Transformer Manufacturing Processes

- Ronnie Minhaz, P.Eng.

Most common types of power transformers:

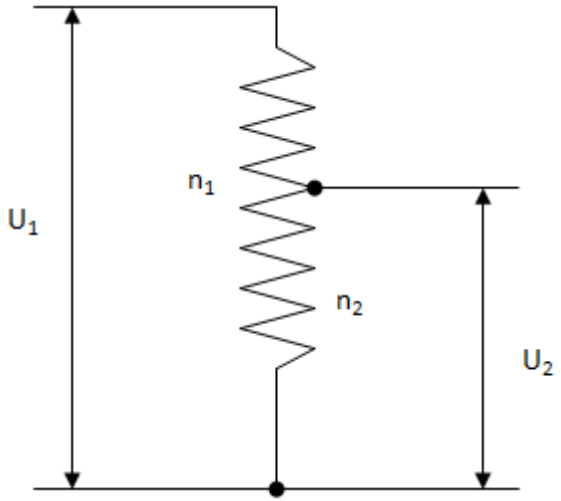
GSU's (Generator Step-Up):

- 2 windings HV/LV
- 3 windings HV/LV1/LV2
- with D.T.C. in HV, typically ± 2x2.5%
  - + 5%
  - - 5%
- normally no L.T.C.
- Connection Wye/Delta
- typical LV: 10, 20, 25 kV
- typical HV: 33, 69, 115, 138, 161, 230, 345, 500 kV
- Single-phase
- Three-phase

Most common types of power transformers:

Auto-Transformers:

- 1 winding (series + common winding)
- 2 windings (series + common) + tertiary winding
- D.T.C. in HV
- L.T.C. in HV or LV
- Single-phase or three-phase
- Connection: always Wye/Wye
- purpose of tertiary winding
  - suppression of harmonics
  - can be buried (no bushings brought out)
  - sometimes brought out for station service voltage
- tertiary sized at 33% of rating
- Auto-transformer has smaller frame size



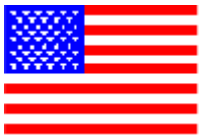
e.g. Rating = 300 MVA
HV = 230 kV
LV = 115 kV

Frame size:
$\frac{230-115}{230} \times 300 = 150$ MVA

Most common types of power transformers:

Step-down transformers:

- 2 winding HV/LV + D.T.C.
- 2 winding HV/LV + L.T.C. winding
- 3 winding HV1xHV2/LV + D.T.C.
  HV1xHV2/LV + L.T.C. winding
  HV/LV1xLV2 + D.T.C.
  HV/LV1xLV2 + L.T.C. winding



D.T.C. ➲ HV
L.T.C. ➲ LV

D.T.C. ➲ LV or HV
L.T.C. ➲ HV or LV

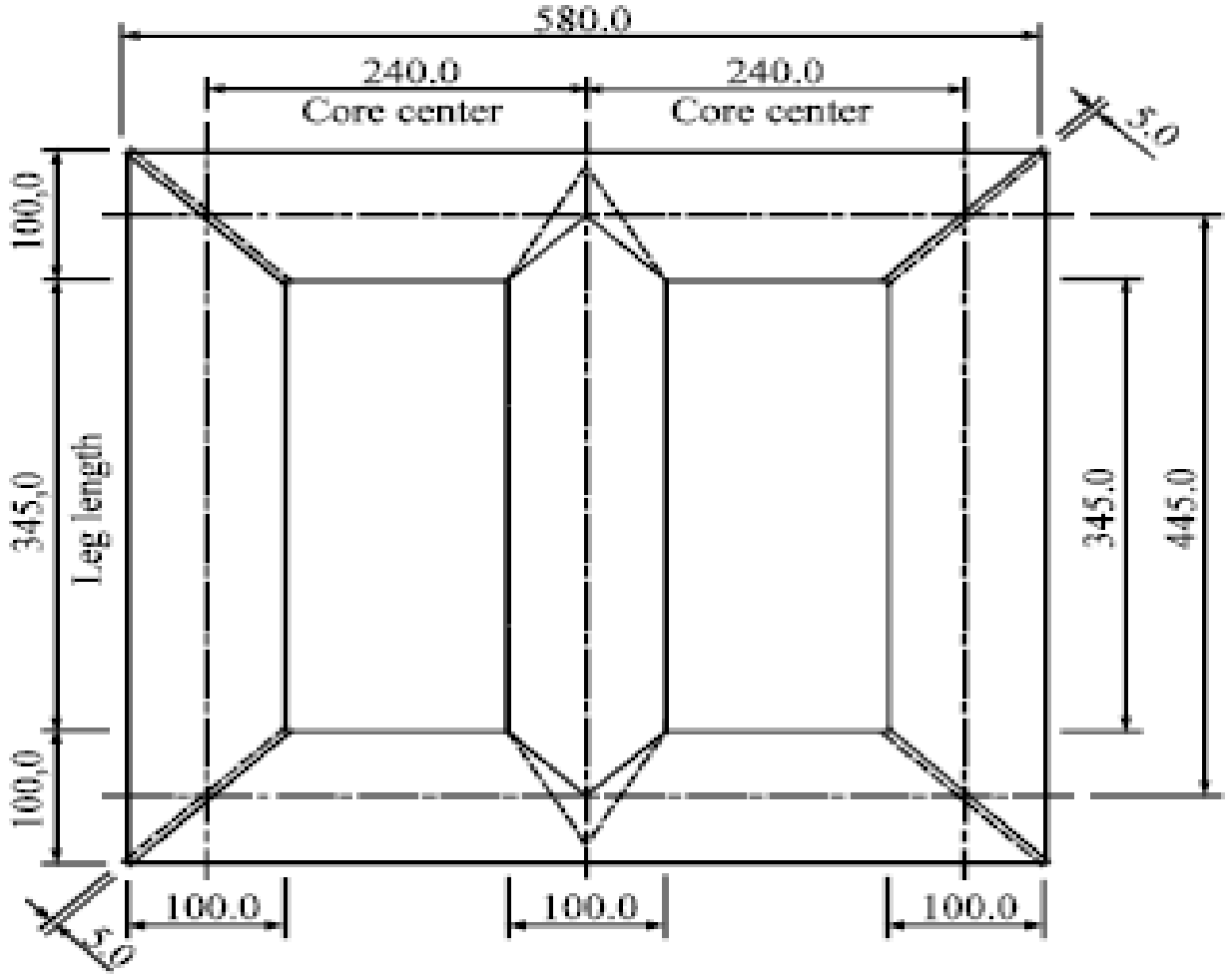
- Connection: Delta - Wye (majority)
  Wye - Delta
  Wye - Wye
- Three-phase

Manufacturing Process:

- ***Core Construction***
- ***Insulation***
- ***Windings***
- ***Core and Coil***
- ***Processing***
- ***Tanks***
- ***Testing***
- ***Shipping***

Manufacturing Process:

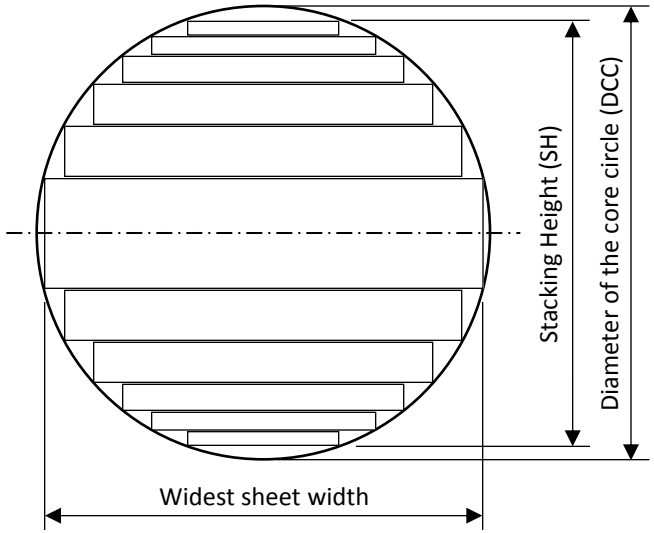
Core Dimensions



Manufacturing Process:

Core Dimensions

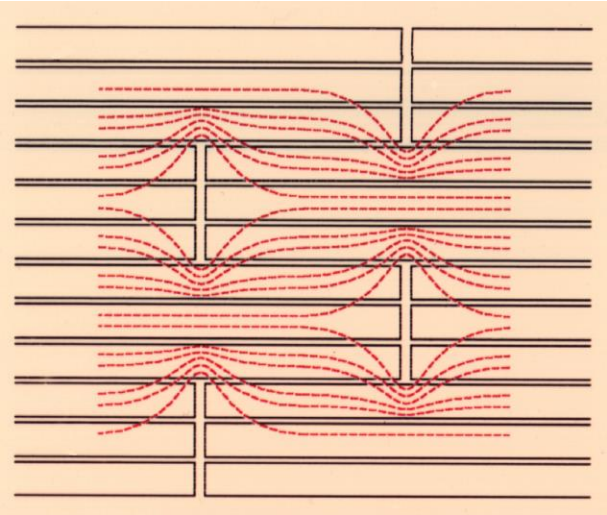
Circular core cross section:



Steps of 5 mm for DCC

Manufacturing Process:

Core stacking methods

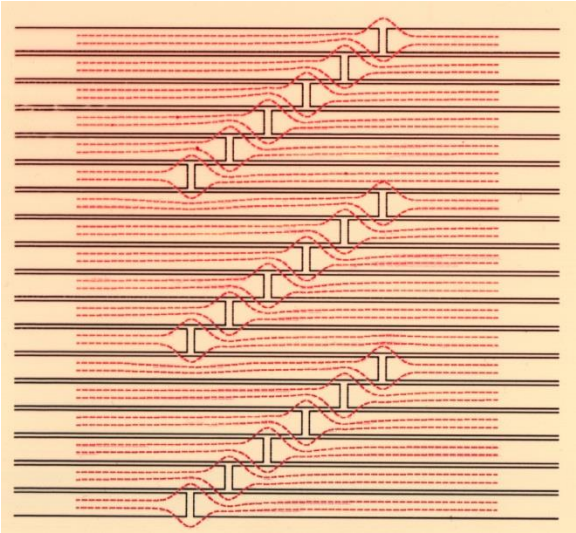


BUTT-LAP STACKING:

- **Local concentration of flux**
- **higher excitation current & core loss.**

STEP-LAP STACKING:

- **Reduced Local flux concentration**
- **lower excitation current & core loss.**



Core Material- Grain Oriented Silicon

M - NON-LS; H - LS H
ZDKH (laser scribed)
ZDMH (mechanically scribed)

Manufacturing Process:

Core Cutting - Georg

- Automatically stacks legs & yokes
- Purchase uncut slit rolls of steel or pre-cut

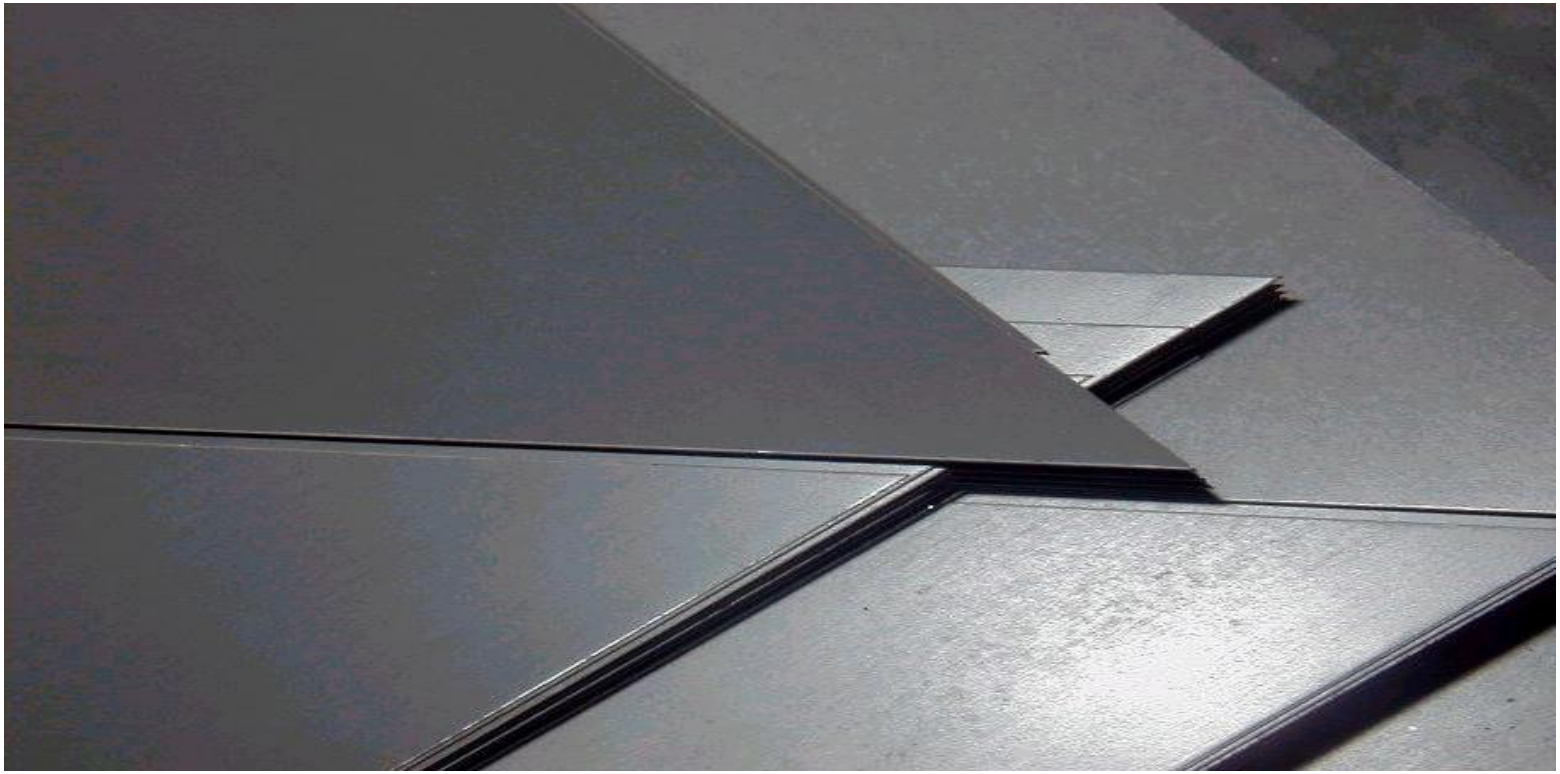
Manufacturing Process:

