PTFE Faced Bearings for Marine Propulsion Applications

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ABSTRACT

PTFE faced bearing technology, already established for hydrogenerator use, has been further developed for civil and military marine applications. The paper describes this type of bearing and the advantages compared with conventional babbitt. Details of testing and a description of a PTFE faced thrust bearing supplied for the Japanese Techno Super Liner project are also presented.

KEY WORDS: PTFE; Bearing; Hydrodynamic; Thrust; Marine; Journal.

INTRODUCTION

In 1839 an American, Isaac Babbitt invented a bearing alloy that was to later bear his name – babbitt metal. More generally known in other parts of the world as whitemetal, the material is an alloy of tin (sometimes lead), copper, and antimony. Tin based whitemetals have been the predominant material for a wide variety of hydrodynamic bearings for many years. Their use for thrust surfaces, such as in the multi-collar thrust blocks of the early steam ships, pre-dates the invention of the tilting pad bearing at the start of the last century. The strengths and weaknesses of the material are well known (Barry and Thwaites, 1983). In particular, babbitt provides a dimensionally stable surface that is easily repaired or replaced. The material is able to absorb hard particles of detritus into its surface without causing further damage. On the other hand babbitt has a relatively low melting point and this leads to an upper limit on the temperatures possible during hydrodynamic bearing operation. If this temperature is exceeded, catastrophic failure of the bearing is likely to ensue within a very short period of time. The effect of the babbitt temperature limit is to restrict the maximum duty (expressed as a combination of speed and load) permissible in any particular bearing. As a further consideration, it can be noted that the main constituent of whitemetal, namely tin, is an expensive commodity which has often been in limited availability in many parts of the world.

With the development of the tilting pad and taper-land hydrodynamic thrust bearings at the beginning of the twentieth century it was natural for engineers to continue to work with the material they knew. Although other materials have been developed for hydrodynamic bearing surfaces, including for example, copper-lead alloys, babbitt has remained the world's preferred choice for most industrial applications.

Almost one hundred years after the invention of babbitt another significant bearing material emerged when, in 1938, Dr Roy Plunkett, a worker at the DuPont research laboratories (Jackson Laboratory in New Jersey), was working with gases related to Freon refrigerants. When checking a frozen, compressed sample of tetrafluoroethylene, Plunkett and his associates discovered that the sample had polymerized spontaneously into a white, waxy solid to form polytetrafluoroethylene or PTFE. The material is still often referred to throughout the world by its DuPont tradename, Teflon.

PTFE AND HYDRODYNAMIC BEARINGS

PTFE has been available as an engineering material for some time in a variety of forms, and is well associated with bearing technology. Its use, however, as a surface material for hydrodynamic bearings is relatively recent. Originating in Russia and China for use in hydrogenerator power plant, its use is attracting much attention in other parts of the world.

The construction of a PTFE faced bearing is similar in many respects to that of a conventional bearing. Fig. 1 shows a cross section through part a typical thrust pad. The pad is generally sector shaped as in the example shown in Fig. 3, relies on some form of pivoting mechanism at its rear surface to produce a convergent lubricating film, has sufficient thickness to support the resultant hydrodynamic loading, and uses oil as the working medium.

It is the pad surface that differentiates the PTFE faced bearing from the more familiar babbitted version. In the latter a relatively thin layer of the tin-based alloy is bonded metallurgically to the steel substrate of the pad, often, in the case of older designs, with the addition of dovetail retention grooves. The alloy surface is then machined to a flat or very slightly crowned profile. Leading edge chamfers or radii are added to help induce the hydrodynamic action at start up. In some cases a system to allow high pressure oil injection between the working surfaces is added to assist start up under heavy loading. This applies typically at specific loads greater than 2.4 MPa (348 lbf/in^2).

