An Oil to Water Conversion of a Hydro Turbine Main Guide Bearing – Technical and Environmental Aspects

Authors:

Conrad Richard, P.Eng – Application Engineer, Thordon Bearings Inc., Canada.

Scott Groves – Hydropower Development Manager, Thordon Bearings Inc., Canada

Abstract:

Hydro-electric turbines operating in remote areas all over the world are producing enormous amounts of clean energy. Nonetheless, a large number of these generating stations have the potential of posing an environmental threat to local ecosystems. Oil and grease have long been considered as one of the primary methods of lubricating the lower turbine guide bearing. As environmental regulations become more stringent, any accidental or operational loss of oil or grease to the environment is not acceptable and can have very grave repercussions. This can be a serious issue in remote areas where detection, monitoring and spill clean-up can be very difficult due to the poor accessibility or general remoteness of the site.

This paper outlines the process of converting a lower turbine guide bearing from an oil lubricated system to a water lubricated system, based on recent works carried out on a turbine in California. This paper will present the components of the water lubricated guide bearing system including a Thordon SXL guide bearing, Thordon SXL radial segmented shaft seals and the overall housing assembly. The system also features Thordon's proprietary tapered keyset design for fast and easy bearing inspection and maintenance. This complete conversion package provides the same operational reliability of an oil lubricated system without any risk of accidental or operational oil discharge to the environment.

Historical:

In mid-2009, initial conversations began with an important electricity producer on the west coast of the U.S. on the subject of converting an oil lubricated turbine main guide bearing to a water lubricated bearing system. The first unit considered for such a project was located in the mountains using runoff from a lake at a higher elevation to generate electricity. This particular unit was originally built in 1927 and is the first of two power houses connected in series. Factors considered in the selection of the first conversion site were the age of the unit and ease of access to the power house. The chosen unit is the older of the two and was determined to be the greatest risk for oil leakage which would have devastating effects on the complete eco-system downstream of the station. It is also the more accessible of the two units at this particular site.

The original installation had the following equipment:

- Oil lubricated metal bearing
- Cast steel split carrier
- Closed loop oil lubrication system with: oil sump system, oil pump, oil distribution piping and oil condition monitoring
- Upper seal and seal housing
- Separate stuffing box to keep the water and the oil separate.

Figure 1: Original Spare White Metal Bearing & Carrier.

In early 2010, conceptual designs were developed for the customer. Initial concepts were developed for two options.

Option 1 was a complete new carrier and bearing assembly that included the following items:

- Water lubricated split Thordon SXL bearing with bronze tapered keyset
- Fabricated split steel carrier

