

Maximizing Hydroelectric Turbine Performance and Reliability

Introduction

Hydroelectric turbines comprise approximately 17% of the total number of power generating units in the United States and Canada. According to a North American Electric Reliability Council (NERC) Generating Availability Report, failures of the wicket gate mechanism, turbine governor, generator bearings and lube oil system are among the top 25 causes of forced and scheduled outages and deratings of hydroelectric turbines. This represents a tremendous opportunity to apply state-of-the-art filtration to improve reliability and availability of hydroelectric turbines.

How They Work Hydroelectric Turbines

There are a number of different hydroelectric turbine designs, but they all incorporate the simple principle of converting the potential energy stored in water to mechanical energy by using a portion of it to rotate a paddle-wheel or propeller-type runner on the turbine. This rotating mechanical energy is used to turn an electric generator to produce electrical energy.

There are two categories of hydroelectric turbines: *Impulse and Reaction*. Impulse turbines are driven by one or more water jets directed tangentially into “buckets” or “paddles” of a wheel-shaped runner turning in air. Reaction turbines are completely immersed in water, and are driven by the difference in water pressure between the pressure side and the discharge side of the runner blade — much like a windmill propeller is driven by the wind.

Hydroelectric turbines can have either a vertical or horizontal shaft orientation. Most reaction turbines have shafts that are vertically oriented. These account for the majority of all hydroelectric turbines in service.

Pumped Storage Hydropower Plants

Power plants produce electricity more economically by maintaining a constant rather than a varying output. However, since the demand for electricity fluctuates, these power plants have a surplus of electricity during “off peak” periods. This surplus “dump” power is



A hydroelectric dam

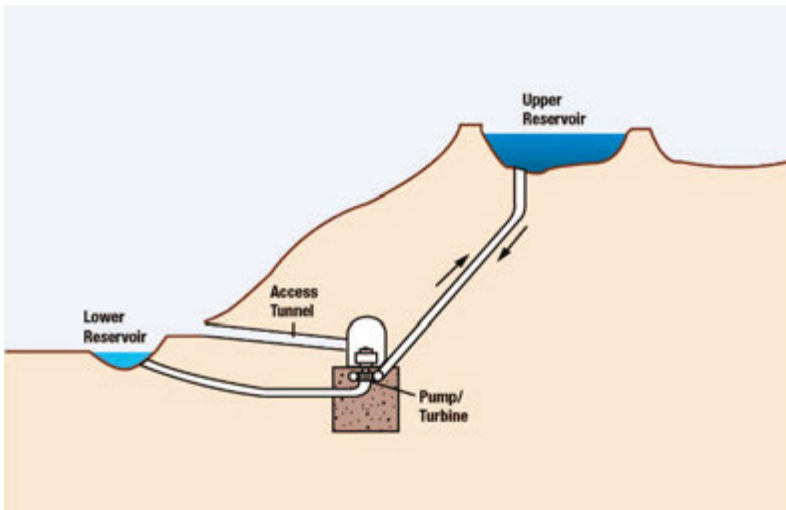


Figure 1. Schematic drawing of a pumped storage hydropower plant

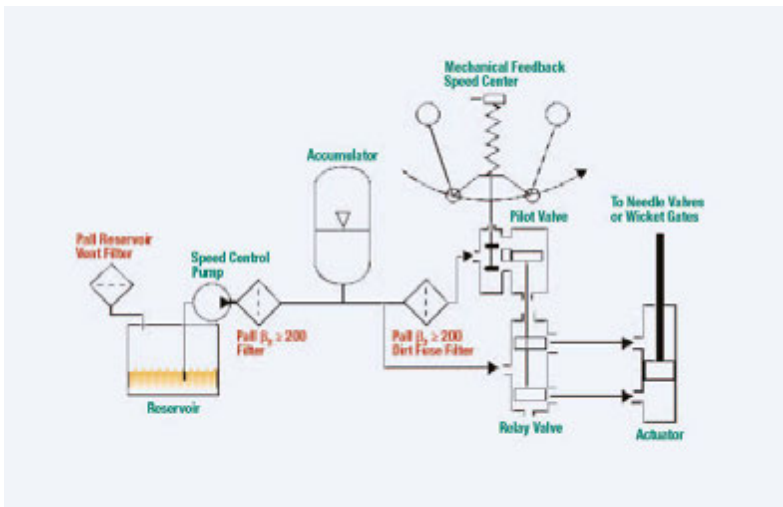


Figure 2. Hydraulic turbine governor utilizing mechanical feedback to sense turbine speed