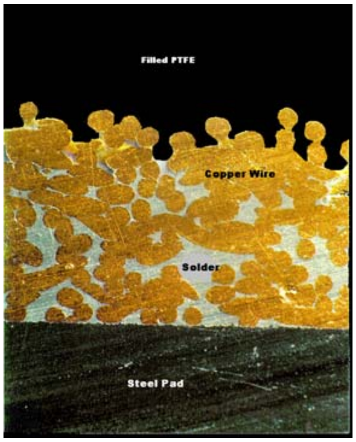

Fig.1 Cross-section through the surface of a PTFE faced pad

The PTFE faced pad, in contrast, has a relatively thick layer of a PTFE/wire mesh composite attached to the steel body of the pad instead of the babbitt. The method of bonding the PTFE to the steel body using wire mesh as an intermediate material is key to the successful operation of the pad. The wire provides not only the means of attachment, but also serves as a compliant layer which allows expansion and contraction of the PTFE in operation. Note that the coefficient of linear expansion of PTFE is an order of magnitude greater than that of the supporting steel. Attachment of PTFE by adhesives, as is often done in some simple slide bearings used on bridge supports for example, would rapidly fail at the joint due to the differential expansion rates encountered at the sliding speeds and temperatures typical of hydrodynamic bearings.
What makes this type of bearing so attractive, however, are the significantly higher specific loadings that are possible (Simmons, Knox and Moss, 1998). The reasons lie in the thermal and frictional properties of PTFE which lead to a number of important benefits. Because PTFE has a higher melting point than conventional babbitt, hydrodynamic bearings may comfortably be operated at higher temperatures and hence at higher pressures. These higher pressures imply in turn reduced power losses of about 20~30% due to the smaller thrust surface that is required. The reduced overall size and weight also results in reduced costs of the capital plant because of smaller shaft forgings, smaller bearing housings, smaller lubrication systems, and a smaller cooler. The exceptionally low coefficient of static friction for PTFE means there is no need for high pressure oil injection between surfaces to overcome the frictional effect of high loads at start up. The bearing has a higher margin of safety against abnormal overloads which leads to increased machine reliability and availability. The material is more tolerant than babbitt, making it ideally suitable for difficult or arduous applications (Knox and Simmons, 2002). Finally when combined with a PTFE faced journal bearing, the complete bearing is electrically insulated.

MARINE APPLICATIONS

Much development has taken place to support the introduction of PTFE faced thrust bearings, principally for application in land-based hydrogeneration systems (Simmons, Knox and Moss, 1998). More recently, testing has been carried out on a specially designed rig which has the capability to explore the full potential of these bearings to operate in a marine environment.
The test rig, shown in Fig. 2, is based on an existing submarine thrust block. Two sets of thrust pads are contained within the block, one on each side of a central thrust collar. The sets of thrust pads are supported in steel retaining rings and in the rear face of one of these rings a series of interconnected hydraulic cylinders allows a load to be applied to the thrust pads. The applied load on one side is transmitted via the thrust collar to the opposing thrust pad assembly on the other side. With 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. 2 Submarine thrust block test rig

In the design of the rig, the original thrust pads were used. However, the PTFE surface area was reduced to approximately half that of the original babbitt thus increasing the specific load up to a maximum of 9.6 MPa (1392 lbf/in^2). This is shown in Fig. 3.

Fig.3 The PTFE faced thrust pad used in test rig

Support for the thrust shaft is provided by babbitted shells at each end of the thrust block. The drive consists of a D.C. electric motor connected through a gearbox and thermometry in both sets of thrust pads provides the principal instrumentation.
To date, testing has covered an envelope of speeds and loads of up to 200 rev/min and 9.6 MPa (1392 lbf/in^2) respectively. At present, endurance testing at maximum load and speed is underway. Fig. 4 shows one of the test pads after about two months of operation. The condition of the pad surface is exceptionally good.

