PTFE FACED BEARINGS

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ABSTRACT

PTFE has become an established alternative bearing material in hydrogenerator usage and has seen further development for both military and commercial applications. The paper will detail the testing and methodology carried out to determine that PTFE bearings are suitable for fitting within a Royal Naval platform. It will describe the type of bearing and its advantages over conventional materials. The MoD funded research work, carried out on full scale test rigs and under theoretical laboratory conditions, that was undertaken prior to fitting the bearings to an operational vessel will be also be drawn upon. Finally the proposed trial method for quantifying the improvement in performance of the bearings in situ during post docking trials will be examined.

Introduction

Since first patented by Isaac Babbit in 1839 the metal alloy babbit metal, or more commonly white metal, has been extensively used in a wide variety of hydrodynamic applications. The merits of white metal are well documented[2]; it provides a stable surface that is capable of absorbing debris and loose particles and can be easily installed, repaired or removed. Against this are a relatively low melting point, which limits the maximum temperature and consequentially maximum load which bearings can withstand. Furthermore failures, when they do occur, tend to be catastrophic with the majority of the bearing material removed, or wiped, in a short space of time. Other bearing materials have been developed, including copper-lead alloys, however if correctly installed and monitored then white metal is a very effective bearing material and as a result remains not only the most common choice for industrial applications but also the baseline against which all other materials are compared.

One such new material is polytetraflouroethylene, or PTFE, discovered by Dr Roy Plunkett, a worker at Du Pont research laboratories, in the USA. Despite being in existence as an engineering material for almost 70 years PTFE had not been considered as a bearing surface material until comparatively recently. For the most part it has seen use in hydrogeneration applications however is now expanding into other applications and areas, including the marine industry.

PTFE Bearing Construction

The construction of the PTFE thrust bearing consists of a relatively thick PTFE layer bonded to the body of the steel pad by means of a PTFE/wire mesh intermediary. A sample cross section through a Pad can be seen in (FIG.1). The purpose of the wire mesh, aside from attaching the PTFE to the pad body, is to provide a compliant layer. Without this compliant layer the difference in expansion rates between the PTFE, whose coefficient of linear expansion is an order of magnitude higher, and the steel would cause the bearing to fail under the cyclic temperature and sliding speeds experience in a typical thrust block. By comparison a white metal bearing consists of a thin layer of the tin-based alloy metallurgically bonded to the steel pad, sometimes with the aid of dovetail retention grooves.

Beyond the materials themselves the two types of pads are of generally similar design. Both are normally sectored shaped, pivoted to produce a hydrodynamic wedge rotating and frequently the leading edges are tapered to help initiate the hydrodynamic layer under start-up conditions. The pad surfaces are either flat or very slightly crowned.

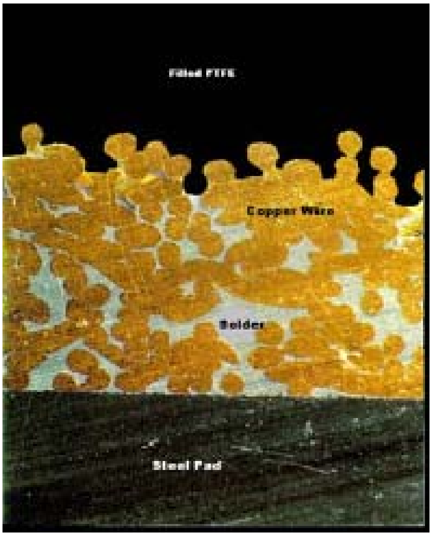

FIG.1 - CROSS-SECTION OF PTFE BEARING[1]

PTFE Advantages

The key advantage of PTFE lies in the friction and thermal properties. PTFE has a higher melting point and can thus operate at higher temperatures and therefore higher pressures. As the materials can withstand higher pressures the thrust surface can be reduced, which can reduce power losses within the thrust block by around 20-30%, or a greater margin of safety can be achieved with existing designs with the intention of increasing reliability. The smaller thrust area allows the overall size and weight of the thrust block to be reduced as the forgings, lubrication systems, bearing housings and coolers can all be reduced in size. This can be viewed in (FIG.2) where conventional white metal and PTFE thrust bearing sections are shown. In the example shown the conventional thrust block has been designed for a 3.5 MPa acceptable pressure whereas the PTFE block, despite offering a weight reduction of nearly 30%, has been designed for an acceptable pressure of 6.5Mpa.