Core ‘Logs’ Stacked

Manufacturing Process:

Core Cutting

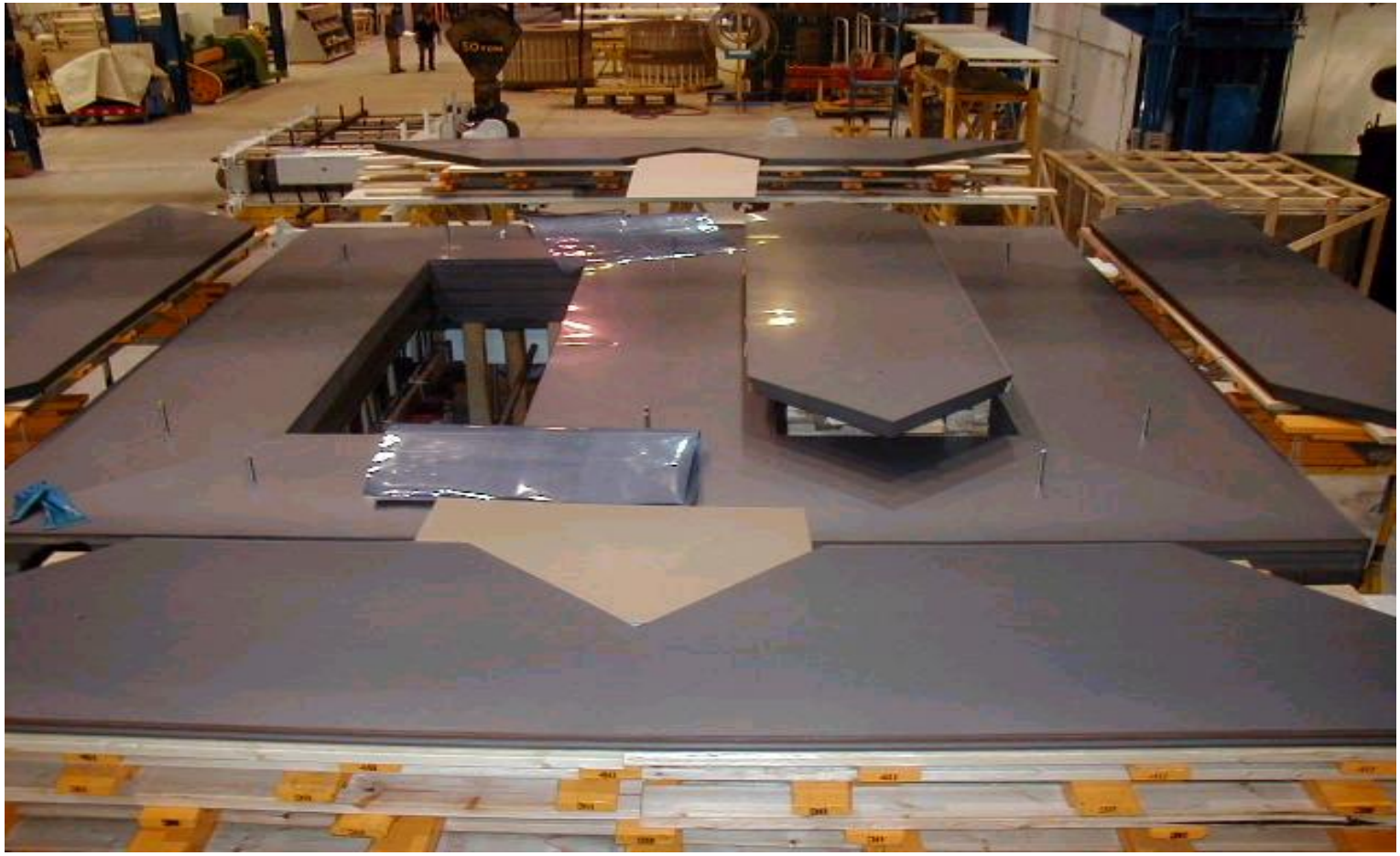
- "Core Form Design"
- Fully mitered & step lapped in corner joints
  - improves flux distribution, minimizes losses & sound level
- Circular core shape
  - provides windings with optimum radial support



Manufacturing Process:

Core Stacking

- **Use of temporary bolt guides for stacking**
- **2, 3, 4 & 5 leg cores manufactured for single & three phase units**



Manufacturing Process:

Core Stacking

- **Oil ducts utilized to control temperature rise**
- **Temporary, Permanent or combination of banding**

Manufacturing Process:

Core Stacking

Type 2 and type 3 cores with DCC = 500 mm

cooling ducts				1 cooling duct				2 cooling ducts				3 cooling ducts			
	SW [mm]	PS [mm]	CS [mm]	No	SW [mm]	PS [mm]	CS [mm]	No	SW [mm]	PS [mm]	CS [mm]	No	SW [mm]	PS [mm]	CS [mm]
1	120	5.8	5.8	1	120	5.8	5.8	1	120	5.8	5.8	1	120	5.8	5.8
2	160	8.9	14.7	2	160	8.9	14.7	2	160	8.9	14.7	2	160	8.9	14.7
3	205	11.5	26.2	3	205	11.5	26.2	3	205	11.5	26.2	3	205	11.5	26.2
4	250	9.4	35.6	4	250	9.4	35.6	4	250	9.4	35.6	4	250	9.4	35.6
5	280	10.9	46.5	5	280	10.9	46.5	5	280	10.9	46.5	5	280	10.9	46.5
6	310	12.9	59.4	6	310	12.9	59.4	6	310	12.9	59.4	6	310	12.9	59.4
7	340	15.1	74.5	7	340	15.1	74.5	7	340	15.1	74.5	7	340	15.1	74.5
8	370	11.8	86.3	8	370	11.8	86.3	8	370	11.8	86.3	8	370	11.8	86.3
9	390	13.3	99.6	9	390	13.3	99.6	9	390	13.3	99.6	9	390	13.3	99.6
10	410	15.5	115.1	10	410	15.5	115.1	10	410	15.5	115.1	10	410	15.5	115.1
11	430	18.6	133.7	11	430	18.6	133.7	11	430	18.6	133.7	11	430	15.0	130.1
12	450	23.7	157.4	12	450	23.7	157.4	12	450	23.7	157.4		DUCT	6.0	136.1
13	470	35.6	193.0	13	470	35.6	193.0	13	470	11.5	168.9	12	450	21.3	157.4
14	490	99.4	292.4	14	490	46.7	239.7		DUCT	6.0	174.9	13	470	35.6	193.0
15	470	35.6	328.0		DUCT	6.0	245.7	13	470	18.1	193.0	14	490	46.7	239.7
16	450	23.7	351.7	14	490	46.7	292.4	14	490	99.4	292.4		DUCT	6.0	245.7
17	430	18.6	370.3	15	470	35.6	328.0	15	470	18.1	310.5	14	490	46.7	292.4
18	410	15.5	385.8	16	450	23.7	351.7		DUCT	6.0	316.5	15	470	35.6	328.0
19	390	13.3	399.1	17	430	18.6	370.3	15	470	11.5	328.0	16	450	21.3	349.3
20	370	11.8	410.9	18	410	15.5	385.8	16	450	23.7	351.7		DUCT	6.0	355.3
21	340	15.1	426.0	19	390	13.3	399.1	17	430	18.6	370.3	17	430	15.0	370.3
22	310	12.9	438.9	20	370	11.8	410.9	18	410	15.5	385.8	18	410	15.5	385.8
23	280	10.9	449.8	21	340	15.1	426.0	19	390	13.3	399.1	19	390	13.3	399.1
24	250	9.4	459.2	22	310	12.9	438.9	20	370	11.8	410.9	20	370	11.8	410.9
25	205	11.5	470.7	23	280	10.9	449.8	21	340	15.1	426.0	21	340	15.1	426.0
26	160	8.9	479.6	24	250	9.4	459.2	22	310	12.9	438.9	22	310	12.9	438.9
27	120	5.8	485.4	25	205	11.5	470.7	23	280	10.9	449.8	23	280	10.9	449.8
				26	160	8.9	479.6	24	250	9.4	459.2	24	250	9.4	459.2
				27	120	5.8	485.4	25	205	11.5	470.7	25	205	11.5	470.7
								26	160	8.9	479.6	26	160	8.9	479.6
								27	120	5.8	485.4	27	120	5.8	485.4

Manufacturing Process:

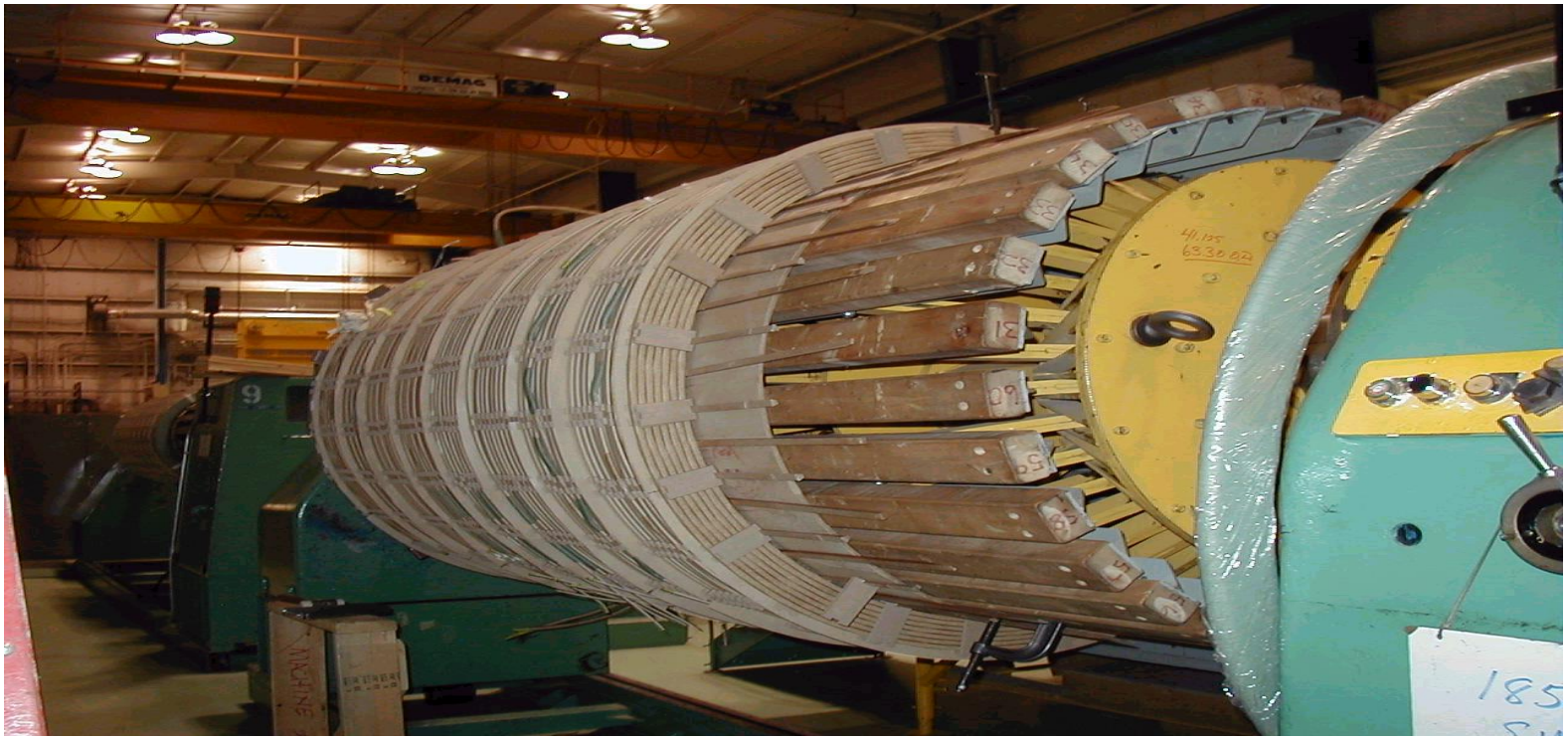
Coil Winding Shop

- Winding room separate from other manufacturing areas
- Positive Pressure
- Horizontal/Vertical winding mandrels

Manufacturing Process:

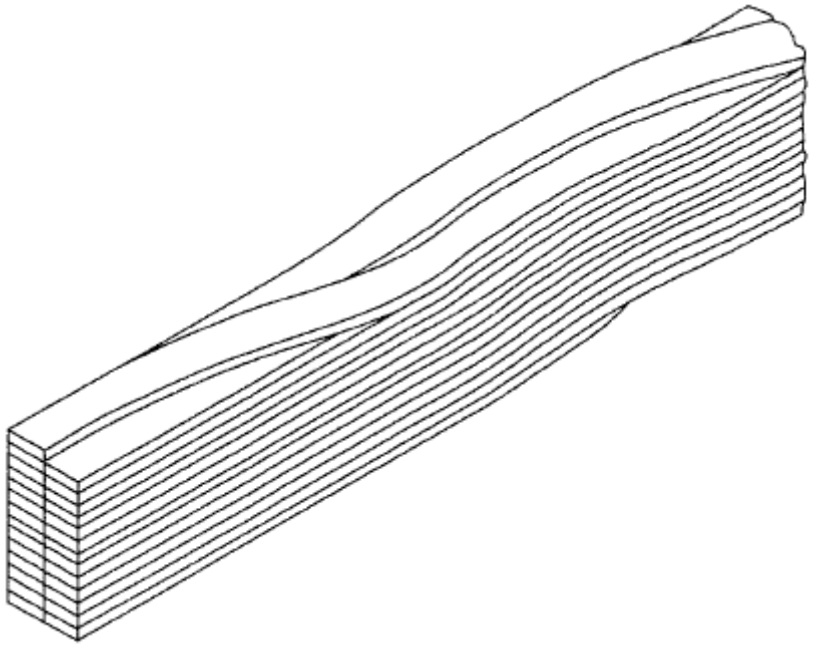
Coil Winding

- Windings are circular concentric type
- Conductor are either copper magnetic wire or continuously transposed conductor
- Conductor purchased pre-wrapped with thermally upgraded paper or Nomex
- High strength wire or epoxy bonded CTC used when high short circuit forces
- Winding type chosen according to voltage & application, Cont. Disc, Interleaved Disc, Helical, etc.



