

The background image shows a large, grey industrial transformer at a power substation. The transformer is mounted on a metal frame and has several high-voltage bushings and insulators on top. In the background, there are several wind turbines under a clear blue sky. The overall scene is an outdoor industrial setting.

# Reliable Manufacturing Process

Transformer Concepts & Applications Seminar  
Goldsboro

Sept 17-19, 2024

**waukesha**  
a prolec ge company

# Dharam Vir

## Vice President of Engineering

Dharam started with Prolec GE Waukesha in 2004 and is currently responsible for engineering at both the Goldsboro and Waukesha facilities. During his 35+ years in the transformer industry, he has held positions in engineering, testing, production and plant operations. His design experience ranges from development of power transformers up to 765kV, shunt reactors and HVDC transformers. Dharam is an active member of the IEEE Transformers Committee and frequent contributor to industry training programs. He holds a Bachelor of Science Degree in Electrical Engineering from University of Delhi (India), an MS in Electrical Engineering from NIT Bhopal, India and an MBA in Finance and Marketing from Bhopal University, India.



# Agenda

Critical quality aspects during

- Winding conductor and coil windings
- Winding Assembly
- Core steel cutting and stacking
- Core Assembly
- Core and coil assembly
- Vapor phase process
- Tanking and final assembly
- Final Testing

# Safety



Visitor and employee safety are paramount in any transformer manufacturing facility, significant hazards exist in any facility and safety programs are in place to safeguard against these hazards....

- PPE *personal protective equipment*
- Forklifts, Cranes, & Aerial Platforms
- Lifting & Hoisting
- Ladder Safety
- Hot Work
- Powered and Hand Tools
- Electrical Safety
- Controlled Substances
- LOTO *Lock Out Tag Out*
- SDS *Safety Data Sheet* & Hazard Communications
- Confined Space
- And many other programs
- Fall Protection

# Quality Assurance

**Exceptional quality** is essential when constructing high-voltage electrical equipment.

Detailed procedures for all processes should be maintained within a **Quality Management System** for operator use and training purposes.

For non-standard processes, **Work Instructions** should be developed by a multi-functional team for operator safety, quality, and clarity.

**Non-Conformances** and **Engineering Change Orders** should be systematically handled within a Quality Management System.

**Contamination control** is critical to eliminate reliability and performance issues



# Quality Assurance

**Tollgates & Inspections** are performed throughout the manufacturing process to ensure compliance with internal, customer, and industry standards.

All **incoming materials must be inspected** for compliance to material specifications prior to application.

**Supplier Quality** personnel may work together with outside vendors to improve the quality of outsourced materials.

In addition to inspections, **preliminary tests** are performed at various points to **verify design** calculations and industry standards.

Once a transformer is fully assembled, it is subjected to **final acceptance testing** prior to shipment.



# Lean Six Sigma Manufacturing

Today, most transformer manufacturers employ Lean Six Sigma manufacturing processes to improve quality, performance, and cost competitiveness of products. In facilities, one often observes...

- Continuous improvement teams utilizing DMAIC (Define, Measure, Analyze, Improve, Control) process
- Visual factory management tools
- 5S workplace organization
- Statistical process controls

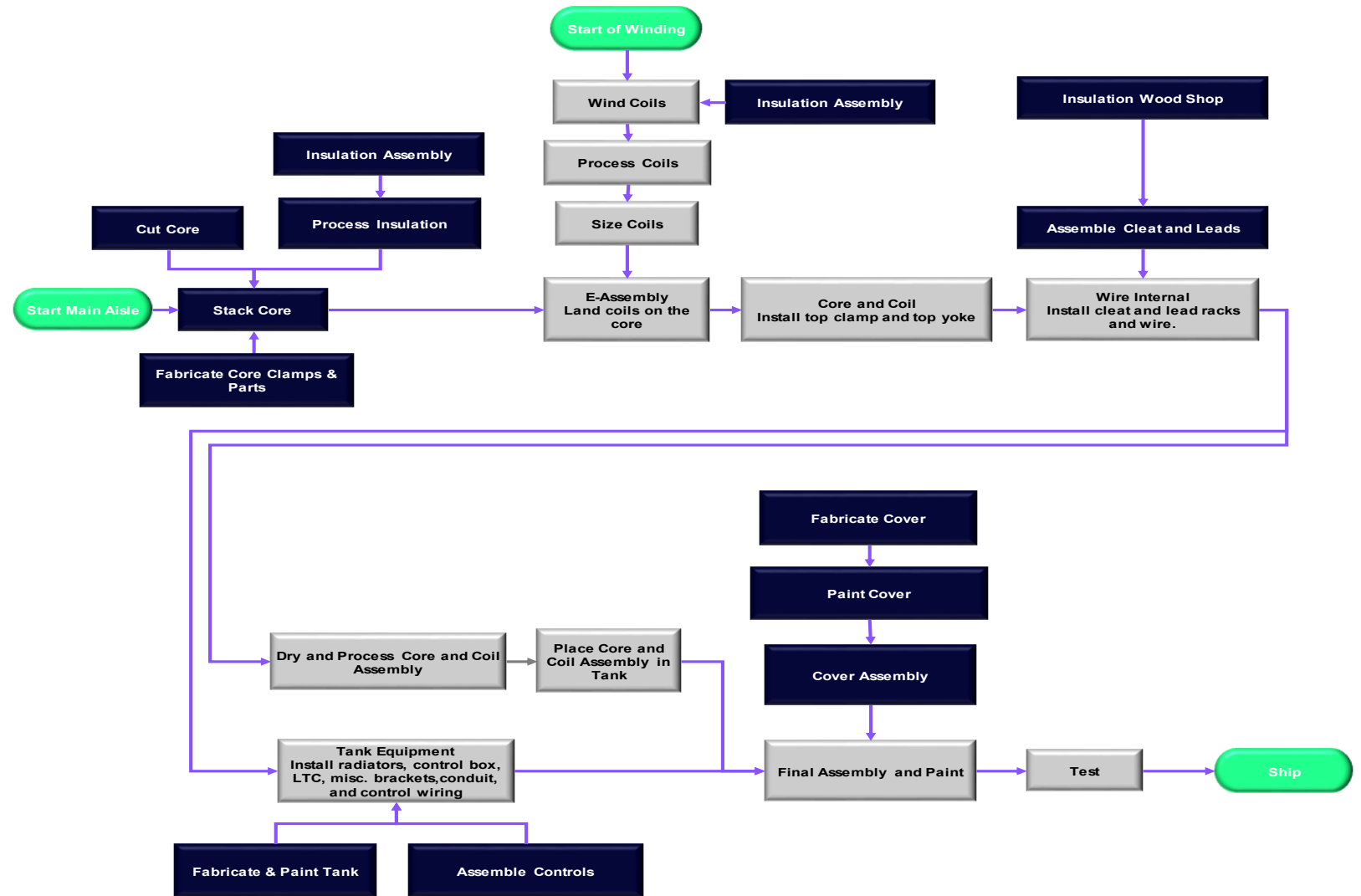
TASK	STATUS	PERSON RESPONSIBLE	STATUS
CONTROL BOX UNIT	●	WPTM	●
CONDUIT UNIT	●	WPTM	●
TRM ASSEMBLY COMPLETE	●	ARC	●
TRM COILS	●	WYFLA	●
TRM READY FOR CORE AND COIL ASSEMBLY	●	WPTM	●
TOP CORE COMPLETE	●	TCM	●
INTERNAL AND EXTERNAL HARDWARE COMPLETE	●	WPTM	●
SOLE AND CORE SHIP TO PENNY	●	WPTM	●
REMOVE BROADCAST SHEET FROM CASE	●	WPTM	●
DRY PACKING OF TOP CORE AND COIL ASSEMBLY	●	WPTM	●
BI-PACKET WORK ROOM	●	WPTM	●
LINE PROCEEDS BACK TO SERVICE	●	WPTM	●
OFFLINE TRM PLACEMENT AND WPTM OFFSET	●	WPTM	●
CONTROL BOX UNIT	●	WPTM	●
CONDUIT UNIT	●	WPTM	●
TRM AND COIL COMPLETE	●	WPTM	●
TRM COILS	●	WPTM	●
TRM READY FOR CORE AND COIL ASSEMBLY	●	WPTM	●
TOP CORE COMPLETE	●	WPTM	●
INTERNAL AND EXTERNAL HARDWARE COMPLETE	●	WPTM	●
SOLE AND CORE SHIP TO PENNY	●	WPTM	●
REMOVE BROADCAST SHEET FROM CASE	●	WPTM	●
DRY PACKING OF TOP CORE AND COIL ASSEMBLY	●	WPTM	●
BI-PACKET WORK ROOM	●	WPTM	●
LINE PROCEEDS BACK TO SERVICE	●	WPTM	●
OFFLINE TRM PLACEMENT AND WPTM OFFSET	●	WPTM	●