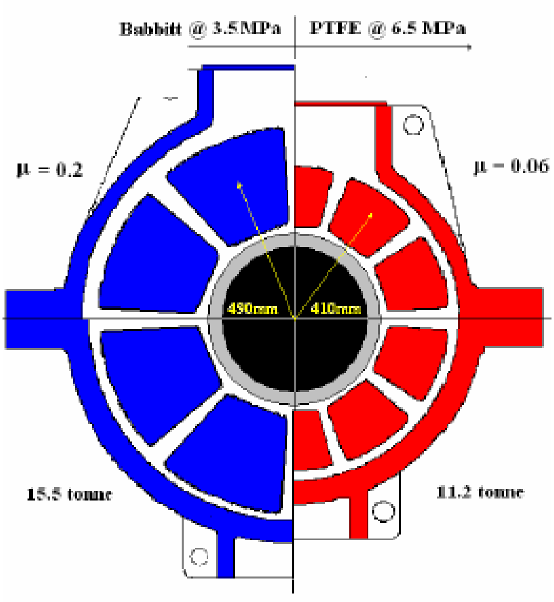

FIG.2 - COMPARISON OF THRUST BLOCK SIZE[1]

PTFE also benefits from a lower coefficient of friction than white metal. Under hydrodynamic operation the friction in a bearing is determined from the level of oil shear and hence is not dependent upon the material properties of the bearing. At start up and when stopping however the oil film has not fully formed and the bearing is operating in the regime of boundary lubrication. As such the coefficient of friction is the key factor in determining the levels of friction present at start up. In some application the reduced coefficient of friction could allow for the removal of the requirement for jacking oil.

Finally, the material properties of PTFE are such that it does not fail in the catastrophic "wipe" fashion associated with white metal and will continue working at temperatures far in excess of those likely to be experienced within a thrust bearing. As an insulator it also enables the thrust block, if fitted with PTFE journals, to be electrically isolated from the shaft.

Submarine Applications

The reduction in size of the thrust block and the reduced coefficient of friction offer considerable advantages. Any reduction in the size of key components on a vessel as space sensitive as a submarine is beneficial, allowing greater space in the immediate vicinity to carry out maintenance. Whilst a 30% saving in thrust block weight and volume is unlikely to affect the layout of a submarine the reduction in length can have implications on bulkhead positioning or the location of other shaftline components. This is not just applicable to submarines but to any vessel, sub-surface or otherwise, where the length of the shaft-line is constrained.

An advantage within submarine applications is the inherent capacity for increased loading. The safety margins in place on the current design of thrust blocks are considerable and typical submarine pressures are an order of magnitude lower than those experienced in the hydrogeneration applications for which the PTFE were originally envisaged. The insulating properties are of interest future generation submarine which for which full electric propulsion is an option but of little benefit to current in-service submarines.

The advantage I would like to examine in more detail here is the reduced coefficient of friction, leading to a reduction in the torque required to start a stationary shaft. This is called break out torque and has major safety implications for a submarine.

Breakout torque

In the normal course of operation a submarine shaft will rarely come to a complete halt, unless changing direction of shaft rotation, as the buoyancy of the submarine is closely linked to her speed through the water as this determines the amount of lift produced by the planes. The most likely cause of a shaft coming to rest is therefore a machinery failure leading to a momentary loss of propulsion. Depending on the nature of the failure the main propulsion system or a secondary back-up mode will be used to restore propulsion. Whichever is available the possibility exists of the shaft needing to be broken away from a stationary position and hence the break-out torque, determined by the coefficient of friction, will need to be overcome.

The situation is compounded by two factors. Firstly, secondary propulsion modes are, by their nature, lower power and probably lower torque than the main drives so in the event of a major failure in which the main propulsion mode is unavailable a lower power, lower torque system will be required to start the shaft rotation. Secondly the relationship between break-out torque and depth means a submarine is least well equipped to cope with a stationary shaft in the region where its impact will be the greatest.

The value of break out torque is largely determined by two factors, the resistance provided by the shaft line components at the surface, which is a constant, and the pressure, and hence friction, on the thrust pad faces which increases with depth. The level of torque required increases linearly with depth and at deep depths the component of break out torque from the thrust pad friction is responsible for the majority of the torque required. Should the submarine be unable to overcome this torque, it could conceivably be left in a situation where it is unable to restart its shaft and has insufficient buoyancy to return to the surface. Unfortunately for a vessel in this position the situation will only deteriorate because as the submarine begins to sink, the hull will contract, increasing the density of the vessel and thereby increasing the rate of descent.