often sold by the facility to pumped storage hydropower plants at low cost. The pumped storage plant uses this inexpensive energy to pump water from a lower reservoir to a higher reservoir, where it is stored. During peak demand periods, the water is released from the higher reservoir and flows through a turbine to generate electricity that can be sold at a premium price.

Some designs use a separate pump and penstock system for the pumping portion of the operation, and a separate turbine and penstock for the generating portion of the operation. The more modern designs use a reversible turbine and a motor/generator to both pump and generate power. They are similar to standard reaction turbines in their function and design and typically have a vertical shaft.

Contamination Control

There are a number of hydroelectric applications that can benefit from Total Fluid ManagementSM, Pall's unique equipment & services integration program designed to yield the highest efficiency at the lowest cost. Among these are inlet valve hydraulic power units (HPUs), turbine bearing lube systems, and the turbine governor system. Of these three, the turbine governor system is by far the most critical application in terms of hydraulic oil cleanliness because of its importance in maintaining the proper rotational speed of the turbine.

Turbine Governor

The governor uses either mechanical or electronic feedback to sense the speed of the turbine. Proportional or directional valves controlled by the governor operate cylinders that open and close wicket gates or needle valves to adjust the flow of water to the turbine in order to maintain a constant turbine speed. Hydroelectric turbines rotate at relatively low speeds compared to steam turbines, with larger hydroelectric turbines rotating at 35-75 rpm, and smaller ones as fast as 150 rpm. The large turbine diameter combined with the massive inertia of the water flowing through it makes precise control of rotational speed a critical concern.

If governor proportional or directional valves do not respond instantly and accurately to fluctuating generator loads, there is a lagging behind of the wicket or needle valve position. This results in an oscillating condition whereby the turbine is constantly speeding up and slowing down. This inefficient power production, although difficult to quantify, leads to loss in revenue for the utility. Furthermore, if this oscillation exceeds the maximum allowable frequency, then the turbine must be shut down, resulting in temporary loss of generating production.

Also, in the event of a sudden loss of load, it is important that the governor act instantly to shut down the turbine to prevent a "runaway" speed condition. Runaway speed is the speed at which the turbine exceeds its designed maximum rotational speed. When this occurs it is possible for the turbine to disintegrate due to massive centrifugal forces.

Neyrpic and Woodward Governor Company are two major manufacturers of hydroelectric turbine governing systems. The Neyrpic governor uses proportional valves to control wicket gates or needle valves, while the Woodward governor uses directional valves. Both of these systems operate at relatively low pressures (approx. 200 psi).

Silt size particles can cause sluggish response, jamming, or wear of valves. This can lead to turbine oscillation or a potentially dangerous “runaway” speed condition. Because of the small clearances in proportional and directional valves (1-8µm) they are inherently sensitive to contamination. For this reason the turbine governor system hydraulic fluid should be maintained at ISO 16/14/12 or better. To accomplish this the following is suggested:

- Install a Pall non-bypass filter assembly with 5µm ($\beta_{5(c)} \geq 1000$) Dirt Fuse elements in-line just upstream of each proportional or directional valve to provide “last chance” protection.
- Install a Pall filter assembly with a 5µm ($\beta_{5(c)} \geq 1000$) element on the pressure line of the HPU to protect valves, pumps, and cylinders.
- Replace the reservoir fill cap with a Pall Reservoir Vent Filter to eliminate the introduction of airborne particles into the HPU reservoir.

