

Electro Magnetic Pulse Technology for hydrodynamic plain bearings – Insights into an innovative coating technology.

Topic: Manufacturing aspects

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Introduction

In a global competition, cost reduction is key. This begins with the system's design, where - besides functionality - cost is the primary parameter. Hence, for an optimal system, the cost structure is also imperative. Usually, two approaches contribute to that: cost-down or power-up. Especially in the latter case, hydrodynamic plain bearings can contribute significantly. On the one hand, hydrodynamic plain bearings require minimal design space. On the other, these machine elements offer high load-carrying capacity and unlimited lifetime under hydrodynamic operation.

In this contribution, we will delve deeper into the technology of hydrodynamic plain bearings, their conventional production methods and how advancements in manufacturing enable high-performance and highly integrative hydrodynamic plain bearing solutions. Special focus will be placed on electromagnetic pulse technology and its validation.

Technology of hydrodynamic plain bearings

In hydrodynamically acting plain bearings, a lubrication gap separates the two surfaces of the bearing partners -shaft and housing or gear, see Figure 1. The hydrodynamic pressure depends on rotational speed, load, and lubricant properties, particularly viscosity. The supply system can be designed in such a way that existing low-pressure pumps can be used, enabling easy integration of hydrodynamic plain bearings (HPBs).

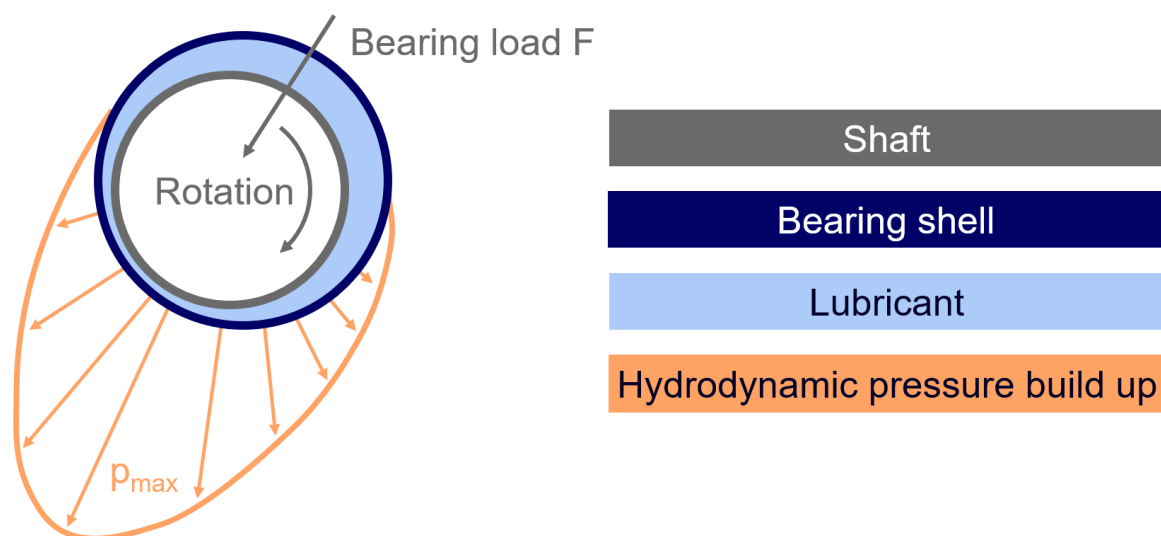


Figure 1: Principle of a hydrodynamic plain bearing

In high-performance drivetrain systems, HPBs - typically in radial design - consist of bearing shells or bushings that meet the requirements for compact construction. Combined with the hydrodynamic operating principle, HPB technology offers advantages such as increased service life, reduced total operating costs, low noise emissions, good damping characteristics, weight savings, high permissible sliding speeds, high load-carrying capacity, and excellent shock load tolerance. To meet the wide range of requirements, Miba relies on a multi-layer bearing structure, as shown in Figure 2. The individual layers and their interaction ensure that the bearings meet the required specifications and deliver the desired performance, distinguishing them from conventional HPB technology. The integration of HPBs is usually done via a thermal press-fit.

