

## Self-lubricating bearings can be resized without impairing performance, service life

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A variety of bearings are used to facilitate the shaft rotation that provides the pumping action in compressor applications. Self-lubricating, metal-polymer bearings have been demonstrated to counter lubricant-starved conditions during startup and shutdown, gas migration, refrigerant dilution and others that adversely affect compressor efficiency and longevity.

These type of bearings offer superior tribological performance and the ability to self-lubricate during periods of marginal or insufficient lubrication. The metal-polymer bearings most frequently used in compressor applications consist of a steel backing for strength and dimensional stability and a porous bronze interlayer impregnated and overlaid with a polymer sliding layer (Fig. 1). The sliding layer is a polymer composition of PTFE with 20 v/o lead filler.

Accurate dimensional tolerances and tight clearances between the shaft and bearing can significantly improve compressor efficiency. Previous study in this area demonstrated that within the specified clearance range, metal-polymer bearings outperformed bimetallic bearings in this regard.<sup>1</sup> Figure 2 shows that use of metal-polymer bearings whose tolerances were as tightly controlled as those of bimetallic bearings resulted in 3% higher efficiency in a typical scroll-type compressor.

A subsequent study was conducted to evaluate the effect of burnishing self-lubricating, metal polymer bearings on their tribological performance and service life under compromised lubrication conditions. The preferred clearance range for the study was 25 $\mu$ m, a level not typically achievable with metal-polymer bearings in the as-installed state, which limits the dimensional tolerances and clearance range of the combined components in the sliding system.

Variations in the bearings' wall thickness and the tolerances of the housings into which they are installed make it virtually impossible to control their clearance without secondary sizing. However, post-installation size adjustment has been shown to reduce bearing life by as much as 70% (Table 1). By comparison, bimetallic bearings can be machined to tighter dimensional tolerances with no adverse effects.

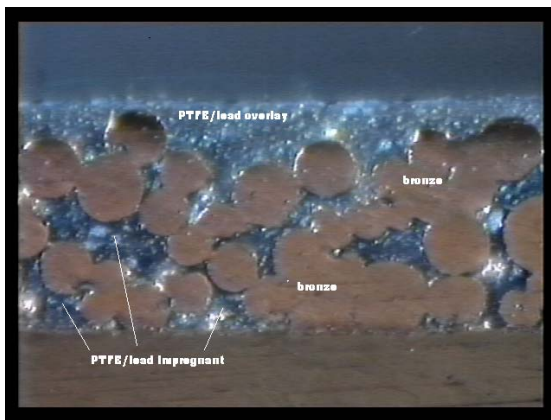


Figure 1: Typical cross-section of a PTFE/ lead metal-polymer bearing

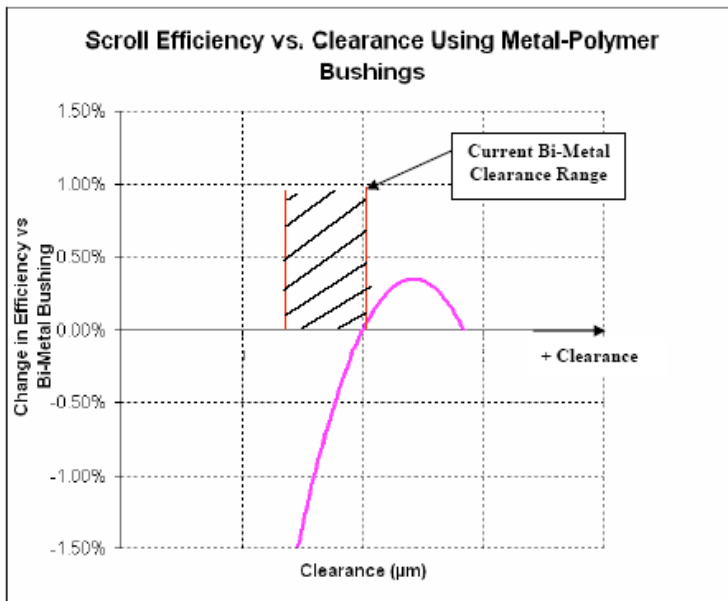
Table 1: Effect of burnishing on life of metal-polymer bearings

