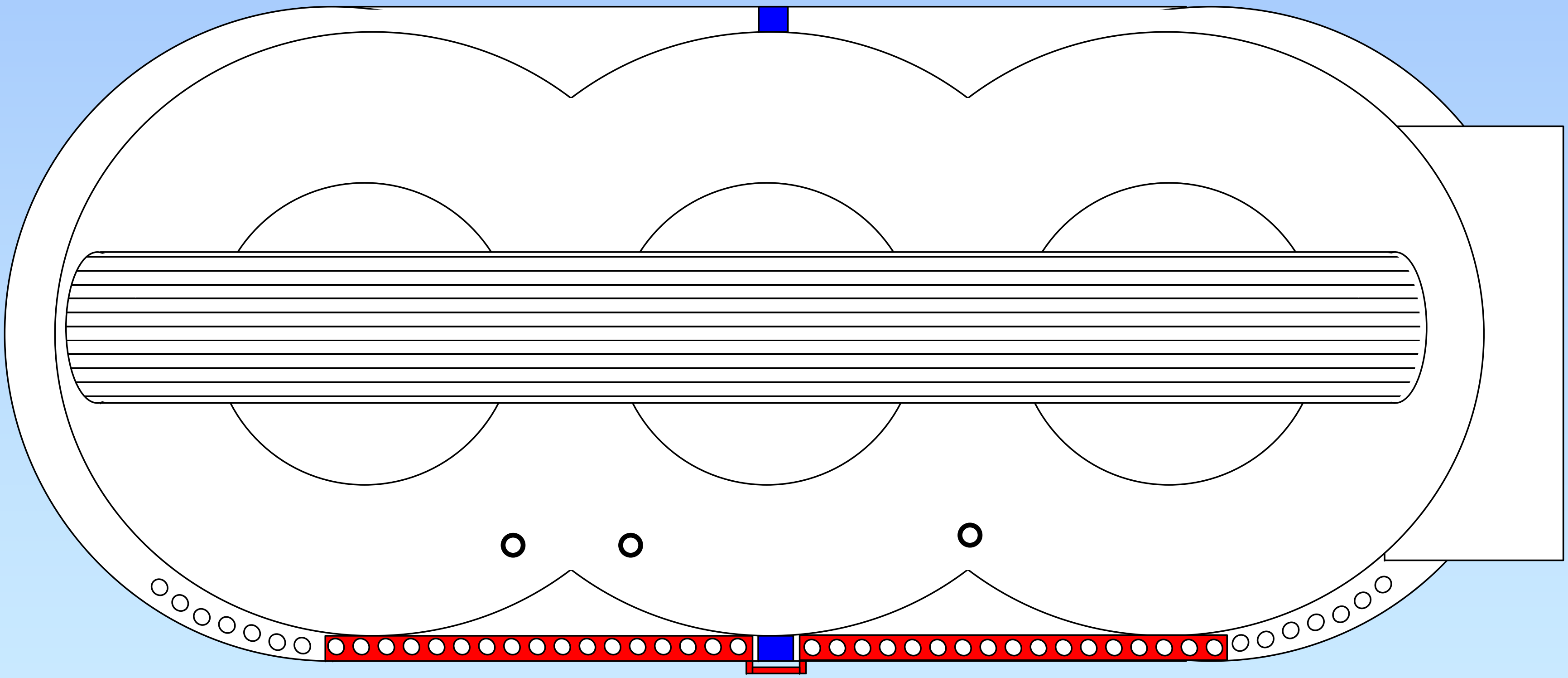
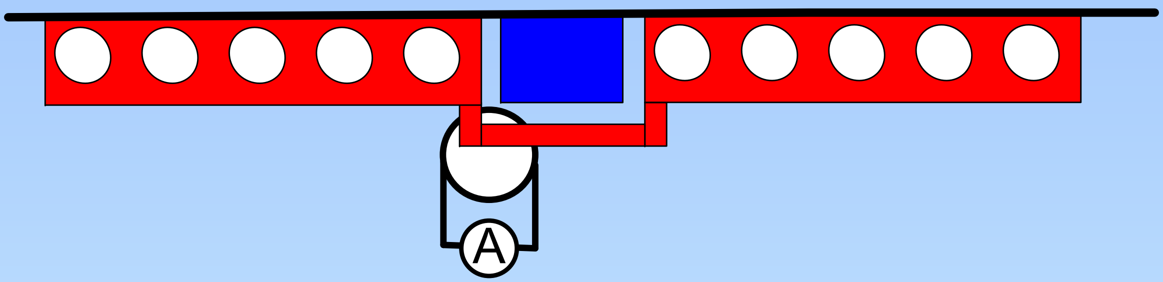
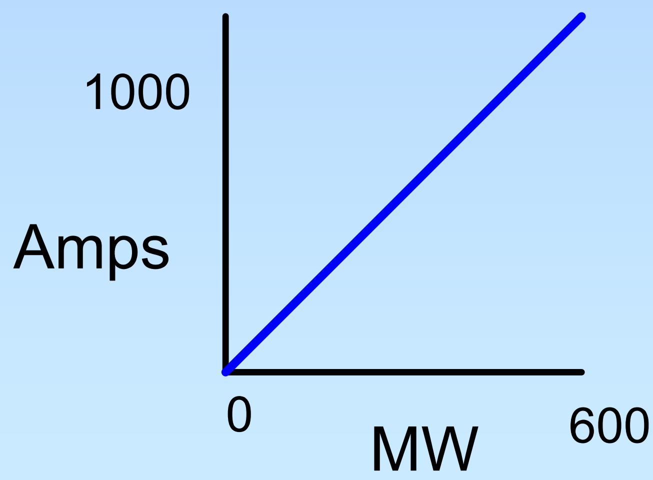
A plan view the tank showing the copper bar. (24)



The current in the bar was proportional to load, with 1000A at 600 MVA (25)





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Ferrybridge Inadequately Cooled Tapping Coils

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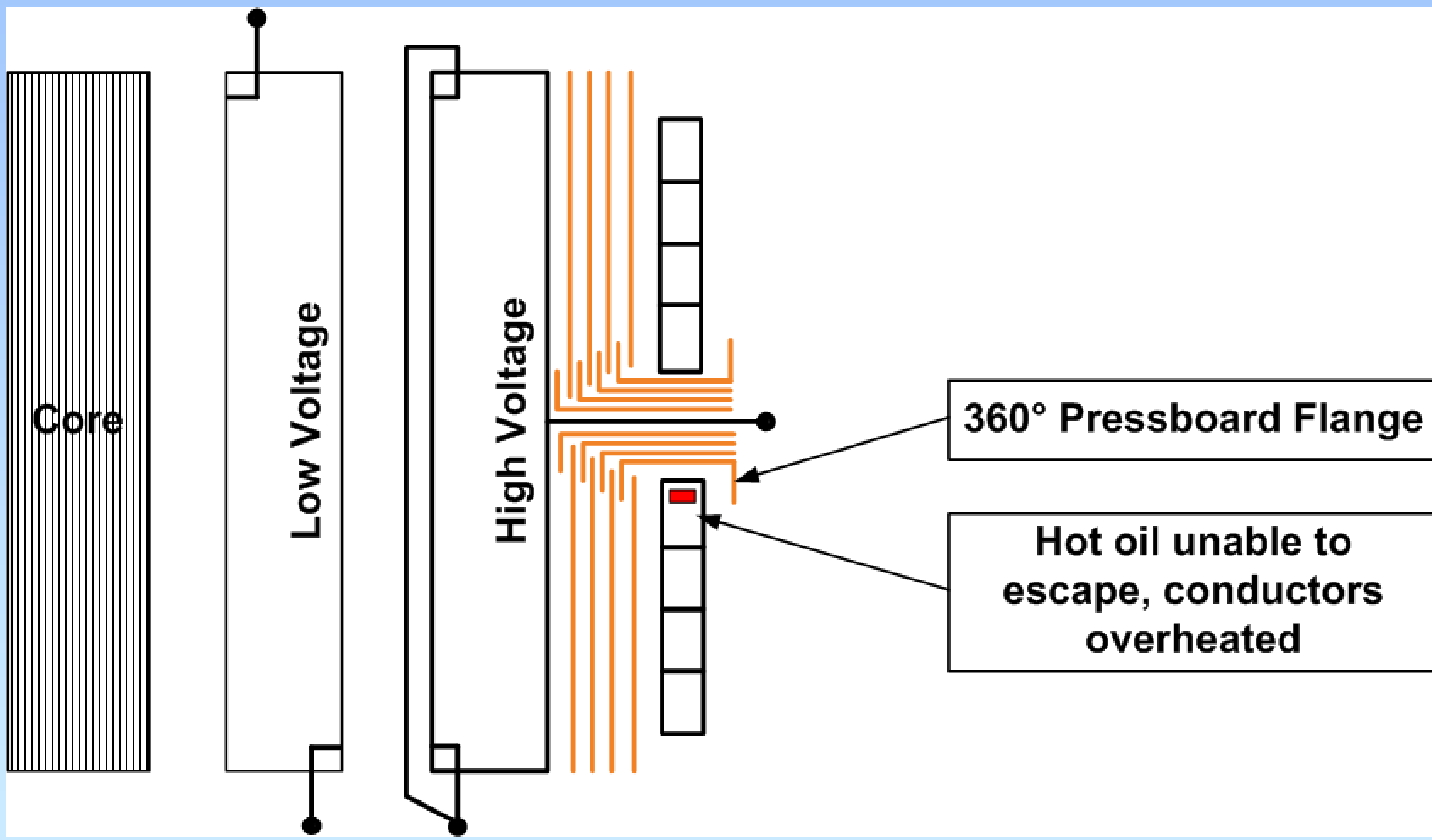
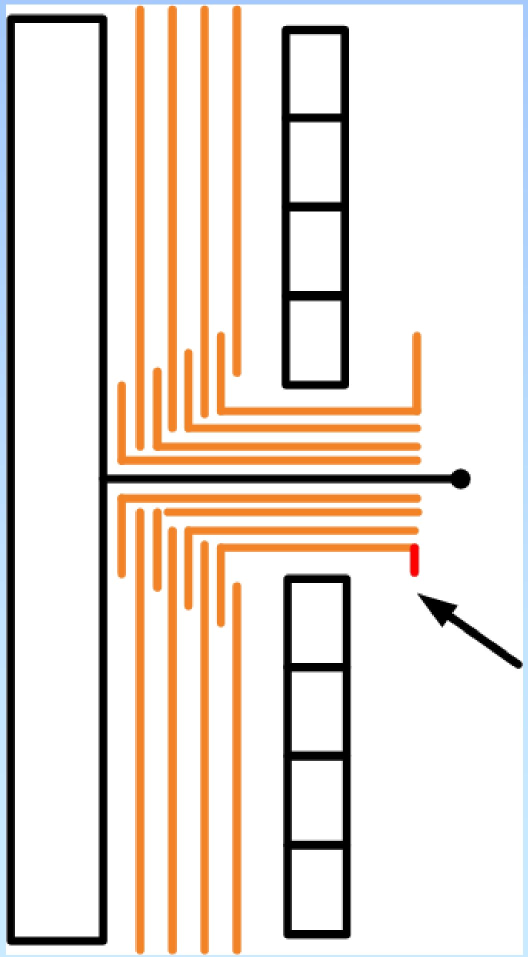
[1] 570 MVA Generator Transformer. Conductors at the top of the bottom tapping section inadequately cooled