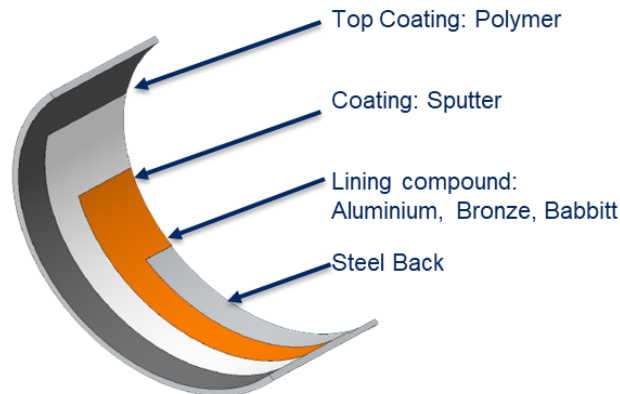


Figure 2: Multilayer bearing

Conventional production methods

Hydrodynamic plain bearings are usually made of tribologically beneficial materials or alloys like white metal, copper- or aluminum-based alloys. Besides the chemical composition, it is of utmost importance to ensure the necessary microstructure in order to allow the material to act as a tribologically beneficial material. To create such a multilayer structure as described above, a wide range of technologies from the following areas have become established over the past decades:

Casting Technology:

The casting process is primarily used in plain bearing production for manufacturing bushings via centrifugal casting and for producing strip material via strip casting.

Forming Technology:

Forming-based production of plain bearings mainly refers to the manufacturing of half-shells or bushings from strip materials using bending processes, as well as the production of bi-metal plain bearing materials via roll cladding.

Coating Technology:

To further enhance performance, additional coating processes such as sputtering, electroplating, and polymer coating can be applied.

In summary, traditional manufacturing processes are multi-stage and well proven. They face limitations when geometric complexity increases. In this case direct coating processes reveal their strength.

Direct coating as high performance and highly effective solution

The direct coating with bearing material enables components with high load carrying capacity, minimum design space and complex geometry deviating from standard cylindrical bearings. It allows integration of bearing functionality in moving parts or their respective counterparts (e.g., shafts or housings), therefore optimizing complete systems. Full utilization of these advantages is only possible by using materials that offer the necessary tribological properties. While direct coating processes are already used for standard material grades, the processing of tribologically enhanced alloys has not yet been possible. This is why Miba is developing coating processes to produce the demanding microstructures that enable high-performance bearing systems beyond conventional materials.

The electromagnetic pulse technology (EMPT)

One possibility to overcome this issue is to apply premanufactured bearing material with desired tribological characteristics without thermal influence on the part. This can be realized by the electromagnetic pulse technology (EMPT), a joining method in which two materials are bonded through plastic deformation - commonly referred to as “crimping.” In this process, the component to be coated (the **substrate**) is placed together with a thin-walled sleeve (the **bearing material**) inside a coil, as shown in Figure 3. In a preceding manufacturing step, a structure (e.g., a knurl) is embossed onto the surface of the substrate.

