Resolving Turbomachinery Trains Low-Low Lube & Seal Oil System Pressure Trip Shutdowns

By Abdulrahman Alkhowaiter 2020

Steam Turbine Driven Gas Compression Train [Dresser Rand]

Standby Lube Oil Pumps Startup Reliability & Failures

Steam Turbine Generators, Gas Compression Trains, and large Pump trains rely heavily on the availability of the main lube oil pump which can be shaft driven on large STG's, steam turbine driven, or electric motor driven. For Gas turbine trains, the majority utilize a shaft driven lube oil pump at the accessory gearbox. The shaft driven pumps can be more reliable but sometimes have their own weakness. For these large turbomachinery trains, when the main lube oil pump fails in service then an automatic switchover is supposed to occur to the standby AC motor driven lube oil pump to prevent shutdown.

For systems without accumulators, this switchover must occur and the standby pump must reach its design rated speed within 3.0 seconds total time from sensing to full speed or the lube oil header pressure will drop below the Low-Low level ESD trip pressure setting of approximately 10.0 psig used on turbomachinery.

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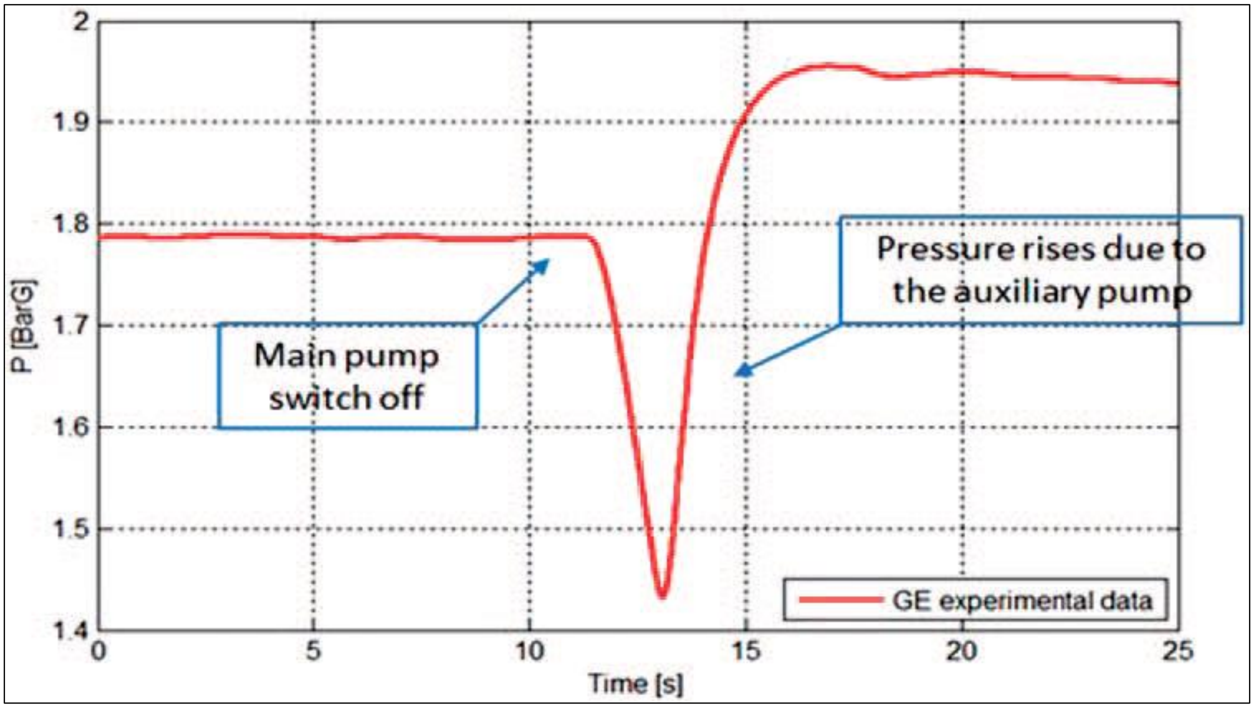
In many refineries and gas plants the large machinery train auxiliary equipment have not been designed properly for 100% reliability of switching action during a trip of main lube or seal oil pump. The result has been frequent plant trips as the critical compression train shutdown initiates a plant shutdown with major disruption. Apart from inadequate system design, in some cases maintenance factors also led to standby pump startup low reliability. Field inspection has shown several common design deficiencies**. In power plants**, the steam turbine driven generator train includes a third DC powered pump as in above picture. This DC pump may assist standby AC unit or it may be for emergency lubrication during shutdown.

The issue of machinery trips from low lube oil pressure is typically caused by a trip of the main oil pump while the machinery train is operating at the conventional lube oil header of 20 psig. This then causes a low pressure alarm to activate once header pressure has dropped to 15 psig alarm. At this point an automatic command is given to start the AC motor driven auxiliary lube oil pump to be able to prevent the oil pressure from dropping below the ESD shutdown level of 10 psi.



