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The Design Aspects of Metal-Polymer Bushings in Compressor Applications

Abstract

Traditional compressor bearings, such as rolling element, leaded-bronze or bi-metal bushings, are greatly affected by wear in marginally lubricated conditions at bearing locations in compressor applications. Metal-polymers offer a unique advantage because of their self-lubricious nature, making them a more reliable solution in those particular conditions. Additionally, they offer other advantages such as being lead-free, reducing noise levels, and lowering friction in comparison to other journal bearings. The range of assembly clearances compared to traditional bearings is one of the biggest obstacles when designing in metal-polymers because of the effect on efficiency. However, with adjustments to system design and/or sizing operations to control clearances, metal-polymers have been commercially utilized in compressor design. This paper focuses on the differences between metal-polymers and traditional compressor bearings in structure, system design, and performance.

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1. Introduction

Compressor operation relies heavily on refrigerant and lubricant mixture in refrigeration and air conditioning systems consisting of many other components. The speeds and loads experienced, theoretically, result in hydrodynamic lubrication for most compressor applications. However, boundary and mixed-film lubrication occurs frequently in situations such as start-up, shut-down, compressor oil "wash out" from gas migration, and the decrease of lubricant viscosity as a result of refrigerant dilution. The period of time that mixed or boundary lubrication conditions occur is dependent upon the system design to obtain steady-state flow.

The performance and reliability of traditional compressor bearings, such as rolling element, leaded-bronze or bi- metal bushings, are highly dependent upon lubrication conditions. Mixed-film and boundary lubrication conditions allowing contact between mating surfaces can result in higher friction and excessive wear. Metal-polymer bushings offer a unique advantage in comparison because of their self-lubricious nature where contact between mating surfaces does not result in high wear or friction. Therefore, metal-polymers offer a more reliable solution in those particular conditions.

Metal-polymer bushings have been utilized in commercial compressor applications for the past 20 years, but it is still a relatively new concept for most of the industry. These commercial successes did not come about without overcoming particular design hurdles related to the differences between traditional compressor bearings and metal- polymers. This paper focuses primarily on metal-polymer differences in structure, system design, and performance.

2. Metal-Polymer Structure

Metal-polymer bushings typically consist of a multi-layer composite structure, beginning with a rigid steel backing, intermediate porous or mesh layer (typically bronze), and a polymer overlay that is impregnated onto the intermediate layer. This polymer overlay, for most compressor applications, will consist primarily of PTFE (polytetrafluoroethylene) and a combination of fillers. The combination of fillers and PTFE is what determines the inherent performance properties of the bushing. Figure 1 shows the cross-section of a metal-polymer bushing with the intermediate layer consisting of porous bronze material.

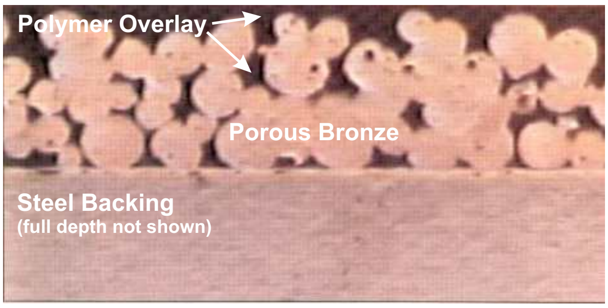

Figure 1: Cross-section of typical metal-polymer bushings

Metal-polymer bushings are typically manufactured in two steps from material that is produced in strip form. This includes some type of adhesion of the intermediate layer to the steel backing, and impregnation of the polymer material. From strip form, the material is slit and wrapped into a bushing. The final dimensions are designed to be used with a press-fit into the housing to obtain a pre-determined installed inner diameter. Another name for this form of a bushing is a split bushing, where it is not a continuous cylinder like a cast bronze or metal bushing.

The precision of the final bushing dimensions depend on manufacturing and measurement capabilities. Typical total tolerance on the final wall thickness of the bushings varies from 20 to 45 µm, depending on the strip thickness. This is for standard parts, but better tolerance control is achievable in certain cases.

