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%
- 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
  
  \[
  \begin{align*}
  \text{HV} &= 230 \text{ kV} \\
  \text{LV} &= 115 \text{ kV}
  \end{align*}
  \]

  \[
  \text{Frame size: } \frac{230-115}{230} \times 300 = 150 \text{ MVA}
  \]
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

- 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

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Manufacturing Process:

Core Dimensions

Circular core cross section:

- Stacking Height (SH)
- Diameter of the core circle (DCC)
- Widest sheet width

Steps of 5 mm for DCC
Manufacturing Process: Core stacking methods

**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)

**BUTT-LAP STACKING:**

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

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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
Manufacturing Process:

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
Manufacturing Process:

Helix – Boomerang MW
Manufacturing Process:

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
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
Manufacturing Process:

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 (or 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

Transformer Consulting Services Inc.
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

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## Manufacturing Process:

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<td>Core Loss after Dielectrics</td>
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## Manufacturing Process:

### Factory tests tests cont.

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<th>Test</th>
<th>Standard</th>
<th>Section</th>
<th>Engineering Instruction</th>
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<td>Core Megger</td>
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<td>CT Resistance</td>
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<td>CT Ratio &amp; Polarity</td>
<td>Std CSA &amp; EMT 200.012.4</td>
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<td>PT Ratio &amp; Polarity</td>
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<td>Hi-Pot: Panels, Fans, Pumps</td>
<td>Std CSA &amp; MI 355.021</td>
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<td>Hi-Pot: PT's &amp; CT's</td>
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<td>PCB Oil Sample</td>
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### ADDITIONAL TESTS

Transformer Consulting Services Inc.
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