Thrust Bearing PTFE Re-Design for Pump Storage Generator

Case Study

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Many pump generating stations exist across North America, with several of them being plagued by thrust bearing failure. As pump storage stations are large in comparison to most other hydroelectric stations, failures are also expensive in nature.

The main issue for the bearings of a pump storage generator/turbine set is that they must support large loads when the unit is turning in either direction. Unidirectional bearings are designed with an eccentric pivot point that allows the bearing to develop better lubrication support at the leading edge of the bearing pad, thus providing better support across the entire pad. When a bearing is bidirectional, it cannot have an eccentric pivot point which limits the bearing's load capacity.

Ontario Power Generation's Sir Adam Beck - Pump Generating Station (PGS) experienced recurrent bearing failures into the early 1990's, at which time there was an exhaustive review of the bearing and its split runner plate design (deemed to be the root cause for several failures). This review resulted in a number of changes to the existing design of the bearing, the assembly tolerances, and the high pressure oil lift system. As well, the adjustable flaps on the stay vanes leading into the runner were welded into one location which choked off some of the water entering the turbine limiting some of the hydraulic thrust.

The thrust bearings at PGS then ran reliably until 2002 when the PGS G4 bearing failed. Investigation into the cause of this failure identified quality issues with the post-overhaul refurbished bearing and a glitch in the shutdown system that could, under some circumstances, allow the unit to rotate without oil lift.

A thrust bearing upgrade could be simply accomplished with the installation of new Polytetraflouroethylene (PTFE) bearing pads to replace the existing Babbitt pads. Permissible thrust bearing loads would then be greatly increased and bearing losses would be minimized. In addition, a newly designed split runner plate with a reliable keyed clamping system, using new high quality hardware, would alleviate the risk of the runner plate becoming loose during operation. Stabilization of the runner plate would contribute to the prevention of catastrophic bearing failures.

Objectives

The reversing oil film bearings have several design requirements in the initial design stage, including the following:

- the bearing must be submerged in oil at all times,
- enough surface speed must be available for the thrust runner plate (rotating ring) to pull oil onto the bearing pads,
- there must be enough bearing area (specific load) to support the weight of the rotating parts and the hydraulic thrust, and
- the bearing must be reliable for operation in both directions of rotation.

Team assembled to rectify the thrust bearing problems:

Hydro Tech Inc. (of Canada) was contracted to correct all of the thrust bearing problems, as well as to increase reliability of the bearing. The directives were as follows:

- design a more secure split runner plate (this plate could not separate or become loose during operation over the life of the bearing),
- design a better way to control the step in both the vertical and horizontal directions,
- eliminate the operational requirement for the bearing pad temperature to be normalized between stops and starts,
- improve the bearing design to maintain the oil film between the runner plate and the bearing pads, and
- refurbish the remaining parts to allow for another 30 years of operation.

To accomplish these goals, Hydro Tech Inc. assembled a team of hydro experts to complete the required tasks. This team consisted of Hydro Tech Inc., EnEnergo of Russia (through North American PTFE) and Canadian Babbitt Bearings Limited. Hydro Tech designed and manufactured the runner plate, completed the initial bearing study, and provided recommendations to increase reliability and improve operational requirements. EnEnergo completed the design and manufacture of the PTFE bearing pads, and Canadian Babbitt Bearing (special thanks to Jonathan Bee) completed all machining on the runner plate. Hydro Tech was responsible for the overall design, refurbishing of the load cells, supply, and any contractual requirements for the bearing which included all site support, assembly and disassembly manuals, and operational manuals.

The Study

The Babbitt study was completed by Hydro Tech using GENMAT bearing design software, and the PTFE bearing pad study was completed by EnEnergo. The following tests and calculations were completed for both Babbitt and PTFE:

- temperatures and runs,
- the maximum safe load for the Babbitt bearing under the old parameters,
- load calculations of specific load on the bearing, and
- oil viscosity changes and the effects to the bearing operation.

