Best Practice Catalog

Lubrication System

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1.0 Scope and Purpose

This best practice for a lubrication system addresses the technology, condition assessment, operations, and maintenance best practices with the objective to maximize performance and reliability of generating units.

The primary purpose of the oil lubrication system is to supply clean oil with appropriate temperature and pressure to the bearings of the turbine-generator during operation. It is also a key reliability system for the other machinery under the Power Train Equipment.

1.1 Hydropower Taxonomy Position

Hydropower Facility → Powerhouse → Power Train Equipment → Balance of Plant/Auxiliary Components → Lubrication System

1.1.1 Lubrication System Components

Bearing lubrication systems are critical to unit operation. There are a number of different types of lubrication system (Pressure, Gravity, and Submersion). The reliability related components of lubrication systems include the lubricant/oil, filter sub-system, cooling sub-system, oil pumps, vessel and piping, console/skid and instrumentation/alarm. [1]

Figure 1 illustrates a typical lubrication system console.

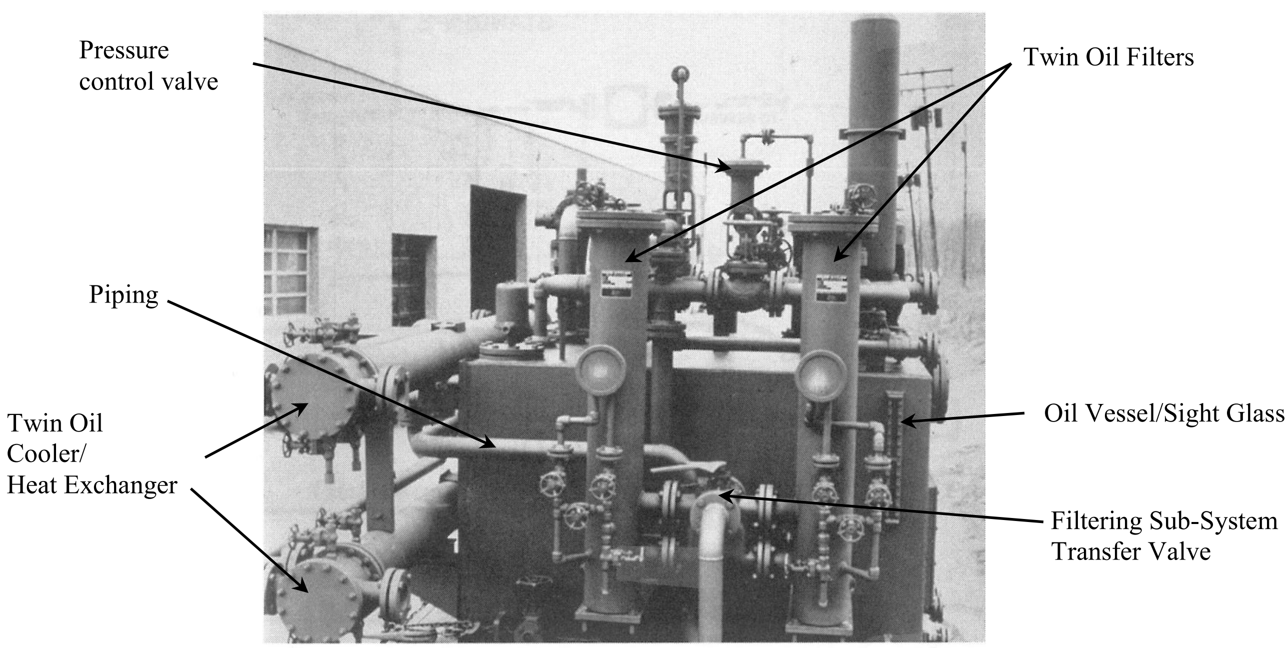

Figure 1: Typical Modular Oil Console Arrangement [3]

Lubricant/Oil: The functions of the lubricant/oil are:

1. Minimize friction and wear in Hydro machinery
2. Maintain internal cleanliness by suspending contaminants or keeping contaminants from adhering to components.
3. Cool moving elements, absorb heat from the contact surface area and transport it to a location in which it can be safely dissipated.
4. Dampen shock; cushion the blow of mechanical shock. A lubricant film can absorb and disperse these energy spikes over a broader contact area.
5. Prevent corrosion or minimize internal component corrosion. This can be accomplished either by chemically neutralizing the corrosive products or by setting up a barrier between the components and the corrosive material.
6. Transfer energy - A lubricant may be required to act as an energy transfer median as in the case of hydraulic equipment

Filter Sub-System: The function of the filter sub-system is to continuously provide clean auxiliary fluid (oil) to the critical equipment. A typical filtration specification for auxiliary system is 10 absolute particle size, that is, the greatest size of any solid particle in the oil film should be 10 micron. There are two types of filtration systems; "inline" and "offline" filtration. The inline filter sub-system consists of a transfer valve (allow transfer from one bank of components to the stand-by bank of components without significant pressure pulsations being introduced into the system), filters, differential pressure indication and alarm. Offline filtration, often call Kidney Loop filtration, functions independently of the designed lubrication system of the unit.