Manufacturing Process:

Continuously Transposed Conductor



Manufacturing Process:

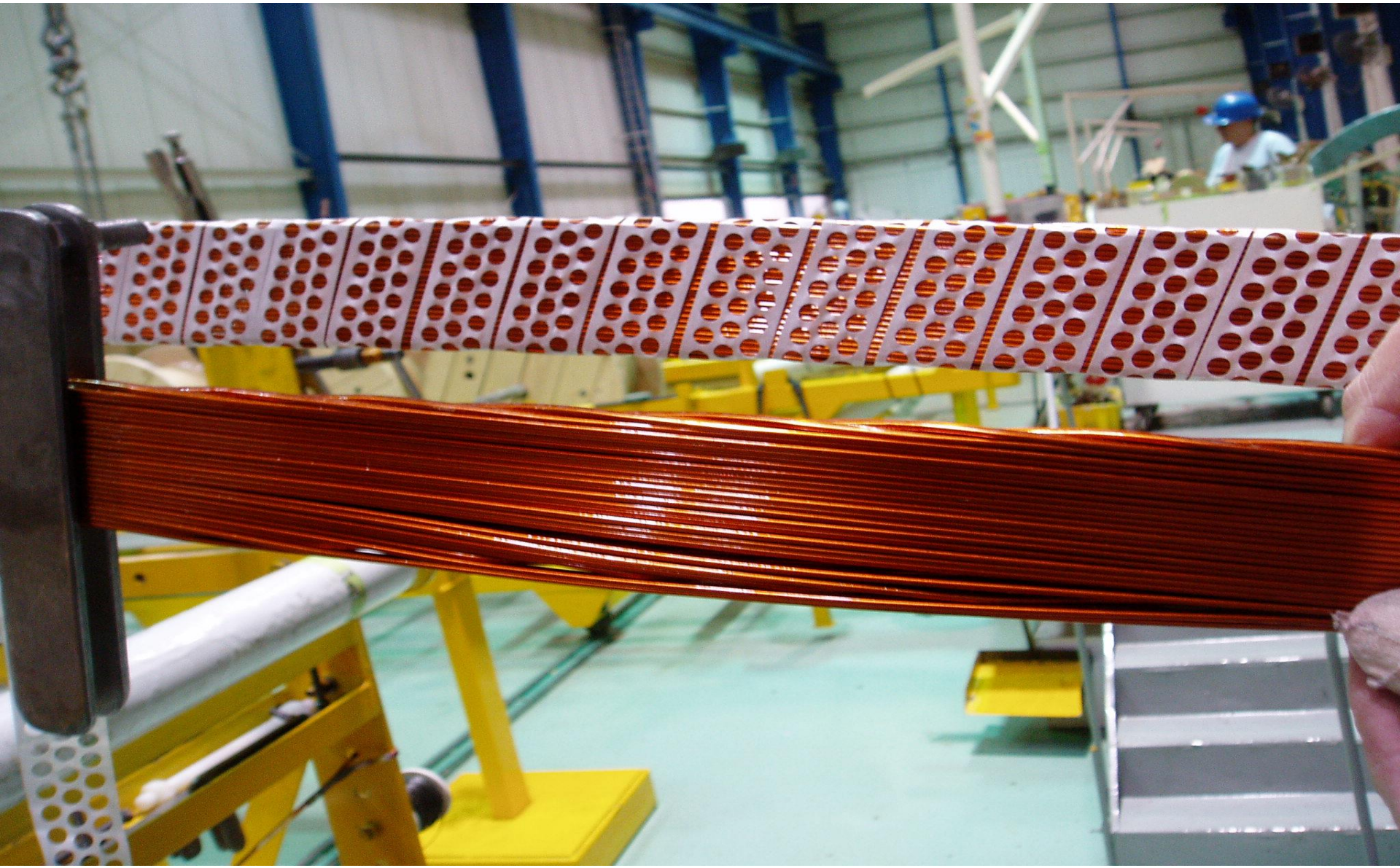
CTC – Thermally upgraded paper

Manufacturing Process:

CTC - epoxy bonded, netting tape

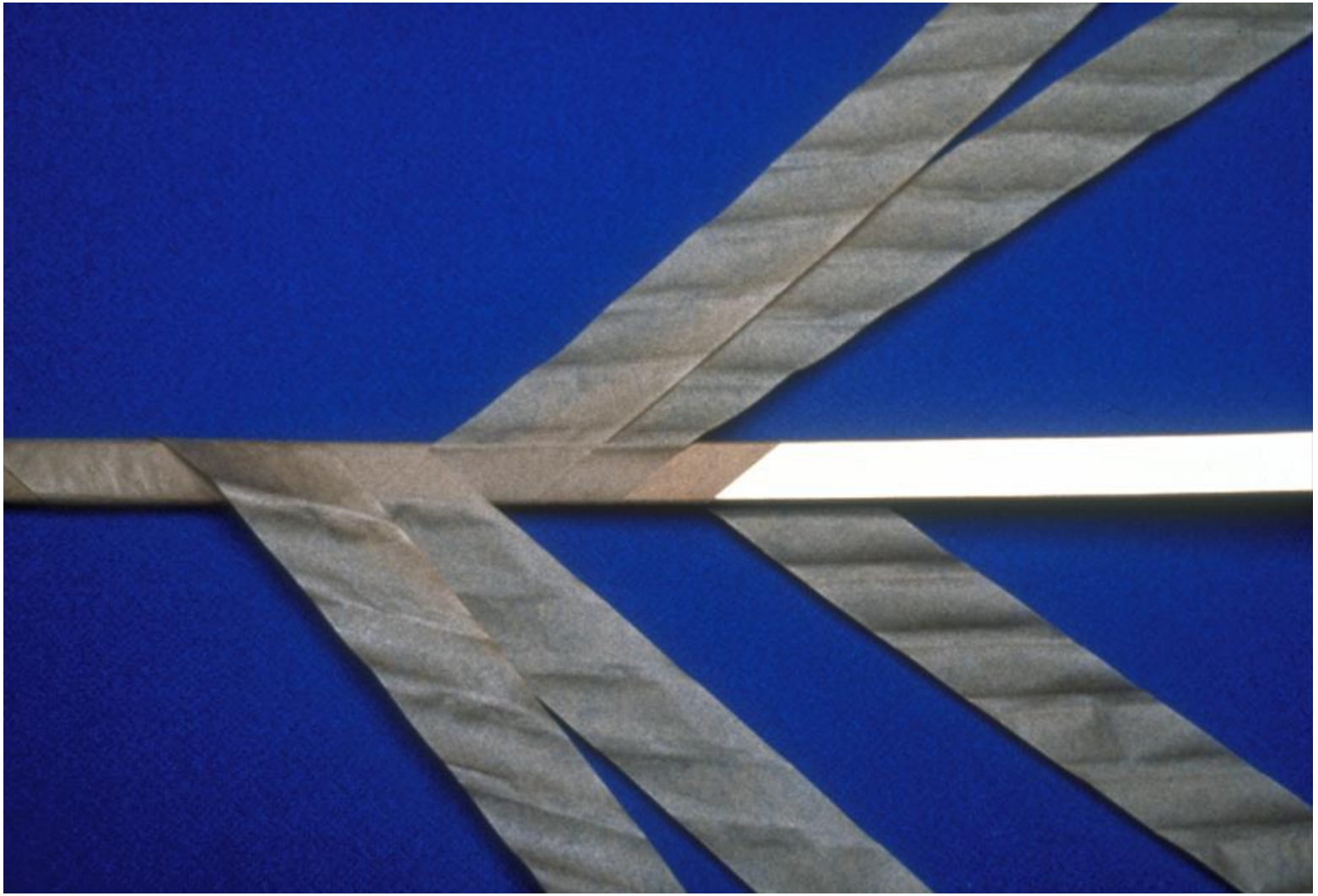
Manufacturing Process:

CTC - Perforated Nomex



Manufacturing Process:

Magnet Wire, Paper Insulated

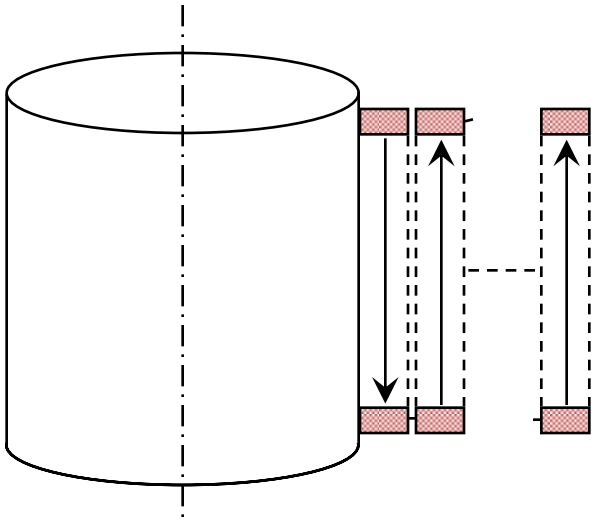


Manufacturing Process:

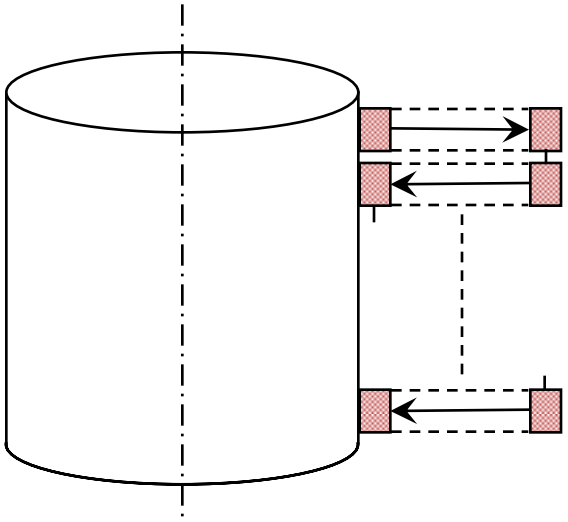
Winding Types

2 main groups

helical windings

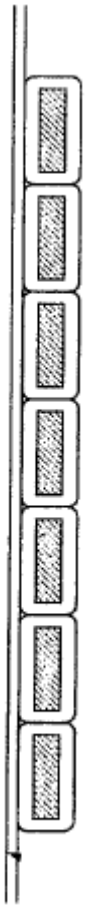


disc windings

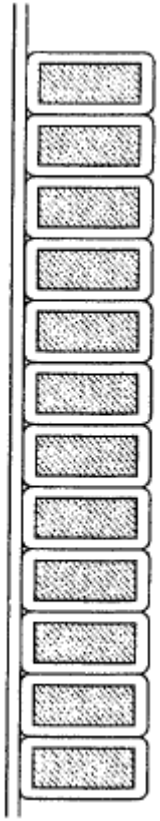


Manufacturing Process:

Flat/Edge Wound



Wound on flat side



Edge Wound

Winding Types

2 main groups

helical windings

- Boomerang
- Giron
- Equally transposed
- Layer and multilayer
- Multistart

Mainly LV, TV, CR and FR

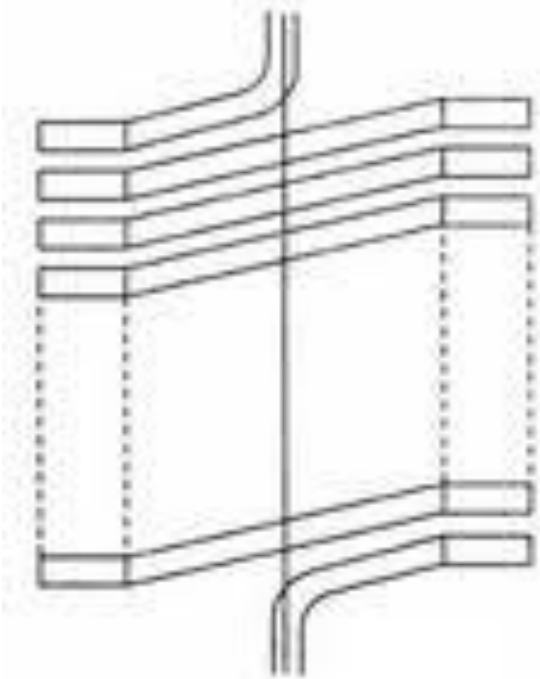
disc windings

- Continuous disc
- Interleaved
- Partial Interleaved
- Axial Interleaved

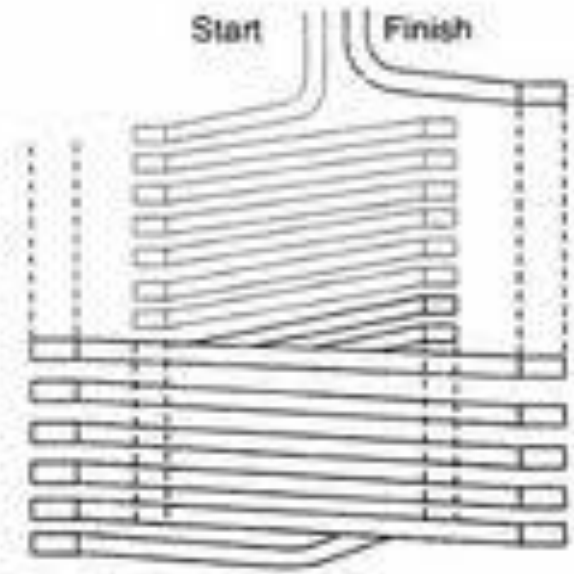
Mainly HV, LV, FR

Manufacturing Process:

Helical Winding



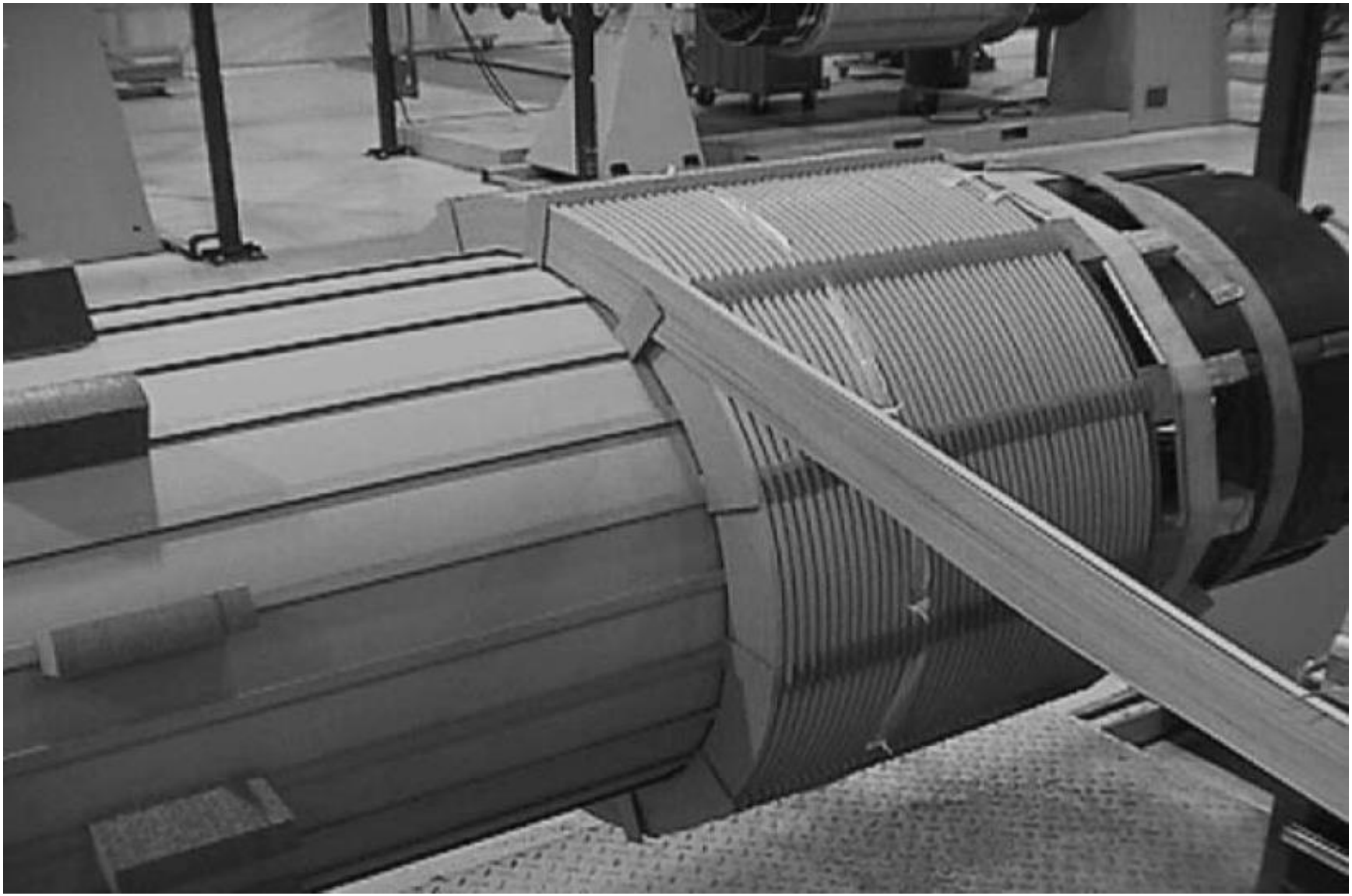
Helical coil (single layer).



Helical coil (double layer).

Manufacturing Process:

Helix – Boomerang MW



Helix- Boomerang, Giron, Double Helix equally Transposed

Use(Varies from Manufacturer to Manufacturer):

- –1 or 2 layers
- –Up to 325 kV BIL for single-layer windings
- –Up to 200 kV BIL for two-layer windings
- –Axial cooling ducts in the winding or with zigzag cooling depending on what kind of helix
- –Preferably with at least one turn between successive transpositions

Advantages:

- –Cheap winding
- –No radial overbuild at the transpositions depends on Boomerang type

Disadvantages:

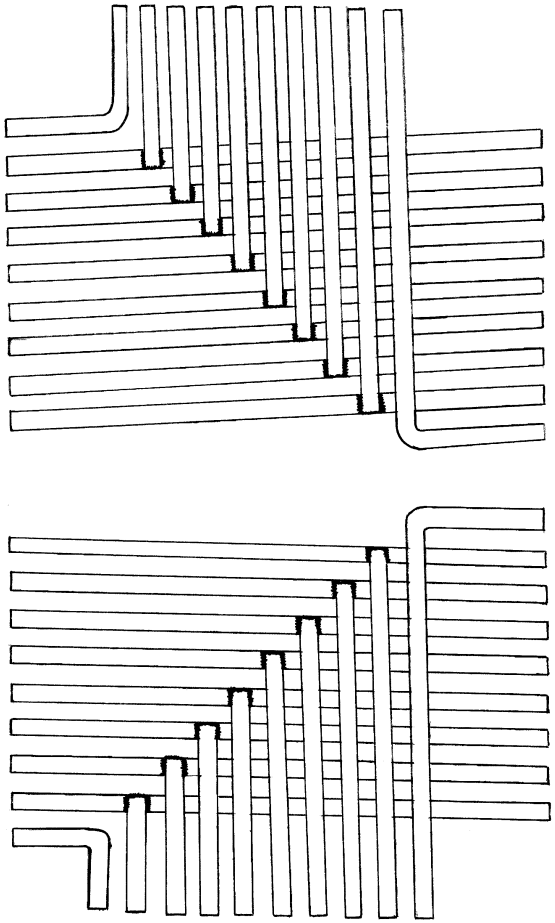
- –One brazing per transposition on Boomerang type
- –Cannot be used for zigzag cooling without radial overbuilds on Giron and Double helix type

Manufacturing Process:

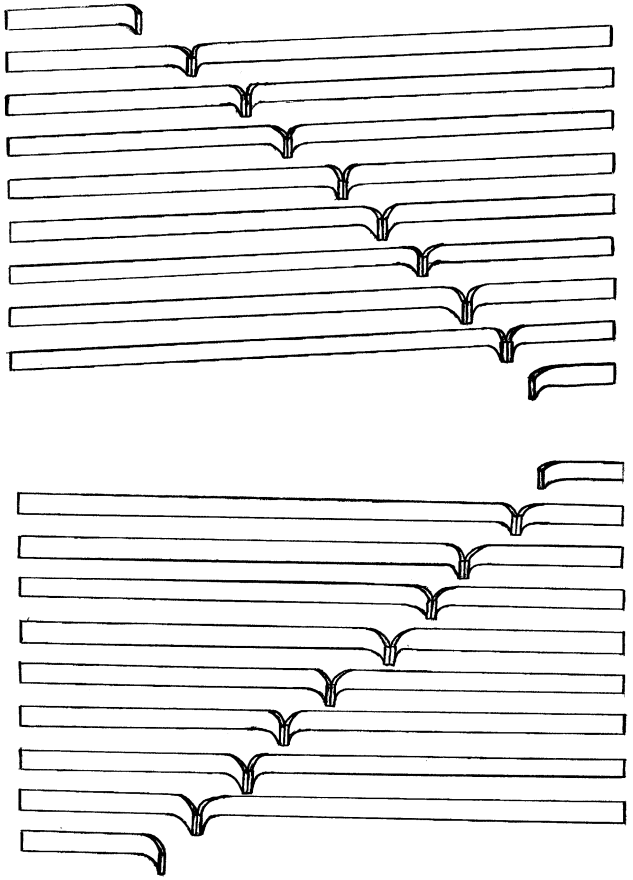
Tapped helix MW / CTC

- Regulating winding(for LV)
- Easy to wind, high Cu cross-section possible
- Eccentric duct necessary if used as inside winding

For inside windings



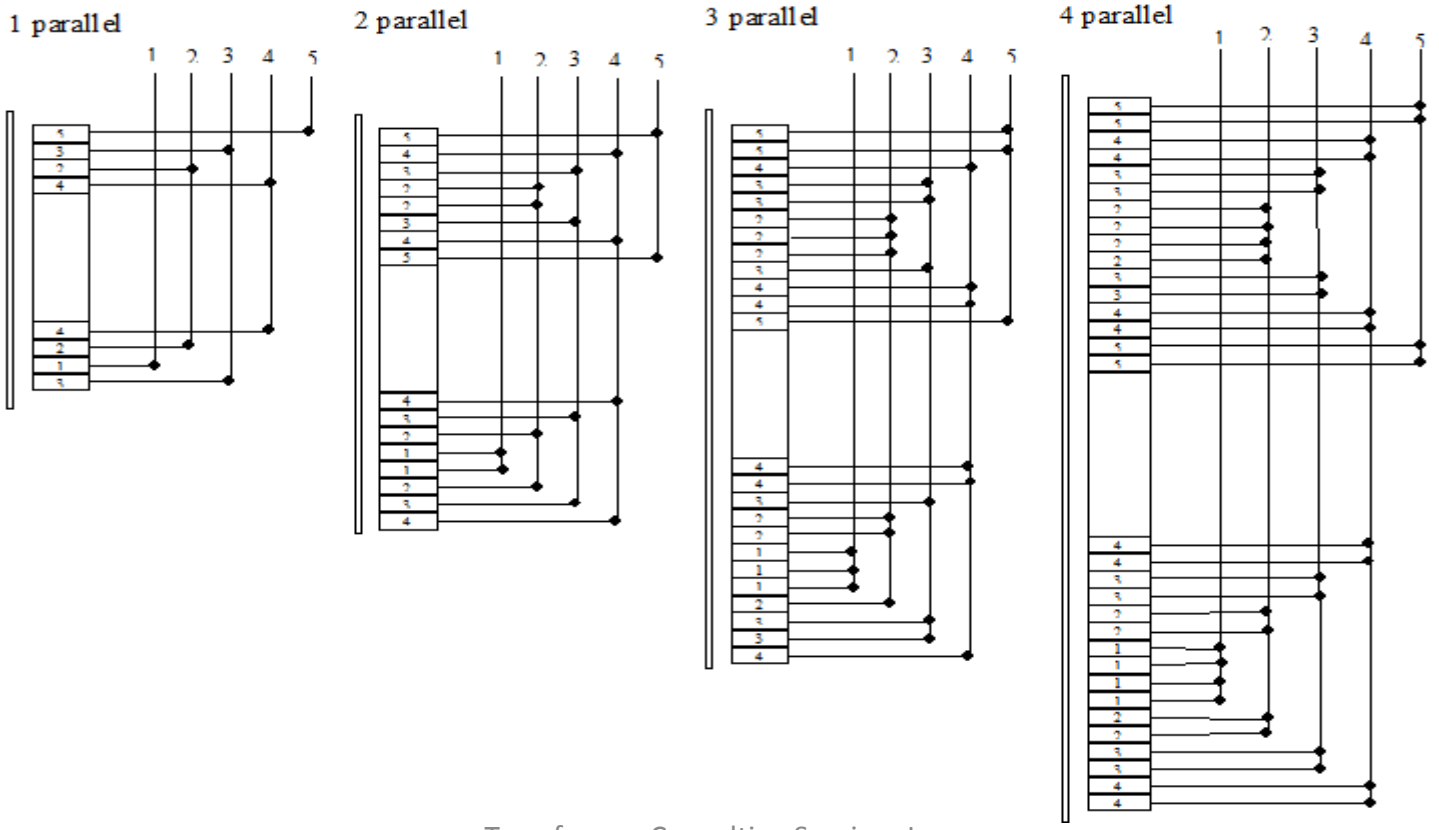
For outside windings



Manufacturing Process:

Multistart MW / CTC

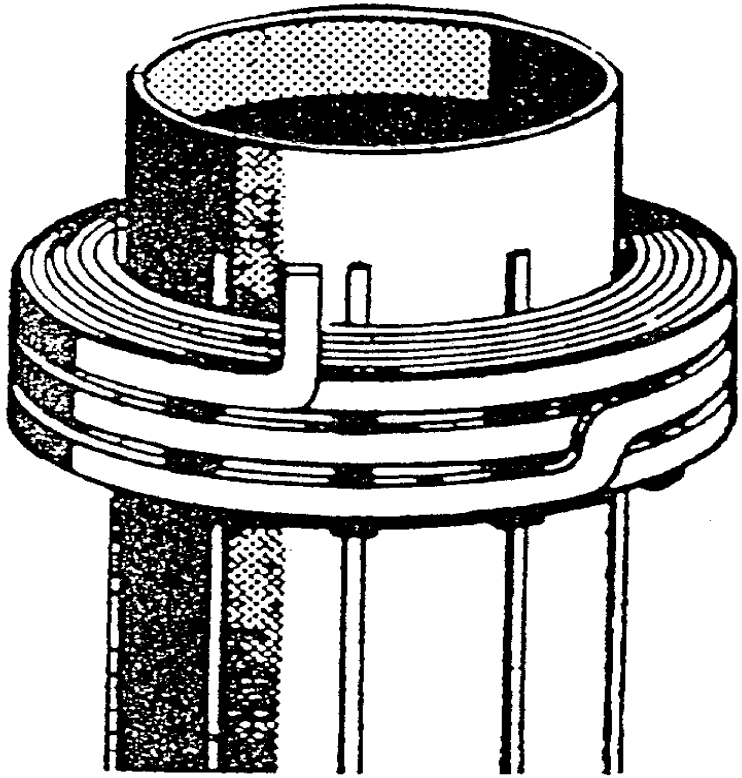
- With ZnO-discs : up to 1050 kV BIL, Without ZnO-discs : up to 450 kV BIL if impulsed and up to 950 kV BIL if not impulsed
- Easy to wind, Uniform Amp-turns distribution, Robust winding, especially when MW is used on the edge
- Medium to high paper insulation thickness needed, due to the voltage difference of 1 or 2 taps between adjacent wires. This can cause high thermal winding gradients.