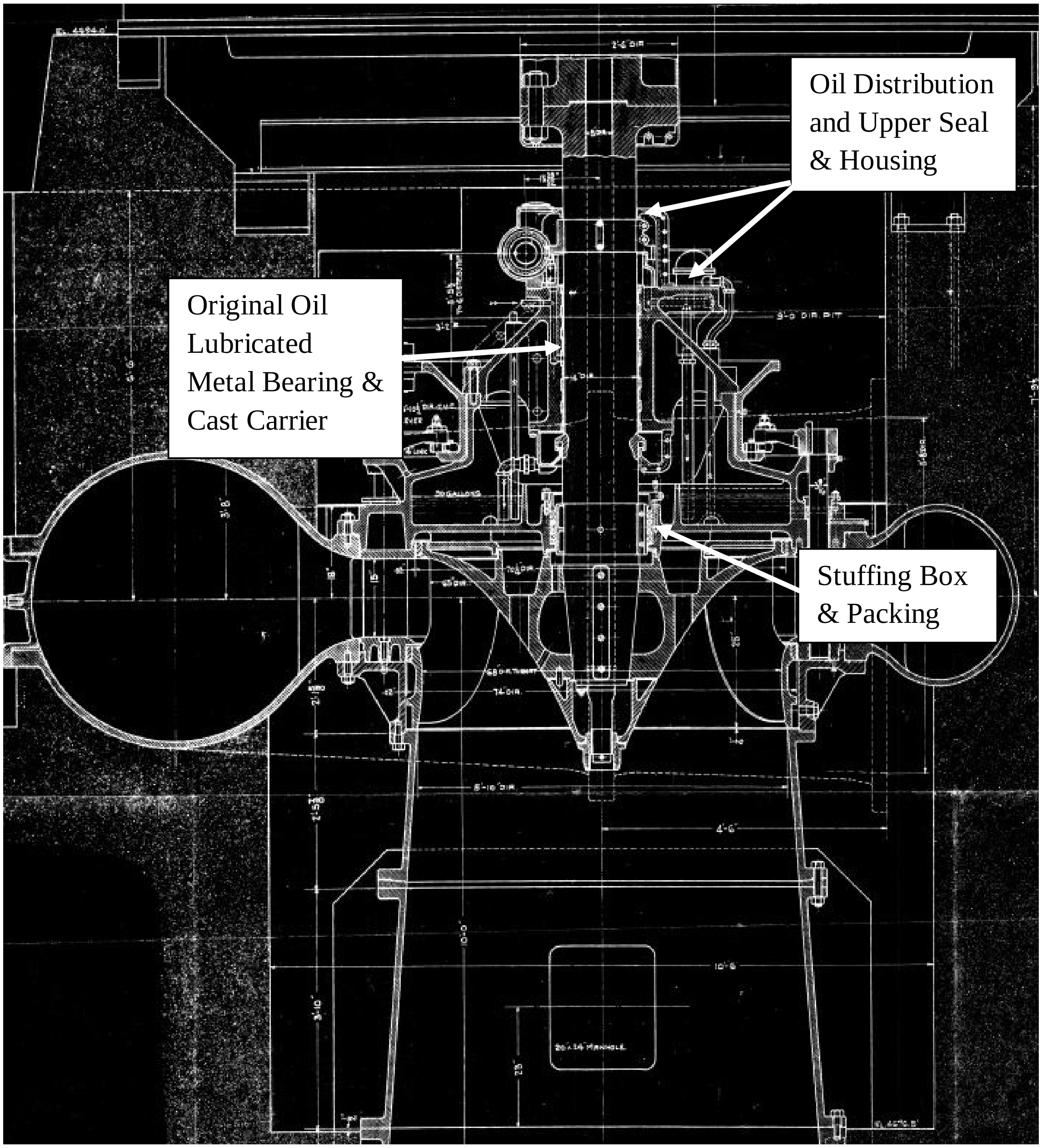

Figure 2: Cross Section of Original Turbine Assembly

- Thordon SXL segmented shaft seals with Thordon Regular backing rings
- Split steel seal housing
- Seal bypass water catch basin with drain pipe
- Discharge water duct
- Design features to accommodate an open system of water flow for cooling and lubrication
- Stainless steel shaft sleeve.

Option 2 was similar to option 1 except a spare bearing carrier would be used that was already on site. The spare carrier was to be modified to accept a new water lubricated bearing, new segmented seals and discharge duct. There was some uncertainty regarding the feasibility of reusing an original carrier due to oil holes in the casting and possible weakening of the structure after the ID had been bored to accept the new bearing.

The final solution that was recommended and chosen by the customer was option 1. This option gave the customer the least amount of unknown variables. Option 1 also had the added benefit (in the customer's eyes) that the original spare carrier was still available for use as plan "B".

With final option 1 chosen and ordered, the design was finalized and production began in late spring 2010. The completed order was supplied in late August and installed during a planned shutdown in October 2010.

