KERR GS THRUST BEARING REPLACEMENT

Gary Peterson, Maintenance Manager, *Energy Keepers Inc.* USA

Mike Dupuis, President, *Hydro Tech Inc.* Canada

Abstract

Soon after Energy Keepers, Inc., a *Corporation of the Confederated Salish & Kootenai Tribes*, took over operation of the SKQ Hydroelectric Facility (formerly Kerr Dam), the generator was taken off line due to a thrust bearing temperature alarm. The 112,646 horsepower Francis turbine 90 MW generator's thrust bearing had failed due to operational error and thrust loading that approached the design limit of the original thrust bearings. After a root cause analysis was performed, it was determined the best path forward was to install PTFE lined thrust bearings due to their higher load capacity and greater efficiency which would allow for cooler operating temperatures. Hydro Tech Inc. was contracted to design and supply the new PTFE thrust bearing.

After approximately one year of operation, four times daily temperature recordings revealed that the PTFE thrust pot oil temperature trends were approximately ten degrees Celsius (10°C) cooler than the previous design within the same operating parameters. The oil will therefore last longer due to the lower operating temperature conditions. Previous oil samples and tests had already shown signs of oil break down (lubricants were being depleted) only five years after the new Francis turbine runner was installed in 2007.

This paper will show recorded data about our experience with the new PTFE thrust bearing and the thrust loading that pushed the original thrust bearing to its limits. The bearing pad temperature monitoring was upgraded to include all eight (8) pads versus the previous monitoring that included only two thrust pads. Also, the paper will compare start-up bearing run temperatures from March 2007 versus February 2016.

In addition, the generator guide bearing (located in the same bearing pot as the PTFE thrust bearing) experienced a complete failure. The thrust bearing operated with Babbitt circulating throughout the thrust bearing pot, and with Babbitt moving past and over the PTFE thrust bearing for a period of six weeks. The results of damage to the PTFE pads (manufactured by EnEnergo (Russia)) are discussed in this paper.

The first recorded thrust bearing failure

The SKQ (formerly Kerr Dam) Hydroelectric Facility's first recorded bearing wipe was documented in 1977. During inspection of the bearing, heavy fretting was found between the thrust block and runner plate. The thrust runner plate splits were fretting and fretted cavities more than 0.018 inches deep were recorded on the mounting surface of the runner plate and the thrust block. Both the thrust runner plate and the thrust block were repaired and brought back into tolerance. It was not recorded how much material was removed from the surfaces to achieve tolerance.

Cracking in the thrust bearing Babbitt was also reported, described at the time as “fatigued from embrittlement.” Also reported was that, “fragments of Babbitt had broken loose from the periphery at the trailing edge.” Later in this paper, a wipe that occurred in 2015 will reveal similar characteristics.

Failure before and at time of overhaul/upgrade in 2006

The generator and turbine were upgraded with a new turbine during a 2006 overhaul. The outage started in 2006 and was completed, with the unit back on line in 2007. The turbine and all parts were removed and refitted with a more efficient turbine runner capable of greater output. As well, all other parts were refurbished during the overhaul.

Upon disassembly of the generator, all bearings were inspected. Cracking and cavitation was found on the Babbitt thrust pads and it was stated by members of plant personnel that the Babbitt was “so damaged; it was surprising the generator was still operating”. In addition, an official report briefly described the Babbitt damaged condition, but no photos were included.

Significant fretting was found between the runner plate and the thrust block. As well, the thrust runner plate mounting surface was severely worn with fretting. Fretting was so extensive between the runner plate and thrust block, and at the split runner plate key, that all surfaces required machining to remove excessive amounts of material (Photos 1 & 2). More than 0.040 inches was removed from both the thrust runner plate and the thrust block to restore tolerances. The thrust bearing pads were re-Babbitted during the overhaul/turbine upgrade.

The thrust bearing was near its load capacity prior to the overhaul during which a turbine runner with greater output was installed. Therefore, if the original loading had caused the Babbitt bearing to destruct over time, it would follow that the rate of wear should increase with the new larger output turbine runner.