Main to Standby Lubrication Pump Switchover Transient Delay

Without accumulators to provide a boost pressure that delays loss of pressure in header, the standby pump must start and reach full speed in two to three seconds. For turbomachinery users around the world, the inability of the overall lube or seal oil system to sustain operation during pump switchovers has led to frequent shutdowns. The inability to solve long term failures is a result of inadequate failure analysis procedures which do not cover a wide range of failure modes and ignore inherent design deficiencies of the total system design. This total system design includes alarm and shutdown pressure instrumentation, electrical reliability of main and standby oil pumps electric motor drivers and their electrical breakers including voltage drop at terminals, lube-seal oil piping which does not trap air pockets, mechanical reliability of the main steam turbine driver or electric motor driver, mechanical reliability of the standby AC motor driven lube oil motor, pump and coupling.

Apart from design, many **maintenance related** factors increase the possibility of low-low pressure trips including inadequate maintenance of components such as lube and seal oil pumps, backpressure control valves, pump check valves, maintenance of the electrical feed system for lube and seal oil pumps that are motor driven, maintenance of lube-seal oil pump and motor bearings, and maintenance of the instruments which measure pressure and perform relay action that initiate startup of standby equipment and tripping.

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Main Oil Pump: Steam Turbine or Motor Drivers Initiate Lube-Seal Oil Pump Trips

1. **Sudden Trips Overspeed Latch**: Root cause of sudden trips of steam turbine driven main lube oil pumps: The most common factor found is that the main steam turbine driven pump undergoes a shutdown caused by turbine overspeed trip linkage suddenly dropping which trips the turbine trip valve. The cause is not due to over speeding but due to a vibrational effect on worn and loose linkages, leading to dropping of the knife edge linkage arm.

2. **Turbine bearing failures:** The turbine driven oil pumps may experience turbine bearings catastrophic failure due to either water in oil contamination, or to leakage of lube oil from the bearing housing reservoirs which are typically small in volume of oil. The contamination failures are caused by leakage of steam into bearings. Solution: Contamination can be prevented by installing steam deflectors between the carbon ring glands and the bearing housing. The shaft mounted deflectors are made of stainless steel and fabricated at shop. Width is 1/8 inch, with outside diameter equal to 2.0 inch plus shaft diameter. Use total interference shrink fit of 0.0025 inch diametral for the bore. Do not utilize the OEM standard deflectors; they are too small to prevent moisture contamination.

3. **Hydraulic Governor**: A third cause of turbine failure is due to a turbine hydraulic governor loss of speed control or shaft coupling failure which leads to loss of speed and shutdown of the turbine driven oil pump. To prevent such failures it's recommended to check alignment of this critical coupling between turbine shaft and its shaft driven governor. Make a PM to replace such couplings. If problem is frequent then request improved heavier duty coupling from turbine vendor. Many of these small couplings use a hub with keyway and small set screw for holding in position. This set screw typically loosens in service causing failure. Best to fabricate new hardened alloy steel hubs with 0.002 inch total hub bore interference fit to eliminate the need for set screws.

4. **Upgrade turbine to modern reliable unit**: Another option is to replace the existing unreliable main pump steam turbines with new modern & reliable design steam turbines. A small modification will be required at site for the steam piping and footing but this is a simple modification. For small turbines such as these it is we strongly advised to insure that mechanical dry gas shaft seals be required in the purchase requisition to raise reliability against steam contamination of bearing housing oil.

5. **If Possible replace turbine with motor:** When an overhead rundown lube oil tank is available, for most cases it is recommended to replace the steam turbine driver with an induction electric motor of identical size to the standby pump motor or larger. Steam turbine driven lube oil pumps are not needed as long as an overhead lube oil tank is available to provide emergency rundown lube oil by gravity. The two motors should be fed from separate substations when possible for higher reliability.

