Condition monitoring of PEEK bearings using temperature measurements
Surveillance de l'état des butées recouvertes de PEEK à l'aide de mesures de température

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The traditional way to monitor the health of fluid-film bearings has been to embed temperature sensors within the body of the bearing pads. This has been a reliable method for bearings that utilize a babbitt coating layer as the sensing element of the temperature sensor is placed close to the surface of the pads where the heat from the film is conducted towards the back of the pad. This method is challenging for fluid-film bearings that have pads with a thermoplastic coating layer. Since most of the heat from the film is insulated from the pad body, detection of sudden changes in film temperature by a body sensor are delayed. In this paper, we present the recent experience at Kingsbury, Inc. where bearing performance evaluation experiments were conducted using traditional and alternative sensor installation methods. It was observed that 'bleed holes' machined on the surface of the pads improve the accuracy of the film temperature prediction by the body sensor while the reliability of the method is not yet established, especially for testing of ultimate load conditions.

La manière traditionnelle de surveiller la performance des butées hydrodynamiques consistait à installer des capteurs de température dans le corps des patins. Il s'agit d'une méthode fiable pour les butées qui utilisent une couche de revêtement en régule, car l'élément de détection du capteur de température est positionné près de la surface des patins d'où la chaleur du film est conduite vers l'arrière du patin. Cette méthode est difficile pour les butées aux patins recouverts d'une couche de revêtement thermoplastique. Étant donné que la plupart de la chaleur du film est isolée du corps du patin, la détection des changements soudains de température du film par un capteur installé dans le corps est retardée. Dans cet article, nous présentons l'expérience récente chez Kingsbury, Inc., où des évaluations des performances des butées ont été menées à l'aide de méthodes d'installation de capteurs traditionnelles et alternatives. Il a été observé que les trous de purge usinés dans la surface des patins améliorent la précision de la prédiction de la température du film par un capteur installé dans le corps du patin, alors que la fiabilité de la méthode n'est pas encore établie, notamment pour tester les conditions de charge ultime.

1 Introduction

The two traditional primary indicators of bearing performance are power loss and babbitt temperature of the pads [1]. In a thrust shoe, the babbitt temperature is monitored by placing a temperature probe, often a thermocouple, just below the babbitt surface within the metal shoe body. Analysis of instantaneous and long-term temperature data is used as a measure of bearing health and possibly a warning of imminent bearing failure. The typical location of the probe is 75% of the shoe angle circumferentially measured from the leading edge and 75% of the distance between the pad inner and outer radii radially, often referred to as the "75/75 location." It is the place in the shoe where the probability of babbitt yielding is greatest. In practice, however, probe locations are limited by physical constraints of the bearing design and can be located elsewhere in the shoe.

Babbitt has many good properties that make it an ideal bearing lining material: it bonds to the metal shoe body easily, it has great machinability properties, it is soft enough to imbed any foreign particles that may be present in the lubricant, it conducts heat away from the lubricant toward the shoe body, and it is soft enough to act as a sacrificial interface between the rotating steel collar and the stationary metal shoe bodies in case of bearing failure. In contrast, two key limitations of babbitt are that its yield point is low (a function of temperature and pressure), and its static coefficient of friction is high compared to other materials, namely thermoplastics.

Thermoplastics have been used by bearing manufacturers for decades and have experienced a renaissance in recent years. This is driven by end-users who have exotic applications, typically process-lube, and the industry trend for machines subjected to ever-increasing loads. Although thermoplastics overcome the limitations of babbitt in such instances, they come with their own challenges. As the name suggests, thermoplastics thermally insulate the lubricant from the shoe body. There are both advantages and disadvantages of this insulating feature, but the biggest disadvantage is that bearing health monitoring method that was so effective for babbitt is now rendered almost useless.

Nevertheless, early studies that involved experimental evaluation of fluid-film bearings with thermoplastic coated pads utilized embedded sensors either in the pad body or the liner material [2-7]. This resulted in incomplete conclusions for bearing performance comparisons of thermoplastic coatings against babbitt due to the insulation effect or additional sensor placements in the rotating collar to predict the film temperature. Some more recent studies also showed the utilization of the embedded sensor in the pad body of bearings where thermoplastic coatings were used [8-9]. Nowicki et al. [9] presented that the temperature sensors placed 22 mm below the bond line of a thrust pad with a 10 mm Polytetrafluoroethylene (PTFE) coating caused a delay of about 5 minutes during a bearing failure incident between the time the film was lost and the body temperature sensors showed a spike.

Alternative methods to mitigate the insulation effect of the thermoplastic coatings were proposed by various studies where either a metal insert was placed in the liner of the pads [10-12] or a tiny hole was drilled at the pad surface to make physical connection of the oil with the temperature sensor placed in the pad body [3,10,13-16]. Metal inserts have been disqualified for inconsistent reading or providing misleading information about bearing distress [10]. The authors of this paper also had previous experience with negative effects of metal inserts in terms of the performance of bearings with thermoplastic coated pads, which was considered to be related to localized heating and non-uniform thermal expansion.

The hole method, on the other hand, where a small enough hole was drilled through the thermoplastic liner, the bond line and the pad material up to the sensor located in the pad body, has shown better performance in reliability and accuracy. Direct contact with the hot oil that fills the hole in the PTFE liner material helped Ettles et al. [3] make more accurate comparisons against the babbitt lined bearing and have allowed them to conclude that film temperature in both bearings were comparable. Glavatskih [13] later expanded the application of the hole method by adding an exit hole on the side of a PTFE-lined thrust pad in order to allow the hot oil contacting the temperature sensor exit the pad and therefore improve the accuracy of the readings by replenishing sensor cavity with fresh hot oil. Later, this method received acceptance by both bearing manufacturers and OEMs in evaluating the performance of Polyether ether ketone (PEEK) bearings. The hole method was used for both thrust and journal bearing monitoring [16] as well as to show that the more accurately captured film temperature can be utilized to make decisions on increased load capacity of PEEK bearings [15]. Additionally, Zhou [10] also showed that the temperature signals recorded using the hole method was in sync with other bearing parameters as compared to the insulated pad body sensor.