<i>Burnishing Interference</i>	<i>Life Reduction</i>
25 $\mu$ m	20%
38 $\mu$ m	40%
50 $\mu$ m	70%

The new study utilized two production compressors with nominal 17mm- and 41-mm diameter shafts and clearance ranges based on the maximum dimensional tolerance of the shaft, housing and bearing. As-installed clearance ranges for the two compressors were:

	I.D.	Min.	Max.	Range
Compressor 1	17mm	10 $\mu$ m	80 $\mu$ m	70 $\mu$ m
Compressor 2	49mm	34 $\mu$ m	109 $\mu$ m	75 $\mu$ m

These clearance ranges were approximately three times the 25 $\mu$ m target for maximum efficiency, so the metal-polymer bearings were resized to tighter clearances than would have been possible in the as-installed state.

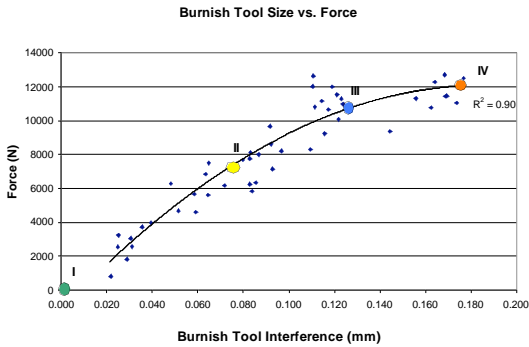


**Figure 2: Efficiency as a function of clearance between bearing and shaft**

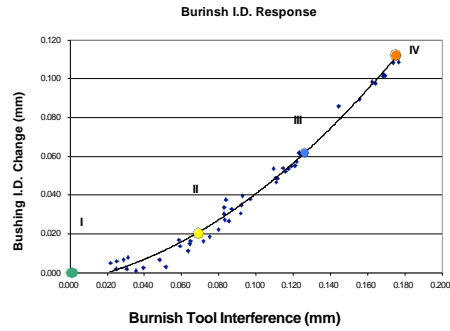
Baseline target bearing life was considered to be the measured life of the standard PTFE-based metal-polymer bearings used in a broad range of compressor applications. The bearings used in the burnishing trials, however, had a liner composition of PTFE and CaF<sub>2</sub> instead of lead.

Bearings with 20mm nominal I.D.s and 23mm nominal O.D.s were installed and supported in a fixed ring to allow a burnishing tool to enlarge their bores. The burnishing tools were pushed through the bearings using an Instron unit with load cell connected to a digital recorder. The bearing I.D.s and tool diameters were measured before and after burnishing. The interference for each test was calculated as the difference between the measured I.D. of the bearing and the maximum diameter of the tool. The force required to push the tool through the bearing and the post-burnishing bearing I.D. were also measured and recorded.