Green = go/work on job  
Red = Stop/work complete

GT-00400      GT 00 497



# Typical Manufacturing Process Flow

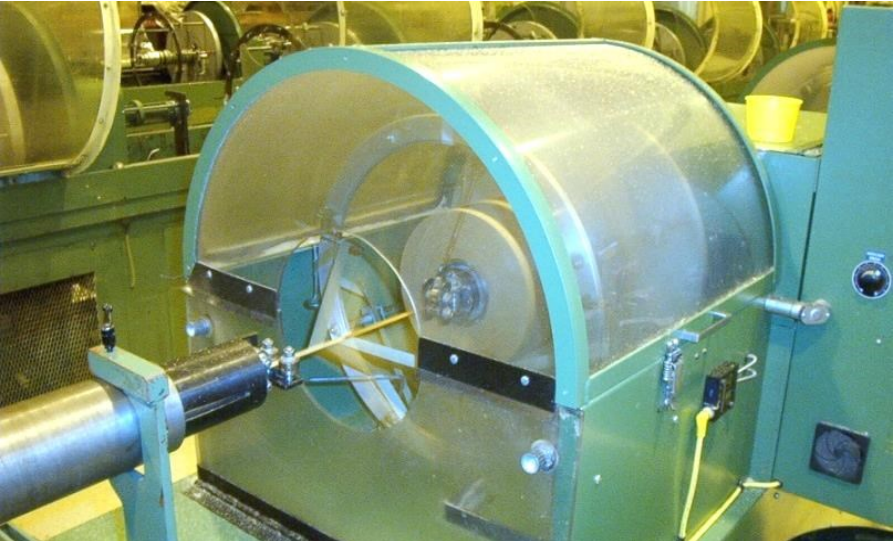
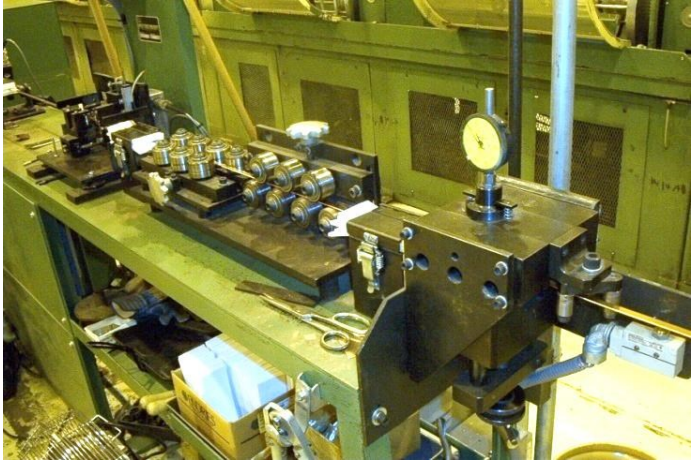




# Typical Manufacturing Process Flow

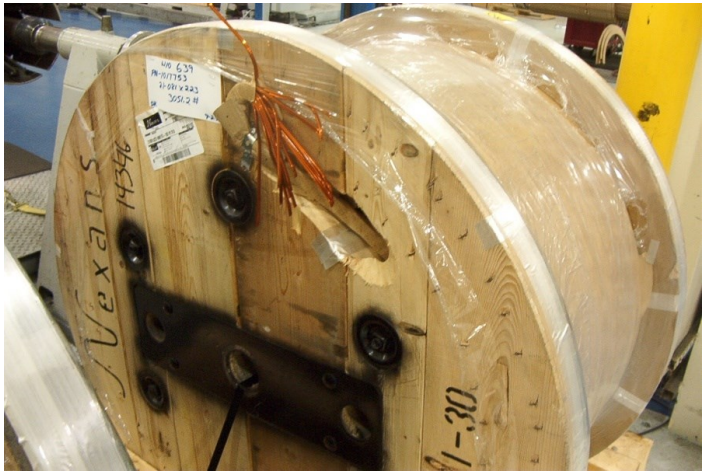
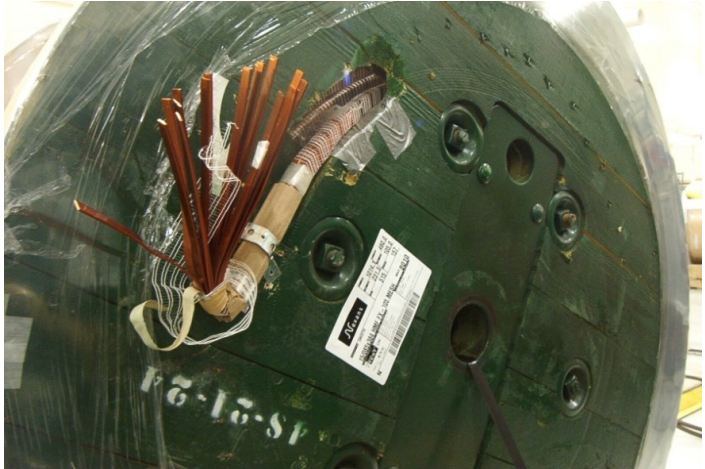
- Production cycle times typically are between 20 and 80 days
- Custom design and manufacturing
- High content of manual assembly