This problem can be overcome with the provision of a system to provide high pressure oil to the thrust pad faces to move the pad away from the thrust block housing and reducing the torque required at start up. Jacking oil, as this system is commonly known, has been fitted to a wide variety of industrial applications, mainly heavy vertical bearings, with much success. In the submarine environment this represents another fluid system, and therefore another possible point of failure, in a location which is already spatially constrained. Replacement PTFE thrust pads however could be fitted as part of the current maintenance cycles when the old pads are removed for inspection. Hence a reduced coefficient of friction thrust bearing seems to offer a simple yet effective solution to the issue of breakout torque which can be fitted to both in service and future submarines.

Rig testing

So far all the testing has been carried out on a specifically designed rig, based on a current S Class thrust block, held by the Equipment Manufacturer, Michell Bearings, in Newcastle. Two sets of thrust pads are contained within the block, one on each side of a central thrust collar. The thrust pads are housed in steel retaining rings and a series of interconnected hydraulic cylinders at the rear face of one of these rings allows a load to be applied to the thrust pads. The applied load on this side is transmitted via the thrust collar to the opposing thrust pad assembly on the other side. In this configuration both sets of pads can be loaded simultaneously with no resultant thrust force being transmitted to the test rig foundation. In effect, the collar is loaded from both sides in much the same way as the disk in a disk brake.

FIG.3 - PTFE THRUST PAD USED IN RIG[1]

During initial suitability tests the original white metal thrust pad design was used however the bearing face was reduced in size so that the surface pressure was closer to that which would be seen on a thrust block designed specifically use with PTFE. In this arrangement the pad pressure during testing was in excess of twice that which would be produced if the bearing face had been retained at the original size, as it will be in proposed future in-service trials. (FIG.3) shows one of the thrust pads tested.

The testing covered a range of speeds and loads up to 200 rev/min and 9.6 MPa which demonstrated the pads had extremely good wear and endurance characteristics[3,4]. The hydraulic cylinders within the thrust block were used to provide comparative breakaway torque data by applying load to both sides of the collar. With the drive system disconnected a lever arm was mounted on the thrust shaft coupling flange. A portable hydraulic cylinder and hand pump were used to exert the force at the end of the lever arm required for breakaway. This process was then carried out for a series of increasing applied thrust loads using both white metal and PTFE pads. The results are shown at (FIG.4) which shows the coefficient of friction at break away plotted as a function of mean pad pressure.

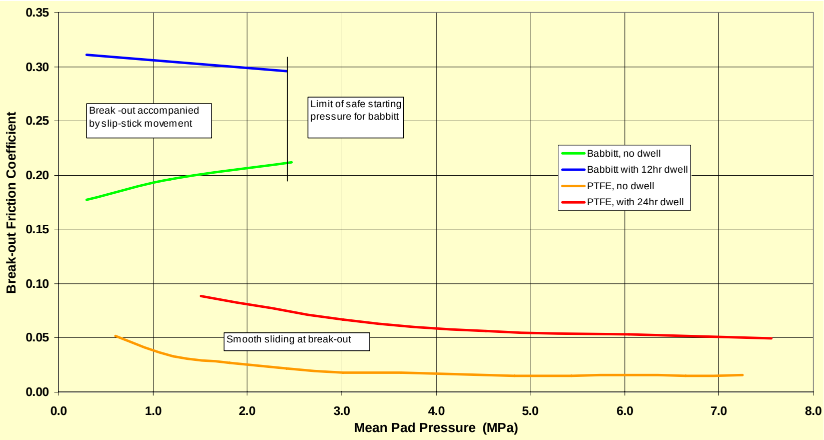

FIG.4 - Break Away Friction For White Metal And PTFE Bearings[1]

Two sets of data were collected for both PTFE and white metal pads. The first readings of break away torque were taken immediately after the application of thrust load whilst there was still a residual oil film between the pads and collar. The other readings were taken after a dwell time of several hours from the application of load. In the case of the white metal pad the maximum pressure was 2.4 MPa (348 lbf/in2). This is the conventional limit for design pressure of white metal pads starting and stopping under load without the assistance of high pressure oil injection. As (FIG.4) shows, the results for white metal gave an initial break away coefficient in the region of 0.2. After a dwell time of 12 hours this value rose to 0.3. These values are typical of what has been experienced in the past across a wide range of marine and industrial plants. By comparison, the coefficients for PTFE are significantly lower. Across the pressure range likely to be used for bearing design the coefficient is typically 0.02 ~ 0.03. After an increased dwell time of 24 hours this value rose to about 0.06. It was noted that in addition to the difference in coefficients of friction, the nature of break away was markedly different too In the case of white metal, break away was accompanied by very pronounced slip-stick motion. In contrast break away with PTFE was extremely smooth with no evidence of slip-stick.

