Maintenance and Inspection of Transformers

Course No: E06-010
Credit: 6 PDH

Elie Tawil, P.E., LEED AP

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.com

This course was adapted from the U.S. Department of the Interior Bureau of Reclamation, Publication "Transformers: Basics, Maintenance, and Diagnostics – Section 3, 4 and 5", which is in the public domain.

3. Routine Maintenance

The following chapters address routine maintenance, as well as specific testing and diagnostic techniques and tools used to assess the condition of transformers (more detail is included for oil-filled power transformers). Some processes are often above and beyond routine maintenance work to keep the transformer operational. Transformer diagnostics require specialized equipment and training. This expertise is not expected to be maintained in every office. In some cases, it may be necessary to contact diagnostics specialists, either inside or outside Reclamation, who have the latest equipment and recent experience.

Figure 25 shows the overall transformer condition assessment methodology, linking routine maintenance and diagnostics.

3.1 Introduction to Reclamation Transformers

Standards organizations such as American National Standards Institute/Institute of Electrical and Electronic Engineers (ANSI/IEEE) consider average GSU transformer life to be 20 to 25 years. This estimate is based on continuous operation at rated load and service conditions with an average ambient temperature of 40 ºC (104 degrees Fahrenheit [ºF]) and a temperature rise of 65 ºC. This estimate is also based on the assumption that transformers receive adequate maintenance over their service life [26]. Reclamation, Bonneville Power Administration, and Western Area Power Administration conduct regular studies to determine statistical equipment life. These studies show that average life of a Reclamation transformer is 40 years. Reclamation gets longer service than IEEE estimates because of operating at lower ambient temperatures and with lower loads. A significant number of transformers were purchased in the 1940s, 1950s, and into the 1970s. Several have been replaced, but Reclamation has many transformers that are nearing, or are already well past, their anticipated service life. We should expect transformer replacement and failures to increase, due to this age factor.

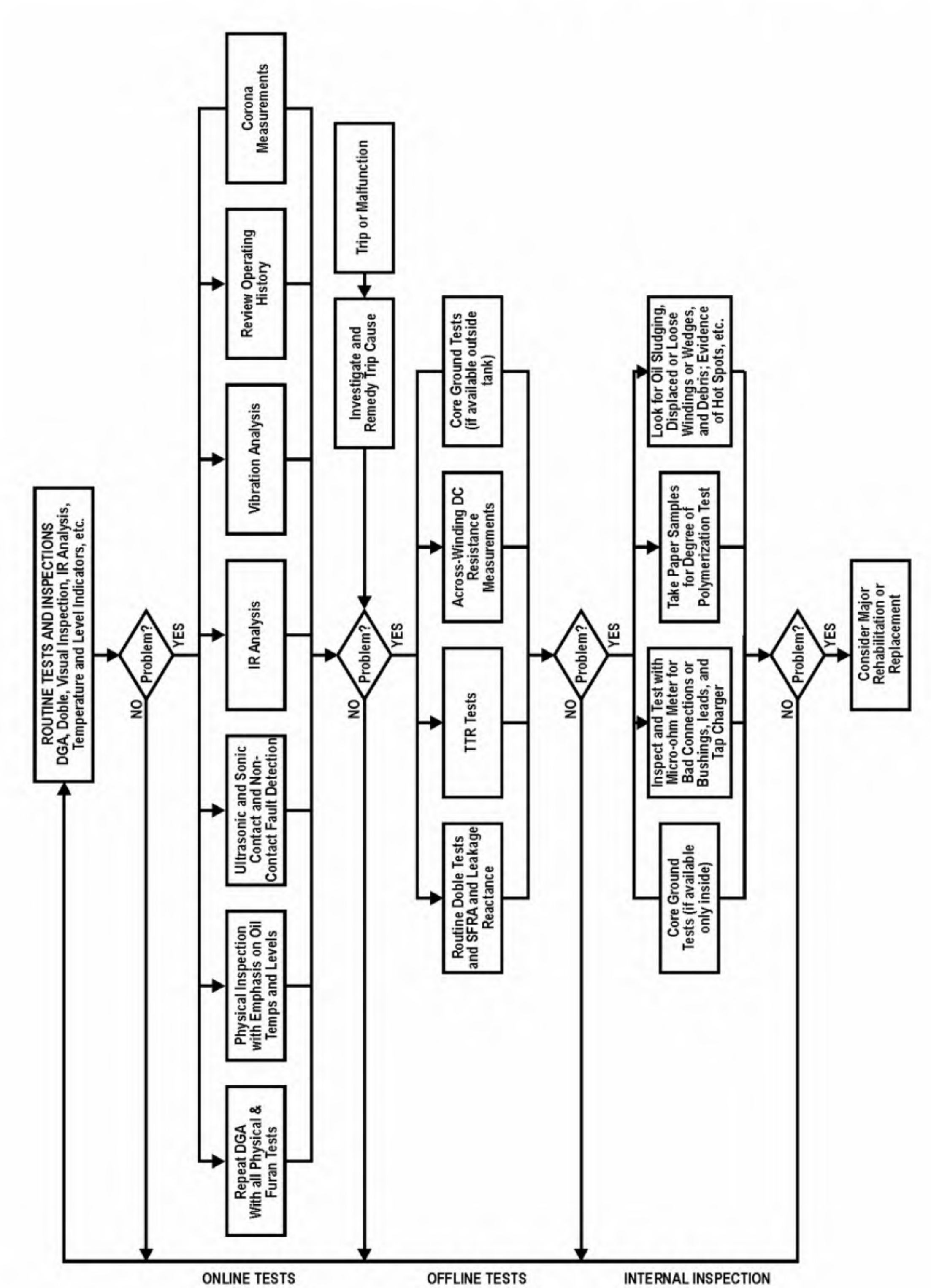

Figure 25 – Transformer Diagnostics Flowchart.

Current minimum replacement time is around 14 months; a more realistic time may be 18 months to 2 years. In the future, lead times may extend well beyond what they are today. Therefore, high-quality maintenance and accurate diagnostics are important for all transformers, but it is absolutely essential for older ones—especially for critical transformers that would cause loss of generation. It is also very important to consider providing spares for critical transformers.

3.2 Transformer Cooling Methods Introduction

Heat is one of the most common destroyers of transformers. Operation at only 8 ºC above the transformer rating will cut transformer life by 50%. Heat is caused by internal losses, due to loading, high ambient temperature, and solar radiation. It is important to understand how your particular transformers are cooled and how to detect problems in the cooling systems. ANSI and IEEE require the cooling class of each transformer to appear on its nameplate. Cooling classifications, with short explanations, appear in sections 3.3 and 3.4. The letters of the class designate inside atmosphere and type or types of cooling. In some transformers, more than one class of cooling and load rating is indicated. At each step of additional cooling, the rating increases to correspond with increased cooling. Note that the letter "A" indicates air, "FA" indicates forced air (fans), "O" indicates oil, "FO" indicates forced oil (pumps), "G" indicates some type of gas, and "W" indicates there is a water/oil heat exchanger.

DRY-TYPE TRANSFORMER MAINTENANCE SUMMARY
(See Section 3.3.)

When new after energizing and allowing temperature and loading to stabilize	• Do an infrared scan and compare with temperature gauge, if any. • If transformer is gas filled (nitrogen [N_2]), check pressure gauge against data sheets; never allow gas pressure to fall below 1 psi. • Check loading and compare with nameplate rating. • Functionally test fans and controls for proper operation. • Functionally test temperature alarms and annunciator points. • Check area around transformer - clear of debris and parts storage. • Check transformer room for proper ventilation.
After 1 week of operation at normal loading	• Perform infrared scan and compare with temperature gauge, if any. • Check temperature gauge, if any, and compare with nameplate rating. • Check loading and compare with nameplate rating.
Annually (Note: The time between these periodic inspections may be increased if the first internal inspection of windings and connections are clean and in good condition and if loading is at or below nameplate rating.)	• Perform an infrared scan before de-energizing. • De-energize and remove panels for internal inspection. • If possible, re-energize, re-load, and do infrared (IR) inspection for hot spots and loose connections. • Use vacuum to remove as much dirt as possible. • After vacuuming, use low-pressure, dry air (20 to 25 psi) to blow off remaining dirt. Caution: Make sure air is dry. • Check for discolored copper and discolored insulation (indicates overheating). • Check tap changer and tap connections. • Check for corroded and loose connections. • Check for loose iron and damaged coils. • Check for carbon tracking on insulation and insulators. • Check for adequate electrical clearance. • Check for cracked, chipped, and loose insulators. • Check base or support insulators, including vibration isolation supports. • If windings are found dirty, add filter material to air intake ports. • Megger® high side windings to low side windings and both high and low side to ground. • Do a turns ratio test if electrical problems are found or suspected. • Check fan blades for cleanliness; remove dirt and dust. • Check fans, controls, alarms, and annunciator points. • Check pressure gauge on N_2 filled transformers; compare with weekly data sheets; never allow pressure to fall below 1 psi. • Check all bolted connections with wrenches or sockets for tightness. • Check for loose mounting for windings. • Check primary, secondary, and ground connections. • Repair all problems found in above inspections.

3.3 Dry-Type Transformers

Cooling classes of dry-type transformers are covered by ANSI/IEEE standard C57.12.01 Section 5.1 [1]. A short explanation of each class is given below.

1. Class AA transformers are ventilated and self-cooled. This means there are ventilation ports located in outside walls of the transformer enclosure. There are no fans to force air into and out of the enclosure, with typically no external fins or radiators. Cooler air enters the lower ports, is heated as it rises past windings, and exits the upper ventilation ports. (Although it is not repeated below; it is obvious that, in every cooling class, some heat is also removed by natural circulation of air around the outside of the enclosure.)
2. Class AFA transformers are self-cooled (A) and additionally cooled by forced circulation of air (FA). This means that there are ventilation ports for fan inlets and outlets only. (Inlets are usually filtered.) Normally, there are no additional ventilation ports for natural air circulation.
3. Class AA/FA transformers are ventilated and self-cooled (same as Class AA in item 1). In addition, they have a fan or fans providing additional forced-air cooling. Fans may be wired to start automatically when the temperature reaches a pre-set value. These transformers generally have a dual load rating—one for AA (self-cooling natural air flow) and a larger load rating for FA (forced air flow).
4. Class ANV transformers are self-cooled (A), non-ventilated (NV) units. The enclosure has no ventilation ports or fans and is not sealed to exclude migration of outside air, but there are no provisions to intentionally allow outside air to enter and exit. Cooling is by natural circulation of air around the enclosure. This transformer may have some type of fins attached outside the enclosure to increase surface area for additional cooling.
5. Class GA transformers are sealed with a gas inside (G) and are self-cooled (A). The enclosure is hermetically sealed to prevent leakage. These transformers typically have a gas, such as nitrogen or freon, to provide high dielectric and good heat removal. Cooling occurs by natural circulation of air around the outside of the enclosure. There are no fans

to circulate cooling air; however, there may be fins attached to the outside to aid in cooling.

3.3.1 Potential Problems and Remedial Actions for Dry-Type Transformer Cooling Systems [15]

It is important to keep transformer enclosures reasonably clean. It is also important to keep the area around them clear. Any items near or against the transformer impede heat transfer to cooling air around the enclosure. As dirt accumulates on cooling surfaces, it becomes more and more difficult for air around the transformer to remove heat. As a result, over time, the transformer temperature slowly rises unnoticed, reducing service life.

Transformer rooms and vaults should be ventilated. Portable fans (never water) may be used for additional cooling if necessary. A fan rated at about 100 cubic feet per minute (cfm) per kilowatt (kW) of transformer loss [6], located near the top of the room to remove hot air, will suffice. These rooms/vaults should not be used as storage.

When the transformer is new, check the fans and all controls for proper operation. After it has been energized and the loading and temperature are stable, check the temperature with an infrared (IR) camera and compare loading with the nameplate. Repeat the temperature checks after 1 week of operation.

Once each year under normal load, check transformer temperatures with an IR camera [4, 8]. If the temperature rise (above ambient) is near or above nameplate rating, check for overloading. Check the temperature alarm for proper operation. Check enclosures and vaults/rooms for dirt accumulation on transformer surfaces and debris near or against enclosures. Remove all items near enough to affect air circulation. To avoid dust clouds, a vacuum should first be used to remove excess dirt. Low-pressure (20 to 25 psi), dry compressed air may be used for cleaning after most dirt has been removed by vacuum. The transformer must be de-energized before this procedure, unless it is totally enclosed and there are no exposed energized conductors. Portable generators may be used for lighting.

After de-energizing the transformer, remove access panels and inspect windings for dirt- and heat-discolored insulation and structure problems [15]. It is important that dirt not be allowed to accumulate on windings because it impedes heat removal and reduces winding life. A vacuum should be used for the initial winding cleaning, followed by compressed air [8]. Care must be taken to ensure the compressed air is dry to avoid blowing moisture into windings. Air pressure should not be greater than 20 to 25 psi to avoid imbedding small particles into insulation. After cleaning, look for discolored copper and insulation, which indicates overheating. If discoloration is found, check for loose connections. If there are no loose connections, check the cooling paths very carefully and check for overloading after the transformer has been re-energized. Look for carbon tracking and cracked, chipped, or loose insulators. Look for and repair loose clamps, coil spacers, deteriorated barriers, and corroded or loose connections.

Check fans for proper operation, including controls, temperature switches, and alarms. Clean fan blades and filters if needed. A dirty fan blade or filter reduces cooling air flow over the windings and reduces service life. If ventilation ports do not have filters, they may be fabricated from home furnace filter material. Adding filters is only necessary if the windings are dirty upon yearly inspections.

3.4 Liquid-Immersed Transformers

Cooling classes of liquid-immersed transformers are covered by IEEE C57.12.00 Section 5.1 [2]. A short explanation of each class follows.

3.4.1 Liquid-Immersed, Air-Cooled

There are three classes in this category.

1. **Class OA:** Oil-immersed, self-cooled. Transformer windings and core are immersed in some type of oil and are self-cooled

OIL-FILLED TRANSFORMER MAINTENANCE SUMMARY

Task	After 1 Month of Service	Annually	3 to 5 Years
Before energizing, inspect and test all controls, wiring, fans, alarms, and gauges.			
In-depth inspection of transformer and cooling system;check for leaks and proper operation. Do a dissolved gas analysis (DGA).	Oil pumps load current, oil flow indicators, fans, etc. See 3.4.6 and 4. Thermometers 4.2 and 4.3. Heat exchangers. Transformer tank 4.1. Oil level gauges 4.4. Pressure relief 4.5. Do a DGA.	Oil pumps load current, oil flow indicators, fans etc. See 3.4.6 and 4. Thermometers 4.2. Heat exchangers 4.2 and 4.3. Transformer tank 4.1. Oil level gauges 4.4. Pressure relief 4.6. Do a DGA.	Check diaphragm or bladder for leaks if there is a conservator. See 4.9.
IR scan of transformer cooling system, bushings, and all wiring.	See 3.4.5.7 and 4.8.	See 3.4.5.7 and 4.8.	
Test all controls, relays, gauges; test alarms and annunciator points.	See all of section 4.	Inspect pressure relief for leaks and indication for operation (rod extension). See 4.5.	Thermometers. See 4.2 and 4.3. Oil level gauges 4.5. Inspect pressure relief 4.5. Sudden pressure relay 4.6. Buchholz relay 4.7. Test alarms, fan, and pump controls, etc. See 3.4.6.
Inspect transformer bushings.	Check with binoculars for cracks and chips; look for oil leaks and check oil levels; IR scan. See 4.8.	Check with binoculars for cracks and chips, look carefully for oil leaks and check oil levels IR scan. See 4.8.	
In-depth inspection of bushings; cleaning/waxing if needed.			Close physical inspection, cleaning/ waxing, and Doble testing, in addition to other listed inspections. See 4.8.
Doble test transformer and bushings.	Doble test transformer and bushings before energizing. See 4.8, 9.3.		See 4.8 and 9.3.
Inspect pressure controls if there is nitrogen over oil in transformer; inspect pressure gauge.	See 4.9.2.	See 4.9.2. Also see 4.9.1 to test pressure gauge if transformer has N_2 over oil with no means to automatically add N_2.	

by natural circulation of air around the outside enclosure. Fins or radiators may be attached to the enclosure to aid in cooling.