3. System Design

In most applications, bearing system design is primarily influenced by the clearance within or between the shaft and bearing surface. For compressors, clearance can be critical from the aspect of efficiency. This relationship will be touched upon further in the following section on performance. However, this section will focus on the differences between typical clearances for traditional compressor bearings and metal-polymer bushings.

3.1 Typical Clearance Range of Metal-Polymers

The polymer surface is a critical factor defining bearing performance. Processing capabilities limit the amount of tolerance that can be controlled because of the composite structure. Accurately forming and measuring a bushing comprised of steel, bronze and polymer can be difficult, and is continuously being studied for improvement. At this point in time, machining is not an option for PTFE based metal-polymers. The thin layer of polymer that lies above the intermediate bronze structure can be a critical component in the performance capability of the bearing surface. Machining away this layer leaves a bronze/polymer matrix, the performance of which can be reduced in comparison with a full polymer surface.

Table 1 demonstrates the difference between typical metal-polymer bushings and standard drawn-cup needle bearing clearances. Both were calculated from ISO h7 and N6 shaft and housing fits. Exact values of the clearance range will vary among manufacturers.

Shaft Size [mm]	Needle		Metal Polymer	
	Max	Min	Max	Min
10	55	10	85	5
20	75	15	115	10
30	75	15	125	10
40	85	20	135	15
50	85	20	160	15

Table 1: Clearance Range Comparison (μm)

Bronze or bi-metal bushings were not included because they typically can be machined after installation. This clearance can then be held within a much tighter range. Additionally, higher-precision needle bearings are available if the clearance range has to be reduced. Rolling element and bi-metal bearings can hold tighter tolerance ranges, but this may not be a factor in applications utilizing metal-polymers.

3.2 Commercial Compressor Applications

Metal-polymer bushings have been used in compressor applications for the past two decades, providing both performance and reliability enhancements. Tables 2 and 3 compare typical clearance ranges used for the traditional compressor bearings and the metal-polymer bushings that replaced them in reciprocating and axial-plate compressors. Additionally, Table 4 shows some examples of commercial scroll clearances for a given shaft size to demonstrate the range of clearances for metal-polymers. Every manufacturer's compressor design is unique, therefore the clearance range required for the same size may be different.

Shaft Size [mm]	Bronze		Metal Polymer	
	Max	Min	Max	Min
40	50	40	115	40
45	55	45	120	45

Table 2: Reciprocating clearance range comparison (μm)

Shaft Size [mm]	Needle		Metal Polymer	
	Max	Min	Max	Min
17	65	15	90	15

Table 3: Axial-plate compressor clearance range comparison (μm)

Shaft Size [mm]	Customer A		Customer B	
	Max	Min	Max	Min
28	115	30	140	50
32	120	35	140	50
40	130	45	160	80

Table 4: Scroll compressor clearance range (μm)

Clearly, metal-polymers can operate effectively and efficiently at clearance ranges that are higher than for bi-metal or needle bearings. In fact, some have shown that the range must be adjusted for proper performance, as discussed in the next section. Replacing a traditional compressor bearing with a metal-polymer will require an investigation to determine the optimal clearance range for best performance.

4. Performance

The performance of metal-polymer bushings in compressors is not just dependent on clearance, but also on the material's ability to withstand the speeds, loads, temperatures and corrosive attack seen in these applications. Typical bearing failures in compressors include wear, fatigue and cavitation. Through polymer bearing science of combining fillers in PTFE, metal-polymer manufacturers have been able to design materials that can handle wear and fatigue as well as, and in most cases, better than traditional compressor bearings. This can be attributed mostly to the self-lubricious nature of the material in marginal and boundary lubricated conditions. Cavitation resistance does not match that of bi-metals, but is adequate for compressor bearing conditions.

Figure 2 gives an example of testing that has been completed comparing the wear resistance of a PTFE based metal- polymer bushing with leaded bronze. Two samples of each type of bushing were tested. Both leaded bronze bushings and one metal-polymer bushing were tested in identical conditions while the load and speed was doubled for the second metal-polymer sample.

The results show that the wear resistance of a metal-polymer bushing is vastly superior in comparison to a leaded bronze even with twice the load and speed.