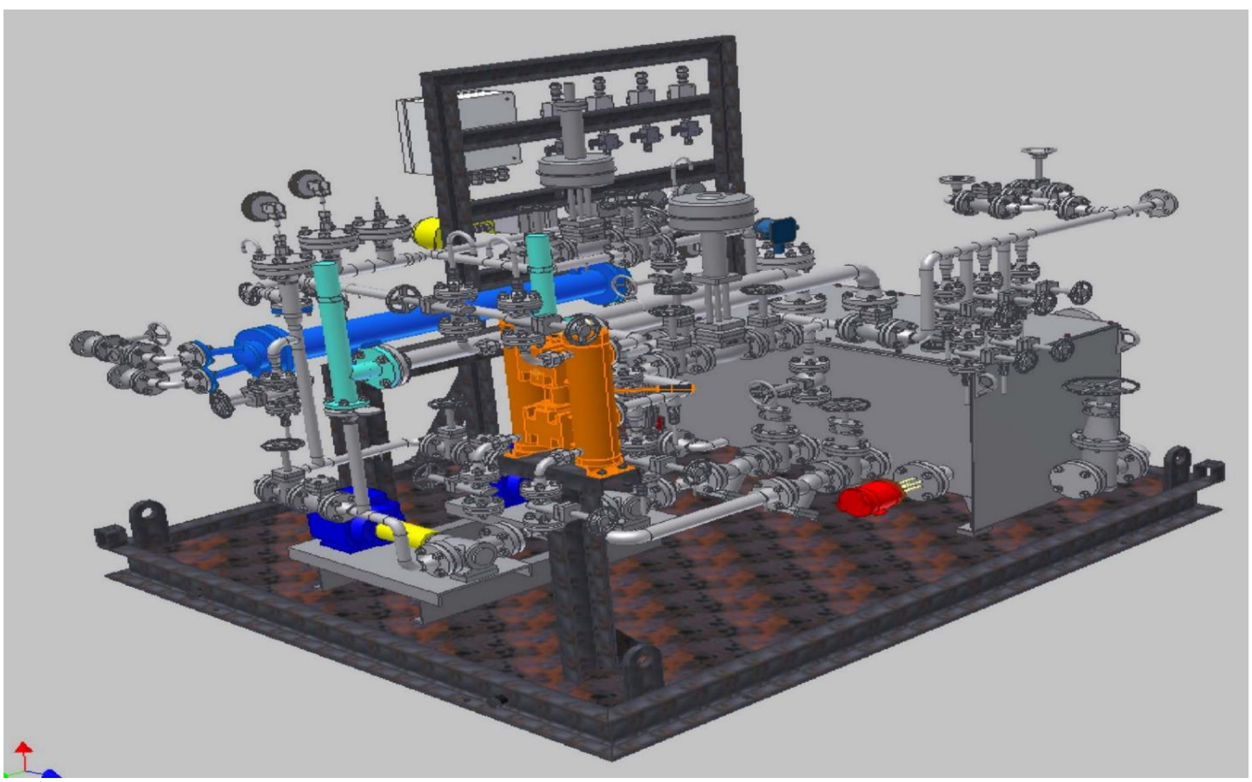
6. **For motor driven main lube or seal oil pumps**, the causes of sudden trips are typically: Electrical breaker trip from overheating due to corrosion at terminals, loose wires, and undersized breakers. Last electrical issue is reduced voltage from main substation. Mechanical causes can include failure of the shaft coupling flexible element shim pack or bolts looseness-shearing, failure of the motor driver bearings from poor lubrication or wear out mode. Finally, trips can be caused by pump internal problems such as high vibration events and seizing due to suction blockages or foreign objects but this is rare.

7. **Switching Oil Filters**: Sometimes the cause of trips is not that the main motor or steam turbine pump has tripped, but low-low oil pressure suddenly occurs because the operators were switching the oil filters online without first removing the trapped air in the newly installed filter cartridge housing. The air trapped inside causes a sudden oil pressure drop after switching to the new filter. The drain or vent must be opened to remove the air by using the small switching valves which send oil into the cartridge housing to equalize pressure.

Auxiliary Pump: Why Standby Pumps Fail to Maintain Lube-Seal Oil Header Pressure

The reasons for inability of the standby pump to start up or produce adequate pressure at the correct time is a multi-dimensional issue that must first be understood clearly. The standby pump is being asked to perform an immediate start to pressurize a hydraulic system filled with oil. The oil system is undergoing very rapid oil pressure drop from its low header pressure alarm level of 15 psig and can decay to the Low-Low shutdown level of 10 psig in three seconds or less without accumulator action. The standby pump and motor typically requires a minimum of 2 to 3 seconds to start and reach rated speed and this assumes that the motor start relay or motor starter is operating correctly.

The lube oil system piping design in some cases was incorrectly designed for proper switchover between main and standby machine. To perform this correctly the system must have carefully designed pump suction and discharge piping which does not trap air. Air causes long delays in oil pressure buildup. In addition, the lube oil and seal oil systems must incorporate correctly sized accumulators whose internal volume is sufficient to provide an oil boost during dropping of lube and seal oil header pressures. The trapped pocket of air occurs in several feet of discharge line after each of the lube oil pumps. This air pocket delays buildup of pressure in the system by more than 10 seconds causing an immediate oil header pressure drop since air is a compressible gas.