Photos 1 & 2: Fretting at the runner plate split key and the thrust block mounting face 2006

Thrust bearing failure in 2014

In 2014, the thrust bearing wiped when a loss in station service caused the oil lube pump to fail. The bearing was replaced without a thorough inspection of the thrust bearing pads as the root cause was the oil lube pump. However, in hindsight, it appears that defects may have been developing in the form of cracks in the Babbitt. One can see the presence of possible cracking on the Babbitt bearing pads in the area in front of the lift pump (Photo 3).

The thrust bearing pads were re-Babbitted, installed, and a full turbine/generator rotational alignment was completed, including balancing of the thrust bearing pads.

Photo 3: Bearing wiped. Potential cracking on Babbitt pad

Thrust bearing failure in 2015

A definitive cause of this thrust bearing failure was a cooling water failure and a contributing factor was that the temperature shutdown was also set too high. The overly elevated setting of the temperature shutdown was implemented due to the elevated operating temperatures normally encountered. This elevated setting did not allow an adequate safety factor to prevent damage to the bearing. However, when the thrust bearing was disassembled, cracking at the outer trailing portion in the Babbitt was also noted on all eight (8) bearing pads. Some of the Babbitt in the cracked Babbitt pieces appeared to be missing. It is possible that some Babbitt had become loose, and that a small fragment of Babbitt had lifted and initiated the bearing wipe.

Inspection of the thrust bearing pads found the cracking and defects to have occurred on each of the eight bearing pads in the same location. Defects were consistent on each pad in appearance, having a size of about 2 inches by 3 inches (Photos 4 & 5). The cracking was also located close to the wiped areas on the thrust pads. It is possible that additional cracking was within the wiped area of the thrust pad, but was now covered with the smeared Babbitt. As noted in the 1977 failed thrust bearing report, the cracking was again located towards the trailing edge on the outer diameter of the thrust bearing pad.

Photo 4: Wiped thrust bearing

Photo 5: Wiped thrust bearing

Findings of the runner plate in 2015

Condition of the runner plate at this time seemed to be fair. The maximum step developed at the split of the thrust bearing runner plate was 0.0003 inches. 90% of the step at each split (across both runner plate splits) was 0.0002 inches or less. This was measured using a tenth of a thousandth dial indicator.

The step measurement method was to sweep a dial from one side of the split to the other side, recording the change in dial reading. The total sweep movement would only need to be ¼ inch in length.

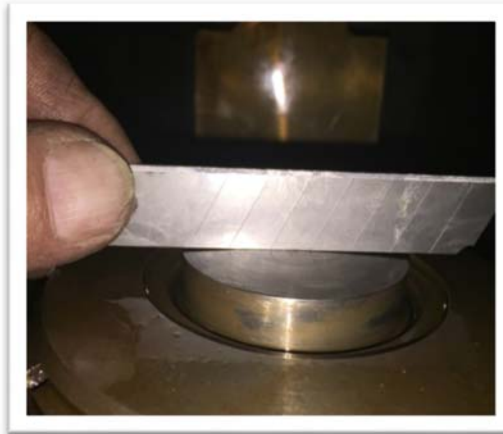
The polish on the runner plate was within the original polish requirements.

Photo 6 & 7: Sweeping the thrust runner split with a 0.0001 inch dial indicator

Load Cells 2015

The thrust bearing pad load cells were inspected and found to have damaged top crown surfaces. After much consultation, the cause of damage remained undetermined. There seemed to be pitting on the load cells, surface roughness was recorded to be as high as 96 Ra. Repair was required as these load cells are used to plumb the generator, and to balance loading of the thrust pads. The rough surface of the load cells would certainly flatten over time, causing the loading to vary from thrust pad to thrust pad. Even though the surface polish was certainly out of specification, the hardness test remained in specification at a Brinell hardness of 430, or better.

It was decided that the surface finish of the load cells must be corrected as the load cells could not be used in their current condition. To polish and rework the current load cells, the outage duration would have been extended. New, stock load cells were sourced and purchased. This allowed freshly calibrated load cells to be installed within days.

Photos 8 & 9: Damaged load cells. Large amounts of pitting had formed on the top surface.

Study of the Babbitt bearing with center pivot point: how some bearings are designed with a center pivot – why this is incorrect

A bearing is more efficient when the pivot point is offset towards the trailing edge of the bearing. We have analyzed this Babbitt thrust bearing to have an optimal offset of approximately 65% towards the trailing edge (with 50% being the mid point of the bearing pad, 100% being the total pad). This bearing pad was originally designed with a pivot point at 50%. By offsetting the pivot point to 65%, the bearing operating temperatures will drop by a calculated value of 6 degrees Celsius.