In this work, we present the implementation of the hole method in monitoring the behavior of flooded and direct-lubricated fluid-film thrust bearings with pads that are coated with babbitt or PEEK. The next section presents the details of the experimental set-up and the bearings used during these tests. Later, factors such as speed, load, pad geometry and existence of side bleed hole are discussed in relation to the accuracy of the temperature measurements obtained using the hole method. Finally, the paper concludes with discussions about the monitoring methods for fluid-film bearings with insulating thermoplastic coatings using methods that do not rely on temperature measurements.

2 Experimental set-up

The experiments conducted to evaluate the effectiveness of the hole method for PEEK bearing monitoring have been achieved using two separate test rigs at Kingsbury's Philadelphia location, namely the high-speed test rig and the vertical test rig. The high-speed test rig utilizes a horizontal shaft that allowed to test two different sizes of direct-lubricated thrust bearings with PEEK pads simultaneously, while the vertical test rig was used to test a flooded PEEK bearing design in a vertical arrangement.

Kingsbury's high-speed test rig is described fully in Reference [17]. The test rig shaft is driven by a variable speed gas turbine with a rated output of 1100 horsepower (820 kW) and a controllable test speed range of 4,000 to 17,000 rpm. The turbine is connected to the test shaft by a flexible coupling. Two identical housings external to the turbine enclosure contain the bearing components (Figure 1). Two tilting-pad journal bearings support the test shaft.

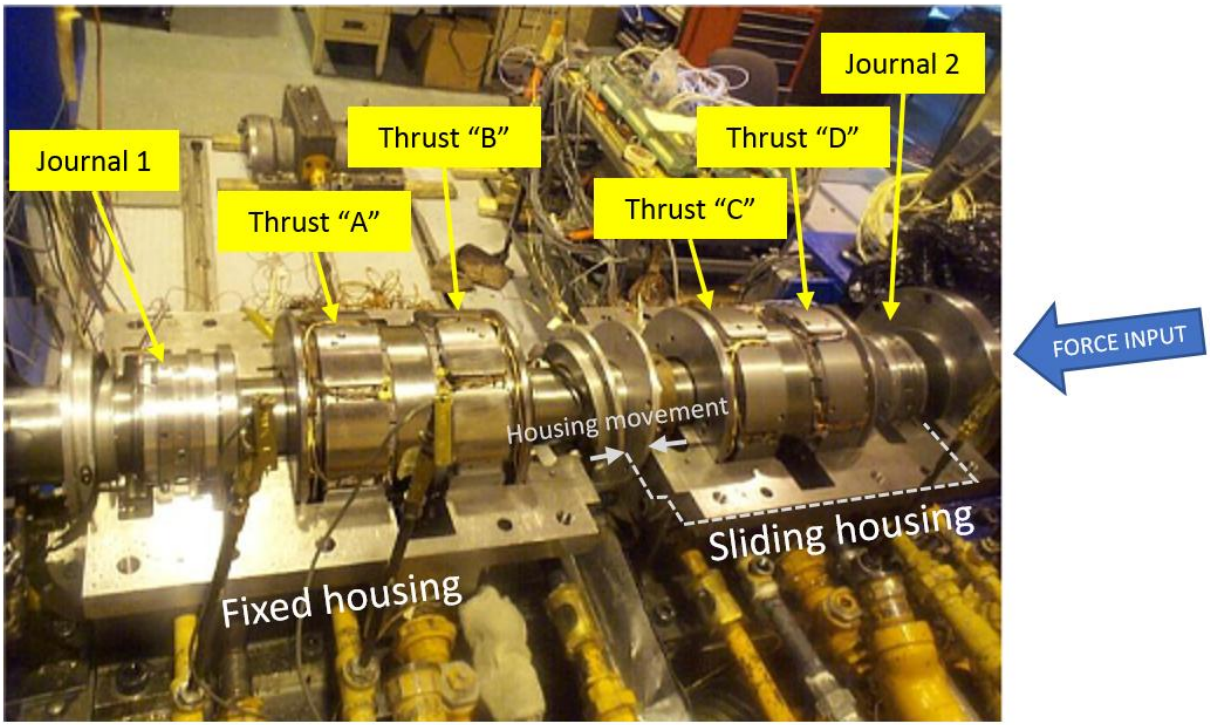


Figure 1. High speed test rig with upper half of the housings removed.

The high-speed test rig was designed to test two double-acting thrust bearings under load. Referring to Figure 1, the fixed housing adjacent to the turbine is firmly secured to the foundation while the sliding housing is restrained but is free to slide axially under rails. An external hydraulic system applies an axial load to the sliding housing. As a result, thrust bearings "A" and "D" are loaded against each other while thrust bearings "B" and "C" remain unloaded. A load cell mounted at the interface of the hydraulic system and the sliding housing measures the applied force. The bearings are carefully shimmed to set the axial clearance and to hold the position of the shaft so that no axial force is transmitted through the coupling to the turbine.

Bearing Position	"A"	"B"	"C"	"D"
Bearing Lining	PEEK	Babbitt	Babbitt	PEEK
Number of Shoes	10	10	6	6
Shoe Material	Steel	Chrome-Copper	Steel	Steel
Oil Supply Method	Groove Oil Supply Inserts	Groove Oil Supply Inserts	LEG®	Groove Oil Supply Inserts
Bearing OD	12in (204.8mm)	12in (204.8mm)	10.5in (266.7mm)	10.5in (266.7mm)
Bearing ID	8.85in (224.8mm)	8.85in (224.8mm)	5.25in (133.4mm)	5.25in (133.4mm)
Bearing Offset	68%	68%	60%	65%

Table 1: Thrust bearings used in the high-speed test rig.