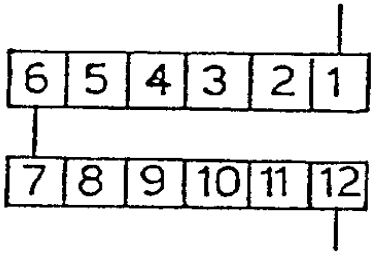


Manufacturing Process:

Continuous disc

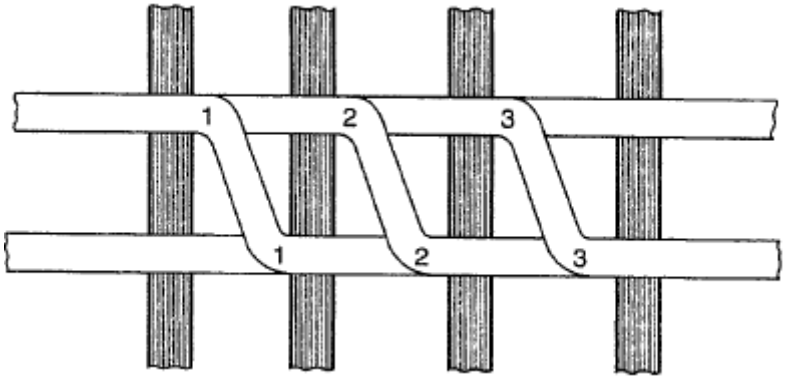
- Many electrical turns, up to 550 kV BIL with key spacers, above 550 kV BIL with key spacers in combination with interleaved part at impulse side
- Easy to wind, No brazing, High axial space factor and reduced manufacturing time for version without key spacers
- Partial turns can cause extra sections, Decreased radial space factor for the version without key spacers





Manufacturing Process:

Continuous disc Transposition

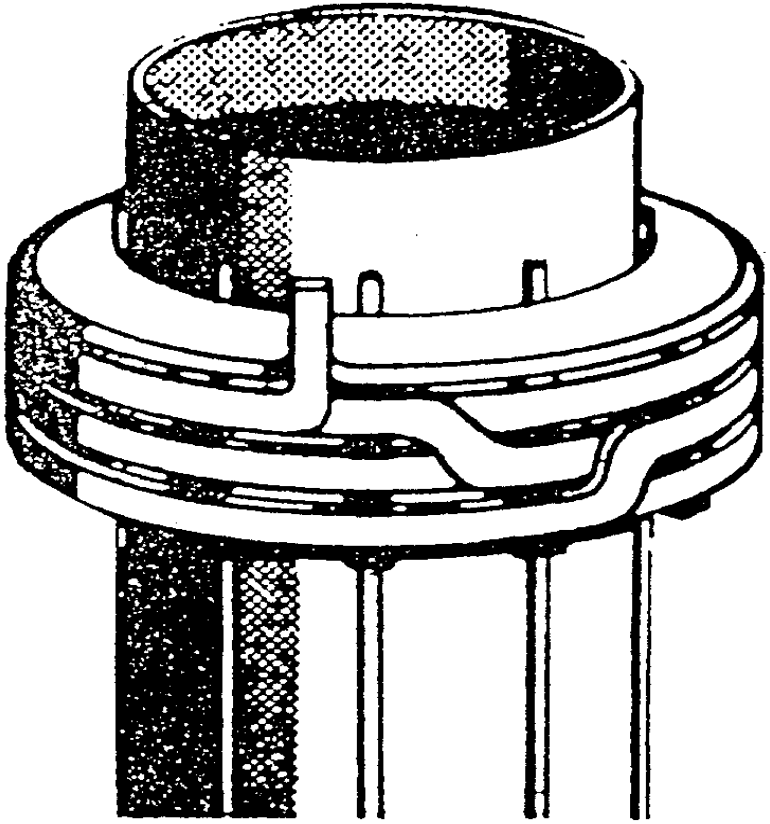


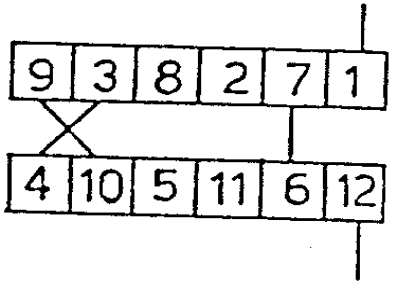
Transposition at each cross over

Manufacturing Process:

Interleaved

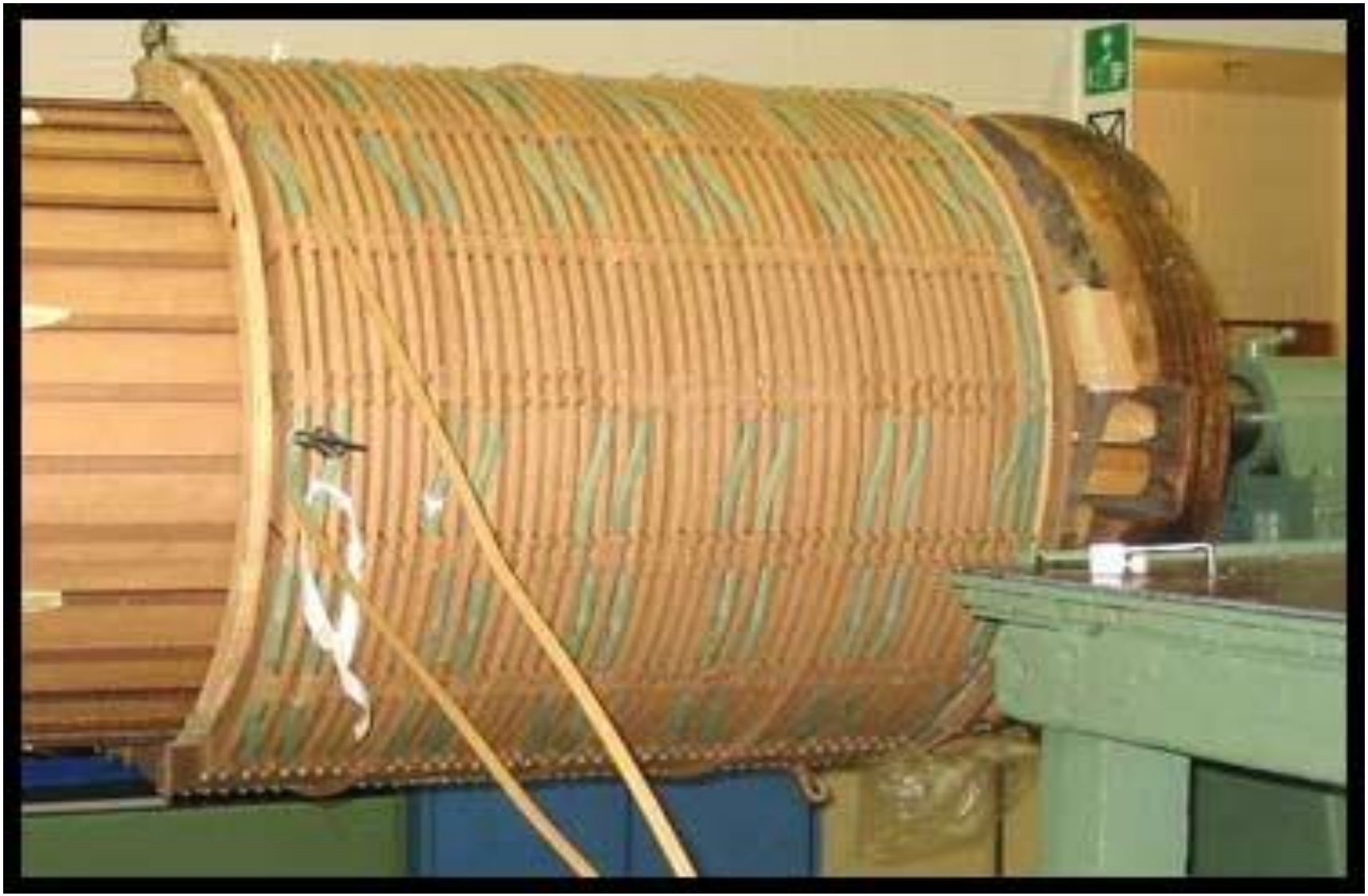
- Many electrical turns, typically above 550 kV BIL, if necessary for impulse reasons Adjacent is standard method for interleaving, Braided interleaving method if necessary for lightning impulse
- High impulse withstand capability, due to improved voltage distribution
- Brazing necessary, and thus very time consuming with CTC, Total number of sections must be even





Manufacturing Process:

Interleaved Winding



Manufacturing Process:

Shielded Winding

Manufacturing Process:

Shielded Winding

Winding Selection

Based on:

- winding voltages: (nominal, test, impulse, …)
  - number of turns
  - electrical clearances
  - ZnO discs allowed?
- winding current:
  - needed Copper cross-sectional area
  - maximum allowed temperature (average and hottest spot)
- cooling type: axial cooling or zigzag cooling
- winding position in the core window

Manufacturing Process:

Lead Connection

- Stress ring and pick tail connected with lead

Manufacturing Process:
Upender

Manufacturing Process:

Insulation Shop

- Insulation Shop separate from other areas
- Winding cylinders and spacers are made from high density pressboard

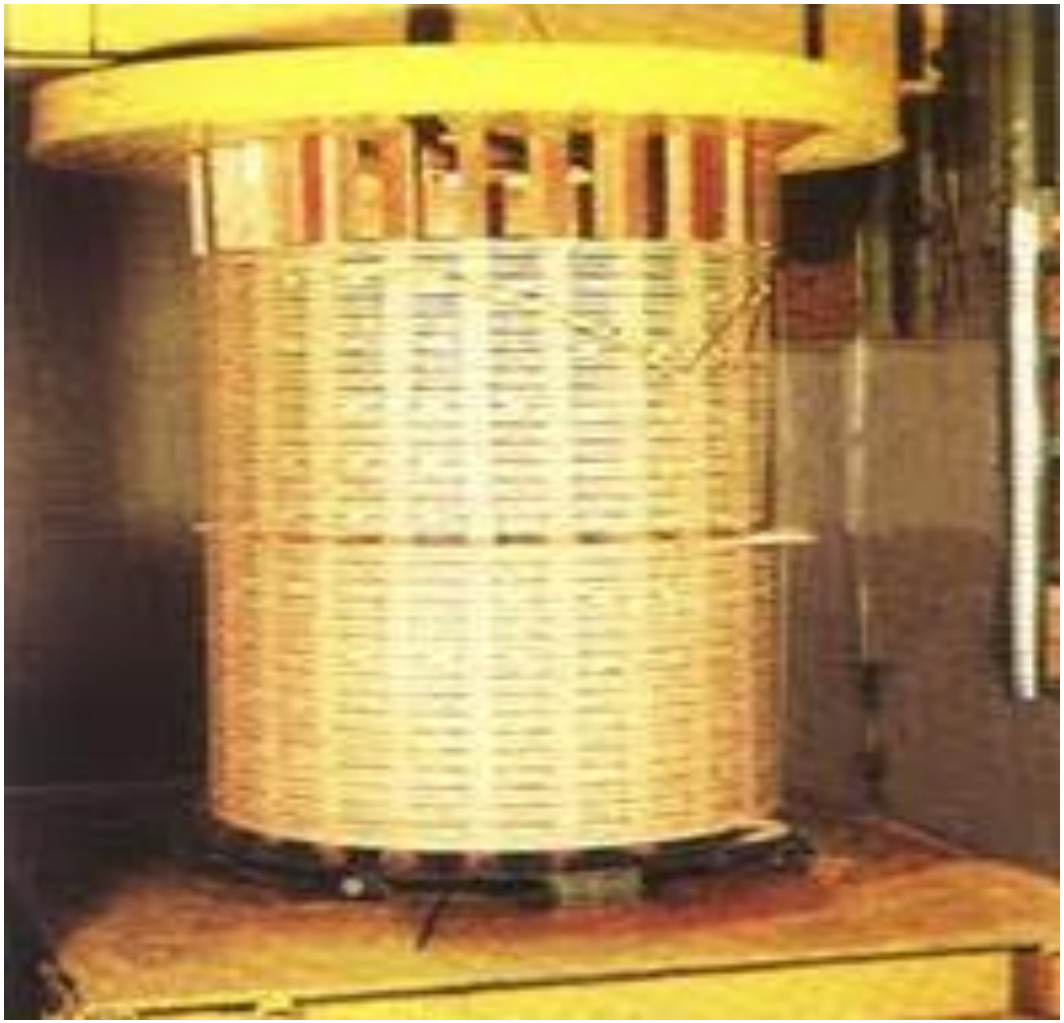
Manufacturing Process:

Complete Winding Insulation Package

Manufacturing Process:

Coil Sizing

- Coil sizing force applied to check and adjust (of stabilize) the winding height



Manufacturing Process:

Coil Assembly

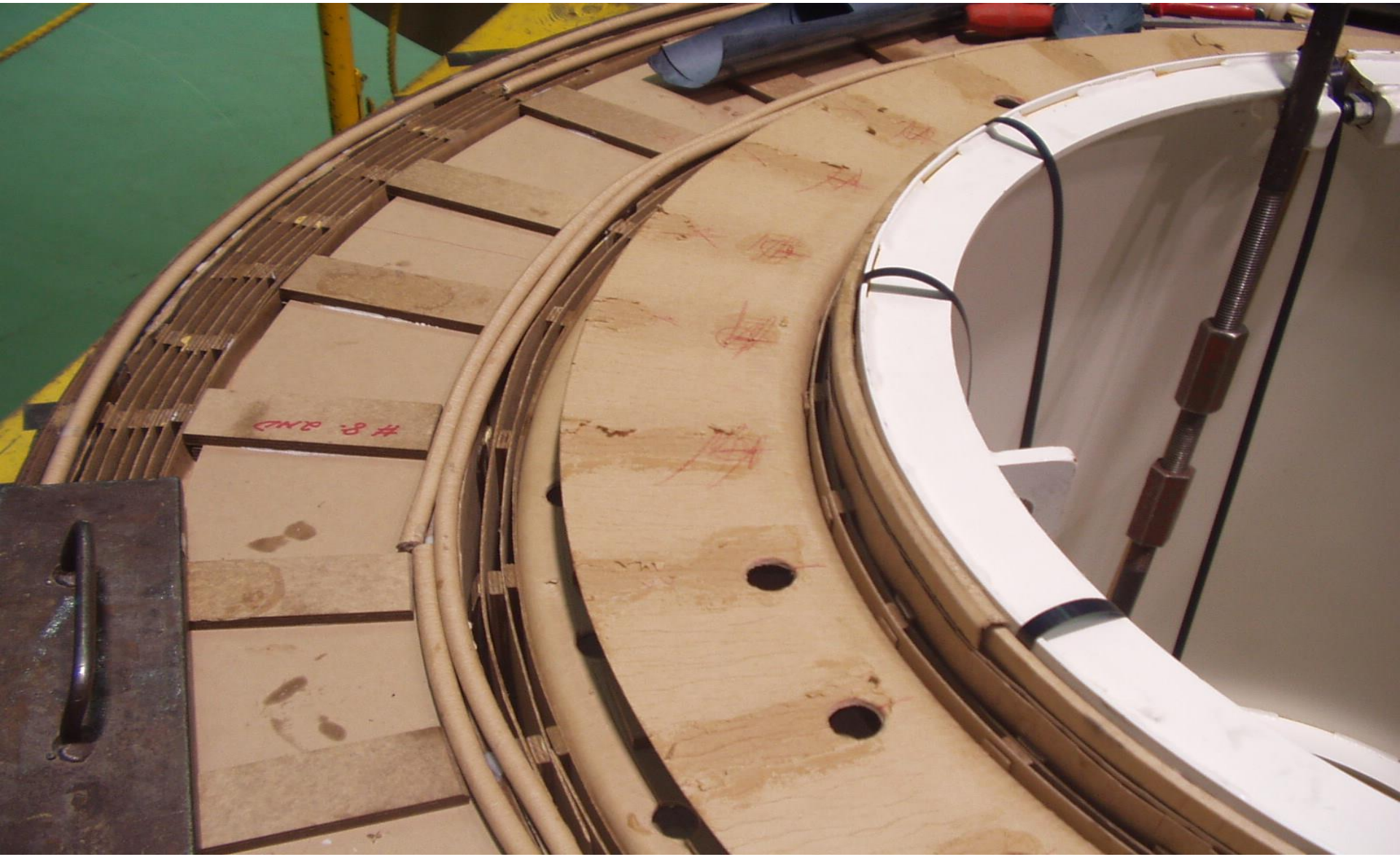
- **Winding type**
- **Conductor Type**
- **Insulation components**