The reason why the bearing operates cooler with the offset pivot point to the trailing edge is simple; the pivot being closer to the trailing edge softens the support under the leading edge. This allows a larger amount of oil wedge to develop at the beginning, or leading edge, of the bearing pad. Due to the larger amount of oil at the leading edge, there will be a larger amount of oil film across the entire bearing pad. When the oil film is too thin, then the thinner oil creates more heat/losses, and increases the chance of metal to metal contact.


Photos 10 & 11: Bearing support directly in the center of bearing pad

Finding the optimum pivot point for the Babbitt bearing

Hydro Tech created a computer model of the original thrust bearing. Once a model was made, the operating parameters were gathered, such as oil temperature, surface speed of the bearing, loading of the thrust bearing, and oil viscosity. The bearing operation was then simulated calculating the oil film thickness, film temperature, and pressure across the entire bearing pad.

Knowing the best location for the pivot point can be easily calculated using the analysis software. Being able to shift the pivot point towards the trailing edge on a new bearing pad may be problematic. The original bearing supports do not allow the pivot point to be relocated easily. Radial, leading and trailing pad support guides are set and one can only economically modify the Babbitt thrust bearing pad itself. To obtain ideal pivot offset, the outer diameter of the bearing pad would need to be offset by 4.25 inches from its current location.

At the time, PTFE bearing pads to be manufactured by EnEnergo (Russia) were considered for the upgrade as an alternative to the Babbitt bearing.

