Plain bearing options for pumps

Pump applications demand a wide range of bearing designs. In this article, Guy Pethybridge (Product Manager) and Nigel New (Product Development) of Waukesha Bearings focus on hydrodynamic bearings, considering how factors such as operating temperature, load and lubricant influence the choice of bearing material. In particular, the characteristics and benefits of polymer bearings are highlighted.

The world of pumps is extremely diverse, with a range of different bearing designs and materials being used. Depending upon size, load and application they can vary from rolling element bearings, hydrodynamic bearings and even magnetic bearings. The hydrodynamic bearing can be lubricated either by oil or the process fluid. Active magnetic bearings, where the rotor is held by a magnetic field in a stator with 0.5 mm to 1 mm clearance all round, require no lubricant at all. Although they are considerably more expensive than the alternative lubricated part, they can show significant economic savings when judged on a total life time cost of ownership. Waukesha Bearings designs and manufactures a variety of hydrodynamic bearings and active magnetic bearings to meet this demand.

Bearing basics

The purpose of the bearing is to minimize or eliminate the wear and minimize the friction between the two surfaces that are in relative motion. In hydrodynamic bearings this reduction in friction and wear is achieved by the creation of a fluid film, which separates the surfaces. The resulting (hydrodynamic) film depends upon the speed and the viscosity of the lubricant, as well as the applied load and bearing size. Thus, with external oil-lubricated bearings the film can safely be as low as 10–20 µm thick. However, in the case of process-lubricated bearings, the viscosity of the pumped fluid is usually very low and consequently the film thickness can be even smaller (may be between 2 and 15 µm). They therefore require specialist bearing materials and design to minimize the consequences of any discrepancy in alignment or surface profile of the bearing or shaft.

Figure 1. Waukesha whitemetal-lined bearing for a water turbine with directed lubrication.

Material options

Table 1 shows the range of bearing materials offered for pump applications, although a magnetic bearing is a design rather than a material option.

The standard bearing arrangement for larger pumps utilizes oil-lubricated, whitemetal-lined bearings with a steel back (Figure 1). These are fitted with seals and sometimes separated from the pump structure by separate glands. The key benefit of whitemetal is its softness, which allows any dirt to embed in it, and its seizure resistance, thus preventing any damage to the shaft. Copper-chrome backings, particularly on tilting pad thrust bearings, can be substituted instead of the steel to reduce operating temperatures by conducting heat away from the surface more rapidly, thus reducing the surface temperature – which in turn leads to a higher operating viscosity and thicker film.

If the load/temperature is too high for whitemetal, aluminium tin (Al-Sn) is a higher strength, higher temperature alternative but which still retains the forgiving nature of whitemetal. For even higher loads and/or temperatures, copper-lead (Cu-Pb) material is a further option. A hardened shaft is required because the surface hardness of the bearing alloy is such that dirt does not embed well, with a resultant increase in the wear rate for a soft shaft.

Process-lubricated bearings

On smaller pumps it is common to use the fluid being pumped as the working lubricant. This greatly simplifies the design and part count with a significant impact upon cost. These applications require additional or different characteristics from the bearing material, which generally fall into two categories – very hard materials and soft polymer materials. Ceramic bearings, normally in the form of silicon carbide, provide excellent wear resistance for pumps where the lubricant contains significant amounts of abrasives (Figure 2). These have proved rugged in 20 years of service when correctly lubricated and handled, but are intolerant of even short failures in lubricant supply and rough handling. A common application for ceramic bearings is water injection pumps in the North Sea, where there is, potentially, a significant sand content in the seawater. The primary property of the ceramic is its hardness and resistance to wear. Silicon carbide is the normal bearing material of choice due to its high thermal conductivity, which helps to minimize thermal effects in the fluid film and thermal stresses in the bearing components.

Figure 2. Waukesha silicon carbide thrust and journal bearings.