Manufacturing Process:

Coil Assembly

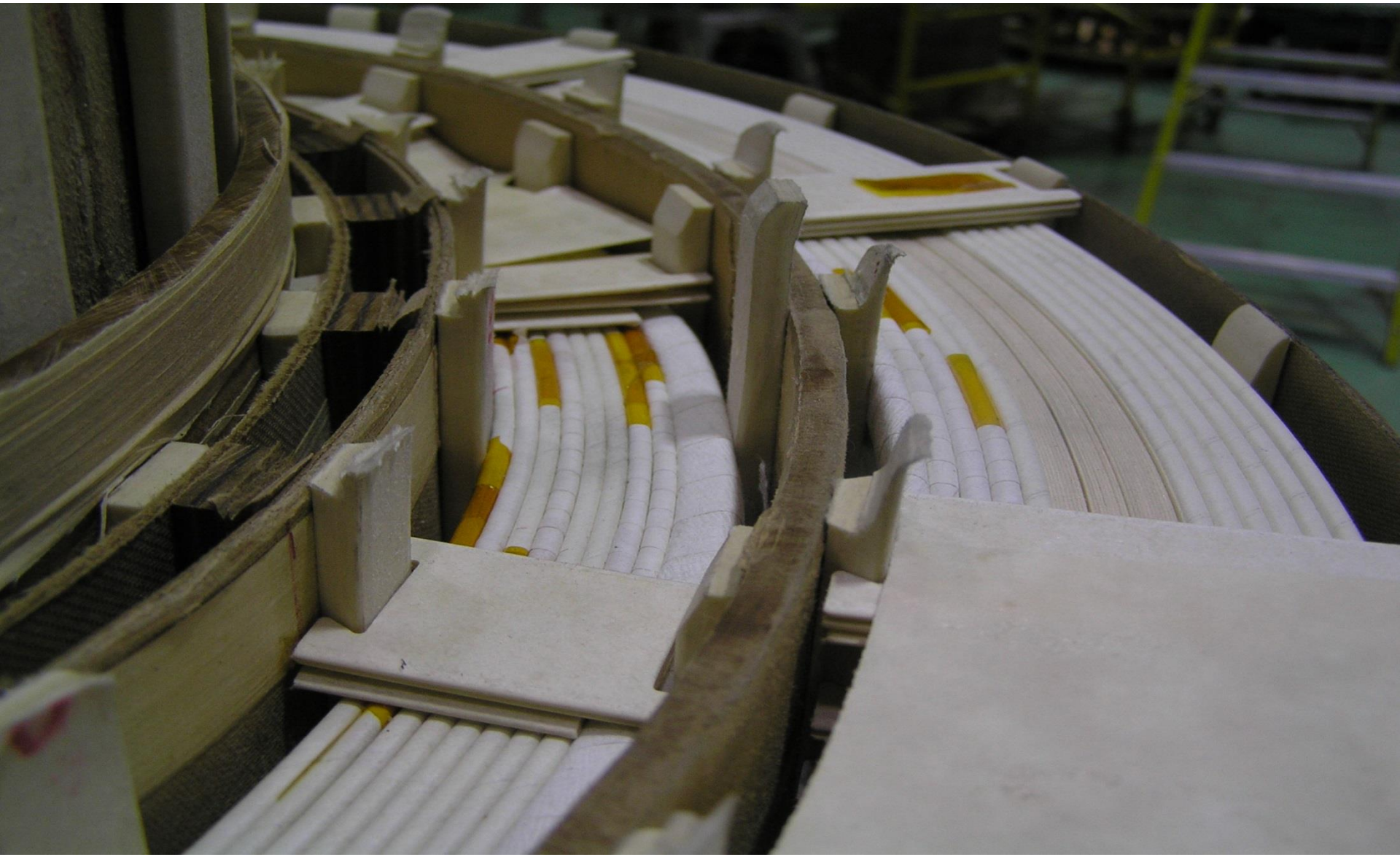
Manufacturing Process:

Coil Assembly



Manufacturing Process:

Coil Assembly



Manufacturing Process:

Coil & Core Assembly

- Exposed edges of core are bonded with low viscosity, high strength epoxy resin which penetrates and bonds laminations.
- Prefabricated coil to clamp insulation is placed on bottom clamps

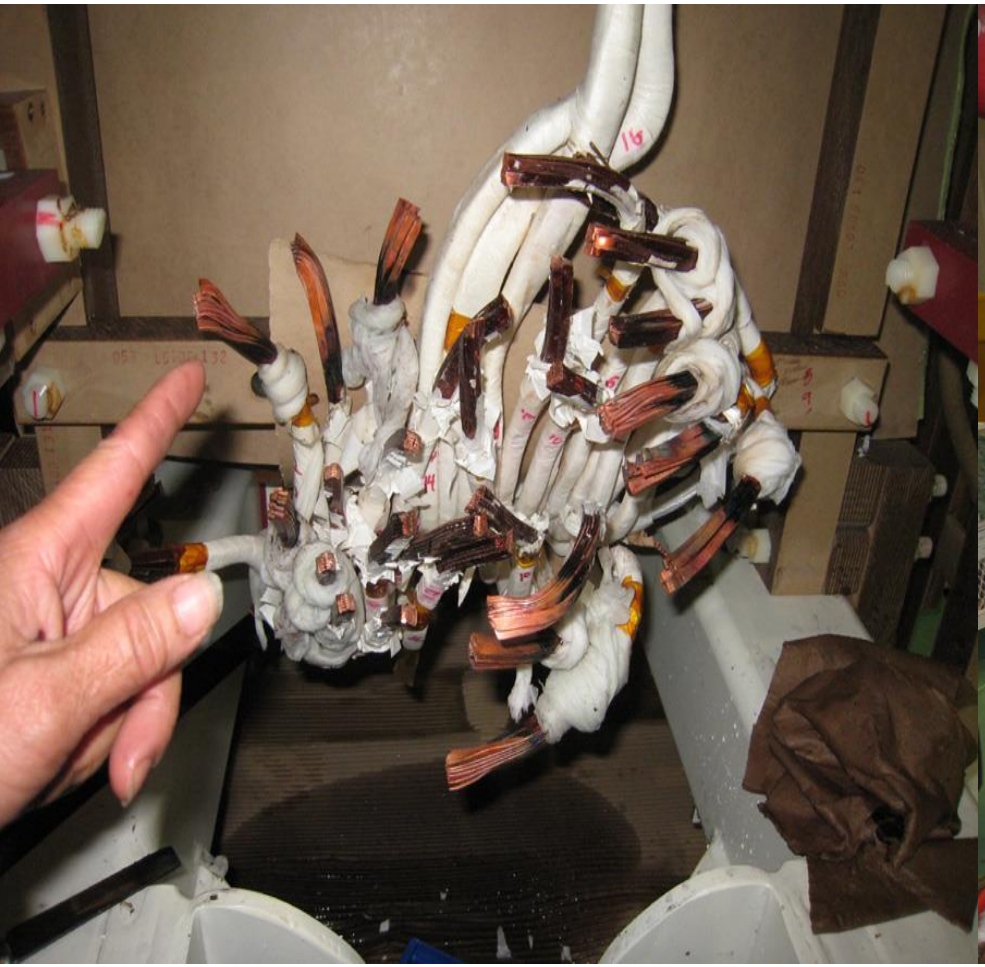
Manufacturing Process:

Coil & Core Assembly

- **Coils lowered over core**
- **Top coil to clamp insulation**
- **Top clamps**
- **Top core inserted**

Manufacturing Process:

Lead Braising

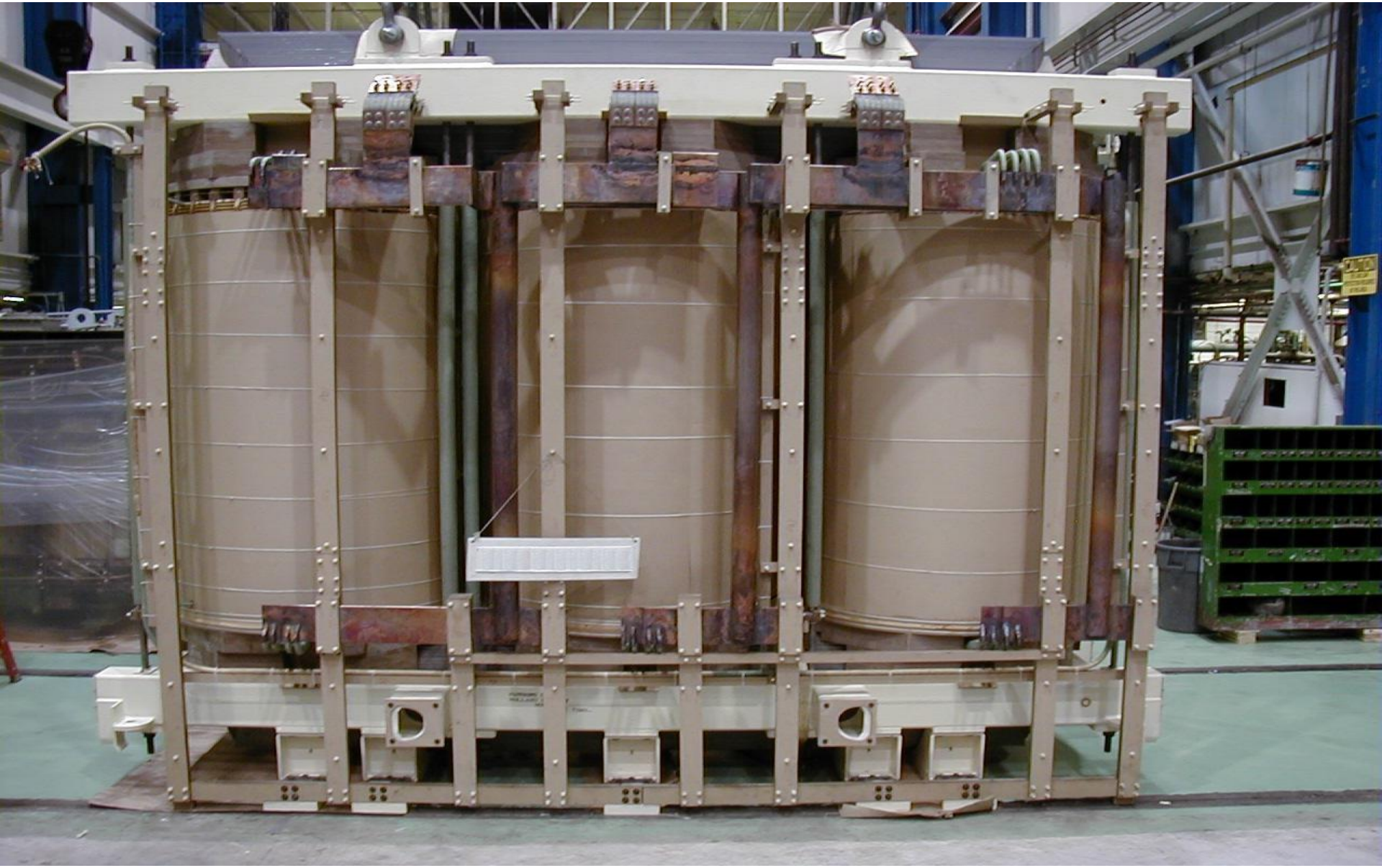


Manufacturing Process:

Lead Braising

Manufacturing Process:

- LV Cu bus bar instead of cable for high current



Manufacturing Process:

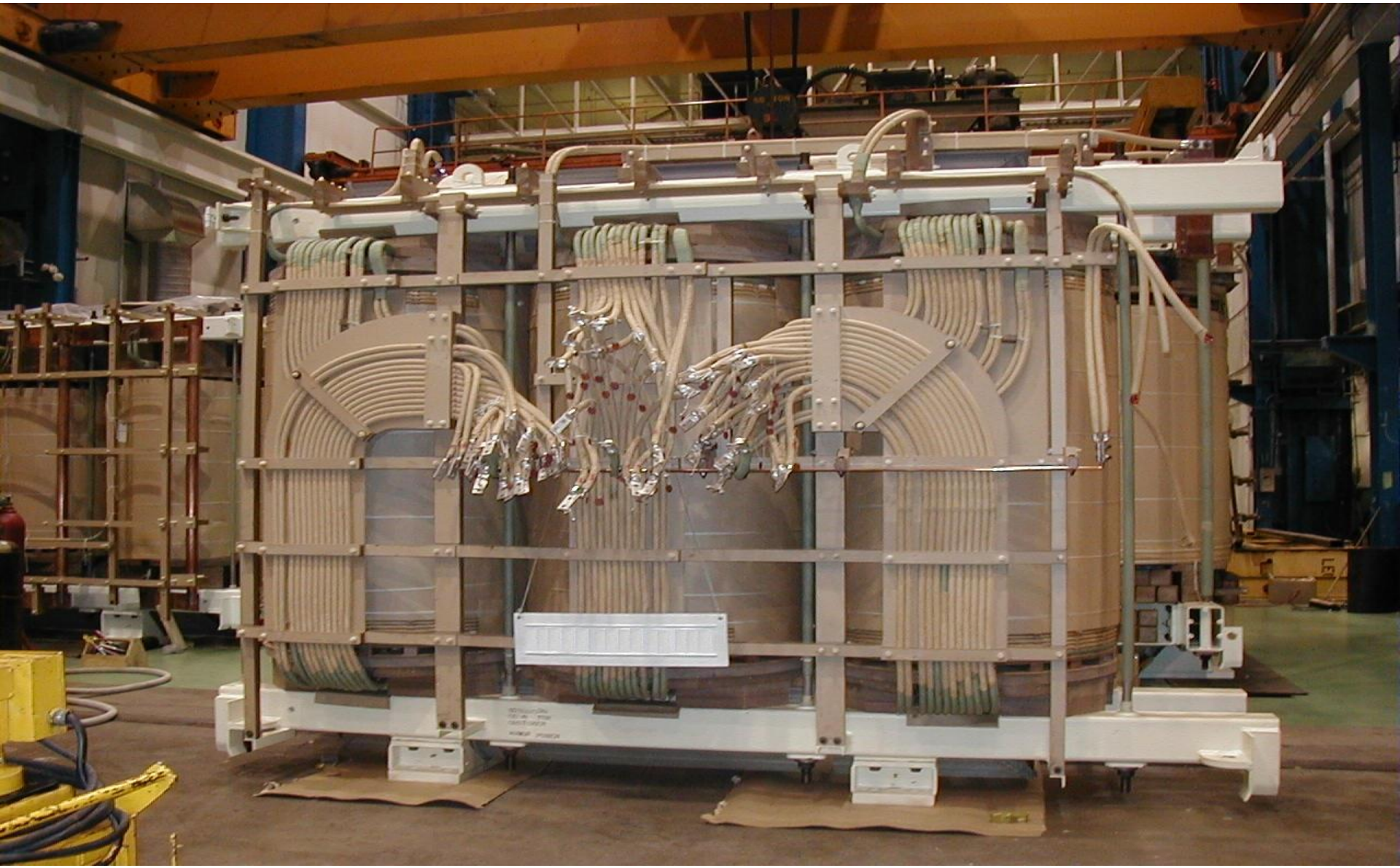
- HV Center Fed with snout and draw lead to bushing; reactor for RMV tap changer