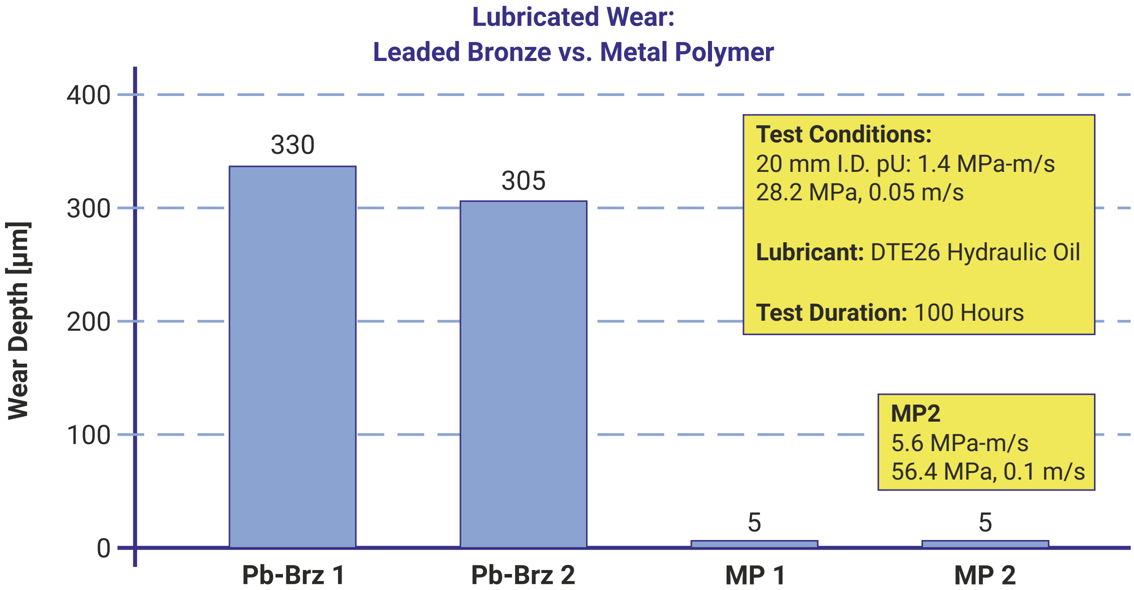

Figure 2: Lubricated wear of leaded bronze vs. metal-polymer bushings with test conditions

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4.1 Hydrodynamic Lubrication in Metal-Polymer Bushings

Conventional hydrodynamic calculations in journal bearings can be used as a guideline to help determine film generation along with other important factors in bearing design. However, there is a unique phenomenon that can occur under certain conditions within metal-polymer bushings, the bearing surfaces of which have lower modulus than bronze, bi-metal or steel. The effect at higher loads can cause elasto-hydrodynamic lubrication (EHL) conditions that produce greater film thicknesses compared with traditional journal bearings under the same conditions. It is widely believed that the compliance of the polymer surface distributes the load more effectively and increases the film thickness. However, even in conditions of poor film generation, metal-polymer bushings still hold the advantage because of their lubricious PTFE surface.

4.2 Maintaining Efficiency with Metal-Polymer Bushings

Because of the increased range of installed tolerances available with metal-polymers, the challenge of maintaining or improving efficiency lies primarily in compressor design. These increased ranges often can cause mating parts within the compressor to not function properly due to high tolerance stack-ups, and therefore increase power consumption or reduce output. However, this has been overcome with proper testing and investigation of changes within the compressor, along with bearing design.

For instance, shaft and housing dimensions can be manipulated to decrease the range of tolerance to the capability limits of the manufacturer. Additionally, ongoing studies with metal-polymer bearing manufacturers are seeking ways of decreasing product tolerance ranges. An additional method that can be used for metal-polymers is a sizing operation, or burnishing, that occurs after bushing installation. This involves pushing through a sizing tool with a specified diameter. If the bushing's inner diameter is less than the sizing tool, the polymer overlay will be compressed, thereby reducing the tolerance range of the installed I.D. However, compressing polymer material can adversely affect performance if the interference is too high. Each PTFE/filler material will react differently to sizing operations. Metal-polymer manufacturers should have more information for their particular materials.