# Winding Conductor Insulation



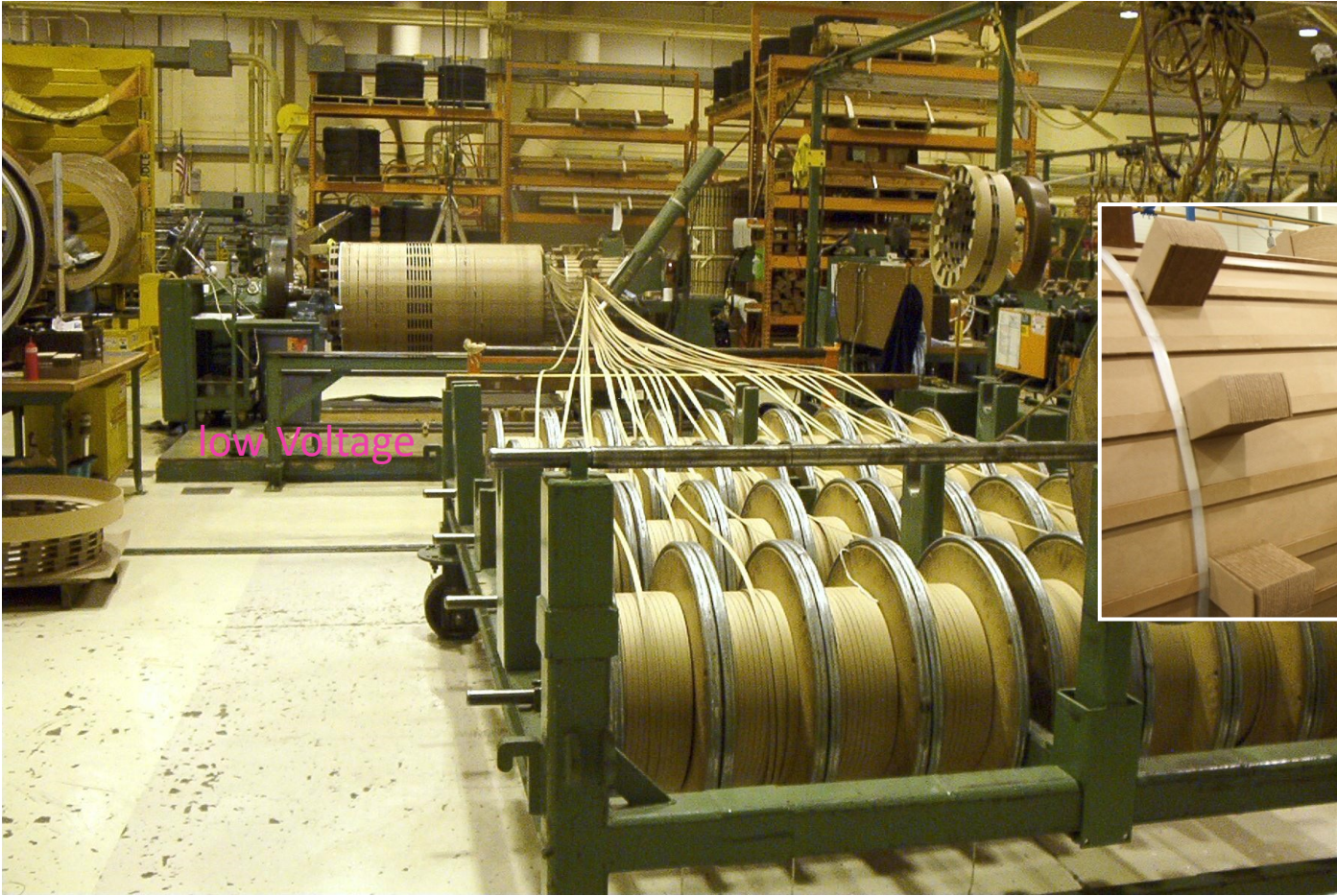
# Winding Conductor for Coil Winding

Received and Inspected



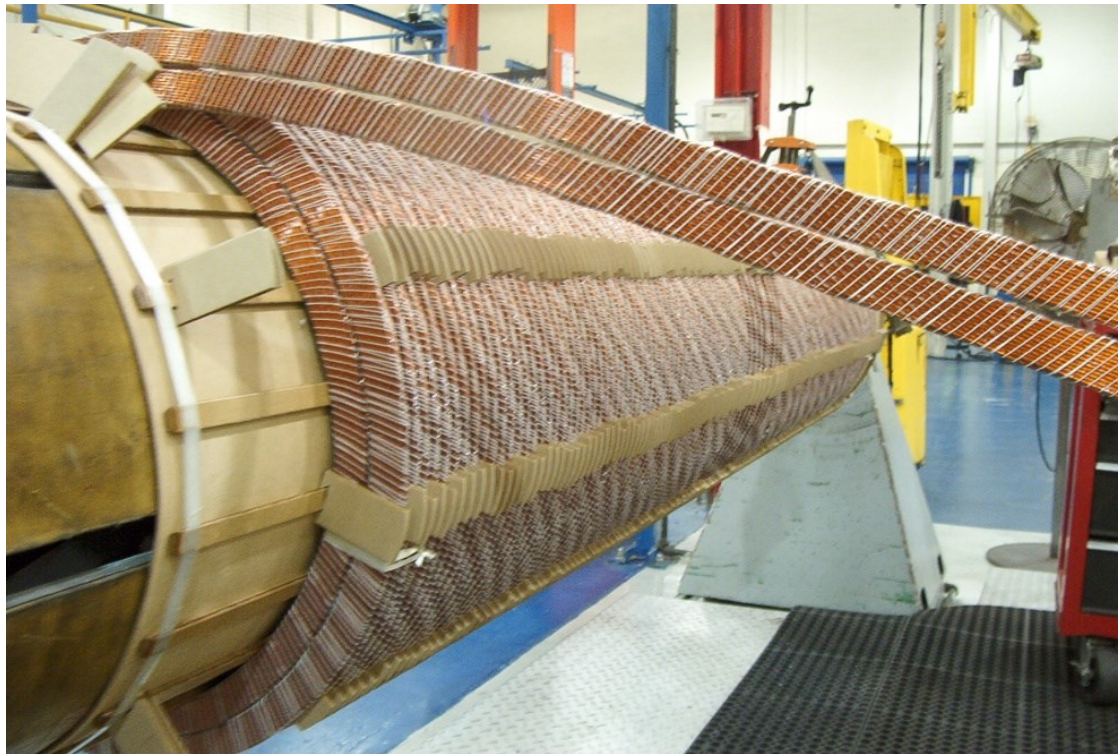
# Coil Winding

Helical  
Winding  
with Multiple  
Magnet Wire



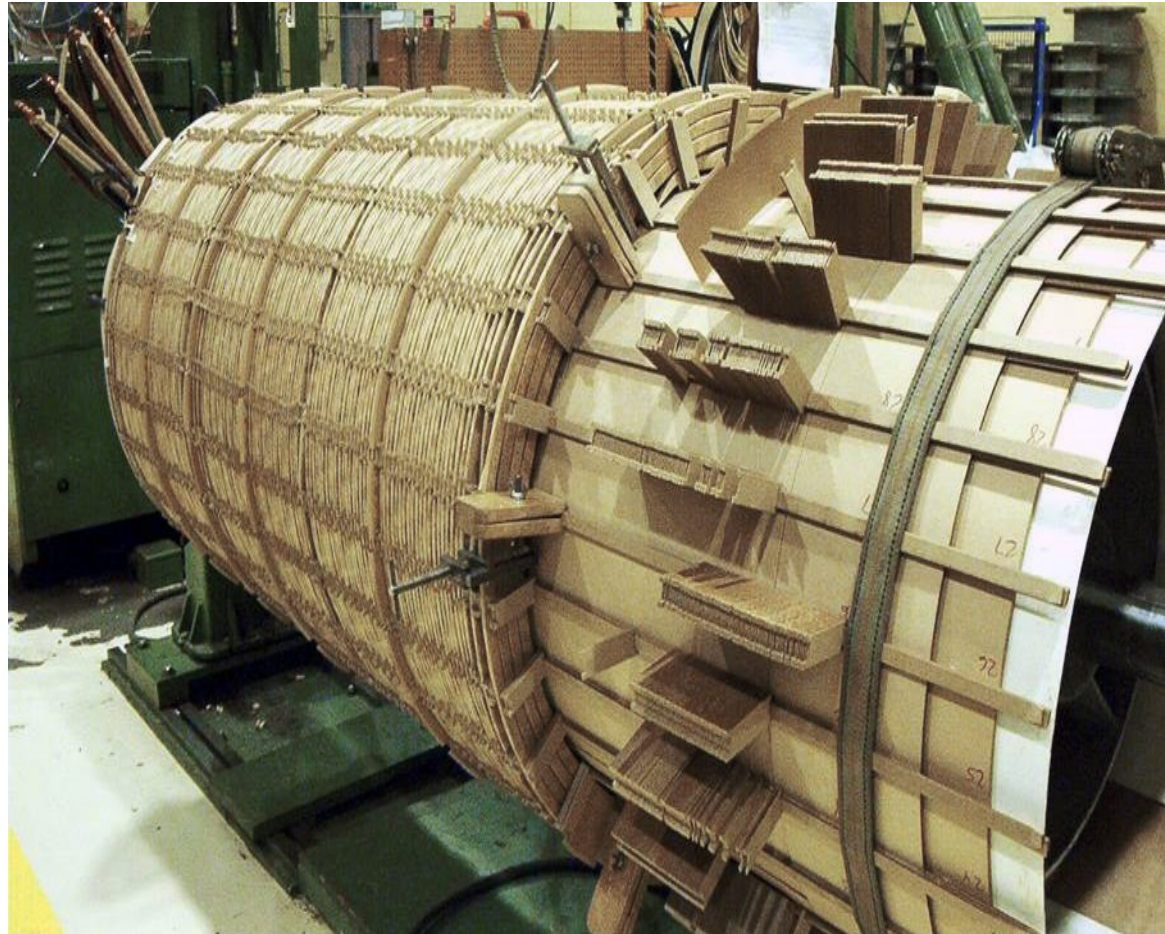
# Coil Winding

## Helical Winding with Two CTCs



# Coil Winding

Helical  
Winding with  
Four CTCs



*Note the placement  
of oil guide washers.*

# Coil Winding *(cont.)*

Disc Winding  
with Magnet  
Wires



# Coil Winding *(cont.)*

Disc Winding  
with CTC on  
Vertical Winding  
Machine





# Coil Winding *(cont.)*

Complete Set of Windings for a Transformer:  
HV, LV and TV



# Winding & Winding Assembly

- Checking of burrs on the winding copper conductor prior to spinning
- During spinning ensure correct overlap of the paper layers
- Ensure the paper used for wrapping is thermally upgraded
- Ensure surfaces of insulation in contact with winding conductors have rounded edges
- Ensure the transpositions in the windings are at the correct locations

# Winding & Winding Assembly

- Proper insulation at the inside and outside cross overs
- On CTC windings pressboard ramps to support conductor at location of cross overs
- Ensure windings are being wound tight to ensure right radial build
- Processing and sizing of windings to close tolerances
- Vertical alignment of radial spacers

# Core Steel

Delivered,  
Inspected with  
Cut to Width

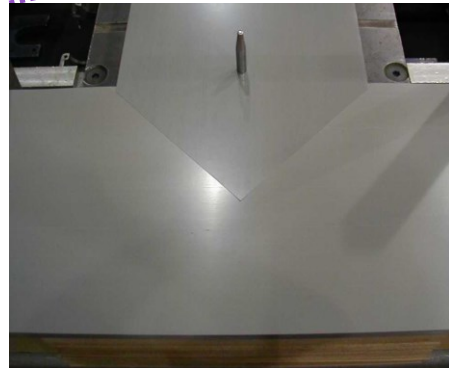
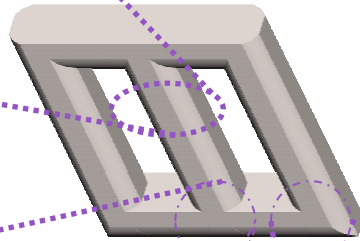
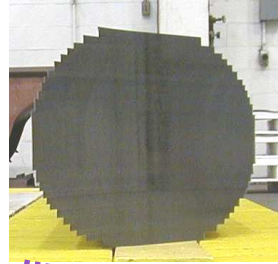