Manufacturing Process:

Coil & Core Assembly

- **Windings are clamped using external or internal tie rods to provide additional support for axial forces**
- **Leads and busbars are rigidly supported to withstand forces from shipping & short circuits**
- **Assembly moved on air cushions**

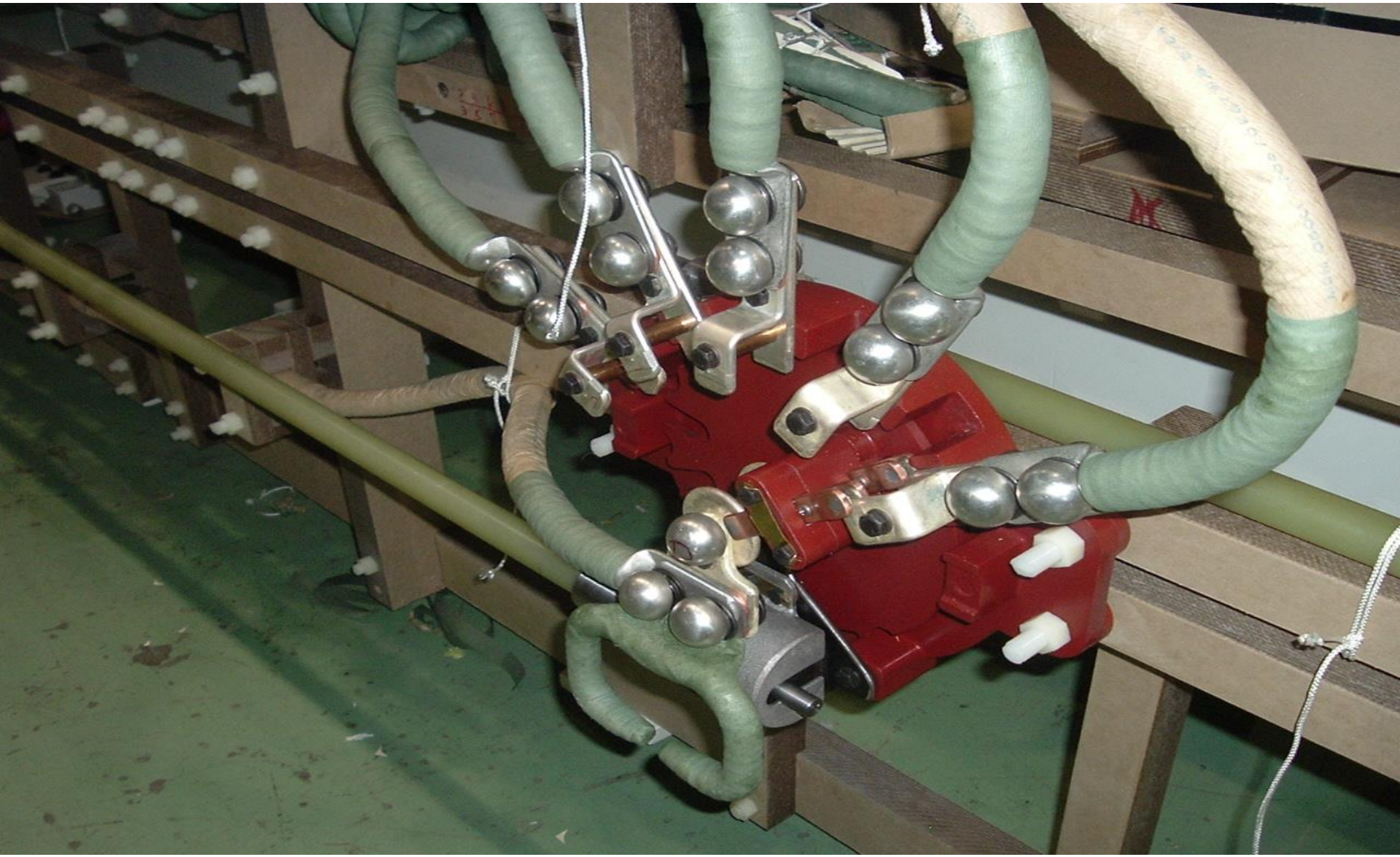
Manufacturing Process:
LTC Lead Connection



Manufacturing Process:

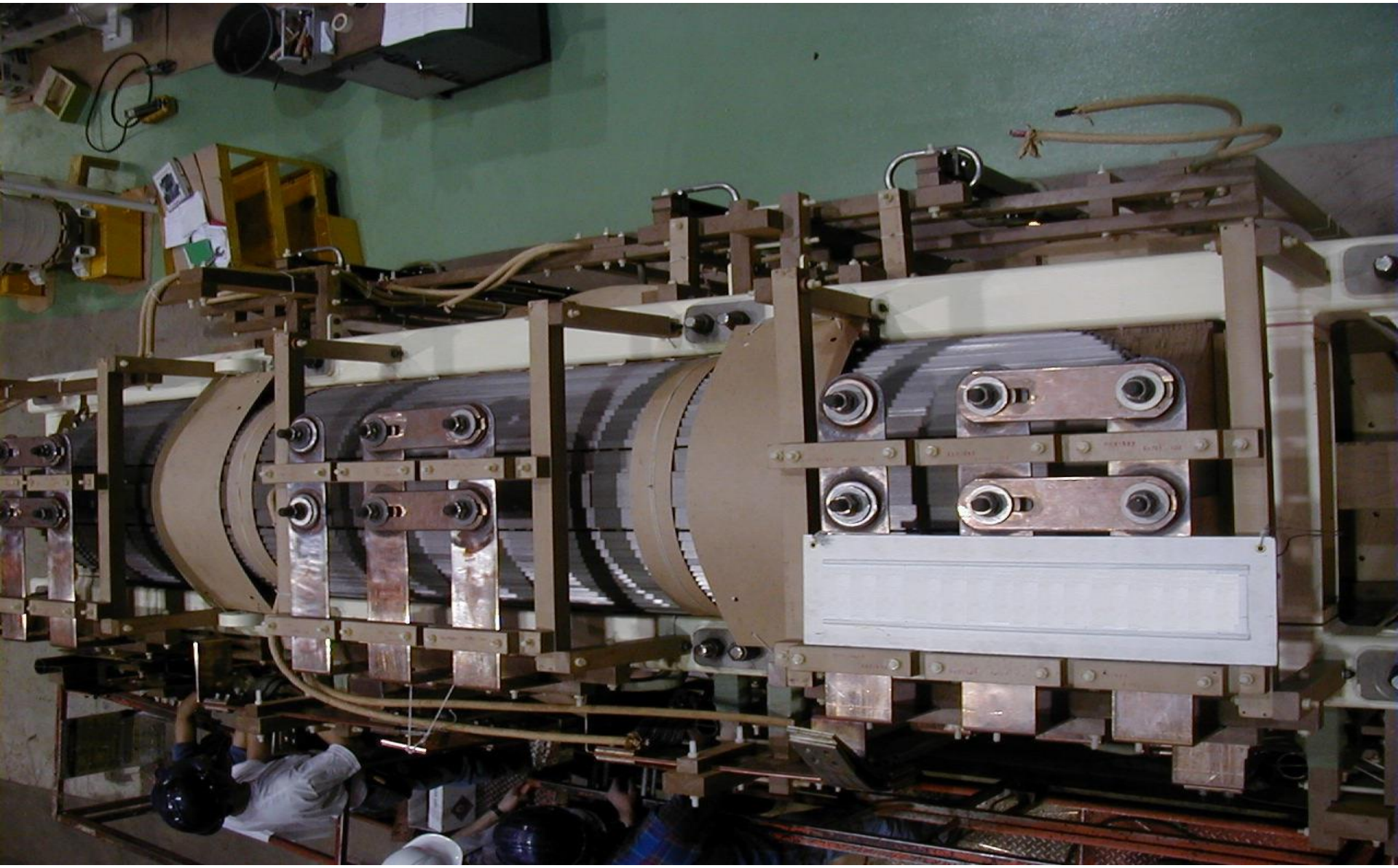
DTC Lead Connection

Manufacturing Process:
DTC Lead Connection



Manufacturing Process:

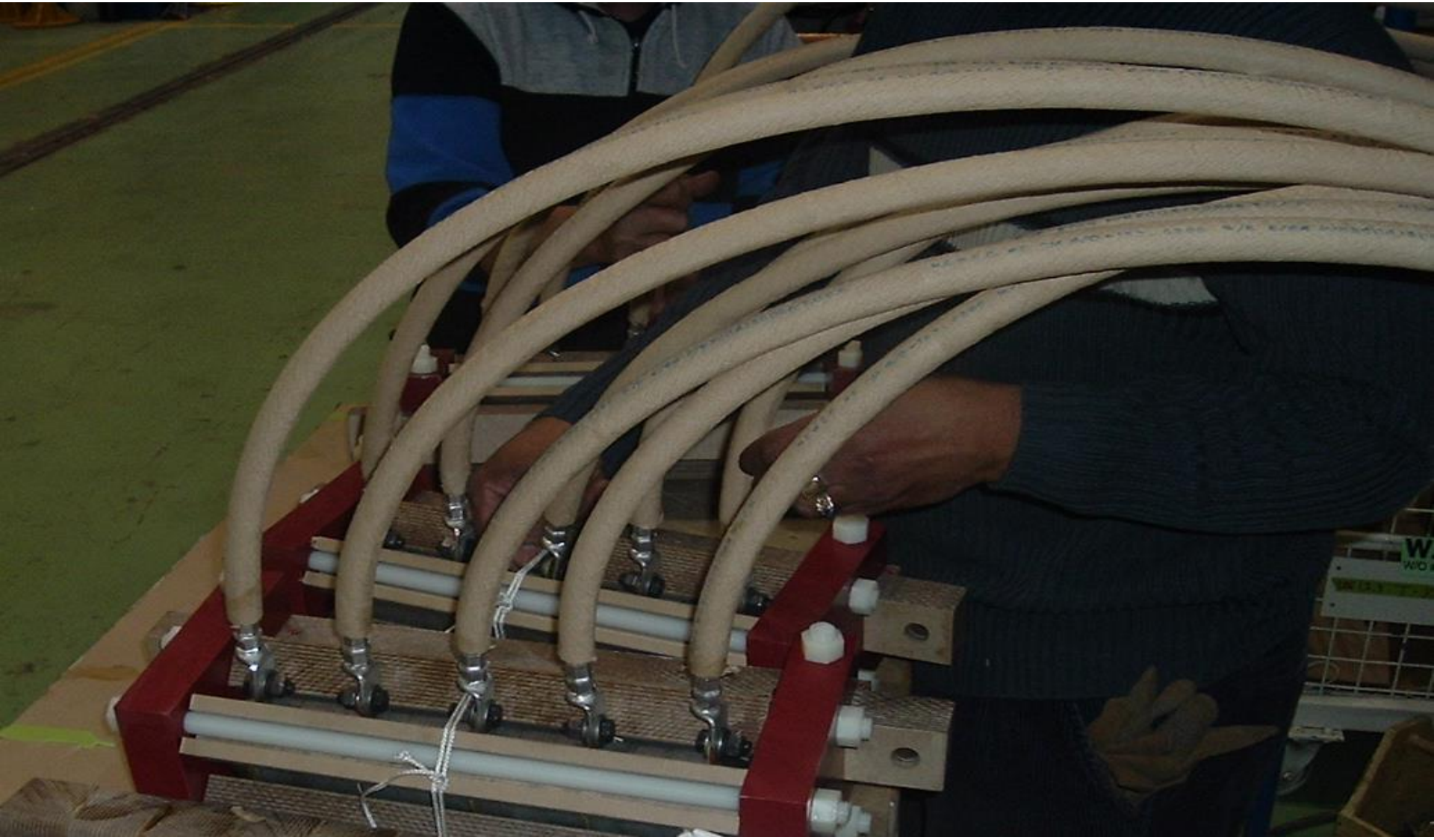
Link Board: Re-connectable LV



Manufacturing Process:

ZnO

- Used for taps usually above 550kV impulse voltage



Manufacturing Process:

Vapor Phase Unit

•Complete core and coil assembly is dried using a vapor phase cycle method

- Power factor & water extraction are continually monitored
- Kerosene is vaporized & drawn by vacuum into autoclave

Manufacturing Process:

Tank Shop

- Designed to withstand full vacuum filling
- Facilities for lifting, jacking, and pulling provided

Manufacturing Process:

Tank Shop

- All tanks are grit-blasted cleaned before priming and painting.
- Inside painted white for good visibility during internal inspections.
- Shunt Packs

Manufacturing Process:

Tank Covers

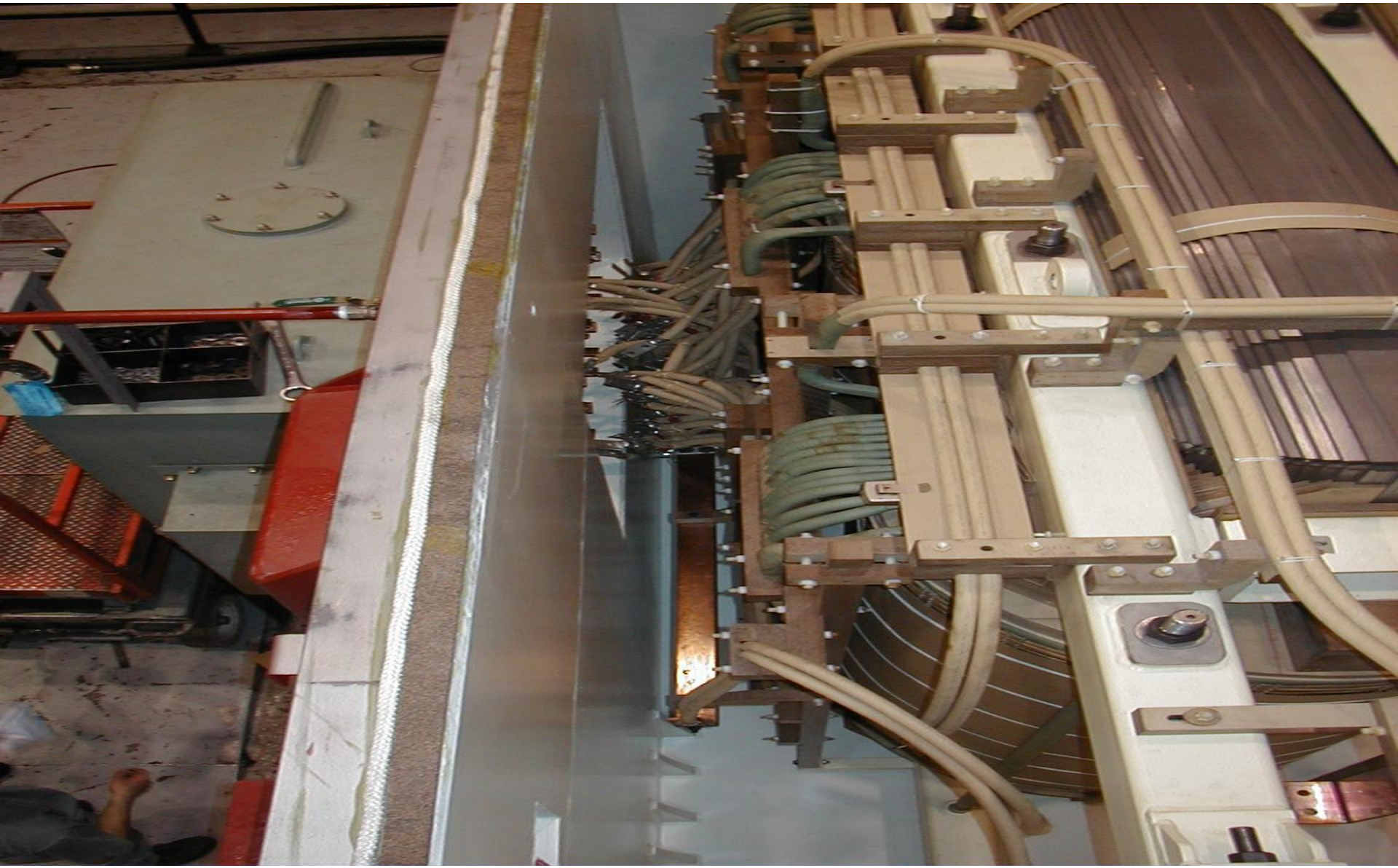
- Raised flanges are provided to prevent water entry
- Cover is designed to prevent water collection
- High quality steel plate is cut by an automated waterbed plasma cutter

Manufacturing Process:

Re-Pack & Tanking

- After vapor phase unit is re-packed and undergoes final hydraulic clamping
- Maximum exposure time to atmosphere is limited to under 16 hours

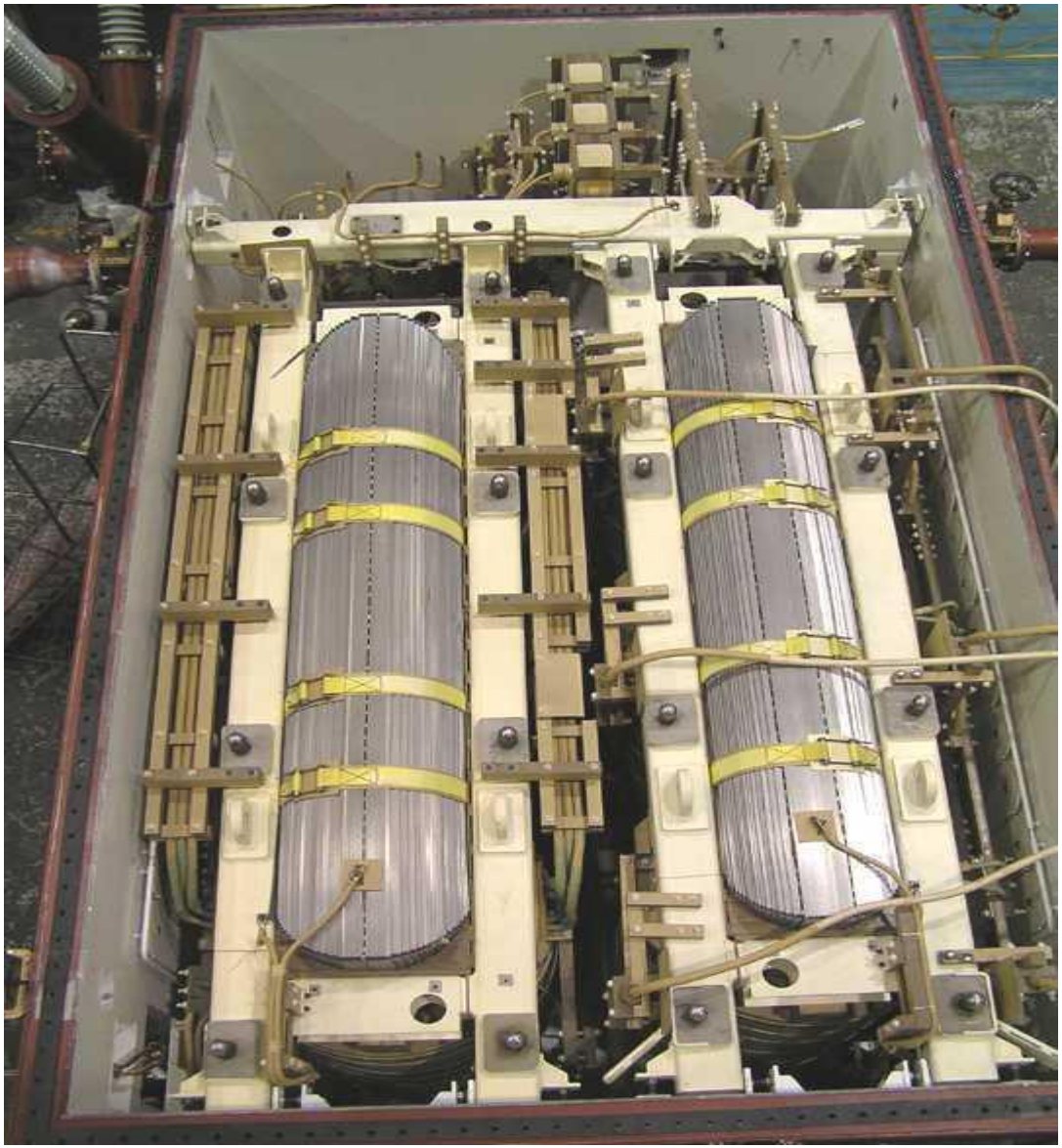
Manufacturing Process:
LTC Lead Connection



Manufacturing Process:
LTC Lead Connection

Manufacturing Process:

Exciter and Series Transformer



Manufacturing Process:

Final Assembly

- Installation of conservator, radiators, pumps, fans, etc.

Manufacturing Process:

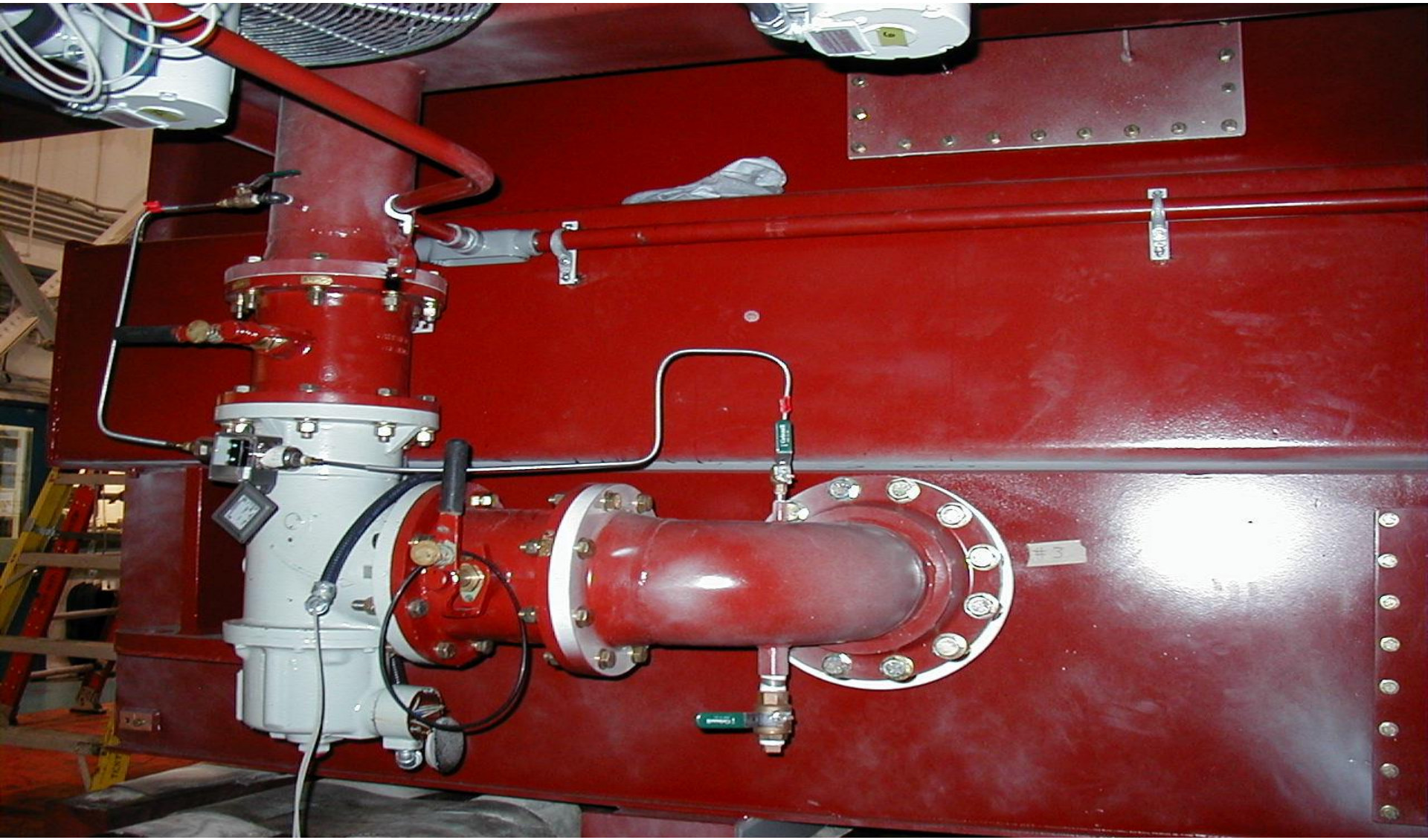
Final Assembly

- Fans bottom mounted

Manufacturing Process:

Final Assembly

- The surge of one pump should die down before the next pump comes-on



Manufacturing Process:

Testing

- **All Industry standard tests :**
  - ✓ **Routine Tests**
  - ✓ **Loss Measurement and Temperature Rise tests**
  - ✓ **Dielectric tests**
  - ✓ **Zero-phase-sequence**
  - ✓ **Audible Sound Level**
  - ✓ **Short-circuit tests, if required (performed at the IREQ lab)**

Manufacturing Process:

Factory Pretest

Test		Standard	Section	Engineering Instruction
Parallel Turns	No	EMT 200.011		
Ratio,Polarity,Core meg.	Std	EMT 200.011		
R.S.G.	Yes	EMT 200.011		
Non Linear Resistors	Std	EMT 200.011		
CT's & PT's	Std	EMT 200.011		
LTC Reactor	Std	EMT 200.011		
LTC Pretest prior to tank.	Std	EMT 200.011.1		

Manufacturing Process:

Factory Tests

Ratio		Std	ANSI C57.12.90	7.3.3		
Polarity		Std		6.2.2		
Resistance		Std		5.3.1		
Core Loss & Exciting Current		Std		8.1		
Load Loss & Impedance		Std		9.1		
Zero Sequence Impedance				9.5		
Temperature Rise Tests	OA			11		
	FA			11		
	Overload			11		
Lightning Impulse	HV			10.3	kV LIL	
	HVN				kV LIL	
	LV				kV LIL	
	LVN				kV LIL	
	TV				kV LIL	
Switching Impulse	HV			10.2	kV SIL	
	LV				kV SIL	
Applied Potential	HV			10.5	kV rms	
	LV				kV rms	
	TV				kV rms	
Induced Potential				10.7		
Partial Discharge				10.8		
Sound Level				13		
110 % Voltage Run			CAN/CSA-C88-M90	16.3.k		
Core Loss after Dielectrics			ANSI C57.12.90 CAN/CSA-C88-M90	8 16.3.k		

Manufacturing Process:

Factory tests cont.

Test		Standard	Section	Engineering Instruction
Dissipation	Std	EMT200.012.6 & ANSI	10.9	
Core Megger	Std	CSA & EMT 200.012.1		
CT Resistance	Std			
CT Ratio & Polarity	Std	CSA & EMT 200.012.4		
PT Ratio & Polarity	Std	CSA & EMT 200.012.4		
Hi-Pot: Panels, Fans, Pumps	Std	CSA & MI 355.021		
Hi-Pot: PT's & CT's	Std	CSA & EMT 200.012.4		
Hot Spot Calibration	Std	CSA & EMT 200.012.8		
Top Oil Calibration	Std	CSA & EMT 200.012.8		
GDR Alarm & Trip	Std	CSA & EMT 200.012.8		
Panel Operation	Std	CSA & EMT 200.012.7		
Line Drop Compensator	Std	CSA & MI 355.105		
Fan, Pump Losses;Klixon	Std	CSA & EMT 200.012.7		
Tapgear Operation	Std	CSA & EMT 200.012.7		
Pressure Tests	Std	CSA & MI 358.012		
Gas-in-Oil Samples				
PCB Oil Sample				
ADDITIONAL TESTS				

Manufacturing Process:

Unit in Test

Manufacturing Process:

Paint Booth

- Epoxy base paint system, meets ANSI C57.12.28

Manufacturing Process:

Shipping Parts

Manufacturing Process:

Shipping Transformer

Manufacturing Process:
Shipping Transformer