Design Features:

Thordon SXL Water Lubricated Bearing:
Water lubricated Thordon SXL bearings have a proven track record as main guide bearings in hydro turbines. Thordon SXL is an elastomeric polymer material offering the combination of strength/stiffness and flexibility/elasticity. Thordon Bearings has supplied many such bearings as replacements for other non-metallic bearings. Experience has shown that Thordon SXL bearings have an excellent wear life and they perform very well in such applications. The Thordon SXL main guide bearing is designed with clearances and a groove arrangement suited for the application. Running clearances for Thordon SXL main guide bearings are driven by the shaft diameter and generally reduce at a rate of approximately 0.0002" per inch of shaft diameter, from a maximum .012" for a 47" diameter shaft. The design also considers the amount of water absorption, thermal expansion and bore closure due to the interference fit. The selected design was for a shaft over liner diameter of 14.75" and housing inside diameter of 16.94". The installed and running clearances were .023" & .006" respectively. A total allowance of .017" is included to compensate for water absorption and thermal expansion. Water absorption will occur during a certain period of time that typically ranges from 2-3 months. However the specific water absorption rate is also dependent on the temperature.

Fabricated Split Steel Carrier:
In order to facilitate the conversion process; a custom carrier was designed to interface with the existing register fits and mounting features in the head cover. The carrier was of fabricated/welded designed and was split so the unit could be installed in position without requiring the removal of the shaft.

Bronze Tapered Keyset:
A tapered keyset is included in the package. The Thordon Bearing's proprietary split tapered key design not only provides anti-rotation retention but it also allows for easy removal of the bearing for replacement or inspection without removing the shaft or the carrier. The key is made

from bronze, not only for corrosion resistance but also for ease of disassembly. In many cases a bearing inspection or replacement can be done in a matter of hours instead of days or weeks.

Thordon SXL Segmented Shaft Seals and Thordon Regular Backing Rings:
As is the case for Thordon SXL main guide bearings, the Thordon SXL polymer also has a proven track record used as a segmented shaft seal. Thordon SXL is being used to replace other non-metallic segmented seals in many applications throughout the world. Another Thordon grade, Regular, is used as backing plates. Custom garter springs are also included to maintain the static and dynamic contacts of the segmented seal segments.