Fig. 4 A PTFE thrust pad after two months testing at 9.6MPa (1392 lbf/in^2)

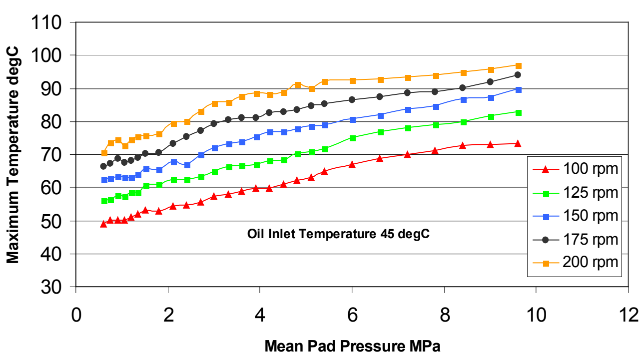

Fig. 5 Maximum thrust pad temperature v shaft speed

Fig. 5 shows a typical set of test results. Steady state temperature readings from the hottest part of a thrust pad are plotted against increasing mean thrust pad pressure for a range of shaft speeds between 100 and 200 rev/min.
By taking advantage of the higher bearing pressures that are allowable using PTFE it is possible to make substantial reductions in the size of bearings. As an example, Fig. 6 shows a comparison, in cross section, between a thrust block designed using 3.5 MPa (508 lbf/in^2), the pressure acceptable for a conventional babbitted design, and 6.5 MPa (943 lbf/in^2) for a PTFE design. The difference in size is immediately obvious. For a given shaft diameter, the higher mean bearing pressure with PTFE allows much smaller thrust pads which, in turn, means that the surrounding casing is smaller too. The smaller overall assembly gives rise to significant weight reductions. In this example, the babbitted design, based on an actual bearing, weighed 15.5 tonne (34171 lbf). The equivalent PTFE design resulted in total weight of 11.2 tonne (24690 lbf), a weight saving of nearly 30%. In addition to the weight saving of the thrust block, a valuable reduction in thrust shaft weight is also realised due to the reduction in collar diameter.

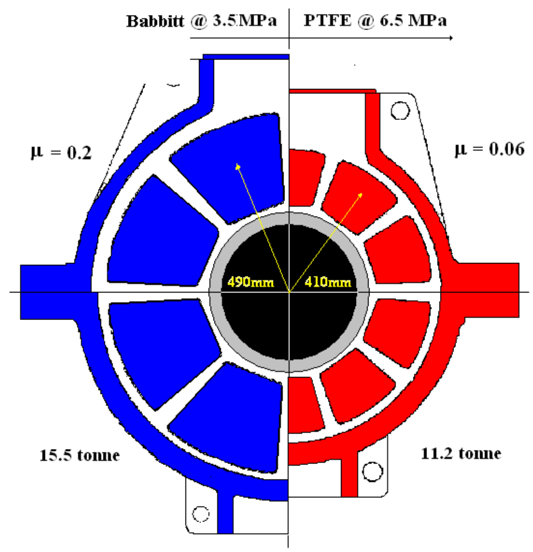

Fig. 6 Comparison between designs of thrust blocks with babbitted and PTFE faced thrust pads

Under hydrodynamic operation the friction in a bearing is a result of oil shear rate and is therefore not dependent upon the materials of the bearing. However at start up and stopping when the bearing is operating in the regime of boundary lubrication the friction coefficient between the materials are all important.
One of the well documented features of PTFE is that it has one of the lowest coefficients of friction of any known solid. This feature can be used to full effect when designing bearings that have to start under load. To examine what benefits might be gained the submarine test rig was set up to do a series of friction trials in which breakaway torque for babbitt-faced and PTFE faced bearings would be compared.
Use was made of the hydraulic cylinders feature within the thrust block to load the collar on both sides. 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 to induce break away. This experiment was carried out for a series of increasing applied thrust loads and both babbitt and PTFE pads. The results are shown in Fig. 7. The graph shows coefficient of friction at break away plotted as a function of mean pad pressure.