Solution:- Insulation cut back round most of the coils



Parallel Tapping Coils

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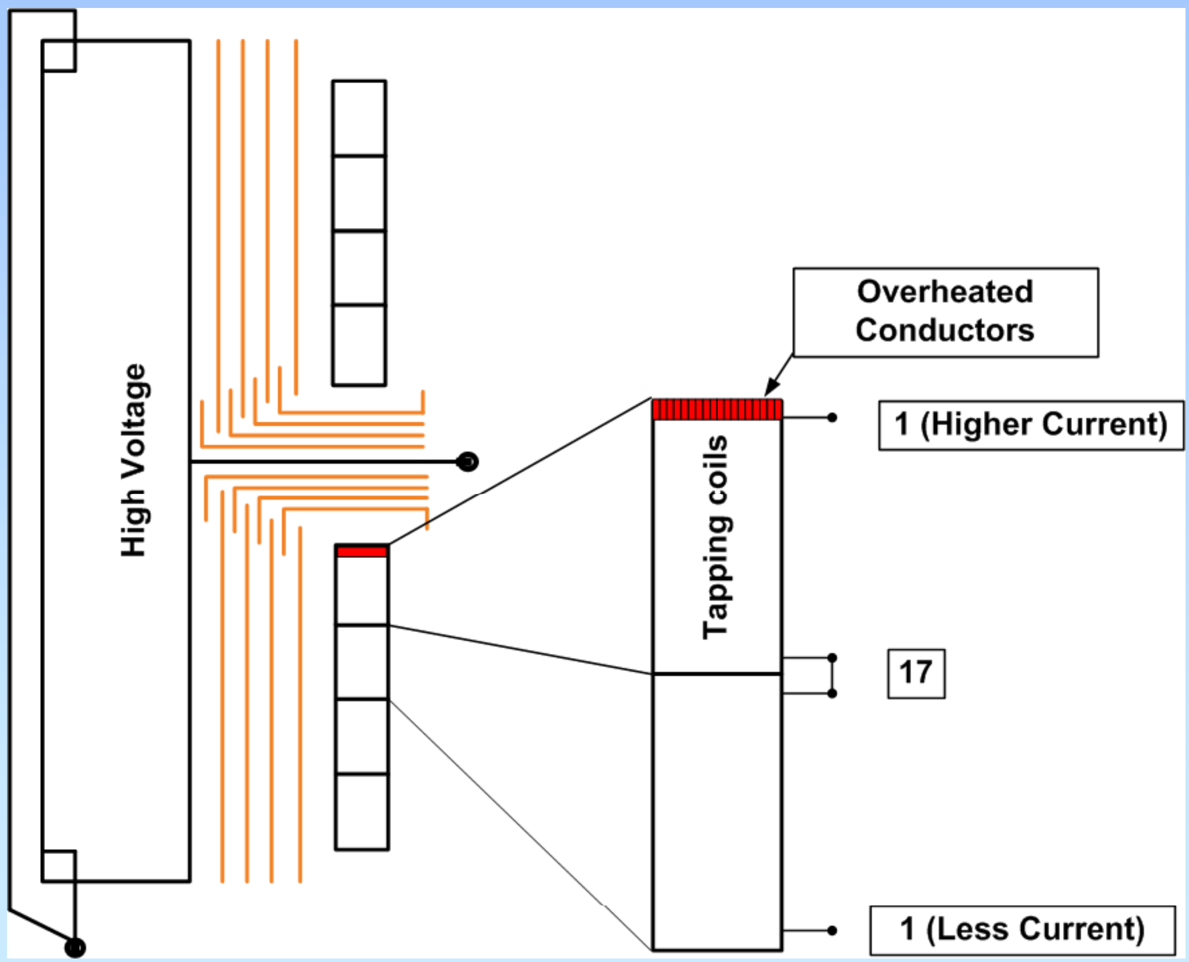
Because of the radial component of the leakage flux the four tap sections did not share the current equally.



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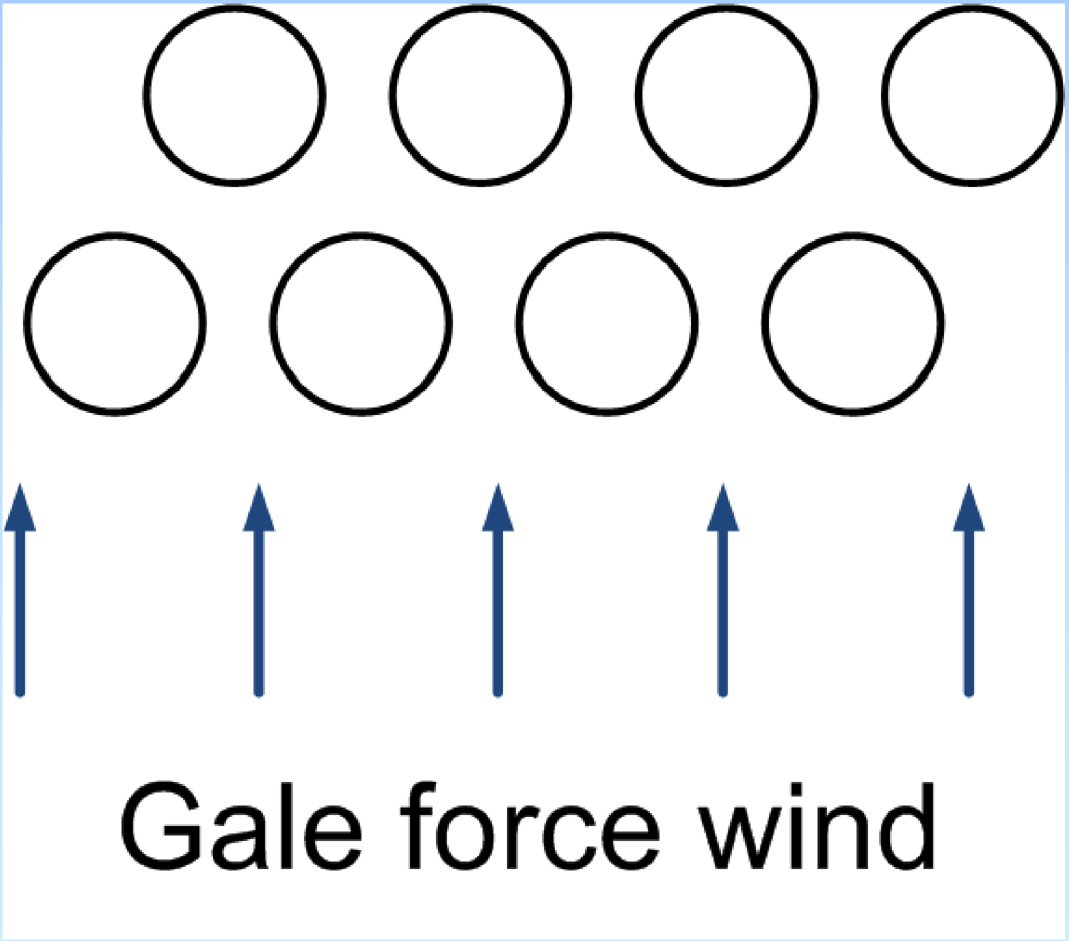
- A re-design was required !

Ferrybridge Power Station cooling tower problem



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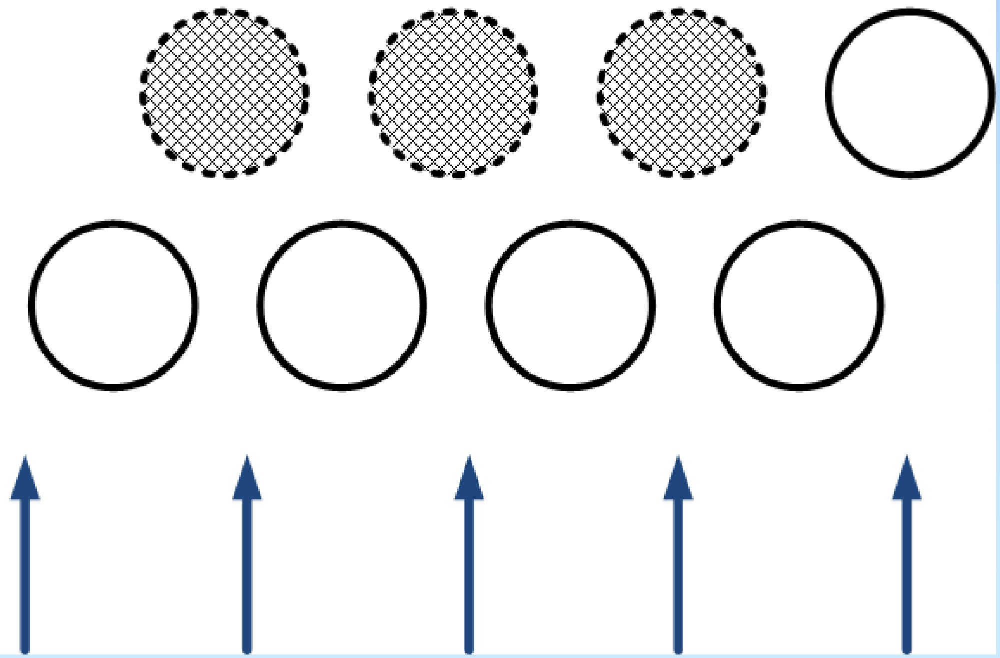
Cooling Towers Collapsed !!