2. Class OA/FA: Liquid-immersed, self-cooled/forced air-cooled. Same as OA, with the addition of fans. Fans are usually mounted on radiators. The transformer typically has two load ratings: one with the fans off (OA) and a larger rating with fans operating (FA). Fans may be wired to start automatically at a pre-set temperature.
3. **Class OA/FA/FA:** Liquid-immersed, self-cooled/forced air-cooled/forced air-cooled. Same as OA/FA, with an additional set of fans. There typically will be three load ratings corresponding to each increment of cooling. Increased ratings are obtained by increasing cooling air over portions of the cooling surfaces. Typically, there are radiators attached to the tank to aid in cooling. The two groups of fans may be wired to start automatically at pre-set levels as temperature increases. There are no oil pumps. Oil flows through the transformer windings by the natural principle of convection (heat rising).

3.4.2 Liquid-Immersed, Air-Cooled/Forced Liquid-Cooled

There are two classes in this group.

1. **Class OA/FA/FOA:** Liquid-immersed, self-cooled/forced air-cooled/forced liquid, and forced air-cooled. Windings and core are immersed in some type of oil. This transformer typically has radiators attached to the enclosure. The transformer has self-cooling (OA) natural ventilation, forced air-cooling FA (fans), and forced oil-cooling (pumps) with additional forced air-cooling (FOA) (more fans). The transformer has three load ratings corresponding to each cooling step. Fans and pumps may be wired to start automatically at pre-set levels as temperature increases (figure 26).
2. **Class OA/FOA/FOA:** Liquid-immersed, self-cooled/forced oil, and forced air-cooled/forced oil, and forced air-cooled. Cooling controls are arranged to start only part of the oil

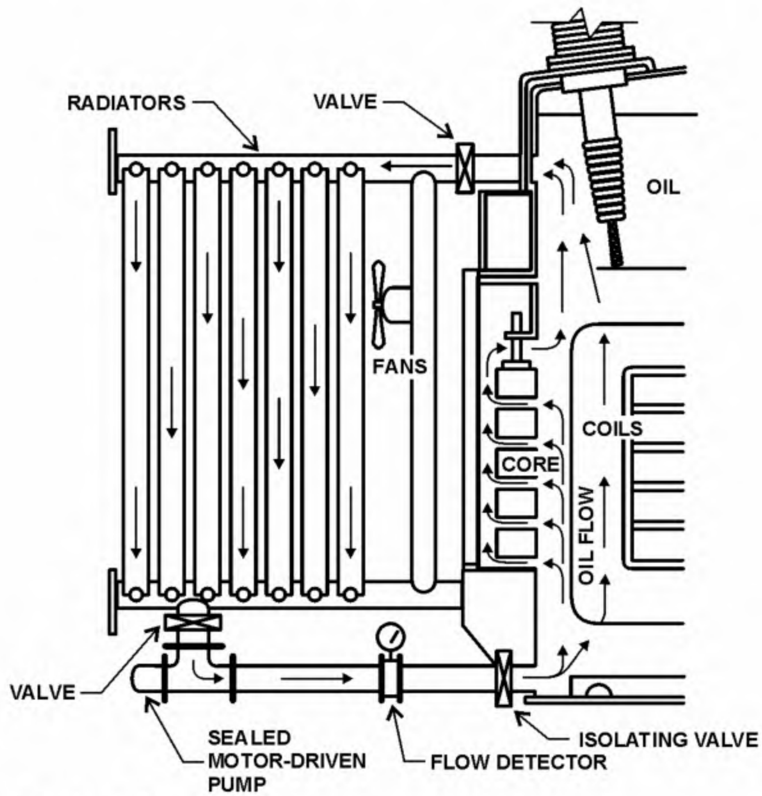

Figure 26 – Typical Oil Flow.

pumps and part of the fans for the first load rating/temperature increase, and the remaining pumps and fans for the second load rating increase. The nameplate will show at least three load ratings.

3.4.3 Liquid-Immersed, Water-Cooled

This category has two classes:

1. **Class OW:** Transformer coil and core are immersed in oil. Typically, an oil/water heat exchanger (radiator) is attached to the outside of the tank. Cooling water is pumped through the heat exchanger, but the oil flows only by natural circulation. As oil is heated by the windings, it rises to the top and exits through piping to the radiator. As oil is cooled, it descends through the radiator and re-enters the transformer tank at the bottom.

2. **Class OW/A:** Transformer coil and core are immersed in oil. This transformer has two ratings. Cooling for one rating (OW) is obtained as in item 1. above. The self-cooled rating (A) is obtained by natural circulation of air over the tank and cooling surfaces.

3.4.4 Liquid-Immersed, Forced Liquid-Cooled

This category has two classes:

1. **Class FOA:** Liquid-immersed, forced liquid-cooled with forced air-cooled. This transformer normally has only one rating. The transformer is cooled by pumping oil (forced oil) through a radiator normally attached to the outside of the tank. Also, air is forced by fans over the cooling surface.
2. **Class FOW:** Liquid-immersed, forced liquid-cooled, water cooled. This transformer is cooled by an oil/water heat exchanger normally mounted separately from the tank. Both the transformer oil and the cooling water are pumped (forced) through the heat exchanger to accomplish cooling.

3.4.5 Potential Problems and Remedial Actions for Liquid-Filled Transformer Cooling Systems

3.4.5.1 Leaks – Tanks and radiators may develop oil leaks, especially at connections. To repair a leak in a radiator core, you must remove the radiator. Small leaks may also develop in headers or individual pipes. These small leaks possibly may be stopped by peening with a ball peen hammer. Some manufacturer's field personnel try to stop leaks by using a two-part epoxy while the transformer is under vacuum. Do not try this unless the transformer has been drained, because a vacuum may cause bubbles to form in the oil that can lodge in the winding and cause arcing. Some contractors will stop leaks by forcing epoxy into the leak area under pressure. This procedure has been successful in many cases and may be performed while the transformer is online. When all else fails, the leak may be welded with oil still in the radiator if proper precautions are carefully observed [3, 4]. Welding with oil inside will cause gases to form in the oil. Take an oil sample for a dissolved gas analysis (DGA) before welding and 24 hours after re-energizing to identify gas increases due to welding. If the leak is bad enough, the tank may have to be drained so the leak can be repaired. Treat leaks carefully; do not ignore them. Oil leaks are serious maintenance and environmental issues and should be corrected. See *Power Equipment Bulletin 23* for further information on leak remediation.

3.4.5.2 Cleaning Radiators – Radiators may need to be cleaned in areas where deposits appear on pipes and headers. Dirt and deposits hamper heat transfer to the cooling air. Finned radiators must be cleaned with compressed air when they become dirty.

3.4.5.3 Plugged Radiators – After 1 month of service and yearly, perform an IR scan and physical inspection of radiators and transformer tanks [4, 8]. Partially plugged radiators will be cooler than those performing normally. You may also feel the radiator pipes by hand. Plugged radiator sections or individual pipes/plenums will be noticeably cooler; however, you will not be able to reach all of them. Radiators may become plugged with sludge or foreign debris; this usually occurs in water tubes on the oil/water heat exchanger. Do not forget to check the bleed line for two-walled heat exchangers.

If plugged radiators are discovered, they must be corrected as soon as possible. Some radiators are attached to the main tank with flanges and have isolating valves. These may be removed for cleaning and/or leak repair without draining oil from the transformer. If radiators are attached directly to the main tank without isolating valves, oil must be drained before cleaning them. If radiators are plugged with sludge, the transformer probably is sludged up also. In this case, the oil should be reprocessed and the transformer cleaned internally. Competent contractors should be obtained if this is necessary.

3.4.5.4 Sludge Formation – If temperature seems to be slowly increasing while the transformer is operating under the same load, check the DGA for moisture, oxygen, acid number, and the interfacial tension (IFT). The combination of oxygen and moisture causes sludging, which may be revealed by a low IFT number and/or acid number. Sludge will slowly build up on windings and core, and the temperature will increase over time.

3.4.5.5 Valve Problems – If your transformer has isolating valves for radiators, check to make sure they are fully open on both top and bottom of the radiators. A broken valve stem may cause the valve to be fully or partially closed, but it will appear that the valve is open.

3.4.5.6 Mineral Deposits – Don't even think about spraying water on the radiators or tank to increase cooling, except in the most dire emergency. Minerals in the water will deposit on radiators as water evaporates and are almost impossible to remove. These minerals will reduce the efficiency of cooling still further. Using additional fans to blow air on radiators and/or the transformer tank is a better alternative [4].

3.4.5.7 Low Oil Level – One IR scan performed on a transformer running at higher than normal temperature revealed that the oil level was below the upper radiator inlet pipe, which prevented oil circulation. The oil level indicator was defective and stuck on normal. These indicators must be tested, as mentioned below.

3.4.6 Cooling System Inspections

After 1 month of service and yearly, inspect and test the fans. Look at the fans whenever you are around transformers in the switchyard or in the powerplant. If it is a hot day and transformers are loaded, all the fans should be running. If one fan is stopped and the rest of the group is running, the inactive fan should be repaired. During an inspection, the temperature controller should be adjusted to start all the fans. Listen for unusual noises from fan bearings and loose blades and repair or replace faulty fans. Bad bearings can also be detected with an IR scan if the fans are running.

After 1 month of service and yearly, inspect and test the oil pumps. Inspect piping and connections for leaks. Override the temperature controller so that the pump starts. Check the oil pump motor current on all three phases with an accurate ammeter; this will give an indication if oil flow is correct and if unusual wear is causing additional motor loading. Record this information for later comparison, especially if there is no oil flow indicator. If the motor load current is low, something is causing low oil flow. Carefully inspect all valves to make sure they are fully open. A valve stem may break and leave the valve partially or fully closed, even though the valve handle indicates the valve is fully open. Pump impellers have been found loose on the shaft, reducing oil flow. Sludge buildup or debris in lines can also cause low oil flow. If motor load current is high, this may indicate impeded pump rotation. Listen for unusual noises. Thrust bearing wear results in the impeller advancing on the housing. An impeller touching the housing makes a rubbing sound, which is different from the sound of a failing motor bearing. If this is heard, remove the pump motor from the housing and check impeller clearance. Replace the thrust bearing if needed, and replace the motor bearings if the shaft has too much play or if noise is unusual.

Three-phase pumps will run and pump some oil even if they are running backwards. Vane type oil-flow meters will indicate flow on this low amount. The best indication of pump running backwards is that sometimes the pump will be very noisy. The motor load current may also be lower than for full load. If this is suspected, due to the extra noise and higher transformer temperature, the pump should be checked for proper rotation. Reverse two phase leads if this is encountered. [4]

After 1 month of service and yearly, check the oil flow indicator. It has a small paddle which extends into the oil stream and may be either on the suction or discharge side of the pump. A very low flow of only about 5-feet-per-second velocity causes the flag to rotate, which indicates normal flow. Flow can be too low, and the indicator will still show flow. If there is no flow, a spring returns the flag to the off position, and a switch provides an alarm. With control power on the switch, open the pump circuit at the motor starter and make sure the correct alarm point activates when the pump stops. Check that the pointer is in the right position when the pump is off and when it is running. Pointers can stick and fail to provide an alarm when needed. Oil flow may also be checked with an ultrasonic flowmeter. Ultrasonic listening devices can detect worn bearings, rubbing impellers, and other unusual noises from oil pumps.

Pumps can pull air in through gaskets on the suction side of the pumps. The suction (vacuum) on the intake side of the pump can pull air through gaskets that are not tight. Pump suction has also been known to pull air through packing around valve stems in the suction side piping. This can result in dangerous bubbles in the transformer oil and may cause the gas detector or Buchholz relay to operate. Dissolved gas analysis will show a big increase in oxygen and nitrogen content [4]. High oxygen and nitrogen content can also be caused by gasket leaks elsewhere.

After 1 month of service and yearly, inspect water-oil heat exchangers. Test and inspect the pumps, as mentioned above. Look for and repair leaks in piping and heat exchanger body. Examine the latest dissolved gas analysis results for dissolved moisture and free water. If free water is present and there are no gasket leaks, the water portion of the water-oil heat exchanger must be pressure tested. A leak may have developed, allowing water to migrate into the transformer oil, which can destroy the transformer. If the heat exchanger piping is double walled, check the drain for water or oil; check manufacturer's instruction manual.

4. Oil-Filled Transformer Inspections

A transformer maintenance program must be based on thorough routine inspections. These inspections must take place in addition to normal daily/weekly data gathering trips to check oil levels and temperatures. Some monitoring may be done remotely using supervisory control and data acquisition (SCADA) systems, but this can never substitute for thorough inspections by competent maintenance or operations people.

After 1 month of service, and once each year, make an indepth inspection of oil-filled transformers. Before beginning, carefully inspect the temperature and oil level data sheets. If temperature, pressure, or oil level gauges never change, even with seasonal temperature and loading changes, something is wrong. The gauge may be stuck, or data sheets may have been filled in incorrectly. Examine the DGAs for evidence of leaks or other problems.

4.1 Transformer Tank

Check for excessive corrosion and oil leaks. Pay special attention to flanges and gaskets (bushings, valves, and radiators) and the lower section of the main tank. Report oil leaks to maintenance, and pay special attention to the oil level indicator if leaks are found. Severely corroded spots should be wire brushed and painted with a rust inhibitor.

4.2 Top Oil Thermometers

These thermometers are typically sealed, spiral-bourdon-tube dial indicators with liquid-filled bulb sensors. The bulb is normally inside a thermometer well, which penetrates the tank wall into the oil near the top of the tank. As oil temperature increases in the bulb, liquid expands, which expands the spiral tube. The tube is attached to a pointer that indicates temperature. These pointers may also have electrical contacts to trigger alarms and start cooling fans as temperature increases. An extra pointer, normally red, indicates maximum temperature since the last time the indicator was reset. This red pointer rises with the main pointer but will not decrease unless manually reset; thus, it always indicates the highest temperature reached since it was reset. See the instruction manual on your specific transformer for details.

4.3 Winding Temperature Thermometers

These devices are supposed to indicate the hottest spot in the winding, based on the manufacturer's heat run tests. At best, this device is only accurate at top nameplate rated load and only if it is not out of calibration [18]. They are not what their name implies and can be misleading. They are only winding hottest-spot simulators, which are not very accurate. Normally, there is no temperature sensor embedded in the winding hot spot. At best, they provide only a rough approximation of hot spot winding temperature and should not be relied on for accuracy. They can be used to turn on additional cooling or activate alarms as the top oil thermometers do.

Winding temperature thermometers work the same way as the top oil thermometer (discussed in section 4.2), except that the bulb is in a separate thermometer well near the top of the tank. A wire-type heater coil is either inserted into, or wrapped around, the thermometer well, which surrounds the temperature sensitive bulb. In some transformers, a current transformer (CT) is around one of the three winding leads and provides current directly to the heater coil in proportion to winding current. In other transformers, the CT supplies current to an auto-transformer that supplies current to the heater coil. The heater warms the bulb, and the dial indicates a temperature, but it is not the true hottest-spot temperature.