Cooling Sub-System: The function of this sub-system is to continuously provide cool auxiliary fluid (oil) at the required temperature to the critical equipment. Most coolers in use in hydropower plants are of a shell and tube heat exchange design as cooling water is readily available. As with filter sub-systems, they consist of a transfer valve (allow transfer from one bank of components to the stand-by bank of components without significant pressure pulsations being introduced into the system), as well as twin heat exchangers and a temperature transmitter and alarm.

Oil Pumps: The function of the oil pumps are to continuously supply the system fluid at the required flow rate. This means it must be capable of interrupted operation for the same period as the turbine it is servicing.

Vessel and Piping: The vessel functions as the oil reservoir for the system. The correct sizing is critical for the hydro equipment that the lubrication system is servicing. Size will be a function of system flow and subsequently the amount of flow the hydro equipment (main guide bearings, thrust bearings) will actually pass. The function of the piping is to connect the console/skid auxiliary equipment (pumps, vessel, etc.) to the Hydro units it services. The typical oil velocities are in the order of 4 to 6 feet per second.

Console/Skid: The function of the console/skid is to house most of the Lubrication System components (pumps, vessel, etc.). Since auxiliary equipment must be maintained and calibrated during operation, it is important for the console/skid to be sized with ample space for maintenance personal.

Instrumentation/Alarms: The function of the instrumentation is to measure and regulate the process variables of the auxiliary fluid (oil) such as flow, temperature, level and pressure. Pressure indicators, temperature indicators, and differential pressure transmitters are examples of key instrumentation.

1.2 Summary of Best Practices

1.2.1 Performance/Efficiency & Capability - Oriented Best Practices

There are no best practices directly associated with the unit efficiency and capacity.

1.2.2 Reliability/Operations & Maintenance - Oriented Best Practices

- Maintain clean, dry oil by periodic analysis of oil condition and regular sampling for visual and laboratory examination.
- Monitor oil filter change time interval (when the filter differential pressure alarm is activated) to clean oil tank and rundown tanks. This will involve maintaining operating and temperature records of hydro plant oil system.
- Stainless steel reservoir, vessels and piping can be used to ensure minimum oil flushing time, optimum machinery component life and unit reliability.
- High pressure lubrication system can be used on thrust bearings to reduce friction during start-up and shut down.
- System pumps having mechanical seals are recommended instead of shaft packing
- Follow correct oil flushing procedures will produce an oil system that does not require frequent on-line filter changeover.

- The use of centrifugal pumps eliminates the need for relief and backpressure (bypass) control valves within the lubrication system
- Monitor turbine vibration. Setting the shaft vibration alarm at 50% of the initial field value will allow early detection of rotor condition change, and initiate investigation and an action plan for corrective action before a rotor or component failure occurs.
- Ensure continuous venting of the non-operating cooler and filter in cold ambient applications.
- Kidney loop filtration should be installed on turbine guide bearing oil systems to remove debris and water continuously.
- Require a Factory Acceptance Test (FAT) for any new oil consoles to duplicate field conditions as closely as possible and record response times for transients.
- Install sight glasses in the drain lines of positive displacement pump relief valve to confirm that the relief valve is not passing.
- Label oil system piping with colored tape to help personnel to understand system operation and how to take corrective action quickly to prevent unit damage.

1.3 Best Practice Cross-references

- I&C - Automation Best Practice
- Mechanical – Francis Turbine Best Practice
- Mechanical – Kaplan Turbine Best Practice
- Mechanical – Pelton Turbine Best Practice
- Mechanical – Generator Best Practice
- Mechanical – Governor Best Practice

2.0 Technology Design Summary

2.1 Material and Design Technology Evolution

Early designs for oil lubricating systems, for vertical hydro turbine-generator bearings, consisted of pumps driven by gears or belts from the main shaft or by simple viscosity pumps which move oil by hydrodynamic action. Horizontal hydro turbine-generator bearings were often lubricated by oil rings riding on top of the shaft. Modern designs have evolved into systems which move the oil by electric motor driven pumps. This has many advantages such as providing electrical controls, backup pumps (AC and DC), and flexible capacities such as flow rates and pressures.