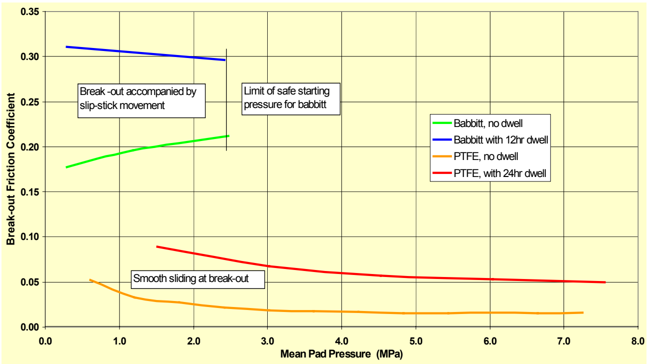

Fig.7 Break away friction for PTFE and babbitt-faced thrust pads

Two sets of data were collected for both PTFE and babbitted 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 after the application of load. In the case of the babbitted pad the maximum pressure was 2.4 MPa (348 lbf/in^2). This is the conventional limiting design pressure for babbitted pads starting and stopping under load without the assistance of high pressure oil injection**.** As Fig. 7 shows, the results for babbitt 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 plant.

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 interesting to note that in addition a major difference in coefficients of friction, the nature of break away was markedly different too. In the case of babbitt, break away was accompanied by very pronounced slip-stick motion. In contrast break away with PTFE was extemely smooth with no evidence of slip-stick.

Although the friction measurements were made with thrust bearings it is expected that PTFE faced journal bearings would exhibit similar low coefficients of friction.

THE JAPANESE TECHNO SUPER LINER

It was commented earlier that the main focus for the development of PTFE faced thrust bearings has been the hydrogenerator market. It is clear however that marine thrust bearings and hydrogenerator bearings are not dissimilar. So when a requirement arose to produce a compact marine thrust bearing in which weight saving was an essential criterion, the use of higher loaded PTFE-faced thrust pads with their reduced thrust surface was an obvious choice.

In the world of marine propulsion the Techno Super Liner (TSL) marks a milestone in the development of water jet propulsion. TSL, Fig. 8, is a 14,500 tonne state-of-the-art vessel whose development was started by the Japanese shipbuilding industry in 1989 as an innovative means of sea transport to meet the requirements of the next generation. TSL is a vessel which runs at high speed reaching, with air lift, a maximum of almost 40 knots. It has light twin hulls of aluminium with two sets of gas turbine engines and water jet pumps for propulsion and four sets of diesel engines for lifting. The current TSL contract is for the biggest vessel of its type in the world to be actually built and operated. In the design of the vessel weight was of paramount importance. This is also true of the bearing which transmits the massive reaction forces from the two propulsion jets to the vessel's structure.

Fig 8 Techno Super Liner

By using PTFE faced thrust pads the main thrust bearings (one per water jet) embody many novel features which set them apart from conventional marine thrust bearings. With weight a significant parameter in the vessel design, the thrust bearings were designed to operate at a specific loading of 5.5 MPa (800 lbf/in^2) which is significantly higher than the more commonplace loadings of around 3.0 to 3.5 MPa (435 to 508 lbf/in^2). With the ability to operate at much higher loading than babbitt, the 2314 kN (232 tonf) thrust load can be carried on much smaller bearings. This reduction in size has resulted in an overall weight saving in the bearings of 4 tonne per vessel. The resulting smaller thrust collars have provided an additional 1 tonne saving per vessel. A scale comparison between the PTFE faced thrust pad used on TSL and a conventional babbitted pad that would have been required is shown in Fig. 9.