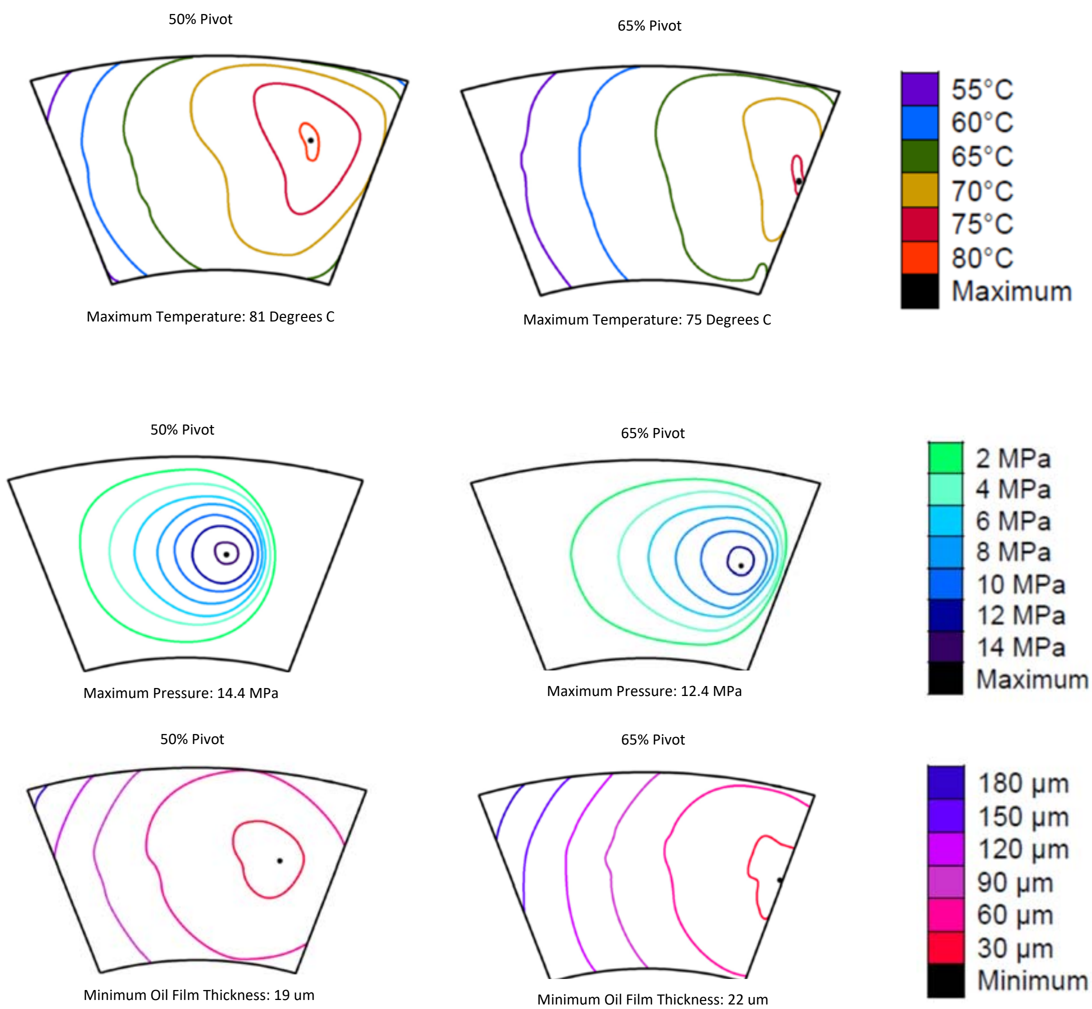


Figure 1: Babbitt bearing pad analysis results

PTFE Bearing Pads

PTFE bearing pads have a different optimum pivot point as compared to Babbitt. As stated above, calculation for the original bearing offset pivot is 65%. PTFE is calculated differently due to the make up of the bearing pad structure. For this bearing, all parameters being equal, the pivot offset was only 55.5% or 5.5% from center. With this calculation, the PTFE bearing pad support offset was only 1-3/8 inches compared with the 4-1/4 inch of Babbitt bearing pad.

As the capacity of PTFE is much larger than Babbitt, the entire surface of the bearing does not have to be covered with PTFE to achieve a larger load capacity than Babbitt. The PTFE surface area can be made smaller, and positioned on the steel to achieve the proper offset necessary for the 55.5% requirement.

Analysing the benefits of a PTFE bearing replacement

A PTFE bearing is constructed by bonding the PTFE to the steel base plate, similar to bonding Babbitt to a steel base. The bearing surface (PTFE or Babbitt) does not structurally support the load, but provides a load bearing surface for oil to achieve a hydrodynamic plane to support the moving load. The PTFE is more efficient at creating an oil wedge and maintaining this load; therefore, the PTFE does not need to cover the entire surface of the steel backing plate.

Reducing the bearing surface will reduce operating losses across the bearing pad. The more one reduces the size of the bearing surface, the more losses will also be reduced until thrust loads start to reach the capacity of the bearing.

How capacity is gained, even though the bearing surface is reduced, is a factor of the bearing material. PTFE has a higher capacity to maintain load. The PTFE remains flexible to spread out the highest-pressure load, and if the bearing loses oil film for a fraction of a second, the bearing does not wipe.

In the case of fixing the pivot point from the original center load, the optimum pivot for PTFE is much closer to center than the optimum pivot for Babbitt. This makes correction of the bearing design easier and less costly with PTFE than modifying the bearing base for a Babbitt bearing pad.

As PTFE is flexible, the cracking that happened on the old Babbitt bearing pads would be eliminated. PTFE maintains structural integrity up to 275 degrees Celsius, approximately three times that of Babbitt. However, the PTFE would experience excessive wear long before this temperature of 275°C was reached. The bearing should never operate above the normal operating range, as a rise in temperature indicates damage is happening to the bearing pad.