# Core Steel (cont.)

Delivered, Inspected with Cut to Width



# Core Steel (cont.)



"V" Notch



Step-Lap Joint

# Stacked Core Legs & Bottom Yoke Epoxy-Coated



Three Phase Core



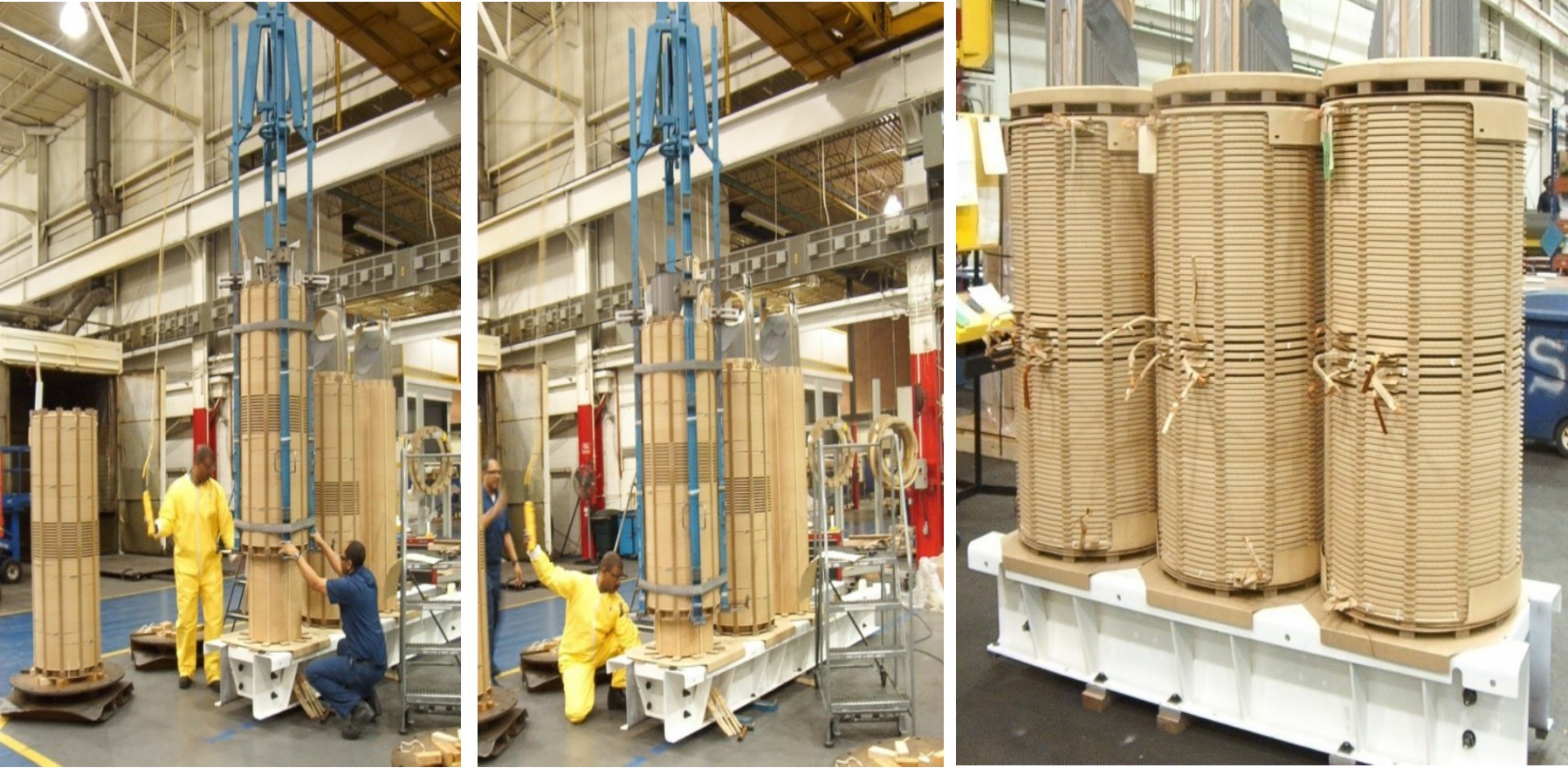
Single Phase Core

# Core & Core Assembly

- Ensure the burrs on the cut edge of core steel are within specified limits
- Proper assembly of core to limit the size of gaps in the core
- Tightness of the core limbs to ensure lower sound levels
- Limbs should be vertical
- Selection of proper insulation under the flitch plate and for the core gaps
- Core grounding strap location and size. Bridging of the core ducts.



# Landing Coils on Core Legs



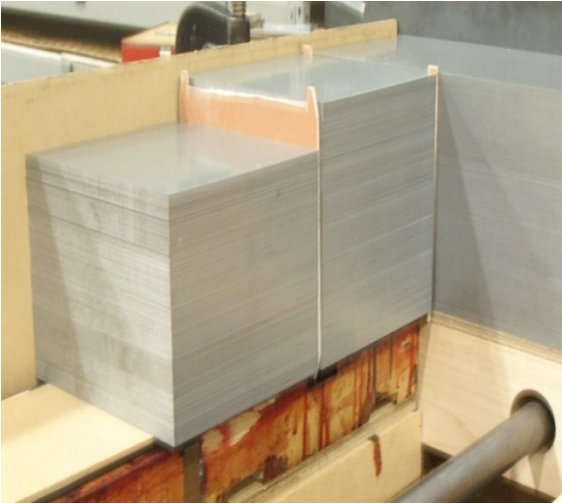
# Coils Assembled onto the Core Assembly



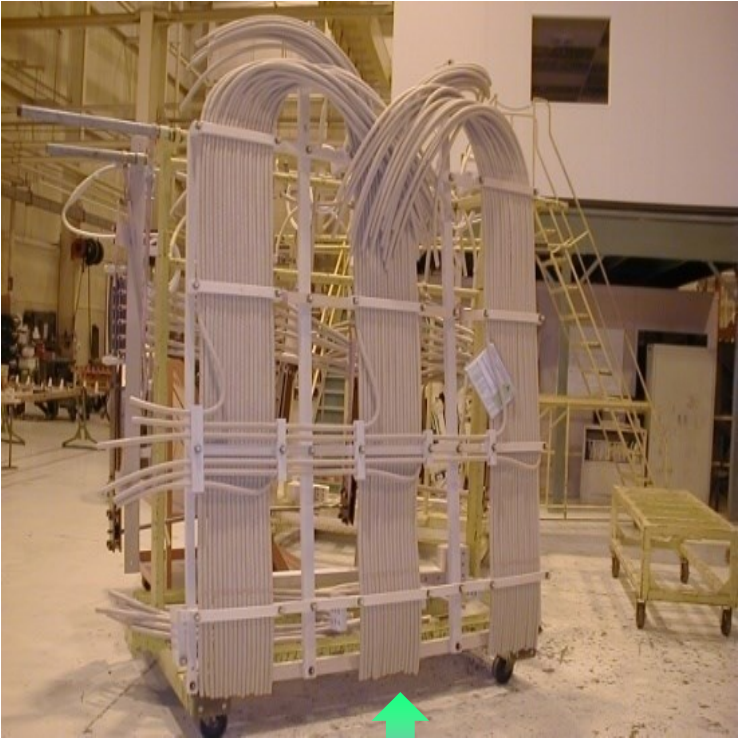
# Core Top Yoke Assembled into the Core & Coil