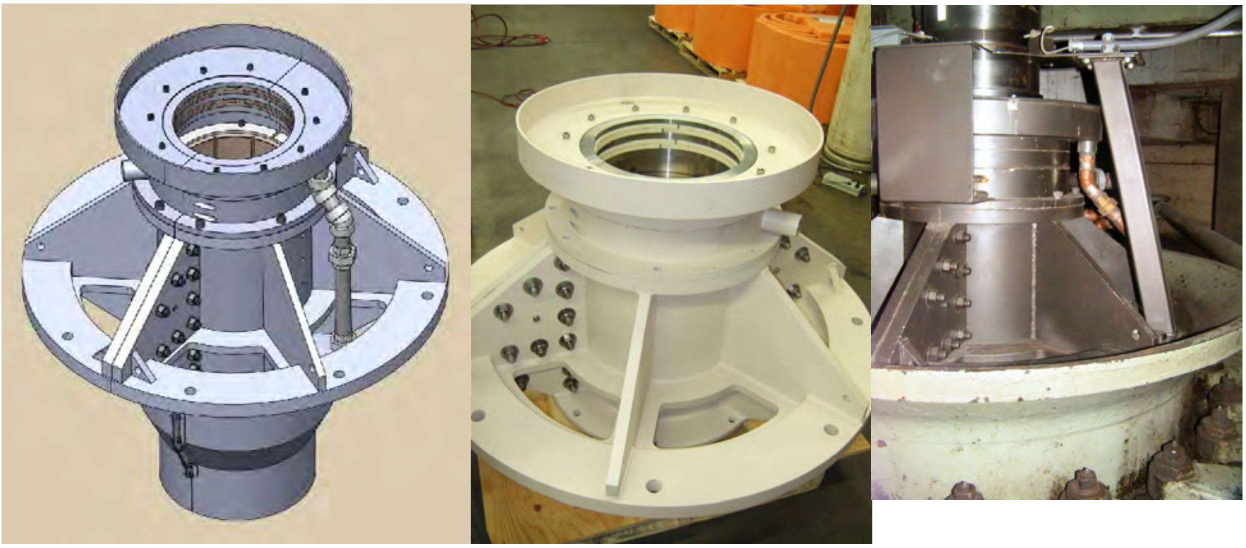

Figure 3: Complete Unit as Designed, Mock-up and As Installed of Option 1

Split Steel Seal Housing:
Each layer of the segmented seal arrangement is contained in a custom designed seal housing. The completed seal housing assembly is designed to be mounted directly onto the top flange of the bearing carrier. The seal housing assembly has connections for water injection for cooling and lubrication of the seals and also the bearing. The arrangement is designed as a two ring segmented seal assembly with the two rings above the water inlet and the bearing below.

Seal Bypass Water Catch Basin with Drain Pipe:
In order for segmented shaft seals to function properly and not overheat, cooling water must leak past the dynamic sealing faces. The geometry and the interface between the seal segments, the housing and the dynamic shaft interface are designed to allow water to flow past the seals and therefore this water needs to be collected. After the water flows through the seals it is collected in the top basin. It then flows out through the drain pipe to the discharge water duct below the bearing.

Discharge Water Duct:
There was an area between the bottom of the bearing/carrier and the existing stuffing box where the shaft was exposed. Because the new system is an open system where the cooling water is fed from the penstock supply and not re-circulated, after the water has passed through the bearing and/or the seals, it has to be disposed of. By including a discharge duct that connects directly to the bottom of the new carrier to divert the water to the existing stuffing box, the water is simply reintroduced to the penstock water. With the original packing and lantern ring removed, water can flow freely through the stuffing box. A small gasket is installed between the ID of the stuffing box and the OD of the discharge duct to stop any splashing. Due to the vacuum conditions at the head cover and the elevation of the powerhouse on the mountain there is no concern about back pressure and a possible flood. The discharge duct also has a connection for the drain pipe from the seal bypass water catch basin.