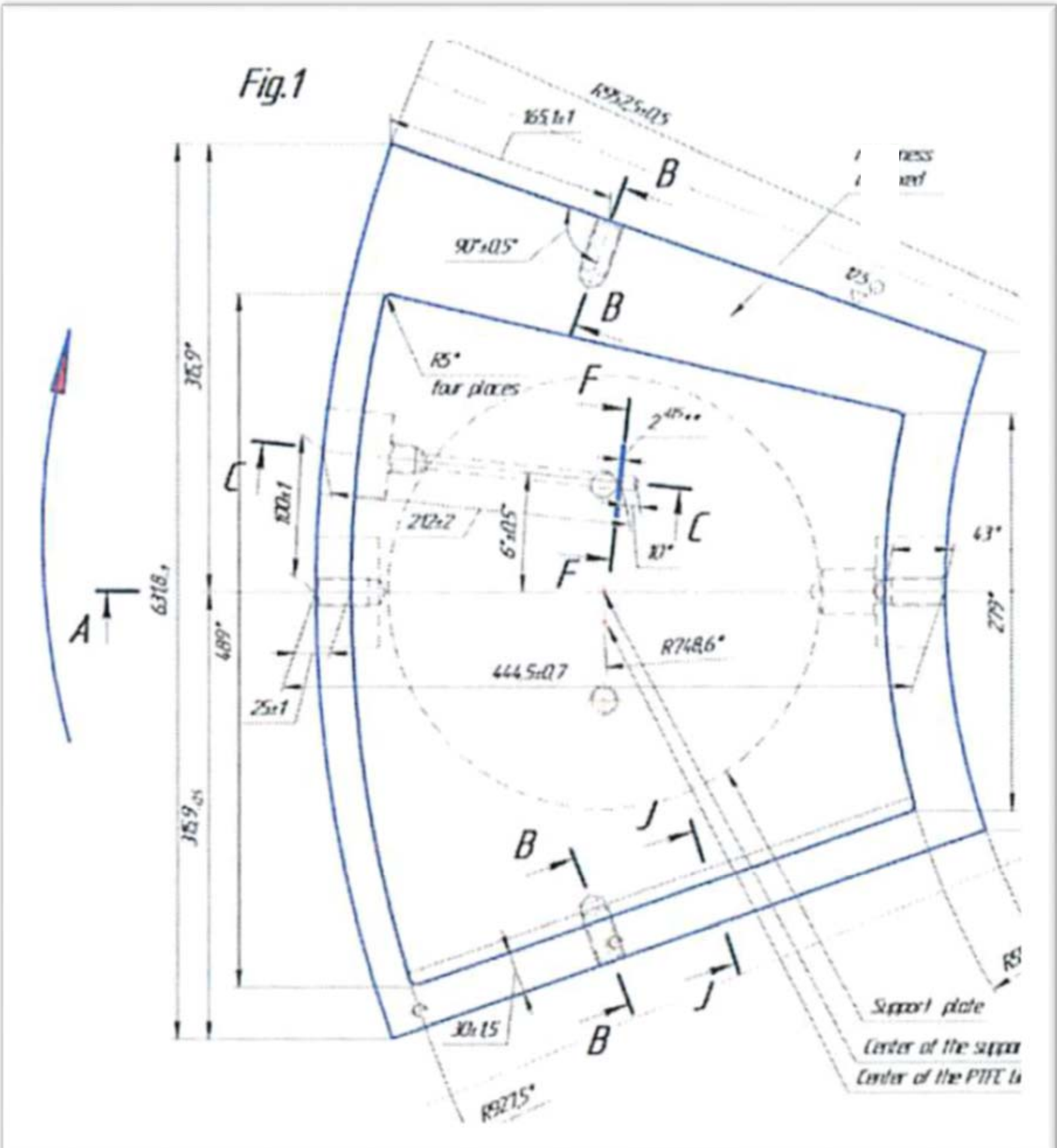


Figure 2: Offset of the PTFE towards the leading edge. This allows more support on the trailing edge. The dotted circle is the center pivot support. (Drawing provided by EnEnergo (Russia))

Actual results of the bearing pad replacement

A rush order of PTFE bearing pads was made in November of 2015 to complete the conversion from Babbitt to PTFE. The PTFE bearing pads were delivered the first week of 2016.

The new bearing temperatures at full load were significantly reduced as compared to the original Babbitt bearing. The thrust bearing, guide bearing, and oil temperatures were reduced by 17.9, 12.0, and 8.0 degrees Celsius respectively.

FIELD REPORT OF ON LOAD HEAT RUN

CONTRACT **PROJECT** Hydro Renovation **CUSTOMER & UNIT NO.** PPLMT, Kerr Hydroelectric Unit No. 3