These devices are calibrated at the factory by changing taps on either the CT or the autotransformer, or by adjusting the calibration resistors in the control cabinet. These devices normally cannot be field calibrated or tested, other than testing the thermometer, as mentioned. The calibration resistors can be adjusted in the field if the manufacturer provides calibration curves for the transformer. In practice, most winding temperature indicators are out of calibration, and their readings are meaningless. These temperature indications should not be relied upon for loading operations or maintenance decisions.

Fiber optic temperature sensors can be imbedded directly into the winding as the transformer is being built; these sensors are much more accurate. This system is available as an option on new transformers at an increased cost, which may be worthwhile, since the true winding "hottest-spot" temperature is critical when higher loading is required.

Thermometers can be removed without lowering the transformer oil if they are in a thermometer well. Check your transformer instruction manual. Look carefully at the capillary tubing between the thermometer well and the dial indicator. If the tubing has been pinched or accidentally struck, it may be restricted. This is not an obvious defect, but it can cause the dial pointer to lock in one position. If this defect is found, the whole gauge must be returned to the factory for repair or replacement; it cannot be repaired in the field. Look for a leak in the tubing system; the gauge reading will be very low and must be replaced if a leak is discovered.

Every 3 to 5 years, and if trouble is suspected, test the thermometer. Suspend the thermometer's indicator bulb and an accurate mercury thermometer in an oil bath. Do not allow either thermometer to touch the side or bottom of the container. Heat the oil on a hotplate, while stirring, and compare the two thermometers while the temperature increases. If a magnetic stirring/heating plate is available, it is more effective than hand stirring. Pay particular attention to the upper temperature range at which your transformers normally operate (50 ºC to 80 ºC). An ohmmeter should also be used to check switch operations. If either dial indicator is more than 5 ºC different than the mercury thermometer, it should be replaced with a spare. A number of spares should be kept, based on the quantity of transformers at the plant. Oil bath test kits are available from the Qualitrol Company. After calling for Qualitrol authorization

(716-586-1515), you can ship defective dial thermometers for repair and calibration to: Qualitrol Company, 1387 Fairport Road, Fairport, New York 14450.

The alarms and other functions should also be tested to see if the correct annunciator points activate, pumps/fans operate, etc.

If the temperature gauge cannot be replaced or sent to the factory for repair, place a temperature correction factor on your data form to add to the dial reading, so that the correct temperature will be recorded. Also, lower the alarm and pump-turn-on settings by this same correction factor. Since these are pressure-filled systems, the indicator will typically read low if it is out of calibration. Field testing has shown some of these gauges reading 15 ºC to 20 ºC lower than actual temperature. This is hazardous for transformers because it will allow them to continuously run hotter than intended, due to delayed alarms and cooling activation. If thermometers are not tested and errors corrected, transformer service life may be shortened or premature failure may occur.

4.3.1 Temperature Indicators Online

Check all temperature indicators while the transformer is online. The winding temperature indicator should read approximately 15 degrees above the top oil temperature. If this is not the case, one or both temperature indicators are malfunctioning. Check the top oil temperature next to the top oil indicator's thermowell with an infrared camera. Compare the readings with the top oil indicator. Reset all maximum indicator hands on the temperature indicating devices after recording the old maximum temperature readings. High temperature may mean overloading, cooling problems, or problems with windings, core, or connections.

4.3.2 Temperature Indicators Offline

When the transformer is offline and has cooled to ambient temperature, check the top oil and winding temperature indicators; both should read the same. If not, one or both temperature indicators are malfunctioning. Check the calibration according to the proper procedure. Also, compare these readings with the indicated temperature on the conservator oil level indicator; all three should agree.

4.4 Oil Level Indicators

After 1 month of service, and every 3 to 5 years, check the tank oil level indicators. These are float operated, with the float mechanism magnetically coupled through the tank wall to the dial indicator. As level increases, the float rotates a magnet inside the tank. Outside the tank, another magnet follows (rotates), which moves the pointer. The center of the dial is normally marked with a temperature of 25 ºC (77 ºF). High and low level points are also marked to follow level changes as the oil expands and contracts with temperature changes. The proper way to determine accurate oil level is to first look at the top oil temperature indicator. After determining the temperature, look at the level gauge. The pointer should be at a reasonable level corresponding to the top oil temperature. Calibrate or replace the conservator oil level indicator if needed, but only after checking the top oil temperature indicator as shown in the above section. If the transformer is fully loaded, the top oil temperature will be high, and the level indicator should be near the high mark. If the transformer is de-energized and the top oil temperature is near 25 ºC, the oil level pointer should be at or near 25 ºC. See figure 27. Reference also IEEE 62-1995™ [20], section 6.6.2.

To check the level indicator, remove the outside mechanism for testing without lowering transformer oil. After removing the gauge, hold a magnet on the back of the dial and rotate the magnet; the dial indicator should also rotate. If it fails to respond or if it drags or sticks, replace it. As mentioned above, defective units can be sent to the factory for repair.

There may also be electrical switches for alarms and, possibly, for tripping off the transformer when the tank level falls. These switches

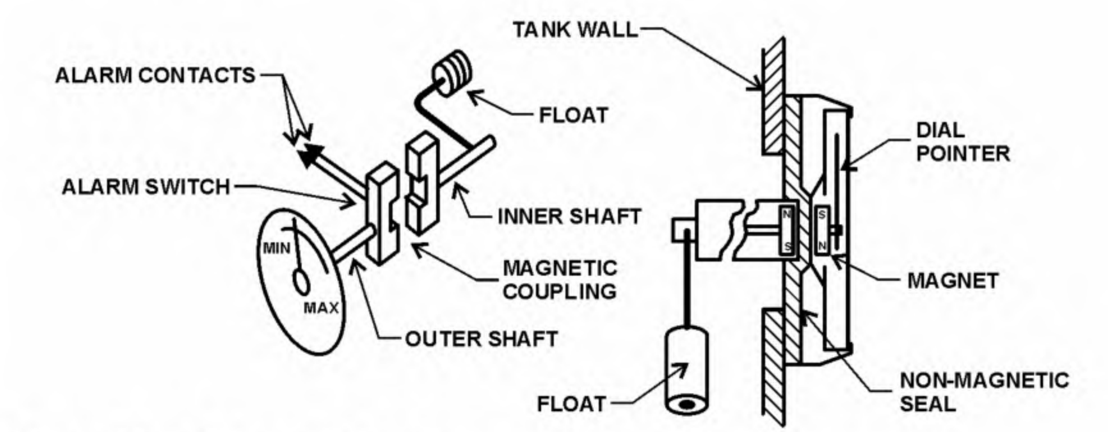

Figure 27 – Oil Level Indicator.

should be checked with an ohmmeter for proper operation. The alarm/tripping circuits should also be tested to see if the correct annunciator points and relays respond. See the transformer instruction book for information on your specific indicator.

Figure 28 – Conservator Oil Level.

If oil has had to be lowered in the transformer or conservator for other reasons (e.g., inspections), check the oil level float mechanism (figure 28). Rotate the float mechanism by hand to check for free movement.

Check the float visually to make sure it is secure to the arm and to ensure that the arm is in the proper shape. Some arms are formed (not straight).

4.5 Pressure Relief Devices

These devices are the transformers' last line of defense against excessive internal pressure. In the event of a fault or short circuit, the resultant arc instantly vaporizes surrounding oil, causing a rapid buildup of gaseous pressure. **If the pressure relief device does not operate properly and pressure is not sufficiently relieved within a**

few milliseconds, a catastrophic tank rupture can result, spreading flaming oil over a wide area. Two types of pressure relief devices are discussed below. Consult your transformer's instruction manual for specifics.

CAUTION:

Never paint pressure relief devices because paint can cause the plunger or rotating shaft to stick. Then, the device might not relieve pressure, which could lead to catastrophic tank failure during a fault. Look at the top of the device; on newer units, a yellow or blue button should be visible. If these have been painted, the button will be the same color as the tank. On older units, a red flag should be visible; if it has been painted, it will be the same color as the tank.

If the pressure relief devices have been painted, they should be replaced. It is virtually impossible to remove all paint from the mechanism and be certain the device will work when needed.

4.5.1 Newer Pressure Relief Devices

Newer pressure relief devices are spring-loaded valves that automatically re-close following a pressure release. The springs are held in compression by the cover and press on a disc which seals an opening in the tank top. If pressure in the tank exceeds operating pressure, the disc moves upward and relieves pressure. As pressure decreases, the springs re-close the valve. After operating, this device leaves a brightly colored rod (bright yellow for oil, blue for silicone) exposed approximately 2 inches above the top. This rod is easily seen upon inspection, although it is not always visible from floor level. The rod may be reset by pressing on the top until it is again recessed into the device. The switch must also be manually reset. A relief device is shown in the open position in figure 29. Figure 30 also shows a pressure relief device with the yellow indicating arm.

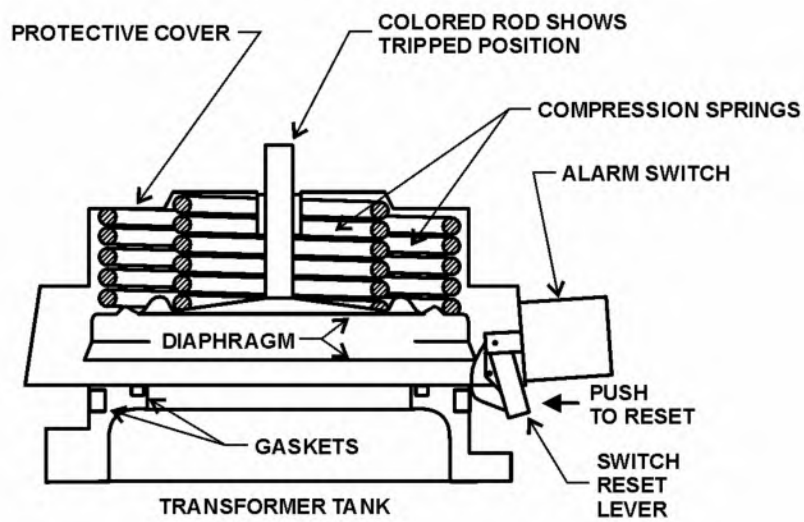

Figure 29 – Pressure Relief Device.

Figure 30 – Photograph of a Pressure Relief Device.

CAUTION:

Do not re-energize a transformer after the pressure relief device has operated and relays have de-energized the transformer, until extensive testing to determine and correct the cause has been completed. Explosive, catastrophic failure could be the result of energization after this device has operated.

CAUTION:

Bolts that hold the device to the tank may be loosened safely, but never loosen screws that hold the cover to the flange without referring to the instruction manual and using great care. Springs that oppose tank pressure are held in compression by these screws, and their stored energy could be hazardous.

Once each year, and as soon as possible after a known through-fault or internal fault, inspect pressure devices to see if they have operated. This must be done from a high-lift bucket if the transformer is energized. Look at each pressure relief device to see if the yellow (or blue) button is visible. If the device has operated, about 2 inches of the colored rod will be visible. Each year, test the alarm circuits by operating the switch by hand and making sure the correct annunciator point is activated. If the relief device operates during operation, do not re-energize the transformer; Doble and other testing may be required before re-energizing, and an oil sample should be sent for analysis.

Every 3 to 5 years, when doing other maintenance or testing, if the transformer has a conservator, examine the top of the transformer tank around the pressure relief device. If oil is visible, the device is leaking, either around the tank gasket or relief diaphragm. If the device is 30 years old, replace the whole unit. A nitrogen blanketed transformer will use a lot more nitrogen if the relief device is leaking; they should be tested as described below.

A test stand with a pressure gauge may be fabricated to test the pressure relief function. Current cost of a pressure relief device is about $600, so testing instead of replacement may be prudent. Have a spare pressure relief device on hand so that the tank will not have to be left open. If the tank top or pressure relief device has gasket limiting grooves, always use a nitrile replacement gasket; if there are no grooves, use a cork-nitrile gasket. Although relief devices themselves do not leak often, the gasket may leak.

4.5.2 Older Pressure Relief Devices

Older pressure relief devices have a diaphragm and a relief pin that is destroyed each time the device operates and must be replaced.

CAUTION:

Replacement parts of an older pressure relief device must be replaced with exact duplicate parts; otherwise, the operating relief pressure of the device will be wrong.

The relief pin determines operating pressure; a number, which is the operating pressure, normally appears on top of the pin. Check your specific transformer instruction manual for proper catalog numbers. Do not assume you have the right parts or that correct parts have been previously installed—look it up. If the operating pressure is too high, a catastrophic tank failure could result.

On older units, a shaft rotates, operates alarm/trip switches, and raises a small red flag when the unit releases pressure. If units have been painted or are more than 30 years old, they should be replaced with the new model as soon as it is possible to have a transformer outage.

Once each year, and as soon as possible after a through-fault or internal fault, examine the indicator flag to see if the device has operated. The flags must be examined from a high-lift bucket if the transformer is energized. A clearance must be obtained to test, repair, or reset the device. See the instruction manual for your specific transformer. Test alarm/trip circuits by operating the switch by hand. Check to make sure the correct annunciator point activates.

Every 3 to 5 years, when doing other maintenance or testing, examine the top of the transformer tank around the pressure relief device. If the transformer has a conservator and oil is visible, the device is leaking, either around the tank gasket or relief diaphragm. The gasket and/or device must be replaced. Before ordering, make sure that the new device will fit the same tank opening. Most devices are made by the Qualitrol Company; contact the manufacturer to obtain a correct replacement.

4.6 Sudden Pressure Relay

Internal arcing in an oil-filled power transformer can instantly vaporize surrounding oil, generating gas pressures that can cause catastrophic failure, rupture the tank, and spread flaming oil over a large area. This can damage or destroy other equipment, in addition to the transformer, and present extreme hazards to workers.

The relay is designed to detect a sudden pressure increase caused by arcing. This relay is very sensitive and will operate if the pressure rises even slightly. If a very small pressure change occurs caused by a small electrical fault inside the tank, this relay will alarm. The relay is set to operate before the pressure relief device. The control circuit should de-energize the transformer and provide an alarm. The relay will ignore normal pressure changes such as oil-pump surges, temperature changes, etc.

Modern sudden pressure relays consist of three bellows (see figure 31) with silicone sealed inside. Changes in pressure in the transformer deflect the main sensing bellows. Silicone inside acts on two control bellows arranged like a balance beam (one on each side). One bellows senses pressure changes through a small orifice. The opening is automatically changed by a bimetallic strip to adjust for normal temperature changes of the oil. The orifice delays pressure changes in this bellows. The other bellows responds to immediate pressure changes and is affected much more quickly. Pressure difference tilts the balance beam and activates the switch. This type of relay automatically resets when the two bellows again reach pressure equilibrium. If this relay operates, do not re-energize the transformer until you have determined the exact cause and corrected the problem.

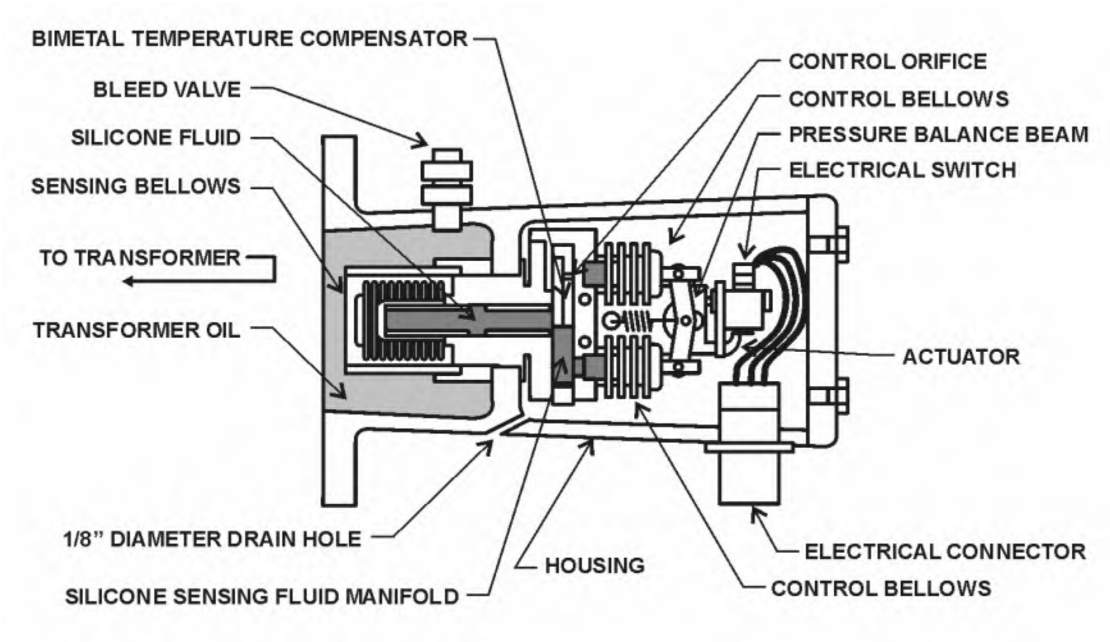

Figure 31 – Sudden Pressure Relay, Section.

