Like for like performance comparison of PEEK and PTFE thrust bearings for use in vertical pump and motor applications
Comparaison à l'identique des performances de paliers de butée en PEEK et PTFE destinés aux applications de pompes et de moteurs verticaux.

Bruce P [a], Butler JB [a] and Dixon SJ [a]

a Michell Bearings Ltd, UK

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Over the past two decades polymer lined hydrodynamic bearings have received much publicity and been shown to offer advantages over whitemetal (Babbitt) lined bearings in a number of circumstances. In particular, both PTFE and PEEK have demonstrated their ability to sustain higher loads than whitemetal, which in turn results in more compact designs and therefore lower associated power losses. More recently PEEK has been publicised as having superior material properties to PTFE with the implication therefore that it must yield superior performance. However there has been very little work undertaken to directly compare the like for like performance of the two materials.

This paper details test work performed with sets of 80mm PEEK and PTFE lined thrust pads, both with identical geometry. Each set was tested at a range of duties typically experienced in vertical pump and motor applications, with sliding speeds between 2.5m/s and 21.2m/s, and specific loads up to 7MPa. The results indicate that within the duty ranges tested PEEK pads can experience operating difficulties, whereas PTFE pads are unaffected and continue to perform as expected.

Au cours des deux dernières décennies, les paliers hydrodynamiques rechargés en polymères ont connu une large publicité et ont démontré qu'ils présentaient des avantages par rapport aux paliers recouverts de métal blanc (régule ou Babbitt) dans un certain nombre de circonstances. En particulier, le PTFE et le PEEK ont démontré leur capacité à supporter des charges plus élevées que le métal blanc, ce qui permet des conceptions plus compactes et donc des puissances absorbées plus faibles. Plus récemment, il a été affirmé que le PEEK possédait des propriétés en tant que matériau supérieures à celles du PTFE, ce qui impliquait donc des performances supérieures. Cependant, très peu de travaux ont été entrepris pour comparer directement les performances des deux matériaux dans des conditions identiques.

Ce document détaille les essais effectués avec des ensembles de butées de 80 mm en PEEK et PTFE, tous deux de géométrie identique. Chaque ensemble a été testé pour différentes conditions généralement rencontrées dans les applications de pompes et de moteurs verticaux, avec des vitesses de glissement comprises entre 2,5 m / s et 21,2 m / s et des pressions spécifiques pouvant atteindre 7MPa. Les résultats indiquent que, dans les limites des plages de charge testées, les patins avec PEEK peuvent rencontrer des difficultés de fonctionnement, alors que les patins avec PTFE ne sont pas affectés et continuent de fonctionner comme prévu.

1 Introduction

Over the past two decades polymer lined hydrodynamic bearings have received much publicity and been shown to offer advantages over whitemetal (Babbitt) lined bearings in a number of circumstances. PTFE (Polytetrafluoroethylene) is now well established in the hydro industry having been developed as a thrust bearing lining material in the 1970's [1] to overcome persistent hydrogenerator thrust bearing failures in the former Soviet Union. By 1990 the vast majority of hydro-electric power stations in Russia had been fitted with PTFE lined thrust bearings [2]. Since then much work has been undertaken [3, 4, 5, 6, 7] to understand the performance of PTFE thrust pads. Today, the current performance and reliability of PTFE technology is such that many large machines have been designed and built with PTFE faced pads as the first choice.

The advantages of using PTFE linings in large thrust pad applications include:

- Higher load carrying capability: Specific loads in excess of 10MPa are cited [6, 7] and certainly Michell Bearings has thrust pads operating in service at 6.3MPa.
- Reduced thermal crowning: PTFE is an insulator, so the thermal gradient through the thickness of the pad is lower, leading to a reduction in distortion and resulting in a flatter operating surface [6, 7].
- Higher starting load capability: Michell Bearings has tested the breakaway capability of PTFE thrust pads under specific loads of 7MPa [8] and supplied bearings for Pelton turbine applications with starting loads of up to 6.2 MPa.
- Durability: PTFE lined thrust pads have proven successful in highly misaligned conditions where whitemetal lined pads have previously failed [5]. In addition, service life of more than 20 years for a single set of pads is reported [8], with the pads undergoing 12-13 start/stops per day.
- Reduced coefficient of friction: PTFE has a much reduced coefficient of friction compared to whitemetal. Tests have shown that PTFE has a breakout coefficient as low as 0.06 compared to 0.18 for whitemetal [8].
- Reduced power loss: Higher load carrying capacity enables a reduction in bearing size to be realised, resulting in power loss savings typically in the order of 20-30% [9]. On several occasions the author's company has been able to reduce thrust surface areas allowing air cooled rather than water cooled bearings to be used.