# Preventive Auto Reactor with Gapped Core for LTC Units

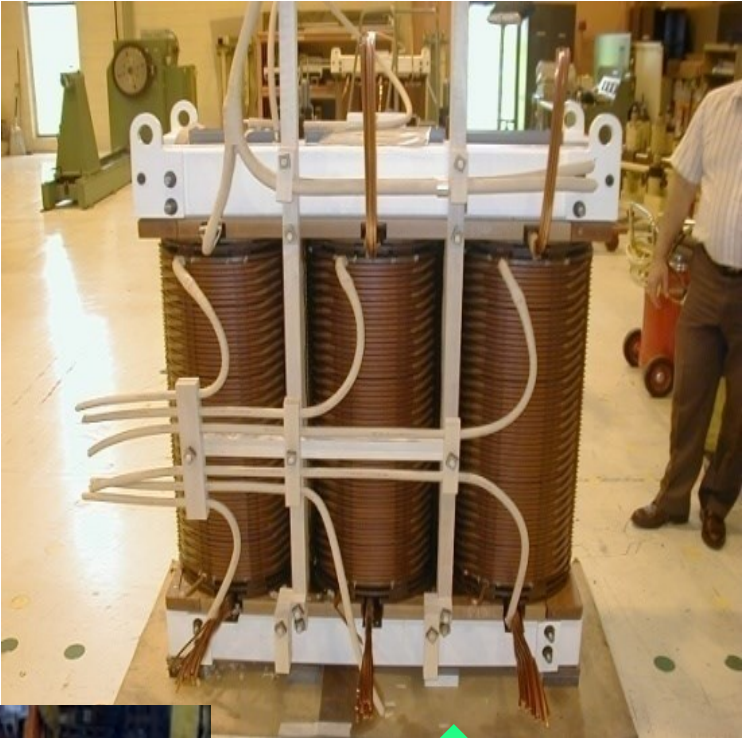


# Addition of Lead Assemblies for Core & Coil



Cleats and Leads

DETC

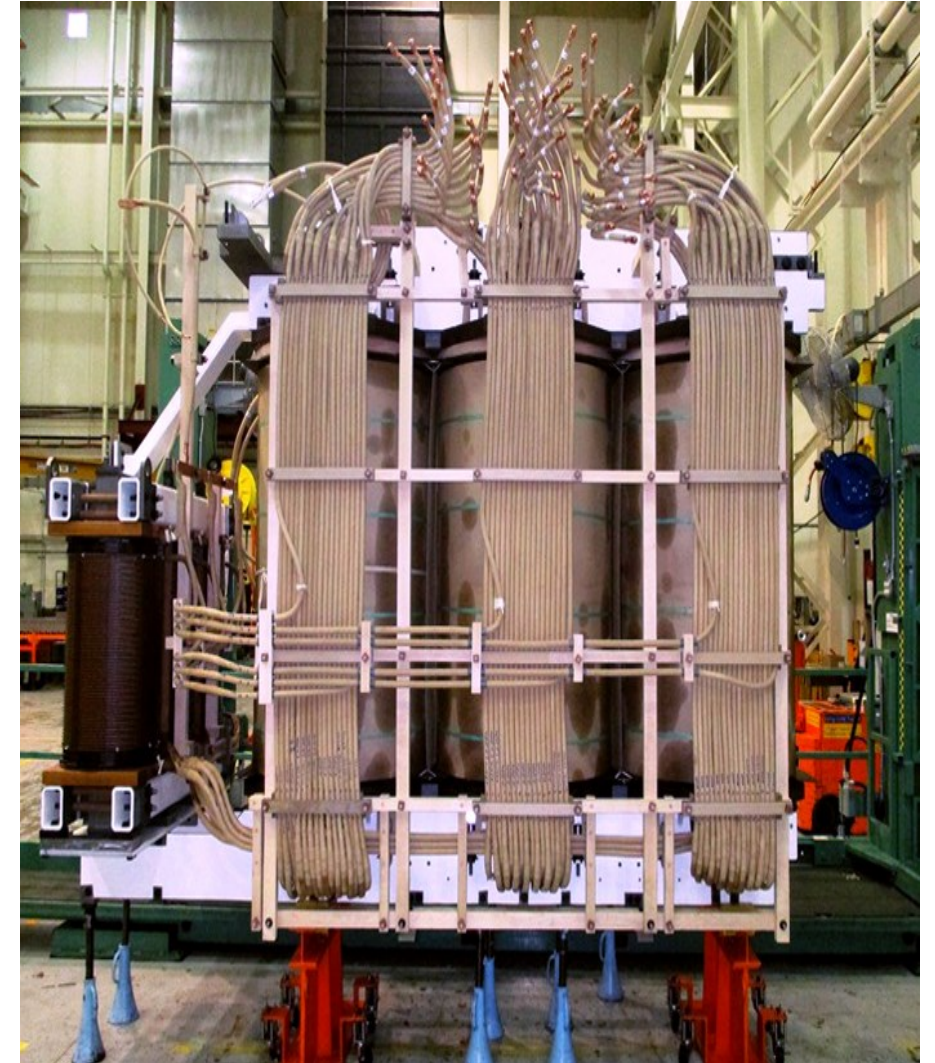


Booster Unit  
(Series) Assembled

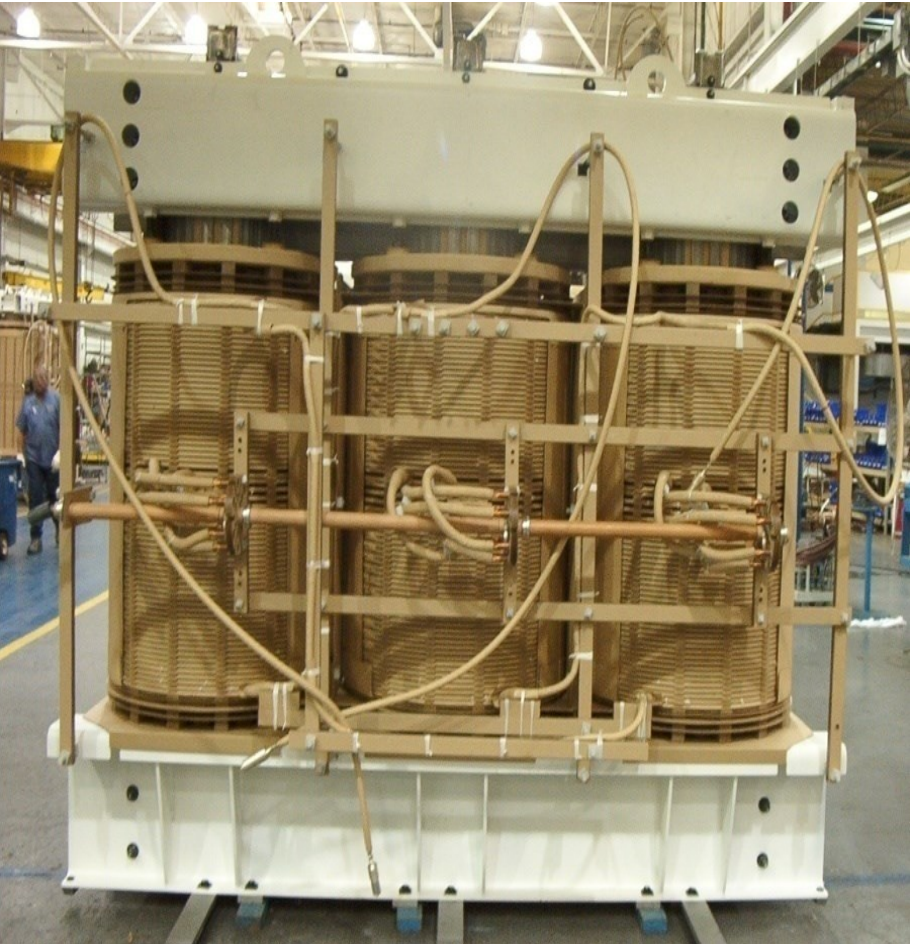
# Addition of Lead Assemblies for Core & Coil

(cont.)