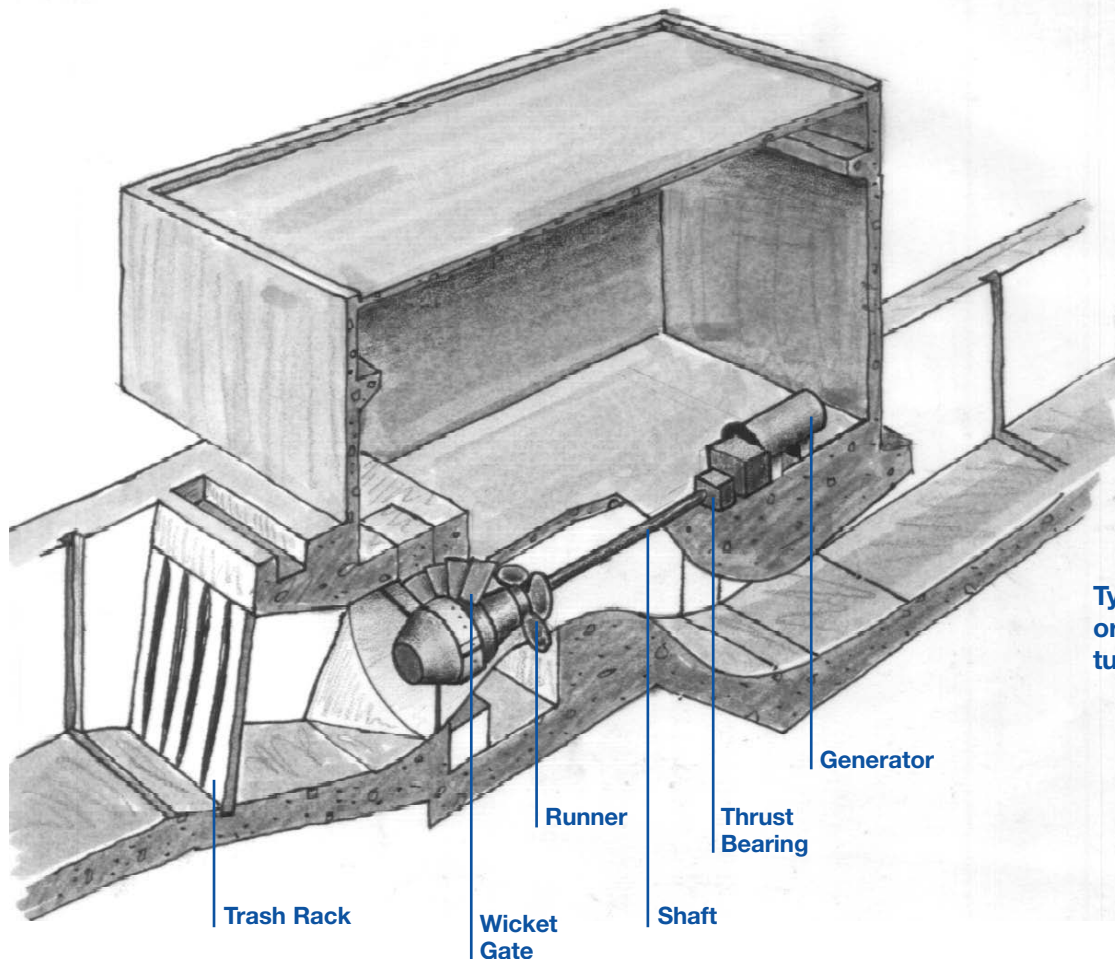
Bearing Lube Oil System

Currently most hydroelectric turbine bearings are inspected and, if necessary, reworked/replaced during regularly scheduled outages. Downtime, reworking or replacing bearings, and labor can be a significant cost to a hydroelectric power producer. The frequency with which these bearings are replaced/reworked can be greatly reduced if proper attention is given to turbine lube oil contamination levels.

Particulate contamination is a major cause of wear and premature failure of bearings. By maintaining cleanliness levels at ISO 16/14/12 or better, journal bearing life can be extended. For turbines that use roller bearings, cleanliness levels should be ISO 15/13/12 or better. Sometimes there are separate lubrication systems for each bearing in the hydroelectric turbine.

These reservoirs vary in size from 45 to 100 gallons, while large central lubrication systems may have 1000 gallon reservoirs. To achieve the required cleanliness level each lubrication system should have a Pall filter assembly either inline (preferred) or in a kidney loop. Turbines with journal bearings or roller bearings require 7µm ($\beta_{7(c)} \geq 1000$) filtration. It is also recommended that fill caps be replaced with Pall Reservoir Vent Filters to eliminate the introduction of airborne particles into the reservoir(s).

