Installation Procedures, New Transformer Oil Processing & Electrical Testing

Goldsboro, NC Engineering Seminar

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Josh Brown
General Manager – Waukesha® Service

Josh Brown joined Prolec GE Waukesha in 2008 at the Goldsboro, North Carolina, location. Starting out as a manufacturing engineer, Josh held several engineering positions of increasing responsibility prior to joining the service team in 2014. He worked various jobs supporting eastern U.S. activity within the Service Group and was promoted to General Manager in 2017. As the general manager, Josh is responsible for leading the Waukesha® Service Group in providing and implementing creative field service solutions nationwide. He has a Bachelor of Science Degree in Systems Engineering from East Carolina University, where he remains an active member of the engineering advisory board. He is also an active member of industry committees and advisory boards.

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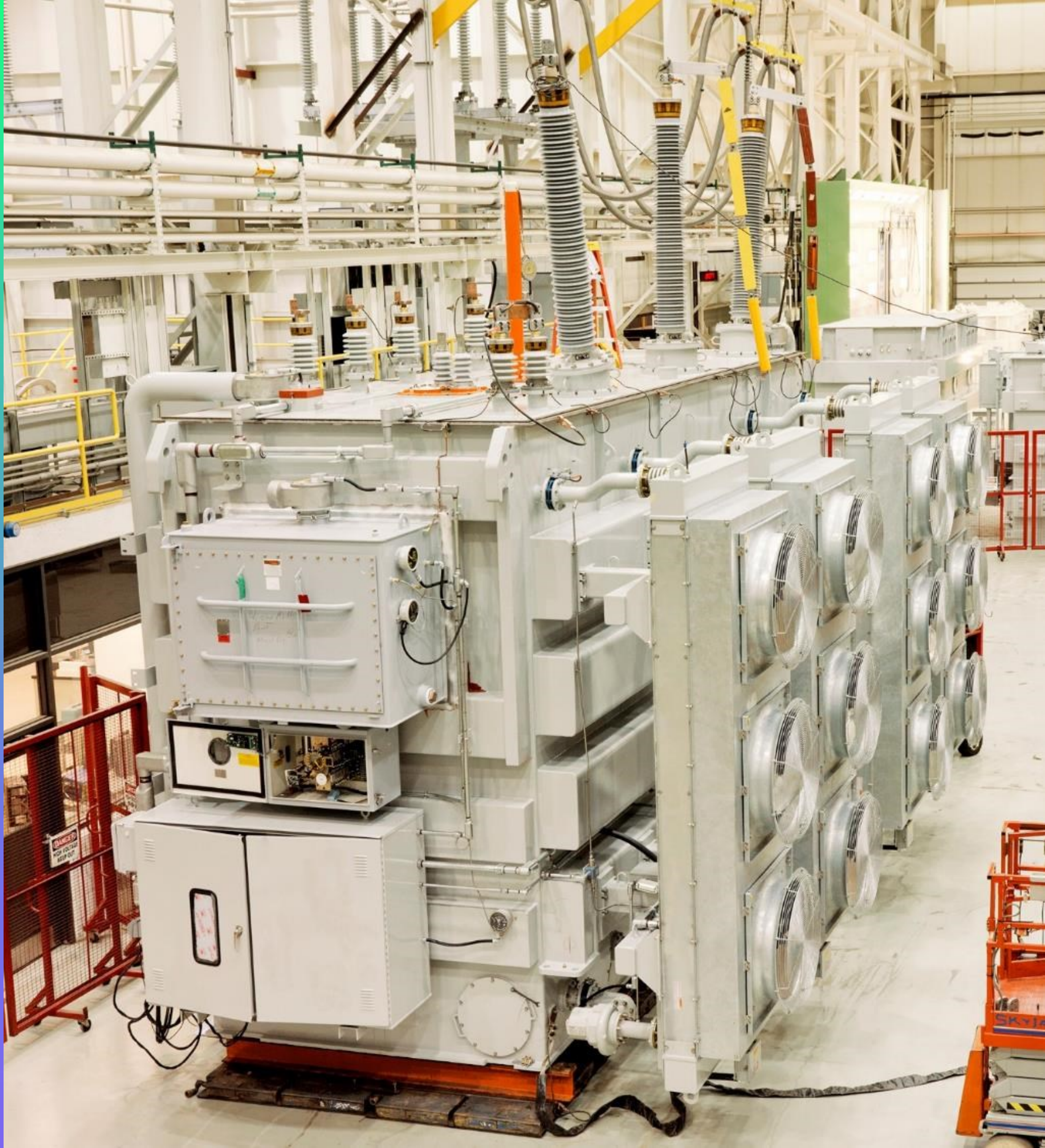

Agenda

- Receiving Inspection
- Unloading
- Field Assembly
- Oil Processing
- Vacuum Filling
- Electrical Testing
- Energization

Introduction

- Develop a site installation plan
- Review OEM Instructions
- Review Applicable Standards
  - IEEE Guide for Installation of Liquid Immersed Power Transformers (C57.93-2019)
  - IEEE Guide for Maintenance and Acceptance of Insulating Oil in Equipment (C57.106-2015)
  - NETA Acceptance Testing Specification 2021
  - IEEE Guide for Diagnostic Testing of Fluid Filled Power Transformers, Regulator, and Reactors (C57.152-2013)
  - IEEE Guide for Failure Investigation, Analysis, and Documentation of Power Transformers and Shunt Reactors (C57.125-1991 Appendix A)

Receipt of Transformer

Receiving Inspection

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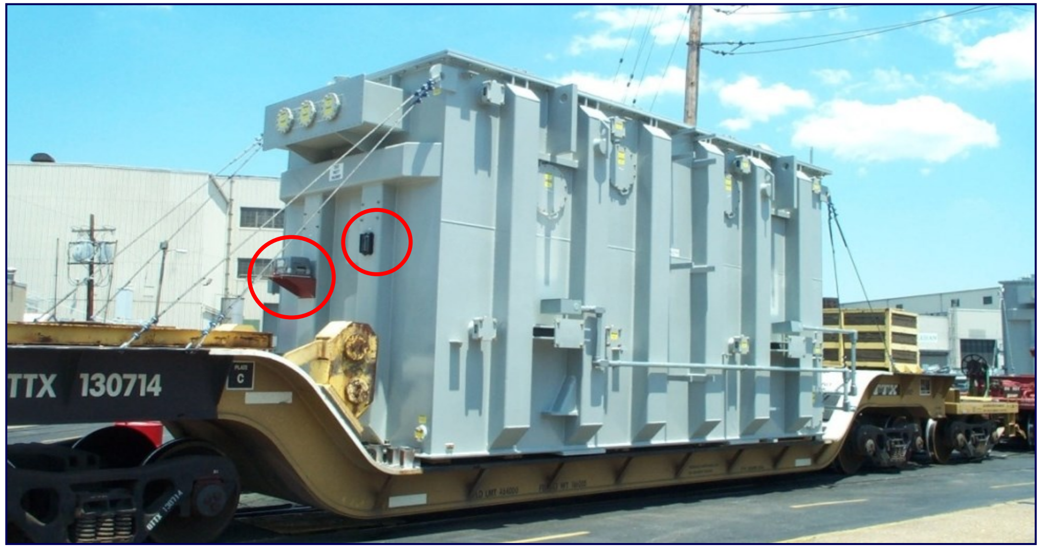
- Complete visual inspection
- Check for movement, shifting, bent or broken tie down rods.
- Check for scratches, dents, broken accessory devices
- Check tank pressure
- Perform dew point measurement
- Perform core ground test
- Inventory and inspect accessories
- Review impact recorder

External Inspection

Impact Recorders



- There are several type of impact recorders
  - Strip Chart Recorder
  - Non-resettable
  - Resettable
  - Data Logging
  - GPS Data Logging
- Mount recorder directly on transformer
- Assure there is adequate battery life & recording paper
- Redundant recorders are recommended for critical shipments
- 2G impacts in lateral & vertical direction and 3G impacts in longitudinal direction warrant further inspection

Receiving Inspection

If damage is evident from visual inspection, impact recorder reading, or testing:

- Notify manufacturer
- Notify carrier
- Do not unload equipment
- Initiate any claim forms
- Perform an internal inspection

Receiving Inspection – Prevention Techniques

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Unloading of Transformer

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Methods

- Cranes
- Beams & hydraulic sliders
- Gantry cranes
- Winch lines/jacks

Unloading of Transformer

Precautions

- Verify use of proper lifting eyes and jacking lugs.
  - Lift angle should not exceed 60°
- Verify location of center of gravity
- Verify proper jacking points
- Verify proper base support locations
- Keep base level while handling
  - Never more than 15° vertical
- Block railcars and trailers to prevent tipping or collapse

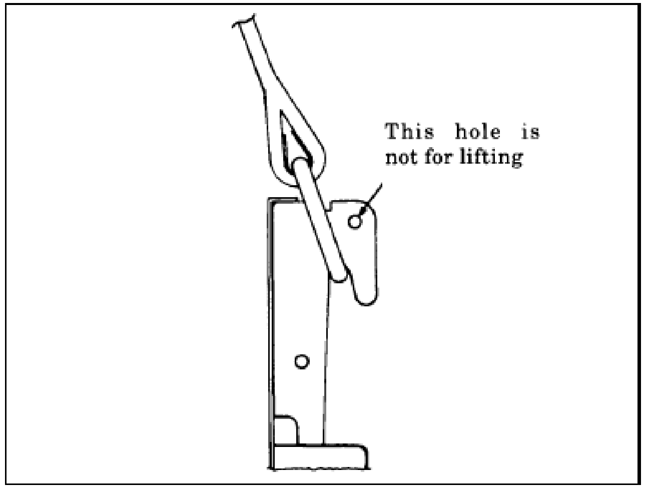


Figure 4-2.

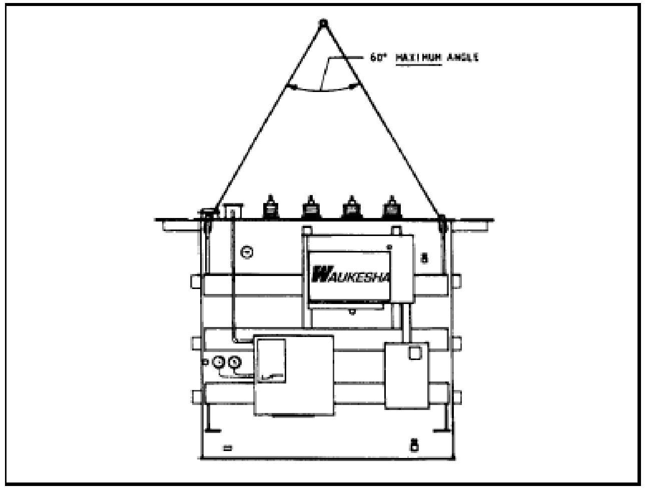


Figure 4-3.

Assembly of Transformer

Preparations

- Devise an assembly plan
  - Assure tool and material availability
  - Minimize potential damage to components
  - Minimize exposure time
- Transformer base should be level and supported per manufacturers instructions
- Transformer should be positioned for adequate air circulation
- Transformer tank should be grounded to system ground
- Verify mechanical pressure relief device is installed

Assembly of Transformer

General Assembly Guidelines

- If supplied, use new gaskets for assembly. Nitrile gasket material can be reused if undamaged.
- Observe manufacturers match marks for component orientation.
- Seal all pipe fittings with Teflon tape or sealing paste.
- Gaskets should be glued on only one side. Petroleum jelly can be applied to minimize damage during assembly.
- Pull flash vacuum, pressurize, and seal transformer each evening.

Cooling Equipment

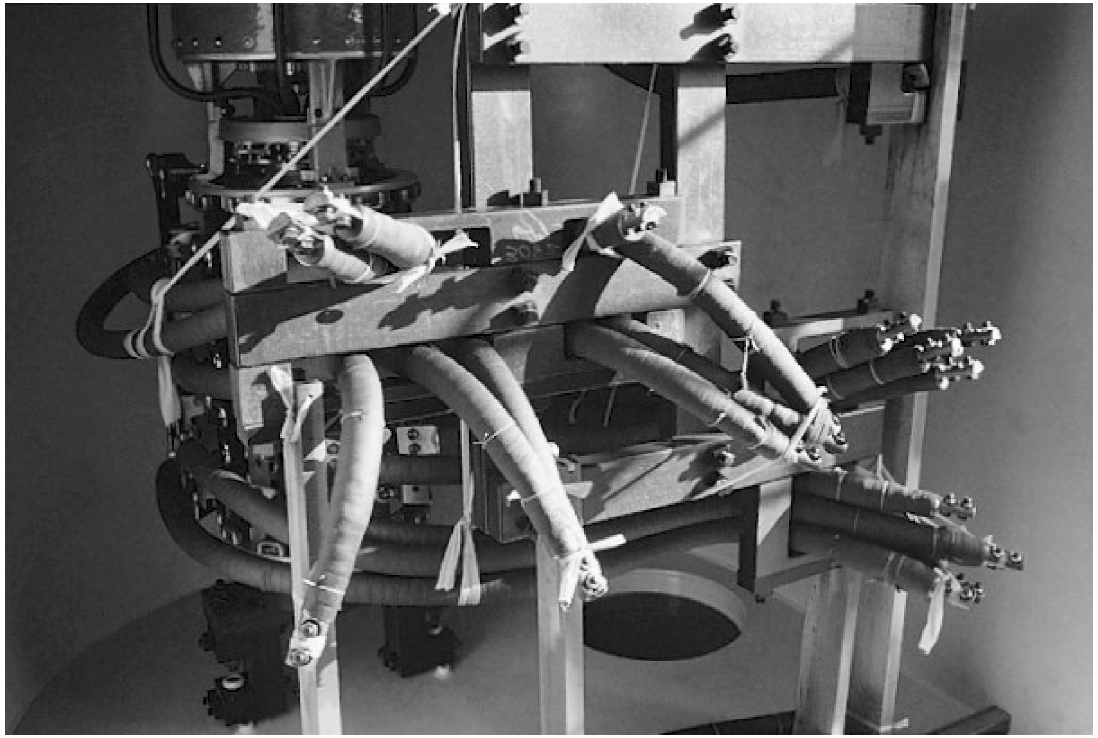
- Cooling equipment should be inspected, cleaned, and flushed, if required
- Replace mounting gaskets and glue gaskets on one side only. Use petroleum to assist with installation
- Mount fans and fan guards
- Mount supports or seismic bracing
- Examine and tighten all packing glands
- Make electrical connections

Turrets and Bushings

- Remove any temporary braces and support
- Install all turrets & connect current transformers
- Perform power factor tests prior to installation of bushings
- Lift and install bushings per manufacturers instructions
- Make current carrying connections, torque, insulate, and install shields as specified
- Install grounding/bonding jumpers and static grounds

Load Tap Changers

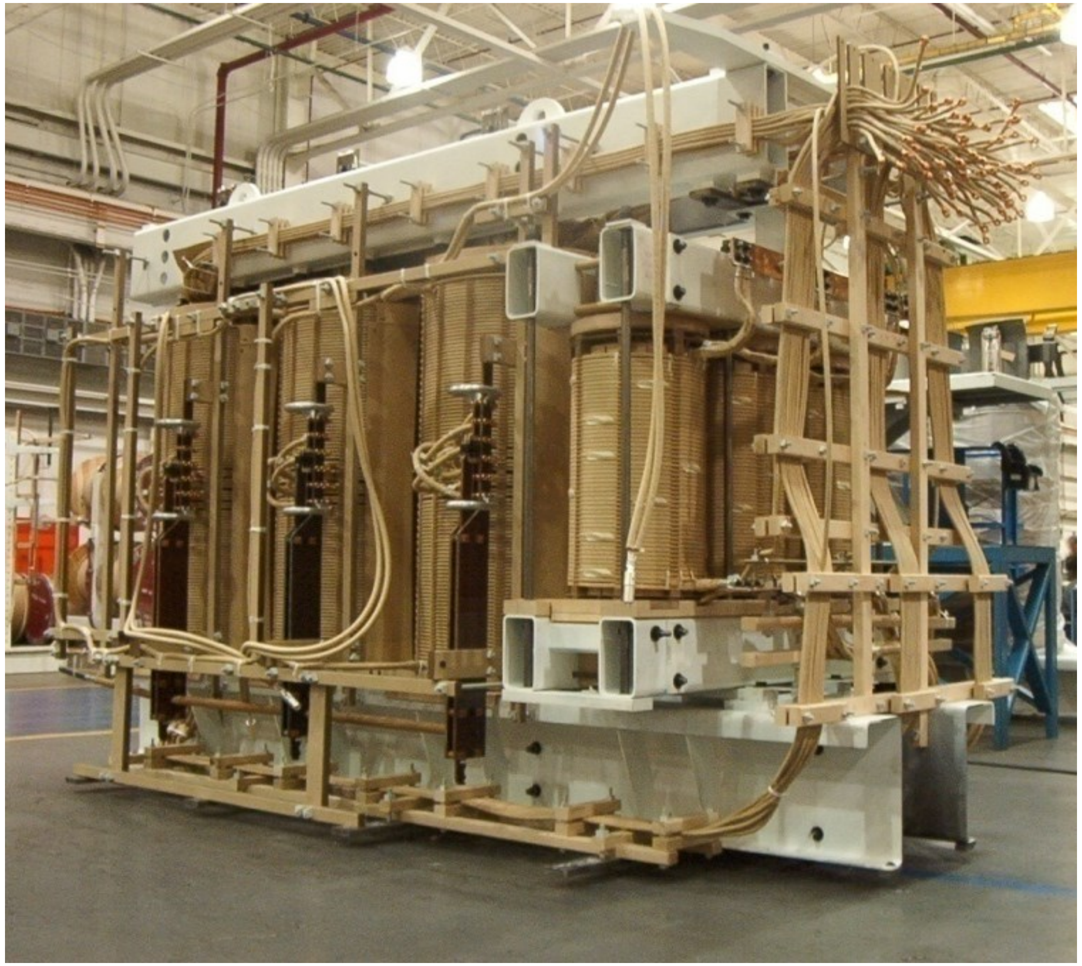
- Remove any shipping braces and supports
- Install motor drive and operating shafts
- If ULTC is removed for shipment, make lead connections to barrier board and insulate as necessary
- Manually and electrically operate ULTC
- Check alignment, timing, and contact pressure