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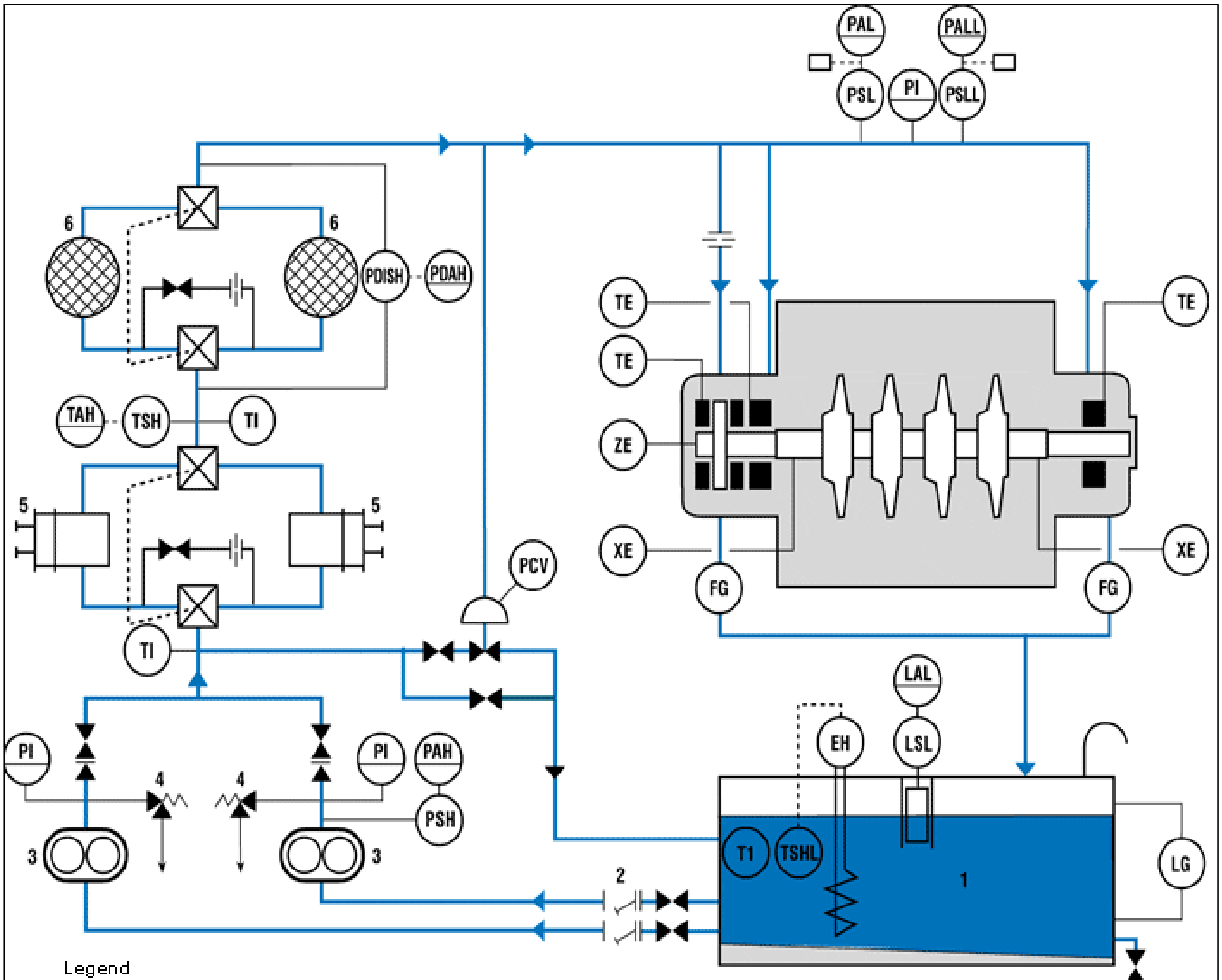


Legend
1 – Oil Reservoir
2 – Suction Strainer
3 – Oil Pump
4 – Relief Valve
5 – Oil Cooler
6 – Oil Filter
– Locally Mounted Instrument
– Panel Mounted Instrument
LG – Level Glass
LSL – Low Level Switch
LAL – Low Level Alarm
PI – Pressure Indicator
PCV – Pressure Control Valve
PSL – Low Pressure Switch
PAH – Low Pressure Alarm and Stand-by Pump Start-up
PSLL – Minimum Pressure Switch
PALL – Minimum Pressure Shut-down
PSH – High Pressure Switch
PAH – High Pressure Alarm
PDISH – High Diff. Pressure Indicator and Switch
PDAH – High Diff. Pressure Alarm
TI – Temperature Indicator
TE – Thermoelement
TAH – High Temperature Alarm
TSHL – High/low Temperature Switch
ZE – Axial Displacement Probe
XE – Radial Probe
FG – Flow Glass