In contrast, the development of PEEK (Polyetheretherketone) as a tilting pad lining material for hydro applications originated in Japan in the early 2000's, but only a few installations have subsequently been reported [10,11]. Other PEEK applications have included special process fluid lubricated bearings and oil lubricated bearings for high speed turbomachinery using small thrust pads [12]. Like PTFE, PEEK has the same claimed advantages when compared to whitemetal, but the material properties of the two polymers have been shown to differ significantly [13, 14]. Compared to PTFE, PEEK exhibits higher strength, stiffness, dimensional stability with temperature and resistance to creep. The implication therefore is that PEEK with its superior material properties must yield superior performance. However, there has been very little work undertaken to directly compare the like for like performance of the two materials in commercially available bearings routinely installed in typical industrial applications.

PTFE thrust pads have been shown to offer advantages over whitemetal not only for large hydrogenerator sized pads, but also for typical reversing vertical pump applications with small (80 mm) thrust pads [15]. In pump applications it is normal to have a requirement for the bearings to sustain short duration reversals unless an anti-rotational backstop is fitted. Hence, unlike the majority of hydro-generators, the bearing thrust pads must be capable of accepting such rotation reversals and, in many cases it is specified that the bearing must be capable of accepting full load during these periods of reverse operation [16].

Although either offset or centre pivot thrust pads can be used for reverse rotations, the advantage of using offset pivot pads in pump applications has long been recognised by leading pump manufacturers. That is the safety and reliability of the thicker and cooler working oil film generated by an offset pivot is utilised during the longer periods of normal forward rotation, with the much shorter durations of reverse rotation (e.g. pump head run-down) being accommodated with acceptance of a slight performance penalty. Whilst it is well established that whitemetal and PTFE lined thrust pads are able to tolerate rotation reversals with offset positioned pivots [5, 6, 8, 15], this is not the case for PEEK lined pads, with no published work known to the authors.

This paper reports the results of a test programme in which PEEK lined 80mm sized offset pivoted thrust pads were tested in forward and reverse rotations. The thrust pads were tested in a mid-range frame size of vertical bearing commonly used in pump and pump motor applications. The test duties replicated those applied to a set of identically sized PTFE lined thrust pads tested previously [15]. The range of test speeds matched those typically experienced in pump applications, but at specific loads significantly higher than those established for whitemetal thrust pads. The results for the PEEK lined pads are compared to those published for the identical PTFE lined pads [15] to determine whether the 'superior' properties of PEEK would translate into superior performance.

2 Test bearing and equipment

The test bearing and loading arrangement is shown in Figure 1 and is identical to that used in the previous PTFE tests [15]. Oil is supplied to the test bearing from an external source and is drawn through the working elements via the pumping action of the rotating thrust collar, which is attached to the shaft. The oil then flows to drain over a weir, which ensures that the test pads are fully submerged with oil. The loading module uses hydraulic pistons to force the shaft downwards against the test thrust pads, which are situated beneath the thrust collar. Forward rotation is defined as clockwise rotation when viewing the shaft and test bearing from above.