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Large Generator Transformer,

Circulating current in end turns

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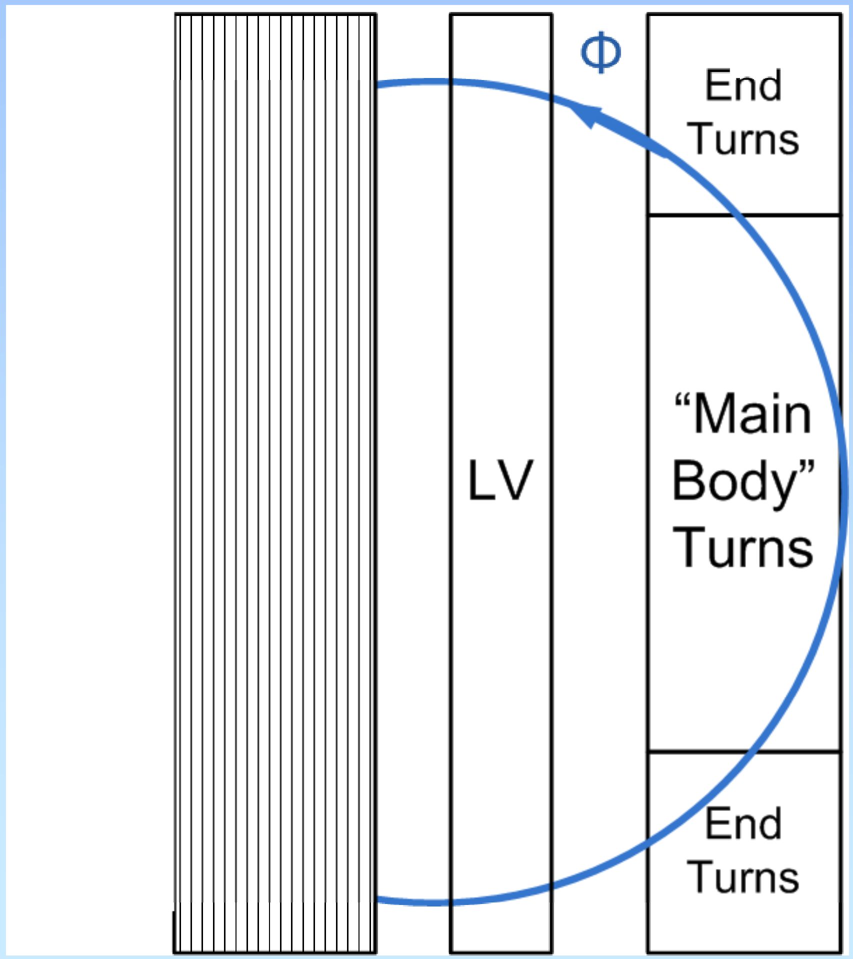
Smaller End Turns



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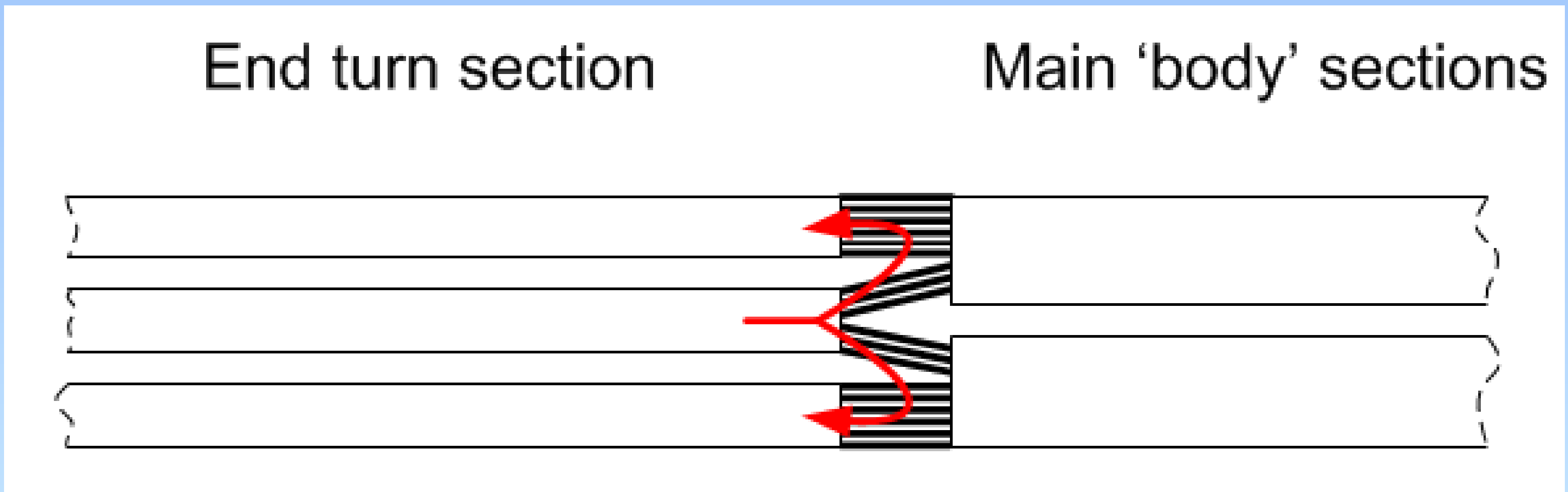
CTC cables (developed view)



Junction between CTC cables allowed for circulating current (red)

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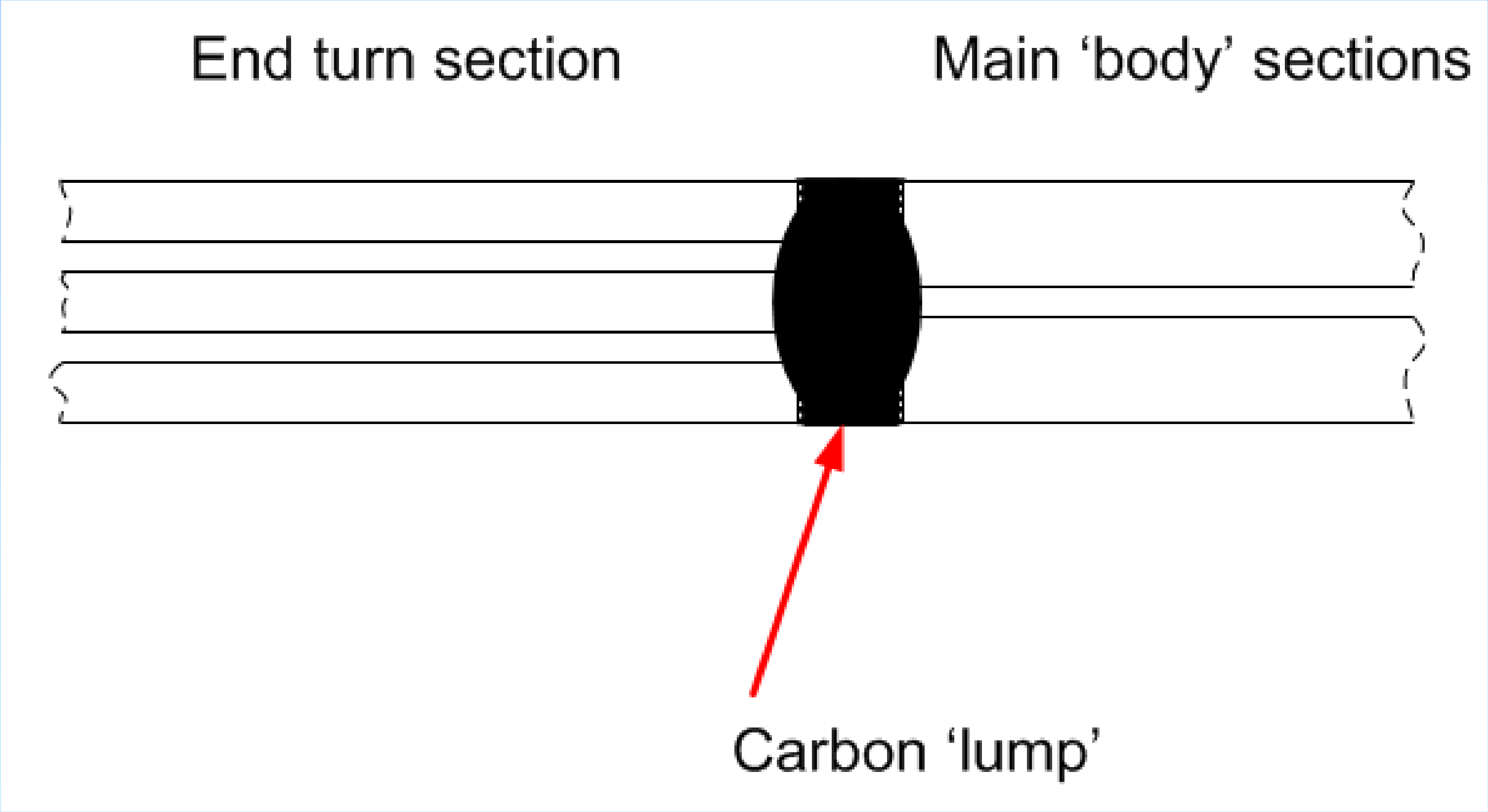
High temperatures allowed oil to “breakdown”, producing H_2 plus C , H_2 “attacked” Cu O to produce H_2O (steam)



The end of the individual conductor strands had been broken by escaping steam, so under magnification it looked like a series of “rivers” and formed.