Oil Preservation Systems

- Sealed system may need to be capped for vacuum filling
- Nitrogen systems will require piping connections and mounting of regulator cabinet. Regulator cabinet to be isolated for vacuum filling
- Conservators should be inspected and pressure tested
- Verify OEM requirements for conservator tanks capability to withstand vacuum

Final Internal Inspection



- Verify no foreign material, dirt, moisture present
- Verify all shipping braces removed
- Verify all bushing connections, corona shield, and insulation barriers installed correctly
- Verify all lead clearances
- Check for proper liquid level gauge operation
- Verify DETC and ULTC operation, timing, and alignment
- Check current transformer mounting and connections
- Inspect coil clamping, spacer alignment, phase barriers oil boxes, and coil wraps

Preliminary Tests

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It is recommended that some preliminary tests be conducted prior to starting vacuum filling operations:

- Dew point
- Core insulation resistance
- Bushing power factor
- Transformer turns ratio
- Current transformer ratio and polarity tests

Tes	Tap	IEEE30 V/I	IEEE45 V/I	IEC 10/50 V/I	NP-Ratio	M-Ratio	% Error
1	X1-X2	0.00 / 0.0000	0.00 / 0.0000	0.00 / 0.0000	400/5.0	78.806	1.4930
2	X1-X3	0.00 / 0.0000	0.00 / 0.0000	0.00 / 0.0000	1200/5.0	238.323	0.6986
3	X1-X4	0.00 / 0.0000	0.00 / 0.0000	0.00 / 0.0000	1500/5.0	298.874	0.3753
4	X1-X5	859.28 / 0.0740	693.04 / 0.0570	918.16 / 0.0856	2000/5.0	400.558	0.1395

Oil Filling Procedures

- Oil-Filled Transformers
- Transformers shipped with dry gas

Transformer Shipped Oil Filled

- Open bottom radiator valves and vent air through top bleeder plug
- Open top radiator valves
- If required, add make-up oil
- Test each individual container (drum, tanker, etc.)
- It is permissible to pump oil into the transformer through a filter press or degassing equipment
- During filling, the added oil should be pumped in at a level below current oil level in tank and should be directed horizontally over core and coil assembly
- It is ***not*** recommended to pull vacuum over the oil in the transformer
- Fill transformer to 25°C mark through upper filter press valve or manhole; attempt for horizontal oil flow to minimize bubbling
- Adjust oil level allowing for temperature compensation per nameplate instructions
- Purge gas space with nitrogen; maximum permissible O_2 is 1.2%
- Take final oil samples
- Observe proper set time for energizing

Transformers Shipped Dry Gas Filled Strategies

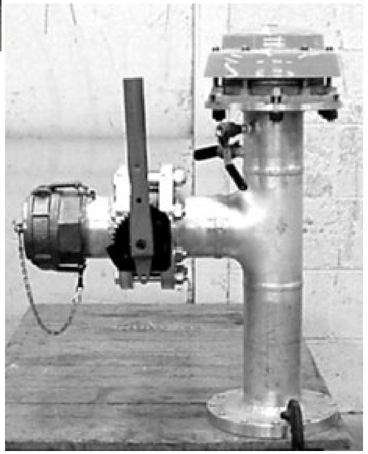
- Confirm main tank gas type before any internal work initiatives (N2/Dry Air/etc.)
- Ensure Dew point measurement is taken daily on main tank
- Record dry gas dewpoint *(utilized daily for internals work or tank pressurization at end of day)*
- Avoid internals activities on high humidity days
- Utilize “flash vacuum steps” for treatment on high humidity results during process
- Perform pressure test prior to initiating vacuum process
- Validate integrity of vacuum system utilizing “blank-off test” on processor unit

Vacuum Filling Preliminary Processes

Prior to beginning vacuum operations, operator must verify…

- Equipment preparations
- Determination of insulation moisture content
    - Utilize assembly daily trend data
- Verification of tank leakage rates
- Field dry out methods
- Low ambient processing

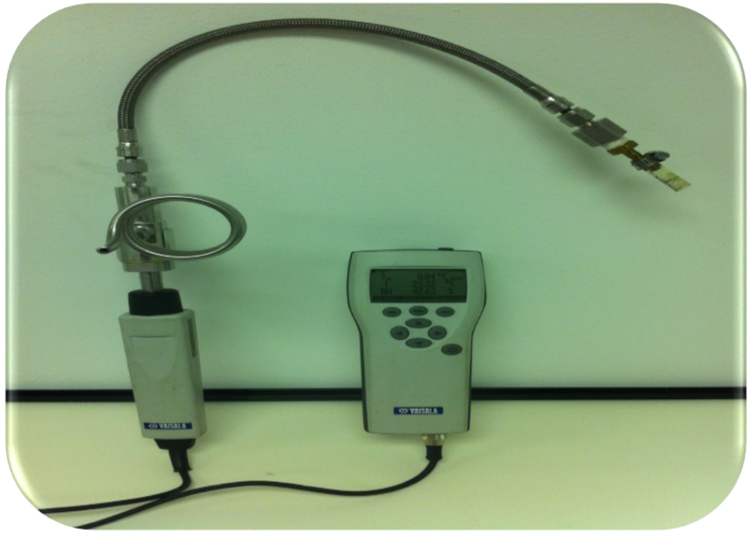
Vacuum Preparations



When preparing for vacuum filling operations, there are several recommendations….

- Ground transformer tank, storage tanks, purification unit, and bushing terminals
- Disconnect any bushing terminations
- Cover transformer cover with tarp
- Isolate all devices not rated for vacuum
- Balance pressure on terminal boards or barriers
- Leave mechanical relief device in position

Insulation Moisture Content



Dew point measurement

- Introduce dry gas and stand idle for 12-24 hours
- Measure dew point of gas
- Record tank pressure
- Record insulation temperature
- Utilize Pieper curve information to calculate moisture content
- Most OEMs have an acceptance range between 0.5 and 1.0%

Insulation Moisture Content

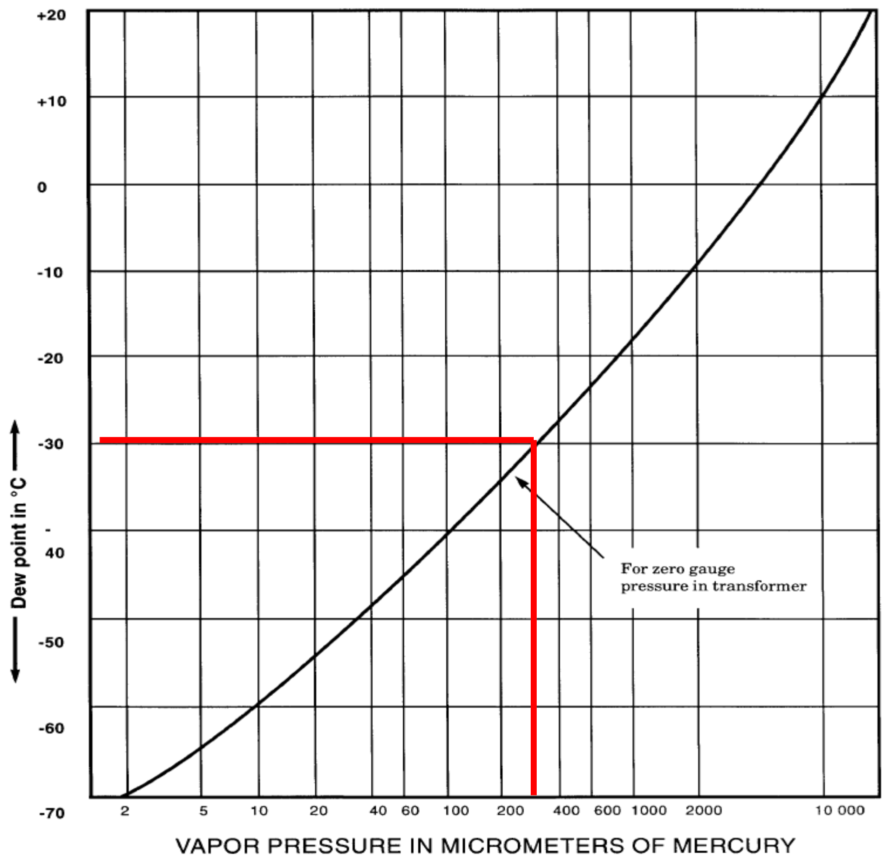


Figure 2-4. Conversion of dew point to vapor pressure.

- Dew point = -30°C
- Tank Pressure = 3 PSI
- Insulation Temp = 30°C

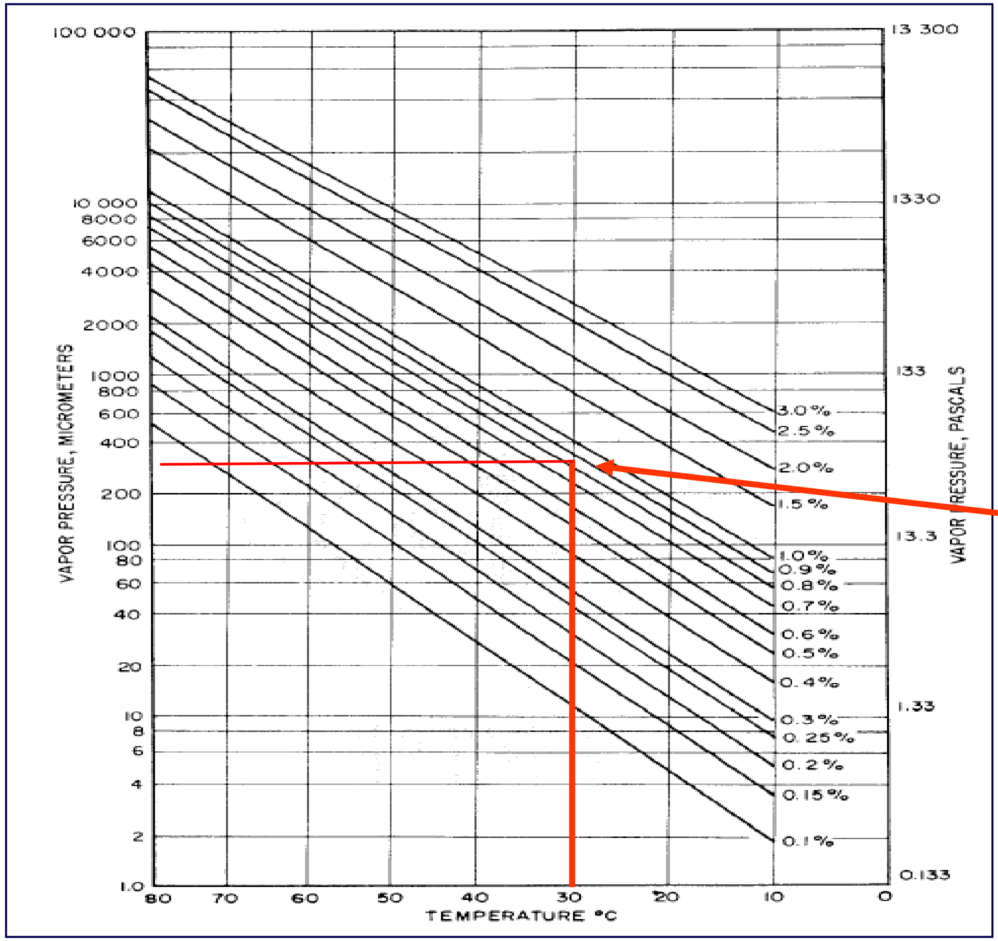
$$V_C = V_P \frac{(14.7 + T_P)}{14.7}$$

$$V_C = 300 \frac{(14.7 + 3)}{14.7}$$

$$V_C = 361.2$$

Source: IEEE C57.93-2019

Insulation Moisture Content



Moisture content is 0.9%.

Source: IEEE C57.93-2019

Verification of Leakage Rate

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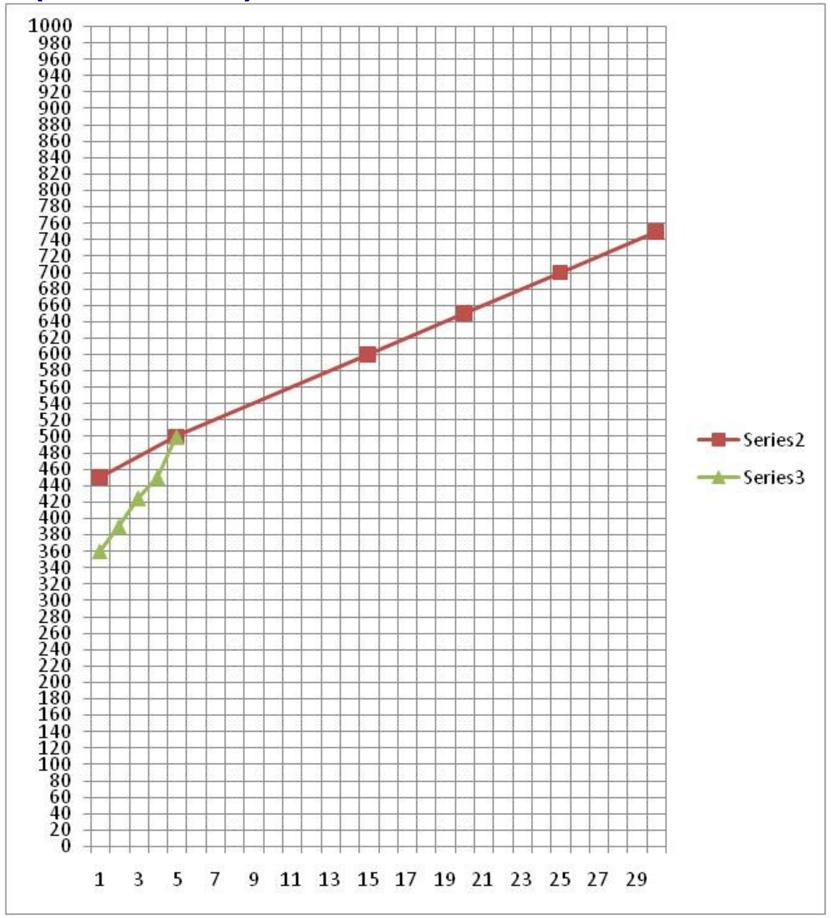
Leaks are detrimental to the vacuum process so it is necessary to verify tightness of transformer. Typically this is verified by:

- Pressure Check
- Vacuum Leak Check
  - Evacuate tank to 2 Torr
  - Isolate pump and take reading 5 minutes later(P1)
  - Take second reading 30 minutes later(P2)
  - Calculate leak rate

Verification Leakage Rate

(P2 -P1) x V < OEM Value



Leak Rate Chart

Tank Oil Volume (Gallons)	Maximum Allowable Leak Rate (Torr Rise in 10 Minutes)
Less than 5000	0.80
5001 – 7500	0.53
7501 – 10000	0.40
10001 – 12500	0.32
12501 – 15000	0.27
15001 – 17500	0.23
17501 - 20000	0.20
20001 - 22500	0.17