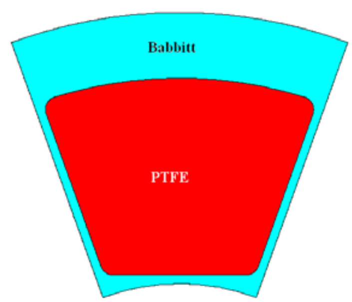

Fig. 9 Comparison between PTFE and babbitted pads for TSL

In addition to PTFE technology the TSL bearings have a unique positioning device which allows the operator to move the water jet impeller axially in order to achieve the optimum operating position, a necessary requirement due to potential hull flexure and distortion. This is achieved by large hydraulic rams which are able to move the entire thrust assembly fore and aft within the bearing casing. In the unlikely event of a failure in the hydraulic system, special failsafe mechanical clamps grip rods connected to the rams and ensure that the thrust collar of the bearing and, thus, the water jet impeller are locked in position.

Fig. 10 The TSL thrust bearing with PTFE-faced thrust pads

The axial position of the thrust collar is monitored by a transducer integral with one of the hydraulic rams and displayed on the bridge. Control of the bearing can be achieved via the bridge or locally. In addition to the main PTFE thrust bearing, an emergency reverse thrust bearing, also PTFE, is provided. A cylindrical babbitt-lined journal bearing shell provides support in the radial direction. Lubrication for the bearing comes from an independent system which has integral coolers and filters. A similar high pressure system supplies the hydraulic rams. Fig. 10 shows one of the TSL bearings and some of its PTFE faced thrust pads in the course of assembly. The completed bearing set with the thrust shafts in situ is shown in Fig. 11.

Fig. 11 The TSL bearings complete with shafts and hydraulic actuator positioning unit

PTFE FACED JOURNAL BEARINGS

So far, attention has been focused on thrust pad development, but testing is currently being carried out on PTFE faced journal pads. Initial successful trials were based on a 200 mm (7.87 in) bore journal pad bearing consisting of 5 pads distributed circumferentially around the shaft with an axial length of 80 mm (3.15 in). Using an existing high speed test rig specific loadings of up to 4.2 MPa (609 lbf/in^2) have been achieved, at sliding speeds up to 75 m/sec (250 ft/sec).
Recently a 450 mm (17.7 in) diameter, eight journal pad bearing capable of replacing one of the babbitted shells in the submarine thrust block rig described earlier has been designed and manufactured, and is currently under test. Fig. 12 shows the upper half assembly of PTFE faced pads. The hydraulic hoses seen running behind the journal pads are for the supply of high pressure oil to hydraulic cylinders to allow the uppermost two pads to be loaded downwards on to the shaft where the reaction is taken by pads in the lower half assembly. In this way, which is analogous to the thrust bearing rig described previously, the bearing can be loaded with no external radial loads being applied to the rig foundations.

Fig.12 Half assembly PTFE faced journal pads

Initial testing of the journal pads over a loading range from 2.1 to 3.2 MPa (305 to 464 lbf/in^2) has been completed with promising results. At 100 rev/min, a mean journal pressure of 3.2 MPa and an oil inlet temperature of 40ºC, the maximum pad temperature recorded was only 56ºC. At slow speeds, particularly when marginal lubrication conditions prevail, the PTFE pads operated without problem. The present indication, thus, is that PTFE faced bearings with no restrictions on low speed operation are likely to be possible.

CONCLUSIONS

Testing under laboratory conditions and operational experience in the field have shown that PTFE faced hydrodynamic bearings to offer advantage by comparison with more conventional designs. In particular, PTFE thrust pads have the potential to provide a solution that has a high degree of safety margin which leads to increased vessel reliability and availability. PTFE bearings allow significant reductions in the size and weight of the thrust block and thrust shaft collar. The use of PTFE faced thrust and journal pads provides a convenient method of achieving insulation against stray electrical currents which is important in electrical machines. Break away friction of PTFE faced bearings has been shown to be very much less than a similar size babbitted design. Looking to the future, PTFE journal pads will almost certainly provide a journal bearing which will have no limitations on operation at low sliding speeds.

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