**Figure 3** depicts the force required to perform the burnishing operations as a function of tool interference.



**Figure 3: Burnishing force as a function of interference**

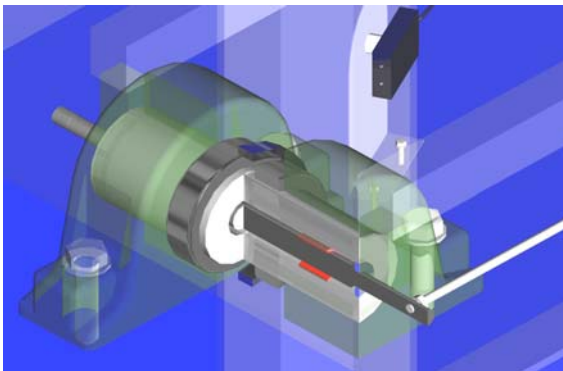


**Figure 4: Diameter change as a function of interference**

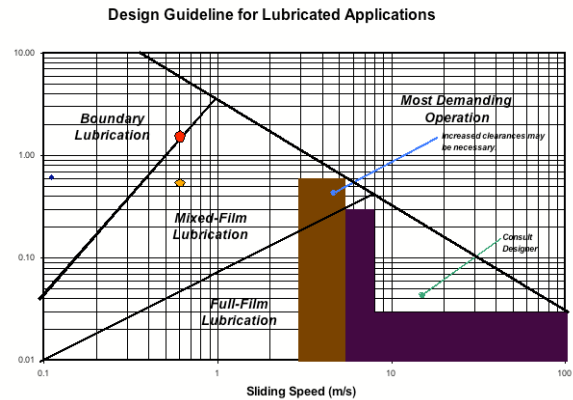
The data in **Figure 4** show the relationship between tool interference and final bearing bore dimension, plotted as diameter increase.

Compressor operations expose plain bearings to a combination of tribological conditions resulting from the relative sliding motion between the shaft and the bearing itself, combined with compressive loads the location of which continually changes around the circumference of the bore. Tribological testing to identify the effect of burnishing was conducted in a unit that simulated these conditions.

The performance of burnished bearings was evaluated using a test rig that simultaneously subjected them to sliding conditions and cyclic loading. The bearings were installed in a cylindrical housing with an installed shaft. **Figure 5** is a cutaway illustration of the test unit showing the housing with two bearings capable of supporting the test shaft, which was fixed to prevent rotation.



**Figure 5: Cutaway illustration of wear tester with rotating housing and stationary shaft**



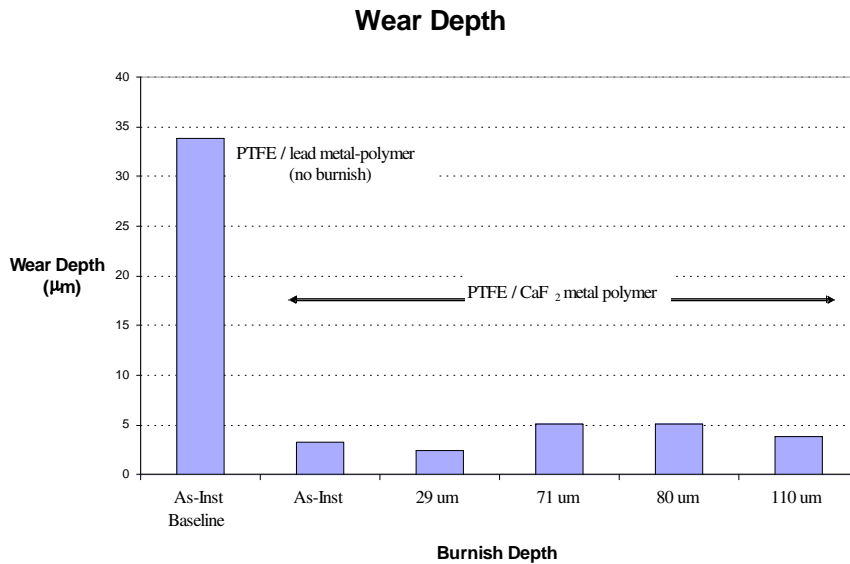
**Figure 6: Lubrication state map indication condition at startup and after frictional heating**

Load arms with fixed weight applied the test load while the housing, filled with DTE 25<sup>®</sup> oil and sealed, was driven in rotation.

Nominal specific load was 3.4 MPa (500 psi), but edge loading from shaft deflection increased actual specific load to 18 MPa (2,600 psi). The housing was rotated at 7,500 rpm, providing a surface sliding speed of 0.78 m/s (153 fpm). Shaft surface finish was 0.12 $\mu$ m R<sub>a</sub> (5  $\mu$ in.). The tests were conducted at ambient temperature (25°C), but frictional heating raised the oil temperature to approximately 95°C under normal operating conditions. Test duration was 200 hours.