The four thrust bearings installed in the high-speed test rig are described in Table 1, and the operating conditions are given in Table 2. Pictures of the loaded bearings "A" and "D", which are the focus of this paper are shown in Figure 2. A National Instruments^{TM} LabVIEW data acquisition system was used to record the test data. Steady-state measurements include shaft speed, applied thrust load, oil flow, oil supply pressures, oil supply temperature, oil drain temperatures, and pad temperatures.

Figure 2. Pictures of the PEEK thrust bearings used in the "A" (left figure) and "D" (right figure) positions.

Additionally, the vertical test rig was used for evaluating the performance of PEEK bearing at lower-speed higher-load conditions compared to the high-speed test rig. The vertical test rig, as shown in Figure 3, is driven by a variable-speed, bi-directional, 50 hp electric motor that is coupled to a vertical shaft that has a non-integral runner with removable runner plates. The runner diameter is 10.625 in (269.875 mm) and has a total thickness of 1.751 in (44.48 mm). A plain journal bearing is used at the top end of the runner for radial positioning.

The thrust collar faces tilting-pad thrust bearing pads on both sides which are custom designed in order to allow adjusting the offset orientation of the spherical shoe support in either a center-pivot, 60% or 40% offset pivot configuration. Hydraulic jacks are placed under each thrust pad of the lower bearing to adjust the load on the bearings, and they also act as a hydraulic equalization mechanism for the lower bearing. The upper bearing utilizes Kingsbury's traditional leveling plates for load balancing between the pads. Removable runner plates allow easy correction of the surface finish during ultimate load tests where the bearings can be pushed to their failure points. The bearings were submerged in a tank as shown in Figure 3 where the lubricating oil was kept at test conditions shown in Table 2 using an external air-based heat exchanger.

Test Rig	High-Speed Test Rig		Vertical Test Rig
Oil Type	ISO VG 32		ISO VG 32
Inlet Temperature	120°F (48.9°C)		140°F (60°C)
Speed	4000-15000 rpm		500 – 2500 rpm
Unit Loads on test bearing	"A bearing" 0 - 1500 psi (0 - 10.3 MPa)	"D bearing" 0 – 1174 psi (0 – 8.1 MPa)	0 – 2400 psi (0 – 16.5 MPa)
Bleed hole location	90/67	90/55	86/60
Oil Supply Flows	9 - 45 gpm (34-170 lpm)		N/A

Table 2: Operating conditions for the PEEK bearings tested.

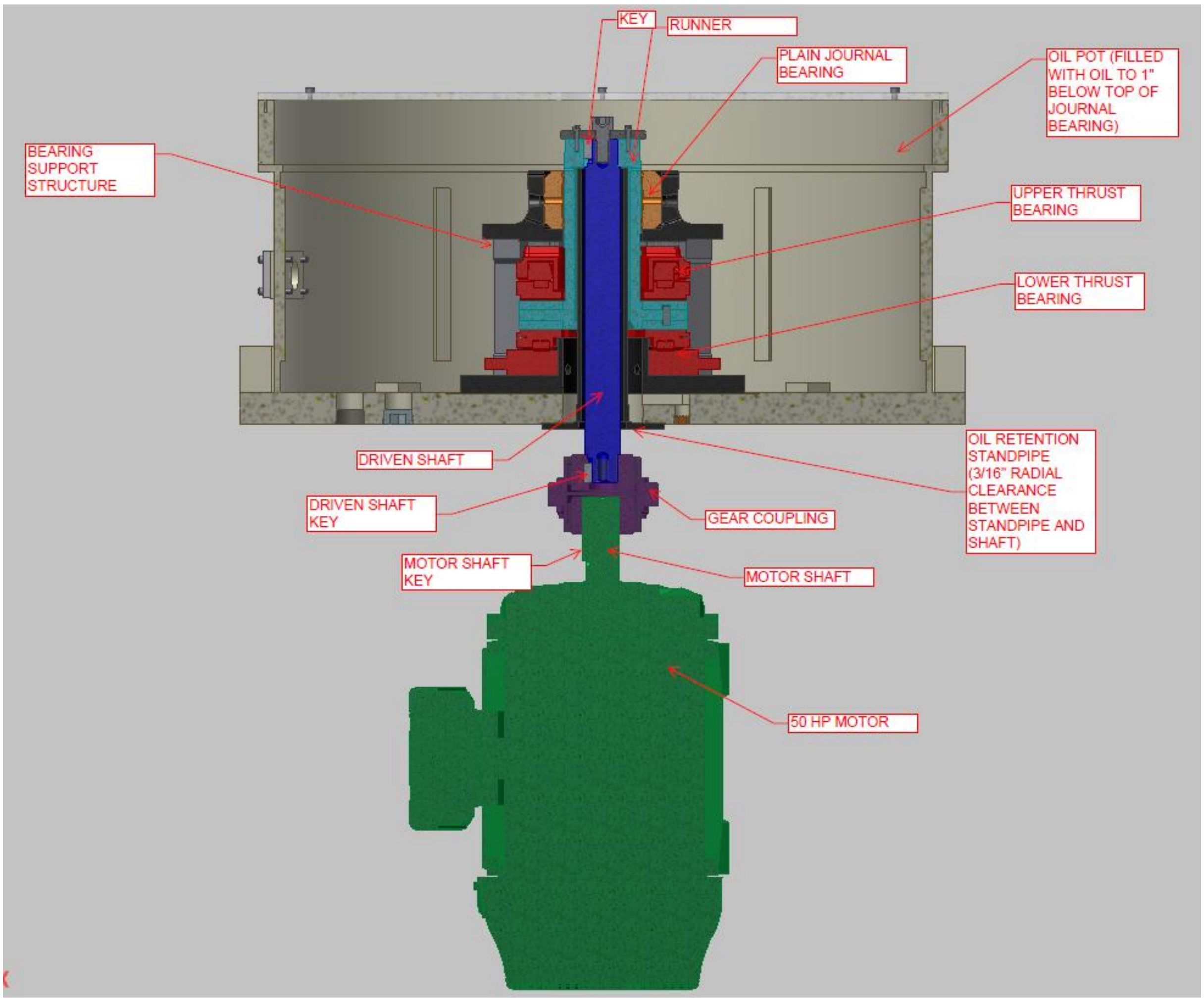
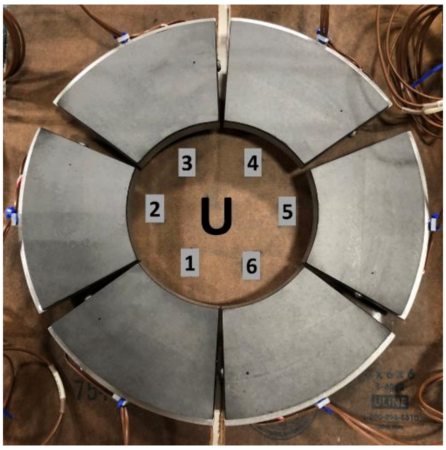