Bearing Study Results

Computer testing revealed the following:

- Bearing specific loading to be within the acceptable range of a Babbitt bearing.
- The speed of the bearing was too slow to maintain a reliable oil wedge using ISO 46 oil.
- Operating temperature of the bearing was found to be within the Babbitt bearing range.
- If the oil viscosity was changed to a thicker oil such as ISO 68, the reliability of the oil wedge dramatically increased.

Root Cause of Previous Failures

There have been several causes for this thrust bearing's failure during the PGS station's history.

Runner plate failure:

The PGS runner plate is a common design that has been used on many bearing assemblies. With this design, several flaws develop as the bearing size increases. Of primary importance, the runner plate key is not as tight as it should be. In addition, the runner plate bolting cannot be torqued properly to ensure proper bolt stretch. Therefore, the runner plate split bolts will sometimes loosen, allowing a step to develop, or break if over tightened allowing the runner plate to separate. With this PGS runner plate design, there is no positive process to separate the runner plate halves. The only process available is to use wedges/spacers and a hammer behind the connecting studs or on the nuts.

Babbitt Bearing Pads

Babbitt expands more with heat than steel. During operation, the bearing pads develop a crown due to the top Babbitt surface expanding more than the bottom steel surface. Each time the PGS generator is shut down, the bearing temperature would have to normalize to eliminate this crown prior to start up or else the bearing would start on a crowned surface. Allowing the temperature to normalize causes time delays between stops and starts, or when reversing directions. In the past, there were operational errors that affected the PGS bearing such as the generator being started shortly after it was shut down. This will cause a bearing failure if sufficient time is not provided to allow the crowning to normalize.

Other Factors

The PGS bearing diameter is too small for the generator RPM. With the bearing diameter being too small, the runner plate surface speed was not fast enough to maintain a reliable oil wedge. At times, the oil film would fail causing metal-to-metal contact which would immediately gall the Babbitt bearing pads and wipe the bearing.

Corrections

The runner plate needed a better bolting process that would not fatigue or loosen over time. A small split runner plate is highly toleranced to prevent a step from developing. The larger the runner plate, the more rigid the key must be. Problems occur when the same design and tolerances are used for both large and small bearings. As the runner plate gets larger, the step is also amplified by the same proportion in magnitude (i.e., double the runner plate size can mean double the developed step). If a vertical step develops, the step will act as a scraper or an oil disruption, depending on the direction in which the step develops. In the PGS case, due to the runner plate being reversible, when a step develops in any direction, it will become a scraper.

The PGS runner plate serves as both thrust bearing runner plate and guide bearing journal. Not only must the horizontal step be controlled, but also the outer diameter must also have minimal tolerances to control the journal step.

The PGS runner plate needed to be designed and manufactured in such a way that proper bolt stretch could be achieved. If a bolt is over-torqued, the bolt becomes fatigued and will loosen or break. If a bolt is under-torqued, the bolt becomes loose which may result in the nut coming free. A proper method of tensioning the split bolts is required.

Photo 1 - Measuring the Runner Plate Flatness

With a tightly fitted key, drawing together the runner plate halves is only part of the problem. On disassembly, one must also be able to separate the plate halves. Ease of disassembly must be designed into the runner plate to prevent site personnel from having to damage the mounting or running surface finishes or split faces. For the new PGS runner plate, 20 to 30 tons of force is required to separate the two halves.

In today's open market environment, requiring that the bearing pads cool between stopping and starting posed a major operational issue. Crowning of the bearing pads had to be minimized in order to allow immediate response when switching from generating to pumping, or vice versa.

As previously mentioned, the runner plate surface speed was too slow to allow proper oil film development. There was no way to increase the RPM of the generator as it is synchronised with the North American grid. Also, increasing the diameter would increase the surface speed of the bearing, however, this was very cost prohibitive as it would involve major modification to the thrust bearing pot and main bracket.