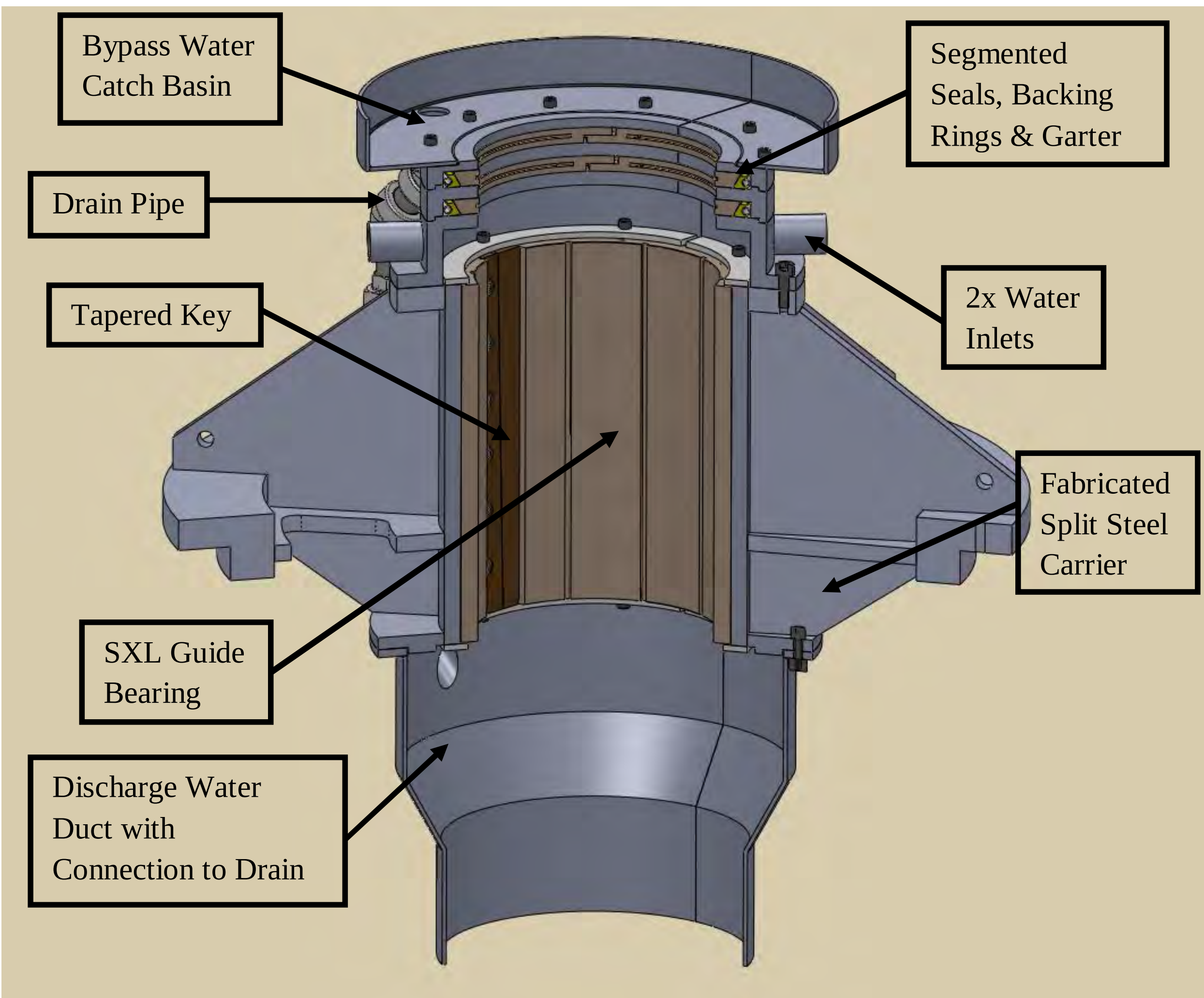

Figure 4: Section of Assembled Supplied Parts

Stainless Steel Shaft Sleeve:
With the original bearing operating with oil lubrication there were no problems from corrosion of the carbon steel shaft. However with water lubrication, corrosion to the shaft is a concern. If the shaft begins to corrode in way of the bearing or the segmented seals, the corrosion could accelerate the wear of the Thordon SXL components. A new stainless steel liner was installed onto the shaft in way of the bearing and segmented seals. The liner was supplied as split and welded together on site. The OD of the liner was final machined in place to a predetermined dimension.

<u>Operating Conditions:</u>

The bearing was designed to operate on the following unit, under the listed conditions:

Manufacturer	Pelton Water Wheel
Year Built	1927
Type	Vertical, Francis
Runner Diameter	5'-10"
Horsepower	13,750
Rated Flow (cfs)	550
Gross Head (ft)	197
Speed (rpm)	257
Shaft Sleeve Outside Diameter (in)	14.75

The customer also knew that the head cover was normally in a partial vacuum condition but full information was not available at the time to indicate the exact amount. Packing from the existing stuffing box had long since been removed and not replaced. However due to powerhouse location, partway up a mountain, there was no major concern of backflow into the powerhouse.

When installation was complete and the turbine was restarted, it was noticed that even at the recommended water flow, there was no water leakage past the seals into the collection basin. It was at this time that the vacuum issue became apparent. The initial reaction was to increase the water flow to as much as 50% above the recommended value but this still did not correct the problem. As a temporary measure, it was recommended that a secondary water supply be provided to the basin in order to reverse flow through the segmented seals for cooling and to avoid overheating.
Some flow and friction loss calculations determined that the void in front of the tapered keyset was almost equivalent to all the other bearing grooves added together. Several options were considered to cure this problem. A possible design feature to ensure the bearing and the seals were continuously flooded was to add a restrictor ring under the bearing. This option was considered and evaluated as a possible solution. Different materials were also considered for use as the restrictor ring. The downside of this option was that very high pressures are required to ensure the required amount of water flow through the typically tight clearance of such rings. The minimum recommended water flow for Thordon polymer bearing materials in a main guide application with similar clearances is 2gallons per minute per inch of shaft diameter. In this particular application the minimum recommended flow rate was ~30gallons per minute. After

much discussion and deliberation, the proposed fix was a spacer that would fill most of the void in way of the keyset. The customer agreed to implement this solution at their next scheduled shut down occurring in a few months. In order to facilitate the installation of the spacer, a new sliding key was machined and the spacer was attached to it. This allowed the new spacer to be installed by simply removing the sliding section of the original keyset and replacing with the new key/spacer assembly.