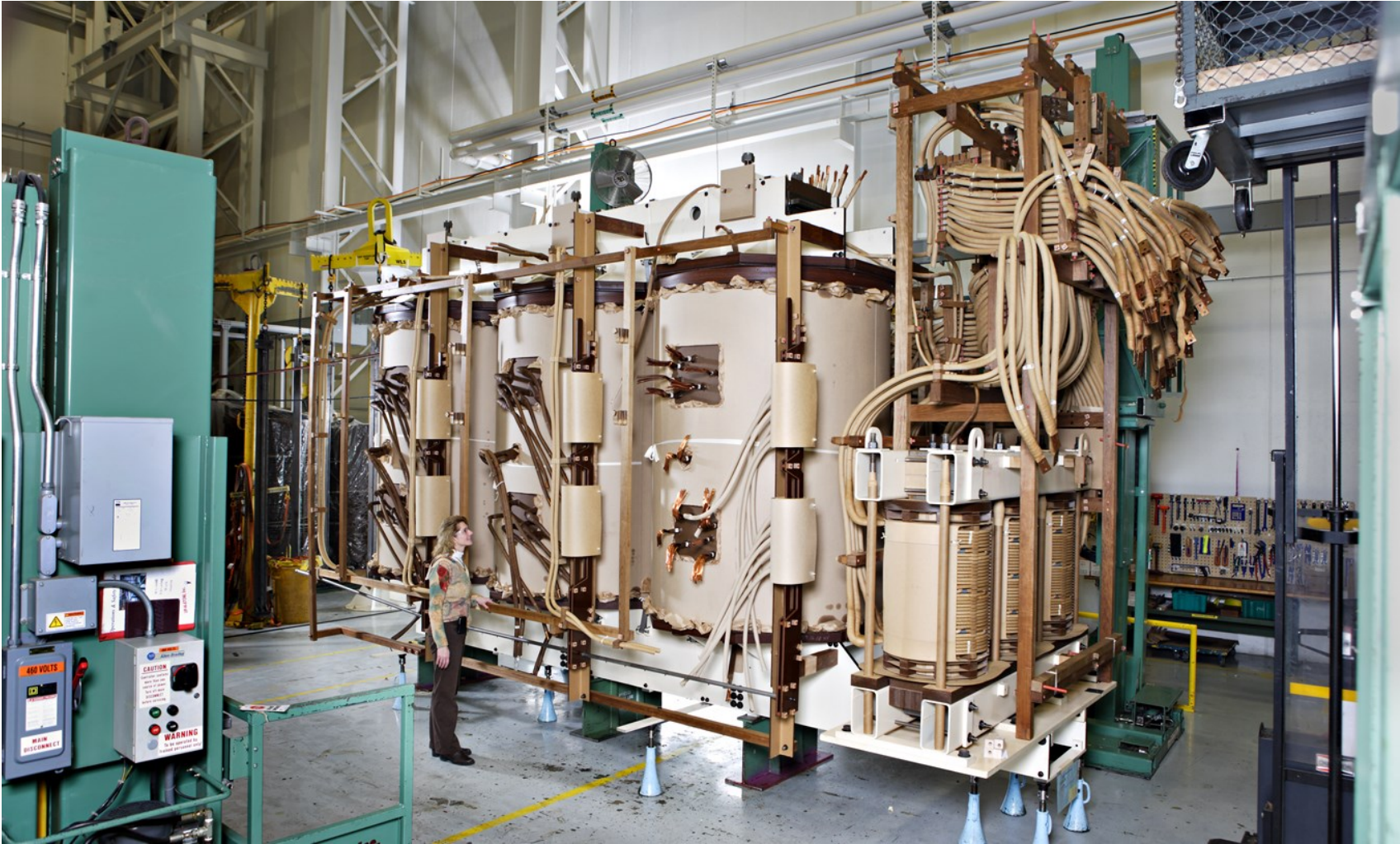
Units Ready for  
Vapor Phase Drying



# Core & Coil Completely Assembled — Simple Unit

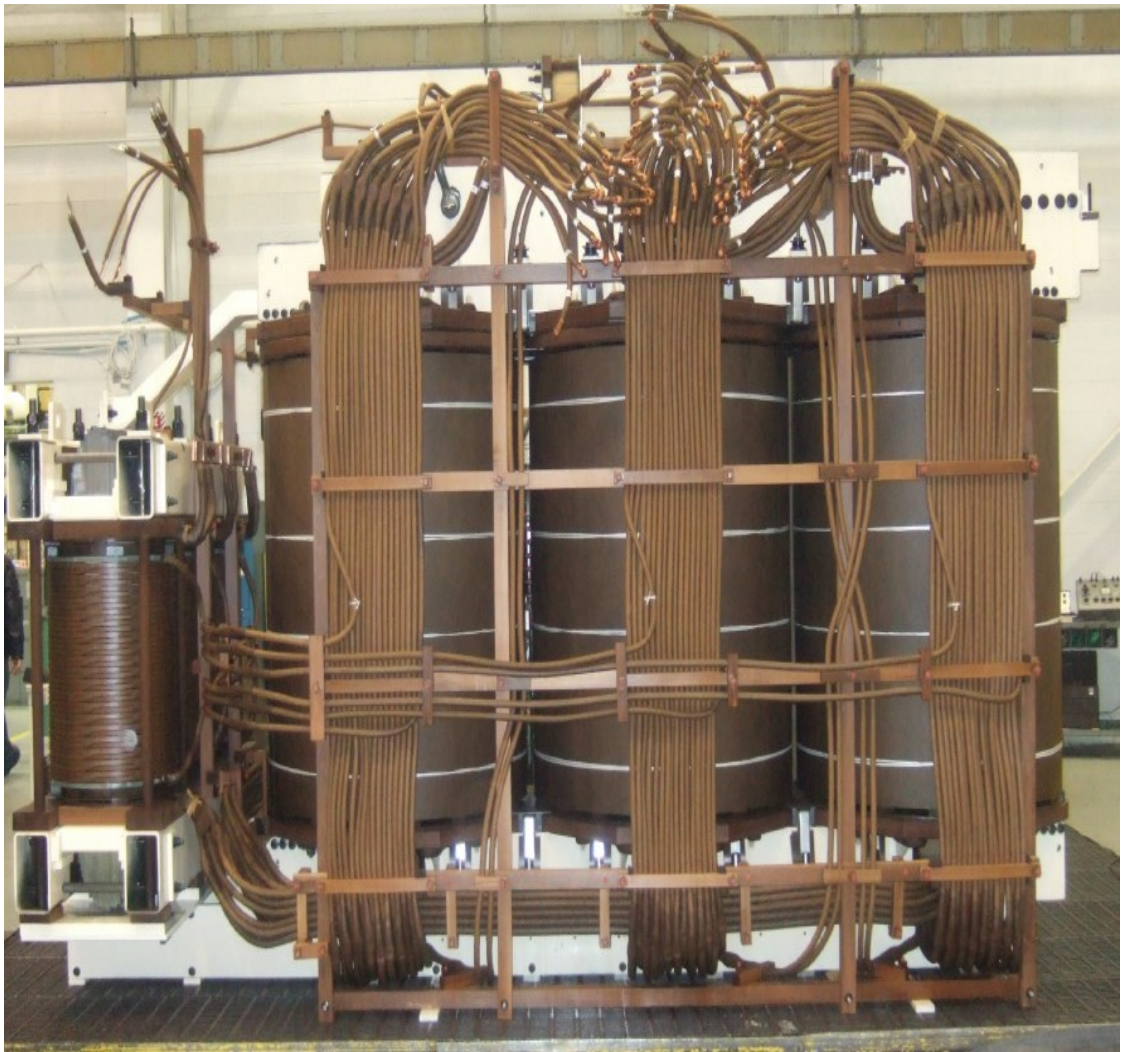


# Completed Core & Coil Assembly

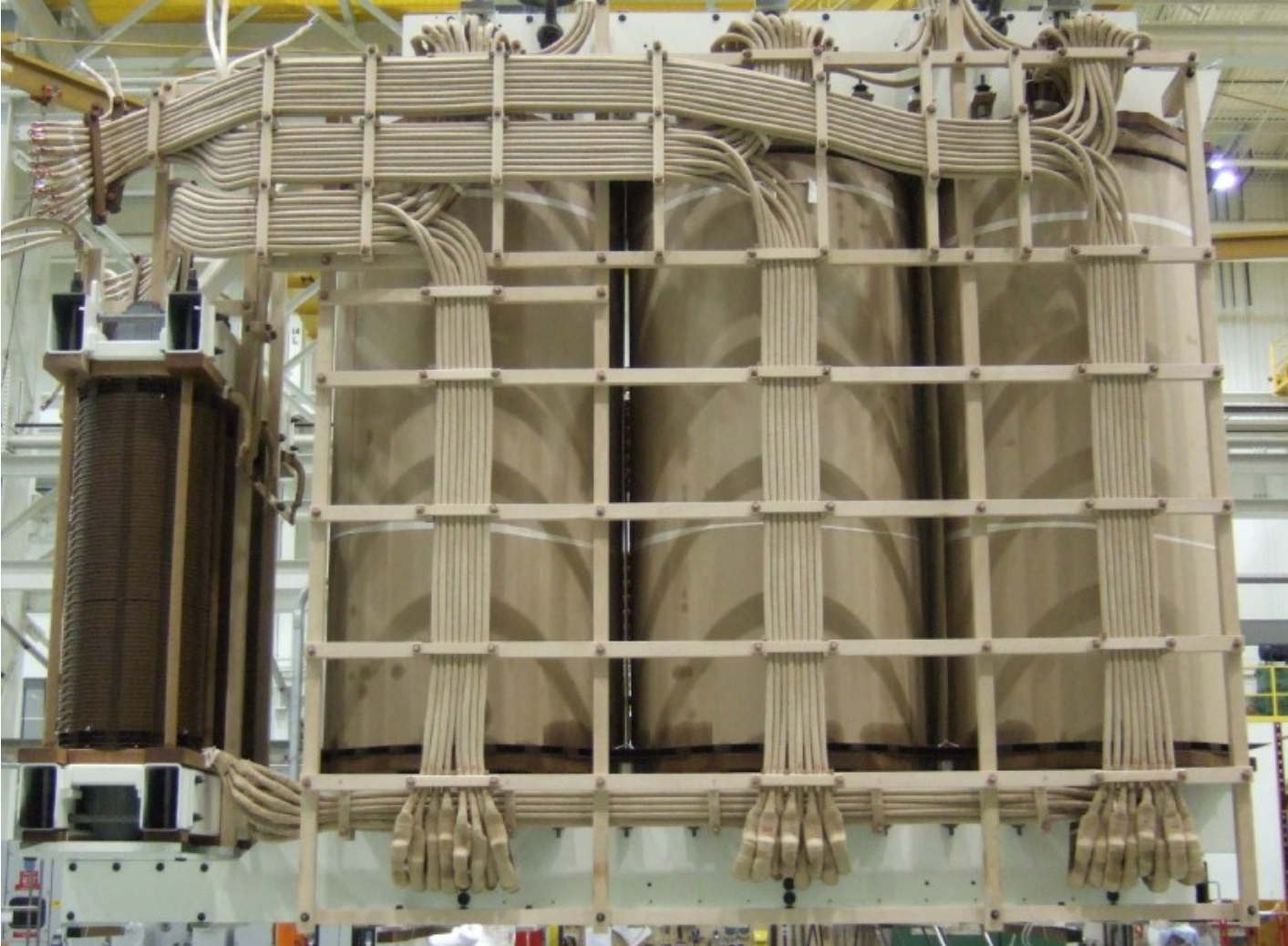




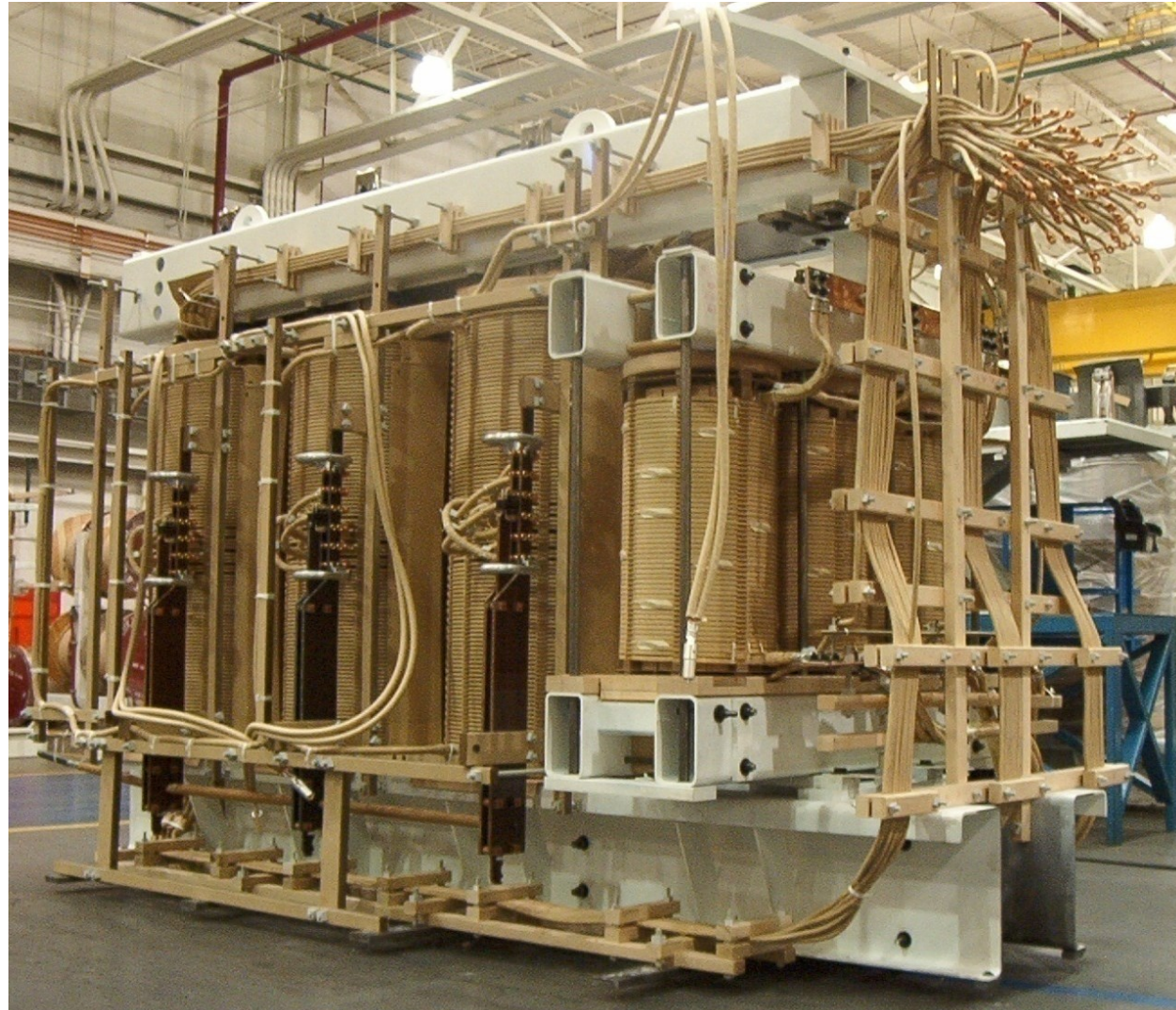
# Core & Coil Assembly Multi Start Windings for LTC