The results of an investigation of the effective clearance upon efficiency are represented below in Figure 3. This experiment was conducted by a manufacturer of a scroll compressor that plotted the performance of a metal-polymer bushing against a machined bi-metal bushing over a range of clearances. Results show an increase in efficiency over a clearance range greater than that required for the bi-metal bearing.

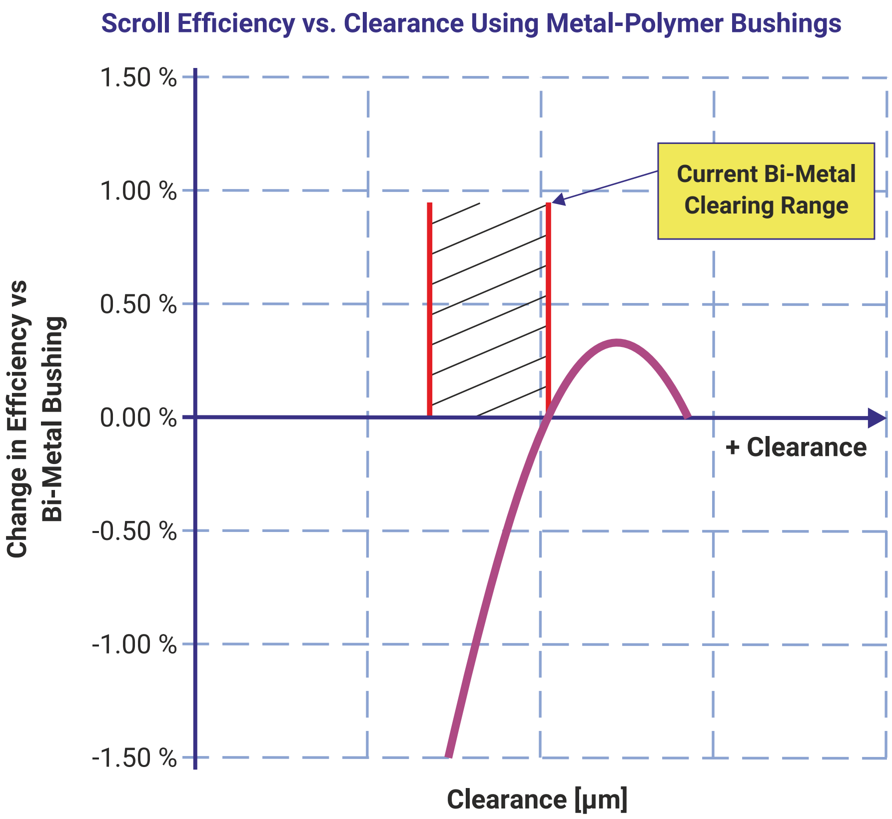

Figure 3: Metal-polymer efficiency vs. bi-metal efficiency over a particular clearance range

There is still a lot of work needed to completely understand the nature of performance within the polymer bushing in relation to compressor system design. This and other types of testing are required to fully comprehend the mechanisms that help drive and maintain performance in compressor applications utilizing metal-polymer bushings. Each design is unique, and therefore will require its own testing and investigation.

5. Conclusion

Designed correctly, metal polymers can provide a more reliable bearing system than traditional journal bearings. PTFE is a natural lubricant that offers better resistance to heat and friction during periods of marginal and boundary lubrication. The compliance of the polymer surface handles misalignments better than traditional compressor bearings, allowing for better system compliance with tolerance stack-ups in the compressor design. Using metal-polymers as direct replacements for traditional compressor bearings is not recommended, as they tend to function differently at various clearances.
Continuous advancements in polymer sciences may lead to the development of a metal-polymer that can be machined at installation to help maintain control of clearances. Additionally, metal-polymers offer new material technology for development of more robust, reliable bushing products that can keep pace with the changes facing the compressor industry (lead-free, 13 SEER, CO2, etc…) better than traditional bi-metal, bronze or rolling element products.

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