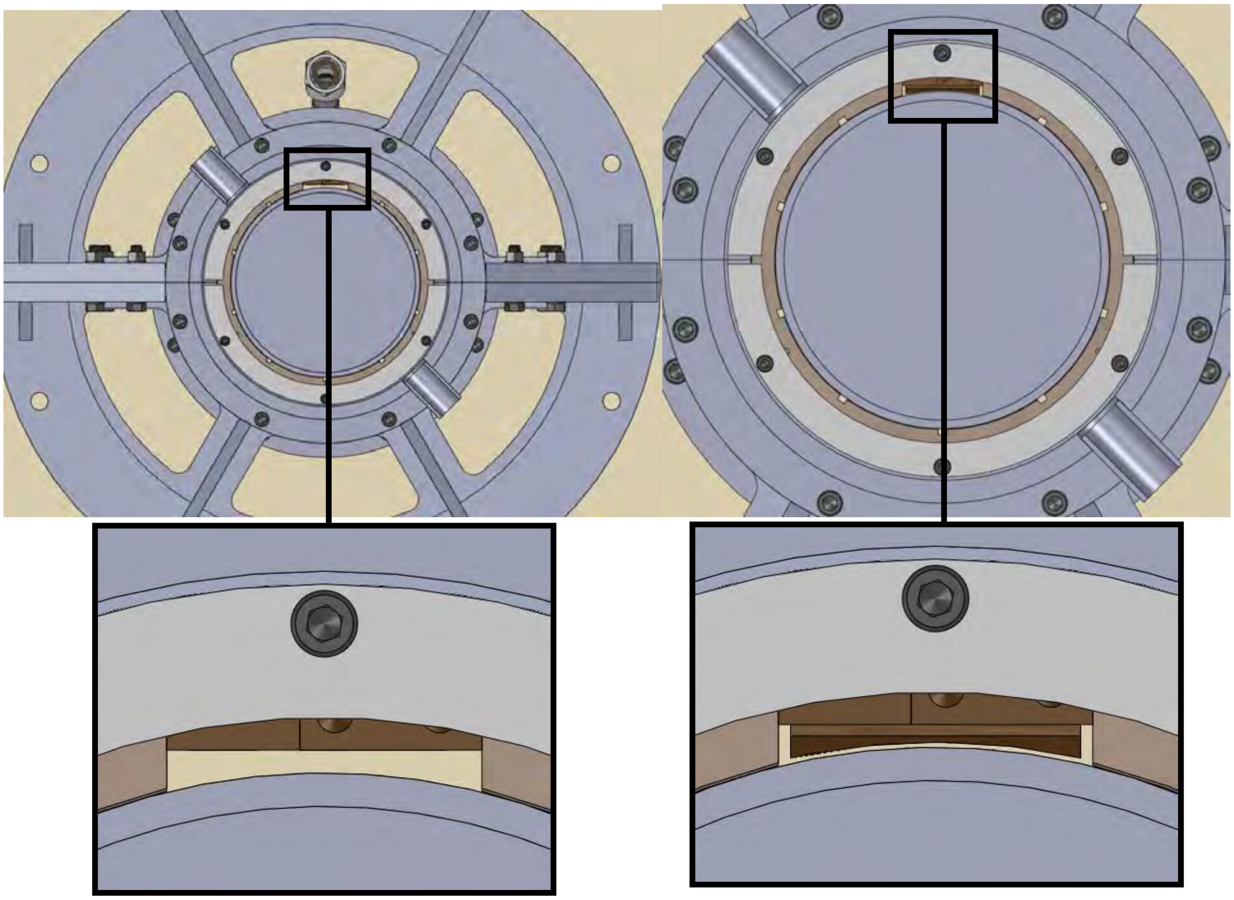

Figure 5: Installation without and with spacer.