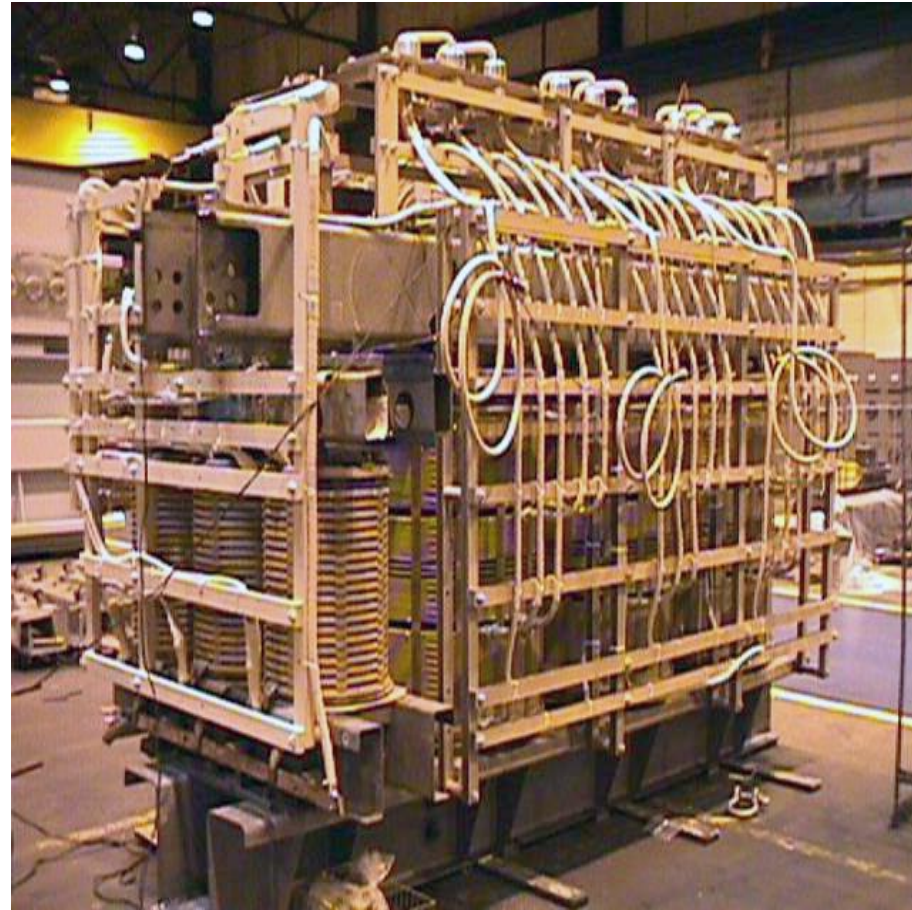
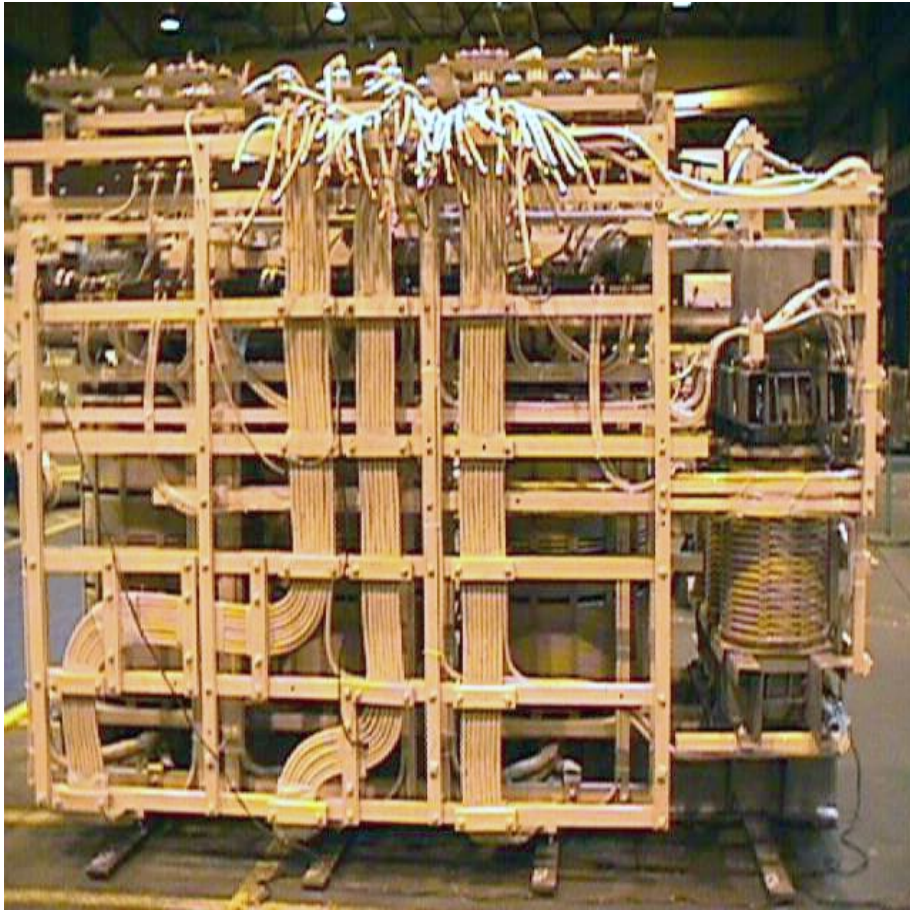
# Core & Coil Assembly Multi Start Windings for LTC *(cont.)*



# Core & Coil Assembled — More Complex Unit



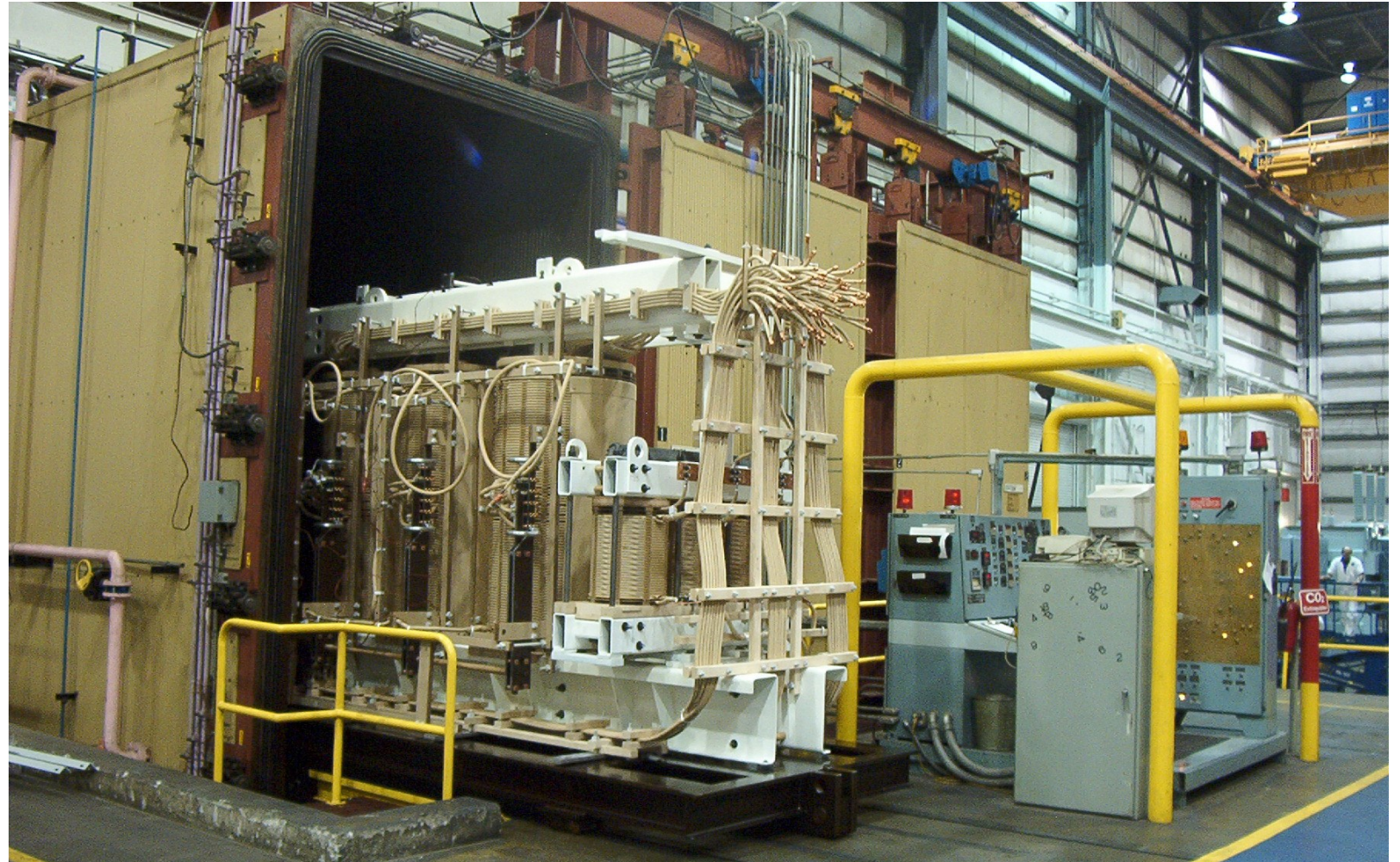
# Core & Coil Assembled — Extremely Complex Unit