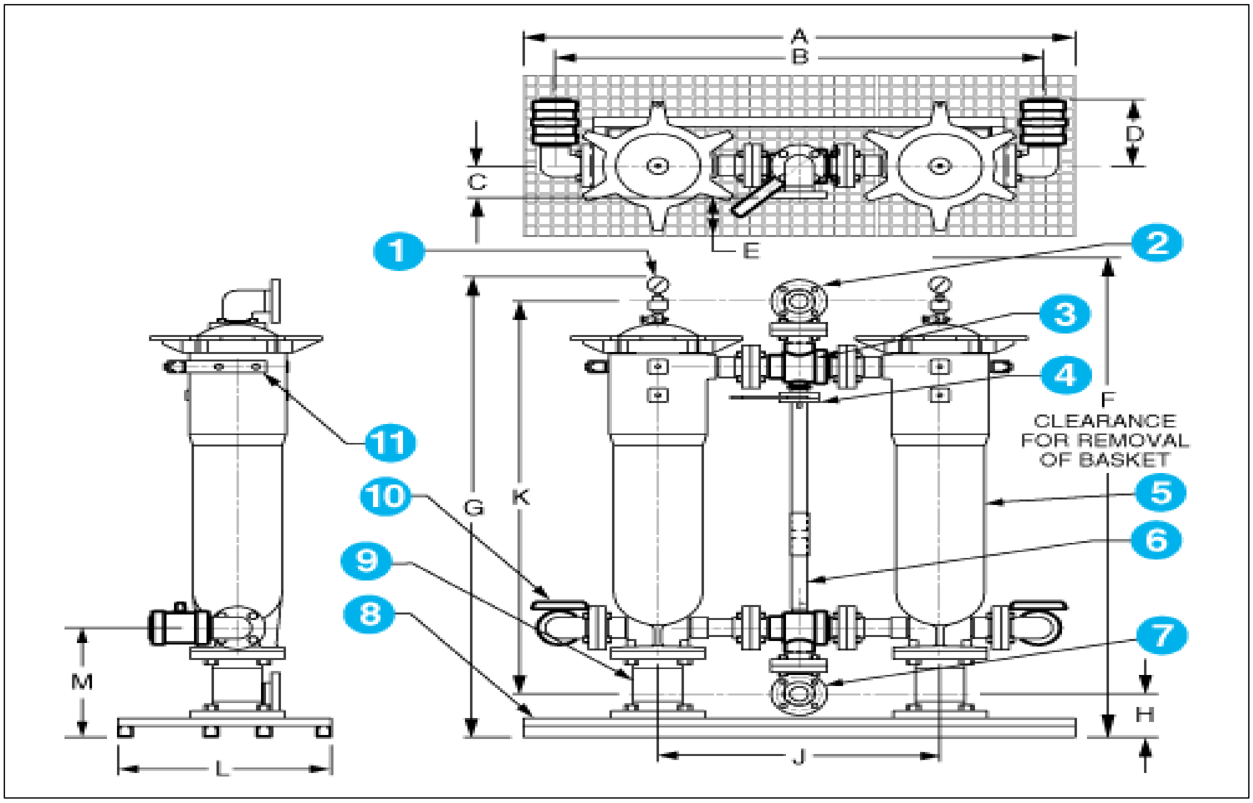
Typical Compressor Lube Oil System (Nuovo Pignone. Florence, Italy)

Recommendations to Solve Standby Lube-Seal Oil Pump Pressurization Failures

1. **Lube-Seal Oil Pump startup pressure reliability:** Air pockets impact both centrifugal and screw type pumps startup so they must be removed permanently. To remove air pockets, add to both lube pumps discharge lines [before check valve] an air bleed line using 1/4 inch SS tubing, back to the oil reservoir or pump suction line. This SS tubing must be routed on supports using angle iron welded to structural base to protect from damage of tubing. The SS tubing should include a 1/8 inch diameter orifice at connection to pipe to reduce flow. No energy is lost as the lube oil backpressure control valve is always recirculating oil back to tank so no net loss of energy occurs with this modification. For horizontal oil pumps, another air bleed line is recommended for the suction line with connection back to reservoir above the oil level. An eccentric reducer is required by the API-614 standard at suction inlet to pump.

2. **Removing trapped air by drilling check valves:** An alternative simple to implement solution to remove trapped air pockets is to remove the two oil pumps check valve flappers or piston to shop and drill a 1/8 inch hole in center of each disk. This hole allows a small but continuous stream of oil to drain back to tank through the standby pump, leaving the pump lines fully primed and ready for immediate operation at any time with zero air buildup. No energy is lost as the lube oil backpressure control valve is always recirculating oil back to tank so no net loss of energy occurs with this modification. A 1/8 inch size hole is chosen as its diameter resists blockage by impurities in the oil. If the lube or seal oil pump discharge exceeds 300 psig then a smaller diameter hole of 3/32 inches is recommended.

3. **Accumulators in Lube or Seal oil system**: For many lube or seal oil systems but not all, an accumulator is supplied to facilitate delaying oil pressure drop during switchovers and reduce transient pressures by providing a minimum of 4.0 seconds transient pressure boost according to API-614 standard. However, on many systems the accumulators are undersized due to design deficiencies by OEM or have failed internally due to poor maintenance. The accumulator with elastomer bladders should be renewed as they wear out and leak. They should be pressurized to a setting pressure of 0.70 x rated lube oil pressure at the connection of accumulator to pipe. Solution: Remove bladders and replace with new bladders and insure Nitrogen gas pressurization at 0.70 x normal oil pressure at the inlet of accumulator. Note: From lubrication system experience, users cannot rely strictly on bladders to maintain switchover delay time as bladders leak nitrogen and have other failure modes including inadequate volume. This is why it is necessary to apply the full report recommendations. See appendix for detailed accumulator sizing calculations. Note: Bladder nitrogen pressure can only be correctly measured by isolating accumulator and bleeding the internal oil pressure.