Advantages of polymer bearings

Polymer bearings provide an alternative in both oil-lubricated applications and those lubricated by the process fluid. These bearings use RPB25P – a polymer based on polyether-ether-ketone (PEEK) – that combines excellent surface properties with a high working temperature. In the conventional oil-lubricated environment, the polymer-faced bearing will run hotter than its metallic counterpart because of the low thermal conductivity of the material. In practice, this leads to thinner working oil films compared to metallic surfaced bearings, but, because of the improved surface properties of the polymer materials, the actual load capacity is, under most conditions, higher. The benefits of a polymer solution can be summarized as: higher operating temperatures up to 250 °C (480 °F); high load capability; corrosion resistance; and high electrical resistivity (better than 10^9 Ωm).

Higher operating temperatures

The high temperature properties of PEEK derive from the large groups, such as phenyl and carbonyl groups

TABLE 1: BEARING MATERIALS SUITABLE FOR PUMP APPLICATIONS

Material	Lubricant	Max operating temperature	Load capacity	Corrosion resistance	Thermal/electrical conductivity	Comments
Whitemetal (babbitt)	Oil	130 °C	Medium	Good (in oil)	High	–
RPB25P (polymer)	Any	250 °C	High	High	Low	Excellent fatigue resistance
Ceramic (SiC)	Any	c. 300 °C	High	High	Low	–
Magnetic	None used	c. 400 °C	Low	High	Low	Can be canned
Al-Sn	Oil	155 °C	Medium	High (in oil)	High	Excellent fatigue resistance
Cu/Pb	Oil	180 °C	Medium	Good (in oil)	High	Hardened counter-face required

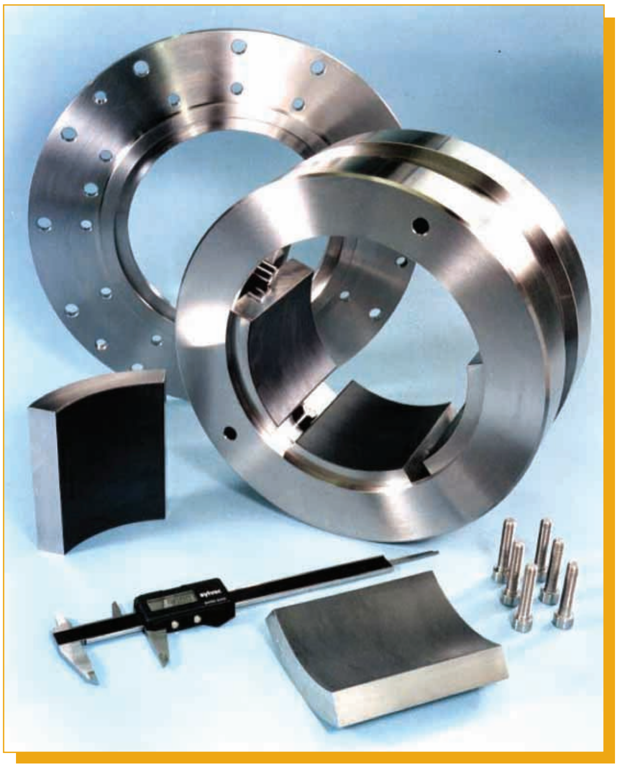
that make up the polymer backbone. These groups provide thermal and thermo-oxidative stability as well as restricting the freedom with which one polymer chain can move relative to another. Hence higher temperatures are required to soften the polymer. Branching of a polymer backbone and cross-linking between chains can also further restrict movement. Materials based on PEEK can operate continuously at temperatures up to 250 °C (480 °F) and, for short periods of time, up to 300 °C. Polymer bearings are used because of their thermal properties in electrical submersible pumps (ESPs) and gas turbines. In the latter case, heat soak along the shaft is no longer taken away after shutdown when the oil supply pumps are not running. The resultant high surface temperature of the shaft requires a bearing material with sufficient thermal capability.

Figure 3. A Waukesha HIDRAX thrust bearing with polymer-lined pads used in electrical submersible pumps.