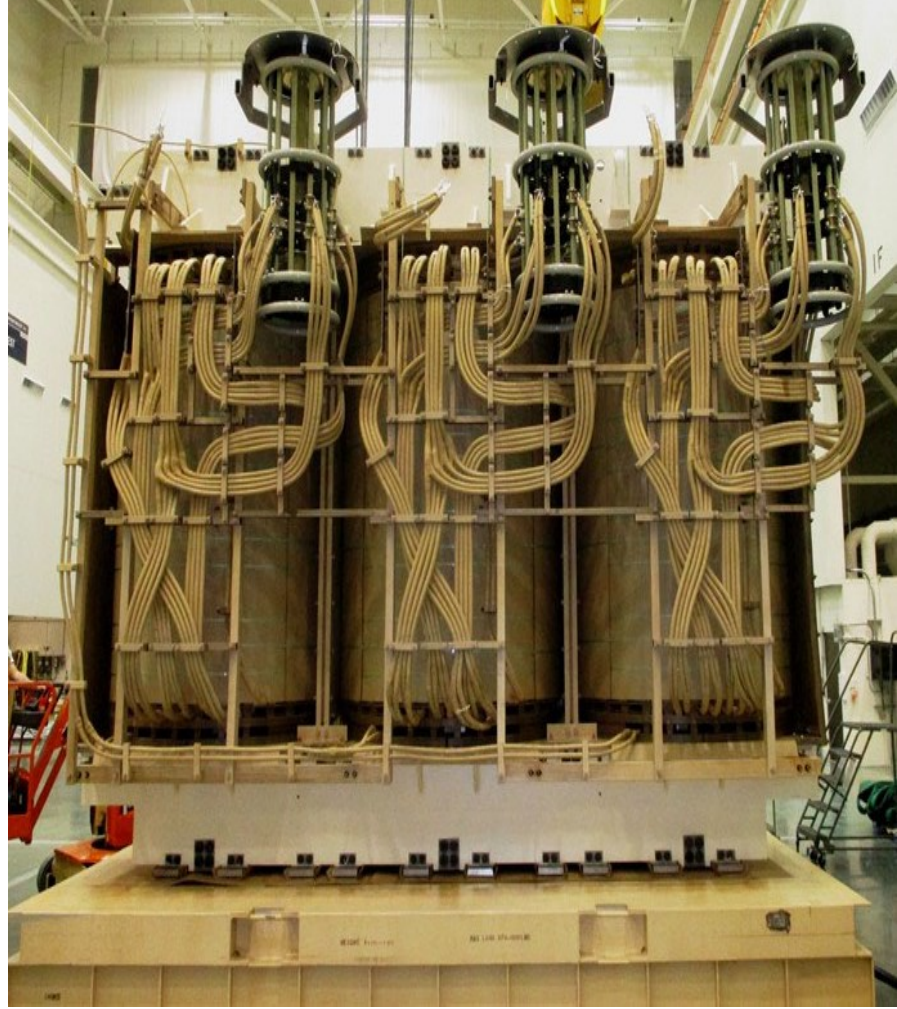
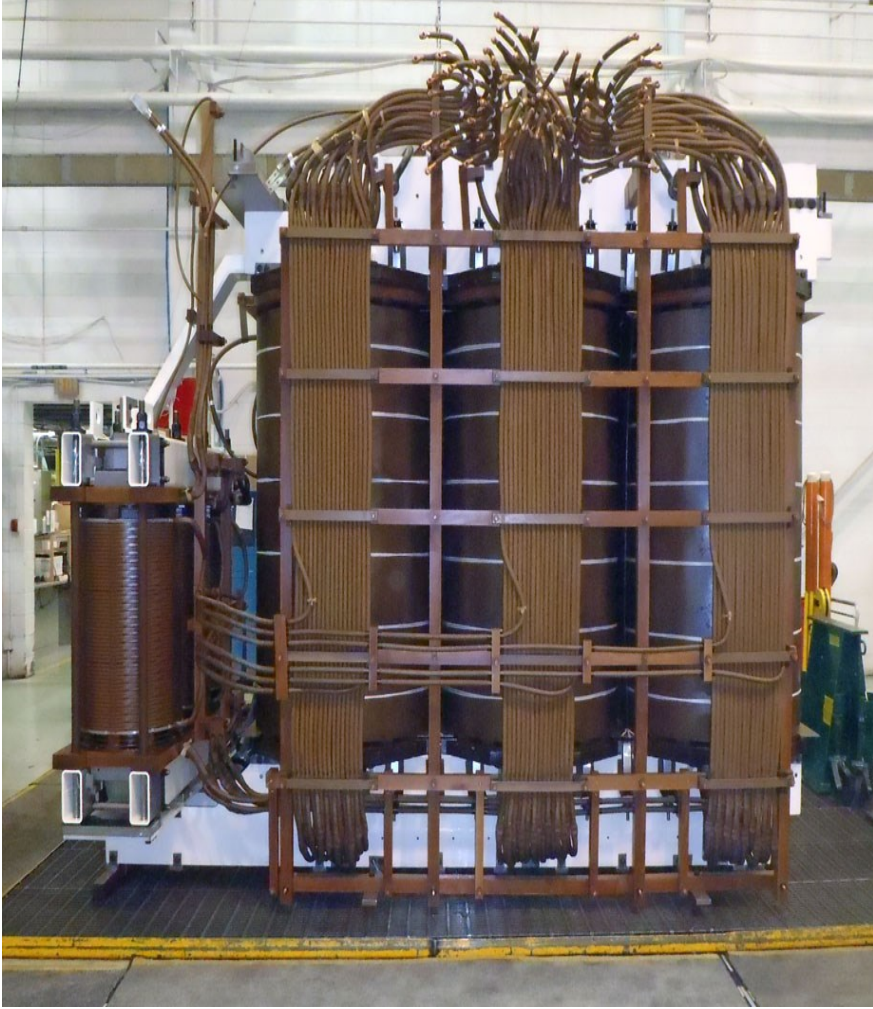
# Internal Assembly

- Assembly of ribs and barriers between coils are tight
- Ensure all spacer columns are fully supported
- Attention to lead exits, banding and handling of leads
- Follow proper procedure for crimping of the leads
- Ensure leads are properly clamped and supported
- Perform ratio test prior to sending unit to vapor phase

# Completed Unit Going into Vapor Phase Drying Chamber



# Core & Coil Assembly Just Out of Vapor Phase

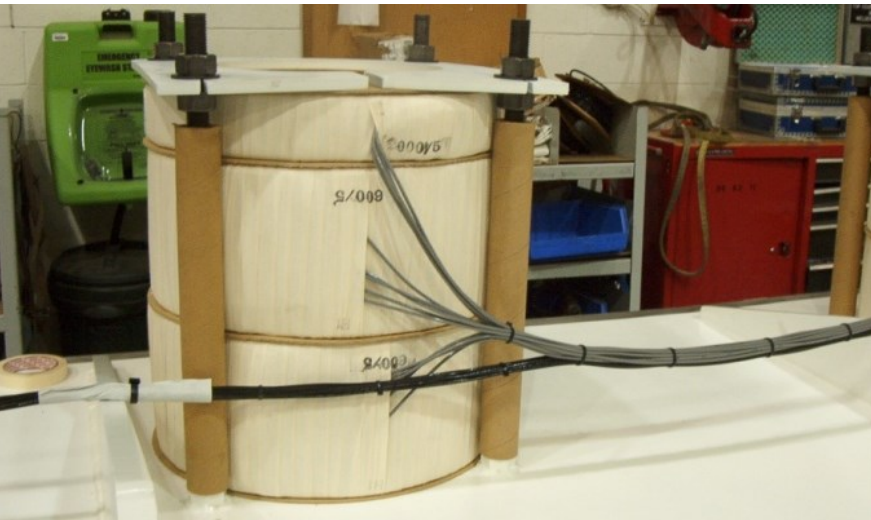


# Vapor Phase Processing

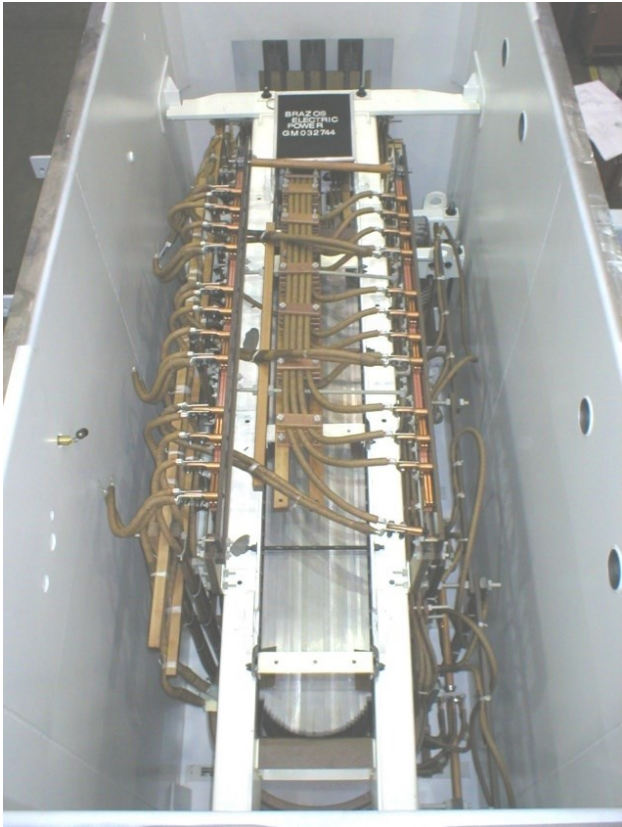
- Use of correct vacuum and heating cycles
- Ensure right temperature and durations for the cycles
- At the end of cycle check sample to ensure moisture content below 0.5%



# CTs Installed & Connected; Components Added



# Tanking Core and Coil and Anchoring in Tank



# Final Assembly

Core & Coil Assembly is tanked, cover welded, bushing installed, etc.



# Vacuum Oil Filling



# Tanking & External Assembly

- Reduce exposure time of the core and coil assembly
- Ensure that the coils have a minimum pressure of 5 N/mm<sup>2</sup>
- All bolts and nuts need to be retightened after vapor phase
- Ensure tightness of all lead connections to bushings
- Pressure test to ensure there are no leakage in the assembled unit
- Adequate processing and wait time prior to start of dielectric test

# Test Bay Equipment for Dielectric Tests



# Factory Testing — EHV Dielectric Test Equipment



# Factory Testing — Test Floor Control Room





# Completely Assembled Transformer Ready for Testing



# Transformer is Completely Tested



# Testing

- Check oil sample for BDV prior to start of test
- Perform low voltage test prior to dielectric tests
- Ensure effective grounding of the core during dielectric test
- Ensure the secondary of the CTs are shorted
- Ensure loss measurement equipment is calibrated per NIST standard
- Ensure tests are performed per IEEE standard

# Shipped to the Customer



# Shipping

- Ensure dew point is less than 0.5%
- Perform megger test on core prior to shipping
- Ensure impact recorders are installed prior to shipment
- Ensure unit is adequately braced to trailer/wagon

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# Questions?



## **Contact**

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