Temperature was not an issue for the PGS bearing; during normal operation the bearing temperatures were not excessive, therefor the oil viscosity was not thinning due to heat. However, the oil film needed to be thicker to allow the bearing to operate at a reliable safety factor. For the PGS bearing, calculations indicated that the new ISO 68 oil would improve the oil film thickness for this slow rotating generator.

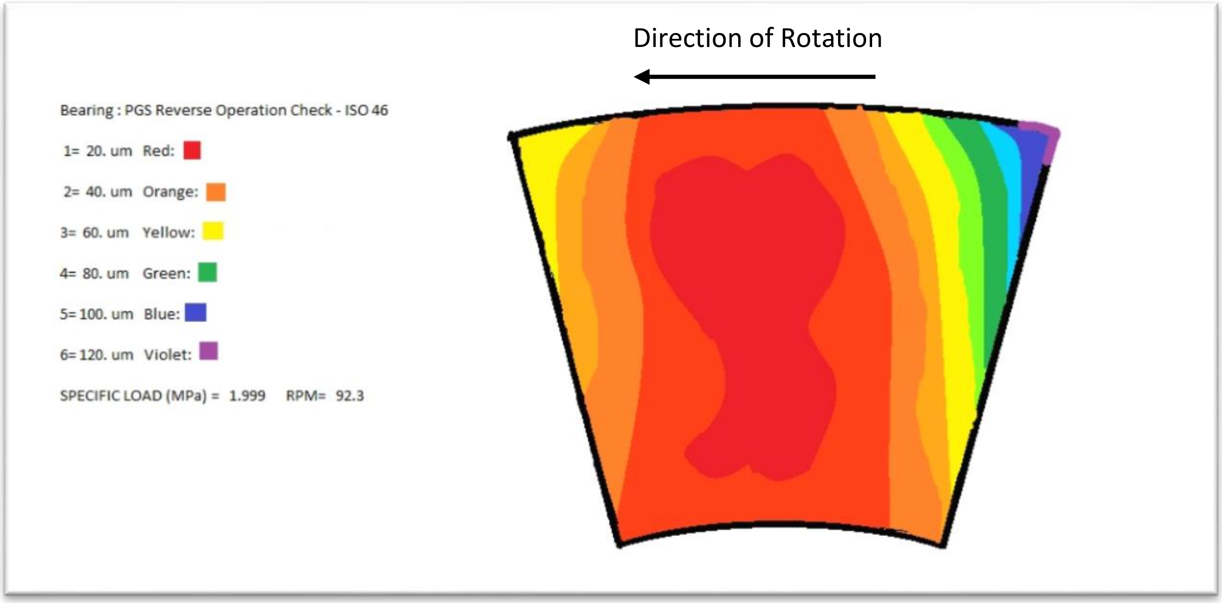

Figure 1 - ISO 46 Oil with Minimal Film Thickness

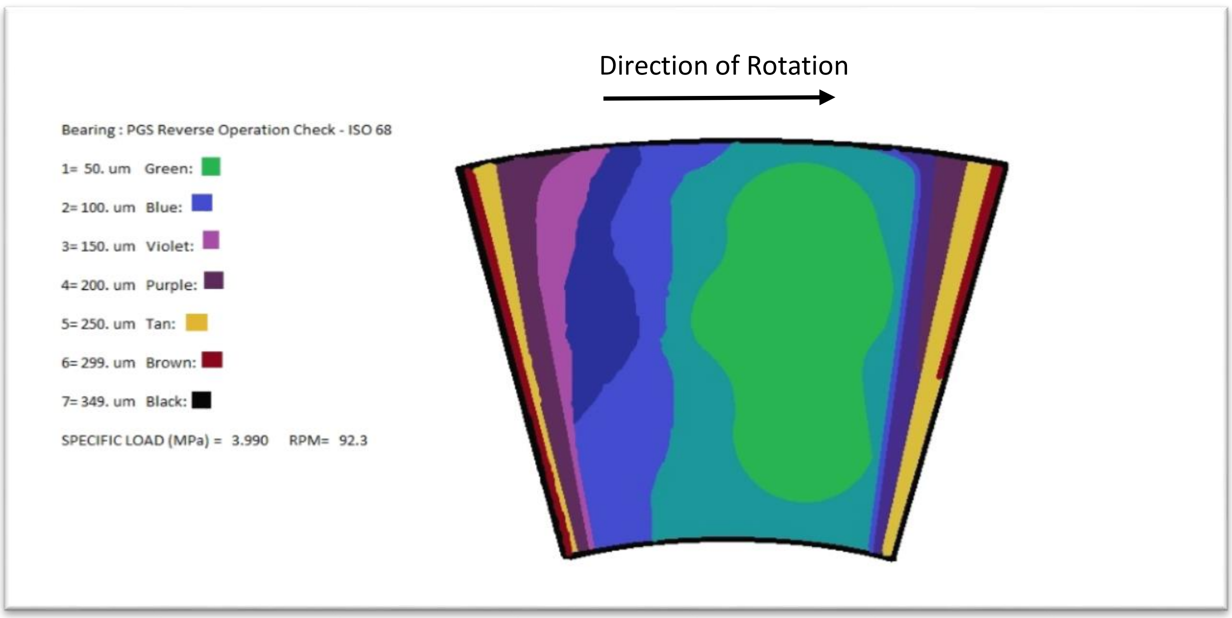

Figure 2 - ISO 68 Oil with Minimal Film Thickness

Despite all of these modifications, there was still opportunity for momentary metal-to-metal contact due to loss of oil film. If the thrust runner (rotating ring) contacts the Babbitt bearing pads for even a split second, the bearing will wipe at every contact. Both Hydro Tech's bearing design software and EnEnergo's bearing design software showed this was still a possibility. This was resolved by redesigning the bearing pads to have a PTFE surface instead of a Babbitt surface. In the rare event that runner plate to bearing pad contact was to occur, with the PTFE bearing pad, the runner plate would slide on the PTFE for the split second, regain its oil wedge, and keep operating, instead of wiping the bearing. In all likelihood, the operator would not register any sort of indication that contact was ever made. The bearing would resume operating again without issue.

Babbitt vs PTFE