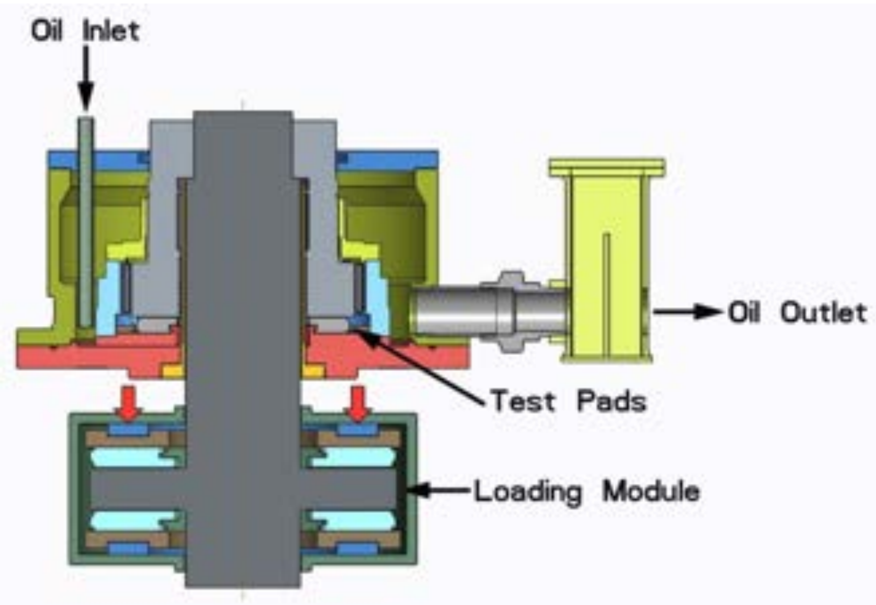

Figure 1 – Test bearing and loading arrangement

The grade of PEEK used was reinforced with 30% carbon fibre, graphite and PTFE. Four of the eight thrust pads contained miniature thermocouples to measure pad temperatures in the same manner used for the PTFE tests. The thermocouples were embedded into the steel backing in both the leading and trailing outer quadrants of the thrust pads. Small holes were drilled through the PEEK surface to meet up with the tips of the thermocouples, hence ensuring that the thermocouples were measuring the oil temperature in the oil film itself. The position of the thermocouple for forward rotation is shown in Figure 2 and the dimensions of the test pads are shown in Table 1. In addition to fitting thermocouples into the thrust pads, probes were also appropriately positioned to measure oil inlet, oil outlet and oil bath temperatures.

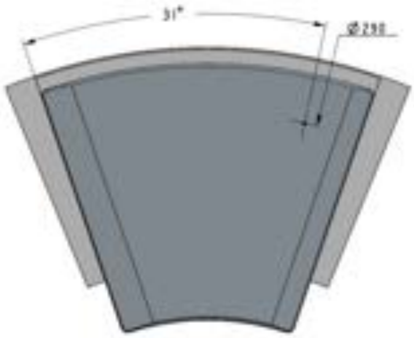

Figure 2 – Test thrust pad showing thermocouple position

Number of thrust pads	8
Outside diameter (mm)	321
Inside diameter (mm)	161
Mean pressure diameter (mm)	254
Thrust pad radial width (mm)	80
Pad angle (degrees)	38
Pivot position (% of pad angle)	60%

Table 1 – Test pad dimensions

3 Test programme

The objective of the test programme was to subject the PEEK thrust pads to identical test duties previously applied to the equivalent sized PTFE pads [15]. Hence, specific loads of 2 to 7MPa would be applied, in both forward and reverse rotation directions, over a speed range of 190 to 1600 rev/min (2.5 to 21.2m/s sliding speeds measured at the mean pressure diameter of the pad). Like the PTFE pads, the PEEK pads were to experience the maximum loading at both the maximum and minimum speed in both directions of rotation. Several cycles of testing were planned with the direction of rotation being reversed between each cycle. The minimum duration of testing at any single duty point was to be 1 hour and the maximum 8 hours. This duration would depended upon the severity of the particular duty in question. The most arduous duties, namely the highest loads at either highest or lowest speeds would be tested for the longest periods whilst less time was to be spent on more moderate cases. Temperature readings were taken once temperature equilibrium conditions were established. Throughout the test, the bearing was fed with ISO VG 32 turbine grade mineral oil at a constant flow of 25 litres/min. The oil inlet temperature was 42°C (±1°C).

4 Test results

The PEEK lined thrust pads successfully completed the test programme in the forward direction of rotation. Figure 3 shows the maximum measured thrust pad temperatures in forward rotation. The maximum temperature reached was 108°C, the same as that reported for PTFE under the same duty condition [15].

A comparison between the PEEK and previously reported PTFE pad maximum operating temperatures in the forward direction [15] is shown in Figure 4, with the results for the 4 and 6MPa duties having been removed for clarity. It can be seen that over the majority of the working speed range and for all levels of load the temperatures of the PEEK pads are slightly hotter than the PTFE pads by up to 5°C.