Field Dry Out Methods

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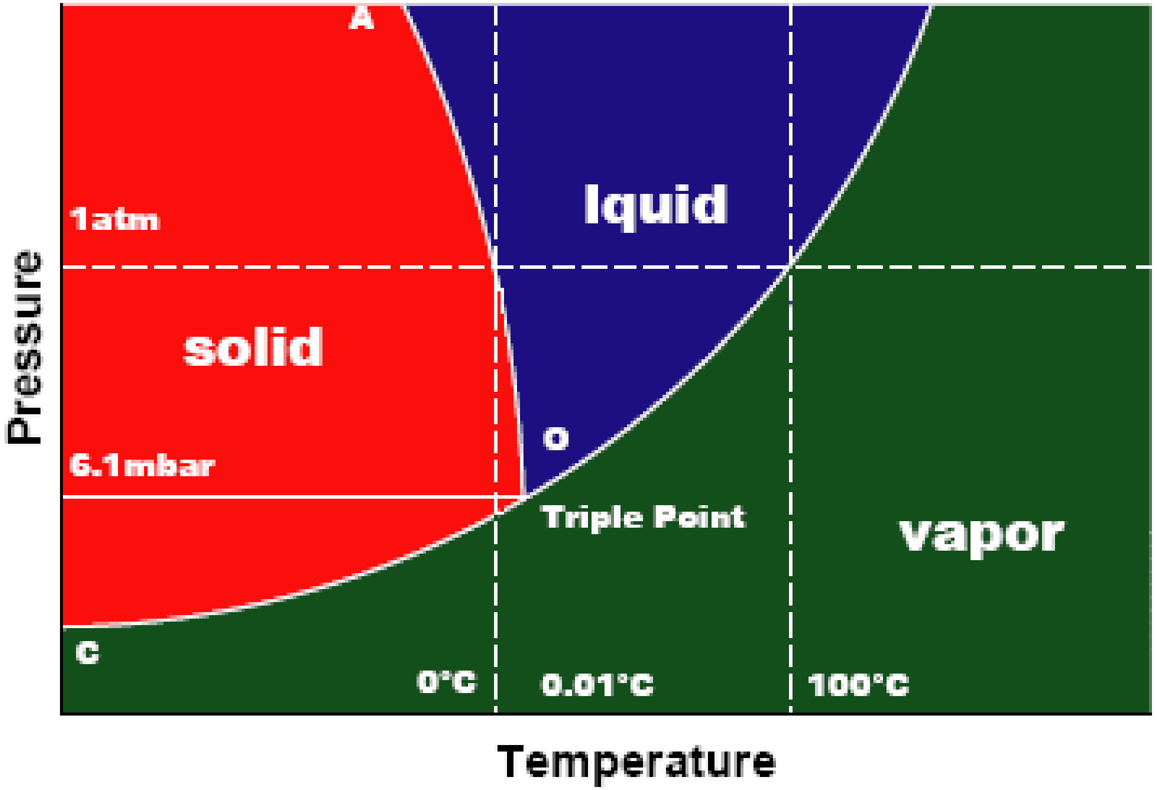
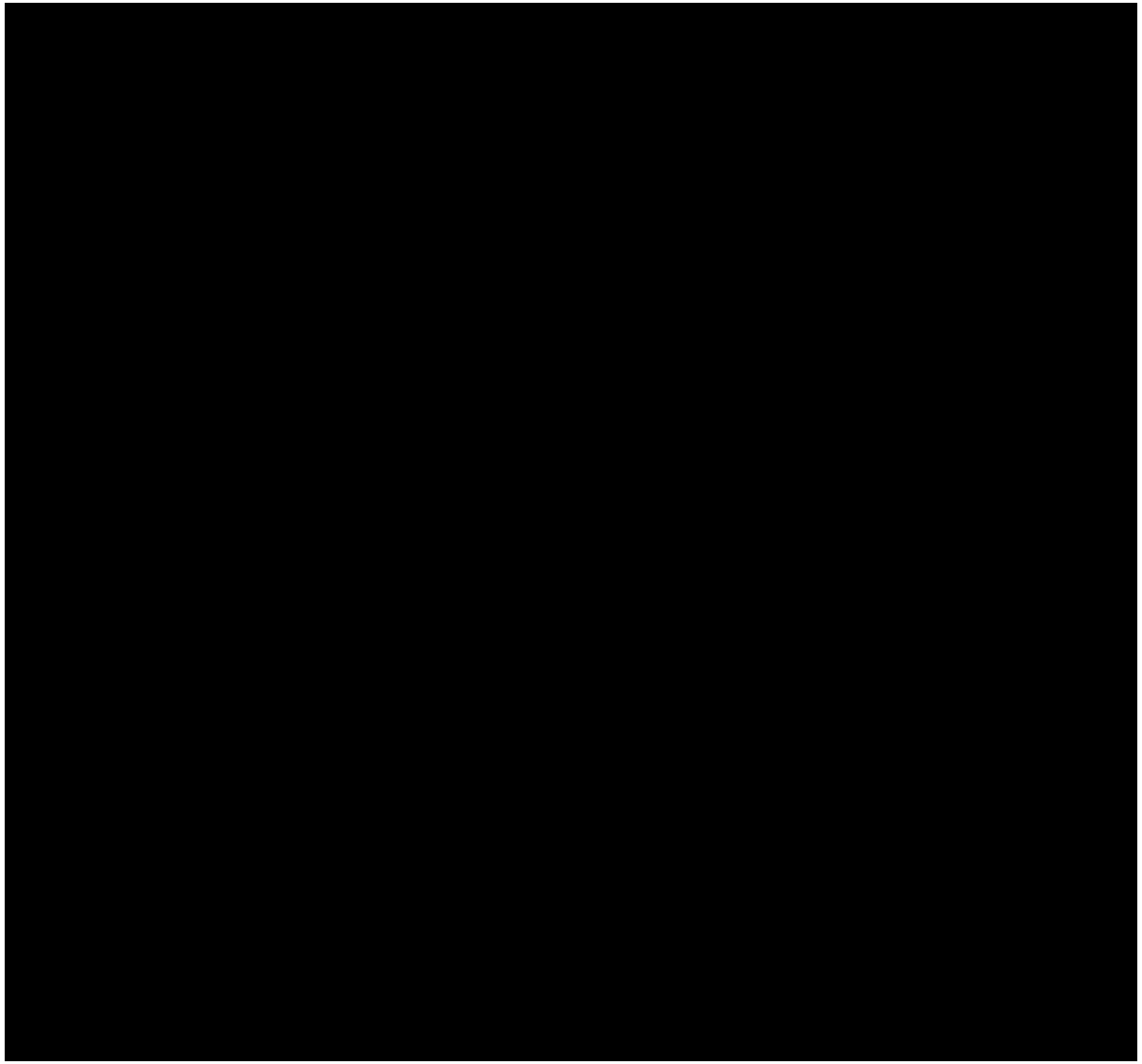


the phase diagram of water

There are multiple methods for field drying of a transformer if the moisture content is found to be above an acceptable limit.

- Vacuum
- Vacuum with Hot Air
- Short circuit and Vacuum
- Vacuum with Hot Oil

Transformer Drying

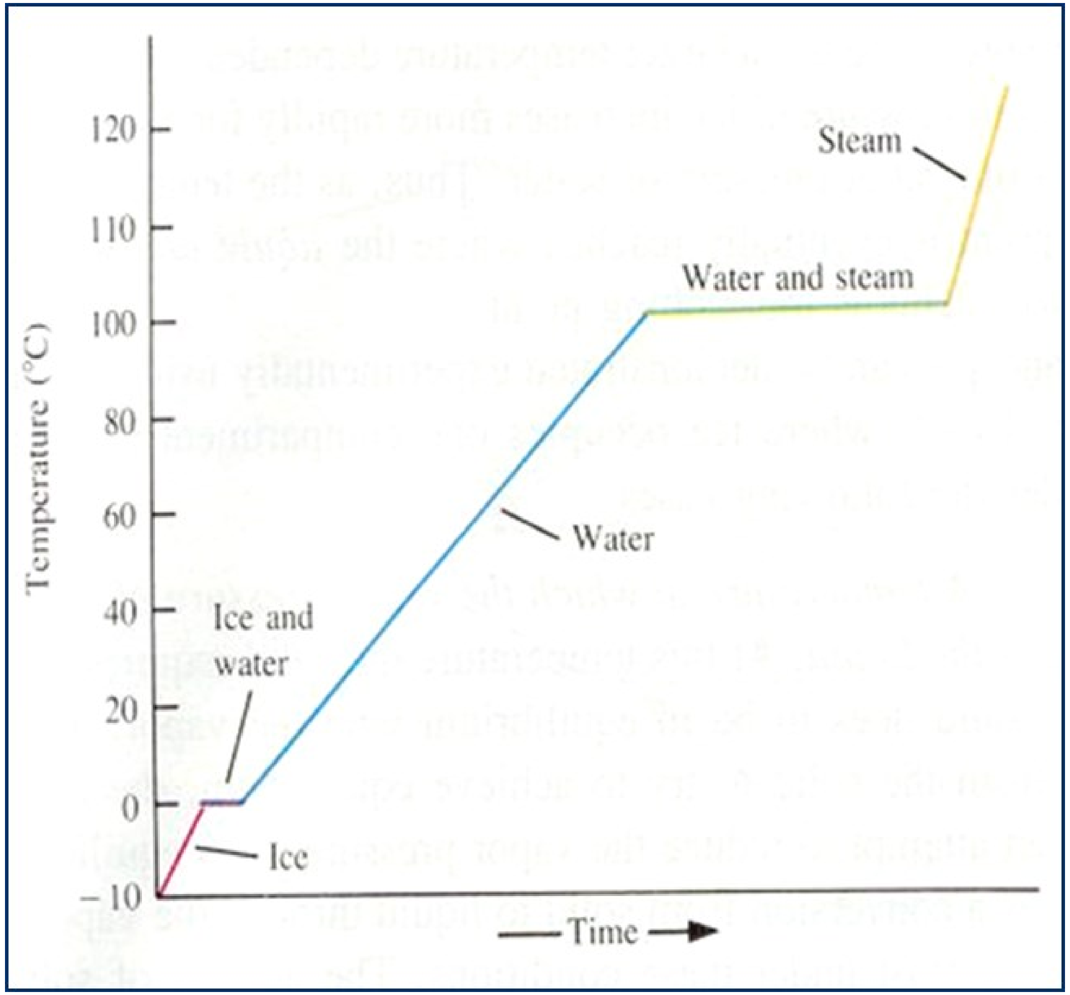


Video courtesy of Baron USA, LLC

Transformer Drying

Importance of Temperature

- Heat required for a phase change comes from the surrounding oil and transformer parts
- As heat moves from the insulation into the water, the temperature of the insulation and transformer drops
- Therefore, replacement heat is added by continuously reheating the oil and pumping it into the transformer
- If the heat is not replaced, freezing can eventually occur

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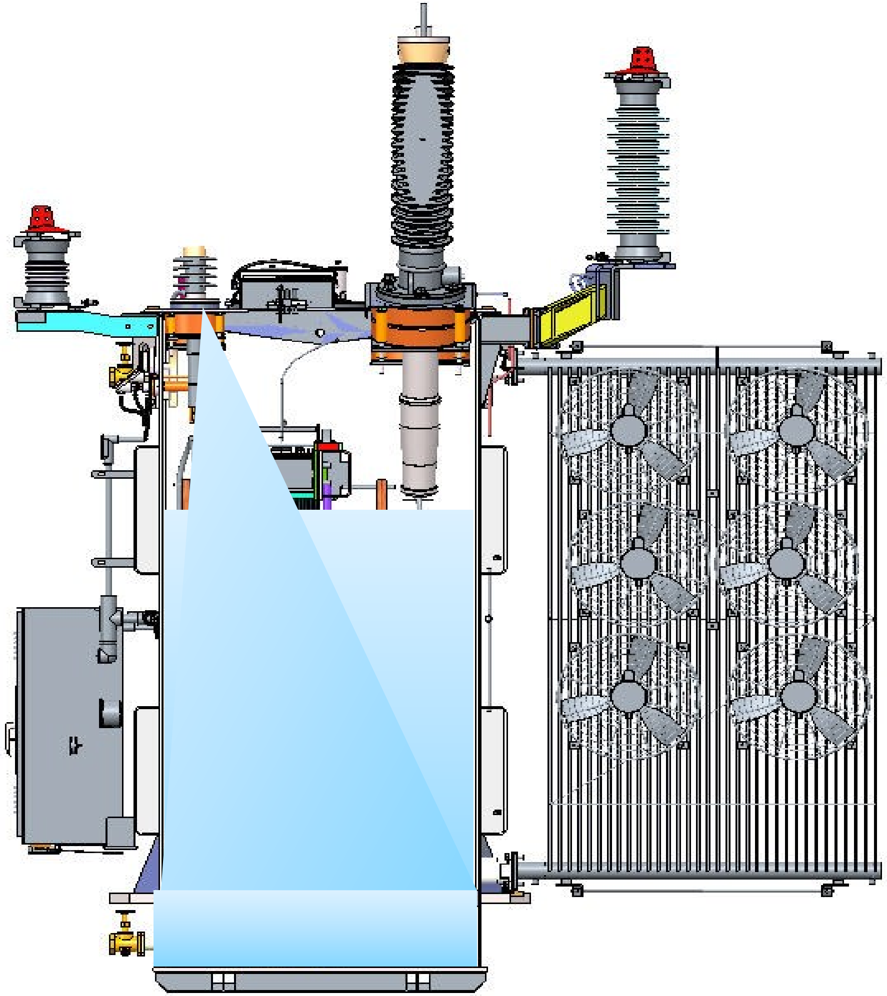
Transformer Dry Out Method

Vacuum

- Good method for removing small amounts of residual moisture
- Transformer is subjected to high vacuum and held for a period of time
- Efficiency of method is increased at higher temperatures
- Cold traps can be used in vacuum line to measure moisture extraction

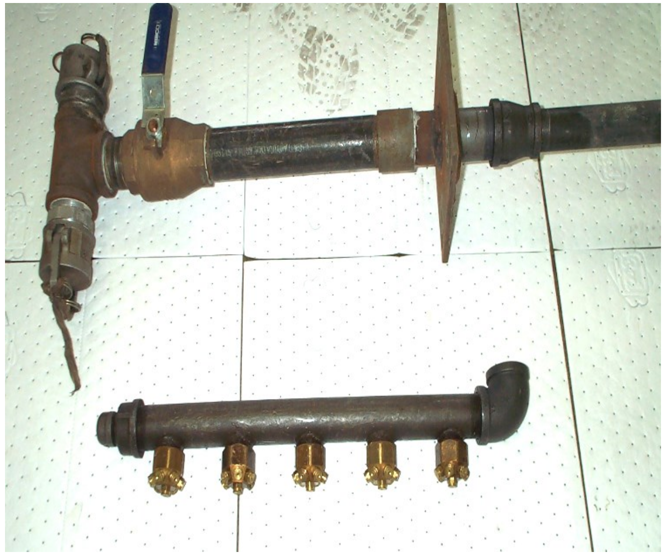
Transformer Dry Out Methods



High Vacuum and Hot Oil

- Evacuate tank
- Introduce oil to heat core/coil assembly
  - If capable, limit oil volume to 10% of total or enough to establish oil circulation
  - Otherwise, cover core/coil assembly
- Circulate oil under vacuum until outlet oil temperature reaches desired temperature, typically 50-70°C
- Drain oil from transformer
- Continue to pull vacuum and monitor moisture through cold trap, if desired

Transformer Dryout Methods



High Vacuum and Hot Oil Circulation

Process is more effective when heat is introduced to increase the vapor pressure of the moisture:

1) Evacuate tank to 2 Torr of less
2) While maintaining vacuum, introduce oil with inlet temperature of 70°C ± 5°C
3) Oil volume to be no less than 10% of total or enough to establish oil circulation
4) Circulate oil under vacuum until outlet oil temperature reaches 50°C
5) Optionally, Monitor moisture extraction through cold trap and cease drying when cold trap is less than 1 oz./hr.
6) Alternatively, monitor with vapor pressure equilibrium chart and cease when vacuum level corresponds to 0.75% at applicable temperature
7) Drain oil from transformer
8) Continue to pull vacuum and monitor moisture through cold trap until moisture extraction rate achieved
9) Confirm result via dew point measurement or vapor pressure rise methodology