2.2 State of the Art Technology

There are number of designs for Lubrication Sub-Systems that have become state of the art technology. Lube and seal oil overhead tanks that are not stainless steel will reduce bearing, oil seal and/or driver control and protection Mean Time before Failure (MTBF), since there cannot be a filter between these tanks and these components. This is due to iron sulfide building up in the small clearances of the unit components, which has resulted in premature failure. Stainless steel reservoir, vessels and piping can be used to ensure minimum oil flushing time, optimum unit component life and unit reliability. If oil flushing times can be reduced, or delayed all together, plant outage times can be significantly reduced. Replacement of existing non-stainless steel oil system piping, components or the entire system can usually be justified in un-spared critical equipment.

The most common cause of oil system induced unit trips is the malfunction of relief valves and/or backpressure control. This can cause an unscheduled shutdown of unit. The use of centrifugal pumps (Figure 2) eliminates the need for relief and backpressure (bypass) control valves. Single stage centrifugal pumps can be used whenever the ambient temperature along with the use of thermostatically controlled reservoir heaters maintain an oil viscosity that allows the use of a centrifugal pump (oil viscosity is low enough to minimize the effect of viscosity on centrifugal pump power – low viscosity correction factors).

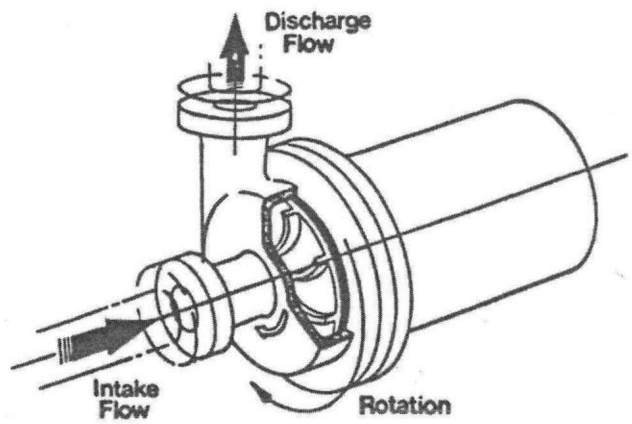

Figure 2: Centrifugal pump operation [3]

Centrifugal pumps cannot be used when high oil viscosities (>400 centiStokes) are required. In those applications a positive displacement pump must be used. The function of all pumps in auxiliary system service is to continuously supply the system fluid at the required pressure and flow rate. In order to ensure reliable, trouble free operation, pump mechanical seals are recommended instead of shaft packing. A properly selected and installed pump mechanical seal in auxiliary system service can operate continuously for a three year period. Function definition will be met: 'to supply the system fluid at the required pressure and flow rate'.

The thrust bearing high pressure lubrication system provides high pressure oil between the thrust shoes and the runner to provide lubrication on start-up and shut-down of a unit. The oil is pumped from the bearing oil pot by a high pressure pump, through a manifold to a port machined in each of the shoes. Figure 3 shows a typical oil ring on a thrust shoe for a high pressure lubrication system. The primary use for the high pressure lubrication system is to reduce friction during start-up and shut down, but it is also a very useful system during alignment. With the system on, it is possible for a couple of people to rotate a unit by hand or move the rotating components laterally on the thrust bearing [2].

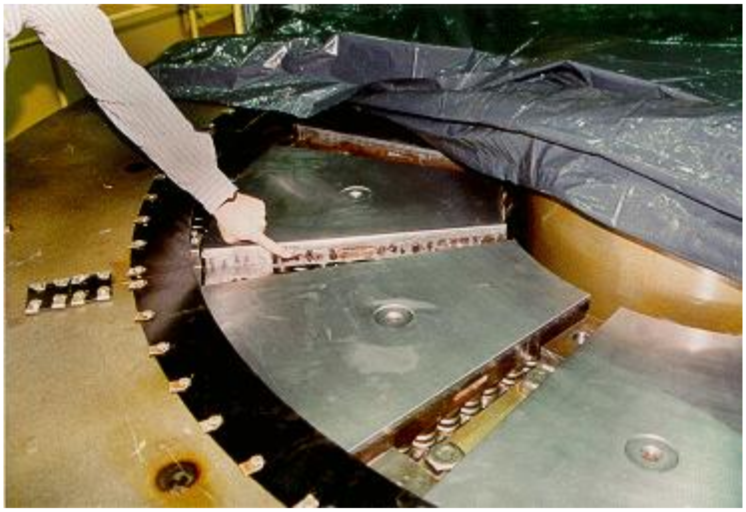

Figure 3: Lubrication Ports on Thrust Bearing [2]

Supplementary oil cleaning can be achieved by a separate system (Kidney Loop Oil Filtration System) in series with the existing lubrication system. (Figure 4)

Figure 4: Kidney Loop Oil Filtration System [L&S Electric, Inc.]