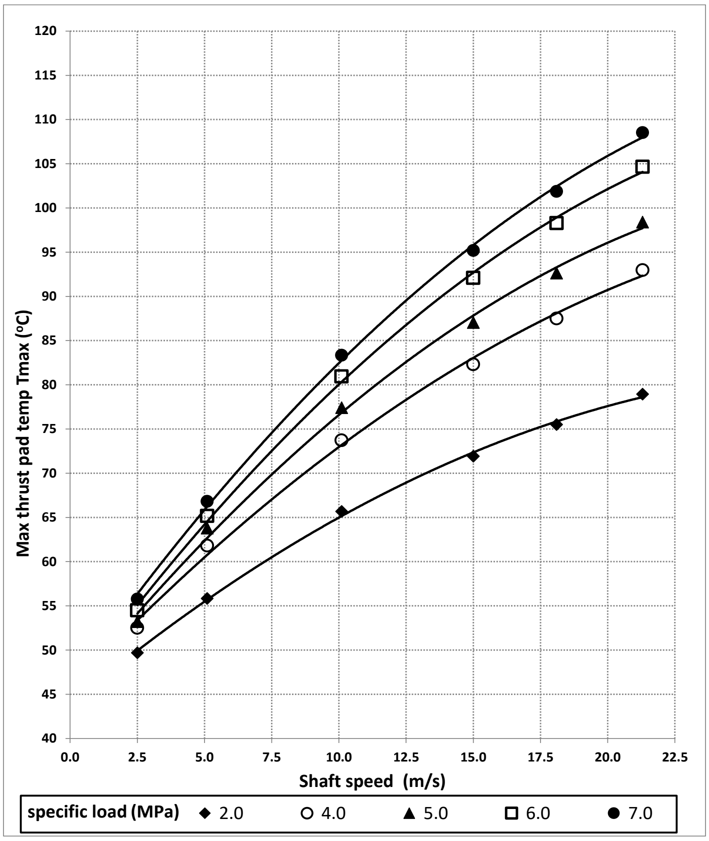

Figure 3 – Max PEEK pad temperature for forward rotation

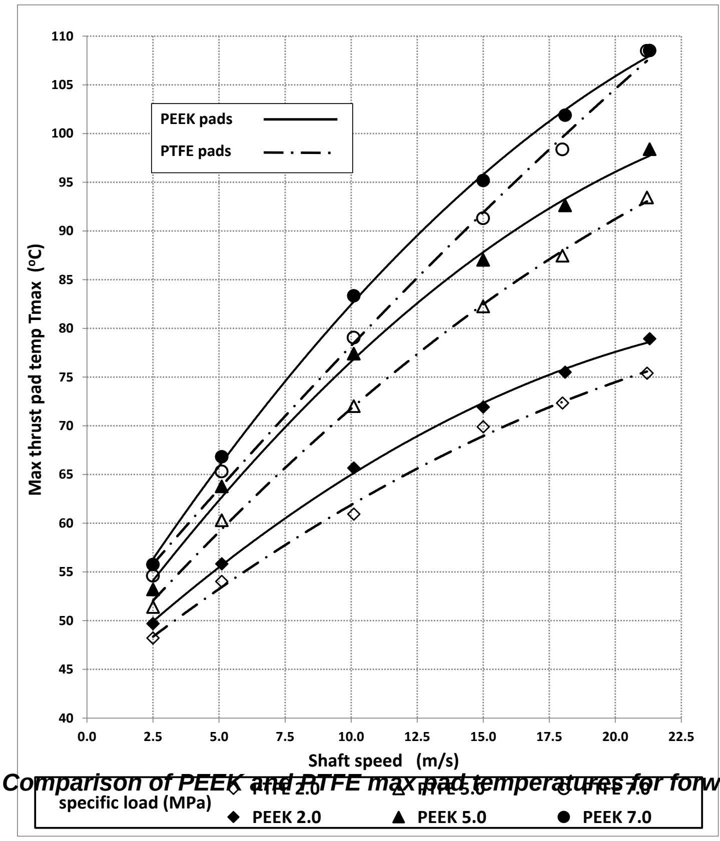

Figure 4 – Comparison of PEEK and PTFE max pad temperatures for forward rotation

During the reverse rotation tests however, significant performance limitations were encountered with the PEEK pads. When running in reverse temperature spikes were experienced on three separate occasions, which lead to a significant curtailment of the test programme. Figure 5 shows the extent of reverse rotation tests completed. Figure 6 compares the PEEK pads reverse rotation results to those of the PTFE pads [15]. Once again, as noted during forward rotation tests, the PEEK pads ran slightly hotter compared to the PTFE pads for the limited number of reverse duties completed at 2 and 3MPa.