DURATION (HRS)				0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7
GENERATOR MW				0	40	40	40	40	40	30	82	82	82	82	82	82
WICKET GATE OPENING (%)				0	48	48	48	48	48	40	100	100	100	100	100	100
TIME (H:M)				10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	16:00	17:00
TEMPERATURE FROM RTD'S / Readings in Degrees Celsius	THRUST BEARING	Shoe No. 2	M1-CH3		67.0	69.0	71.0	73.0	74.0	74.0	75.0	75.0	75.0	76.0	76.0	76.0
		Shoe No. 3	M1-CH1		61.0	64.0	67.0	69.0	70.0	71.0	71.0	72.0	72.0	72.0	73.0	73.0
		Shoe No. 6	M1-CH4		67.0	69.0	71.0	73.0	73.0	75.0	75.0	75.0	75.0	76.0	76.0	76.0
		Oil	M2-CH1		39.0	41.0	44.0	46.0	47.0	47.0	48.0	48.0	49.0	48.0	49.0	49.0
	GENERATOR GUIDE BEARING	Shoe No.1 7	M1-CH2		55.0	56.0	63.0	66.0	66.0	68.0	68.0	69.0	69.0	69.0	69.0	69.0
		Runout by dial indicator 1/1000"		At the end of each power level					3.0							3.0
	TURBINE GUIDE BEARING	US	M2-CH2		33.0	35.0	38.0	40.0	41.0	43.0	43.0	43.0	44.0	45.0	46.0	47.0
		DS	M2-CH3		37.0	39.0	42.0	45.0	45.0	46.0	48.0	49.0	50.0	50.0	51.0	52.0
		Oil	M2-CH4		18.0	19.0	21.0	22.0	23.0	23.0	24.0	25.0	25.0	26.0	26.0	27.0
		Runout by dial indicator 1/1000"		At the end of each power level					5.0							5.0
	STATOR WINDINGS	Ph. A	RTD #7					46.0	47.0	44.0	69.0	79.0	83.0	86.0	88.0	90.0
		Ph. B	RTD #6					46.0	46.0	44.0	68.0	77.0	81.0	84.0	86.0	89.0
		Ph. C	RTD #8					46.0	47.0	45.0	70.0	80.0	84.0	87.0	89.0	91.0
THERMO METER	AMBIENT AIR							12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8
	COOLING WATER IN							4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
	COOLING WATER OUT															

Figure 3: Bearing temperatures during the 2007 commissioning runs

Hydro Tech Inc

FIELD REPORT OF BEARING OIL & METAL TEMPERATURES

SHT # 1 / 2

Water 39 Deg F

HTI Contract ____________b HTI Project PTFE thrust pads replacement CUSTOMER & UNIT NO. Energy Keepers, Kerr Hydroelectric Unit No. 3

DURATION (HRS)		0	15	30	45	60	15	30	45	60	15	30	45	60	15	30	45	60	15	
GENERATOR MW		0	3	50	50	50	50	50	50	70	70	70	70	70	70	84	84	84	84	70
WICKET GATE OPENING (%)		0	12	56	57	57	54	54	54	76	73	73	73	74	74	100	100	100	100	75
SPEED [% of rated 112.5 rpm]		0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
TIME (H:M)		10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	13:00	13:15	13:30	13:45	14:00	14:15	14:30	16:00
TEMPERATURE FROM RTD'S / Readings in Degrees Celsius / THRUST BEARING	Shoe No. 1	21	44	47	49	50	52	52	53	54	55	55	56	56	56	57	57	57	57	57
	Shoe No. 2	21	47	49	52	53	55	55	56	57	58	59	59	60	60	60	60	60	60	61
	Shoe No. 3	21	46	48	51	52	54	54	55	56	57	58	58	59	59	59	59	59	59	60
	Shoe No. 4	21	45	47	50	51	53	53	54	55	56	57	58	58	58	58	58	58	58	59
	Shoe No. 5	21	44	47	49	51	53	53	54	55	56	56	57	57	57	57	57	57	57	58
	Shoe No. 6	21	39	42	45	47	49	50	51	52	53	54	54	55	55	55	55	55	55	56
	Shoe No. 7	21	42	44	46	48	50	50	51	51	52	53	53	54	54	54	54	54	54	55
	Shoe No. 8	21	44	46	48	50	52	53	53	54	55	56	57	57	57	57	57	57	57	58
	Oil	20	33	33	35	35	37	37	38	38	39	40	40	40	41	40	41	41	40	42
	Cooler Temp Oil In Deg C	27		39.0	40.0	41.0	42.0	43.0	43.0	43.0	43.5	44.0	45.0	45.0	45.0	45.0	45.0	45.0	46.0	47.0
	Cooler Temp Oil Out Deg C	15		25.0	25.0	26.0	26.0	27.0	27.0	27.0	27.5	28.0	28.5	29.0	29.0	29.0	29.0	29.0	29.0	30.0
	Cooler Temp Deg F Water In	39																		
GENERATOR GUIDE BEARING	Shoe No. 7	21	43	45	47	49	51	51	52	53	55	55	56	56	57	56	56	56	56	58
	Shoe No.1 7	20	47	49	50	51	53	54	54	56	57	58	58	59	59	59	59	59	58	60
	RTD of GEN	At end of each rpm										66.0	68.0	69.0	69.0	75.0	80.0	82.0	85.0	76.0
	Runout dial ind. 1/1000" X	At end of each rpm										2.2	2.2		2.0				2.0	
	Runout dial ind. 1/1000" Y	At end of each rpm										2.6	2.6		2.0				2.0	
TURBINE GUIDE BEARING	US	10	29	30	31	33	35	36	37	38	39	40	40	41	42	42	42	43	43	46
	DS	10	33	35	37	38	40	41	42	43	44	45	46	47	47	48	48	48	49	51
	Oil	8	14	14	15	16	18	18	49	20	20	21	22	23	23	24	24	24	25	26
	Runout dial ind. 1/1000" X	At end of each rpm										2.5	2.5		4.0				3.0	
	Runout dial ind. 1/1000" Y	At end of each rpm										2.6	2.7		4.0				3.0	