This system can reduces failures caused by dirty oil thus increased life and performance of pumps, valves, servos, oil heads and other various hydraulic mechanisms. It can promote extended oil life and help eliminate moisture in oil.

3.0 Operation & Maintenance Practices

3.1 Condition Assessment

Samples of oil or any deposits need to be taken at regular intervals for visual examination and laboratory analysis. Best practice includes daily visual examinations, monthly laboratory examinations for general system and oil conditions, and six-month laboratory examinations for a more in-depth determination of future oil life. By doing this, detection can be made at the start of deterioration, contamination or other troubles early and corrective action can be taken [4]. Figure 5 illustrates the oil film and the testing involved.

Lubricant/oil condition assessment testing [5]:

- Viscosity — ASTM D445
- RPVOT (Rotary Pressure Vessel Oxidation Test) — ASTM D2272
- Water Content — ASTM D1744
- Acid Number — ASTM D664, ASTM D974
- ISO Cleanliness — ISO 4406
- Rust — ASTM D665
- Water Separability (Demulsibility) — ASTM D1401
- Foam — ASTM D892
- ICP Metals — ASTM D6130

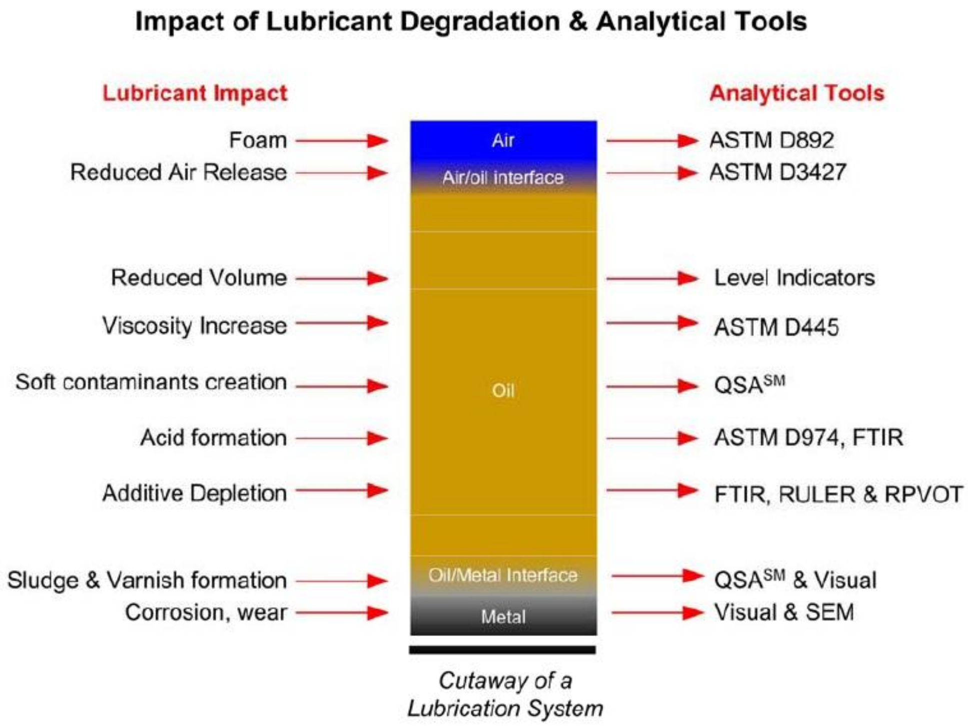

Figure 5: Testing for lubricant degradation in a Turbine Oil System [5]

Another condition assessment activity may involve the replacement an old lubrication system within a hydro modernization project where assessing newly purchased lubrication consoles is important for the long term success of the plant. It is a best practice to require a Factory Acceptance Test (FAT) for the oil console to duplicate field conditions as closely as possible and record response times for transients (main pump trip and two pump operation) to ensure optimum oil system field reliability.