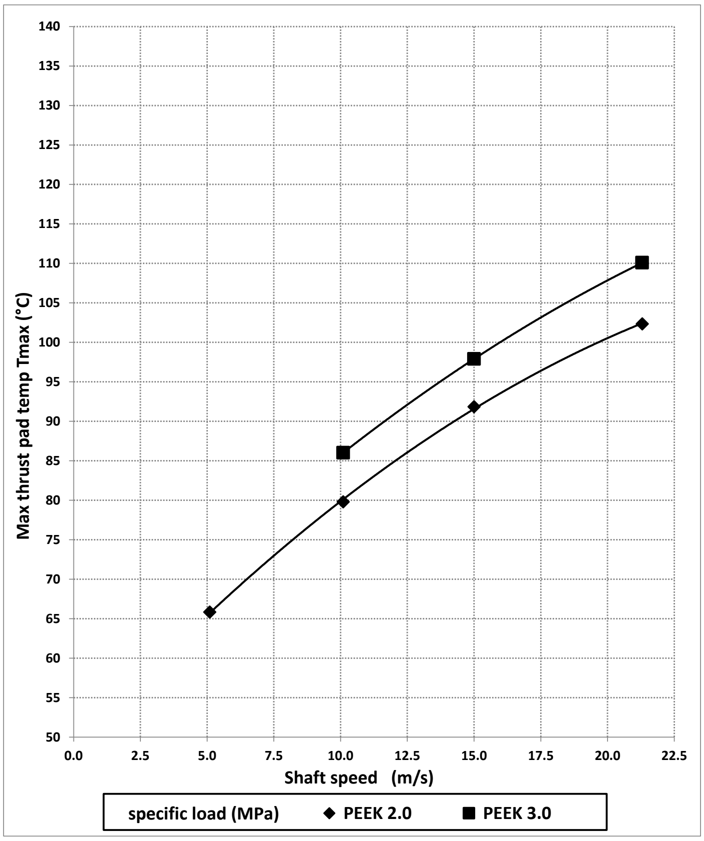

Figure 5 – Max PEEK pad temperature for reverse rotation

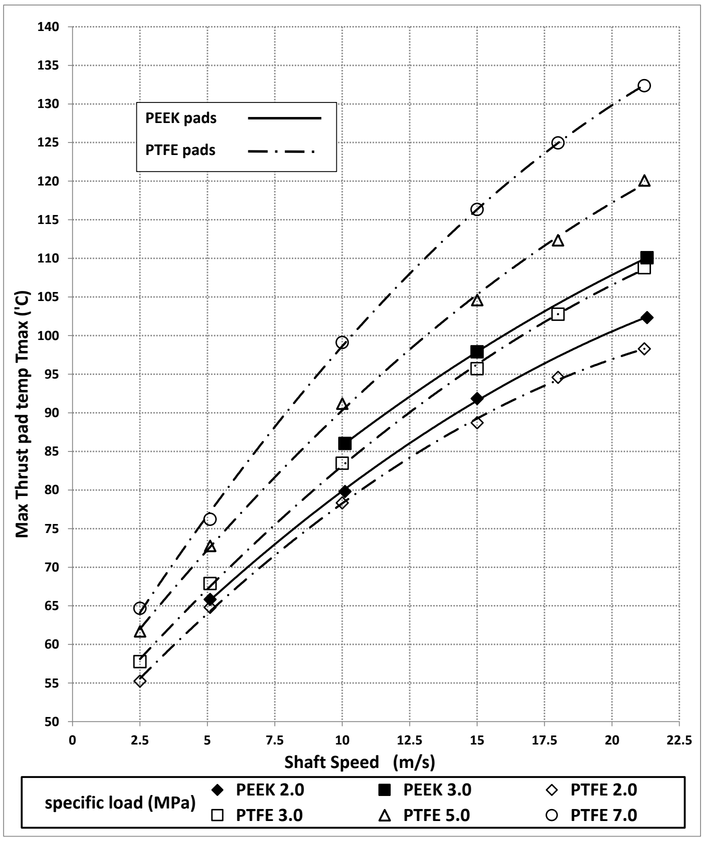

Figure 6 – Comparison of PEEK and PTFE max pad temperatures for reverse rotation

The first temperature spike occurred at a specific load of 2MPa and 190 rev/min (2.5m/s). This unexpected excursion came after a successful period of reverse operation between speeds of 380-1600 rev/min (5.0–21.2m/s) and 2MPa specific load. Figures 7 and 8 show the pre-test and post-temperature spike condition of one of the PEEK pads, which is representative of the whole set. After the temperature spike all of the pads were found to exhibit a highly polished central area of approximately 45 to 50mm in radial width between the leading and trailing edge chamfers. As forward rotation is defined as clockwise, this is therefore left to right when viewing Figures 7 and 8. Thus in reverse rotation the right hand side of the thrust pad becomes the leading edge of the pad. Clearly contact has occurred between the pad surface and the runner face and the oil film has been lost over the full circumferential length of the pad resulting in a bearing failure.