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Tap Changer Failure

in Brazil

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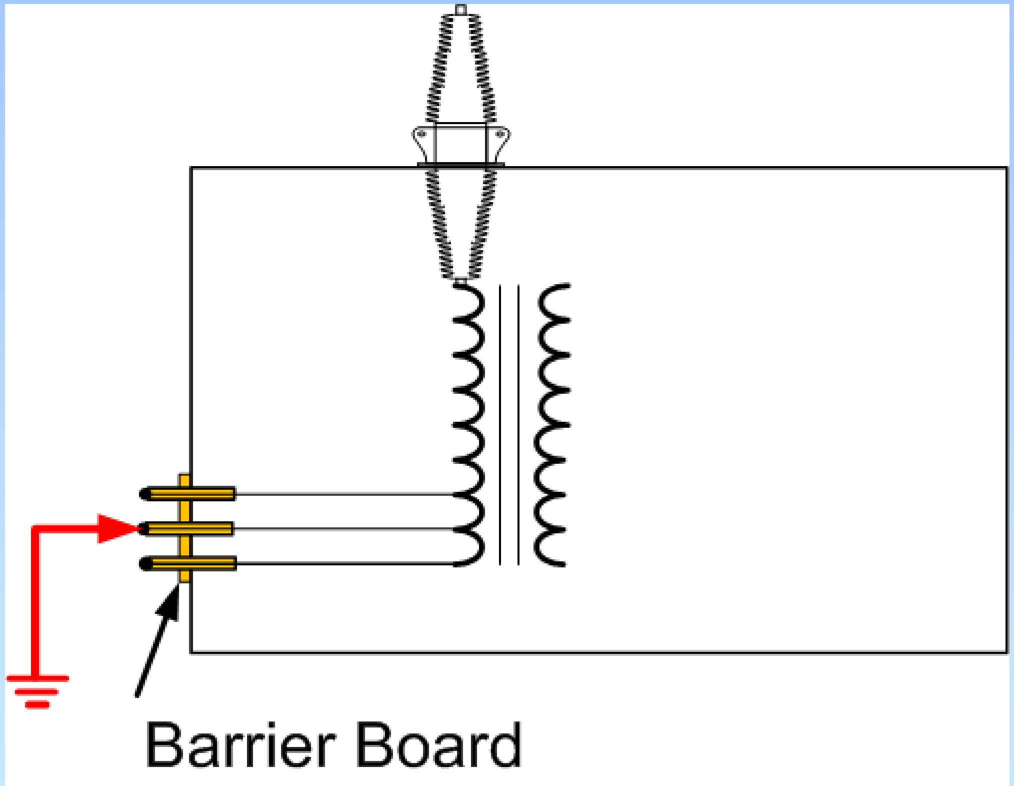
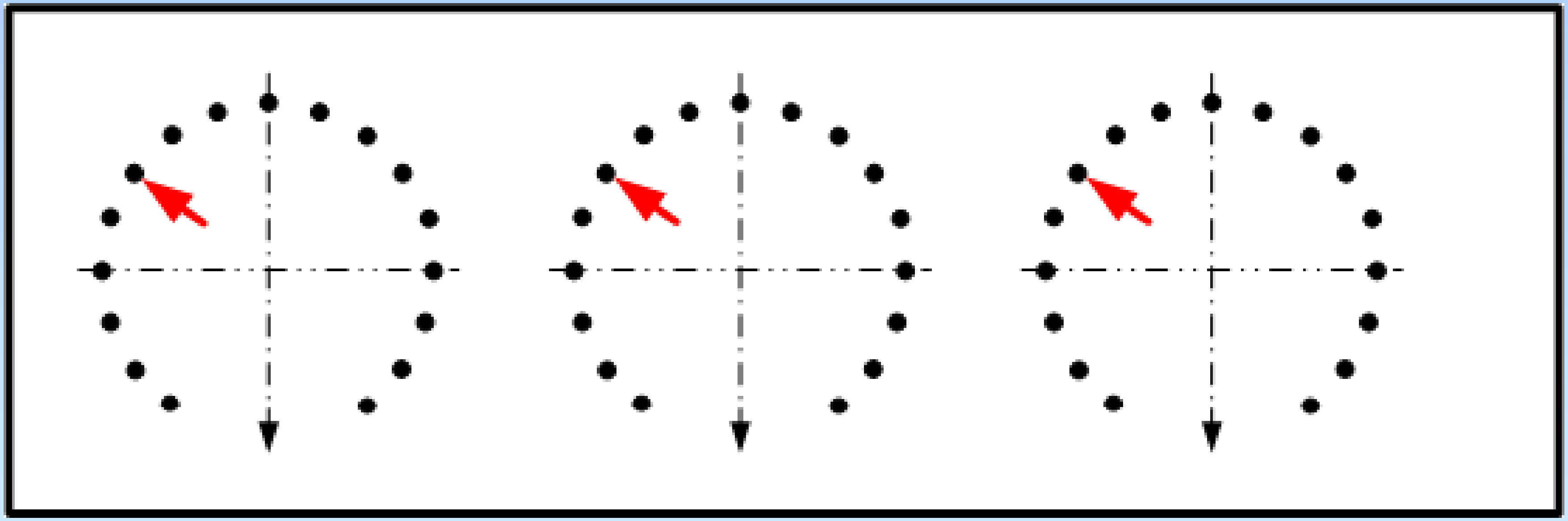
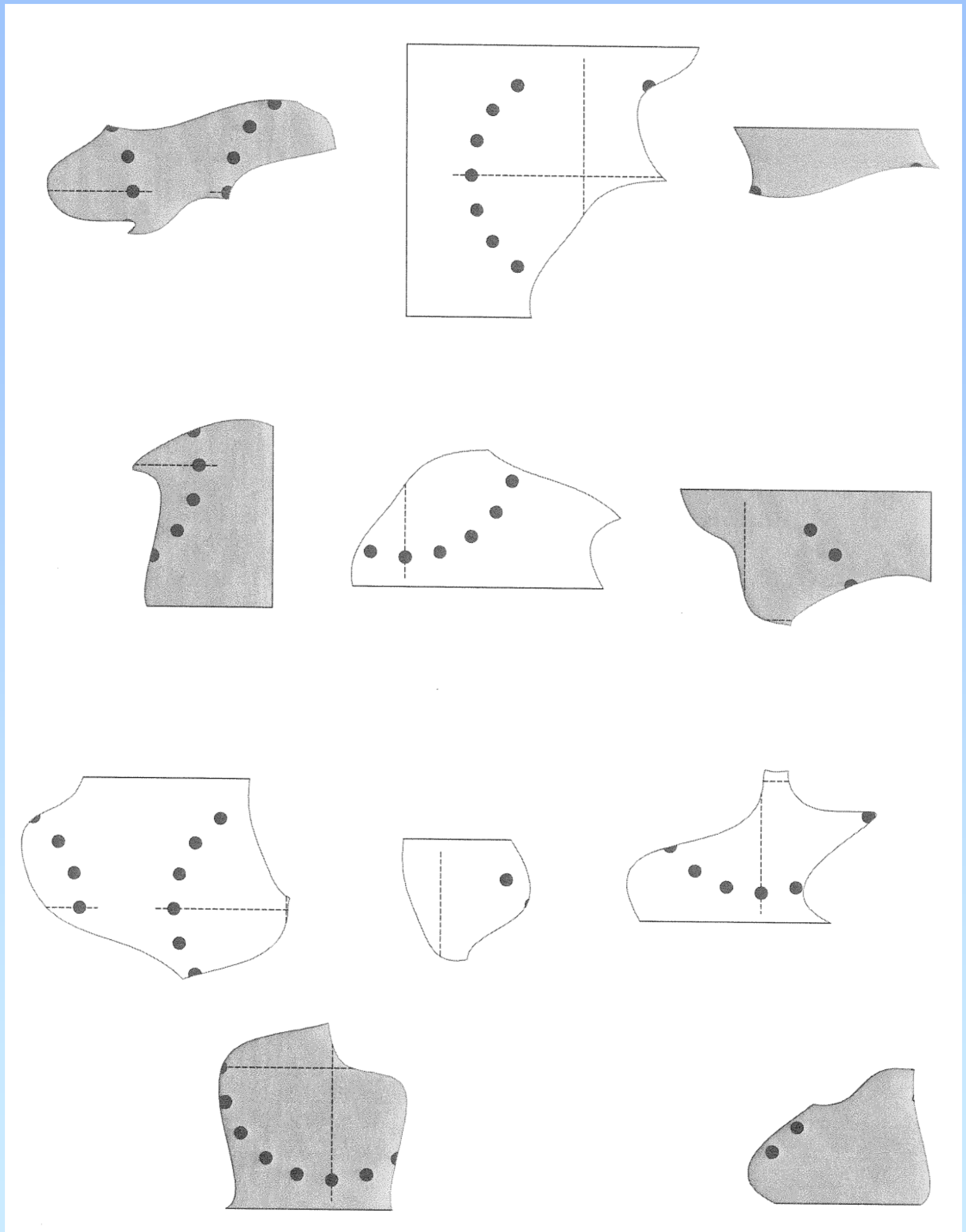
Transformer Taps



Tap Changer Barrier Board with one tap selected



Teshmont



- On arrival the epoxy barrier board was in numerous pieces.
- Assembling them as a jigsaw resulted in.....

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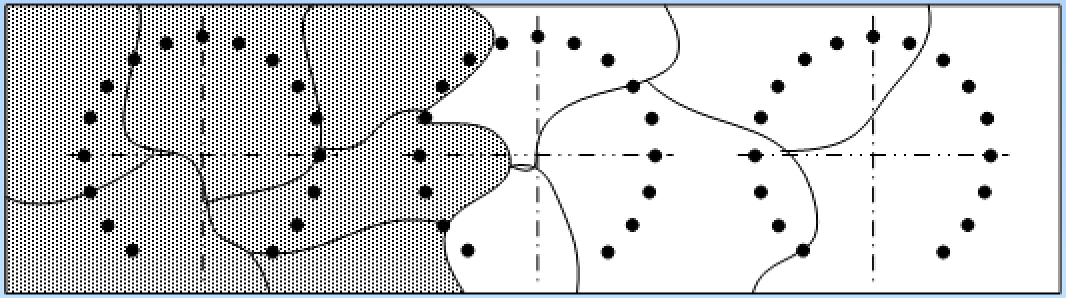
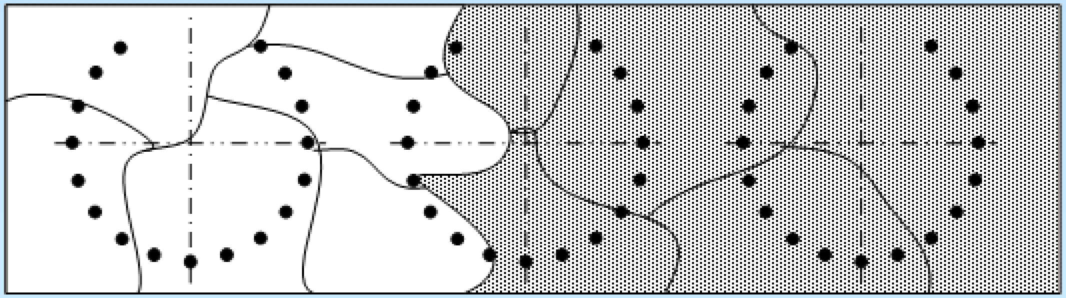
Tapchanger Barrier Board Failure