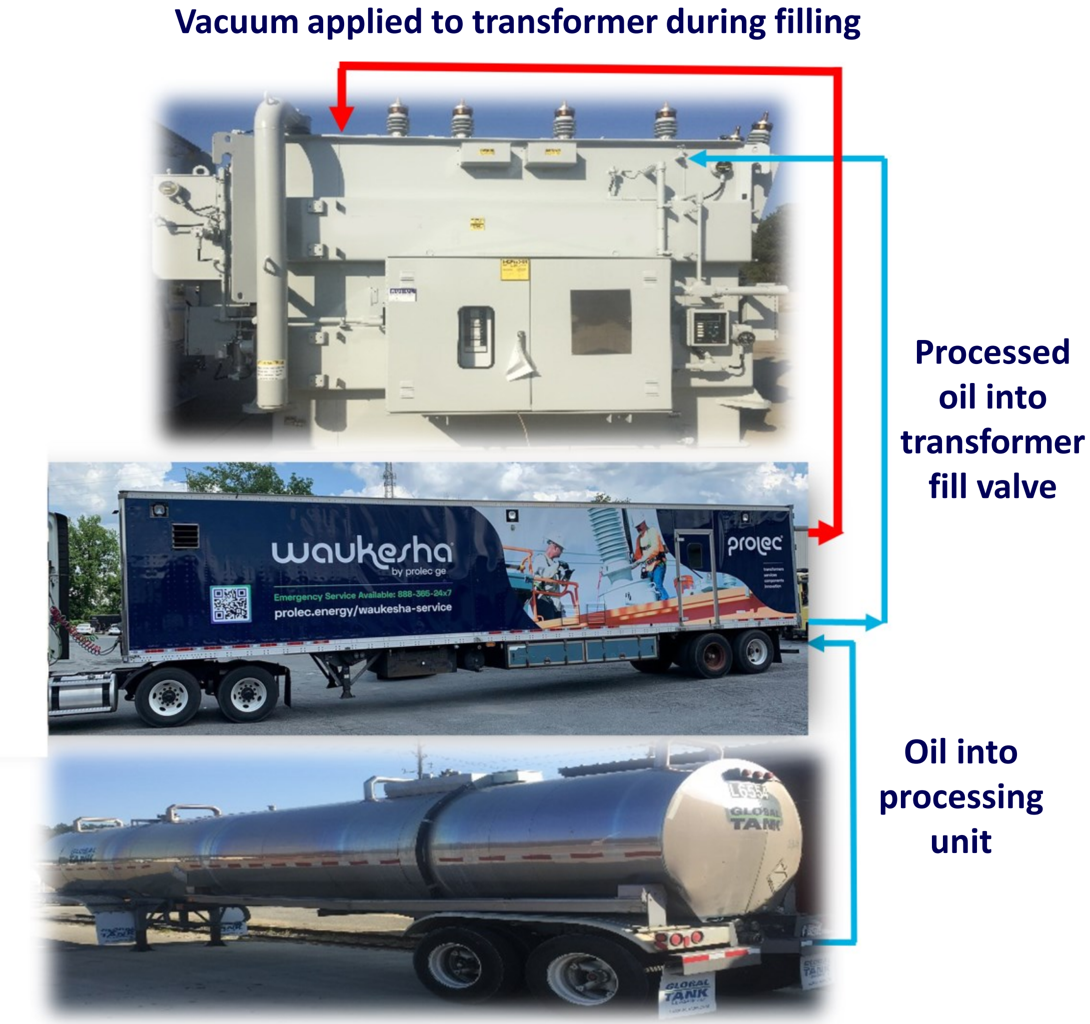
Low Ambient Processing

Vacuum is ineffective when the insulation temperature approaches the freezing point.

Therefore, the insulation temperature must be elevated…

- Evacuate tank to 10 Torr of less
- While maintaining vacuum, introduce oil with inlet temperature of 70°C ± 5°C
- Circulate oil under vacuum until outlet oil temperature reaches 10°C
- Drain oil from transformer
- Immediately begin vacuum operations

Vacuum Oil Filling



- Evacuate tank hold for specified duration
- Pretest oil
- Fill transformer under vacuum
- Verify inlet oil temperature
- Verify positive head pressure an inlet valve
- Monitor oil level during fill
- Fill at specified fill rate

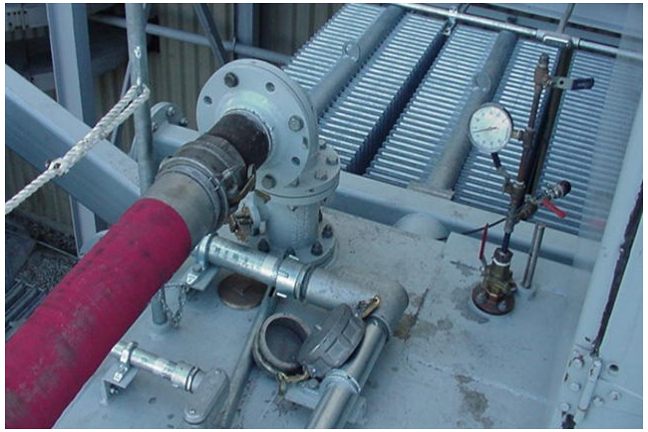
Vacuum & Oil Filling Specifications

	Voltage, kV	≤69 kV	138 kV	230 kV	345 KV	500 kV	765 kV
Preparation	Complete all assembly	yes	yes	yes	yes	yes	yes
	Dew point measurement	yes	yes	yes	yes	yes	yes
	Core & Coil minimum temperature, Celsius	10	10	10	10	10	10
	Drain all oil prior to final vacuum	yes	yes	yes	yes	yes	yes
	Close oil preservation system valve	yes	yes	yes	yes	yes	yes
	Open all cooler equipment	yes	yes	yes	yes	yes	yes
Vacuum	Final Leak Test	yes	yes	yes	yes	yes	yes
	Absolute Pressure Maximum, Torr	2	2	1	0.75	0.5	0.5
	Vacuum Hold Time, Hrs.	12	24	48	48	60	72
Oil Filling	Fill from Top or Bottom	T/B	T/B	T/B	T/B	T/B	T/B
	Oil Temp Minimum, Celsius	50	50	50	50	50	50
	Oil Temp Maximum, Celsius	80	80	80	80	80	80
	Degasser required or Filter Press only	D/F	D/F	D	D	D	D
	Vacuum during filling Maximum, Torr	1	1	1	0.75	0.5	0.5
	Rate of filling, GPM Maximum	30	30	30	30	30	30
	Oil Recirculation, # of passes	2/3/4	2/3/4	2/3/4	2/3/4	2/3/4	2/3/4
	Minimum Stand Time, hrs	12	24	24	48	48	72

*Retain a copy of all Certificates of Authenticity for each tanker arriving at site to support oil filling operations

Source: IEEE Guide C57.93-2019

Vacuum Filling Instructions



- In inclement weather, take necessary precautions to prevent moisture intrusion should a leak develop
- Make connections from pumping system to transformer as short as possible to increase efficiency
- Make sure there are no low spots in hoses for moisture to collect
- Use large diameter hoses (4”) to increase pumping efficiency

Vacuum Filling Instructions (cont.)

- Conduct vacuum leak test
- Pull vacuum per OEM specifications
- Prior to adding oil to transformer, the oil should be tested to verify OEM specifications are met:
  - Moisture content: 30 PPM maximum value
  - Dielectric strength (ASTM-877): 30 kV minimum value
  - Power factor: 0.05% @ 20°c maximum value
  - Interfacial tension: –40 dynes/cm minimum value

Vacuum Oil Filling

Once the prescribed vacuum hold time is completed, the transformer is filled:

- Verify proper acceptance criteria of oil
- Fill oil into upper fill valve or bottom fill valve
- Validate that inlet temperature meets minimum specification
- Verify positive fill pressure at fill location
- Fill at specified flow rate or liquid level change
- Monitor level through site glass

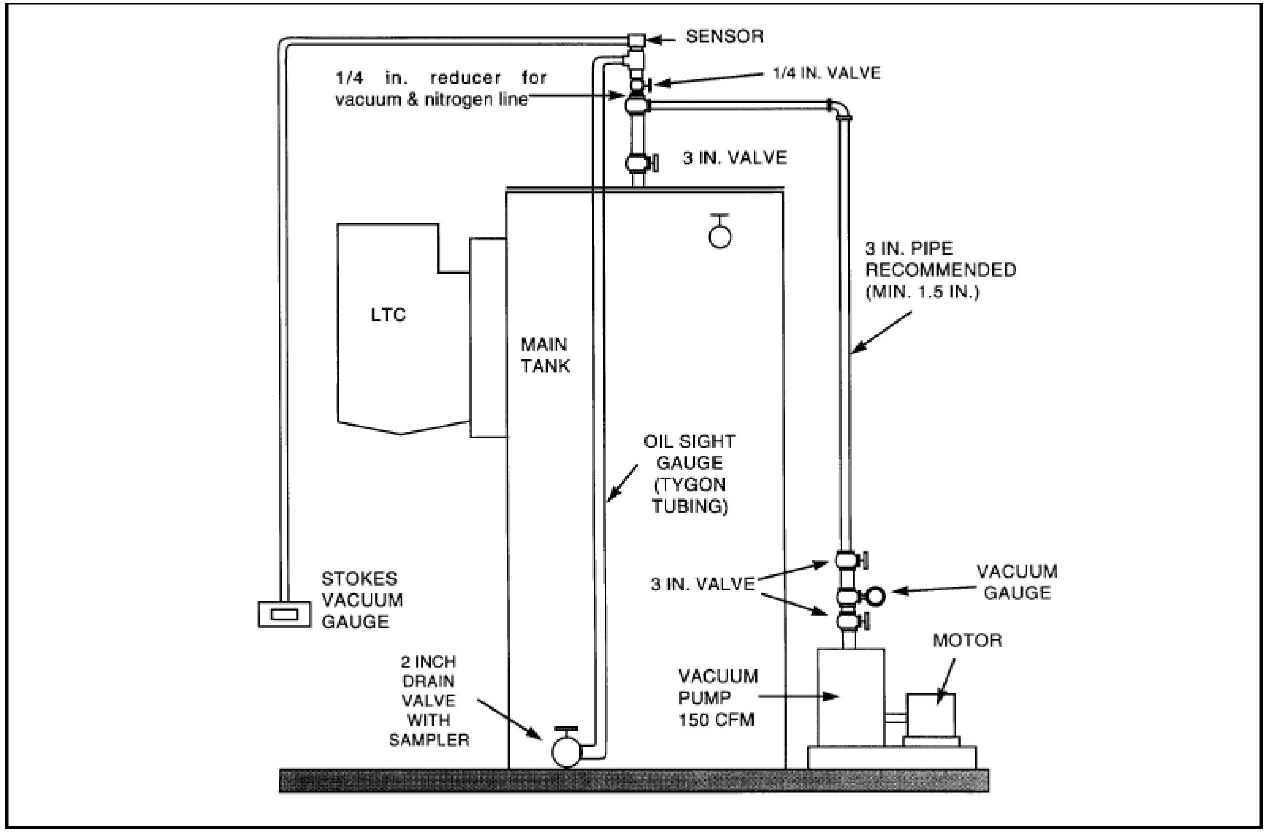


Figure 5-1. Typical piping arrangement for vacuum-filling.

Oil Filling (cont.)

- When oil reaches 6” to 8” from cover, stop filling and isolate vacuum pump
- For sealed or nitrogen blanketed systems, displace vacuum with dry nitrogen
- For COPS* system, displace vacuum with dry gas or oil
- Fill COPS* system once tank pressure reaches slight positive pressure
- *Review option for breaking vacuum with oil*

**COPS = Conservator Oil Preservation System, often referenced as COPS tank*

Vacuum Oil Filling

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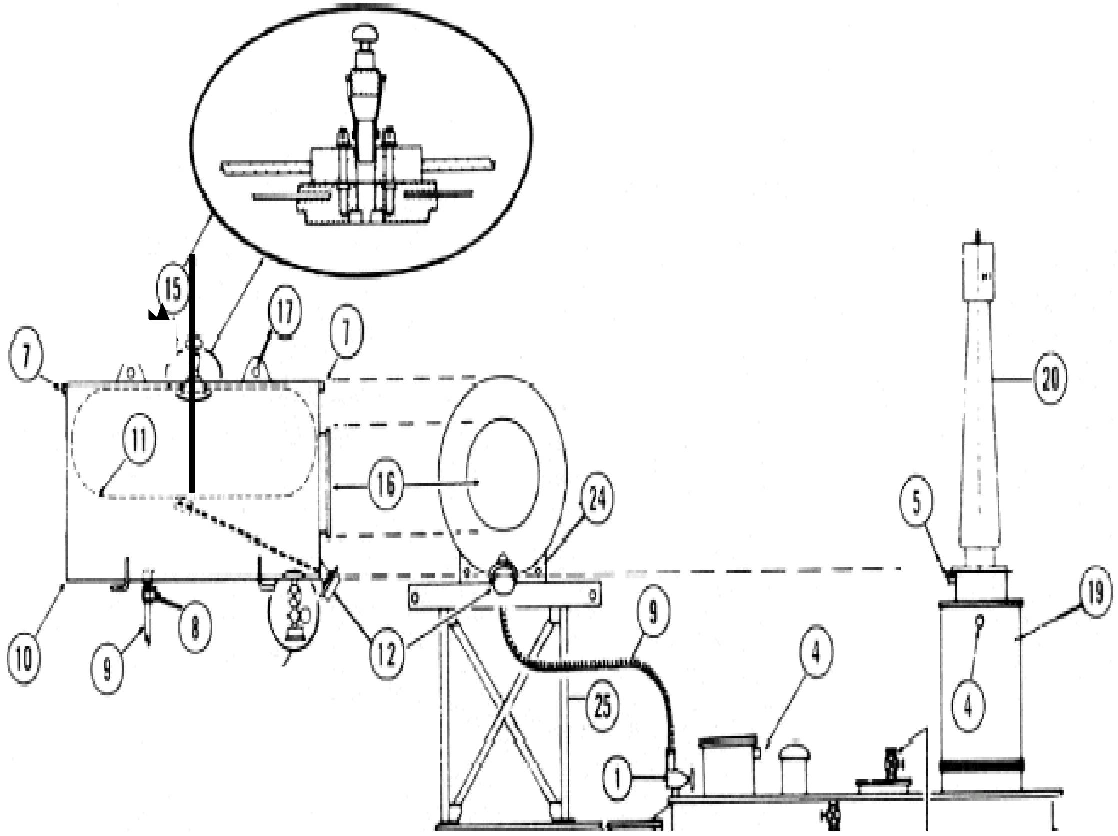
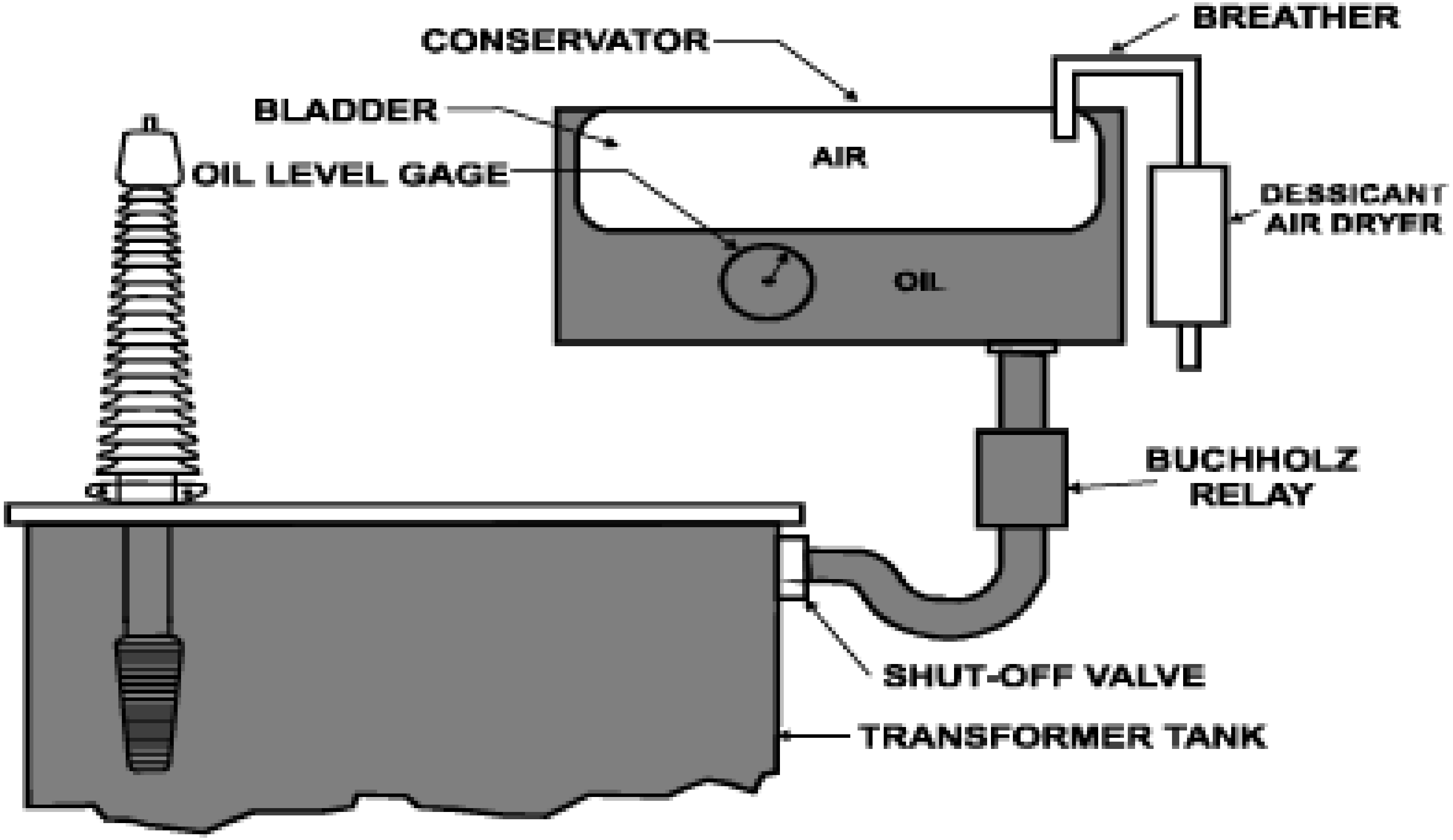
- For sealed or nitrogen blanketed systems, displace vacuum with dry nitrogen
- For conservator system, displace vacuum with dry gas or oil
- Fill conservator system once tank pressure reaches slight positive pressure