Figure 7 – Pre-test PEEK pad

The second and third temperature spikes occurred at 4MPa and 760rev/min (10m/s) and, at 3MPa and 380 rev/min (5m/s) respectively. Figures 9 and 10 show the condition of the one of the pads following each of these temperature spikes. In both cases it can be seen that the polished areas are highly reflective and more extensive than that observed after the first temperature excursion (Figure 8). All eight pads in each of the sets were affected to the same extent as the pads shown in Figures 9 and 10.

Figure 9 – PEEK pad after second temperature spike

Figure 10 – PEEK pad after third temperature spike

It is worth noting that after the first temperature excursion no reconditioning of the pad working surfaces was undertaken. A full cycle of forward rotation tests at 2-7MPa and a set of reverse rotation tests at 2MPa were both successfully completed at speeds between 380-1600 rev/min (5.0–21.2m/s) after the first failure. Operating temperatures were within 2-4°C of those recorded in the earlier tests before the damage occurred and the appearance of the polished areas remained unchanged. Hence it would appear that the polishing associated with the first temperature spike did not significantly affect the continued operation of the pads. After the second temperature spike the thrust pads were reground to return the working surfaces to the as new condition, so Figure 10 shows the damage sustained by the renewed surface.

5 Discussion

Whitemetal thrust pads typically operate at 4.2MPa under normal conditions and 5.5MPa for transient conditions, such as closed valve operation. In this test programme, the objective was to run the PEEK pads continuously in both forward and reverse rotations at loads 67% higher than generally accepted maximums for whitemetal across a speed range that would result in unacceptably low oil film thicknesses for whitemetal lined pads. Whilst the performance of the PEEK pads was similar to that of the directly equivalent sized PTFE pads in the forward rotation tests, they were unable to match them in reverse.

The oil film thickness calculated using conventional techniques for an 80mm offset pivot pad running at 7MPa and 2.5m/s is 5 microns or less depending upon the direction of rotation. Such film thicknesses take operation into the mixed friction lubrication regime. In comparison, for the reverse duties where the PEEK pads experienced temperature spikes (i.e. 2MPa at 2.5m/s, 3MPa at 5m/s and 4MPa at 10m/s) the predicted oil film thicknesses are between 9-10 microns. Such values coincide with the generally accepted 10 micron safe minimum working film thickness limit for an 80mm pad [17].

Given the unexpected outcome of the tests the question arises as to why the PEEK pads could only operate under films in the mixed friction lubrication regime during forward rotation, whereas PTFE successfully operated in both directions of rotation. Ettles at al [6] suggest that through local surface elasticity effects the overall pressure field in an offset or centre pivoted PTFE lined pad can adjust to give a centre of pressure forward of centre. Similarly, Glavatskih et al [18] describe how the actual film shape can adjust in a manner that allows the bearing to carry loads. Such adjustments are credited to local deformations of the PTFE layer, which can be much greater than the general level of film thickness and are due to the high elasticity or compliant nature of the PTFE.

Compression tests [13] have shown that PTFE deflects an order of magnitude more than PEEK under the same load and its initial shape can change due to creep to follow a counter surface shape. The effect on the magnitude of the deflection with increasing temperature was also found to be much more significant in PTFE. It would appear that although such material properties could initially be interpreted as inferior they might actually be beneficial under certain operating conditions.

6 Conclusions

Offset pivoted 80mm size PEEK lined thrust pads were able to successfully support, in the forward direction only, specific loads to 7MPa across a speed range typical of vertical pump. In the reverse rotation direction significant performance issues were encountered when operating in line with the 10 micron safe minimum working film thickness for an 80mm pad.

In contrast, identically sized PTFE thrust pads have previously been shown to operate without any signs of distress and with the working surfaces remaining in excellent condition when subjected to the same duty conditions and cycles of rotation reversals.

For duties typically experienced in vertical pump and pump motor applications, the higher strength and stiffness of PEEK did not produce superior performance when compared to PTFE lined pads. Successful reverse rotation operation of PTFE lined pads across the test programme duties is attributed to the compliant nature of the PTFE lining.

7 References

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