- Products of the failure on both sides of the board, indicating mechanical failure before electrical failure



- Front



- Back

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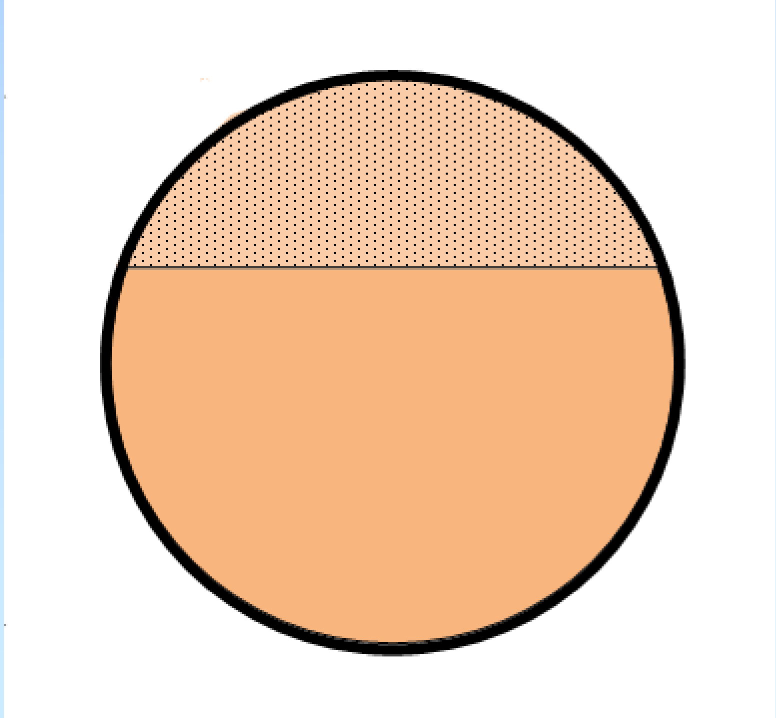
Detailed Examination

- From inside the transformer tank, looking into a cooling tube showed a “tide mark”



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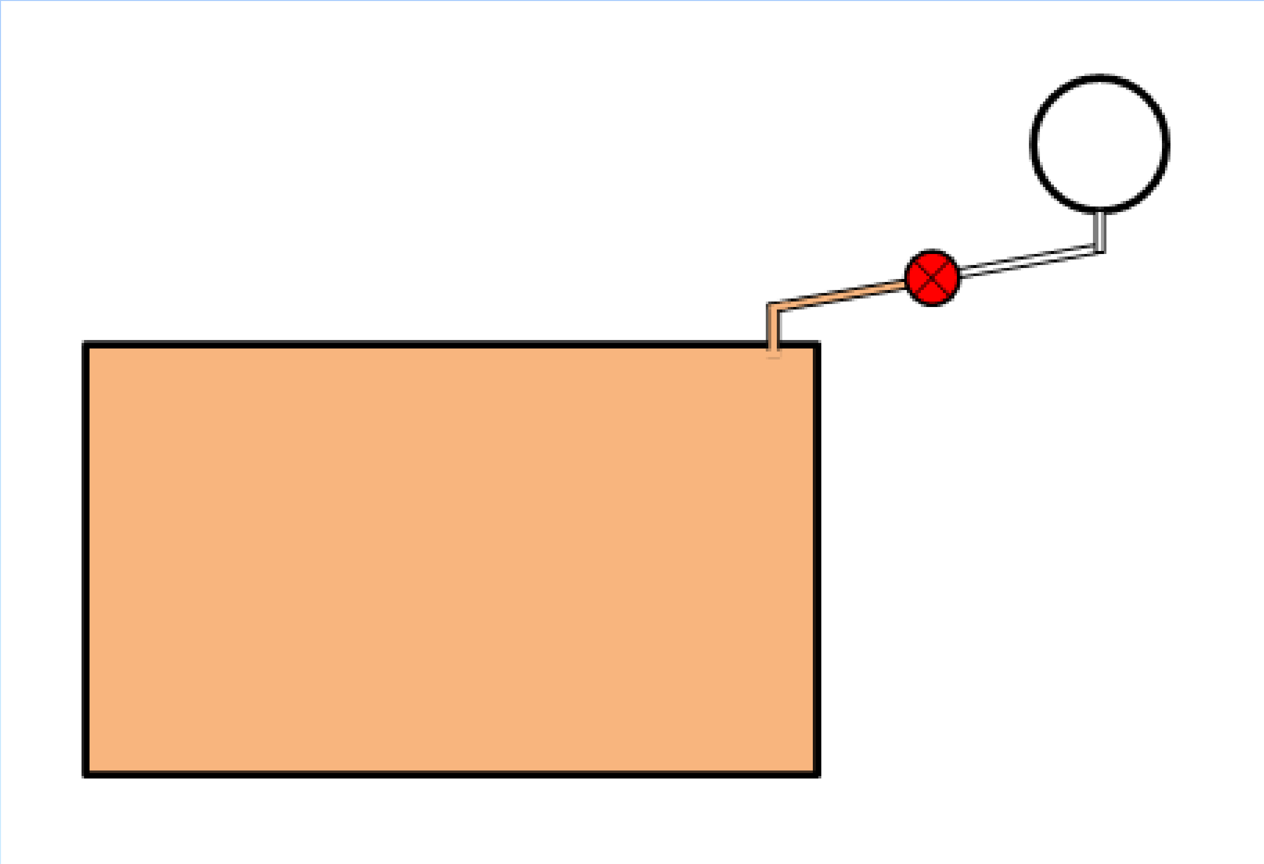
On questioning, it was admitted that the valve to the conservator had been always closed



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- Generator Transformer Tank after LV Winding Failure and Fire

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- Damage to Core laminations from hot plasma gas emanating from below

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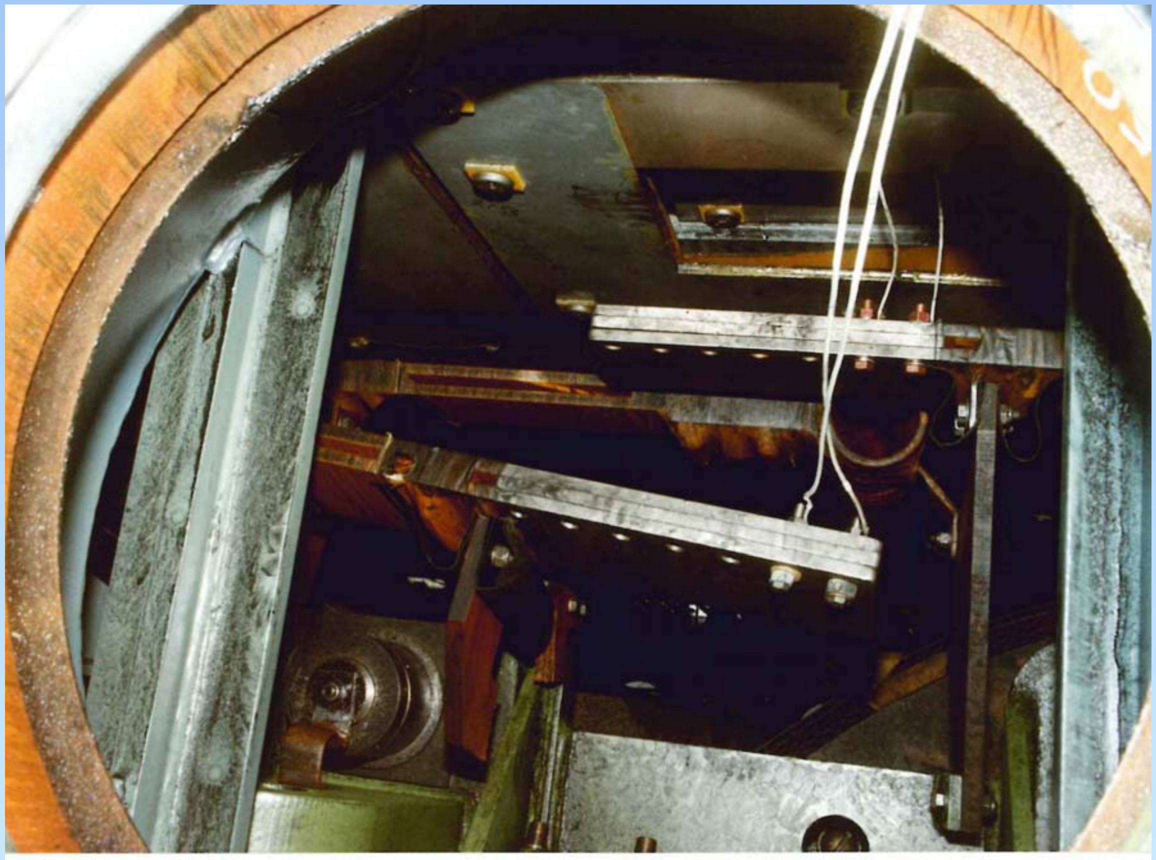
- LV busbars of end phase, forced apart by short circuit forces