Figure 3. Schematic showing the main components of the vertical test-rig at Kingsbury, Inc.



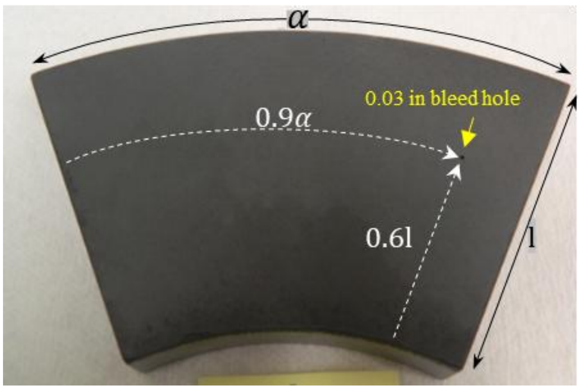


Figure 4. Pictures of the PEEK thrust bearing pads used in the vertical test rig (left figure) and close-up picture of a PEEK pad showing the 'bleed hole' (right figure).

The first test of the PEEK bearings used a traditional method of body sensors; namely, J-type thermocouples were installed from the bottom of the individual shoes so that they were flush with the underside of the PEEK layer. These were installed at the 75/75 location. A full test suite as described in Table 2 was carried out for this configuration. Then, "bleed holes" were machined through the PEEK pad surfaces and thermocouples were installed in a cavity below the hole around the 90/60 location (90% of the pad arc as measured from the leading edge and 60% of the pad width as measured from the inner radius). The location was chosen to be comparable to the 75/75 temperature measurement as close as possible [13]. The idea was to allow hot oil at the surface of the pad to flow, or bleed, into the hole, and that the thermocouple would then measure the oil temperature. To facilitate the flow of fresh hot oil over the thermocouple, exit holes were machined into the pads on the trailing edges following the work of Glavatskih [13]. This would create a continuous oil flow across each of the thermocouples. Another test suite was carried out with this configuration with both the 75/75 and the 90/60 temperature sensors installed. The specific 90/60 location was not feasible to install the sensor in the pads tested and the exact circumferential and radial location of the hole used for each three bearings is shown in Table 2. Finally, the exit holes were plugged, and a third test suite was carried out at the same operating conditions in order to evaluate the effect of the exit holes on the accuracy of the temperature measurements with the hole method.

During these experiments, LabVIEW software was utilized to control and monitor the operation of the test rigs. Thermocouples with a range of 24°F - 1400°F (0°C -760°C) and accuracy of 0.4% of reading was used to collect the temperature data, while Omega PX303 sensor with 0 – 10,000 psi range and 0.25% accuracy was used for the pressure in the loading mechanism of the vertical test rig. The high-speed rig utilized a load cell with 50,000 lbf capacity and accuracy of ± 0.15% of full scale. The vertical test rig also was instrumented with a motor power meter with 65 hp capacity and 0.5% accuracy. Transient and steady-state data logs are stored where the transient log stores the data every second by averaging 120 samples per second and steady-state log stores 30-second averages of the transient data.

