The development of PTFE (polytetrafluoroethylene)-faced hydrodynamic thrust bearings for hydrogenerator application in the United Kingdom

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Abstract: Polytetrafluoroethylene (PTFE)-faced hydrodynamic thrust bearings have been used for many years in the former Soviet Union and in the People's Republic of China for large hydrogenerator applications. Although there has been some recent interest in other countries, few installations of this sort have previously been reported in Europe or the USA. This paper describes the state of the art and the development and laboratory testing of a prototype set of PTFE pads. Following these trials, a second larger set of thrust pads was designed for use in the pumped-storage hydroelectric power station at Ffestiniog in North Wales. The pads were installed in September 1996 and inspected in May 1997. After nearly 3000 h of operation including 900 separate occasions when the system was started up under load, the pads were found to be in excellent condition. Further hydrogenerator installations of PTFE-faced pads are planned as a result of this successful development.

Keywords: PTFE bearings, hydrodynamic bearings, thrust bearings, hydrogenerators

1 INTRODUCTION

Polytetrafluoroethylene (PTFE)-faced bearings have been widely used for heavy-duty thrust bearing applications for many years in Eastern Europe and the People's Republic of China but hitherto have had little exposure in other parts of the world. The purpose of this paper is twofold: to summarize the state of the art so far as it can be discerned from the available literature and to report on the design and testing of PTFE-faced thrust pads, first for laboratory experiments and then for a major UK generating facility.

2 BACKGROUND

Tin-based alloys known as whitemetals or babbitt have been the predominant material for a wide variety of hydrodynamic bearings for many years. Their use for thrust surfaces, such as in the multicollar thrust blocks of the early steam ships, pre-dates the invention of the tilting pad bearing at the start of the present century. The strengths and weaknesses of the material are well known [1]. In particular, whitemetal provides a dimensionally stable surface that is easily repaired or replaced. The material is forgiving in the sense of being able to absorb into its surface hard bits of detritus without causing further damage. On the other hand whitemetal 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 whitemetal 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 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 that they knew. Although other materials for hydrodynamic bearing surfaces including, for

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example, copper–lead alloys have been developed for specialist use, whitemetal has remained the world's preferred choice for most industrial applications. The position of whitemetal is so established that a recent major review of thick-film bearing analysis and design [2] makes almost no mention of bearing materials save to confirm the conventional use of whitemetal for thrust pads and then to refer in passing to the very recent work of Uno *et al.* [3] mentioned below.

An important exception in the use of whitemetal for hydrodynamic thrust bearing surfaces is in the countries of the former Soviet Union and China where, since the 1960s, PTFE-lined thrust pads have been developed for major thrust bearing applications [4]. According to Shen [5] referring to the Chinese experience, in the post-war years up to the 1970s, most thrust bearings for medium and large hydroelectric units were fitted with whitemetal-lined pads. These bearings ran well and caused no problem until pressure to increase generating capacity caused duties to increase and led to a series of failures at 'almost every hydroelectric unit through the 1970s'. Shen reported that, for the Chinese installations, the most common problem was high bearing temperature leading to local collapse of the whitemetal layer and wiping of the central areas and trailing edges of pad surfaces. Aleksandrov [6], reporting from the Soviet Union, also referred to regular bearing failures; four to six cases of bearing damage per year were said to be normal. Aleksandrov also noted the use of high-pressure forced-lubrication (jacking) systems to improve reliability by reducing friction at start-up and run-down. Jacking systems of this sort are in conventional use for start-up and shut-down in all parts of the world for large vertical machines. They work by injecting high-pressure oil, via channels in the pads, to the interface between the pads and collar to create a temporary load-carrying hydrostatic film.

Aleksandrov listed the benefits of PTFE: an extremely low coefficient of friction when paired with steel (0.04–0.09), unique chemical stability, excellent dielectric properties and good mechanical strength. A negative feature of PTFE is that its mechanical properties are highly temperature dependent. Thus, a temperature rise from 20 to 80 °C leads to a decrease in compressive strength by a factor of 3. Even more significant, PTFE is subject to excessive creep, i.e. deformation under load, even at low temperatures. For example, Aleksandrov cited the residual strain of PTFE after 24 h loaded to 10 MPa at 22 °C as 6.6 per cent. These latter properties prevent PTFE from being used as a bearing facing material in an unmodified form. The design approach suggested by Soifer *et al.* [4] and Baiborodov *et al.* [7] involves the application of sheet PTFE to a liner 8–10 mm thick made from bronze wire coils. The PTFE is applied under pressure which causes it to flow into gaps in the wire coil to a depth of 1–1.5 mm. In this way a firm bond is formed between the PTFE facing material and the wire coil underlayer. Aleksandrov suggested that, because in this design the PTFE only partially penetrates the wire cushion below, the pad retains resilience. This enables a reduction in local contact stresses on the friction surface and ensures during start-up a uniform load over the entire area of the pad face even when there is waviness on the surface of the thrust collar.