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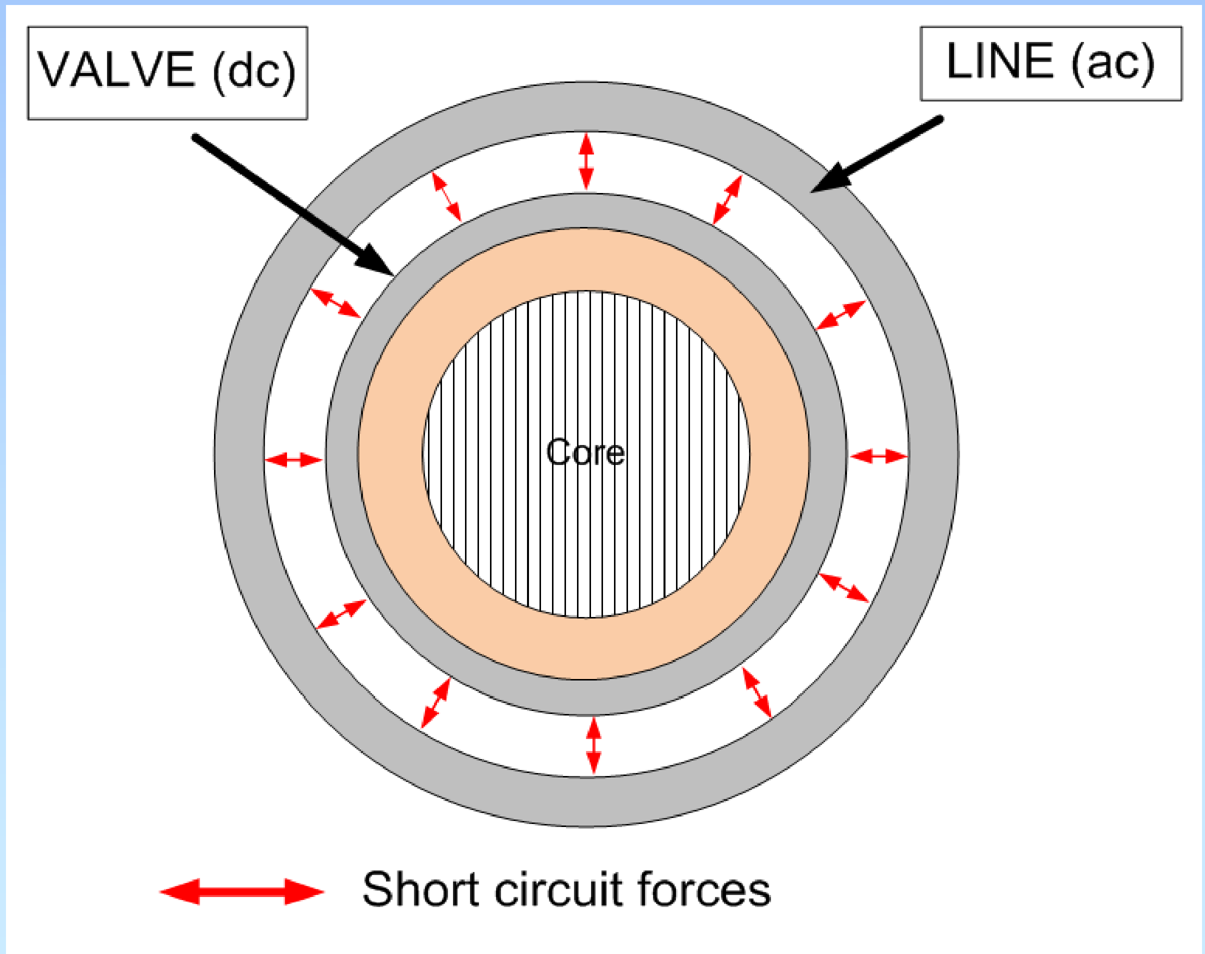
Converter transformer with the valve winding next to the core



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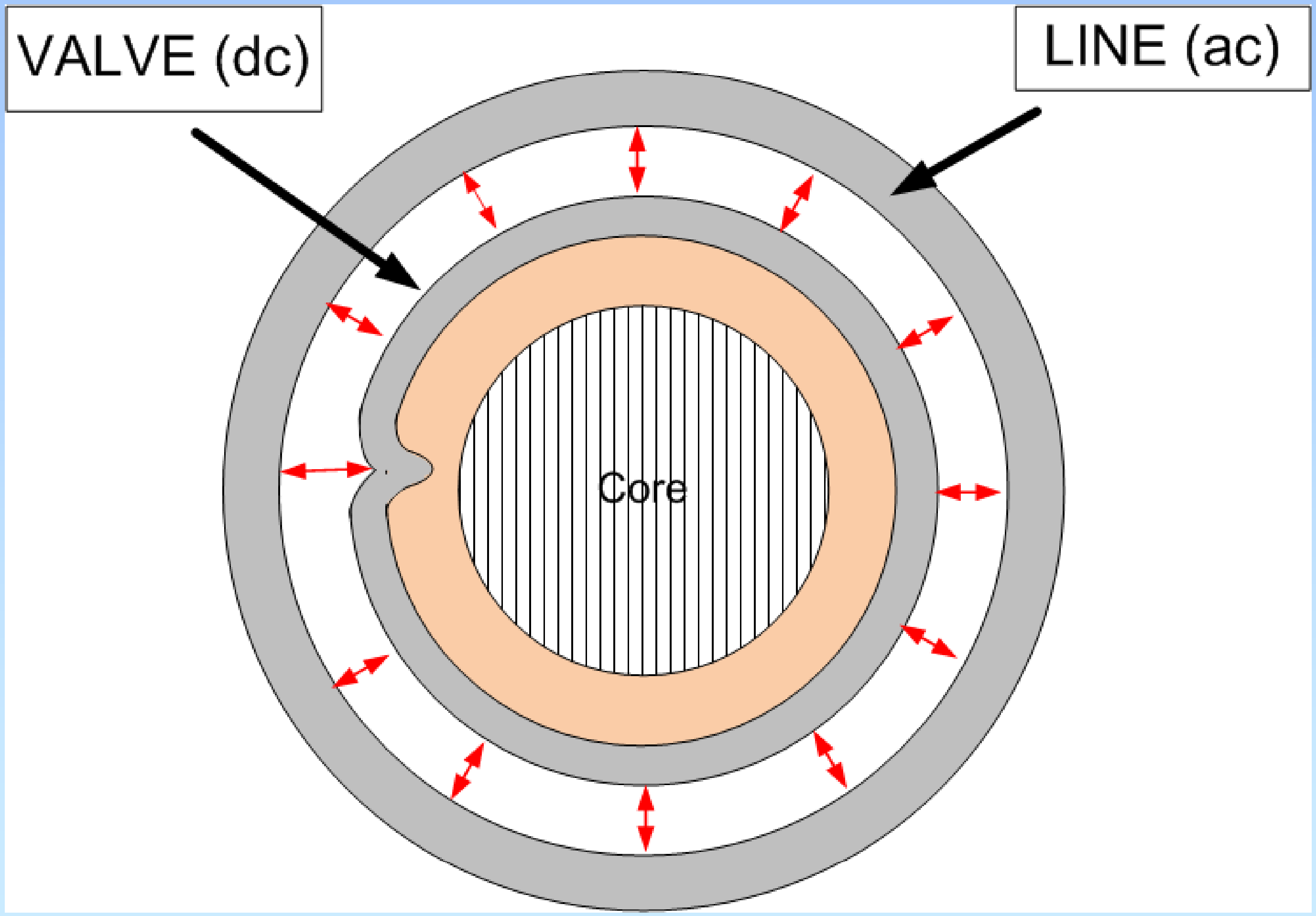
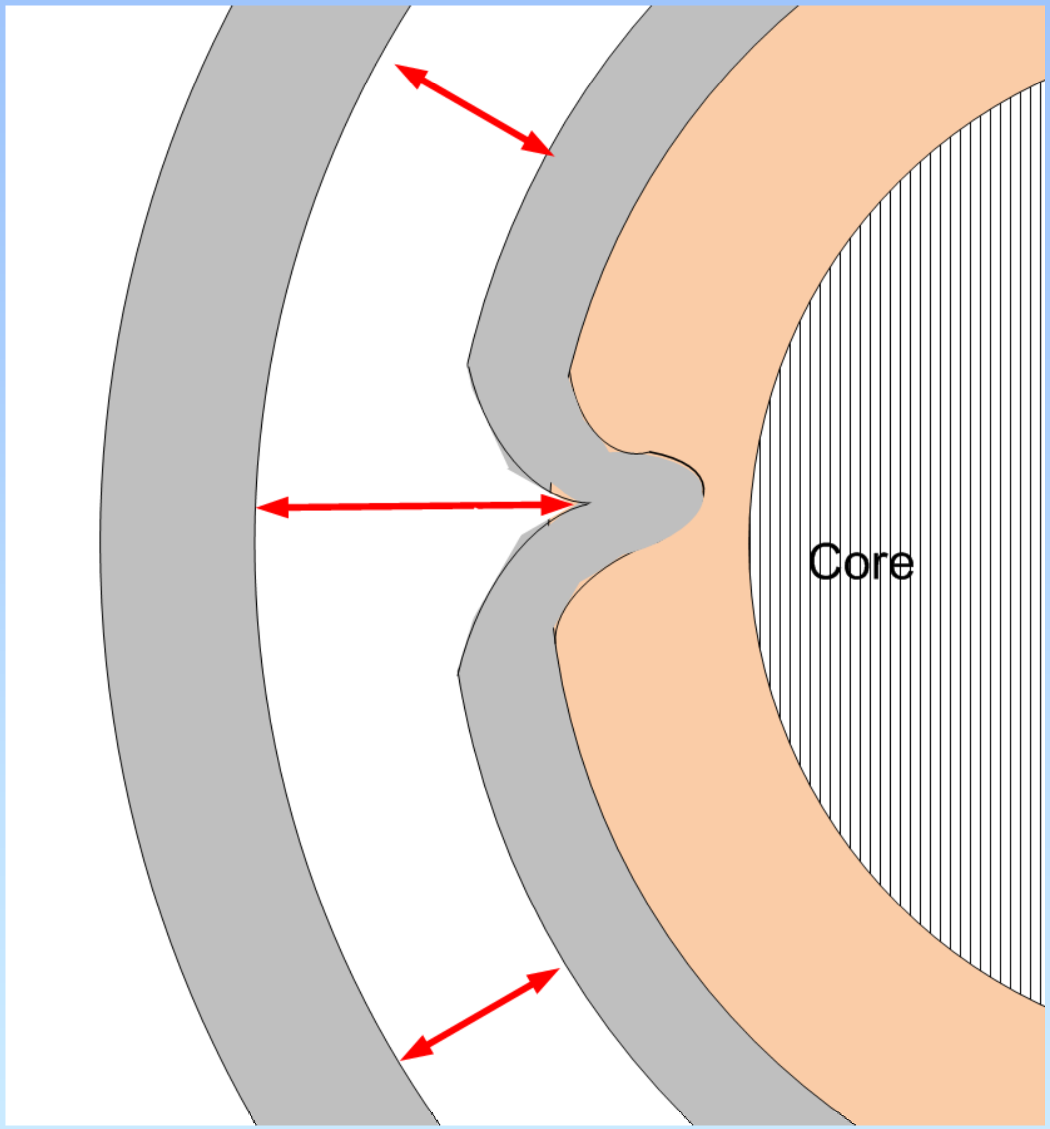
Collapse of a converter transformer valve winding



