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Lead-free Bearings for High Performance Gas Engines

Miba has a long tradition in lead-free bearing types, complying with the environmental protection rules. Miba is now offering a new lead-free bearing generation for high performance engines with improved tribological behavior.

AUTHORS

Dipl.-Ing. Dr. techn. Katrin Zorn is Head of Technology Competence Center at Miba Gleitlager Austria GmbH in Laakirchen (Austria).

Dipl.-Ing. Alexander Eberhard is Technology Unit Leader Material & Process Development of Technology Competence Center at Miba Gleitlager Austria GmbH in Laakirchen (Austria).

Dipl.-Ing. Matthias Schinagl is Project Manager in Technology Competence Center at Miba Gleitlager Austria GmbH in Laakirchen (Austria).

Dipl.-Ing. Emil Bakk is Technology Unit Leader Testing of Technology Competence Center at Miba Gleitlager Austria GmbH in Laakirchen (Austria).

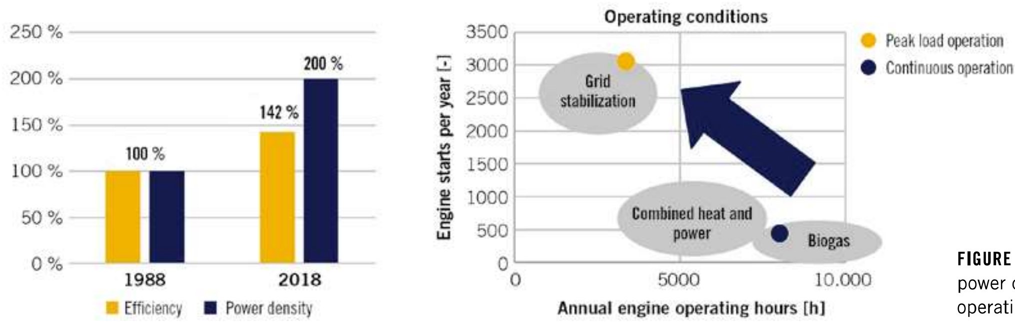


FIGURE 1 Trend towards higher power density and changing operating conditions (© Miba)

TRENDS IN GAS ENGINE SYSTEMS

Environmental regulations, alternative energy production, and hybridization all change the operating conditions for engines and thereby the operating conditions for the crankshaft bearing. Hybridization leads to a higher specific load but a more continuous rating with fewer or smaller engines. This is leading to Peak Firing Pressures (PFPs) beyond 200 bar and a Brake Mean Effective Pressure (BMEP) of more than 20 bar. For example, Innio Jennbacher has doubled the power density and increased efficiency by 42 % with their Jenbacher Type 6 engine family since market launch in 1988, **FIGURE 1** [1].

CO_2 reduction requires gas and alternative fuel engines or engines with fast start-stop operations with a reduced running time. Under peak load operations, they only see up to 3000 starts and 3000 operation hours per year, **FIGURE 1** [1]. For comparison: a traditional biogas operation would run approximately 8000 h per year, having not more than one engine start per day.

In addition, the Registration, Evaluation, and Authorization of Chemicals (REACH) regulation of the EU demands completely lead-free solutions soon. Especially many large engines today still use lead containing bearing material for high performance reasons.

CHALLENGES FOR GAS ENGINE BEARINGS

The abovementioned trends toward higher power density and changing operating conditions in gas engines lead to the following three challenges for engine bearings: shock loading, flexible engine structure and chemical resistance.

The higher shock loading on bearings is due to the typically higher spread in the absolute firing pressures at approximately ± 20 bar compared to the nominal firing pressures that can be seen in gas engine bearings, **FIGURE 2**. In diesel engines, such a spread would be smaller and expected at approximately ± 5 bar. Engine knocking may also lead to overloads on the bearings and is mainly caused by variations in the gas quality and a higher sensitivity of the whole combustion system than in diesel engines. This can be addressed by the electronic balancing of the firing pressures and by adaptions in the bearing design, specifically by the choice of high strength bearing materials that can withstand this higher spread of firing pressures.