In his 1981 paper, Aleksandrov [6] was able to report that PTFE thrust bearing pads had been in use for some considerable time in nine hydrogenerator units at five power stations. The earliest of these installations appears to have been in 1974 as described by Baiborodov *et al.* [7]. By 1990, according to Aleksandrov and Plaxtonov [8], PTFE-faced thrust bearings had been installed in the majority of hydroelectric power stations in the Soviet Union. The development of PTFE-faced thrust bearings in China seems to have followed a similar course to that of the Soviet Union, albeit a few years later. The first installation in China was in the early 1980s, and by 1994 a number of medium-sized units had undergone conversion to PTFE pads [5]. From the limited amount of information available, it seems clear that the design approach used in China, with the PTFE face bonded to a resilient intermediate layer, is essentially the same as that used in the Soviet Union.

The reports from the Soviet Union and from China all record satisfactory operation and clear advantages deriving from the use of PTFE-faced bearings. In particular, significantly higher specific operating loads, up to 5.6 MPa [5], 6.0 MPa [6] or 6.5 MPa [8], are reported which compare very advantageously with the 3.5 MPa specific load typical for whitemetal-faced bearings. Significantly higher start-up loads than are usual for whitemetal-faced bearings are also claimed. Furthermore, the need for high-pressure forced lubrication at start-up and shut-down is removed with considerable cost savings.

The greater permitted specific operating loads lead to smaller pad areas for given loads and in turn to savings in the energy losses incurred by the bearings. Aleksandrov and Plaxtonov [8] specifically considered operation of PTFE-faced bearings with a high oil temperature and concluded from extensive industrial testing that an increase in the oil bath temperature from 30–35 to 60 °C led to an energy loss reduction of 20–30 per cent due to the resulting decrease in the viscosity of the oil film. It should be noted, however, that, in many installations in other parts of the world including the United Kingdom, oil bath temperatures up to 60 °C have been common for many years.

One evident concern for the pioneers of PTFE-faced bearings was that of surface wear. Aleksandrov [6] reported trials at one hydrogenerator station where the bearings were subjected to an applied load of 5.8 MPa, 250–300 starts per annum and an annual operating time of about 5500 h. The maximum wear, recorded as a reduction in thickness at the trailing edge of the pad, was 0.12 mm after 1 year and 0.18 mm after operation for 2 years.

Given the weight of evidence now available it is not surprising that engineers in other parts of the world, including Japan [9], should now be seeking to take advantage of the PTFE-faced bearing developments reported in the former Soviet Union and in China. For example, Uno *et al.* [**10**] have provided information about experimental work involving the evaluation of the friction and abrasion properties of four kinds of filled PTFE material. This is in contrast with earlier installations that appear to have made use of unfilled PTFE as the surface material. Very recently the same research team has reported an extension of its work to examine the performance of PTFE as the surface material for thrust bearings [**3**] while Choudhary *et al.* [**11**] provided a brief report of similar work which is possibly still at a slightly earlier stage.

PTFE, filled and unfilled, and other polymeric com-pounds have been investigated intensively for their proper-ties of friction and wear. A good summary of some work in this area is provided by reference [**12**]. The main application of PTFE in bearing technology has been for the development of dry sliding bearings (see, for example, references [**13**] and [**14**]), with little suggestion, other than as mentioned above, that the material may also have an important role in hydrodynamic bearings. Nevertheless it is interesting to note some very recent fundamental work investigating the sliding friction and wear behaviour of PTFE composites under lubricated conditions [**15**].

In the remainder of this paper a description is provided of the pilot experimental work carried out to prove a PTFE-faced bearing design for use in the United Kingdom. Details are then provided of the initial industrial installation in 1996 at the Ffestiniog pumped storage electricity generation facility in North Wales. An abbreviated version of the paper was presented at the First World Tribology Conference in London in September 1997 [**16**].