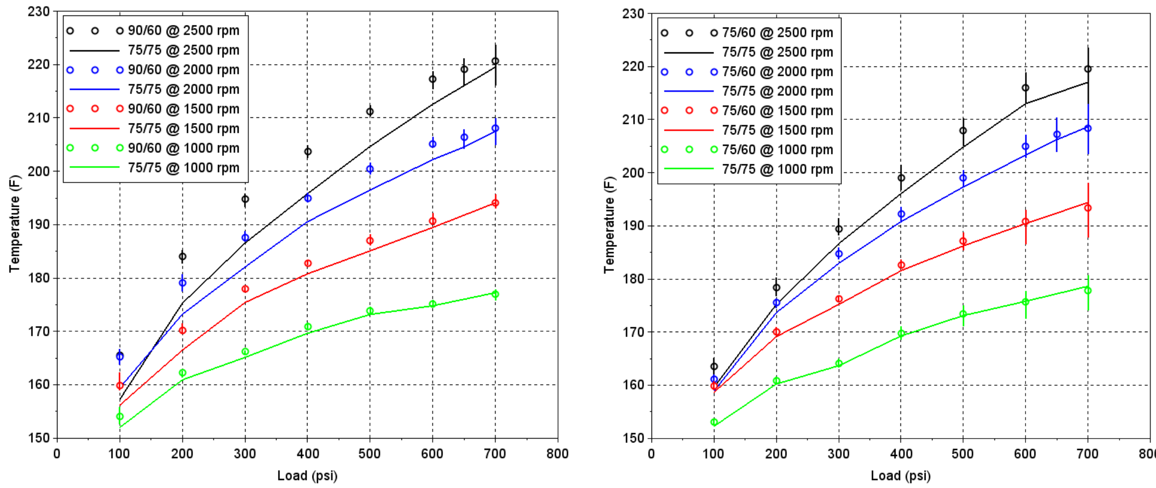
During the start-up of either the high-speed test rig or the vertical test rig the shaft is started to spin with light axial load on the thrust bearings. The rotation speed is gradually increased to warm-up speed levels during a transition period where the oil temperature is slowly raised to desired levels at the supply lines to the bearings in the high-speed rig or within the oil sump surrounding the bearing housing in the vertical test rig. Once the temperature reaches the desired level, the speed is adjusted to the value to conduct the specific test and the axial load is then increased at specified increments where steady-state conditions are established by keeping the rotation speed, the inlet temperature and the load on the bearing is kept within, ± 50 rpm, ±1 F and ± 5 psi, respectively. In the high-speed rig where the flow to each bearing is individually controlled, the steady-state criteria for flow rate is ± 0.2 gpm. Once these conditions are met at a given operating condition over a 30 seconds period, then the data is averaged for that period and recorded to obtain the steady-state value.

3 Results

3.1 Steady-state behavior

The steady-state temperature obtained with the hole method was evaluated first to understand if the conditions of the film at the pad surface could be measured accurately and reliably. In order to achieve this, babbitted steel pads for the vertical test rig bearing were instrumented using the hole method in addition to the traditional temperature sensor under the babbitt layer at the 75/75 location. The 75/75 sensors were used as the reference values to compare the measurements obtained with the hole method since they are comparable due to the absence of the insulation effect as in the case of PEEK lined pads.

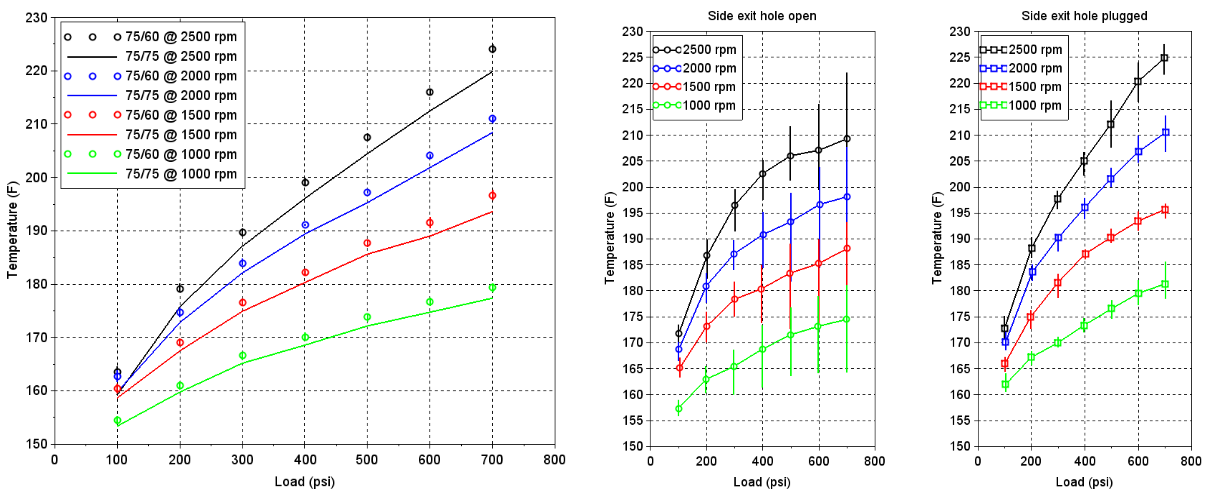
Figure 5(a) below shows that when the hole is located at 90/60 location on the pad surface, the temperature detected using the hole method matches well with the temperature measured at the 75/75 location. The circular symbols shown in Figure 5 are average of 6 pads and the error bars indicate the variation of temperature between pads. The disparity of temperature between pads is very low and is observed to increase with increase in speed and load with a maximum value of 8 F at 2500 rpm and 700 psi. In the next test, the holes at 90/60 location were puddled in with babbitt and then machined flat and new holes were drilled at the 75/60 locations. It was observed that the gap between the temperatures measured at the 75/75 sensor and the sensor using the hole method decreased while the disparity between the pads have increased as shown in Fig. 5(b). Note that the solid lines in Figures 5(a) and 5(b) demonstrate the repeatability of the test measurements.



(a)	*(b)*

Figure 5. Oil film temperature measurements with the 'bleed hole' at 90/60 vs body sensor at 75/75 position (a) and oil temperature at 75/60 location vs body sensor at 75/75 location (b) with 60% offset pivot babbitt pads.

The 'bleed hole' measurements shown in Fig. 5 were obtained with a 0.040 in [1.016 mm] hole drilled at the trailing edge side of the pads. It was found that when the side exit hole was closed, the disparity between the temperature measured at the babbitted pads using the hole method at 75/60 location has reduced significantly as shown in Fig. 6(a). The positive effect of plugging the side exit hole has been evaluated for the PEEK lined bearing pads used in the vertical test rig which is also shown in Fig. 6(b). The hole in the PEEK pads were placed at the 90/60 location; however, when the side exit hole was left open the variation of temperature was too large with similar trends in the babbitt pad case where the error bars increased with increase in speed and load. Figure 6(b) shows that when the side hole was plugged in the PEEK pad then the deviation of individual pad temperatures measured with the hole method reduced substantially and the accuracy of the measurements have been improved.