Figure 4: Bearing temperatures during the 2015 commissioning runs

One year after the PTFE thrust bearing was installed, the generator experienced a guide bearing failure.

During commissioning and testing for the generator exciter one year later, oil in the generator guide bearing was under filled. The generator was being put through a series of tests with some of the alarms and temperature shutdowns disabled. During a lengthy run at speeds of less than normal operating RPM, it was noticed that the guide bearing temperatures were 140.0 degrees Celsius. The generator was immediately shut down.

Some oil was drained from the bearing pot, and the pot inspected. No Babbitt could be visually detected in the bearing pot. Additional oil was added to the bearing pot to bring the oil level up to the normal operating level. A test run was completed to see if the temperatures would rise again; the guide bearing temperatures only climbed to normal operating temperatures. The generator was then shut down.

After this test run, further discussions took place about the state of the guide bearing, the ability of the thrust bearing to withstand small particles of Babbitt, and the possibility of running the generator with the suspected wiped guide bearing.

Discussions about the financial benefits of generating power were weighed against the potential of causing further damage to the guide bearing, and damaging the thrust bearing. If only a short duration of running time was achieved, the cost of replacing the thrust bearing pads would reach the break-even point after only a few days. At the time, market conditions were very good.

Operating parameters were developed to limit further damages. Temperatures and run-out limits were set and recorded in case a full stop became necessary.

The generator and turbine were put into operation for six weeks, earning an estimated 1.5 million dollars. The generator was then taken out of service and the thrust and guide bearings were disassembled.

A large amount of Babbitt was found throughout the bearing pot, including large chunks up to approximately 1.5 by 2.5 inches in size. Babbitt had been dragging across the PTFE thrust bearing pads for the duration of the six-week operating time. The thrust bearing temperature did not experience a noticeable rise above regular operating temperature.

A full inspection of the thrust bearing pads was completed. There was some grooving in the PTFE, and an average of about 0.002 to 0.004 inches of material was worn away. The PTFE bearing pad has approximately 0.040 inches of PTFE above the wire mesh, therefore, approximately 5 to 10% of the bearing material was worn away.

The bearing pot was completely cleaned and new guide bearing pads were installed. The generator and turbine were aligned and the thrust bearing pad loads balanced. The generator is currently operating at normal capacity. Now that the oil is clean again, one can reasonably expect that the bearing still has 30 years or more of life remaining.