A Babbitt bearing works best with an offset of 15 to 25 percent pivot point towards the trailing edge. This however creates an issue for a reversing bearing as there can be no offset due to the bearing rotating in both directions. The bearing pivot point must be in the center of the bearing, which lowers the ability for the bearing to achieve full capacity for its size.

A PTFE bearing works best with an offset of 5 to 7 percent pivot point towards the trailing edge. This means that when the pivot point is moved to the center of the bearing, the Babbitt bearing pad loses much more capacity than the PTFE bearing pad. Due to the proximity of its optimum pivot point, this design parameter for PTFE affords the PTFE reversing bearing with more capacity than a Babbitt reversing bearing.

About PTFE Thrust Bearing Pads (as provided by EnEnergo)

The new PGS thrust bearing pads have PTFE lining of the frictional surface instead of Babbitt lining. To overcome PTFE’s low strength against deformation, the PTFE is reinforced with bronze wire mesh embedded into the PTFE below the running surface. The wire mesh is reliably soldered to the pad steel base. The PTFE operating surface has unique design tapers to provide optimal oil film for the speeds and loads of the PGS bearing. Also, consideration is given for elastic deformation of the PTFE. PTFE lining features excellent antifriction and anti-scratch properties as well as high electric insulation. The dry friction coefficient between Teflon lining and the steel runner plate friction surface is from 0.05 to 0.08, about 20% to 30% compared with the coefficient of Babbitt. Heat-conductivity coefficient for PTFE lining is only 0.05% from heat-conductivity coefficient for steel-Babbitt, which dramatically reduces crowning.