Old style sudden pressure relays have only one bellows. A sudden excessive pressure within the transformer tank exerts pressure directly on the bellows, which moves a spring-loaded operating pin. The pin operates a switch that provides alarm and breaker trip. After the relay has operated, the cap must be removed and the switch must be reset to normal by depressing the reset button.

Once every 3 to 5 years, the sudden pressure relay should be tested according to manufacturer's instructions. Generally, only a squeeze-bulb and pressure gauge (5 psi) are required. Disconnect the tripping circuit and use an ohmmeter to test for relay operation. Test the alarm circuit and verify that the correct alarm point is activated. Use an ohmmeter to verify the trip signal is activated or, if possible, apply only control voltage to the breaker and make sure the tripping function operates. Consult the manufacturer's manual for your specific transformer's detailed instructions.

4.6.1 Testing Suggestion

Figure 32 shows an example relay. Inspect the isolation valve to ensure it is open. With the transformer offline and under clearance, functionally test the sudden pressure relay by slowly closing the isolating valve. Leave it closed for a few seconds and reopen the valve very suddenly; this should activate the alarm. If the alarm does not activate, test the relay. If the relay fails to function, replace it with a new one.

Figure 32 – Photograph of a Sudden Pressure Relay.

4.7 Buchholz Relay (Found Only on Transformers with Conservators)

The Buchholz relay (figures 33 and 34) has two oil-filled chambers with floats and relays arranged vertically—one over the other. If high eddy currents, local overheating, or partial discharges occur within the tank, bubbles of resultant gas rise to the top of the tank. These bubbles rise through the pipe between the tank and the conservator. As gas bubbles migrate along the pipe, they enter the Buchholz relay and rise into the top chamber. As gas builds up inside the chamber, it displaces the oil, which decreases the oil level. The top float descends with the oil level until it passes a magnetic switch, which activates an alarm. The bottom float and relay cannot be activated by additional gas buildup. The float is located slightly below the top of the pipe so that once the top chamber is filled, additional gas goes into the pipe and continues up to the conservator. Typically, inspection windows are provided so that the amount of gas and relay operation may be viewed during testing. If the oil level falls low enough (conservator empty), the bottom float activates the switch contacts in the bottom chamber.

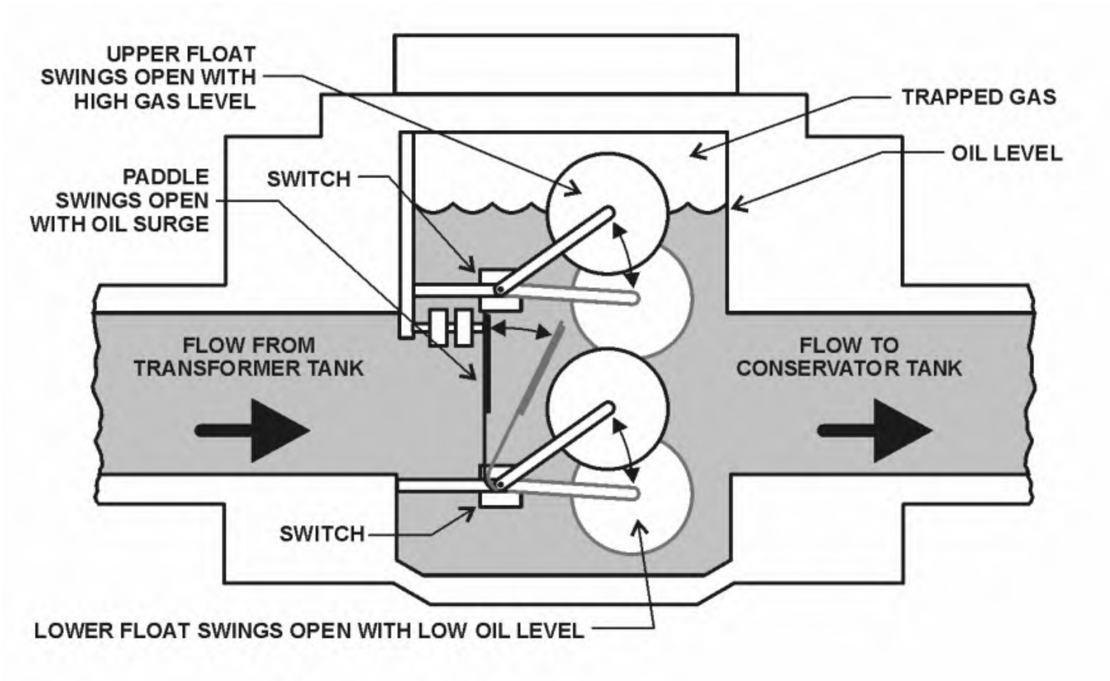

Figure 33 – Buchholz Relay, Section.

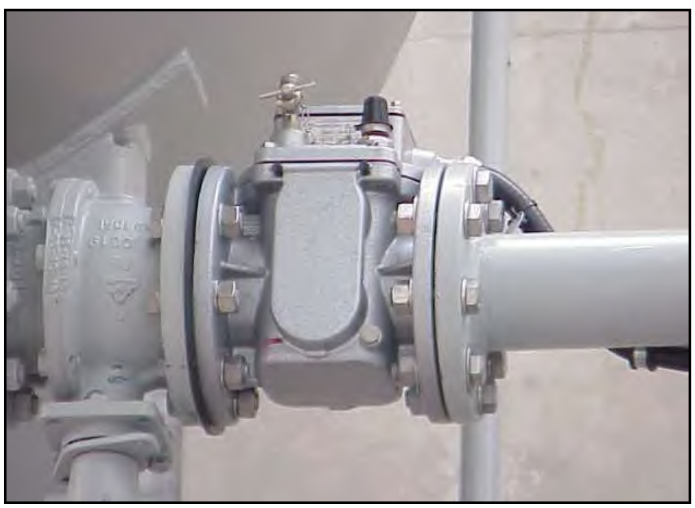

Figure 34 – Photograph of a Buchholz Relay.

These contacts are typically connected to cause the transformer to trip. This relay also serves a third function, similar to the sudden pressure relay. A magnetically held paddle attached to the bottom float is positioned in the oil-flow stream between the conservator and transformer tank. Normal flows resulting from temperature changes are small and bypass below the paddle. If a fault occurs in the transformer, a pressure wave (surge) is created in the oil. This surge travels through the pipe and displaces the paddle. The paddle activates the same magnetic switch as the bottom float mentioned above, which trips the transformer. The flow rate at which the paddle activates the relay is normally adjustable. See your specific transformer's instruction manual for details.

Once every 3 to 5 years, while the transformer is de-energized, functionally test the Buchhholz relay by pumping a small amount of air into the top chamber with a squeeze-bulb hand pump. Watch the float operation through the window (center in figure 32). Check to make sure the correct alarm point has been activated. Open the bleed valve and vent air from the chamber. The bottom float and switching cannot be tested with air pressure. On some relays, a rod is provided so that you can test both bottom and top sections by pushing the floats down until the trip points are activated. If possible, verify that the breaker will trip with this operation. A volt-ohmmeter may also be used to check the switches. If these contacts activate during operation, it means that the oil level is very low, a pressure wave has activated (bottom contacts), or the transformer is gassing (top contacts). If this relay operates, do not re-energize the transformer until you have determined the exact cause.

If a small amount of gas is found in this relay when the transformer is new (a few months after startup), it is probably just air that has been trapped in the transformer structure and is now escaping; there is little cause for concern.

If the transformer has been online for some time (service aged), and gas is found in the Buchholz, oil samples must be sent to the lab for DGA and extensive testing. Consult with the manufacturer and other transformer experts. A definite cause of the gas bubbles must be determined and corrected before re-energization of the transformer.

4.8 Transformer Bushings: Testing and Maintenance of High-Voltage Bushings

When bushings are new, they should be Doble tested as an acceptance test. Refer to the M4000 Doble test set instructions, the *Doble Bushing Field Test Guide* [9], and the manufacturer's data for guidance on acceptable results.

CAUTION:

Do not test a bushing while it is in its wood shipping crate, or while it is lying on wood. Wood does not insulate as well as porcelain and will cause the readings to be inaccurate. Keep the test results as a baseline record to compare with future tests.

After 1 month of service and yearly, check the external porcelain for cracks and/or contamination (requires binoculars). There is no "perfect insulator"; a small amount of leakage current always exists. This current "leaks" through and along the bushing surface from the high-voltage conductor to ground. If the bushing is damaged or heavily contaminated, leakage current becomes excessive, and visible evidence may appear as carbon tracking (treeing) on the bushing surface. Flashovers may occur if the bushings are not cleaned periodically.

Look carefully for oil leaks. Check the bushing oil level by viewing the oil-sight glass or the oil level gauge. When the bushing has a gauge with a pointer, look carefully, because the oil level should vary slightly with temperature changes. If the pointer never changes, even with wide ambient temperature and load changes, the gauge should be checked at the next outage. A stuck gauge pointer coupled with a small oil leak can cause explosive failure of a bushing, damaging the transformer and other switchyard equipment. A costly extended outage is the result.

If the oil level is low and there is an external oil leak, check the bolts for proper torque and the gasket for proper compression. If torque and compression are correct, the bushing must be replaced with a spare. Follow instructions in the transformer manual carefully. It is very important that the correct type of gasket be installed and the correct compression be applied. A leaky gasket is probably also leaking water and air into the transformer, so check the most recent transformer DGA for high moisture and oxygen.

If the oil level is low and there is no visible external leak, there may be an internal leak around the lower seal into the transformer tank. If possible, re-fill the bushing with the same oil and carefully monitor the level and the volume it takes to fill the bushing to the proper level. If it takes more than 1 quart of oil, make plans to replace the bushing. The bushing must be sent to the factory for repair, or it must be junked; it cannot be repaired in the field.

CAUTION:

Never open the fill plug of any bushing if it is at an elevated temperature. Some bushings have a nitrogen blanket on top of the oil, which pressurizes as the oil expands. Always consult the manufacturer's instruction manual which will give the temperature range at which the bushing may be safely opened. Generally, this will be between 15 °C (59 °F) and 35 °C (95 °F). Pressurized hot oil may suddenly gush from the fill plug if it is removed while at elevated temperature, causing burn hazards. Generally, the bushing will be a little cooler than the top oil temperature, so this temperature gauge may be used as a guide if the gauge has been tested as mentioned in section 4.3.

About 90% of all preventable bushing failures are caused by moisture entering through leaky gaskets, cracks, or seals. Internal moisture can be detected by Doble testing. See *FIST 3-2* [10] and *Doble Bushing Field Test Guide* [9] for troubles and corrective actions. Internal moisture causes deterioration of the insulation of the bushing and can result in explosive failure, causing extensive transformer and other equipment damage, as well as hazards to workers.

After 1 month of service and yearly, examine the bushings with an IR camera [4, 8]; if one phase shows a markedly higher temperature, there is probably a bad connection. The connection at the top is usually the poor one; however, a bad connection inside the transformer tank will usually show a higher temperature at the top as well. In addition, a bad connection inside the transformer will usually show hot metal gases (ethane and ethylene) in the DGA.

Once every 3 to 5 years, perform a close physical inspection and cleaning of the bushings [10]. Check carefully for leaks, cracks, and carbon tracking. This inspection will be required more often in atmospheres where salts and dust deposits appear on the bushings. In conditions that produce deposits, a light application of Dow Corning grease DC-5 or GE Insulgel will help reduce risk of external flashover. The disadvantage of this treatment is that a grease buildup may occur. In high humidity and wet areas, a better choice may be a high-quality silicone paste wax applied to the porcelain, which will reduce the risk of flashover. A spray-on wax containing silicone, such as Turtle Wax brand, has been found to be very useful for cleaning and waxing in one operation, providing the deposits are not too hard. Wax will cause water to form beads, rather than a continuous sheet, which reduces flashover risk. Cleaning may involve just spraying with Turtle Wax and wiping with a soft cloth. A lime removal product, such as “Lime Away,” also may be useful. More stubborn contaminants may require solvents, steel wool, and brushes. A high pressure water stream may be required to remove salt and other water soluble deposits. Limestone powder blasting with dry air will safely remove metallic oxides, chemicals, salt-cake, and almost any hard contaminant. Other materials, such as potter’s clay, walnut or pecan shells, or crushed coconut shells, are also used for hard contaminants. Carbon dioxide (CO_2) pellet blasting is more expensive but virtually eliminates cleanup because it evaporates. Ground-up corn-cob blasting will remove soft pollutants, such as old coatings of built-up grease. A competent, experienced contractor should be employed, and a thorough, written job hazard analysis (JHA) should be performed when any of these treatments are used.

Corona (air ionization) may be visible at the tops of bushings at twilight or night, especially during periods of rain, mist, fog, or high humidity. At the top, corona is considered normal; however, as a bushing becomes more and more contaminated, corona will creep lower and lower. If the bushing is not cleaned, flashover will occur when corona nears the grounded transformer top. If corona seems to be lower than the top of the bushing, inspect, Doble test, and clean the bushing as quickly as possible. If flashover occurs (phase to ground fault), it could destroy the bushing and cause an extended outage. Line-to-line faults also can occur if all the bushings are contaminated and flashover occurs. A corona scope may be used to view and photograph low levels of corona indoors under normal illumination and outdoors at twilight or night. High levels of corona may be viewed outdoors in the daytime if a dark background is available, such as trees, canyon walls, buildings, etc. The corona scope design is primarily for indoor and night use; it cannot be used with blue or cloudy sky background. This technology is available at the Technical Service Center (TSC), D-8450.

Once every 3 to 5 years, depending on the atmosphere and service conditions, the bushings should be Doble tested. Refer to Doble M-4000 test set instructions, *Doble Bushing Field Test Guide* [9], *FIST 3-2* [10], and the manufacturer's instructions for proper values and test procedures. Bushings should be cleaned prior to Doble testing. Contamination on the insulating surface will cause the results to be inaccurate. Testing may also be done before and after cleaning to check methods of cleaning. As the bushings age and begin to deteriorate, reduce the testing interval to 1 year. Keep accurate records of results so that replacements can be ordered in advance, before you have to remove bushings from service.

CAUTION:

See the transformer manual for detailed instructions on cleaning and repairing your specific bushing surfaces. Different solvents, wiping materials, and cleaning methods may be required for different bushings. Different repair techniques may also be required for small cracks and chips. Generally, glyptal or insulating varnish will repair small scratches, hairline cracks, and chips. Sharp edges of a chip should be honed smooth, and the defective area should be painted with insulating varnish to provide a glossy finish. Hairline cracks in the surface of the porcelain must be sealed because accumulated dirt and moisture in the crack may result in flashover. Epoxy should be used to repair larger chips. If a bushing insulator has a large chip that reduces the flashover distance or has a large crack totally through the insulator, the bushing must be replaced. Some manufacturers offer repair service to damaged bushings that cannot be repaired in the field. Contact the manufacturer for your particular bushings if you have repair questions.