Since start-up of the water lubricated system, the unit was monitored actively and no other issues were identified. The SXL bearing was operating smoothly and not showing any signs of overheating or other malfunction. The customer even requested the opinion of Thordon Bearings on a possible delay the planned shutdown for several more months until the end of the spring runoff. It was determined that if all else was operating smoothly, that there should be no issue with a delayed shutdown provided the bearing operation was monitored.

Eventually in May 2011, the unit was put offline and the bearing and seals were removed, inspected and reinstalled along with the new spacer. Prior to removal of the components, there were some concerns of a possible overheating of the installed components, but after inspection,

they were found to be in good condition and all of the same parts were re-installed. Immediately after start-up, water began flowing up past the segmented seals into the collection basin. This was an indicator that the newly installed spacer was creating a sufficient amount of restriction to force water up through the segmented seals for cooling and lubrication.
The customer has maintained a typical monitoring schedule with the unit. It has performed well ever since, and the customer is very pleased with the operation.

Indeed, the same customer placed another order in late 2011 for a second unit conversion. This unit is for the power house located downstream from the first and gets its water supply from the tailrace of the first unit. This conversion package was installed in April / May 2012.

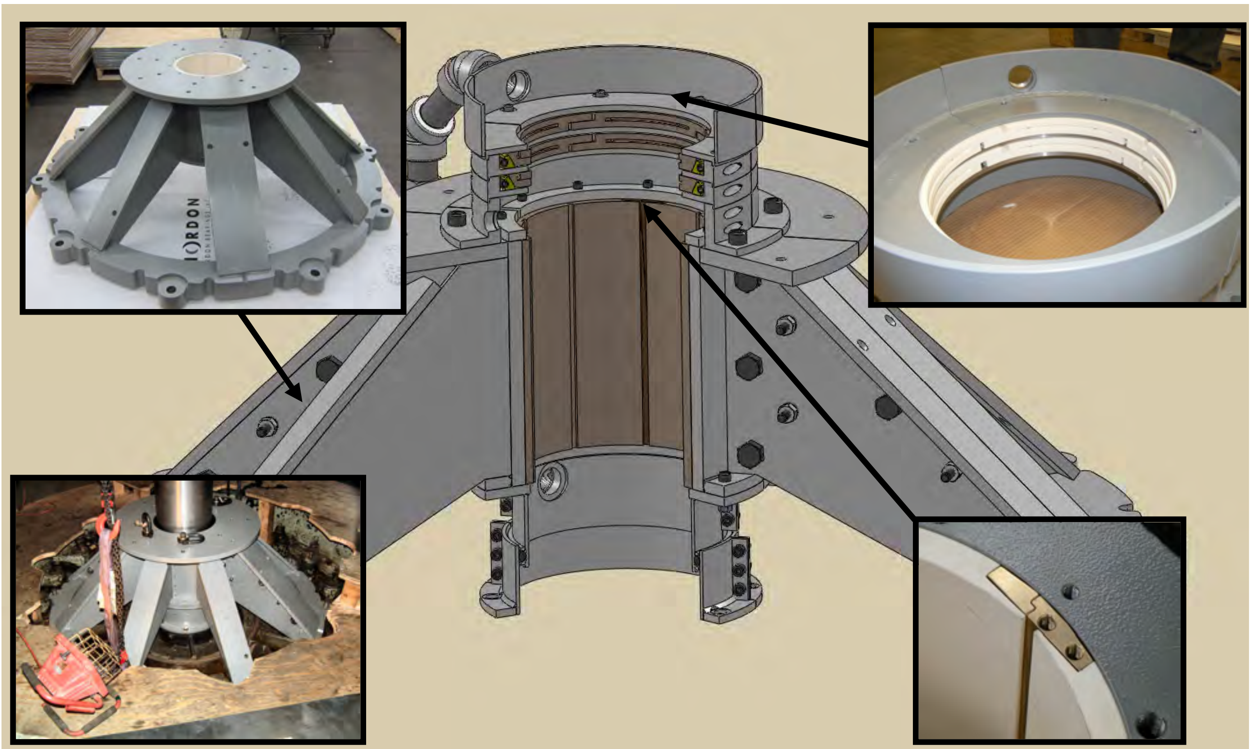

Figure 6: Section of Fabricated Water Lubricated Bearing Assembly for 2nd Power House

Lessons Learned:

Further to this project and installation there are factors to be considered more carefully in conversion projects.
With most of Thordon Bearings' oil to water conversion experience coming from the marine industry where propeller shafts are horizontal and bearings are always submerged due to the draft of the vessel, vacuum was never a concern. However since this project, the identification of a vacuum condition has become a major consideration in the design of water lubricated hydro-turbine lower guide bearings. Engineering calculations are now performed to determine the

pressure balance in the system from the cooling water injection to the area where the water exits the bearing. The friction loss through the bearing clearance and through the grooves is calculated using the Hazen–Williams Equation for Pressure Loss in Pipes. The groove amount and decision on the design (or need) for a spacer in way of the tapered key is based on a requirement to have sufficient water pressure above the bearing to split the water flow. The majority of the water flows through the bearing but some is also diverted up through the segmented seals. Even in the presence of a partial vacuum, seals are still required to ensure that the proper amount of cooling water is directed through the bearing.