4. **Excessive oil flow demand**; Some standby pump switchover failures are caused by a delay lag time in building up header pressure by the pump. There can be an un-recognized excessive flow demand from the train process machinery which includes steam turbines, gearboxes, motors, compressors or driven pumps. This demand can be above the original OEM design flow rating for the lube oil pumps and may be caused by the user neglecting to reinstall the full set of original orifices on lube or seal oil lines. For example, on most gearboxes there is supposed to be a main inlet feed oil orifice that has been sized for correct flow for gearbox. If removed, this introduces excessive consumption of oil and the lube oil pumps then operates towards the back of their curves which overloads the drivers meaning that the motor-pump startup acceleration time to produce correct system pressure is now increased.

5. **Why two pumps may be operating at same time:** When the main lube or seal oil pump is operating, sometimes it does not produce enough flow and pressure to maintain the lube or seal oil header pressure and the second standby pump automatically starts once the low alarm setting of 15 psi has been reached. As a result there are now two pumps operating. The cause of this phenomena is that there is typically found a leaking check valve in the standby pump discharge line, or a leaking manual valve on the pump discharge which allows recycling

of oil back to reservoir. As the main pump is operating, part of its flow is lost by going backward through the standby pump check valve or through the manual globe valve and entering the oil reservoir. This problem is invisible and can only be fixed by removing and overhauling or renewing both pumps check valves and pump manual recycle valves at shop. A second possible cause is that the lube oil backpressure control valve can malfunction. Its job is to maintain oil header pressure by leaking back to the reservoir, but it may be faulty and allowing excessive leakage flow back to oil reservoirs. For screw pumps the piping is equipped with relief valves; when faulty, these will return some leakage flow back to reservoir. All of the above reduce capability of the standby pump to achieve short startup period.

6. **Pump Internal Wear, blocked suction, or Internal piping leakage**: The main lube oil or auxiliary pumps may have internal wear causing internal recirculation inside pump and reduced output flow compared to new condition. When called upon to start, it will produce a slower rise in system pressure compared to new. In addition, suction blockages at the main or auxiliary pumps can occur, or leaking pipes internally when pump discharge piping is inside reservoir and not visible. Lube Pumps especially of screw type should be overhauled every 5 to 7 years. Centrifugal pumps may operate ten years between overhauls.

7. **Shutdown Relay Time Delay:** Add time delay to the Low-Low lube and seal oil pressure shutdown relays: To allow for normal startup time delays due to standby motor relay action and starting time to reach full speed, it is best practice to implement a 3.0 second time delay to the low-low-oil pressure trip relay to insure achieving 100% reliability of lube or seal oil pump switchover action without harming the machinery or causing a plant shutdown. This is applied to the relay, not to the pressure transmitter. Note: For all turbomachinery trains with overhead lube oil rundown tanks, these have more than 5 minutes [300 seconds] oil capacity during low-low oil pressure shutdowns, so a 3.0 second time delay can never harm the equipment. The startup of the standby pump is not being delayed by this time delay action, it is only the total train shutdown trip function logic which is being delayed.

8. **Automatic Switchover Failure due to Pump set on Manual Switch**: In some cases, the automatic switchover from main to auxiliary pump has failed because the standby pump motor's local Hand-Off-Auto switch at oil skid was forgotten in the manual mode by the operator. The automatic control signal is sent to start this motor but the electrical signal does not reach the motor. It is preferred to study this motors startup logic with plant electrical and control engineers to formulate a solution to prevent this failure mode. Plants cannot rely on human error to protect machines. At the minimum, a red flashing light should be automatically energized whenever the control switch is left on manual position.

9. **Lube Oil Headers Pressure Settings**: Normal Header is at 20 to 22 psig and low Alarm at 15 psig which activates standby pump. Low-Low-oil ESD pressure shutdown is at 10 psig. For a few rare manufacturers the design oil header pressure is set at 35 psig and for such cases only use manufacturer settings. Notice that increasing the low alarm setpoint to 16 psig will increase available switchover time which helps to reduce switchover failures, however it increases the possibility of frequent auto starts of the standby pump due to normal pressure variation in the main oil header. Therefore it is not recommended to raise the low oil pressure setting above 15 psig. Reducing it below 15 psig is also not advisable.

10. **Perform an off-line test of the lubrication pumps switchover**. Once all the above system improvements are applied, it is now time to make a system functional test. The purpose of this test is to ensure that the auxiliary oil pump has the ability to start and produce sufficient pressure to overcome a main shutdown [10 psi typical shutdown setting]. The auxiliary pump is supposed to activate at the low pressure alarm setpoint of 15 psi header pressure. There should always be redundant pressure transmitters providing signals to the control system. Actual test procedure: While main process machine is off, start the main lubricating pump which is motor or turbine driven and leave operating for at least 10 minutes. It is preferred to do this test while lube oil is still hot just after a train shutdown.