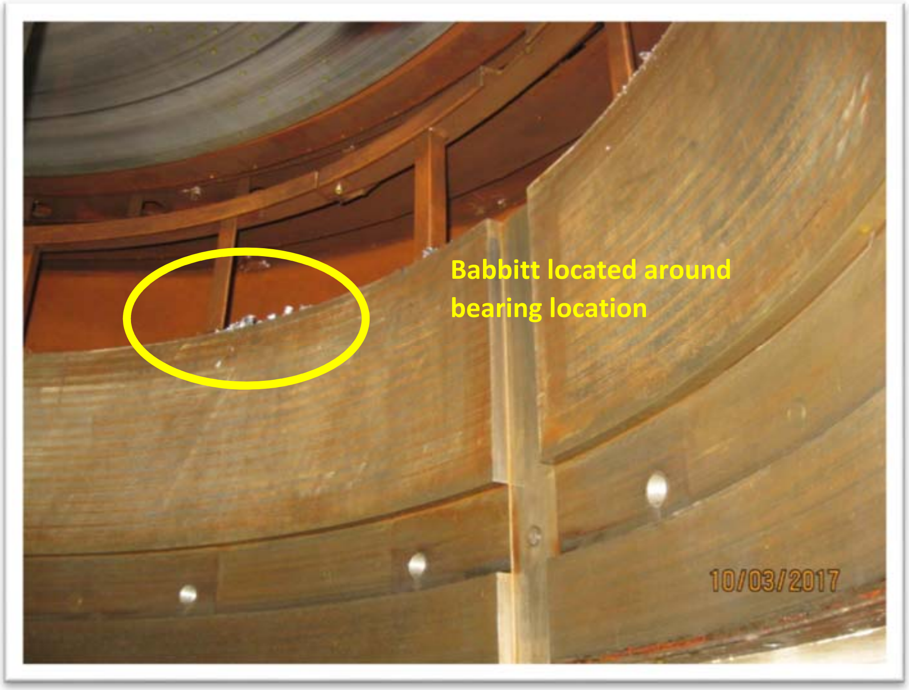


Photo 12: Babbitt in the bearing pot

Photo 13: Babbitt chunks located on thrust bearing support base

Photo 14: Babbitt removed from the bearing pot

Photo 15: Heavy grooving on the PTFE surface. One wear mark removed.
Only 0.002 inches of material was worn.

Photo 16: Heavy grooving on PTFE surface

Conclusion

The bearing upgrade from Babbitt to PTFE ensured long-term functionality with appropriate safety factor. Due to the higher specific load capacity of PTFE, the bearing surface could be reduced which resulted in lower bearing losses. These losses were observed as a reduction in the operating bearing temperatures: a reduction of 17 degrees Celsius on the thrust bearing, 8 degrees Celsius in the bearing oil, and 12 degrees Celsius in the upper guide bearing.

Not only was capacity of the thrust bearing increased, but the PTFE thrust bearing was capable of operation during abnormal conditions. Even though the PTFE thrust bearing had Babbitt material passing through the bearing for a six-week duration, the bearing did not fail. The generator produced revenue of $1.5 million during this time which would never have been possible with the old bearing. In addition to the revenue gained, no repair of the PTFE thrust bearing pads was required after the bearing pot was cleaned. It is likely that even with shutting down the generator when the guide bearing was wiped, the original Babbitt thrust bearing would have also wiped during that short window of operation.

Although the PTFE thrust bearing proved able to withstand such extreme operating conditions, it is not recommended that this be considered normal, nor should it be attempted in the future.

AUTHOR BIOGRAPHIES

Gary Peterson is currently the Maintenance Manager for Energy Keepers, Inc. which operates the SKQ Hydroelectric Facility (formerly Kerr Dam Project). Gary is directly involved with budgeting and installation for capital improvements and performing the predictive/preventive maintenance on the three hydro generating units.

Gary graduated from Montana State University in 1983 with a Bachelor of Science Degree in Civil Engineering, and is a Registered Professional Engineer. He was first employed by the Montana Power Company (MPC), later purchased by PPL. For the last 18 years, he has been involved with the operations and maintenance of hydro units.

Mike Dupuis C.E.T. has been President and Lead Technical Designer of Hydro Tech Inc. since 2001. Having worked exclusively in the hydro electric field for 25 years, Mike has extensive experience in overhauling and upgrading generator/turbines, alignments, and bearing design (including Babbitt and PTFE bearings, and many types of water lubricated materials for turbine bearings).

Mike has worked extensively in the PTFE thrust bearing field since 2005, while also maintaining his Babbitt bearing expertise. Currently, Hydro Tech Inc. has supplied seventy-five PTFE bearings in operation, and five more PTFE bearing upgrades are in progress within North America. To date, Mike and Hydro Tech have a 100% success rate on all bearing designs, both Babbitt and PTFE.