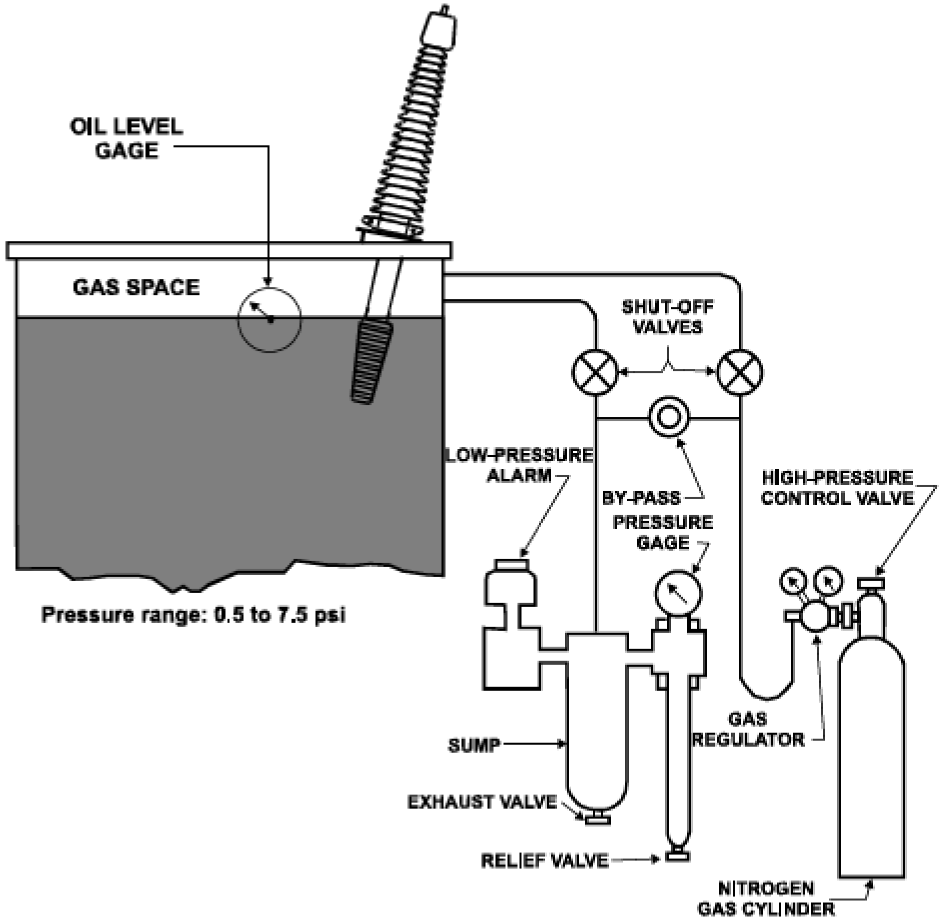


Vacuum Oil Filling

- Adjust oil level in accordance with OEM instructions for given average oil temperature
  - Utilize nameplate data for oil offsets by temperature
- If required by OEM specification, perform oil circulation process
- Bleed all vent locations and reactivate isolated devices
- Observe stand time
- Confirm oil quality


CONSERVATOR
BREATHER
BLADDER
AIR
OIL LEVEL GAGE
DESSICANT
AIR DRYER
OIL
BUCHHOLZ
RELAY
SHUT-OFF VALVE
TRANSFORMER TANK

Oil Filling (cont.)



Caution: When replacing nitrogen cylinders, do not just order a "nitrogen cylinder" from the local welding supplier. Nitrogen for transformers should meet ASTM D-1933 Type III with - 59 °C dew point as specified in IEEE C-57.12.00-1993, paragraph 6.6.3 [27, 2].

Oil Level Verification

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N2 Blanketed Unit

OIL LEVEL BELOW TOP SURFACE OF THE HIGHEST POINT OF THE HIGHEST MANHOLE FLANGE AT 25°C IS 8.5 INCHES.
OIL LEVEL CHANGES 0.81 INCHES PER 10°C CHANGE IN OIL TEMPERATURE.
INHIBITED OIL 0.30 % DBPC
OPERATING PRESSURE OF OIL PRESERVATION SYSTEM IS 8 LBF/IN^2 POSITIVE TO 3.0 LBF/IN^2 NEGATIVE.
TANK DESIGNED FOR 10 LBF/IN^2 POSITIVE AND FULL VACUUM FILLING.
CONTAINS NO DETECTABLE LEVEL OF PCB (LESS THAN 1 PPM) AT THE TIME OF MANUFACTURE.
DESIGN ALTITUDE OF 3300 FEET AMSL.

Oil Level Verification

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Conservator Unit

MAIN TANK DESIGNED FOR 10 LBF/IN^2 POSITIVE AND FULL VACUUM FILLING.
CONSERVATOR TANK WITH AIR FILLED BLADDER NOT DESIGNED FOR FULL VACUUM.
OIL LEVEL CHANGES 2.9 INCHES PER 10°C CHANGE IN OIL TEMPERATURE.
INHIBITED OIL 0.30 % DBPC
LIQUID LEVEL 25 INCHES BELOW TOP OF CONSERVATOR BREATHER MOUNTING FLANGE AT 25°C.
CONTAINS NO DETECTABLE LEVEL OF PCB (LESS THAN 1 PPM) AT THE TIME OF MANUFACTURE.
DESIGN ALTITUDE OF 3300 FEET AMSL.

Oil Temperature Verification

Determining Average Oil Temperature

- Take oil temperature from liquid temperature gauge.
- Using infrared gun or tape on thermometer, record oil temperature at bottom of unit.
- Average the two readings.
- Determine correction factor measurement for each unit based on nameplate data as shown on previous slides.

NOTE:

- On the N2 unit, measure from the PRD to the top of the oil as indicated earlier.
- On the conservator unit, stick a dowel through the breather opening and determine where it lands on top of the bag which indicates oil level. Put a piece of tape on the dowel after calculating level.

Vacuum Filling Instructions

- Vacuum and oil filling is meant to be a continuous process
- If power interruption occurs during filling process, isolate transformer; after restoring power, you can resume process if vacuum level did not exceed 10 mm of hg, but if vacuum level exceeded 10 mm of hg, the transformer must be drained and process restarted
- If criteria is not met while filling, entire tank must be drained and process restarted beginning with dry vacuum
- Verify process in OEM manual in the event of process interruption

Acceptance Testing

Field Acceptance Testing – Transformer Assembly

Prior to Assembly

- Dew Point (initial)
- Core Ground Test (initial)

After Assembly, Prior to Filling

- Transformer Turns Ratio (AC)
- Current Transformer Testing (AC)

Post Vacuum Oil Processing/Filling

- Power Factor Testing (AC)
- Excitation Testing (AC)
- Frequency Response Analysis (AC)
- Insulation Resistance (DC)
- Winding Resistance Testing (DC)
- Core ground test (final)
- Controls and Alarm checks
- Oil Sample/DGA

Core Resistance (Megger)

- **Purpose**
  - Prove insulation integrity of core from ground potential and test for inadvertent core grounds
- **Method**
  - Using megger instrument, 1000V is applied for one minute to core ground strap
  - Some transformers may have multiple core grounds and/or a separate clamp/end-frame ground; each should be tested independently
    - Preventative autotransformer
    - Series transformer
    - Clamp
  - Some transformers may be constructed such that core ground strap is not accessible

Core Resistance (Megger)

Acceptance Criteria

- Minimum standard acceptance limit is 100 megaohms when corrected to 20°C
- Test is sensitive to temperature, moisture and contamination
- Measured values will be different in air and oil

Processed Oil in New Transformer

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Test	Standard	Unit	Voltage	Value
Dielectric Breakdown	ASTM-D1816 w/ 1mm gap	min, kV	< 69 kV	25
			> 69 - <230 kV	30
			> 230 kV	35
Neutralization Number	ASTM-D974	max, mg KOH/g	< 69 kV	0.03
			> 69 - <230 kV	0.03
			> 230 kV	0.03
Interfacial Tension	ASTM-D971	min, Dynes/cm	< 69 kV	38
			> 69 - <230 kV	38
			> 230 kV	38
Moisture Content	ASTM-D1533	max, PPM @ 60°C Avg. Oil Temp.	< 69 kV	20
			> 69 - <230 kV	10
			> 230 kV	10
Power Factor	ASTM-D924	max, % @ 25°C	< 69 kV	0.05
			> 69 - <230 kV	0.05
			> 230 kV	0.05

Take baseline DGA prior to energization

Field Acceptance Testing

Test	Type of Faults Detected	Good	Caution	Concern
Bushing Power Factor (% at 20°C)	Bushing insulation defect	<0.5%	0.5%-1%	>1%
Bushing Capacitance	Shorted condenser or test tap problems	<10% change from baseline		>10% change from baseline
Winding Power Factor (% at 20°C)	Defects in winding insulation or moisture	<0.5%	0.5%-1%	>1%
Winding Capacitance	Winding deformation / Open core ground	<10% change from baseline		>10% change from baseline
Leakage Reactance/LV Impedance	Winding deformation / Through fault damage	<3% change from baseline		>3% change from baseline
Transformer Turns Ratio	Open or shorted windings / improper polarity	< 0.5% standard deviation		>0.5% standard deviation
Winding Insulation Resistance (20°C)	Defects in winding insulation or moisture	> 1000 MΩ		< 1000 MΩ
DC Winding Resistance	Poor connections - winding, bushings, tap changer	<2% phase to phase deviation	2-5% phase to phase deviation	>5% phase to phase deviation
Winding Excitation	Core problems /shorted turns	<10% change from baseline		>10% change from baseline
Core Insulation Resistance (20°C)	Shorted core/damaged core insulation	> 100 MΩ		< 100 MΩ

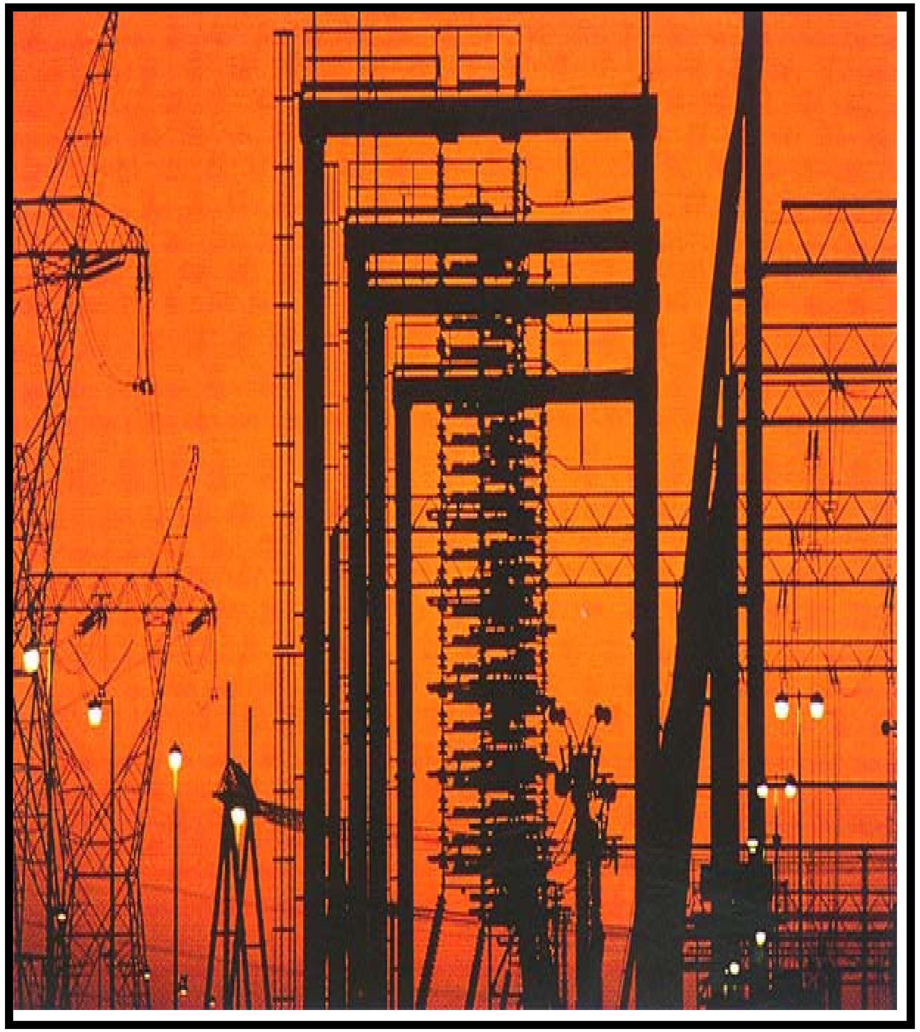
Energization Procedures

- Prior to energizing transformers, verify the following
  - Electrical and oil tests have been complete and have met minimum standards
  - Stand time after oil filling has been met
  - Cooling controls have been set to automatic operation
  - All temporary grounds and shorting wire have been removed
- Energize the transformer with no load from either the high voltage or low voltage side. If possible, it is recommended that voltage be raised in increments.
- Based upon primary voltage class, IEEE recommends a soak period before an operator begins to pick up load on a transformer.

Voltage Class	Suggested Minimum Energizing Period (hours)
230 ≥ 800 kV	12
0 < 230 kV	8

Source: IEEE C57.93-2019

Energization Procedures



- **During the energization period without load, it is recommended that close observation of the transformer be made.**
  - Excessive audible noise
  - Check of liquid temperatures, winding temperatures, and ambient temperature
  - Check of tank pressure
  - Check of oil level indicators
  - Check of gas detector relay.
- **Within the first month of operation, a DGA sample should be taken for baseline analysis**

Questions?

Thank you!