11. **Detail Procedure of Functional Test:** Shutdown the main lube oil pump while holding a timer in the hand. Start timer when the lube header oil pressure decay has reached 15 psig which should be your existing low pressure alarm point which then energizes the standby pump. Note: The oil pressure will be dropping and decaying toward the 10 psi ESD limit during this period. At this moment the auxiliary lube oil pump should have started and the lube oil pressure should be increasing toward the normal header pressure of 20 psig. When reaching 15 psig Alarm point, shut off the timer. The total time span from Low Alarm startup of Auxiliary until reaching 15 psig is the startup time delay period. This time span should be a maximum of three seconds for systems without accumulators. For systems with large capacity healthy accumulators and added time delay in shutdown relay, up to 8.0 seconds total time to reach 15 psig is typical maximum recommended. For all tests, the lube oil pressure in header should not decay below 11.5 psig otherwise the system is considered to have failed as there should be a minimum margin of 1.5 psi above ESD limit. Perform this test using a newly installed pressure gauge on oil header or calibrated transmitter. The functional test should be repeated three times to ensure that results are constant and accurate.

Attch-1: Main Lube Oil Vertical Submerged Pump STG Unit

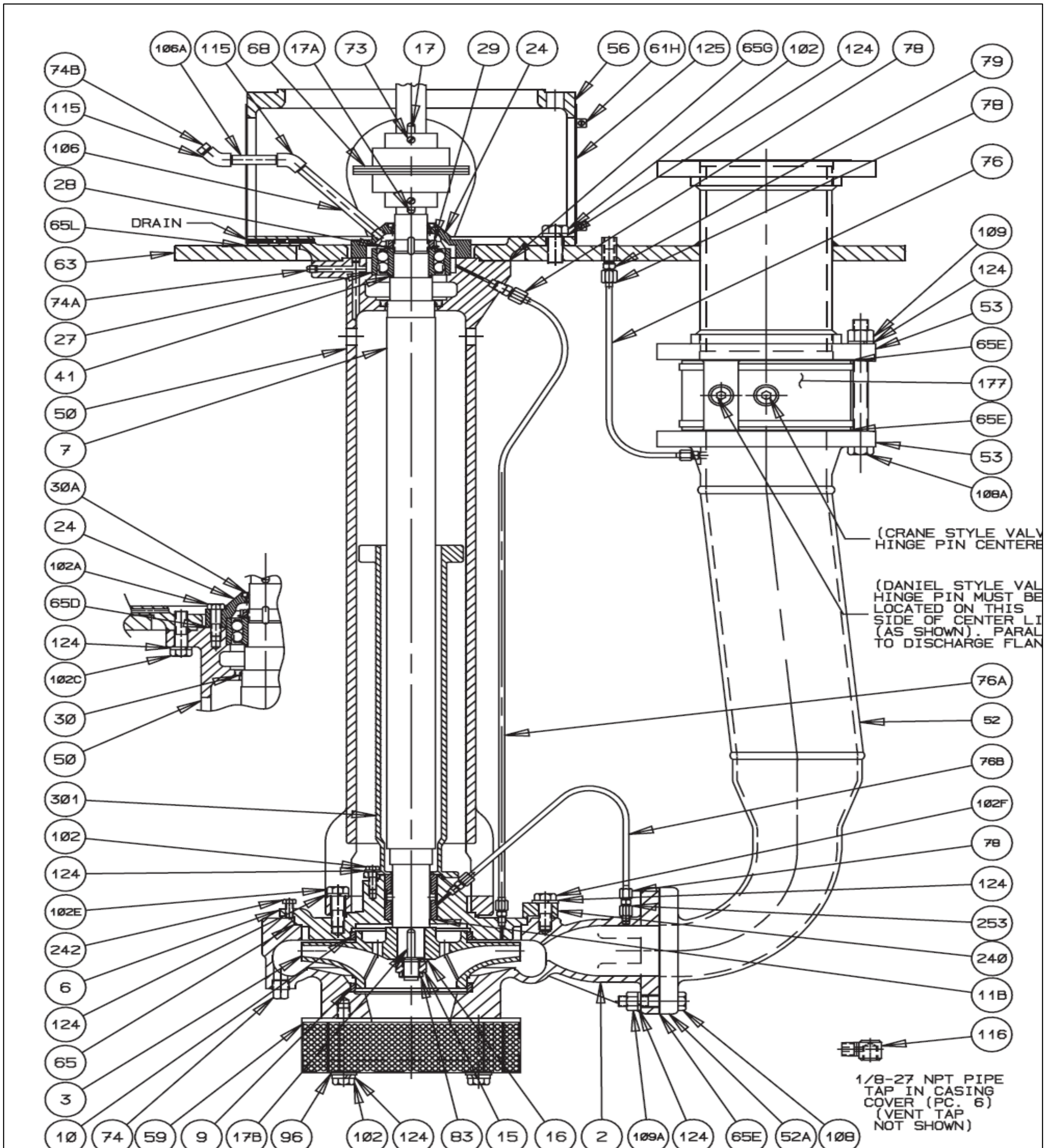
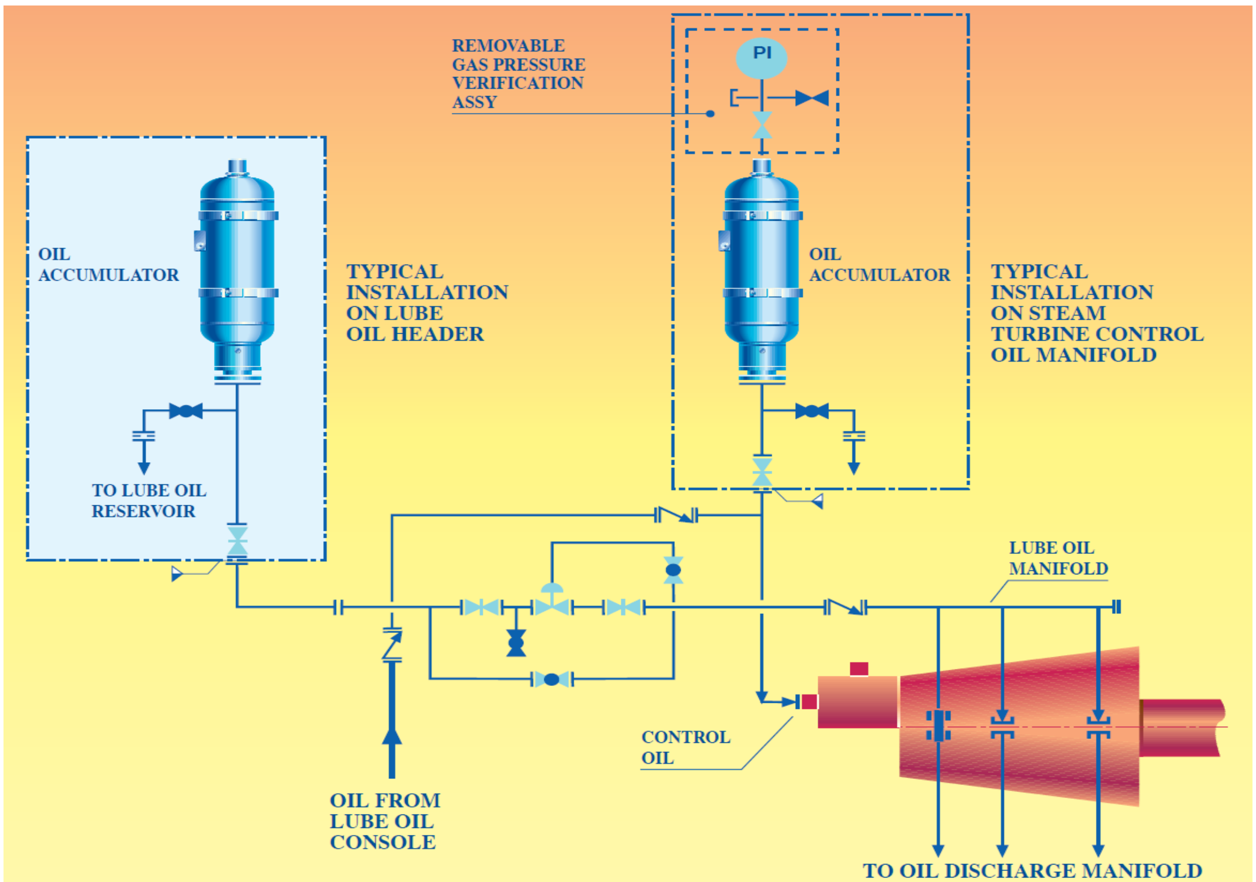


FIGURE 1. VCRE VERTICAL LUBE OIL PUMP

Attch-2: Accumulators in Control and Lubrication Oil System: Sizing Formula



1. **Accumulator Emergency Oil Sizing**: Find the total oil flow-rates from lube system manual P&ID and by field calculation. Calculate the existing total system lube oil flowrate at highest temperature. Add all feeds such as thrust bearing feed oil + outboard radial + inboard radial oil flow + gearbox or gear coupling oil flow for total train machinery. A typical thrust bearing uses 25 GPM. A typical tilt pad radial bearing uses 12 GPM. Convert oil flow to liter per second.

2. **Accumulator Nitrogen Fill Pressure Is 0.70** x Header normal pressure at its inlet connection. The Accumulator(s) volume available is only: Total volume in liter x [1- 0.70]. The reason for setting at 0.70 x system pressure is to give partial compression of bladder to allow return.

3. **Accumulator Lube Oil Capacity Available** for emergency flow above trip pressure of 10 psig: CAP= [Total ACC Volume in liter x [1- 0.70]] x [Header pressure - 10 psig]/Header pressure.

4. **Time Interval [seconds] of Emergency Feed oil** = Accumulator CAP/Normal total flowrate L/S.