As a minimum, the following items should be included in the FAT:

- Auto start of the auxiliary pump
- Two pump operation
- Relief valve checks
- Bypass (backpressure) valve proper valve position and stability
- Transfer valve operation
- Cooler tube leak check
- Filter pressure drop and particle check for bypassing
- Accumulator pre-charge and bladder condition (if applicable)
- Supply valve(s) – proper valve position and stability
- Proper supply flow, pressure and temperature

Failure to completely check all oil system component functions during the FAT will result in delayed start-up and possible lower than anticipated unit reliability for the life of the process unit. Chart recorder data for all transient checks (pump trip and two pump operation) and transfer valve check, are required to be supplied for confirmation that oil supply pressure during the transient event does not fall to the trip setting.

3.2 Operations

All gravity drain oil systems accumulate debris (oil sludge, etc.) in the oil reservoir over time. Increasing frequency of oil filter change (significant increase – say from once per year to once every six months) indicates a need to clean the oil reservoir and rundown tanks at the next turnaround. It is a best practice to monitor oil filter change time (when the filter differential pressure alarm is activated) to clean oil tank and rundown tanks. This is a predictive approach that will minimize oil reservoir and overhead tank cleaning cycles while still ensuring unit reliability. Every time the unit is shut down, any oil contained in the tank and all associated debris enters the seal without the benefit of filtration. Therefore, attention should be given to any overhead seal oil tanks that have never been cleaned, but are exposed to the process gas and associated process debris.

In cold climates (ambient temperatures below 15° C at any time of the year), cool, static oil in the non-operating cooler and filter will cause a transient pressure drop when it is comes on-line. Low oil pressure alarms will occur for critical equipment (e.g., when auxiliary pump does not start or does not start in time). It is a best practice to continuously vent the non-operating cooler and filter in cold ambient applications. An enable reliable operational transfer (cooler or filter) always maintains this non-operating equipment with open ventilation and at the same temperature as the operating equipment. Where an alarms/trip has been caused by the issue noted above, operating procedure should be revised and orificed vents installed if required.

Since only the oil film keeps gear and screw components from contacting each other, a plugged main pump suction strainer will rapidly increase pump clearance and cause the auxiliary pump to start. It is a best practice to install differential pressure transmitters to alarm on high differential pressure, for control room monitoring, around pump suction strainers – especially screw and gear pumps. The source of the main pump strainer blockage will eventually plug the auxiliary strainer and result in auxiliary pump damage.

It is very difficult to confirm that a positive displacement pump relief valve is not passing. A friction-bound relief valve can cause an unexpected shutdown of an oil system by passing an additional amount of oil that can force the start-up of an auxiliary pump, thus exposing the unit to a shutdown if the auxiliary pump does not start in time. It is a best practice to install sight glasses in the drain lines of positive displacement pump relief valve to confirm that the relief valve is not passing.

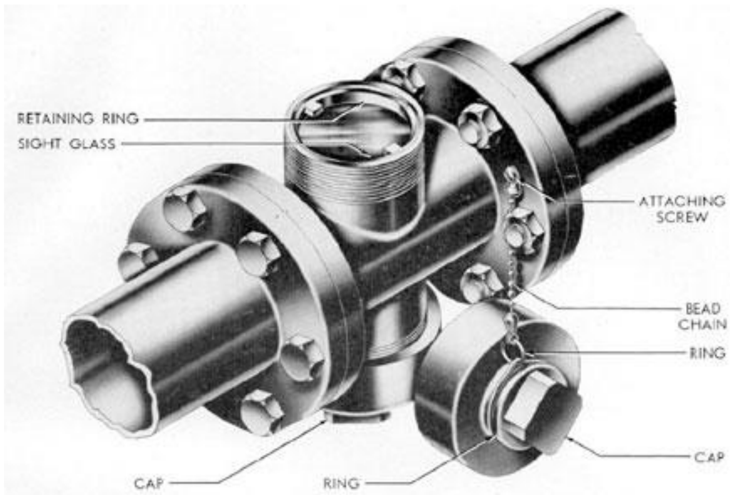

Figure 6: Sight glasses in the drain lines [Maritime Park Association]

Most oil system relief valves are the modulating type with a small bypass hole to prevent sticking of the valve. This allows a small continuous flow to pass through the valve. Feeling the discharge line of the relief valve gives a false impression of valve condition. Using a sight glasses is a correct way to confirm the proper operation of relief valves.