4.9 Oil Preservation Sealing Systems

The purpose of sealing systems is to prevent air and moisture from contaminating oil and cellulose insulation. Sealing systems are designed to prevent oil inside the transformer from coming into contact with air. Air contains moisture, which causes sludging and an abundant supply of oxygen. Oxygen, in combination with moisture, causes greatly accelerated deterioration of the cellulose. This oxygen-moisture combination will greatly reduce service life of the transformer.

Sealing systems on many existing Reclamation power transformers are of the inert gas (nitrogen) pressure design; however, Reclamation has many other designs. Current practice is to buy only conservator designs with bladders for transformer voltages 115 kV and above and capacities above 10 MVA. Below these values, we buy only inert gas pressure system transformers, as depicted in figure 36 (page 79).

Some of the sealing systems are explained below. There may be variations of each design, and not every design is discussed. Early sealing system types are discussed first, followed by more modern types.

4.9.1 Sealing Systems Types

4.9.1.1 Free Breathing – Sealing systems have progressed from early designs of "free breathing" tanks, in which an air space on top of the oil is vented to atmosphere through a breather pipe. The pipe typically is screened to keep out insects and rodents and turned down to prevent rain from entering. Breathing is caused by expansion and contraction of the oil as temperature changes. These earlier designs do not use an air dryer, and condensation from moisture forms on inside walls and tank top. Moisture, oxygen, and nitrogen would also dissolve directly into oil from the air. This is not the best design. As mentioned before, a combination of oxygen and moisture accelerates deterioration of cellulose insulation. Moisture also decreases dielectric strength, which destroys insulating quality of the oil and causes sludge to form. If you have one or more of these earlier design transformers, it is recommended that a desiccant type air dryer be added to the breather pipe.

4.9.1.2 Sealed or Pressurized Breathing – This design is similar to the free breathing type with the addition of a pressure/ vacuum bleeder valve. When the transformer was installed, pressurized dry air or nitrogen was placed on top of the oil. The bleeder valve is designed to hold pressure inside to approximately plus or minus 5 psi (figure 35). The same problems with moisture and oxygen occur as previously described. However, these problems are not as severe because "breathing" is limited by the bleeder valve. Air or nitrogen (N_2) is exhausted to the outside atmosphere when a positive pressure greater than 5 psi occurs inside the tank. This process does not add moisture and oxygen to the tank. However, when cooling, the oil contracts and, if pressure falls 5 psi below the outside atmosphere, the valve allows outside air into the tank, which pulls in moisture and oxygen.

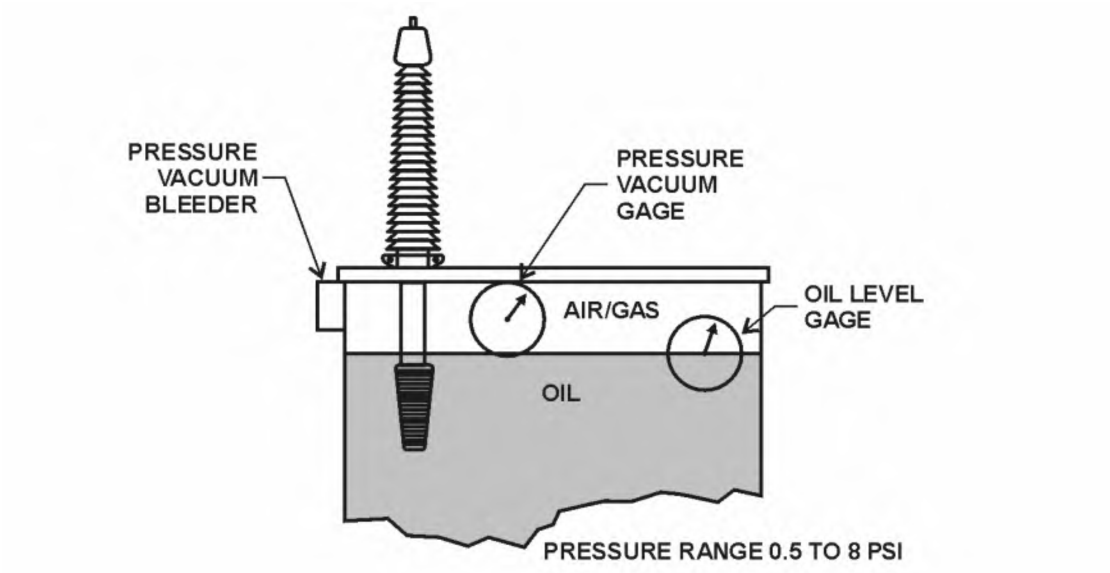

Figure 35 – Pressurized Breathing Transformer.

Once each year, check the pressure gauge against the weekly data sheets; if the pressure never varies with seasonal temperature changes, the gauge is defective. Add nitrogen if the pressure falls below 1 psi to keep moisture laden air from being pulled in. Add enough N_2 to bring the pressure to between 2 and 4 psi.

4.9.1.3 Pressurized Inert Gas Sealed System – This system keeps space above the oil pressurized with a dry inert gas, normally nitrogen (figure 36). This design prevents air and moisture from coming into contact with insulating oil. Pressure is maintained by a nitrogen gas bottle with the pressure regulated normally between 0.5 and 5 psi. Pressure gauges are provided in the nitrogen cubicle for both high and low pressures (figure 37). A pressure/vacuum gauge is normally connected to read low pressure gas inside the tank. This gauge may be located on the transformer and normally has high-pressure and low-pressure alarm contacts. See section 4.9.2, which follows.

If the transformer has a nitrogen blanket, check the pressure gauge for proper pressure. Look at the operators recording of pressures from the pressure gauge. If this does not change, the gauge is probably

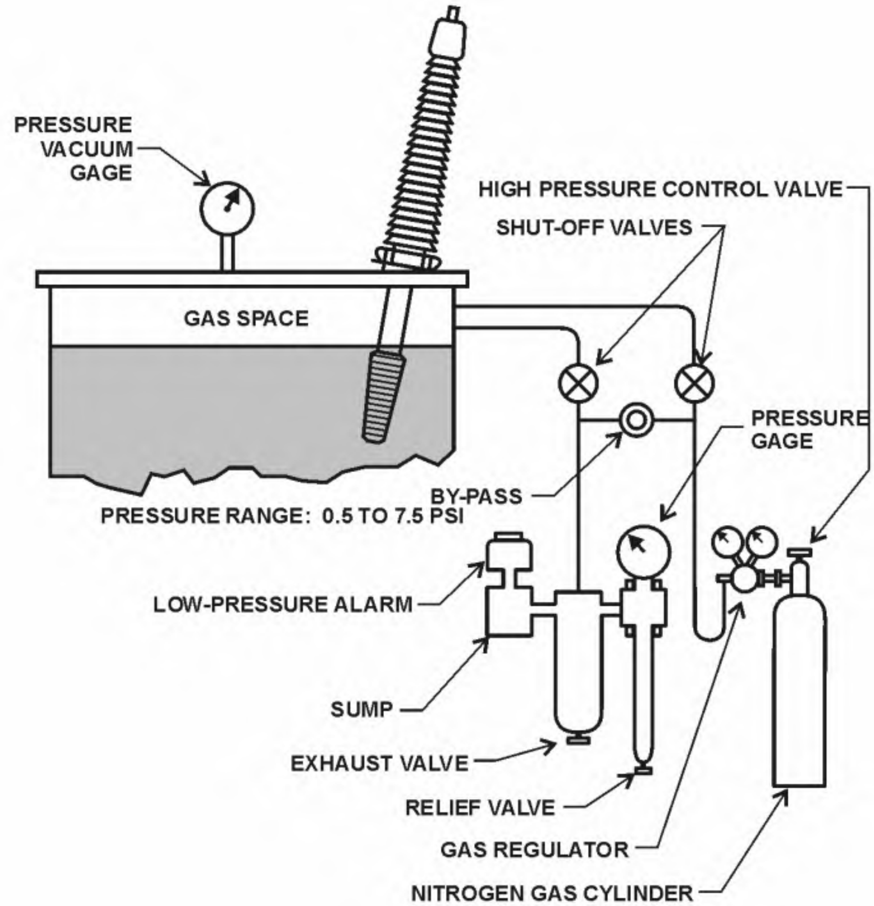

Figure 36 – Pressurized Inert Gas Transformer.

CAUTION:

When replacing nitrogen cylinders, do not just order a "nitrogen cylinder" from the local welding supplier. Nitrogen for transformers should meet American Society for Testing and Materials (ASTM) D-1933 Type III with -59 °C dew point as specified in IEEE C-57.12.00-1993, paragraph 6.6.3 [29, 2].

---

defective. Check the nitrogen bottle to insure the nitrogen is the proper quality (see *Power Equipment Bulletin No. 5* [40]). Check for any increased usage of nitrogen which indicates a leak. Smaller

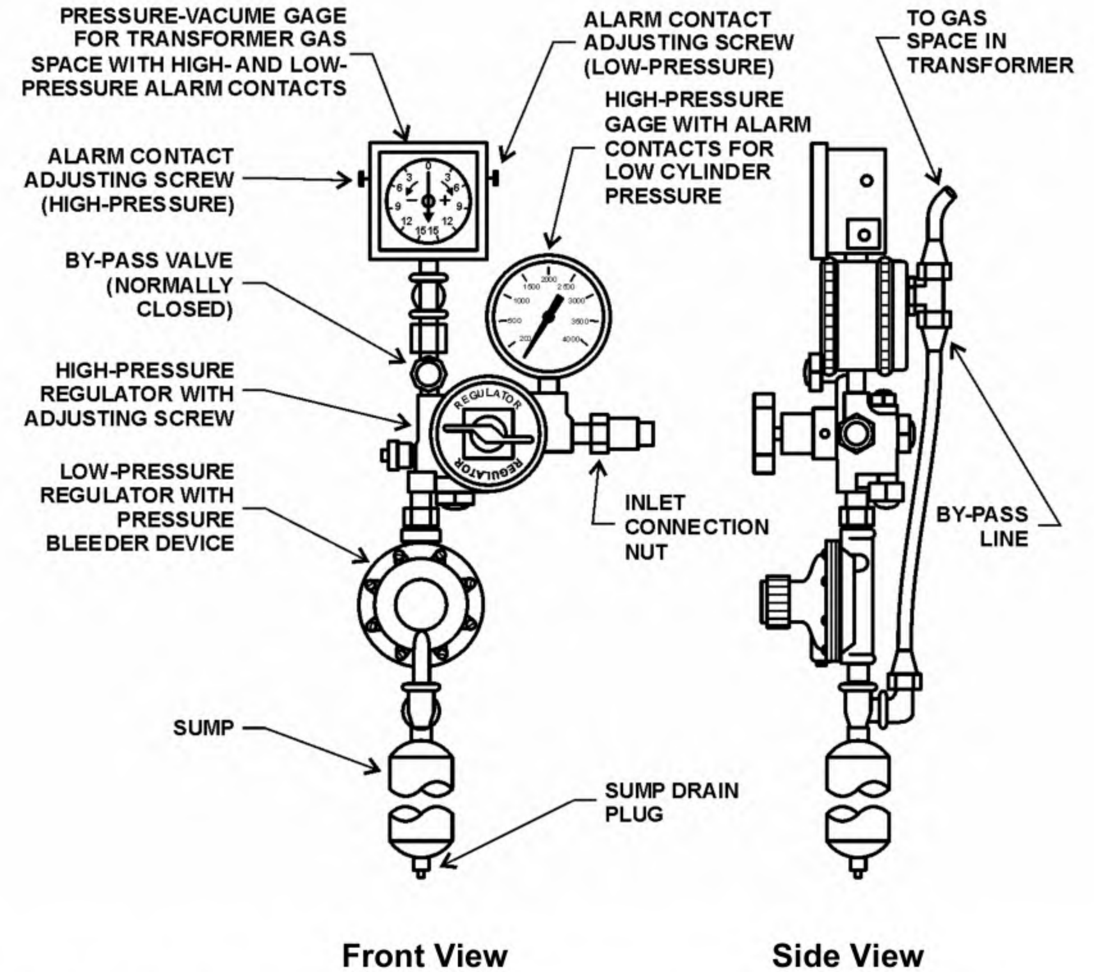

Figure 37 – Gas Pressure Control Components.

transformers such as station service or smaller generator-step-up transformers may not have nitrogen bottles attached to replace lost nitrogen. Be especially watchful of the pressure gauge and the operator's records of pressures with these. The pressure gauge can be defective for years, and no one will notice. The gauge will read nearly the same and will not vary much over winter and summer or night and day. Meanwhile, a nitrogen leak can develop, and all the N_2 will be lost. This allows air with oxygen and moisture to enter and deteriorate the oil and insulation. Watch for increased oxygen and moisture in the DGA. An ultrasonic and sonic leak detection instrument (P-2000) is used for locating N_2 leaks. Soap bubbles also may be used.

4.9.2 Gas Pressure Control Components

After 1 month of service and yearly, inspect the gas pressure control components. There is normally an adjustable, three-element, pressure control system for inert gas, which maintains a pressure range of 0.5 to 5 psi in the transformer tank. There is also a bleeder valve that exhausts gas to atmosphere when pressure exceeds relief pressure of the valve, normally 5 to 8 psi.

CAUTION:

The component part descriptions below are for the typical, three-stage pressure regulating equipment supplying inert gas to the transformer. Your particular unit may be different, so check your transformer instruction manual.

4.9.2.1 High-Pressure Gauge – The high-pressure gauge is attached between the nitrogen cylinder and high-pressure regulator that indicates cylinder pressure. When the cylinder is full, the gauge will read approximately 2,400 psi. Normally, the gauge will be equipped with a low-pressure alarm that activates when the cylinder is getting low (around 500 psi). However, gas will still be supplied, and the regulating equipment will continue to function until the cylinder is empty. Refer to figure 37 for the following descriptions.

4.9.2.2 High-Pressure Regulator – The high-pressure regulator has two stages. The input of the first stage is connected to the cylinder, and the output of the first stage is connected internally to the input of the second stage. This holds output pressure of the second stage constant. The first stage output is adjustable by a hand-operated lever and can deliver a maximum pressure equal to the pressure in the cylinder (2,400 psi when full) down to zero. The second stage output is varied by turning the adjusting screw, normally adjusted to supply approximately 10 psi to the input of the low-pressure regulator.

4.9.2.3 Low-Pressure Regulator – The low-pressure regulator is the third stage and controls pressure and flow to the gas space of the transformer. The input of this regulator is connected to the output of the second stage (approximately 10 psi). This regulator is typically set at the factory to supply gas to the transformer at a pressure of approximately 0.5 psi, and it needs no adjustment. If a different pressure is required, the regulator can be adjusted by varying spring tension on the valve diaphragm. Pressure is set at this low value because major pressure changes inside the transformer result from expansion and contraction of oil. The purpose of this gas feed is to make up for small leaks in the tank gaskets and elsewhere so that air cannot enter. Typically, a spring-loaded bleeder for high-pressure relief is built into the regulator and is set at the factory to relieve pressures in excess of 8 psi. The valve will close when pressure drops below the setting, preventing further loss of gas.

4.9.2.4 Bypass Valve Assembly – The bypass valve assembly opens a bypass line around the low-pressure regulator and allows the second stage of the high-pressure regulator to furnish gas directly to the transformer. The purpose of this assembly is to allow much faster filling/purging of the gas space during initial installation or when the transformer tank needs to be refilled after being opened for inspection.