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Typical horizontally oriented hydroelectric turbine

System Components

Though there are different types of hydroelectric turbine and pumped storage designs, they almost always incorporate the following components:

Penstock

The penstock is a conduit used to carry water from the dam or reservoir to the turbine.

Runner

There are a number of different kinds of runners. They translate the linear motion of the water into rotational motion by the use of blades or buckets. Many designs look very much like large propellers, while others are modern versions of the paddle wheel. Some propeller-type runners have the capability of varying their pitch blade for optimum performance in varying flows and head pressures.

Governor

This is the system that automatically monitors and maintains the speed of the hydraulic unit. It is also used to synchronize the generator to the system frequency (Hz) for connection to the power grid, and to shut down the unit in the event of a sudden loss of load. As with steam turbines, malfunctioning of the governor could result in a dangerous runaway (overspeed) condition.

Wicket Gate

These are angularly adjustable, streamlined components that direct and control (throttle) water flow to the runner in reaction-type hydroelectric turbines. They are regulated by the governor via mechanical-hydraulic or electro-hydraulic controls.

Needle Valve

The needle valve is used to regulate the flow of water to the runner in impulse-type hydroelectric turbines, and is regulated by the governor via mechanical-hydraulic or electro-hydraulic controls.

Inlet Valve

The inlet valve is located upstream of the turbine and is used to cut off the flow of water in the event of an emergency or for maintenance. These valves are often spherical or butterfly valves, and are usually operated by hydraulic power units.

Main Guide Bearing

This bearing is located closest to the turbine runner and radially supports the rotating runner and shaft assembly. Many designs incorporate an upper and lower guide bearing.