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Contact

Josh Brown
General Manager - Service

Prolec-GE Waukesha, Inc.
Goldsboro, NC

Josh.Brown@prolec.energy
T 919-580-3205
M 919-330-3357

www.waukeshatransformers.com

Acceptance Testing Appendix

Core Resistance (Megger)

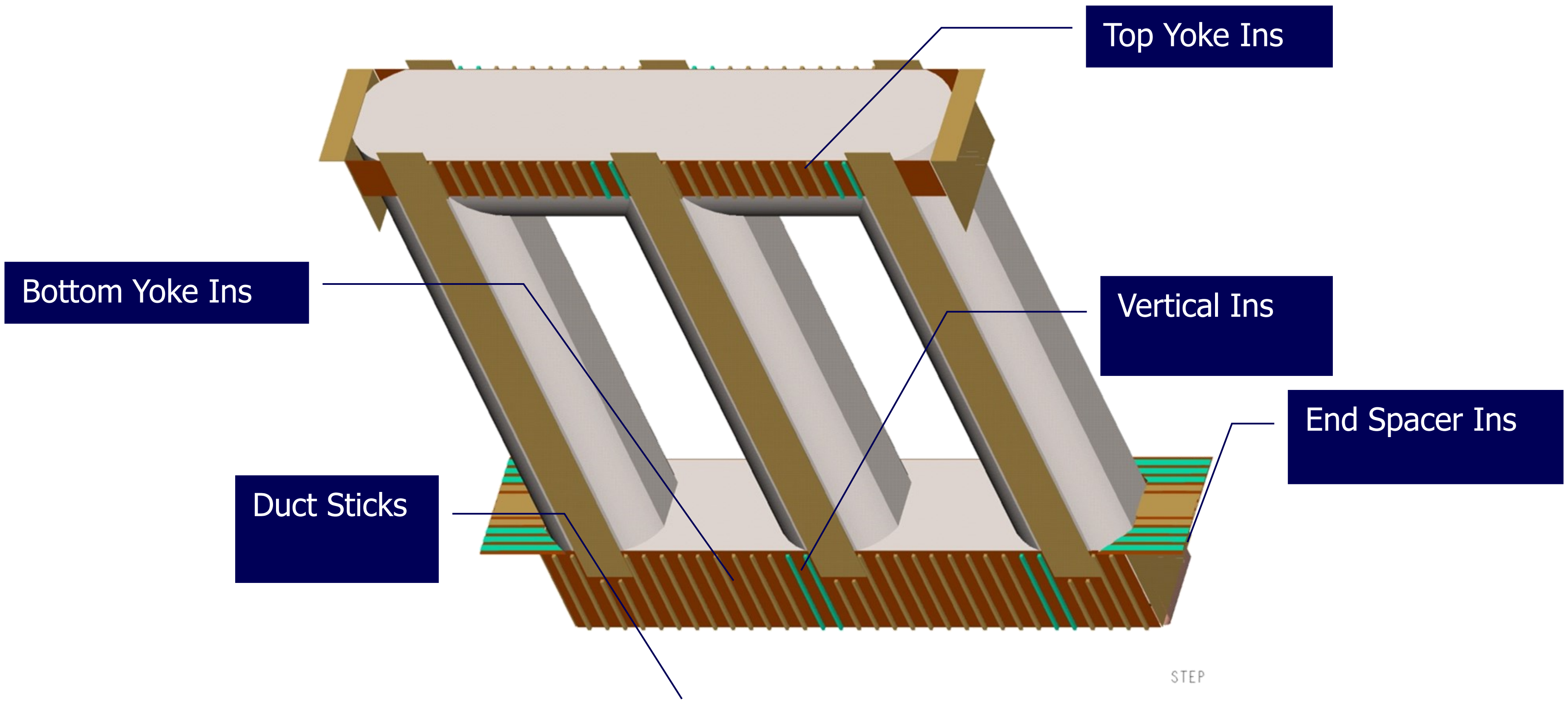
- **Purpose**
  - Prove insulation integrity of core from ground potential and test for inadvertent core grounds
- **Method**
  - Using megger instrument, 1000V is applied for one minute to core ground strap
  - Some transformers may have multiple core grounds and/or a separate clamp/end-frame ground; each should be tested independently
    - Preventative autotransformer
    - Series transformer
    - Clamp
  - Some transformers may be constructed such that core ground strap is not accessible

Core Resistance (Megger)

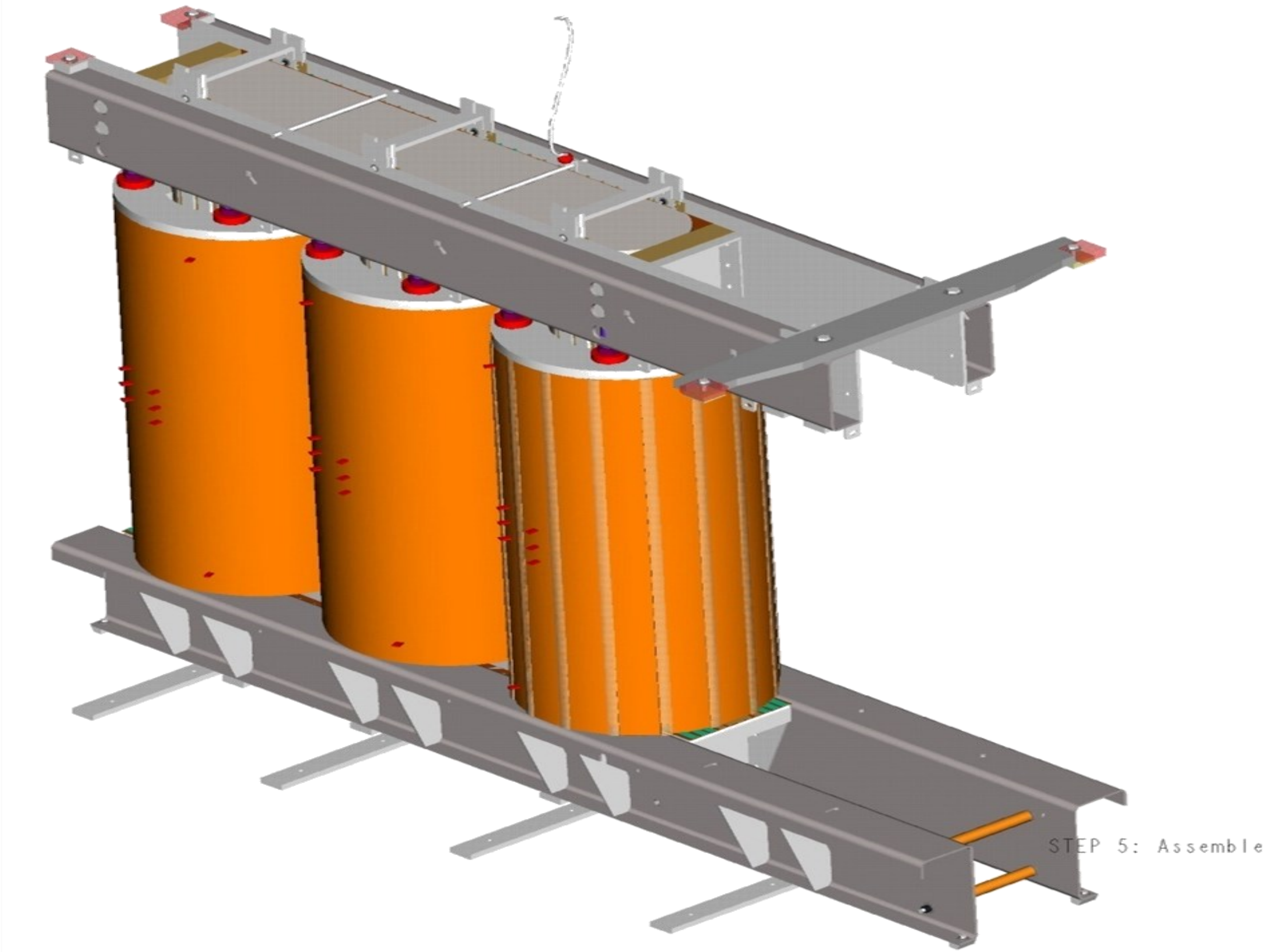
Acceptance Criteria

- Minimum standard acceptance limit is 100 megaohms when corrected to 20°C
- Test is sensitive to temperature, moisture and contamination
- Measured values will be different in air and oil

Core Insulation Resistance (Core Megger)



Core Insulation Resistance (Core Megger)



Field Acceptance Testing – Transformer Assembly

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Prior to Assembly

- Dew Point (initial) ☑
- Core Ground Test (initial) ☑

After Assembly, Prior to Filling

- Transformer Turns Ratio (AC)
- Current Transformer Testing (AC)

Post Vacuum Oil Processing/Filling

- Power Factor Testing (AC)
- Excitation Testing (AC)
- Frequency Response Analysis (AC)
- Insulation Resistance (DC)
- Winding Resistance Testing (DC)
- Core ground test (final)
- Controls and Alarm checks
- Oil Sample/DGA

Transformer Turns Ratio

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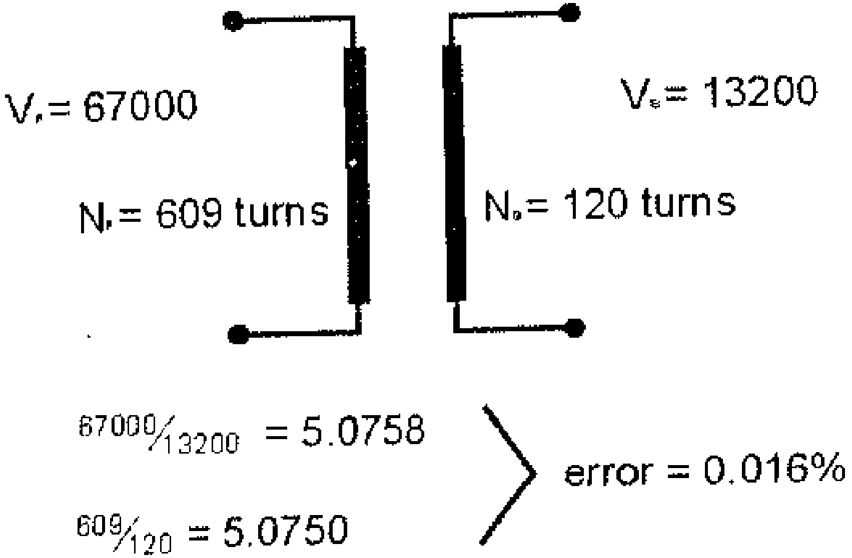


Purpose

Test is done to verify all internal connections and winding configurations are correct.

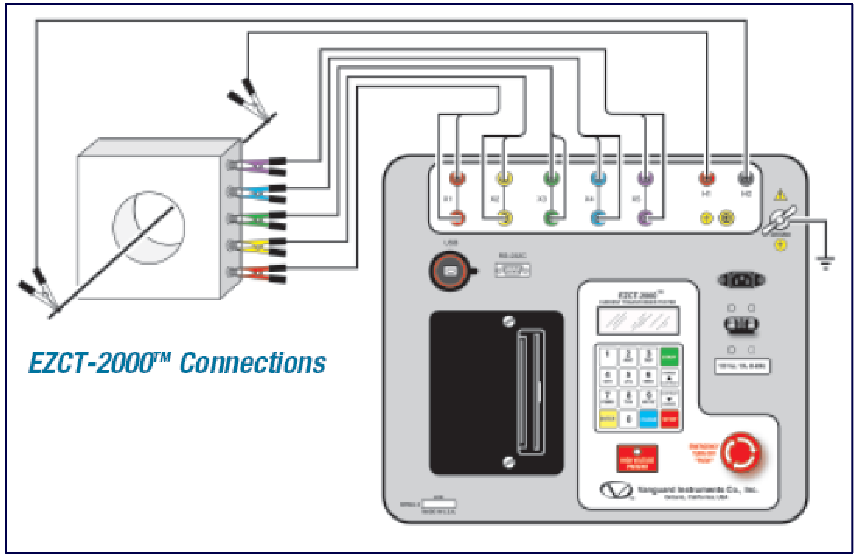
Method

Tests are conducted using low voltage ratio bridge or three phase power supply and voltmeters.

Voltage is applied to the primary winding and the voltage is measured on a secondary winding.

Test is conducted at multiple tap positions. Ratio is calculated in accordance with nameplate values.

CT Ratio, Polarity & Excitation Current



- Verify proper ratio and polarity of current transformers
- Ratio and excitation current can be verified either by primary current injection or secondary voltage injection
- Polarity is verified by battery polarization or buck/boost circuits
- Varied depending on relay accuracy and burden rating of the CT; generally ±1% of calculated ratio

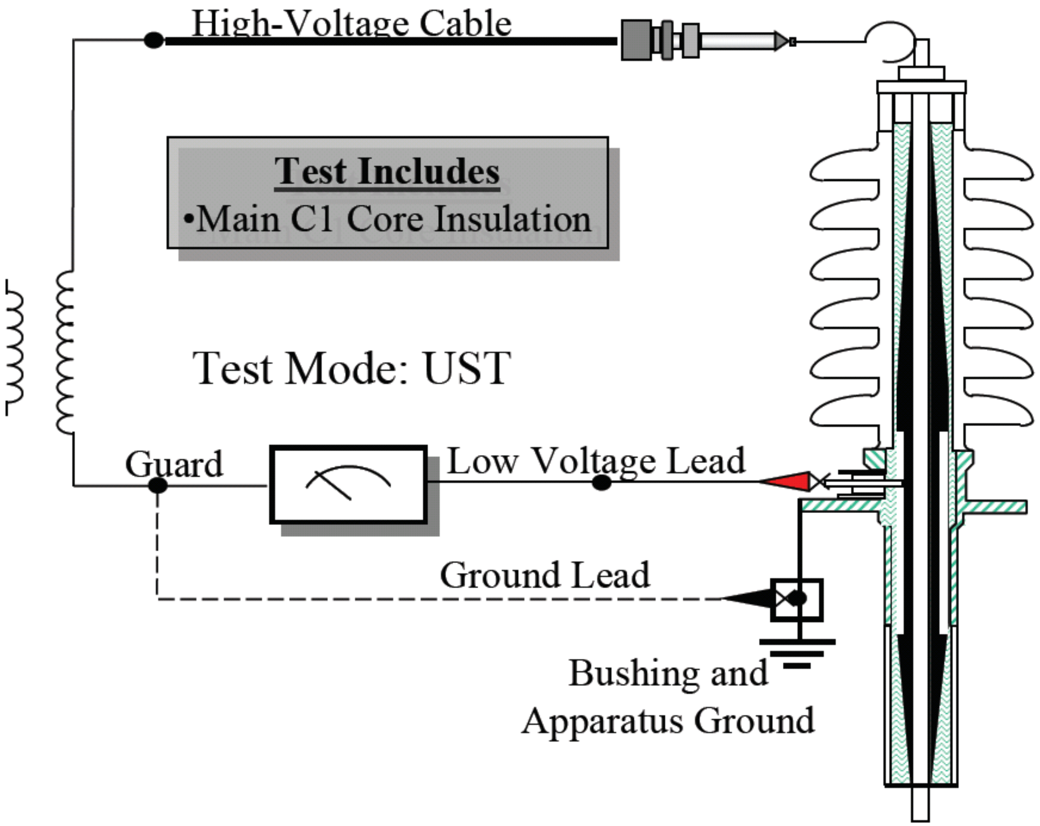
Power Factor Testing – Bushings

Purpose

Detection of moisture or foreign contamination in the insulation structure or damage or excessive contamination to external surfaces.

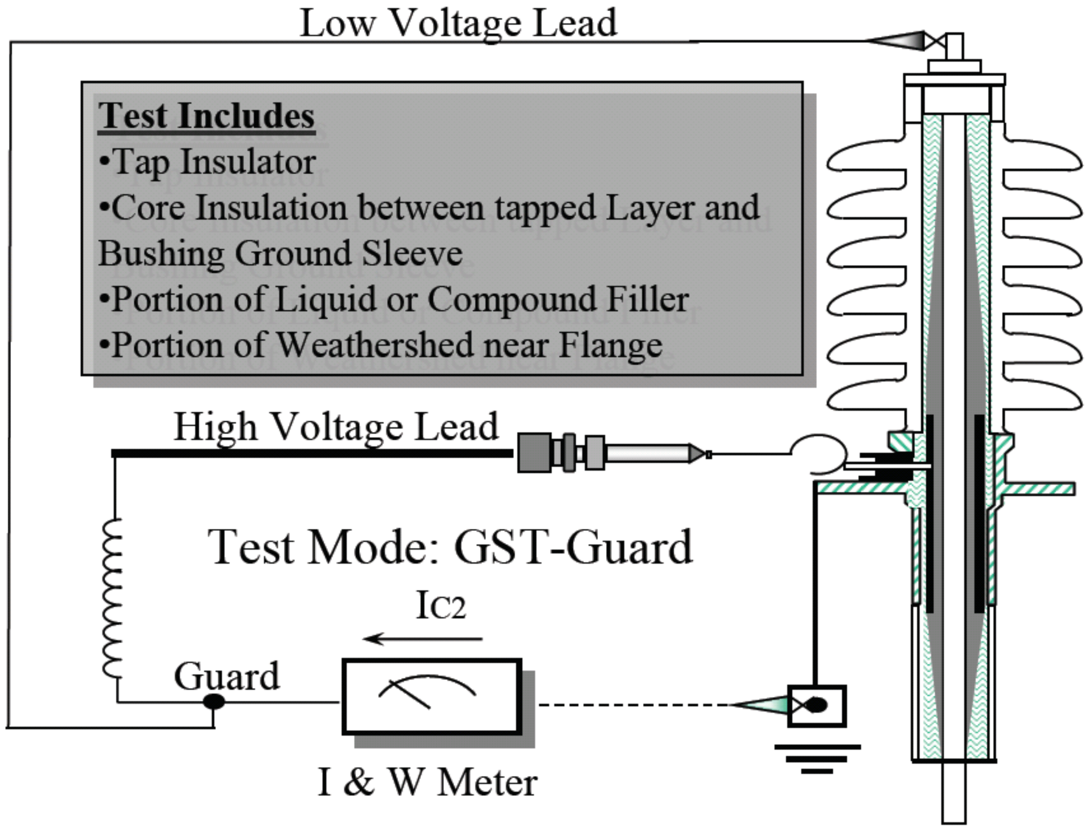
Method

- Insulation power factor bridge is used to measure power factor and capacitance of bushings.
- Test voltages are determined by bushing design and construction.
- Power factor bridge shall be capable of a test voltage of 10 kV.
- Readings are corrected to standard temperature.
- Testing is highly susceptible to temperature, humidity and contamination.