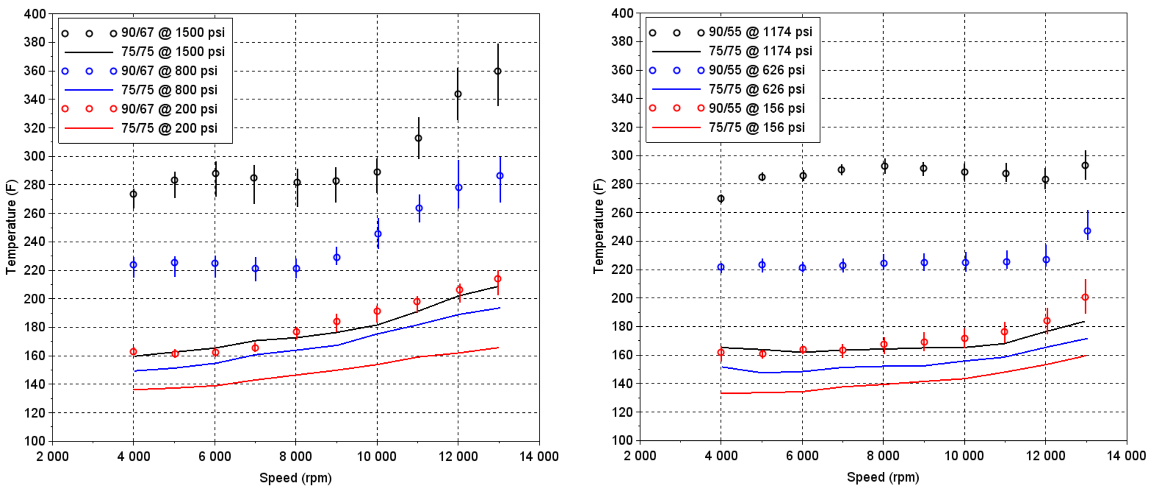


(a) *(b)*

Figure 6. Effect of the side exit hole in temperature measurements with the hole method at (a) 75/60 location in the 60% offset pivot babbitt pad and (b) 90/60 location in the 60% offset pivot PEEK pad in the vertical test rig.

It is important to establish a low variance of pad temperature in the experiments that aim to study the behavior or tilting pad thrust bearings as it indicates a good load equalization behavior of the bearing; however, the relatively larger disparity in the temperature measurements of PEEK pads obtained with the hole method made it more challenging to judge for that effect. The method seems to be more successful with the regular babbitted pads since the babbitt layer is conducting heat into the cavity where the sensor is located, and the transfer of heat is not solely relied upon the small volume of oil that fills the 0.030 in [0.762 mm] bleed hole. Since the conduction through the PEEK layer is significantly reduced then the oil becomes the primary mechanism of heat transport which was observed to vary from pad to pad larger than the ones in the babbitted bearing.

Similar temperature measurements obtained with the hole method during steady-state tests at the high-speed test rig are presented in Fig. 7 (a) and (b). It should be mentioned that the side exit hole has not been machined on either of these bearing pads based on the observation in the vertical test rig as shown in Fig. 6(b). As mentioned previously in the experimental set-up section, the first testing campaign with these PEEK bearings only included a 75/75 body sensor under the 0.125 in (3.175 mm) thick PEEK layer, the results of which are also plotted in Fig. 7 for comparison (solid lines). The 75/75 insulated sensors not only show significantly lower temperatures compared to the ones obtained using the hole method, but they also fail in capturing the change in bearing behavior with an increase in speed as seen in Fig. 7 (a), where the 'A bearing' was observed to go through a laminar-to-turbulent transition behavior around 8000 rpm as indicated by the 'bleed hole' measurements, while the trend for the 75/75 temperature shows a steadily rising profile. Similarly, the 'D bearing' is observed to go through a similar transition at 1174 psi case starting at 12,000 rpm which cannot be predicted with the body sensor at the 75/75 location.



(a) ***(b)***

Figure 7. Comparison of film temperature measured using the hole method at (a) 90/67 location in the 'A bearing' PEEK pads and (b) 90/55 location in the 'D bearing' PEEK pads in the high-speed test rig.

The high-speed tests also showed that the negative effect of speed and load on the consistency of the temperature measurements between pads of the same bearing, where the variation of individual pad temperatures from the average value has increased significantly, even with the side exit hole plugged, when compared to the variation of temperature detected in the vertical test rig experiments. This could indicate that the performance of the hole method does not improve meaningfully for a direct lube bearing in contrast to a flooded bearing.