PTFE is a petroleum product which holds oil better than metal, and with the specially machined tapers on the leading edges of the bearing pads, the oil wedge develops at lower speeds, practically from the moment of unit start-up to unit stoppage. It is possible to start the generator just after stopping (hot start) since the PTFE bearing pads resist crowning. It is also possible to start the unit after lengthy stoppage (up to 1 month) without jacking the rotor prior to starting.

Creation of the lower speed oil wedge eliminates the need for a high pressure oil injection system (HPOI). As widely known, if a HPOI system is designed improperly, or if it malfunctions at any time during the life of a bearing, the HPOI can be the root cause of bearing failures. Maintenance costs are also reduced by eliminating the HPOI system. Since there is no HPOI system to maintain (breaker, motor, starter, pressure transducers, filter and other maintenance), costs are reduced while adding reliability.

PTFE has an estimated 1.5 - 2 times increased specific load capacity compared to Babbitt lining. With the PGS bearing pad dimensions being equal to the original Babbitt pads, the new bearing has a substantially increased load capacity. Should one of the bearing pads be loaded incorrectly, the highly loaded pad will wear more quickly than the others. This will automatically re-distribute the load evenly amongst the pads, with the more loaded pad (the high pad) wearing down to equal the remaining bearing pads.

PTFE has the advantage of adding additional electrical insulation to the thrust bearing from shaft circulating currents.

Service life of the PTFE pads is defined by wear of their PTFE surface. If dirt or other foreign material damages one of the bearing pads, no damage will transfer to the neighboring pads. During scheduled inspections and overhauls it is sufficient to perform only visual inspections of the pads' friction surface. Wear can be visually inspected by viewing the wear grooves located on the surface of the PTFE. This wear occurs mainly during brief periods of time within the starting/stopping processes, when there is no full hydro-dynamic oil film. The wear rate depends on the number of start/stop procedures, on the smoothness of the runner "mirror" surface, and on the oil-bath purity. If the oil pot is kept clean, and alignment is proper, the wear rate is very low. On large size units with high specific load, after 15-20 years of operation, wear was as low as 0.2-0.3 mm. With the PTFE having full thickness of approximately 1 mm above the wire mesh layer, the life of a PTFE bearing can be extremely long.

Results:

The best real-time indicator of how a bearing is functioning is the temperature at which the bearing is operating. The original PGS bearing had one resistance temperature detector (RTD) in the center of the bearing pad. The centered location of the original Babbitt bearing's RTD recorded only a best-fit temperature for both rotational directions.

The new bearing pad has two RTD holes to allow the temperature to be measured at the hottest spot in both rotational directions. Towards the trailing edge is where the warmest temperatures develop on a bearing pad. Unfortunately, during assembly, additional RTD's were not available for installation. Therefore, only one RTD was placed at the trailing edge of the generating side of the bearing pad; the other RTD hole was left empty. Because of this, a direct temperature comparison between the old pad and new pad cannot be made.

Photo 2 - PTFE Bearing Pad

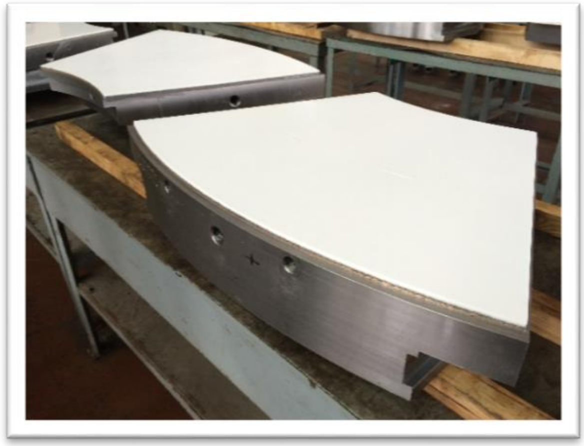

Photo 3 - PTFE Bearing Pad with RDT Holes

When a bearing is first put into operation, it will initially operate at a slightly higher temperature and then slowly wear into final operating temperature within a couple of months. One can expect the bearing temperature to lower approximately 3 degrees in the first two to three months of operation.