Power Factor Testing – Bushings

- C1 test checks main core insulation
- C2 test checks tap insulator and core insulation between capacitance tap and ground flange
- Hot collar tests can be done for solid bushing



Power Factor Testing – Bushings

Acceptance criteria

Standard acceptance limit for bushings is 0.5% when corrected to 20°C.

Typical maintenance limits:

Good < 0.5%
Deteriorated 0.5% - 1.0%
Investigate > 1.0%

- Recommended that the readings be compared to nameplate values. Bushings should be replaced when the measured power factor doubles the nameplate value or capacitance is in excess of 110% of the nameplate value.
- Natural ester filled units will have higher measured power factor by 2 to 4 times those of mineral oil filled transformers

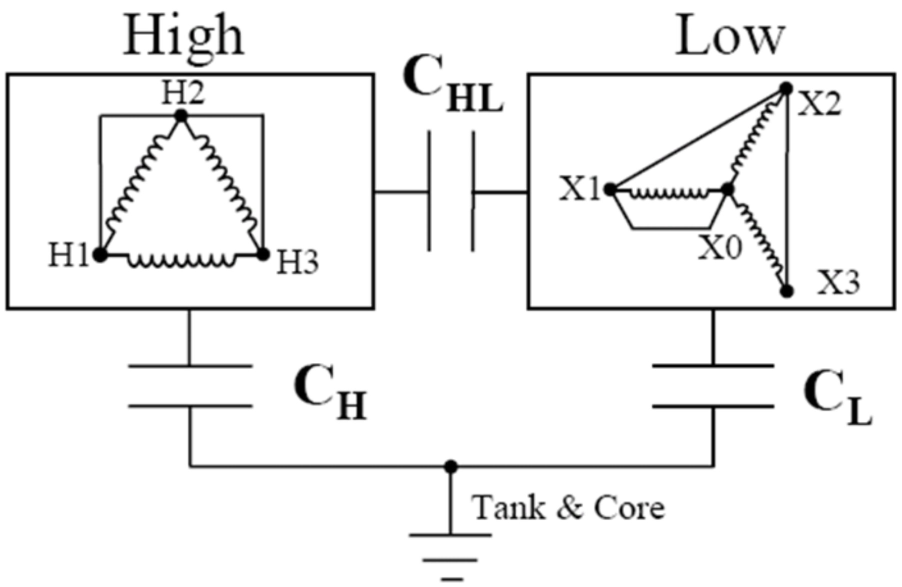
Power Factor Testing – Windings

Purpose

- Detection of moisture or foreign contamination in the insulation structure.
- Test can also detect changes in geometrical configuration of windings or damage to ground and static shields.
- Sensitivity to temperature, moisture, contamination

Method

- Insulation power factor bridge is used to measure power factor and capacitance of windings.
- Power factor bridge shall be capable of a test voltage of 10kV.
- Tests typically completed at 10kV.
- Testing his highly susceptible to temperature, humidity and contamination.



Power Factor Testing – Windings

Acceptance criteria

Standard acceptance limit for new transformer windings is 0.5% when corrected to 20°C.

Natural ester fluid filled transformers will have a higher power factor typically 2 to 4 times greater than measured in mineral oil.

For maintenance testing, the following limits are defined by Doble Engineering:

Less than 0.5%	Good
> 0.5% but < 0.7%	Deteriorated
> 0.5% but < 1.0% & Increasing	Investigate
>1.0%	Bad

Winding Excitation

Purpose

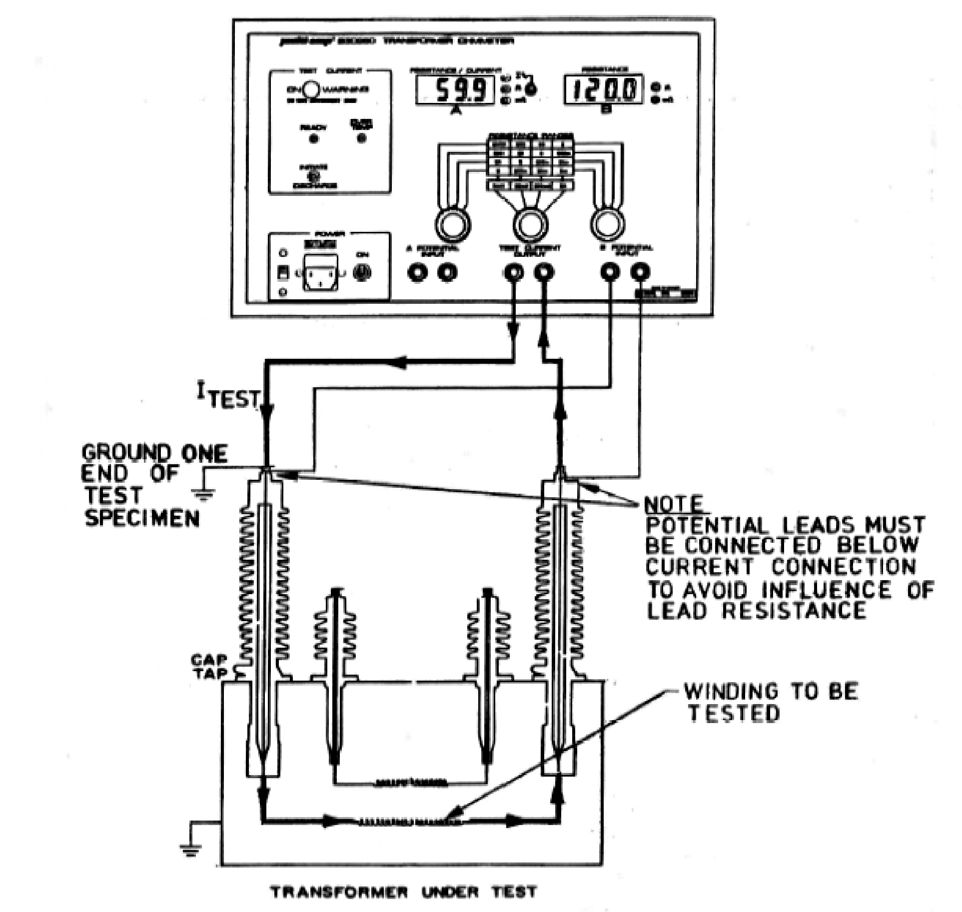
Maintenance test generally recognized to detect any changes in the magnetic circuit. Verify internal connections and detection of any poor connections.

Method

- Voltage source is applied to winding and exciting current is measured.
- Test is most often done with power factor bridge test set at 10 kV.
- Test is very sensitive to temperature and must be corrected.

Acceptable Criteria

This is a repeat test. All subsequent tests are compared to original baseline test for indications of variance. Recommend no more than 5% phase to phase variation on field measurements.



Winding Excitation

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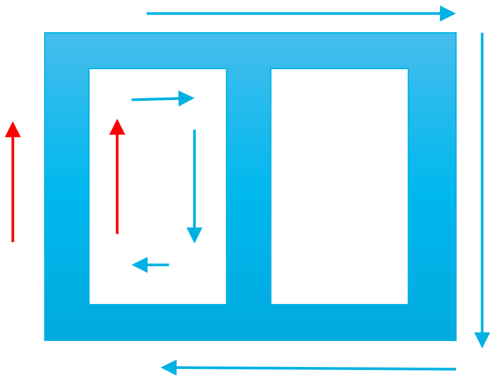
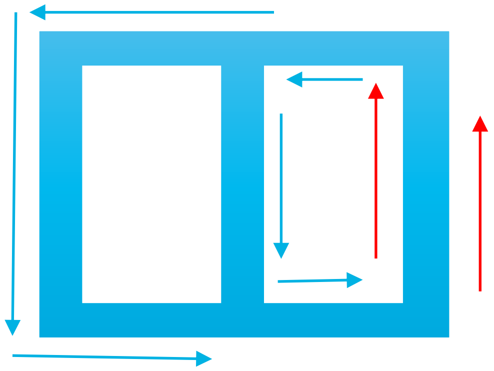
A Phase Excitation

A B C



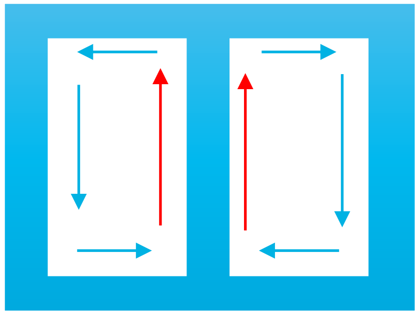
C Phase Excitation

A B C



B Phase Excitation

A B C



A = C

B < A and C

Winding Excitation

Acceptance Criteria

- This is a repeat test. All subsequent tests are compared to original baseline test for indications of variance. Residual magnetism can effect results.
- Typical 2 High, 1 Low pattern for typical 3 limb core form transformer. Center phase should be the phase with lower current.
- Shell form and 5 leg core form design may have different current pattern.
- LTC with a reactor/preventive auto will have different current patterns in bridging and non-bridging positions.

Test No.	Test Mode	Energize	UST	Ground	Float	I_e
1	UST	H_1	H_0	*	H_2H_3, $X_1X_2X_3$ $(Y_1Y_2Y_3)$	H_1–H_0
2	UST	H_2	H_0	*	H_1H_3, $X_1X_2X_3$ $(Y_1Y_2Y_3)$	H_2–H_0
3	UST	H_3	H_0	*	H_1H_2, $X_1X_2X_3$ $(Y_1Y_2Y_3)$	H_3–H_0

*Normally grounded terminal(s) of the X and/or Y windings must be grounded.

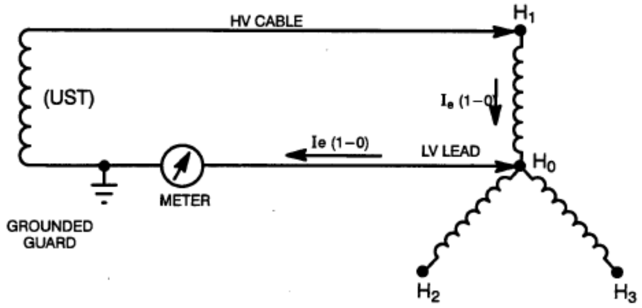


Figure 5.18 Measurement of I_e in a Wye-Connected Transformer Winding (Routine Method)

Frequency Response Analysis

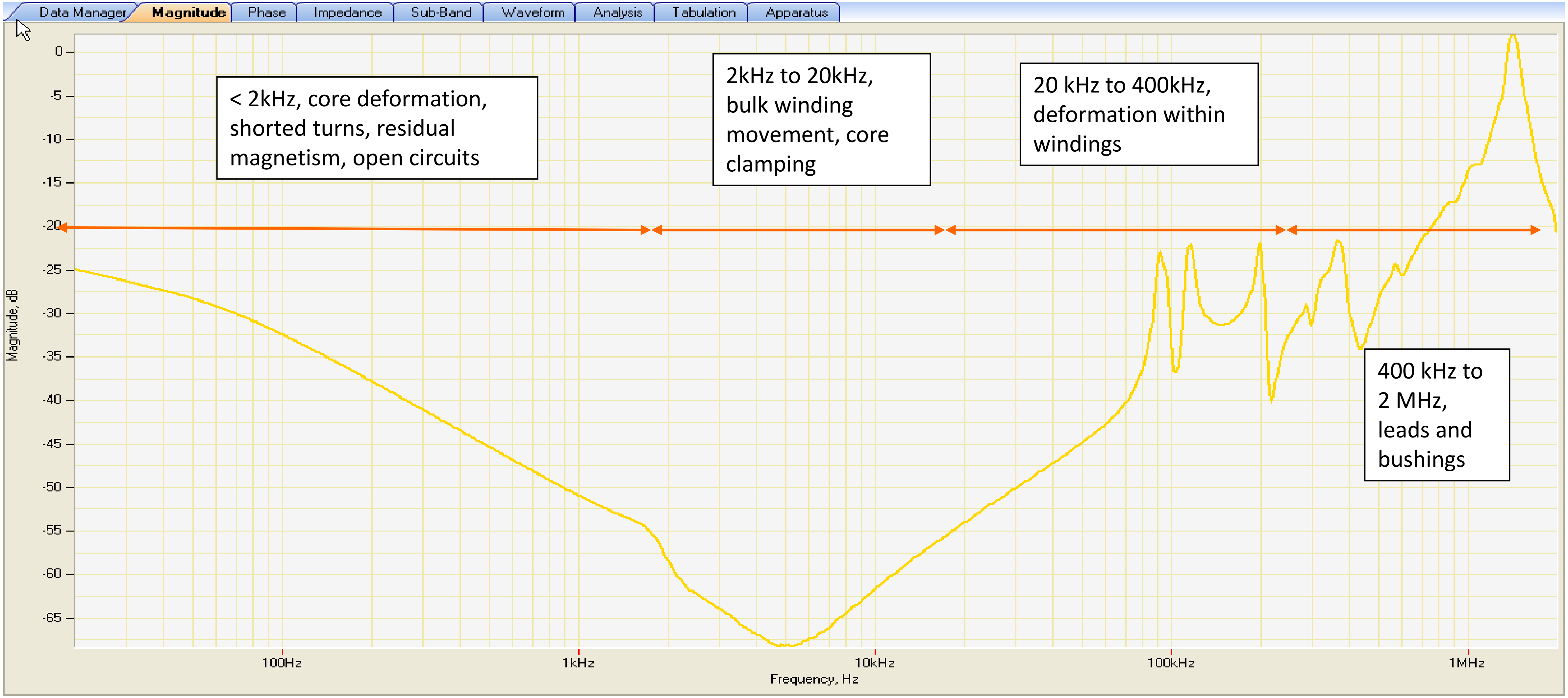
Test Methods
- Impulse method (Framit)
- Sweep Frequency Method (Doble)
- Traces are not comparable between methods

Test for Winding Movement
- Deformation
- Winding Clamping
- Short Circuit Damage

Comparison Test
- Identical 1-Phase Units
- Phases on 3-Phase Unit
- Against Previous Test

Doble SFRA Test

Doble SFRA Test



Insulation Resistance (Megger)

Purpose

Prove insulation integrity between windings and between the winding and ground potential.

Severe contaminants or insulation failure can be detected.

Polarization index can detect changes in insulation structure over time.

Method

Using megger instrument, 1000V to 5000V is applied for one minute between windings and between windings and ground. If polarization index (PI) measurement is required, test voltage must be applied for 10 minutes in each test configuration.

Test is sensitive to moisture, temperature and contamination.

Insulation Resistance (Megger)

Acceptance Criteria

Minimum standard acceptance limit is 1000 Megaohms when corrected to 20°C.

Test is sensitive to temperature, moisture and contamination.

Measured values will be different for different fluids. Natural ester fluid filled transformers will have a reduced megger value up to 10 times less than measured in mineral oil.