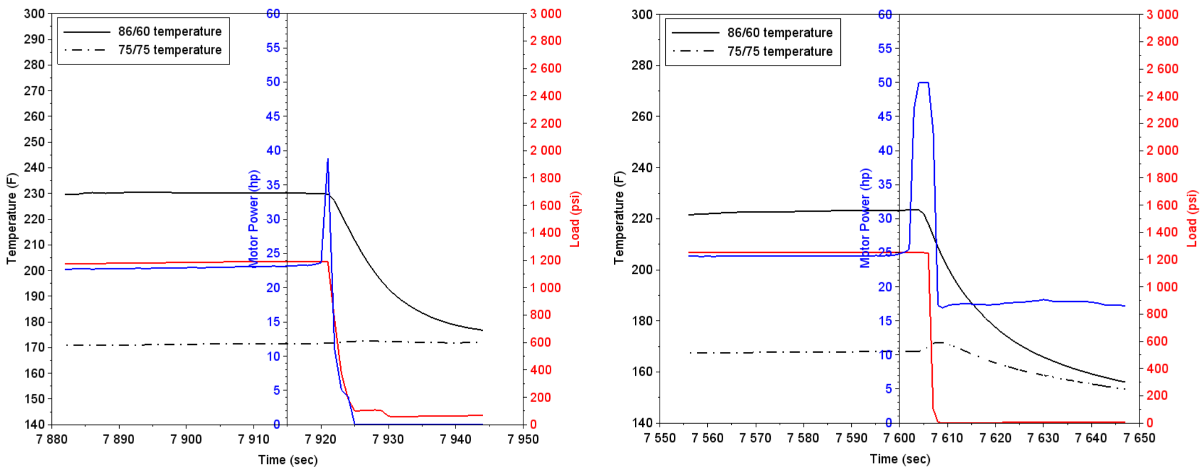
3.2 Transient behavior

The steady-state temperature measurements are useful in characterizing the performance of the bearing at certain operating conditions obtained for long periods of time when the bearings are operating in the hydrodynamic lubrication regime with sufficient film thickness established in the bearing. Additionally, temperature sensors embedded in thrust bearing pads can function as an alarm mechanism during start-up or shut-down periods or in scenarios where the hydrodynamic lubrication regime is not satisfied anymore due to loss of film or excessive thermal expansion.

The transient behavior of the temperature measurements detected below the 'bleed holes' in the PEEK pads was captured for such events that were purposefully created in the vertical rig when the axial load on the bearings was increased until the rotating runner surface has made contact with the PEEK pad surfaces. Figure 8 shows two examples of wipe incidents for the 10.5" (266.7 mm) flooded tilting-pad PEEK bearing when the shoe support was located at the circumferential center of the pad and when it was located at a 60% offset position in the direction of rotation. The black dashed and solid lines in Fig. 8 represent the temperature measurements using the hole method at 86/60 location and the sensor within the pad body at 75/75 location, respectively. These measurements were obtained simultaneously during the same experiment. The power consumed by the electric motor was also recorded and is plotted in blue in Fig. 8, while the axial load applied on the bearings is shown in red.

The tests were conducted mainly as a steady-state test until the bearing indicated that it was undergoing distress which for a babbitted bearing presents itself either with a rapid increase in the 75/75 pad temperatures or in the motor power. Figure 8 shows that neither the 75/75 sensor nor the sensor at 86/60 position with the 'bleed hole' were able to detect the local heating caused when the runner made contact with the pads. For the PEEK bearing with center-pivot pads running at 2000 rpm, the recorded motor power increased by about 20 hp before the axial load was decreased, while a similar jump in motor power was observed with the 60% offset pivot PEEK pads at 1500 rpm. The 75/75 sensor in the offset pivot pad was able to pick up a slight increase in temperatures, which was delayed by about 5 seconds when compared to the instant when the motor power spiked.

It can be suggested that during a wipe incident most of the heat generated is conducted through the pad and the rotating collar instead of heating the oil. In addition, the rupture of the oil film during the wipe event could have disrupted the transfer of heat through the 'bleed holes'. Finally, post-wipe assessment of the pads revealed that the PEEK material had melted and smeared over the pad surface in the area of the wipe, with some of the PEEK residue being carried over to the next pad, which has partially or completely clogged the 'bleed holes'.



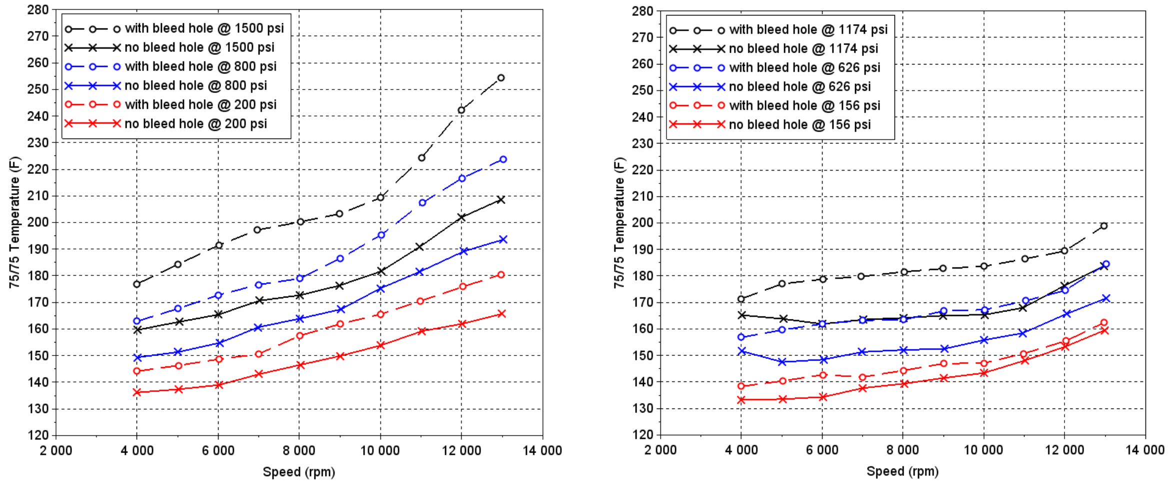
(a) *(b)*

Figure 8. Transient behavior of average pad temperatures of PEEK thrust bearing pads in the vertical test rig for (a) center-pivot position at 2000 rpm and (b) 60% offset pivot position at 1500 rpm during a wipe incident.