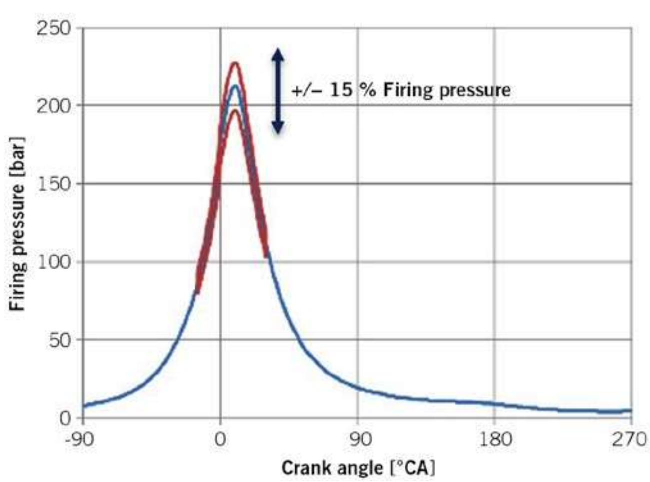


FIGURE 2 Engine bearings must withstand shock loadings in gas engines (© Miba)

The trend toward higher power density leads to more mechanical deformations along the whole cranktrain. Such a more flexible engine structure needs to be addressed with high attention to the bearing assembly conditions. The risk of bearing back fretting can be prevented with bearing back coatings.

New high-speed engines demand low Sulfated Ash, Phosphorous, Sulfur (SAPS) oil formulations with reduced base reserve. These have been state of the art for many years. Along with the increase in the power output of engines, stresses that are placed upon the lubricant have also increased. The design changes of the pistons lead to a situation where the lubricant gets closer to the combustion zone and that leads to the higher thermal stress of the lubricant. Higher temperatures increase the formation of weak organic acids, which are harmful to the stability of the oil and may trigger engine component corrosion. This faster drop in lubricant stability may, in some cases, lead to an elevated risk of selective lead corrosion in lead-bronze bearings.

CHOICE OF BEARING MATERIALS

In gas engines, a wide variety of bearing types are used, **TABLE 1**. The most influencing factor on the choice of the bearing material is the bearing load, wear resistance and its emergency running capabilities.

For medium bearing loads, typically steel-aluminum bi-metal bearings are used, for example steel-AlSn25CuMn.

In case of higher bearing loads, typically tri-metal bearings with soft overlays need to be applied, like steel-CuPb22Sn2-PbSn18Sn2. For even higher bearing loads, tri-metal bearings with sputter overlays from steel-CuPb22Sn2-AlSn20Cu sputter or even four-layer sputter bearings with Synthec running-in layers from steel-CuPb22Sn2-AlSn20Cu Sputter-Synthec are required. The additional 6 µm Synthec polymer formulation overlay provides additional running-in properties for the AlSn20Cu sputter overlay, delivering additional robustness for the highest load applications [2].

AlSn bi-metal bearings and leaded tri-metal bearings are state-of-the-art bearings offering good system robustness as well as longevity and adequate cost and are available for all engine sizes – from passenger car engines up to large low-speed engines. Tri-metal bronze bearings are traditionally available up to the 600 mm bore engine class.

For around ten years, lead-free bronzes have been available for passenger cars and in heavy duty truck engines. Millions of bearing shells have been installed with positive field experience since the launch of the Daimler heavy-duty engine platform. Lead-free bronze bearings are also in series application in high power density gas and diesel

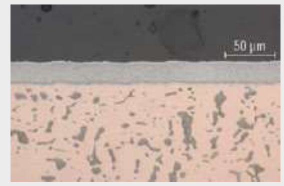
	Material family	Bearing load capability	Bearing robustness	
Medium speed gas engines	Steel-aluminum	Medium	High	
Medium speed gas engines / High speed gas engines	Steel-bronze-soft overlay	Medium/high	High	
High speed gas engines	Steel-bronze-sputter (-synthec)	High/extreme	Medium	 

TABLE 1 Load capability and robustness of gas engine bearing materials (© Miba)