Teshmont



The Valve Winding Collapsed into the supporting insulation

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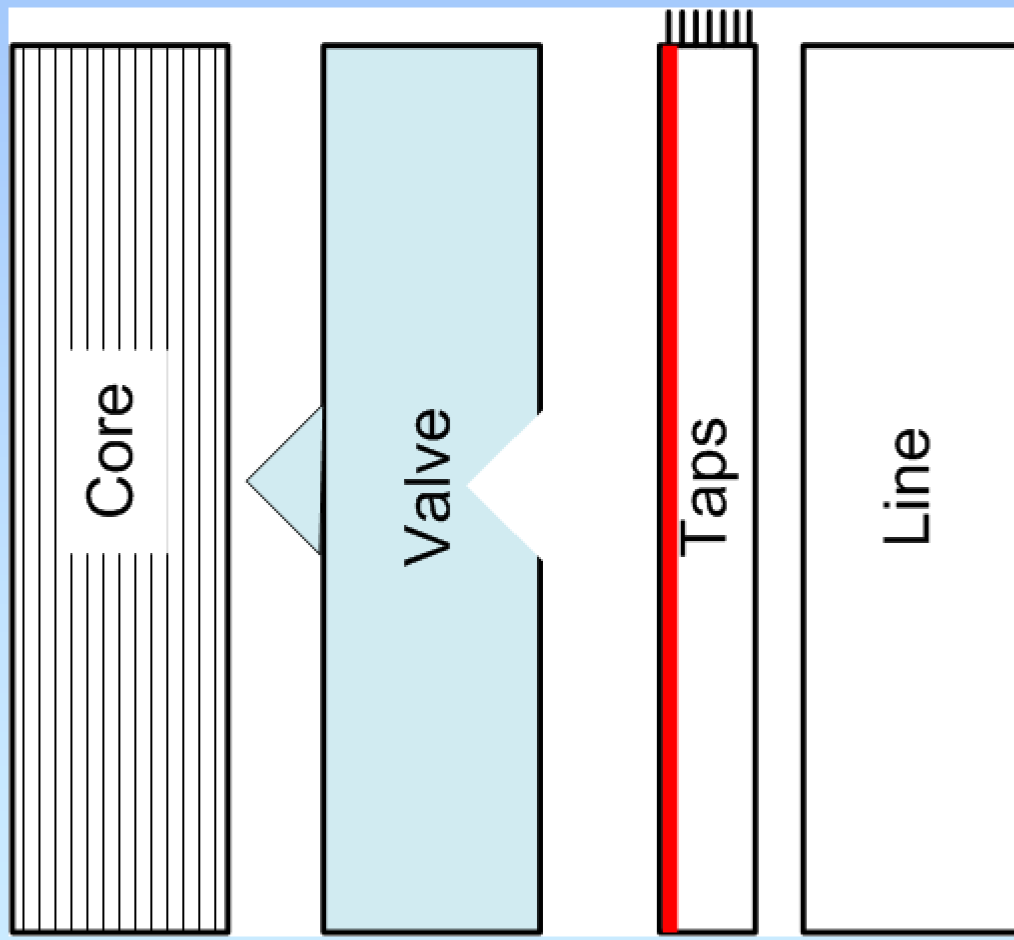
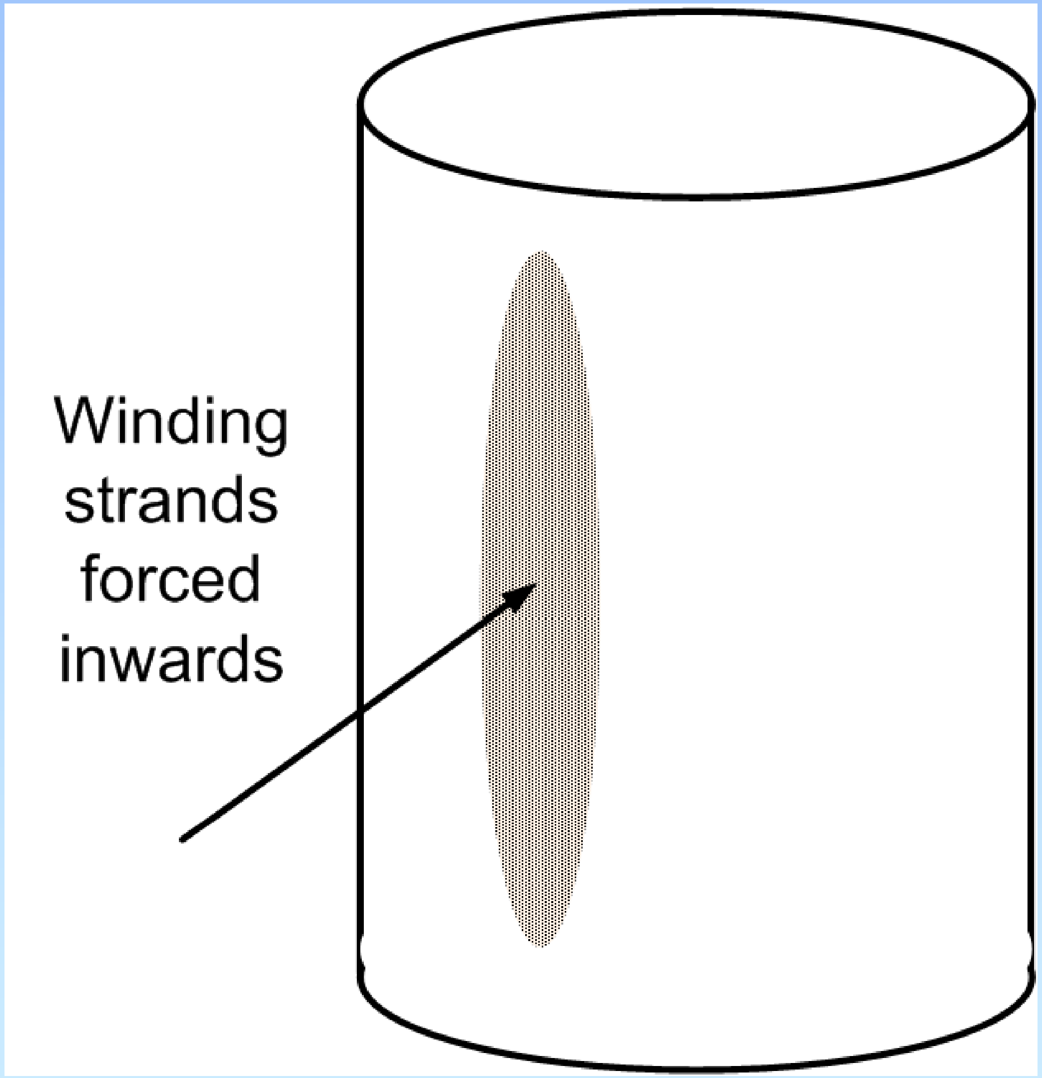
Impedance valve to tap section on partially collapsed phase lower



Teshmont



When stripped down another phase of the transformer showed signs of initial collapse

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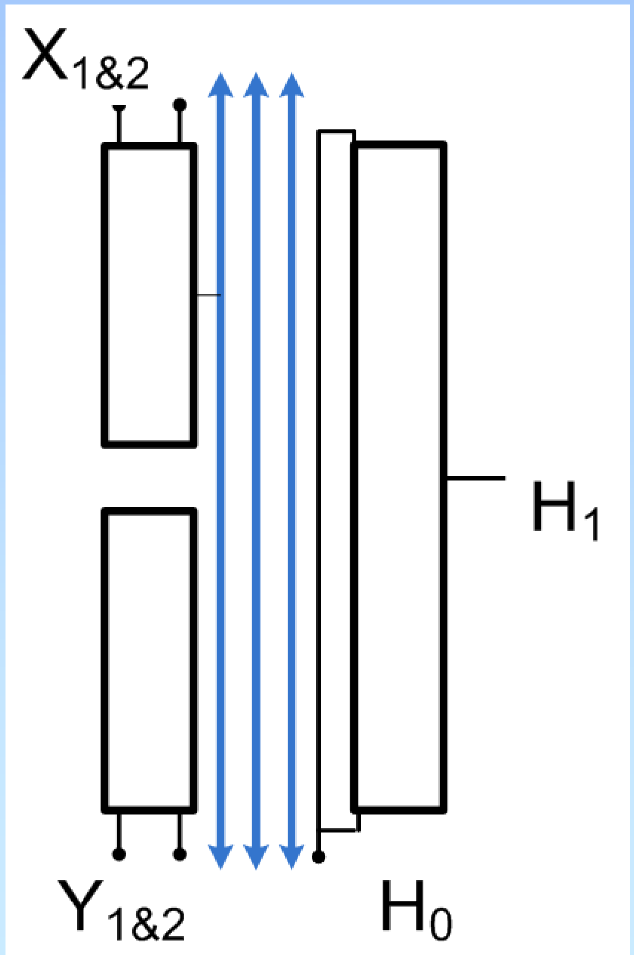
Generator transformers, 3-phase 3-winding



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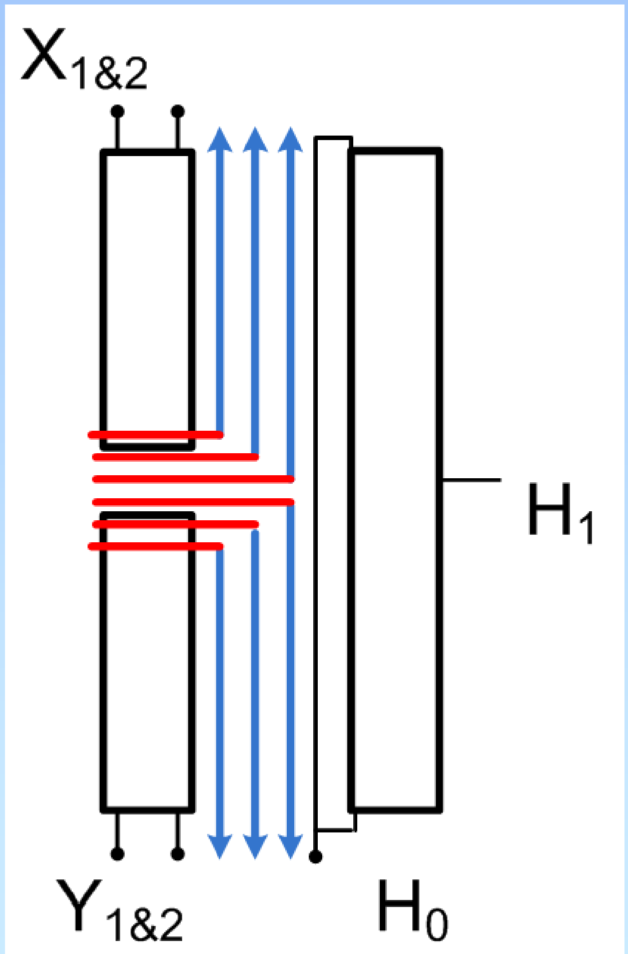
Highgate Converter transformers, 3-phase 3-winding