3.3 Effect of the 'bleed holes' on the bearing operation

So far, the issues regarding the monitoring of the bearing operation via measurement of the film temperatures with the hole method have been discussed. Another interesting observation was made when during consecutive testing campaigns in the high-speed test rig: a change in the 75/75 temperature measurements of the 'A bearing' PEEK pads was observed. During the first set of tests, the 'A' and 'D' bearing pads only had the thermocouples embedded in the pad body 0.040 in (1.016 mm) below the PEEK/steel interface. In the second set of tests, in addition to the existing 75/75 sensors, the sensors with the 'bleed hole' drilled from the PEEK surface up to the sensor cavity were mounted at the 90/67 location in the 'A bearing' pads and at the 90/55 location in the 'D bearing' pads, respectively. Both test campaigns covered the same speed, load, inlet temperature and oil flow conditions.

In Figure 9 below, the solid lines and the dashed lines present the 75/75 temperatures before and after the 'bleed holes' were placed in the PEEK pads, respectively. Both pads showed an increase in the pad temperatures after the holes were opened in the pads. All the other bearing operation outputs such as the drain temperatures, power loss, axial shaft position and unloaded bearing temperatures ('B' and 'C' bearings) were similar in the two sets of tests; therefore, it was concluded that the oil entering the 0.030 in (0.762 mm) 'bleed hole' was creating a local hot spot in the pad base metal below the PEEK layer and it was primarily being conducted through the steel pad body laterally and heating up the 75/75 sensors.



(a) *(b)*

Figure 9. Localized heating caused by the 'bleed holes' in (a) 'A bearing' pads and (b) 'D bearing' pads tested at the high-speed test rig.

Figure 9 shows that the heat transfer from the hot film into the pad body through the leak path created via the 'bleed holes' resulted in an increase of up to 20 F and 40 F in the insulated temperatures detected by the 75/75 sensors in the 'D' and 'A' bearings, respectively. One reason for the higher temperature jump in the 'A bearing' pad sensor is due to the close proximity of the 75/75 location to the 90/67 location as compared to the 'D bearing' pad. The distance between the two sensor locations in the 'A bearing' pad was 0.35 in (8.89 mm) while in the 'D bearing' pads they were apart by 0.68 in (17.272 mm).

Pad deformation due to thermal expansion is important in the operation of fluid-film bearings where it has been considered to help with the development of the hydrodynamic wedge for the pressure development in the film, especially for center pivot pads, while excessive 'crowning' can lead to instabilities in the film and jeopardize the successful operation of the bearing. It is known that the PEEK material entraps the majority of the heat and has a higher coefficient of thermal expansion compared to steel; however, since the PEEK layer is considerably thin compared to the total thickness of the steel thrust pad, there is not a large temperature gradient created in the pad body, since the steel layer is generally at uniform temperature levels, close to the temperature of the surrounding oil. Therefore, the local heat generation within the steel layer caused by the 'bleed hole' is undesirable, since it can result in an uneven temperature distribution within the steel layer and cause the pad to deform thermally in an unpredictable way. One of the ways to mitigate this effect could be to extend the sensor cavity into the PEEK layer and place the sensor closer to the pad surface away from the steel layer; however, caution must be taken not to damage the bond layer between the PEEK and the steel layer and the PEEK layer above the sensor should be sufficiently thick to prevent any dimpling around the 'bleed hole'.

4 Conclusions

In this study, two separate test rigs at Kingsbury Inc.'s R&D laboratory were utilized to evaluate the performance of temperature sensors installed in thrust bearing pads with PEEK linings as a monitoring tool. The flooded and direct-lubricated thrust bearings used in the tests showed that the API 670 standard established for monitoring babbitted bearings with temperature sensors does not apply to bearings that utilize pads with thermoplastic coatings due to the insulation effect as well as the delay in detecting sudden changes in the film.

The accuracy of the film temperature readings was significantly improved using the hole method, where the sensor tip does not make contact with the solids, but rather with the oil delivered from the film. The exit hole on the side of the bearing pads, which aims to allow for convection heat transfer in addition to the conduction through a static column of oil, was not justified, as the variation of the readings between individual pads was shown to dramatically increase when the whole side exit hole was open.

The "bleed holes" worked almost perfectly with the side exit hole plugged for a babbitted pad when compared against the 75/75 temperatures; however, the disparity levels were still significant in the case of the PEEK bearing pads with values 40°F (22°C) higher observed in high-load and high-speed cases. Since PEEK bearings are proposed to perform better than babbitted bearings at higher speed and load situations, a reliable film temperature monitoring method is necessary to operate safely at these operating conditions. An intermediate remedy for field applications could be provided by instrumenting all the pads in the bearing, as compared to single pad in a babbitted bearing, and using the maximum temperature recorded as the criteria for bearing health monitoring.

Nevertheless, the hole method was not observed to be a good candidate to use as an alarming mechanism for PEEK bearings as it could not detect the changes in the pad surface temperature. Nowicki and Morozov have reported that proximity probes facing the collar surface could have triggered a shutdown of a large hydroelectric plant 69 seconds earlier if they had been used as the alarm criteria instead of the temperature sensor embedded in the thrust pad coated with a PTFE layer [8]. Similar solutions should be provided for PEEK bearings as well, since the temperature sensors in the pad with or without the 'bleed holes' fail to indicate bearing distress. One technology Kingsbury Inc. is investigating is to measure strain and deformation levels in the bearing pad to identify sudden changes in bearing operation, which is the topic of a future paper.

Finally, the hole method was observed to create local hot spots in the pad body beneath the PEEK layer which can cause uneven thermal growth within the pad. This could present similar instances of bearing instability that were experienced when metal inserts were embedded in the PEEK layer exposed to the film layer to allow the passage of heat to the sensor location. This aspect of the hole method should also spur further investigation of alternative sensors such as ultrasonic methods for remote sensing of temperature or highly sensitive strain gauges as mentioned above.

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