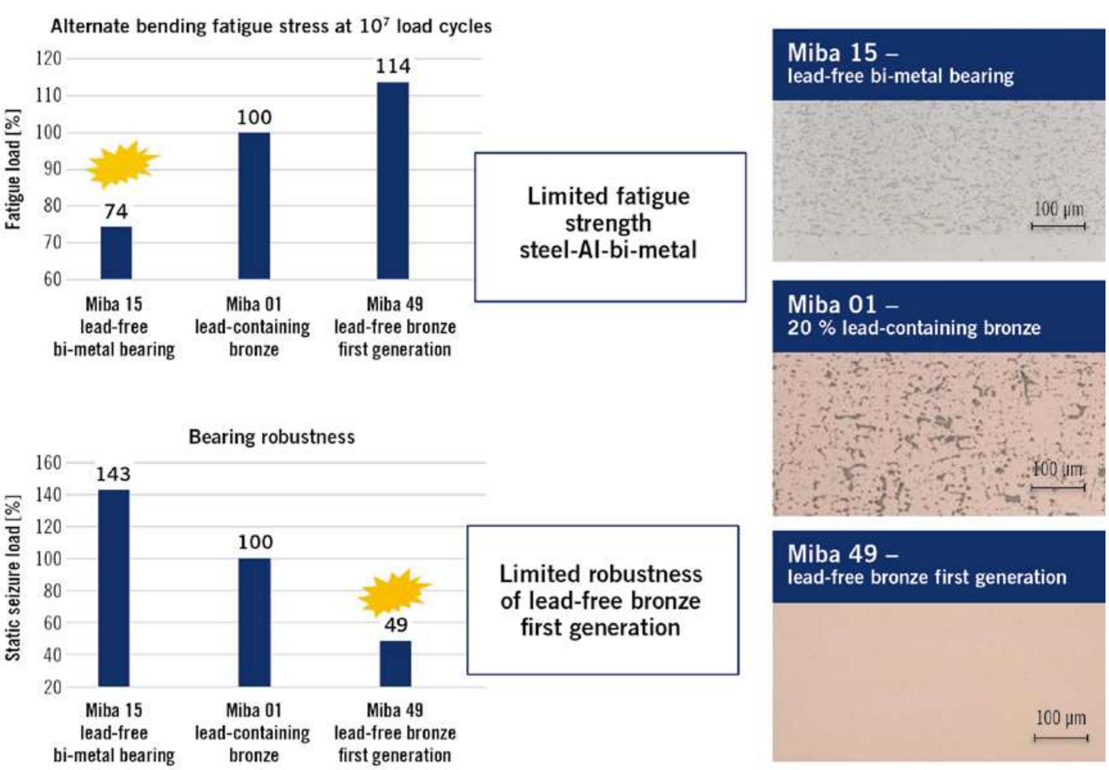


FIGURE 3 Performance and structure of lead-bronze and state-of-the-art lead-free materials (© Miba)

engines. However, due to their limited robustness, they are only suited for engines with bore sizes of up to 200 mm.

EU LEGISLATION DRIVING REPLACEMENT OF LEAD-CONTAINING MATERIALS

Lead (Pb) has already been banned in 2006 under Restriction of Hazardous Substances (ROHS), which restricts the use in electrical and electronic products and which affected the use of lead-containing bearing materials in smaller mobile gendrives only. However, REACH identified lead as a Substance of Very High Concern (SVHC) and included it on the candidate list in June 2018. In a worst-case scenario, inclusion in Annex XIV (representing a lead ban) is expected by 2025. This high legislation uncertainty is not only relevant for the European Market; typically, other countries follow soon after. For example, China has similar regulations with “China REACH.” This results in a general uncertainty for the entire engine market.

PERFORMANCE OF LEAD-FREE BEARING TYPES

Alternate bending tests give a good indication for bearing load capabilities, whereas static seizure load tests (where Miba tests the seizure loads on bearing test rigs by constantly increasing the load until the failure of the bearing) and misalignment tests provide valuable information on the robustness of bearing material families [3]:

Today, lead-free state-of-the-art materials are AlSn bi-metal bearings (Miba 15) or lead-free bronze materials (Miba 49). However, both cannot fulfill the high robustness and at the same time excellent fatigue strength of lead-containing bronze (Miba 01), **FIGURE 3**.

Where modern AlSn bi-metal bearings provide excellent robustness, the necessary fatigue strength is not given at higher bearing loads. On the other hand, the lead-free homogeneous bronze shows excellent fatigue strength (even higher than lead bronze Miba 01), but without the required robustness, therefore, the operational risk is elevated as shown [4].

Fortunately, in combination with coatings, special design features, and improved engine cleanliness, such homogeneous lead-free bearings can be widely used in