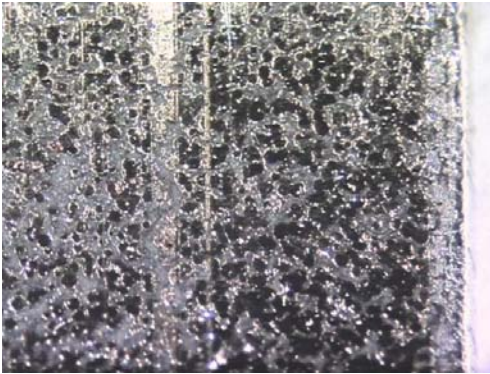
The lubrication-state map in **Figure 6** was used to calculate the primary oil-film conditions, including boundary, mixed-film and hydrodynamic-film lubrication. The two points within the rectangle indicate the range of oil-film conditions present during the tests. Startup lubrication was calculated to be in a mixed-film state. As frictional heating increased the oil temperature, viscosity decreased causing a transition to boundary lubrication. This condition was particularly conducive to evaluating the effect of burnishing on bearing wear and fatigue.

**Figure 7** shows wear depth for the four burnished test bearings to have been in the 0 to 5 $\mu$ m range, compared with approximately 40 $\mu$ m for the baselines PTFE/lead metal-polymer bearings.



**Figure 7: Wear depth as a function of burnishing depth in comparison with baseline material**

**Figures 8a and 8b** show wear in the load zones of the tested bearings; note the greater proportion of bronze particles showing through the wear surface of the PTFE/lead bearing than the PTFE/ CaF<sub>2</sub> bearing, indicating deeper wear beneath the original bearing surface.



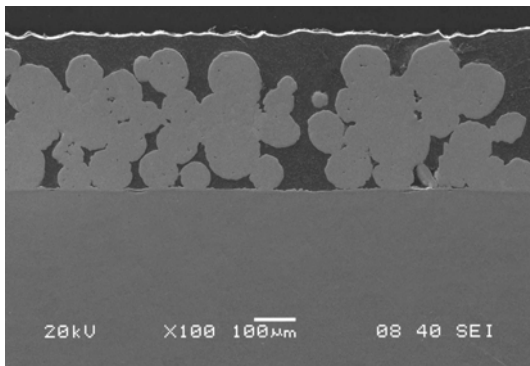
**Figure 8a: PTFE/lead bearing 33µm wear loss**



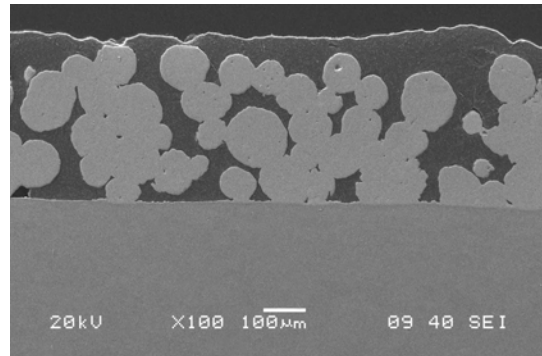
**Figure 8b: PTFE/CaF<sub>2</sub> bearing 5µm wear loss**

The useful life of the baseline PTFE/lead bearing is considered to be consumed at a wear depth of approximately 65µm, at which point the surface will typically have about 70% bronze exposure. The resulting reduction in PTFE content will result in increased friction and decreased efficiency.

The combination of cyclic compressive loading and relative sliding motion can cause subsurface cracking that can lead to spalling or delamination of the polymer sliding layer. The loss of this layer can result in increased friction and wear as the underlying bronze structure slides directly against the steel shaft. However, no delamination was observed within the load zones of the tested bearings. Further investigation of the tested bearings using an electron microscope to examine their cross-sections revealed no subsurface cracking that would indicate fatigue damage (Figures 9a and 9b).



**Figure 9a: Cross-section of tested PTFE/CaF<sub>2</sub> bearings with 30µm burnish**



**Figure 9b: Cross-section of tested PTFE/CaF<sub>2</sub> bearings with 110µm burnish**

The results of these tests confirm that metal-polymer bearings can be burnished to depths in excess of 100 microns without compromising their performance or longevity. Indeed, wear performance for all the test bearings equaled or exceeded that of the unburnished baseline bearings. These results underscore the potential for metal-polymer bearings to meet both the tribological performance and tight tolerance requirements of compressor applications.