Following initial testing, full face PTFE pads were produced. An image showing the full set of pads produced can be seen in (FIG.5).

FIG.5 - FULL FACE PTFE THRUST PAD[1]

The full face pads were then subjected to a similar testing regime to that previously described including break-out trials and endurance and high loading runs. The tests have included, up to the end of March 2007, 300 hours run at maximum submarine deep dive speed and at a pressure of 9.6 MPa. As the pressure is now applied over the full face of the pads the value of axial force required is significantly higher than that which would be experience at deep dive depth. On removal the pads were found to be in an extremely good condition, with almost no signs of wear visible. In addition to these results the maximum temperature during operation was also recorded, a typical graph of which against shaft speed can be seen in (FIG.6). The inlet temperature for all these readings was 45 degrees centigrade and each point on the graph represents a different load condition, equating to the maximum value expected at the given speed. From the graph it can be seen we have a slow increase in temperature with increased load and speed and no anomalies or changes of gradient. All of which indicate the pad is performing as designed and within limits, results that are born out by the lack of wear seen on the removed pads. These results also tie in with the temperature trends recorded previously on the reduced face pads.

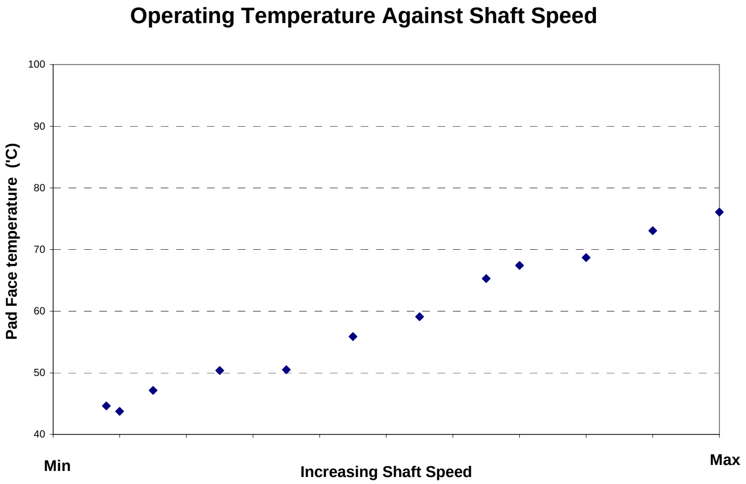

FIG.6 - PAD TEMPERATURE AGAINST SPEED[1]

During this stage of the testing an ultrasonic testing Quality Assurance technique was simultaneously developed for examining new pads. Specifically this technique was used to monitor the size of de-lamination "voids" between the steel pad and copper/wire solder layer that can develop during manufacture. This technique enabled the presence of these voids, even within the centre of the pad, to be identified and the pad rejected prior to installation. Pads with void areas have been run under full load conditions successfully, with no void growth, and there is no reason so suggest the compressive loading in a thrust block would initiate pad failure from void growth. The voids however represented a potential weak point and it was thus felt appropriate to address them during manufacture.

Future Testing

The proposed next stage is to complete a comprehensive safety case review, with a view to fit and trial the pads on an HM Ship, paving the way for potential trials onboard an HM Submarine. If fitted the trial will prove that the PTFE bearings are a suitable replacement for the white metal variant currently fitted and will be composed of fitting the item and then monitoring performance. By its nature thrust bearing performance is difficult to monitor, short of catastrophic failure, so once fitted this part of the trial will be confined to inspecting and recording the state of the bearings in accordance with the current maintenance cycle.

Summary

Laboratory testing and data from operational experience in hydrogenerator power stations has shown that PTFE bearings offer a number of advantages over conventional white metal bearings. In particular the reduced size of the bearings and lower coefficient of friction offer benefits particularly pertinent to the submarine fleet. The reduced size of the PTFE thrust bearing enables a 30% saving in weight and volume to be achieved over the thrust block unit, a considerable benefit for an operating environment where space and weight is at a premium. The lower coefficient of friction of PTFE enables the main shaft to be broken away at depth using lower torque, thus providing increased safety of operation in a maritime service where safety, and any improvement thereof, is of the utmost importance. These advantages have been corroborated by test work carried out on a full scale submarine thrust block rig and it is intended will ultimately be confirmed by data from an in-service platform.

Acknowledgements

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