CAUTION:

During normal operation, the bypass valve must be closed,
or pressure in the tank will be too high.

4.9.2.5 Oil Sump – The oil sump is located at the bottom of the pressure regulating system between the low-pressure regulator and shutoff valve C. The sump collects oil and/or moisture that may have condensed in the low-pressure fill line. The drain plug at the bottom of the sump should be removed before the system is put into operation, as well as once each year during operation, to drain any residual oil in the line. This sump and line will be at the same pressure as the gas space in the top of the transformer. The sump should always be at a safe pressure (less than 10 psi) so the plug can be removed to allow the line to purge a few seconds and blow out the oil. However, always look at the gas space pressure gauge on the transformer or the low-pressure gauge in the nitrogen cabinet, just to be sure, before removing the drain plug.

4.9.2.6 Shutoff Valves – The shutoff valves are located near the top of the cabinet for the purpose of isolating the transformer tank for shipping or maintenance. These valves are normally of double-seat construction and should be fully opened against the stop to prevent gas leakage around the stem. A shutoff valve is also provided for the purpose of shutting off the nitrogen flow to the transformer tank. This shutoff valve must be closed prior to changing cylinders to keep the gas in the transformer tank from bleeding off.

4.9.2.7 Sampling and Purge Valve – The sampling and purge valve is normally located in the upper right of the nitrogen cabinet. This valve is typically equipped with a hose fitting; the other side is connected directly to the transformer gas space by copper tubing. This valve is opened while purging the gas space during a new installation or maintenance refill, and it provides a path to exhaust air as the gas space is filled with nitrogen. This valve is also opened when a gas sample is taken from the gas space for analysis. When taking gas samples, the line must be sufficiently purged so that the sample will be from gas above the transformer oil and not just gas in the line. This valve must be tightly closed during normal operation to prevent gas leakage.

4.9.2.8 Free Breathing Conservator – This design adds an expansion tank (conservator) above the transformer so that the main tank may be completely filled with oil (figure 38). Oil expansion and air exchange with the atmosphere (breathing) occur away from the oil in the transformer. This design reduces oxygen and moisture

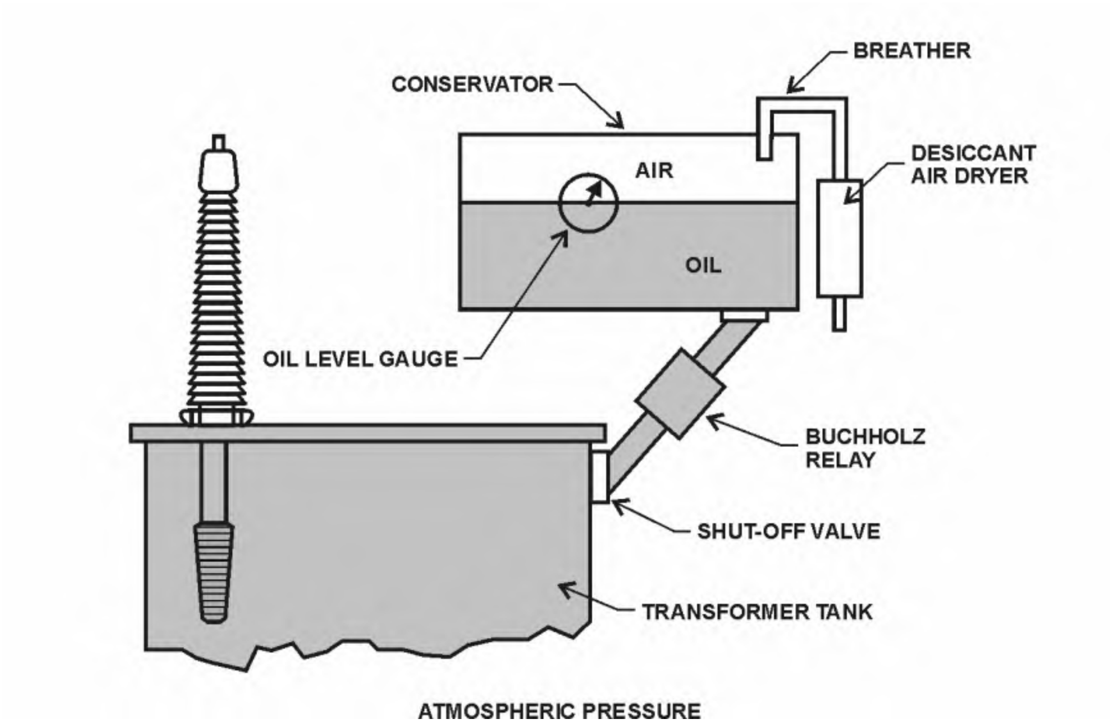

Figure 38 – Free Breathing Conservator.

contamination because only a small portion of oil is exchanged between the main tank and conservator. An oil/air interface still exists in the conservator, exposing the oil to air. Eventually, oil in the conservator is exchanged with oil in the main tank, and oxygen and other contaminants gain access to the insulation.

If you have transformers of this design, it is recommended that a bladder or diaphragm-type conservator be installed (described below) or retrofitted to the original conservator. In addition, a desiccant-type air dryer should also be installed.

4.9.2.9 Conservator with Bladder or Diaphragm Design – A conservator with bladder or diaphragm (figure 39) is similar to the design in figure 38 with an added air bladder (balloon) or flat diaphragm in the conservator. The bladder or diaphragm expands and contracts with the oil and isolates it from the atmosphere. The inside of the bladder or top of the diaphragm is open to atmospheric pressure through a desiccant air dryer. As oil expands and contracts and as

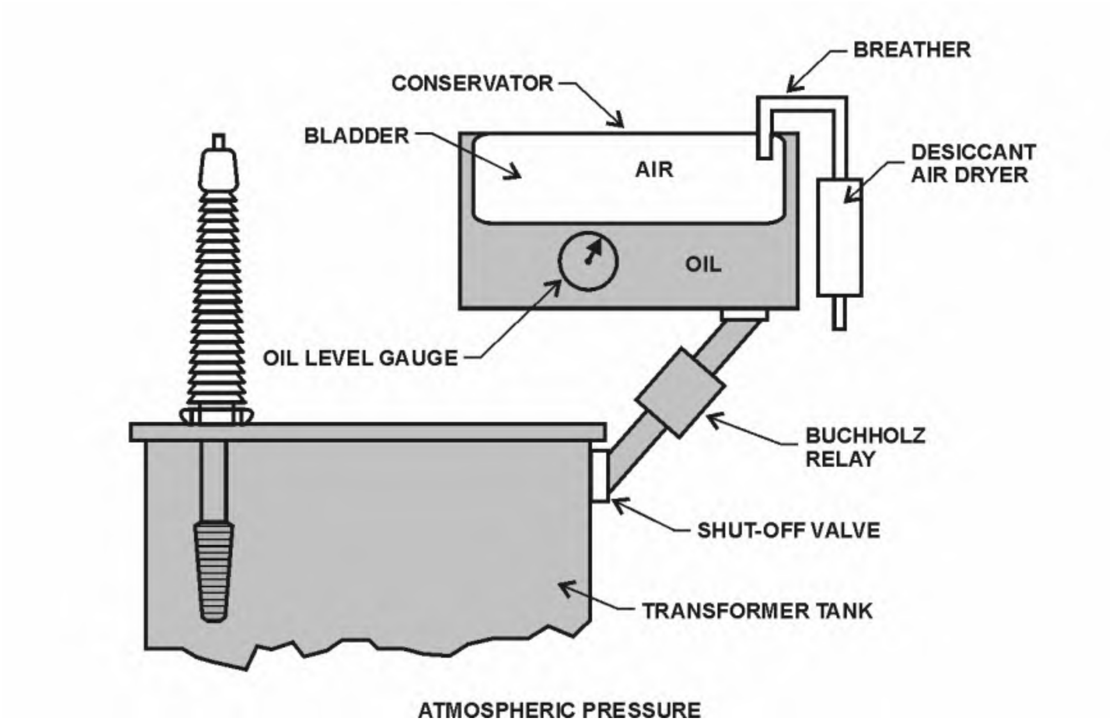

Figure 39 – Conservator with Bladder.

NOTE:

A vacuum will appear in the transformer if piping between the air dryer and conservator is too small; if the air intake to the dryer is too small, or if the piping is partially blocked. The bladder cannot take in air fast enough when the oil level is decreasing due to rapidly falling temperature. Minimum ¾- to 1-inch piping is recommended. This problem is especially prevalent with transformers that are frequently in and out of service and located in geographic areas with large temperature variations. This situation may allow bubbles to form in the oil and may even activate gas detector relays, such as the Buchholz and/or bladder failure relay. The vacuum may also pull in air around gaskets that are not tight enough or that have deteriorated (which may also cause bubbles) [4].

---

atmospheric pressure changes, the bladder or diaphragm "breathes" air in and out. This keeps air and transformer oil essentially at atmospheric pressure. The oil level gauge on the conservator typically is magnetic, like those mentioned earlier, except the float is positioned near the center of the underside of the bladder. With a diaphragm, the level indicator arm rides on top of the diaphragm. Examine the air dryer periodically and change the desiccant when approximately one-third of the material changes color.

4.9.2.9.1 Conservator Inspection **–** If atmospheric gases (nitrogen, oxygen, carbon dioxide) and, perhaps, moisture increase suddenly in the DGA, a leak may have developed in the conservator diaphragm or bladder. With the transformer offline and under clearance, open the inspection port on top of the conservator and look inside with a flashlight. If there is a leak, oil will be visible on top of the diaphragm or inside the bladder. Re-close the conservator and replace the bladder or diaphragm at the first opportunity by scheduling an outage. If there is no gas inside the Buchholz relay, the transformer may be re-energized after bleeding the air out of the bladder failure relay. A DGA should be taken immediately to check for oxygen (O_2), N_2, and moisture. However, the transformer may be operated until a new bladder is installed, keeping a close eye on the DGAs. It is recommended that DGAs be performed every 3 months until the new bladder is installed. After the bladder installation, the oil may need to be de-gassed if O_2 exceeds 10,000 parts per million (ppm). Also, carefully check the moisture level in the DGAs to ensure it is below recommended levels for the particular transformer voltage. Check the desiccant in the breather often; never let more than two-thirds of the desiccant become discolored before renewing it. All efforts must be made to keep the oxygen level below 2,000 ppm and moisture as low as possible.

4.9.2.9.2 Conservator Breather Inspection – Check the dehydrating (desiccant) breather for proper oil level if it is an oil-type unit. Check the color of the desiccant and replace it when approximately one-third remains with the proper color. See figure 40 for a modern oil-type desiccant breather. Notice the pink desiccant at the bottom of the blue indicating that this portion is water saturated.


Figure 40 – Conservator Breather.

Notice also that oil is visible in the very bottom 1 inch or so of the unit. Many times, the oil is clear, and the oil level will not be readily apparent. Normally, there is a thin line around the breather near the bottom of the glass; this indicates where the oil level should be. Compare the oil level with the level indicator line and refill, if necessary. Note the 1¼-inch pipe going from the breather to the conservator. Small tubing (½ inch or so) is not large enough to admit air quickly when the transformer is de-energized in winter. A transformer can cool so quickly that a vacuum can be created from oil shrinkage with enough force to puncture a bladder. When this happens, the bladder is destroyed; and air is pulled into the conservator creating a large bubble.


Figure 41 – Photograph of a Bladder Failure Relay.

4.9.2.9.3 Bladder Failure (Gas Accumulator) Relay. The bladder failure relay (not on diaphragm-type conservators) (figure 41) is mounted on top of the conservator for the purpose of detecting air bubbles in the oil. The relay will also serve as a backup to the Buchholz relay. If the Buchholz relay overfills with gas and fails to activate an alarm or shut down, gas will bypass the Buchholz and migrate up into the conservator, eventually to the bladder failure relay. Of course, these gases should also show up in the DGA. However, DGAs are normally taken only once per year, and a problem may not be discovered before these alarms are activated. Figure 42 shows a modern relay. Check your transformer instruction manual for specifics because designs

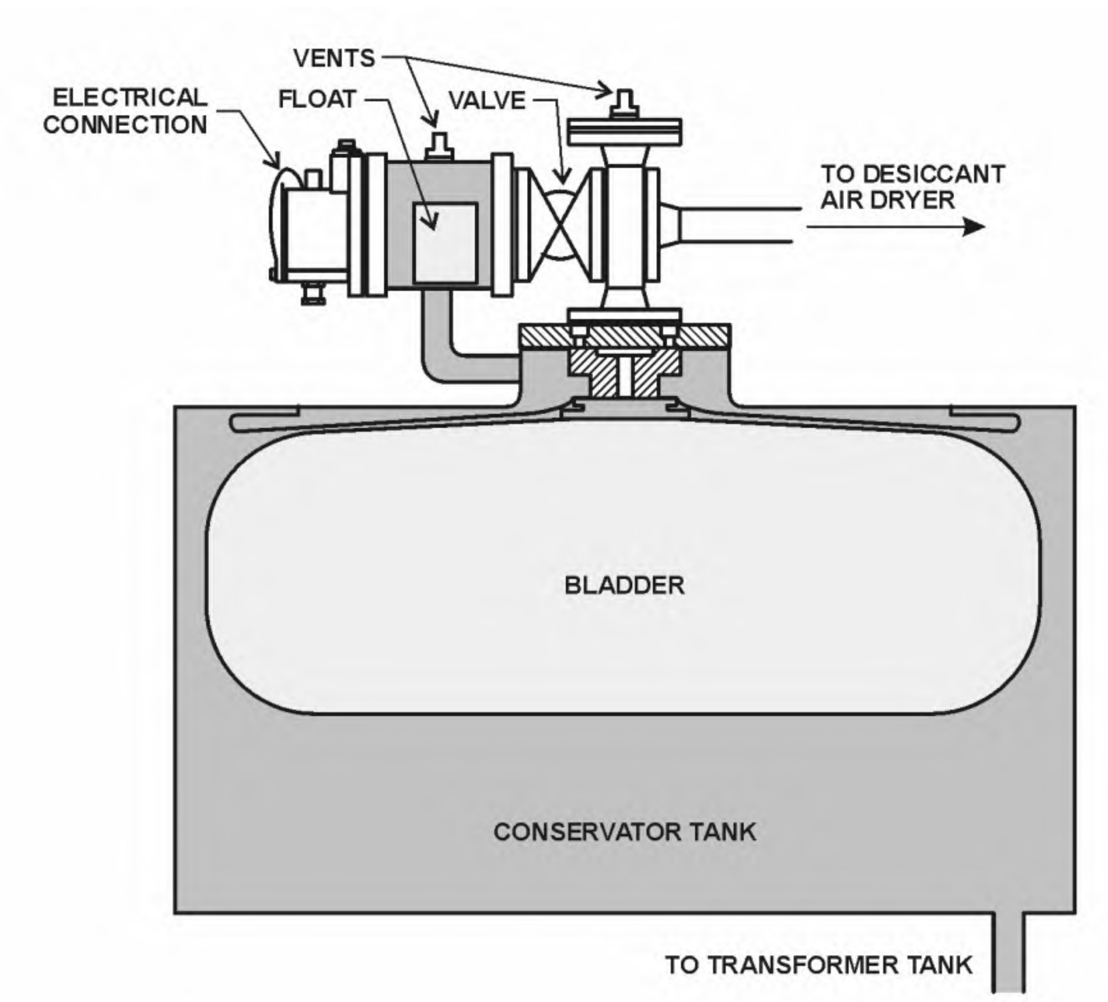

Figure 42 – Bladder Failure Relay.

vary with manufacturers. No bladder is totally impermeable, and a little air will migrate into the oil.

If a hole forms in the bladder, allowing air to migrate into the oil, the relay will detect it. As air rises and enters the relay, oil is displaced and the float drops, activating the alarm. It is similar to the top chamber of a Buchholz relay, since it is filled with oil and contains a float switch.