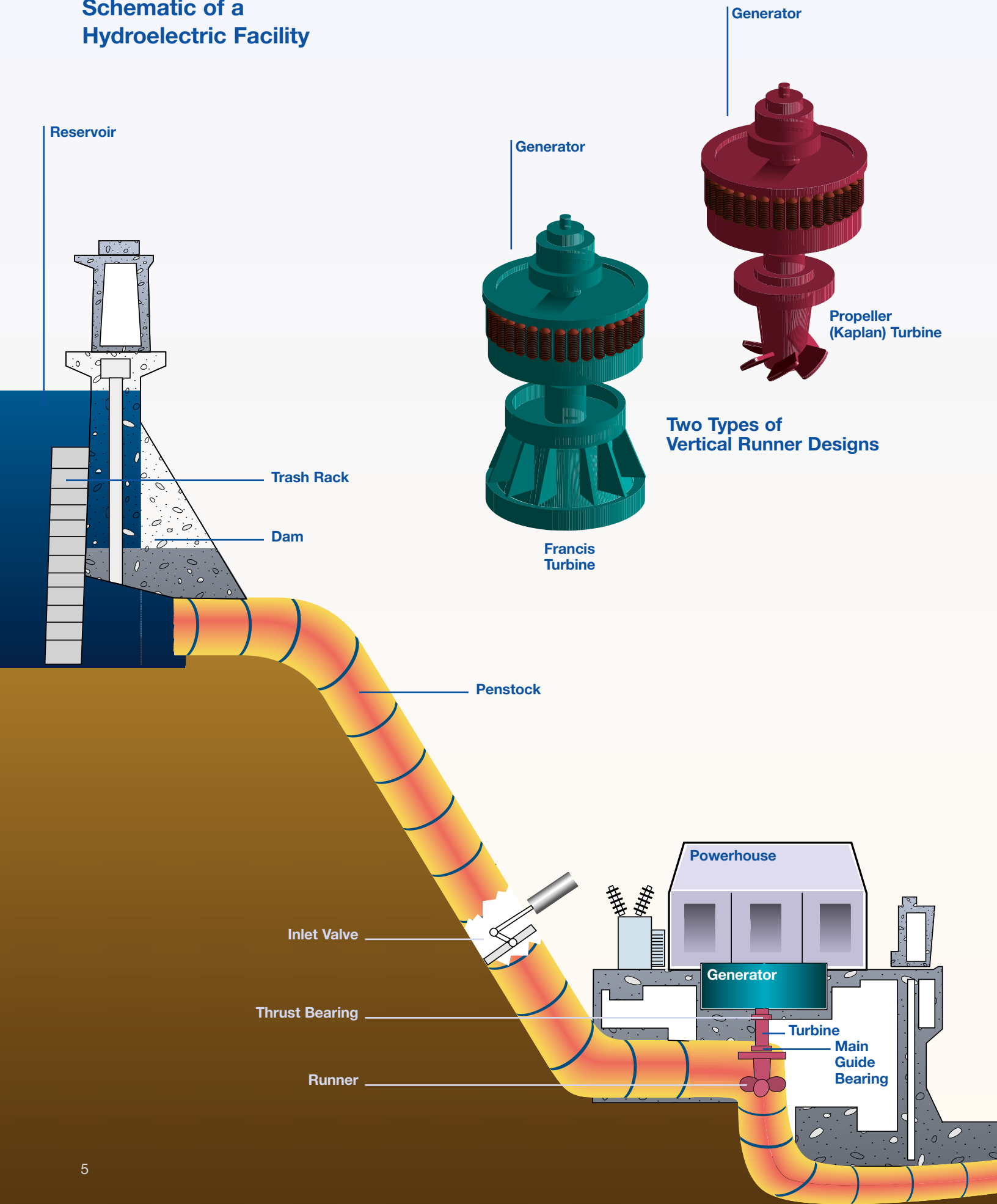
Thrust Bearing

The thrust bearing carries the weight of the turbine and the generator's rotating parts for vertical turbine designs. It can be located directly above or beneath the generator rotor. Horizontal designs may have two thrust bearings, or a double-acting thrust bearing to carry the axial thrust in both directions.

Lift Pump

Some large hydroelectric turbines are equipped with lift pumps (sometimes called jacking oil pumps) that are used to pump low flow, high pressure oil to the bearings during the process of increasing the rotor speed from minimum speed up to maximum design-rated speed. The turbine bearing journals are hydrostatically lifted off the bearing race in order to reduce metal-to-metal contact at lower rotational velocities.

Schematic of a Hydroelectric Facility



Lift Pump

Large hydroelectric turbines may use a lift pump prior to start-up or shutdown to prevent metal-to-metal contact of bearings. By forcing pressurized oil into turbine bearings, the journal is lifted from the race until, in the case of the turbine start-up, sufficient hydrodynamic forces are generated by the rotation of the bearing to achieve operating clearances.

Because the clearances in the turbine bearing are minimal during start-up and shutdown, it is important to maintain lift pump oil cleanliness at ISO 15/13/12 or better. To achieve this cleanliness level it is recommended that a Pall filter assembly with a $7\mu\text{m}$ ($\beta_{7(c)} \geq 1000$) element be installed either in the lift pump pressure line (preferred) or in a kidney loop off the turbine lube oil reservoir.

Water Removal

Because of their proximity to water, hydroelectric turbine lube oils often have unacceptably high water content. This can result in a variety of problems ranging from bacterial/fungal growth and premature oil degradation to component wear and failure. Bearing journal scoring can occur as a result of insufficient oil film thickness caused by water contamination. Water can also cause the rusting of pipes and other components producing particles that promote wear of bearings and performance degradation in proportional and directional valves.

For these reasons it is recommended that a Pall vacuum dehydration purifier be used to reduce the water concentration well below the saturation level of the oil. A major turbine manufacturer recommends the use of vacuum dehydration purifiers in continuous operation to remove water contamination. The Pall purifier's integral, high-efficiency $\beta_{x(c)} \geq 1000$ filtration will remove damaging rust and wear particles already in the system, while its water removal capabilities will help prevent other problems associated with water contamination.

Drinking Water

Due to the remote location of many hydro plants and the lack of municipal water supply, each location is required to produce their own potable water. Older technology has traditionally been used, but as local regulations regarding how potable water is produced become more stringent, plants are forced to look at equipment upgrades to meet the tighter requirements.

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