Regarding the control aspects of the system, it is best practice that existing lubrication systems be modified to be Triple Modular Redundant (TMR) if any trip system un-scheduled shutdowns have occurred. Oil systems without TMR shutdown logic experience lower reliability than TMR systems and corresponding lower serviced unit reliability. TMR shutdown functions for two-out-of-three voting will positively eliminate shutdown instrumentation related failures and prevent spurious shutdowns. Require TMR transmitters for all shutdown functions in new project work or field modifications, to maximize serviced unit reliability.

Similarly, oil systems installed as late as the 1980s use single switches for pressure and temperature protection of machine components. These old devices expose the plant to unscheduled shutdowns. It is a best practice to replace mature plant switches with TMR transmitters in all trip circuits for optimum oil console and serviced unit reliability.

TMR smart transmitters (two-out-of-three voting for a trip) ensure accurate and reliable operation, and prevent spurious trips. Many plants have registered low machine reliability and corresponding revenue losses because of the malfunctioning of old instrumentation. Considering forced outages, it is easy to justify the installation of TMR smart transmitters for all trip circuits in critical equipment installations.

Failure to mark and monitor control valve stem position in oil systems has led to many surprises and replacements soon after a turnaround. It is a best practice to monitor control valve stem position to identified worn components and allowed replacement during an outage. By monitoring the control valve position (see Figure 6), a determination of components wear (rotary pumps, bearings and seals) will ensure corrective action is taken during an outage. Marking the position of control valves (marking the stem and valve yoke with a straight edge) at the beginning of a run will give an instant indication of component wear for the following items:

- Rotary pumps (screw or gear) – if the bypass valve is closing over time.
- Bearing wear – if the lube oil supply valve is opening over time.
- Control component wear – if the control oil supply valve is opening over time.
- Seal wear – if the seal oil supply valve is opening over time.

Figure 7: Typical collection of data from the control valve assembly

Check the position of all marked control valves prior to the turnaround meeting to determine if the affected components need replacement during the turnaround. Remember that turnaround action does not affect product revenue, but unplanned action does! Replacement of an oil pump can take two days considering alignment. Replacement of a bearing or seal can take three to five days.

Using colored tape or paint to define each individual line of the system (supply lines, return lines, bypass lines) promotes ownership and personnel awareness on site thus increasing system safety and reliability. It is a best practice to label oil system piping with colored tape to help personnel to understand system operation and how to take corrective action quickly to prevent unit trips. Figure 7 shows examples of piping labels. Many critical machine unit shutdowns are the result of not monitoring the local instrument and components in the system. Failure to properly label piping, instruments and components leads to neglect and corresponding low oil system reliability.

Figure 8: Typical Piping Labels

3.3 Maintenance

Maintenance of an oil lubricated bearing and its reliability is directly connected to the quality of the supplied oil used for lubrication and cooling. Any contamination of the oil either with debris or water will increase the likelihood of a bearing failure.

Oil filters are usually positioned downstream of the oil coolers to prevent carbon steel (iron sulfide) particles from entering the machinery components and causing pre-mature wear/failure. Shell and tube oil coolers typically have the water in the tubes and oil in the shell and are made of carbon steel for cost reasons. It is a best practice to use of stainless steel coolers and filters. This can easily be justified and will ensure maximum life of machine components.

Lubrication system flushing may be either a displacement flush after a drain and fill, or a high velocity flush for initial turbine oil fills. A displacement flush is performed concurrently during turbine oil replacement, and a high velocity flush is designed to remove contaminants entering from transport and commissioning of a new turbine. Displacement flushes, using separate flush oil, are to remove residual oil oxidation product that cannot be removed by draining or vacuum. A displacement flush is conducted by utilizing lubrication system circulation pumps without any modification to normal oil circulation flow paths, except for potential kidney loop filtration. This flush is typically done based on a time interval vs. cleanliness (particle levels) to facilitate the removal of soluble and insoluble contaminants that would not typically be removed by system filters.

Best practices in high-velocity flushing are as follows:

- Supply and storage tanks should be clean, dry and odor-free. Diesel flushing is not acceptable.
- Two to three times' normal fluid velocity achieved with external high-volume pumps, or by sequential segmentation flushing through bearing jumpers.
- Removal of oil after flush is completed to inspect and manually clean (lint-free rags) turbine lube oil system internal surfaces.
- High-efficiency bypass system hydraulics to eliminate the risk of fine particle damage [5].