Every 3 to 5 years usually during Doble testing or if the bladder failure alarm is activated (if the conservator has a diaphragm), place the transformer under clearance and check the Buchholz relay for gas, as mentioned in section 4.7. Open the conservator inspection port and look inside with a flashlight.

Bleed the air/gas from the conservator using the bleed valve on top of the conservator. If the transformer is new and has been in service for only a few months, the problem most likely is air escaping from the structure. With the transformer under clearance, open the inspection port on top of the conservator and look inside the bladder with a flashlight. If oil is found inside the bladder, it has developed a leak; a new one must be ordered and installed.

CAUTION:

Never open the vent of the bladder failure relay unless you have vacuum or pressure equipment available. The oil will fall inside the relay and conservator and pull in air from the outside. You will have to recommission the relay by valving off the conservator and pressurizing the bladder or by placing a vacuum on the relay. See your specific transformer instruction manual for details.

CAUTION:

When the transformer, relay, and bladder are new, some air or gas is normally entrapped in the transformer and piping and takes some time to rise and activate the relay. Do not assume the bladder has failed if the alarm activates within 2 to 3 months after it is put into operation. If this occurs, you will have to recommission the relay with pressure or vacuum. See your specific transformer instruction manual for details. If no more alarms occur, the bladder is intact. If alarms continue, look carefully for oil leaks in the conservator and transformer. An oil leak is usually also an air leak. This may be checked by looking at the nitrogen and oxygen in the dissolved gas analysis. If these gases are increasing, there is probably a leak; with a sealed conservator, there should be little of these gases in the oil. Nitrogen may be high if the transformer was shipped new and was filled with nitrogen.

4.10 Auxiliary Tank Sealing System

The auxiliary tank sealing system incorporates an extra tank between the main transformer tank and the conservator tank. Inert gas (normally nitrogen) is placed above oil in both the main and middle tanks. Only oil in the top conservator tank is exposed to air. A desiccant air dryer may, or may not, be included on the breather. As oil in the main tank expands and contracts with temperature, gas pressure varies above the oil in both (figure 43).

Changes in gas pressure cause oil to go back and forth between the middle tank and the conservator. Air containing oxygen and moisture is not in contact with oil in the main transformer tank. Oxygen and moisture are absorbed by oil in the conservator tank and interchanged with oil in the middle tank. However, since gas in the middle tank interchanges with gas in the main tank, small amounts of oxygen and moisture carried by gas still make their way into the transformer.

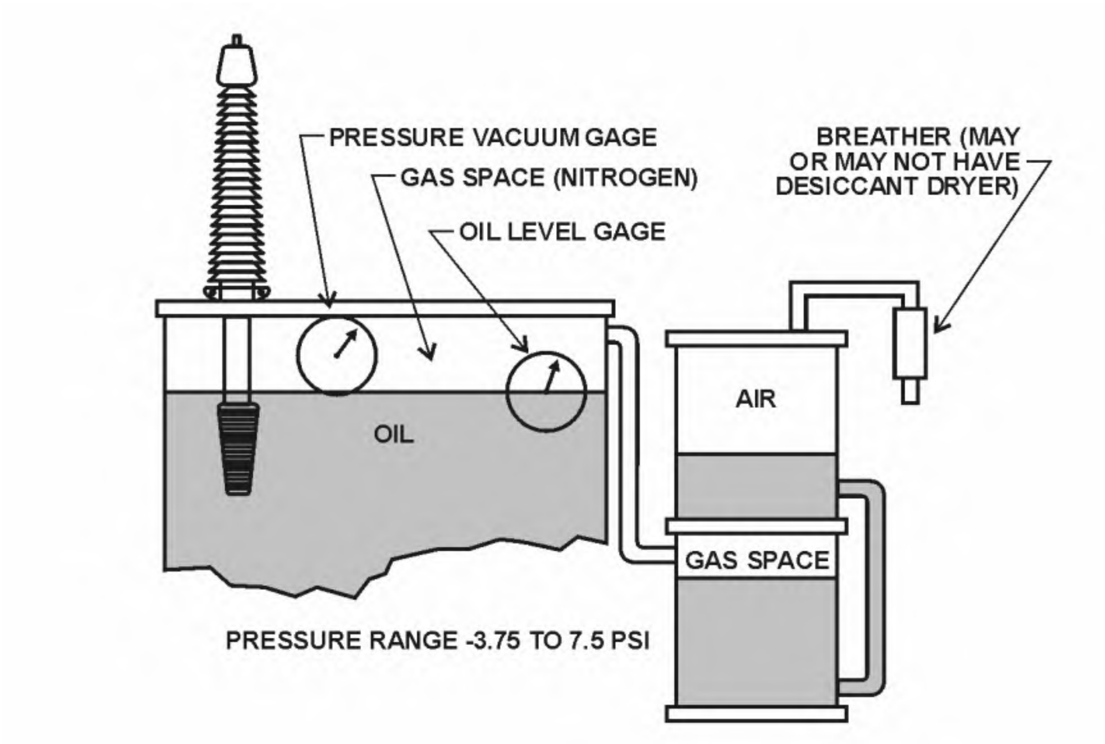

Figure 43 – Auxiliary Sealing System.

With this arrangement, the conservator does not have to be located above the main tank, which reduces the overall height. If you have one or more of these type transformers without desiccant air dryers, they should be installed.

5. Gaskets

Gaskets have several important jobs in sealing systems [7]. A gasket must create a seal and hold it over a long period of time. It must be impervious and not contaminate the insulating fluid or gas above the fluid. It should be easily removed and replaced. A gasket must be elastic enough to flow into imperfections on the sealing surfaces. It must withstand high and low temperatures and remain resilient enough to hold the seal, even with joint movement from expansion, contraction, and vibration. It must be resilient enough to avoid taking a “set,” even when exposed for a long time to pressure applied with bolt torque and temperature changes. The gasket must have sufficient strength to resist crushing under applied load and resist blowout under system pressure or vacuum. It must maintain its integrity while being handled or installed. If a gasket fails to meet any of these criteria, a leak will result. Gasket leaks result from improper torque, choosing the wrong type of gasket material, or choosing the wrong size gasket. Improper sealing surface preparation or the gasket taking a "set" (becoming hard and losing its resilience and elasticity) will also cause a leak. Usually, gaskets take a set as a result of temperature extremes and age.

5.1 Sealing (Mating) Surface Preparation

Clean the metal surface thoroughly. Remove all moisture, oil and grease, rust, etc. A wire brush and/or solvent may be required.

CAUTION:

Take extra care that rust and dirt particles never fall into the transformer. The results could be catastrophic when the transformer is energized.

After rust and scale have been removed, metal surfaces should be coated with Loctite Master gasket No. 518. This material will cure after you bolt up the gasket, so additional glue is not necessary. If the temperature is 50 ºF or more, you can bolt up the gasket immediately. This material comes in a kit (part No. 22424) with primer, a tube of material, and instructions. If these instructions are followed, the seal will last many years, and the gasket will be easy to remove later, if necessary. If the temperature is under 50 ºF, wait about ½ to 1 hour after applying the material to surfaces before bolting. If you are using cork-nitrile or cork-neoprene, you can also seal gasket surfaces (including the edge of the gasket) with this same material. Loctite makes other sealers that can be used to seal gaskets, such as "Hi-tack."

GE glyptol No. 1201B-red can also be used to paint gasket and metal surfaces; but it takes more time, and you must be more cautious about temperature. If possible, this work should be done in temperatures above 70 ºF to speed paint curing. Allow the paint to completely dry before applying glue or the new gasket. It is not necessary to remove old glyptol, or other primer, or old glue if the surface is fairly smooth and uniform.

Choose the correct replacement gasket. The main influences on gasket material selection are design of the gasket joint, maximum and minimum operating temperature, type of fluid contained, and internal pressure of the transformer.

CAUTION:

Most synthetic rubber compounds, including nitrile (Buna N), contain some carbon, which makes it semiconductive. Take extra care to never drop a gasket or pieces of gasket into a transformer tank. The results could be catastrophic when the transformer is energized.

5.2 Cork-Nitrile

Cork-nitrile should be used if the joint **does not have grooves** or limits. This material performs better than cork-neoprene because it does not take a set as easily and conforms better to mating surfaces. It also performs better at higher temperatures. Be extra careful when you store this material because it looks like cork-neoprene (described in section 5.3), and they easily are mistaken for each other. Compression is the same as for cork-neoprene, about 45%. Cork-nitrile should recover 80% of its thickness with compression of 400 psi in accordance with ASTM F36. Hardness should be 60 to 75 durometer in accordance with ASTM D2240. (See published specifications for E-98 by manufacturer Dodge-Regupol Inc., Lancaster, Pennsylvania.)

CAUTION:

Cork nitrile has a shelf life of only about 2 years, so do not order and stock more than can be used during this time.

5.3 Cork-Neoprene

Cork-neoprene mixture (called coroprene) can also be used; however, it does not perform as well as cork-nitrile. This material takes a set when it is compressed and should only be used when there are no expansion limiting grooves. Using cork-neoprene in grooves can result in leaks from expansion and contraction of mating surfaces. The material is very porous and should be sealed on both sides and edges with a thin coat of Glyptol No. 1201B red or similar sealer before installation. Glyptol No. 1201B is a slow drying paint used to seal metal flanges and gaskets, and the paint should be allowed to dry totally before installation. Once compressed, this gasket should never be reused. These gaskets should be kept above 35 ºF before installation to prevent them from becoming hard. Gaskets should be cut and sealed (painted) indoors at temperatures above 70 ºF for ease of handling and to reduce paint curing time. Avoid installing cork-neoprene gaskets when temperatures are at or near freezing because the gasket could be damaged and leak. Cork-neoprene gaskets must be evenly compressed at about 43 to 45%. For example, if the gasket is ¼-inch thick, 0.43 x 0.25 = 0.10. When the gasket is torqued down, it should be compressed about 0.10 inch. Or you may subtract 0.1 from ¼ inch to calculate the thickness of the gasket after it is compressed. In this case, ¼ = 0.25 so 0.25 minus 0.10 = 0.15 inch would be the final distance between the mating surfaces after the gasket is compressed. In an emergency, if compression limits are required on this gasket, split lock washers may be used. Bend the washers until they are flat and install enough of them (minimum of three), evenly spaced, in the center of the gasket cross section to prevent excessive compression. The thickness of the washers should be such that the gasket compression is limited to approximately 43%, as explained above.

5.4 Nitrile "NBR"

Nitrile "NBR" (buna N) with 50 to 60 duro (hardness) is generally the material that should be chosen for most transformer applications.

CAUTION:

Do not confuse this material with butyl rubber. Butyl is not a satisfactory material for transformer gaskets. The terms butyl and buna are easily confused, and care must be taken to make sure nitrile (buna N) is always used and never butyl.

Replace all cork neoprene gaskets with nitrile **if the joint has recesses or expansion limiting grooves**. Be careful to protect nitrile from sunlight; it is not sunlight resistant and will deteriorate, even if only the edges are exposed. It should not be greased when it is used in a nonmovable (static) seal. When joints have to slide during installation or are used as a moveable seal (such as bushing caps, oil cooler isolation valves, and tap changer drive shafts), the gasket or O-ring should be lubricated with a thin coating of DOW No. 111, No. 714, or equivalent grease. These are very thin and provide a good seal. Nitrile performs better than cork-neoprene; when exposed to higher temperatures, it will perform well up to 65 ºC (150 ºF).

5.4.1 Viton

Viton should be used only for gaskets and O-rings in temperatures higher than 65 ºC or for applications requiring motion (shaft seals, etc.). Viton is very tough and wear resistant; however, it is very expensive ($1,000+ per sheet). Therefore, it should not be used unless it is needed for high wear or high temperature applications. Viton should only be used with compression limiter grooves and recesses.

Store nitrile and viton separately, or order them in different colors; the materials look alike and can be easily confused, causing a much more expensive gasket to be installed unnecessarily. Compression and fill requirements for Viton are the same as those for nitrile, as outlined above and shown in table 3.

Table 3 – Transformer Gasket Application Summary

Gasket Material	Best Temperature Range	Percent Compar-ison	Compatible Fluids	UV Resist	Best Applications
Neoprene Use nitrile, except where there is ultraviolet (UV) exposure, or use viton.	-54 to 60 °C (-65 to 140 °F) not good with temperature swings	30 to 33	Askarels and hydrocarbon fluids	Yes	Use only with compression limits or recesses and use only if UV resistance is needed.
Cork-Neoprene (Coroprene) This material takes a set easily.	0 to 60 °C (32 to 140 °F)	40	Mineral oil R-Temp Alpha 1	No	Use only for flat to flat surface gaskets with no grooves or compression limits.
Cork-Nitrile (best) does not take a set as easily as cork-neoprene.	-5 to 60 °C (23 to 140 °F)	40	Mineral oil R-Temp Alpha 1	No	Use only for flat to flat surface gaskets with no grooves or compression limits.
Nitrile (Buna N) Use this except in high temperature, high wear, or UV.	-5 to 65 °C (23 to 150 °F)	25 to 50	Mineral oil R-Temp, Alpha 1 Excellent for Hydrocarbon fluids	No	O-rings, flat and extruded gaskets; use with compression limiters or recess only.[1]
Viton Use for high wear and high temperature applications.	-20 to 150 °C (-4 to 302 °F)	30 to 33	Silicone, Alpha 1 Mineral oil	Yes	High temperature; O-rings, flat and extruded gaskets; use with compression limiter groove or recess.[2]

[1] Nitrile (buna N) can also be used in low wear applications and temperatures less than 65 °C.
[2] Viton O-rings are best for wear resistance and tolerating temperature variations.

5.5 Gasket Sizing for Standard Groove Depths

Nitrile is the chosen example because it is the most commonly used material for transformer gasketing. As shown in table 3, nitrile compression should be 25 to 50%. Nitrile sheets are available in 1/16-inch-thick increments.

Gasket thickness is determined by groove depth and standard gasket thickness. Choose the sheet thickness so that ¼ to ⅓ thickness of the gasket will protrude above the groove; this is the amount available to be compressed (see table 4). Gasket sheets come in standard thicknesses in 1/16-inch increments. Choose one that allows a of the gasket to stick out above the groove, if possible, but never choose a thickness that allows less than ¼ or as much as ½ of the gasket to protrude above the groove. Do not try to remove old primer from the groove.

Table 4 – Vertical Groove Compression for Circular Nitrile Gasket

Standard groove depth (in inches)	Recommended gasket thickness (in inches)	Available to compress (in inches)	Available compression (percent)
3/32	1/8	1/32	25
1/8	3/16	1/16	33
3/16	1/4	1/16	25
1/4	3/8	1/8	33
3/8	1/2	1/8	25

Horizontal groove fill is determined by how wide the groove is. The groove width is equal to the outer diameter (OD) minus the inner diameter (ID) divided by two:

$$\frac{OD-ID}{2}$$

Or just measure the groove width with an accurate caliper.

Room left for the gasket to expand while being compressed is equal to the width of the groove minus the width of the gasket. For nitrile, the amount of horizontal room needed is about 15 to 25%. Therefore, you need to cut the gasket cross section so that it fills about 75 to 85% of the width of the groove.

For example, an 8-inch OD groove with a 6-inch ID, $\frac{OD-ID}{2}$, is $\frac{8-6}{2}$ = 1 inch. Therefore, the width of the groove is 1 inch. Because we have to leave 25% expansion space, the width of the gasket is 75% of 1 inch, or ¾ inch. So that the gasket can expand equally toward the center and toward the outside, you should leave one-half the expansion space at the inner diameter of the groove and one-half at the outer. In this example, there should be a total space of 25% of 1 inch or (¼ inch) for expansion after the gasket is inserted, so you should leave ⅛-inch space at the OD and ⅛-inch space at the ID. See figure 44.