Winding Resistance

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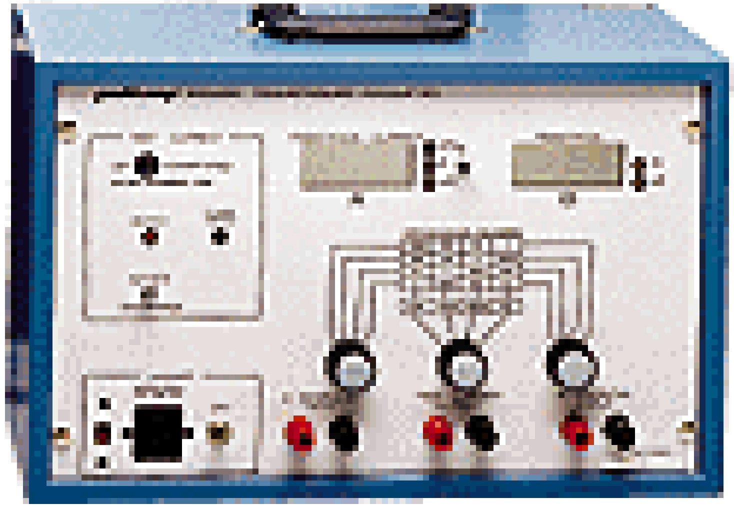
Purpose

- Verify internal connections and detection of any open or poor connections. This is often done as a maintenance type test



Method

- Using Wheatstone or Kelvin bridge, resistance of the transformer winding is measured.
- Test is very sensitive to temperature and must be corrected to standard temperature for comparison.
- The test is generally performed single phase of each section of a winding.

Winding Resistance

- Measurements must be corrected to a standard temperature for comparison
  - 75°C is standard temperature correction for 55°C rise
  - 85°C is standard temperature correction for 65°C rise
- Test correction equations for 55°C Rise
  - Copper Winding
    - $$R_{75} = \frac{R_T\,(234.5 + 75)}{(234.5 + t\,)}$$
  - Aluminum Winding
    - $$R_{75} = \frac{R_T\,(228.1 + 75)}{(228.1 + t\,)}$$
    - t = test temperature in degree C
    - R_T = test resistance

Controls Verification

- Control and relays function of the transformer must be verified. Cooling controls, gas detection system, fault detection systems, flow gauges, liquid level gauges, and temperature gauges must be checked for operation and calibration in accordance with manufacturer's specification.
- Control wiring insulation is tested for shorts, cracks, or other weaknesses.
- Wiring receives "hipot" test at
  - 2500 VDC for current transformer wiring
  - 1500 VDC for all other control wiring
  - Sensitive electronic devices must be disconnected

Field Acceptance Testing – Transformer Assembly

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Prior to Assembly
- Dew point (initial) ☑
- Core ground test (initial) ☑

After Assembly, Prior to Filling
- Transformer Turn Ratio (AC) ☑
- Current Transformer Testing (AC) ☑

Post Vacuum Oil Processing/Filling
- Power Factor Testing (AC) ☑
- Excitation Testing (AC)☑
- Frequency Response Analysis (AC) ☑
- Insulation Resistance (DC) ☑
- Winding Resistance Testing (DC) ☑
- Core ground test (final) ☑
- Controls and Alarm checks ☑
- Oil sample/DGA

Difference Between Factory and Field Testing

Dew Point

Factory

- Secured with Pressure
- Measured in Controlled Environment

Field

Must be measured properly:

- Temperature Swings
- Below Freezing measurement
- Sun Exposure

Conclusion

- Actual meter reading may not be the same
- % moisture is repeatable for measurement on rail car or truck from factory
- Measure in morning just before sun rise
- Do not measure in freezing temperatures
- Future readings have no correlation with factory or initial measurement

Core Insulation Resistance (Core Megger)

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Factory

- Measured on Test Floor
- Measured just before shipping

Field

- Measured upon receipt of transformer in shipping condition
- Measured after assembly
- Measured during PM testing or after repairs

Conclusion

- Do not use previous measurements as baseline
- Too much variability in measurements

Bushing Power Factor (C1 & C2)

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Bushing Factory

- Fresh processing of insulation material
- Measured in rack with measurements recorded on the nameplate

Transformer Factory

- Typically not measured separately in the factory

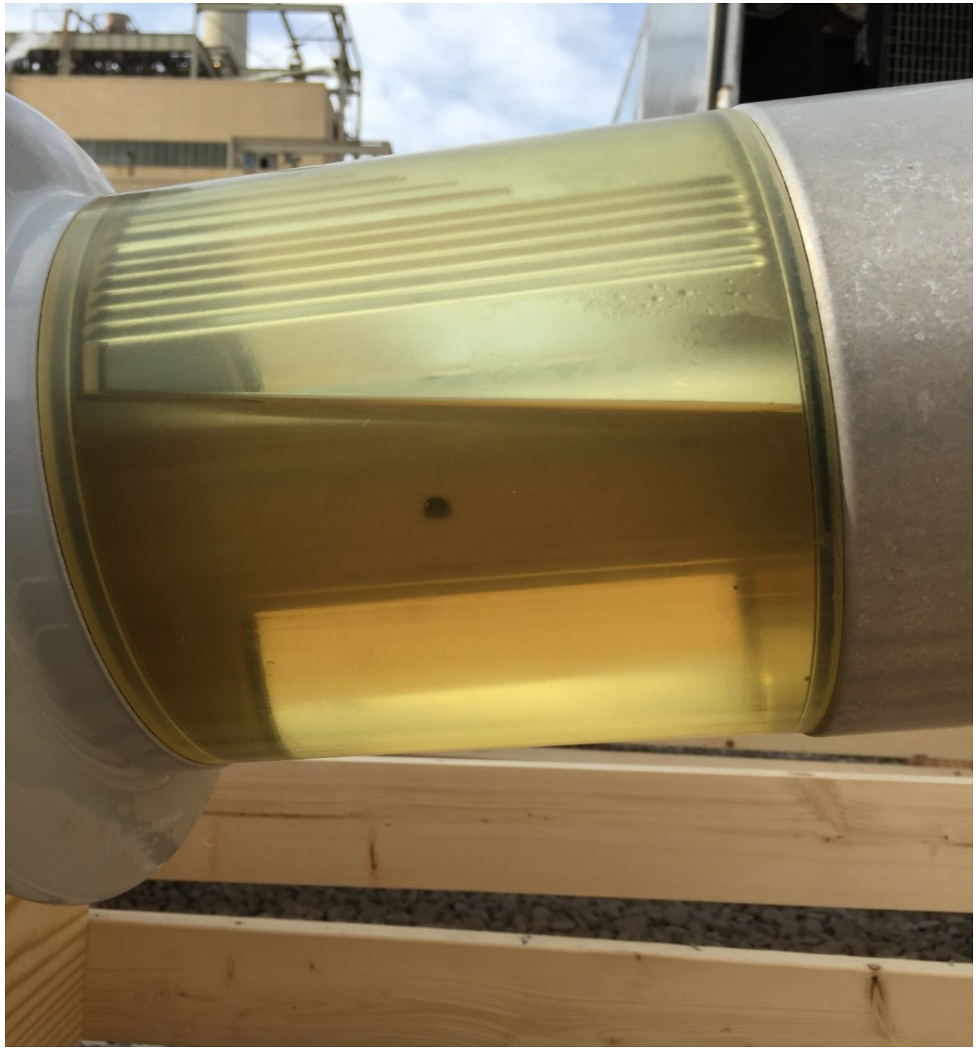
Field

- Must make adjustments if shipped horizontally
- Must clean the bushings properly and use clean slings or rack
- Do not measure in shipping crates
- Can not measure if freezing

Conclusion

- If measured outside transformer, power factor and capacitance measurements should match nameplate (both C1 and C2)
- If measured inside transformer:
  - C1 power factor and capacitance measurements should match nameplate — the nameplate can be used as baseline for future measurements
  - C2 measurements may change — use the measured C2 values after installed as baseline for future measurements

Bushing Power Factor (C1 & C2)



CT Tests

CT Factory

- Everything is tested
- CT is certified and factory report is available

Transformer Factory

- Typically: polarity, ratio and control wiring hi pot completed

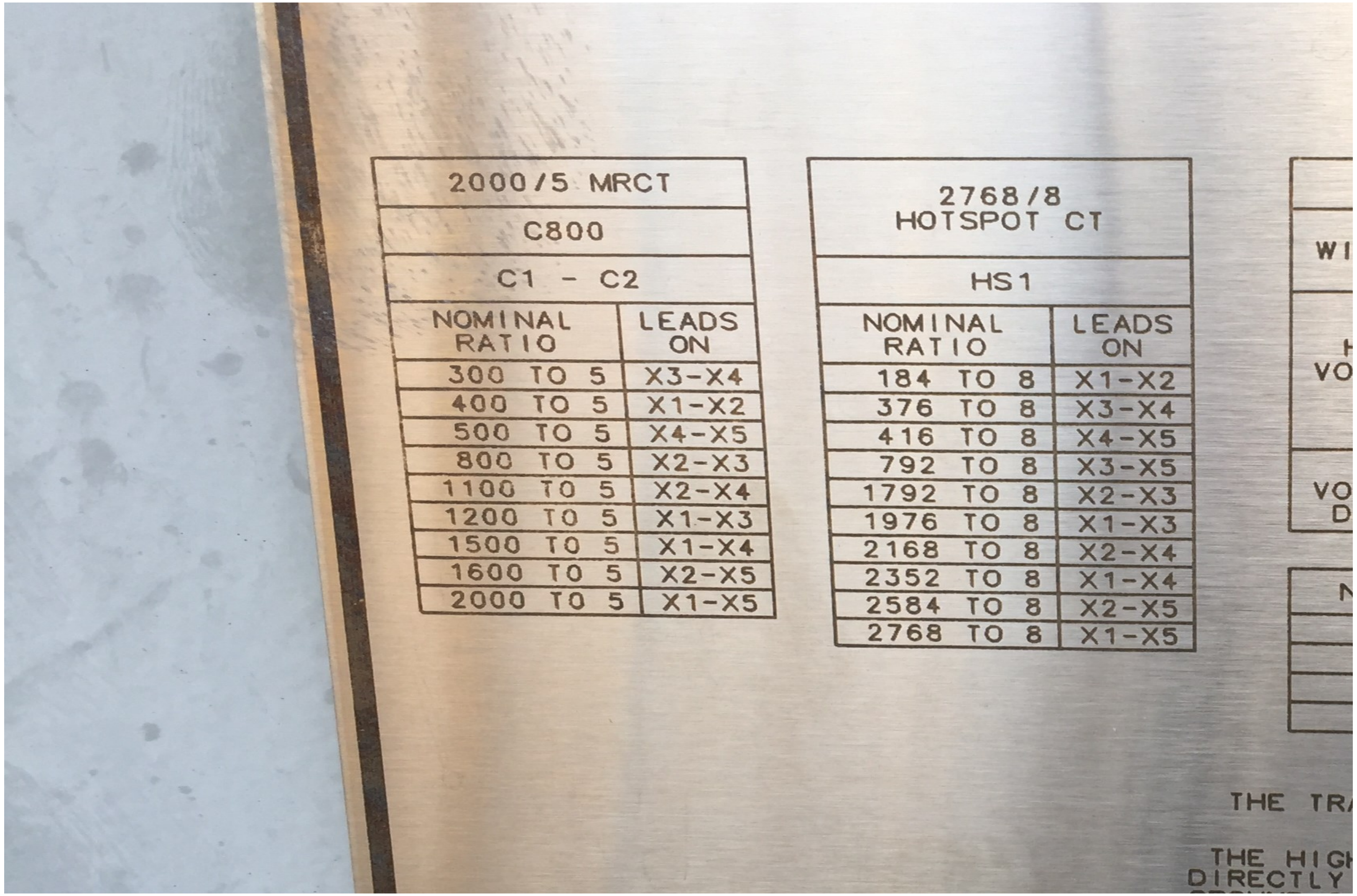
Field

- Polarity, ratio, saturation 1–5
- Sometimes resistance, insulation resistance

Conclusion

- The Transformer nameplate is base line.
- These are repeatable test.

CT Tests


2000/5 MRCT
C800
C1 - C2
NOMINAL RATIO
LEADS ON
300 TO 5 X3-X4
400 TO 5 X1-X2
500 TO 5 X4-X5
800 TO 5 X2-X3
1100 TO 5 X2-X4
1200 TO 5 X1-X3
1500 TO 5 X1-X4
1600 TO 5 X2-X5
2000 TO 5 X1-X5
2768/8
HOTSPOT CT
HS1
NOMINAL RATIO
LEADS ON
184 TO 8 X1-X2
376 TO 8 X3-X4
416 TO 8 X4-X5
792 TO 8 X3-X5
1792 TO 8 X2-X3
1976 TO 8 X1-X3
2168 TO 8 X2-X4
2352 TO 8 X1-X4
2584 TO 8 X2-X5
2768 TO 8 X1-X5

Transformer Turns Ration (TTR)

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Factory

- Testing is compared to the nameplate and winding configuration drawings

Field

- Equipment is important
- Can have external influence

Conclusion

- Ratio results are repeatable.
- Usually the nameplate can be used as a baseline.
- Factory test data is better as a baseline.
- If heavy external influence in the field or equipment differences, then use first field test as baseline.

Winding Insulation Resistance (Winding Megger)

Factory

- Megger is not an accurate measuring with large insulation packages.
- Looking for large numbers

Field

Can use factory for ballpark:

- If large difference, then use another piece of equipment.
- If large difference remains after changing equipment, as long as high number and power factor are "on," test is acceptable.

Conclusion

- Megger equipment is not very repeatable.
- Always look for large number.
- If question with megger readings, refer to Power Factor Readings.

Winding Power Factor

Factory

- Transformer has just been processed
- Factory provides a controlled environment

Field

- Bushings have to be cleaned properly
- Field environment is not controlled

Conclusion

- Do not expect direct correlation between factory and field measurements
- After first field test, use previous test as baseline
- Trend results

Excitation

Factory

- Test is usually performed before losses are measured
- No external influences
- Factory provides a controlled environment

Field

- Field sometimes has other units or overhead lines, etc.

Conclusion

- Dependent on residual magnetism
- Use first field test as a baseline
- Trend results
- The % are fairly repeatable.
- All subsequent tests are compared to original baseline test for indications of variance

Frequency Response Analysis

Factory

- Only measured if required in customer's specification
- Test floor
  - Oil-filled: All bushings installed
- Shipping configuration
- Factory provides a controlled environment

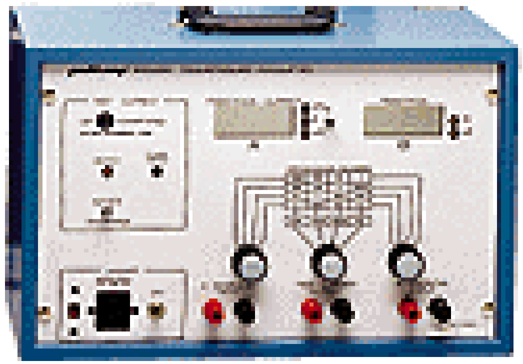
Field

- Shipping configuration
- After assembled and filled

Conclusion

- Factory test are bae line for first test in the field
- First field test should be baseline for the rest of the transformer life
- If no test are available from factory or field then compare phase to phase.

Winding Resistance Factory Measurements



- Why temperature is so important in the factory
- Cold resistance reading (simplified)
  - Transformer filled for days
  - Never energized
  - Transformer is stored inside building
  - Core, oil and winding temps are ambient
  - Thermocouples are located at the top and bottom of the radiator or cooler bank
  - At this point, measurements are compared phase-to-phase to calculations
- Temperature rise resistance
  - Resistance measurements are used to determine the temperature of the windings
  - Using Temperature correctly:
    - $Rs = Rm\ (Ts + Tk\ /\ Tm + Tk)$
    - Rs = resistance at desired temperature
    - Rm = resistance measured
    - TS = desired reference temperature (deg C)
    - Tm = temperature at which the resistance was measured (deg C)
    - TK= constant 234.5 for copper or 225.0 for aluminum

Winding Resistance Field Measurements

Temperature Considerations

Measurement Methods

- Place a thermometer in contact with the tank wall
- Use a liquid temp indicator
- On nitrogen units, you can open a manhole and drop a temp indicator in the oil

Issues

If just taken out of service, the core and coil will be hotter than the oil temperature as they are the source of heat of the oil temperature

If just processed, temperatures will be inconsistent top to bottom and core to oil

Sun pounding on the transformer during the day will make the ambient changes swing much more than in the factory

Conclusions

- Phase-to-phase comparisons are used in the field
- % are usually repeatable

Common Issues Found With Test

1) **Bushing Power Factor**
    1) Power Factor in Crate
    2) Hard to PF Bushings on Straps if Large Bushing
    3) Supposed to have standing up for 24 hours
2) **Resistance Readings not making since**
    1) Make sure that you have give enough time to let readings settle
    2) If taking too long then check into different setups
3) **SFRA or Excitation not correct**
    1) Check for magnetized core
4) **Megger should show inductive kick**
    1) How often do you 20,000 Meg Ohms +
    2) If no inductive kick then core ground might not be connected to the core ground.