The results shown in the graphs below are during commissioning and the first operating runs. The final running temperatures will be better than those shown below.

Generating Mode

The bearing temperature leveled out at 58 degrees Celsius with the RTD placed in the bearing pad's trailing edge, the hottest part of the bearing pad. Starting and stopping was smooth.

Pumping Mode

The bearing temperature leveled out at 55 degrees Celsius with the RTD placed in the bearing pad's leading edge, not in the hottest part of the bearing pad. However, calculations indicate that the temperature range between RTD placement and the actual hottest part of the bearing pad, is within 5 degrees. Starting and stopping was smooth.

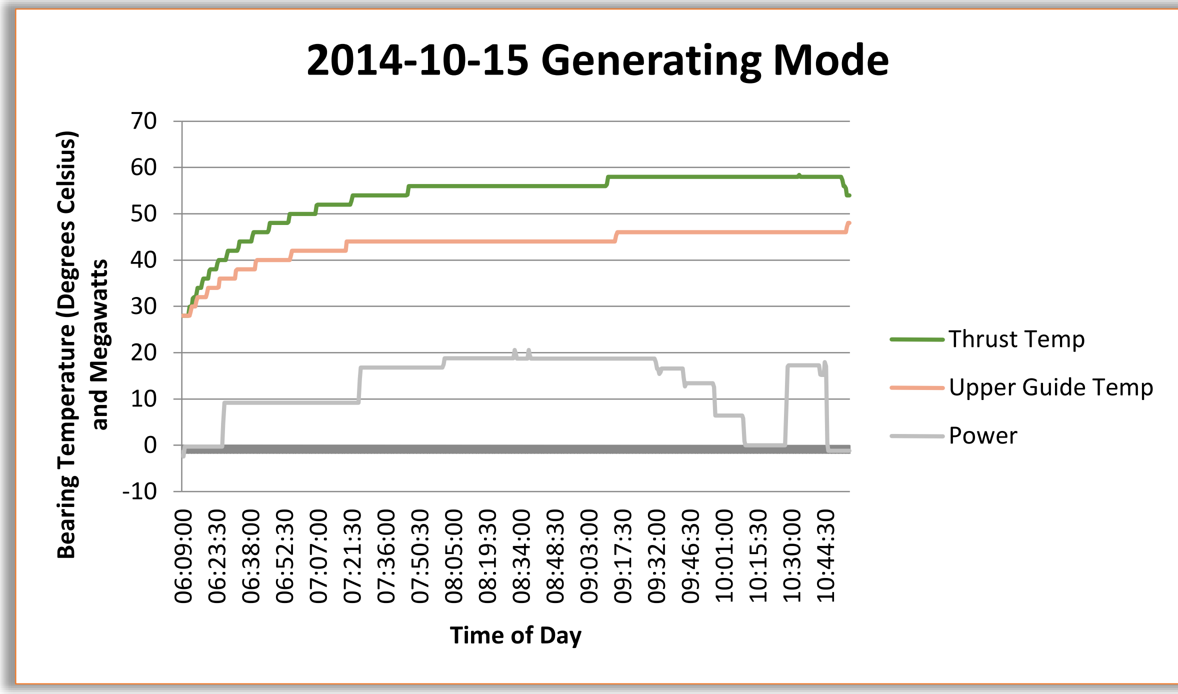

Figure 3 - Bearing Temperature in Generating Mode

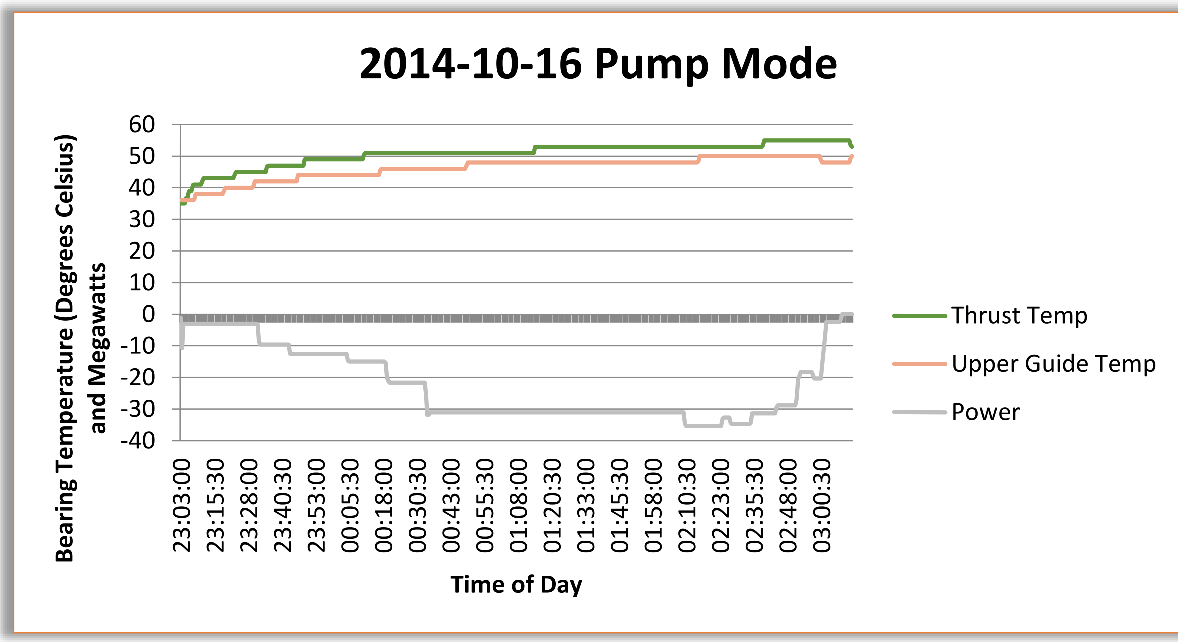

Figure 4 - Bearing Temperature in Pump Mode

Conclusion

Refurbishing and upgrading the PGS thrust bearing has produced the following outcomes.

Improvements of the bearing now have the runner plate with a clamping value at the split faces being 100 tons total, with a step of less than 0.0001 inches on assembly at both the vertical and horizontal split joints.

The thicker ISO 68 oil is now providing a more reliable oil film while operating at a standard temperature of 58 degrees Celsius.

The PTFE bearing pads are providing a more dependable service life due to PTFE's ability to carry higher loads and withstand a momentary oil film loss. With the surface dimensions being the same as the old Babbitt bearing pads, a 50% or better load capacity has been achieved.