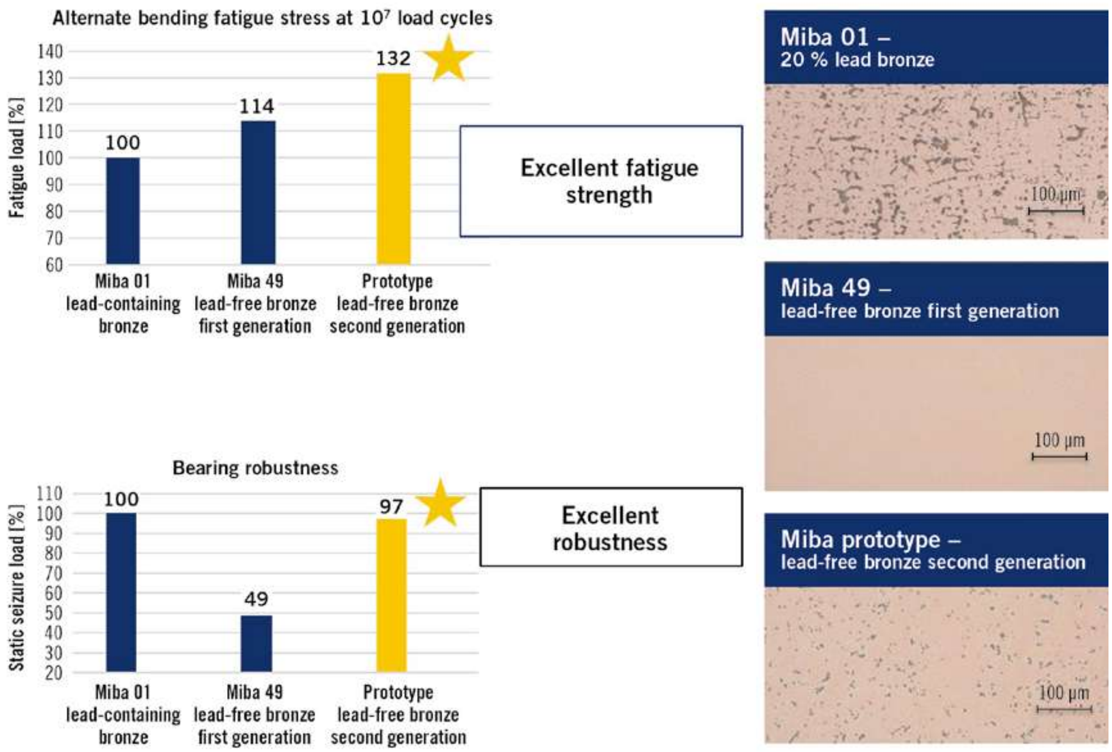


FIGURE 4 Performance and structure of lead-free first generation and lead-free second generation material compared to lead-bronze (© Miba)

FIGURE 5 Engine bearing test rigs designed to overload bearings for functional tests such as misalignment (© Miba)

heavy-duty truck engines as well as diesel and gas high speed engines. Performance may become problematic only for large engines with bore sizes > 200 mm.

The legislation uncertainty for lead bronze materials paired with the fact that lead-free materials today cannot withstand the high load capability and at the same time robustness have forced Miba to start the development of a robust lead-free second generation bearing material. Additional goals for this development are more robust and in the long term more oil compatible bearing systems, adding more degrees of freedom to the engine designer, and providing less strict frame conditions for the operator.

SECOND GENERATION LEAD-FREE BRONZE

FIGURE 4 compares the microstructures of heterogeneous lead-bronze CuPb22Sn2 (Miba 01), homogeneous lead-free bronze CuSn5Zn (Miba 49), and the new second generation lead-free bronze CuSnZnX (Miba Prototype). The excellent tribological behavior of lead-bronze can be explained by the heterogeneous structure having tribologically active lubricant phases and load bearing hard phases at the same time.

The limited robustness of lead-free first generation in large engines with bore sizes > 200 mm is reflected by the homogeneous structure of the lead-free material CuSn5Zn. The material does not include a secondary phase with beneficial tribological properties; this increases the risk for unpredictable, spontaneous seizure events.

The major driver in the development of the new lead-free second generation was therefore the combination of the heterogeneous structure of leaded bronzes with the high strength of the homogeneous lead-free lining materials. That was achieved by the addition of secondary phases supporting the formation of tribologically active layers during service. These secondary intermetallic phases are formed during the compound casting processes and optimized by the specific thermomechanical post-processing.

The robustness of the second generation lead-free bronze was significantly improved and shows seizure load test results comparable to well-known low-seizure high-leaded materials. Still the fatigue strength of the new material is significantly higher than in CuPb materials and shows even higher values than the lead-free first generation. Misalignment tests are additionally performed on engine test rigs, to prove the robustness of bearing types. Here, wear tests are performed under a misalignment of the shaft of 40 µm which is generating an unsymmetrical load at one bearing edge and leading to local overload, enforcing seizure, **FIGURE 5** [3]. Even in this harsh test, the new lead-free second generation displayed its excellent tribological properties for critical running conditions while the same performance as for lead bronze material Miba 01 has been achieved.

SUMMARY AND OUTLOOK

The increase of alternative energy production and emission regulations drives increasing power density in gas engines and a change in the operating conditions; with many more start and stop events. The consequence: increasing demands in higher loadable bearing types capable of dealing with an increasing amount of mixed friction.

Miba has developed a new second generation of lead-free bronze, offering excellent robustness, excellent fatigue strength, and long-term oil robustness. The first bearing types have been successfully tested on bearing test rigs and in the first prototype engines. Parts are available now for all gas engine sizes, for small end connecting rod bushings as well as for big end connecting rod bearings and the main bearings for engine tests.

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