High load capability

RPB25P has excellent surface properties that allow it to run with thinner films and hence higher loads than one would normally use for metallic bearings. Major users of polymer-lined axial bearings (Figure 3) are manufacturers of ESPs for pumping oil wells. ESPs are strictly limited on space, but the head can be very high and high ambient temperatures cannot be reduced by external cooling circuits. Polymer-lined axial bearings in ESPs commonly operate at loads of 8 MPa (1200 psi) and ambient temperatures well in excess of 100 °C. High load capability has also been put to use for both radial and axial bearings in subsea booster pumps and for applications lubricated by low-viscosity fluids, such as water and freon. Safe operation at high loads in thin process films allows cost reduction because of the resulting compact bearing design. It may also be the only economic solution where space is a critical factor.

Figure 4. Polymer-lined radial bearing.



Corrosion resistance

RPB25P is chemically resistant to most solvents allowing it to be used with most process fluids.

Electrical insulator

The high resistivity (>10^9 Ωm) of RPB25P can prevent electrical discharge from occurring within the bearing. This can be a problem in bearings adjacent to electric motors (or generators) where stray fields can create re-circulating electric currents.

Polymer bearing design

Polymer bearings can come in several formats for axial and radial bearings (Figure 4). The standard design uses a polymer lining, bonded to a steel-backing via a porous metallic interlayer. This interlayer provides a mechanical key to ensure strong bonding of the lining to the backing, as well as adding additional strength to the lining material. The backing material can be any material to which the interlayer can be bonded and includes bronze and both mild and stainless steel.

An alternative for axial bearings, operating with low viscosity process fluids, is to have a solid polymer pad, as in the following application history.

Case study: reverse osmosis supply pumps

Seawater desalination by reverse osmosis (RO) is a major expanding world market. To serve this demand, FMC Technologies of Houston, TX, USA, developed a high-pressure, compact, lightweight, corrosion resistant pump that needed a design review to improve its mean-time-between-failures (MTBF). The pump is an axial-piston, swash-plate pump that uses polymer pistons, valves and a G-10 or FR4 casing to minimize the weight and provide corrosion resistance. A test and development programme was required to resolve issues over the robustness of the bearings and valves.

A priority for this type of application is to replace traditional grease/oil lubricated bearings with process lubricated bearings (PLBs). Any grease or oil used for lubrication would leak and contaminate the pump by fouling the semi-permeable membranes used in the RO process.

Previously FMC had been using a grooved PEEK thrust washer that had a marginally adequate life of 1000 hours. The bearing was subject to failure if any of the design requirements were not met. To improve the MTBF, FMC was looking for a bearing with a higher load capacity that could tolerate greater misalignment, interruptions in the flow of lubricant, brief overloads, and the passage of debris.

On the basis of these criteria, Waukesha Bearings recommended a tilting pad design that in-house testing showed had sufficient load capacity and was capable of passing debris through the large gaps between pads. Other advantages lay in the HIPERAX bearing's compactness and the ease with which it could be retrofitted into the pump. Additionally, the bearing offered improvements in mechanical efficiency and reduced maintenance costs as the thrust pads can be replaced independently of the housing.

The HIPERAX design (Figure 5) uses tilting pads that are made from a fibre-reinforced polymer. The pivot arrangement allows the pad to deflect under the load as well as to tilt and form the wedge of lubricant that is critical to hydrodynamic performance. This deflection acts in a similar way to the thermal crowning of standard white-metal (babbitt) lined, steel-backed pads.

Since the instalment of the HIPERAX bearings, FMC's pumps have run in excess of 5000 hours without either a single bearing failure or any sign of wear, despite the passage of significant amounts of debris.

Figure 5. A Waukesha HIPERAX thrust bearing with solid polymer pads.

It is clear that the designers of the next generation of pumps have many options available to cope with the wide range of pump operating conditions. Polymers, metals and ceramics all have particular benefits in the right circumstances. ■

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