4.0 Metrics, Monitoring and Analysis

4.1 Measures of Performance, Condition, and Reliability

In standard ASTM D4378-08 [7], an equation was developed for turbine severity, **B**, is as follows:

$$B = M\,(1 - X/100)/(1 - e^{-Mt/100})$$

Where: **B** is the turbine severity
M is the fresh oil makeup expressed as the percent of total charge per year
t is the years of oil use
X is the used oil oxidation resistance in the Test Method D 2722 rotary pressure vessel text expressed as % of fresh oil

In standard ISO 4406, oil cleanliness levels are defined by three numbers divided by slashes (/). The example below illustrates the use of ISO 4406 code chart.

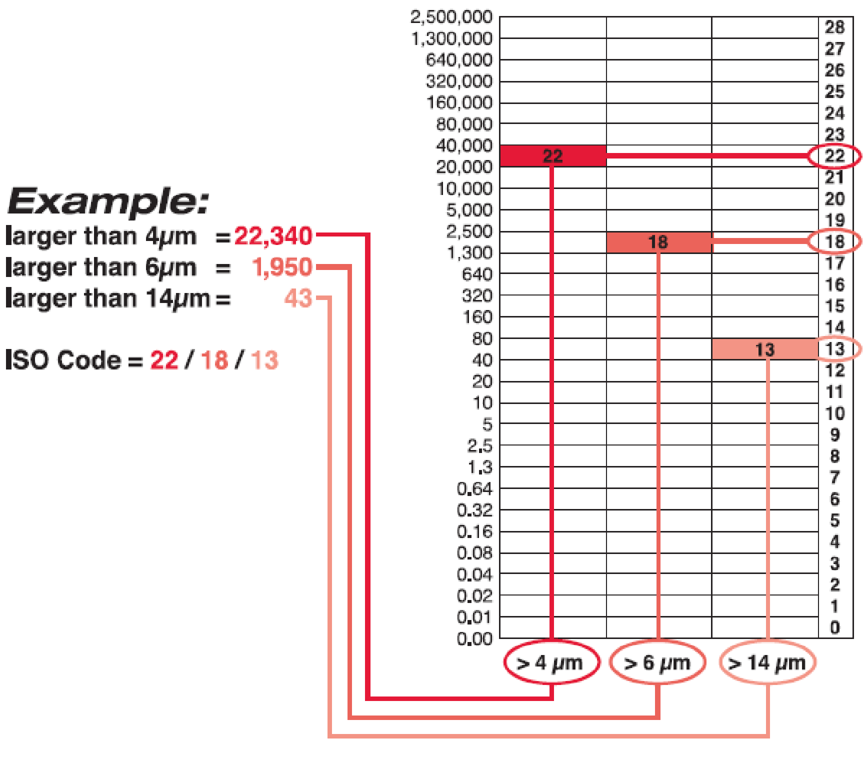

Figure 9: ISO 4406 Code Chart [8]

These numbers correspond to 4, 6 and 14 micron. Each number refers to an ISO Range Code, which determines by the number of particles for that size (4, 6 and 14mm) and larger present in 1ml of oil.

4.2 Analysis of Data

Analysis of test data is defined in standard ASTM D4378-08.

The analysis of data using the oil cleanliness levels from the ISO 4406, are illustrated below:

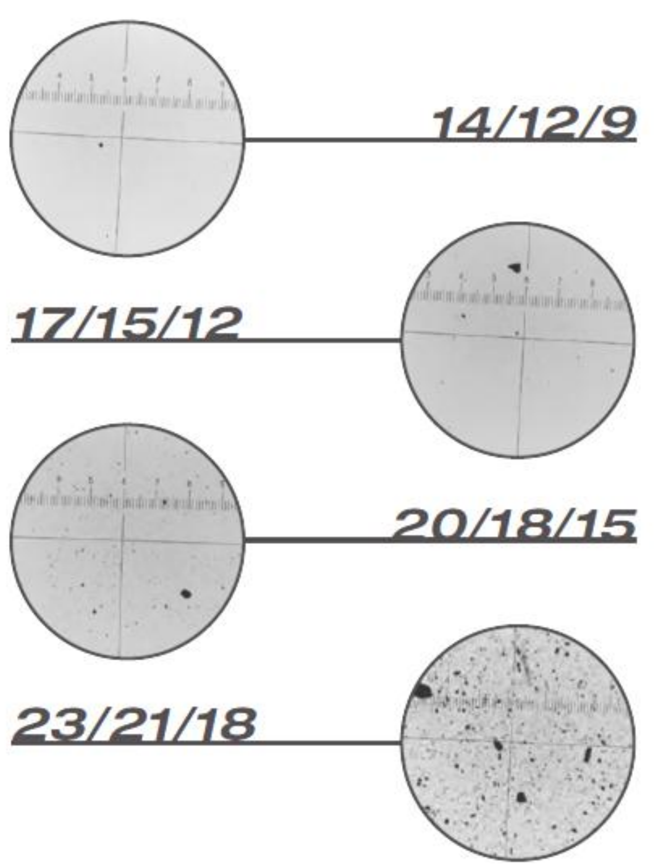

Figure 10: Oil Cleanliness Levels [8]

4.3 Integrated Improvements

Interpretation of test data and recommended actions are defined in ASTM D4378-08.