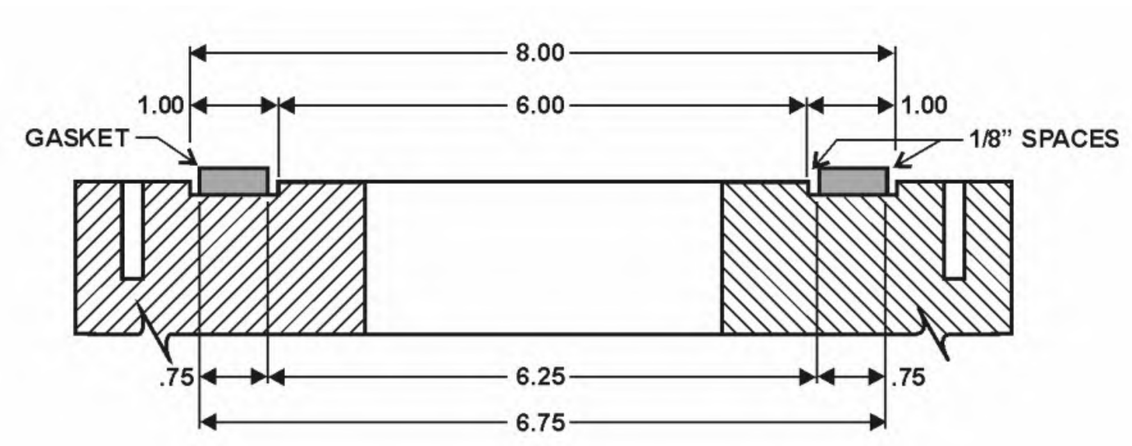

Figure 44 – Cross Section of Circular Gasket in Groove.

Always cut the outer diameter first. In this example, the outer diameter would be 8 inches **minus** ¼ inch, or 7¾ inches.

NOTE:

Since ⅛-inch space is required all around the gasket, ¼ inch must be subtracted to allow ⅛-inch on both sides. The inner diameter would be 6 inches plus ¼ inch, or 6¼ inches. Note that ¼ inch is subtracted from the OD but added to the ID.

To check yourself, subtract the inner radius from the outer radius to make sure you get the same gasket width calculated above. In this example, 3⅞ inches (outer radius, ½ of 7¾), minus 3⅛ inches (inner radius, ½ of 6¼), is ¾ inch, which is the correct gasket width.

5.6 Rectangular Nitrile Gaskets

Rectangular nitrile gaskets larger than sheet stock on hand can be fabricated by cutting strips and corners with a table saw or a utility knife with razor blade. Applying a little transformer oil or WD-40 oil makes cutting easier. Nitrile is also available in spools in standard ribbon sizes. The ends may be joined using a cyanoacrylate adhesive (super glue). Although there are many types of this glue, only a few of them work well with nitrile. Since all these glues have a very limited shelf life, remember to always keep them refrigerated to extend their shelf life. Lawson Rubber Bonder No. 92081 best withstands temperature changes and compression. The Lawson part number is 90286, and it is available from Lawson Products Co. in Reno, Nevada, (702-856-1381). Loctite 404 also works but does not survive temperature variations as well. It is available at NAPA Auto Parts Stores. Shelf life is critical. Always secure a new supply when a gasketing job is started; **never** use an old bottle that has been on the shelf since the last job.

NOTE:

Maximum horizontal fill of the groove should be 75 to 85%, as explained above in the circular gasket section. However, it is not necessary to fill the groove fully to 75% to obtain a good seal. Choose the width of ribbon that comes close to, but does not exceed, 75 to 80%. If one standard ribbon width fills only 70% of the groove and the next size standard width fills 90%, choose the size that fills 70%. As in the circular groove explained above, place the gasket so that expansion space is equal on both sides. The key point is that the cross-sectional area of the gasket remains the same while the cover is tightened; the thickness decreases, but the width increases. See below and figure 45.

CAUTION:

Nitrile (buna N) is a synthetic rubber compound and, as cover bolts are tightened, the gasket is compressed. Thickness of the gasket is decreased, and the width is increased. If a gasket is too large, rubber will be pressed into the void between the cover and the sealing surface. This will prevent a metal-to-metal seal, and a leak will result. It is best if the cross-sectional area of the gasket is a little smaller than the groove cross-sectional area. As cover bolts are tightened, the thickness of the gasket decreases, but the width increases so that cross-sectional area (thickness times the width) remains the same. Care must be taken to ensure that the gasket cross-sectional area is equal to or slightly smaller (never larger) than the groove cross-sectional area. This will provide space for the rubber to expand in the groove so that it will not be forced out into the metal-to-metal contact area (see figure 45). If it is forced out into the “metal-to-metal” seal area, a leak generally will be the result. When this happens, our first response is to tighten the bolts, which bends the cover around the gasket material in the metal-to-metal contact area. The leak may stop (more often, it will not); but the next time the cover is removed, getting a proper seal is almost impossible because the cover is bent. Take extra care to correctly size the gasket to prevent these problems.

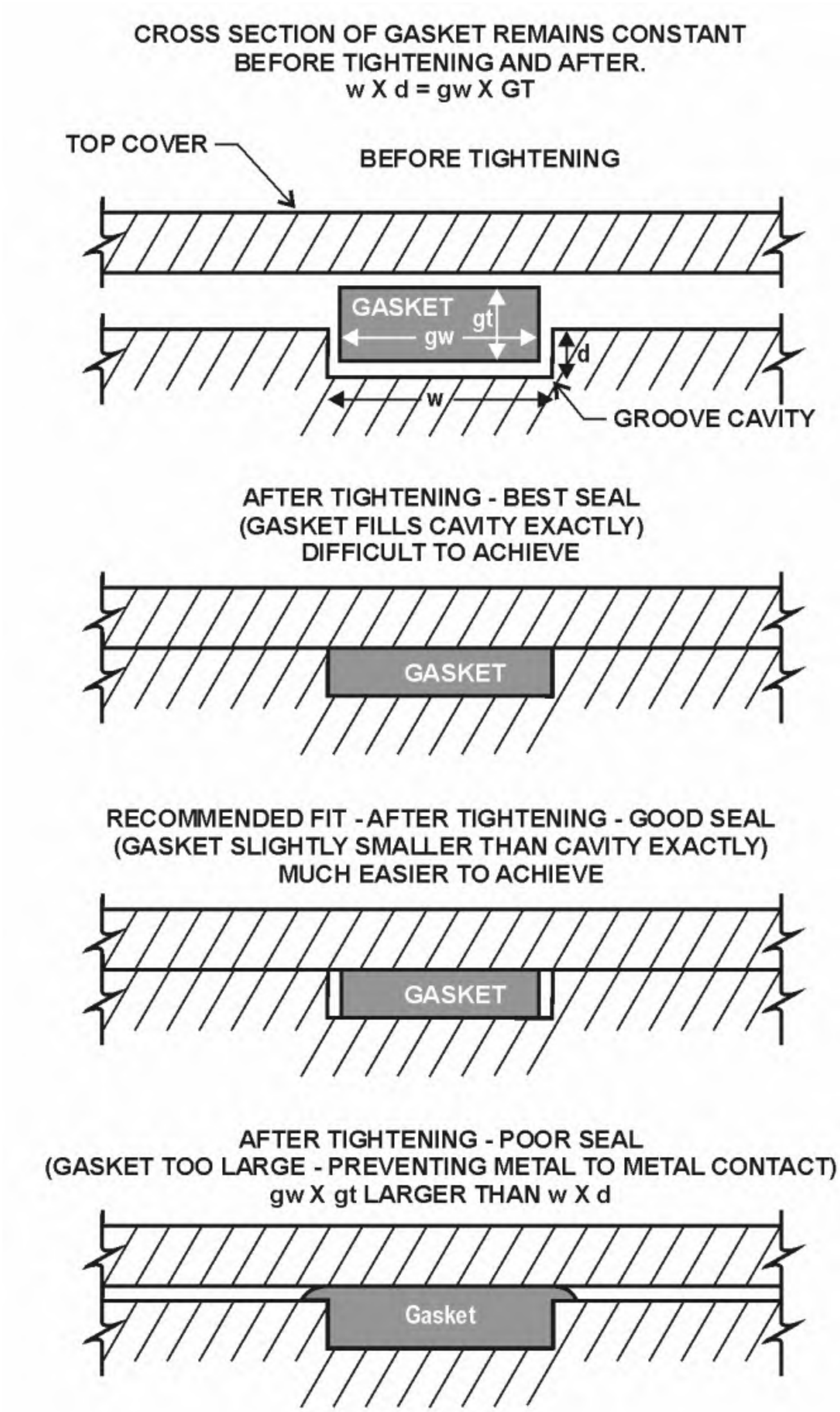

Figure 45 – Cross Section of Gasket Remains Constant Before Tightening and After. wxd = gw x gt

---

CAUTION:

On some older bushings used on 15-kV voltages and above, it is necessary to install a semiconductive gasket. This type bushing (such as GE type L) has no ground connection between the bottom porcelain skirt flange and the ground ring. The bottom of the skirt is normally painted with a conductive paint, and then a semiconductive gasket is installed. This allows static electric charges to bleed off to the ground. The gaskets are typically a semiconductive neoprene material. Sometimes, the gasket will have conductive metal staples near the center to bleed off these charges. When replacing this type gasket, always replace with like material. If like gasket material is not available, use cork-neoprene.

NOTE:

Failure to provide a path for static electric charges to get to the ground will result in corona discharges between the ground sleeve and the bushing flange. The gasket will be rapidly destroyed, and a leak will result.

When bonding the ends of ribbon together, the ends should be cut at an angle (scarfed) at about 15 degrees. The best bond occurs when the length of the angle cut is about four times the thickness of the gasket (see table 5). With practice, a craftsperson can cut 15-degree scarfs with a utility knife. A jig can also be made from wood to hold the gasket at a 15-degree angle for cutting and sanding. The ends may be further fine-sanded or ground on a fine bench grinder wheel to match perfectly before applying glue.

Thin metal conductive shim stock may be folded over the outer perimeter around approximately one-half the circumference. These pieces of shim stock should be evenly spaced around the circumference and stick far enough in toward the center so that they will be held when the bolts are tightened. As an example, if the gasket

Table 5 – Vertical Groove Compression for Rectangular Nitrile Gaskets

Standard Groove Depth (inches)	Standard Ribbon Width (inches)	Recommended Gasket Thickness (inches)	Available to Compress (inches)	Available Compression (inches)
3/32	1/4	1/8	1/32	25
1/8	5/16	3/16	1/16	33
3/16	3/8	1/4	1/16	25
1/4	3/4	3/8	1/8	33
3/8	3/4	1/2	1/8	25

is 8 inches in diameter, the circumference would be πD or 3.1416 times 8 inches = 25.13 inches in circumference. Fifty percent of 25.13 is about 12½ inches. Cut 12 strips 1-inch wide and long enough to be clamped by the flange top and bottom when tightened. Fold them over the outside edge of the gasket, leaving a little more than a 1-inch space between, so that the shim stock pieces will be as evenly spaced as possible around the circumference.

5.7 Bolting Sequences to Avoid Sealing Problems

If proper bolt tightening sequences are not followed or if improper torque is applied to the bolts, sealing problems will result (see figure 46). A slight bow in the flange or lid top (exaggerated for illustration) occurs, which applies uneven pressure to the gasket. This bow compromises the seal, and the gasket will eventually leak.

Figure 47 illustrates proper bolting sequences for various type flanges/ covers. Bolt numbers show the correct tightening sequences.

The numbers do not have to be followed exactly; however, the diagonal tightening patterns should be followed. By using proper torque and the illustrated sequence patterns, sealing problems from improper tightening and uneven pressure on the gasket can be avoided. Use a torque wrench and torque bolts according to the head stamp on the bolt. Check the manufacturer's instruction book for pancake gasket torque values.

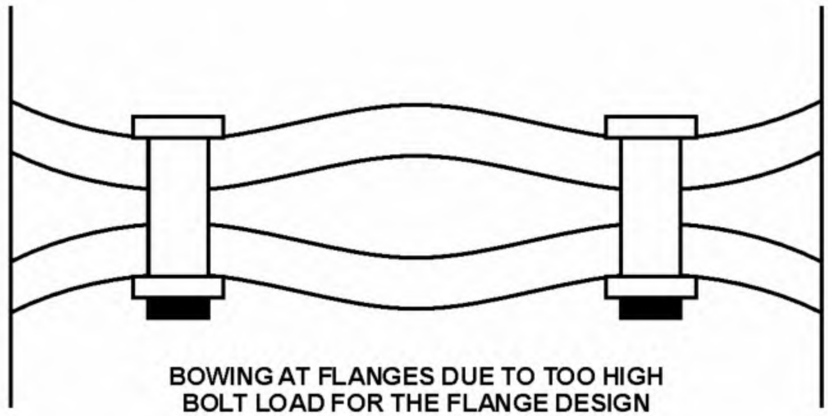

Figure 46 – Bowing at Flanges.

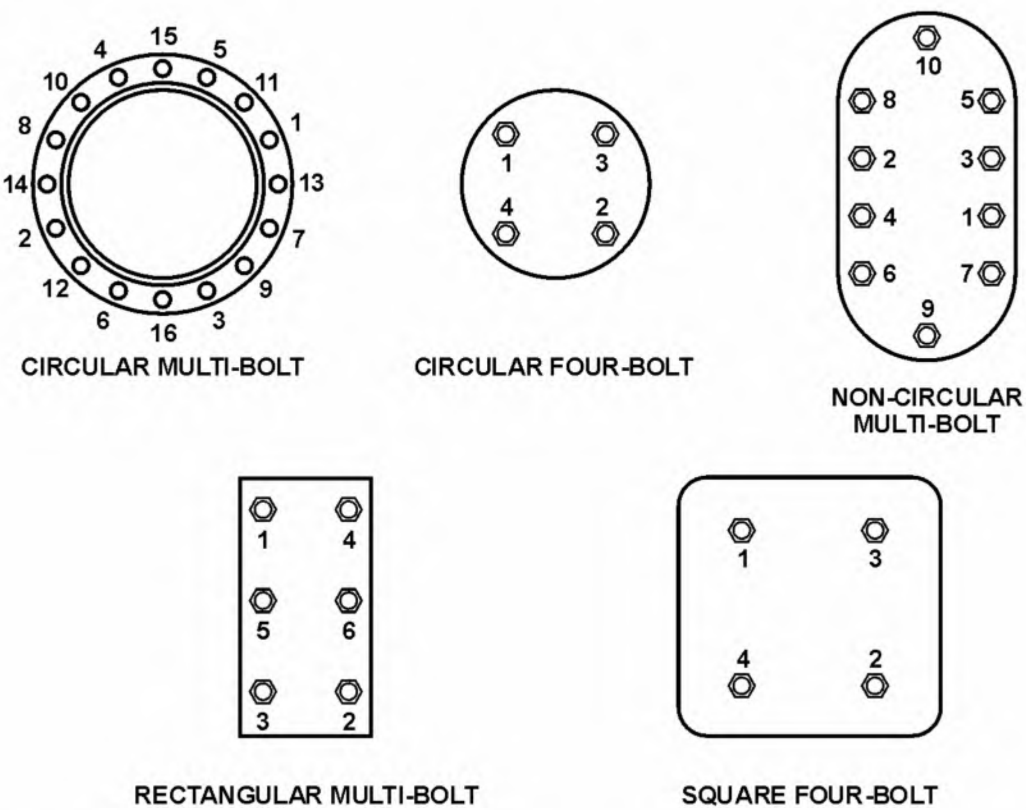

Figure 47 – Bolt Tightening Sequences.