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Insulation damage inside LV

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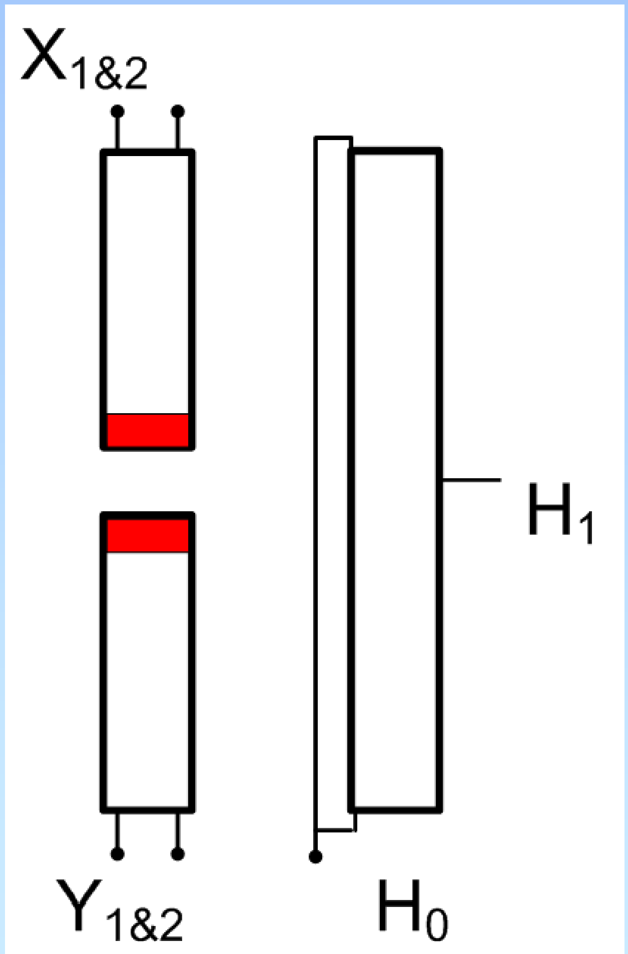
Harmonic Flux overheated end turns on LV's to over 150°C



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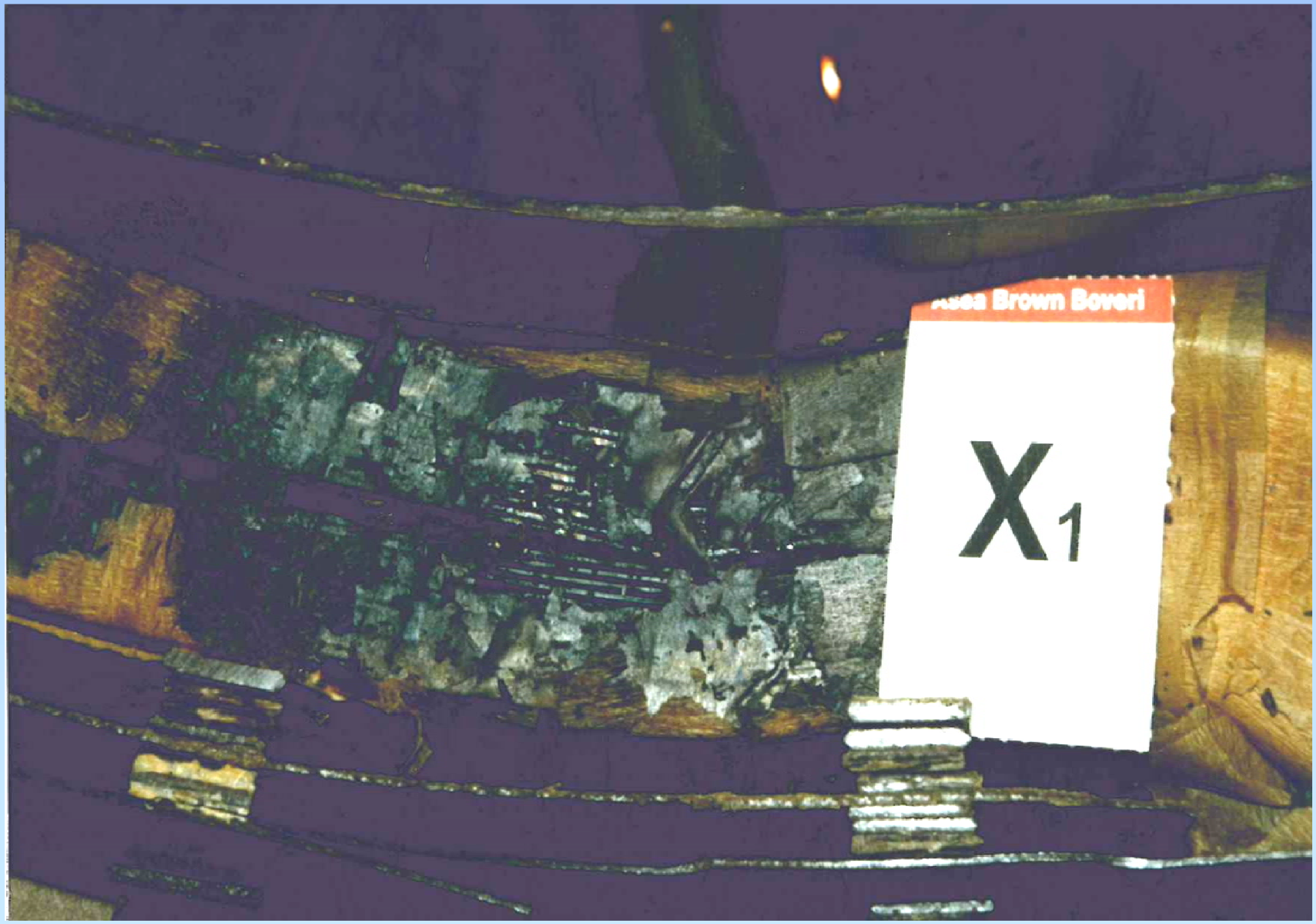
End of X_1 winding



Teshmont

Reference:

- Thermal problems caused by harmonic frequency leakage fluxes in 3-phase, 3 winding converter transformers

by

- Forrest & Allard
  - IEEE Transactions on Power Delivery Jan 2004

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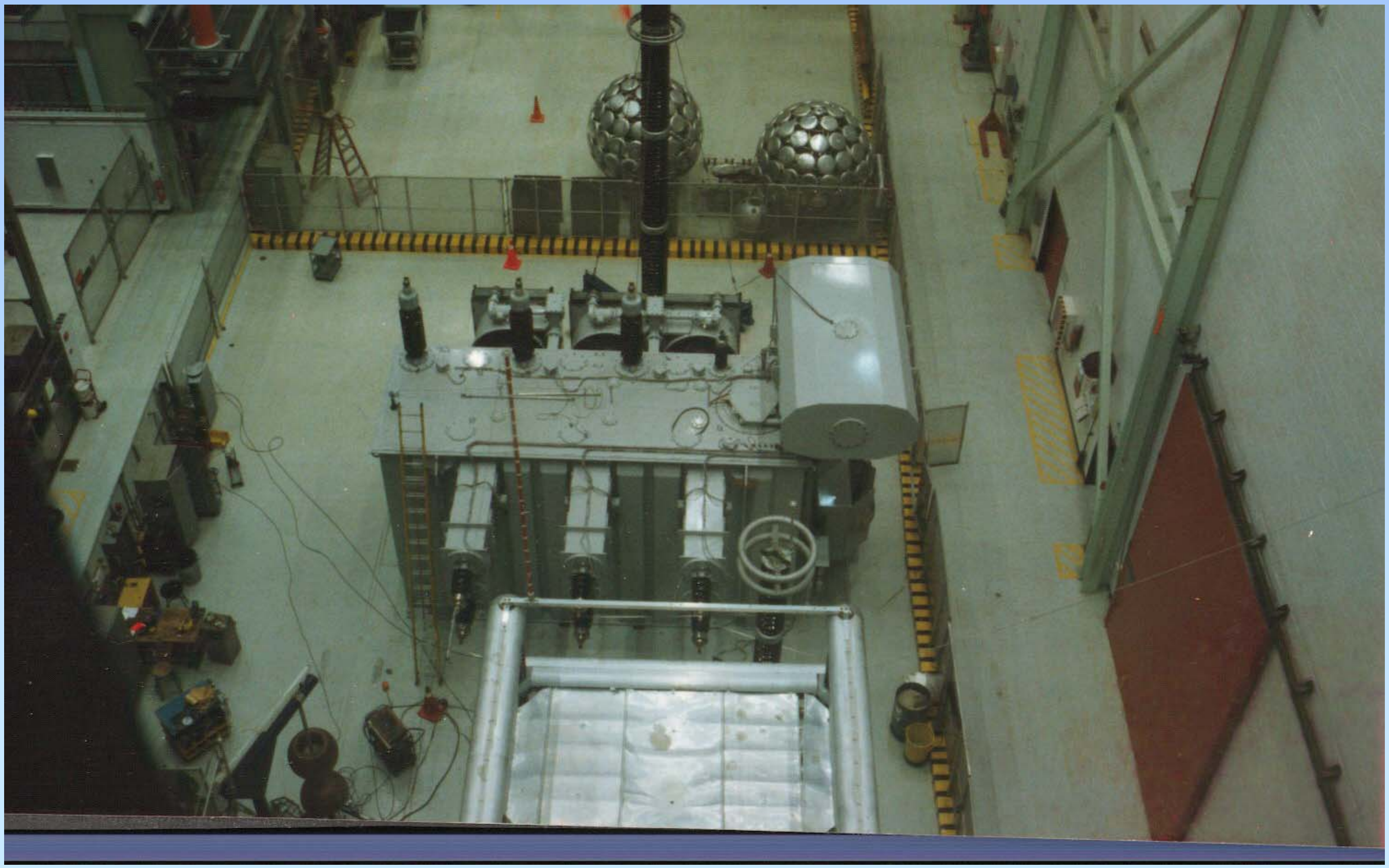
Highgate Transformer on test



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- Thank you for your attention

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