As expected, calculations on further projects have shown that the void in way of the key is more of a factor on units with small to medium size shafts (less than 16” - 18” diameter). On units with larger shafts (greater than 30” diameter), the number of grooves in the bearing is such that the void in way of the grooves is large enough that the void at the key is no longer such an important contributor to the flow area.
The requirement for minimum flow is also dependant on the shaft diameter and increases by a factor of 2 for each increment in shaft diameter. Therefore, units with large shafts require much more water flow compared to smaller units. The higher water flow results in greater friction loss even without a spacer in way of the key. Each proposal has to be evaluated on a case by case basis.

Conclusion:

With the large amount of hydro turbines in operation all over the world and with many of them being multiple decades old, the risk of operational oil leaks is a big concern. Many generating stations are located in remote locations and others are in close proximity to environmentally sensitive areas. Not to mention that contaminated water streams can have adverse effects on ecosystems and watersheds many miles downstream.
With environmental policies and legislations at every level of government becoming more stringent, the potential environmental and financial costs of an oil leak are causing many energy producers to seriously consider water lubrication over conventional oil systems; either for conversions or for new construction projects.

To eliminate any risk of oil leakage, Thordon Bearings can prepare custom designed solutions of water lubricated lower guide bearings. Solutions can range from a simple bearing supply to a complete bearing / carrier / segmented seal assembly conversion package. Working with hydro-electric turbine operators around the world, Thordon Bearings is not just providing bearings to fit an application, but developing bearing solutions to resolve and overcome bearing application challenges.

Thordon Bearings has long been at the forefront of providing premium bearing material for water lubricated applications. With this hydro-turbine example and other current oil to water conversions, Thordon is quickly becoming an experienced global provider of custom engineered solutions that remove all the risks of oil loss to the environment.

Author Biographies:

Conrad Richard*, P.Eng is an Application Engineer at Thordon Bearings Inc. Conrad completed his Bachelor Degree in Mechanical Engineering at the Université de Moncton, in 1997 and has worked in several different industries ranging from mining to machine design for the optical industry before joining Thordon in 2009.*

Scott Groves *started his career at Thordon Bearings in March of 2002 in the commercial department, assuming the role of sales manager in Canada and the Western US in 2003. Scott was appointed Thordon Bearing' global hydro business development manager in 2011. Scott has extensive experience with operating mechanism bearing conversions as well as turbine guide bearing oil to water conversion.*