The integration of the ISO 4406 oil cleanliness levels can be used for the selection and specification of system characteristics and the equipment that it services.

Finding the cleanliness level required by a system

1. Starting at the left hand column, select the most sensitive component used in the system.
2. Move to the right to the column that describes the system pressure and conditions.
3. Here you will find the recommended ISO class level, and recommended element micron rating.

	Low/Medium Pressure Under 2000 psi (moderate conditions)		High Pressure 2000 to 2999 psi (low/medium with severe conditions[1])		Very High Pressure 3000 psi and over (high pressure with severe conditions[1])	
	ISO Target Levels	Micron Ratings	ISO Target Levels	Micron Ratings	ISO Target Levels	Micron Ratings
Pumps						
Fixed Gear or Fixed Vane	20/18/15	20	19/17/14	10	18/16/13	5
Fixed Piston	19/17/14	10	18/16/13	5	17/15/12	3
Variable Vane	18/16/13	5	17/15/12	3	not applicable	not applicable
Variable Piston	18/16/13	5	17/15/12	3	16/14/11	3[2]
Valves						
Check Valve	20/18/15	20	20/18/15	20	19/17/14	10
Directional (solenoid)	20/18/15	20	19/17/14	10	18/16/13	5
Standard Flow Control	20/18/15	20	19/17/14	10	18/16/13	5
Cartridge Valve	19/17/14	10	18/16/13	5	17/15/12	3
Proportional Valve	17/15/12	3	17/15/12	3	16/14/11	3[2]
Servo Valve	16/14/11	3[2]	16/14/11	3[2]	15/13/10	3[2]
Actuators						
Cylinders, Vane Motors, Gear Motors	20/18/15	20	19/17/14	10	18/16/13	5
Piston Motors, Swash Plate Motors	19/17/14	10	18/16/13	5	17/15/12	3
Hydrostatic Drives	16/15/12	3	16/14/11	3[2]	15/13/10	3[2]
Test Stands	15/13/10	3[2]	15/13/10	3[2]	15/13/10	3[2]
Bearings						
Journal Bearings	17/15/12	3	not applicable	not applicable	not applicable	not applicable
Industrial Gearboxes	17/15/12	3	not applicable	not applicable	not applicable	not applicable
Ball Bearings	15/13/10	3[2]	not applicable	not applicable	not applicable	not applicable
Roller Bearings	16/14/11	3[2]	not applicable	not applicable	not applicable	not applicable

1. Severe conditions may include high flow surges, pressure spikes, frequent cold starts, extremely heavy duty use, or the presence of water
2. Two or more system filters of the recommended rating may be required to achieve and maintain the desired Target Cleanliness Level.

Figure 11: ISO 4406 Target Level Chart [8]

5.0 Information Sources:

Baseline Knowledge:

1. EPRI, *Hydro Life Extension Modernization Guides: Volume 4-5 Auxiliary Mechanical and Electrical Systems* TR-112350-V4 – Palo Alto, CA – 2001
2. USBR, *Alignment of Vertical Shaft Hydro Units, Facilities, Instructions, Standards and Techniques Volume 2-1* – Colorado - 2000

State of the Art:

3. Forsthoffer, W., E., *Best Practice Handbook for Rotating Machinery* – 2011
4. McKenna, K., P. E., *Turbines and Their Lubrication -The Engineered Difference*, Spring 2001
5. Hannon, J., B., *How to Select and Service Turbine Oils* - Machinery Lubrication, July 2001
6. ANALYSTS, INC, *Vitalpoint Advanced Fluids Assessment* - Form 40601208 – 2008

Standards:

7. ASTM D4304, *Standard Specification for Mineral Lubricating Oil used in Steam and Gas turbines* -2006
8. ISO 4406 Code, *HYDAC Innovative Fluid Power: Overview Brochure* – 1999

It should be noted by the user that this document is intended only as a guide. Statements are of a general nature and therefore do not take into account special situations that can differ significantly from those discussed in this document.

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