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).

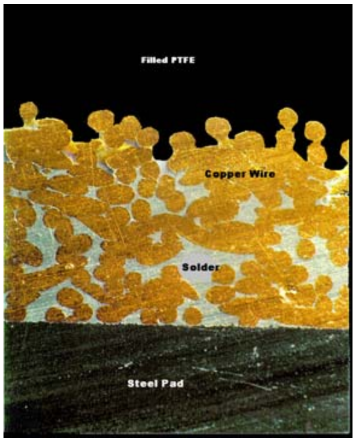

Fig.1 Cross-section through the surface of a PTFE faced pad

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)

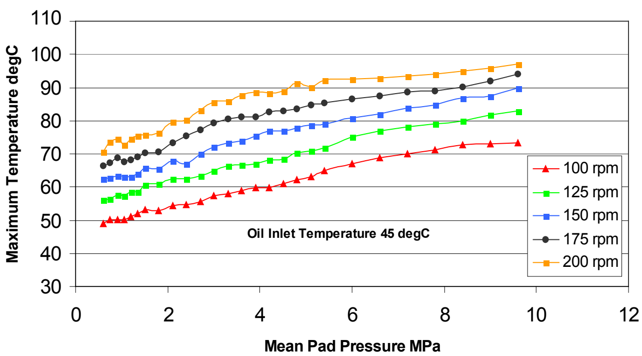

Fig. 5 Maximum thrust pad temperature v shaft speed

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.