Operational limitations for stopping and starting have been eliminated. The generator is now able to stop and immediately reverse directions.

The high pressure oil injection system has been removed. This has eliminated maintenance for this system, while also eliminating a potential failure mode.

With the increase in load capacity of the thrust bearing, the turbine stay vane flaps were put back in service allowing the full output of the turbine/pump and generator/motor.

Authors:

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Michael Dupuis has been the President and CEO of Hydro Tech Inc. since 2001. As Lead Design Consultant, Mike has extensive experience in thrust bearing design (both PTFE and Babbitt), overhauling and upgrading hydro generator/turbines, alignments, maintenance, and hydro electric generator operations, Mike has worked exclusively in the hydro electric field for the past twenty-three years.

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Tihomir Maricic graduated in Mechanical Engineering from the University of Nis, Yugoslavia, in 1981. After graduation he joined the crew of the builders of Iron Gates 2 Hydroelectric Development Project. After moving to Canada, he used this experience in international and domestic hydro projects as a design engineer and consultant with ACRES International and project engineer with VaTech Hydro. In 2006 Tim joined Ontario Power Generation as a Senior Plant Engineer with Asset Management Department of Niagara Plant Group working on major unit overhaul projects. He is currently a Senior Engineer Specialist in Plant Engineering Services as Technical Lead for major overhauls.