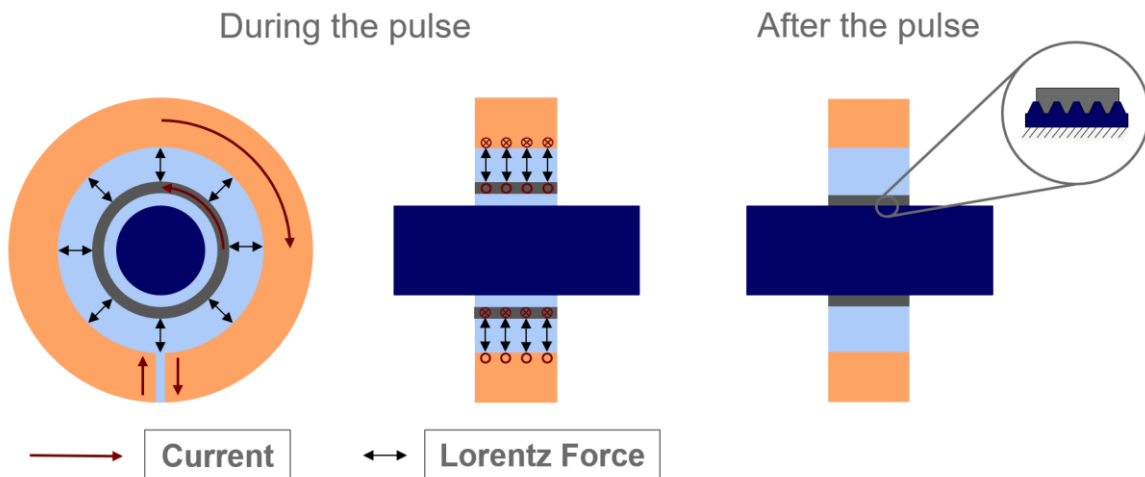


Figure 3: Principle of the EMPT

During the joining process, a radial Lorentz force acts on the sleeve, accelerating it towards the structured surface. Due to the high acceleration, the sleeve undergoes plastic deformation and conforms to the embossed structure, creating a mechanical interlock between the two materials. The resulting bond relies entirely on this form-fit connection for its functionality.

The individual process steps are illustrated in Figure 4. In the first two steps, a thin-walled bushing is manufactured, and the surface of the substrate to be coated is structured accordingly. In the third step, the two components are joined using electromagnetic forming. Finally, the directly coated shaft undergoes finishing in the last process step, tailored to the specific application and customer requirements.



Figure 4: EMPT Process steps

As part of the development work, tribological tests were carried out on crimped shafts both on internal test benches and on real demonstrator components for a wind turbine.

Tribological characterization

For the internal tests, specimens were coated with three different bearing materials and subjected to a testing campaign on a Miba internal bearing test bench simulating the bearing loads of a main planetary gearbox in a wind turbine. Exemplarily, one test sequence out of the campaign is shown in Figure 5.

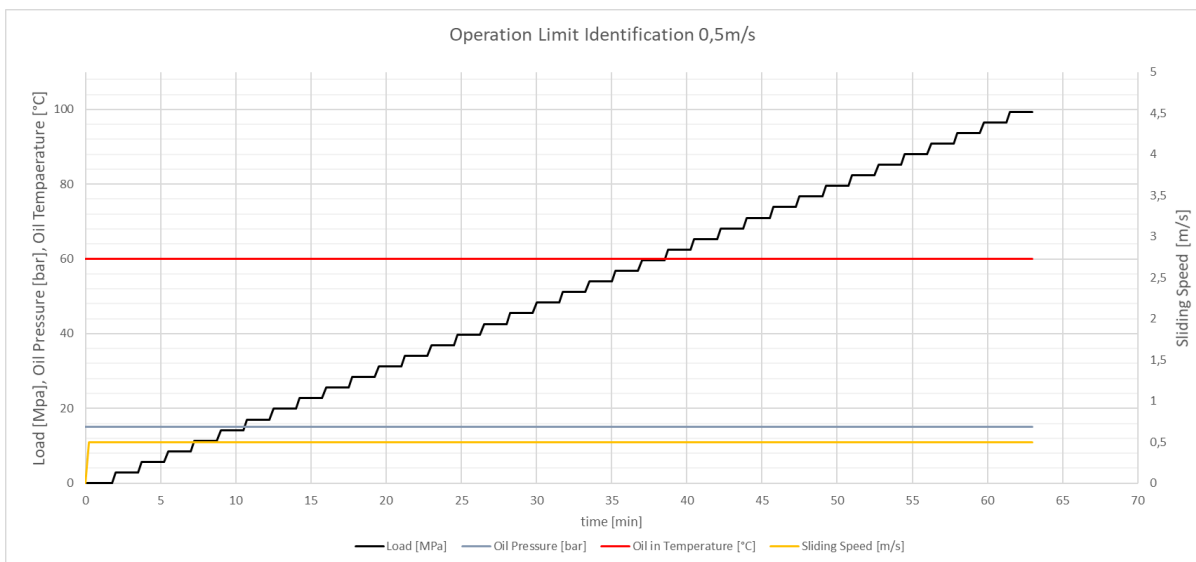


Figure 5: Operational limit identification for a wind main gear box planetary stage 1

The tested bearing alloys included two high-performance materials - one being an aluminum-tin alloy already established in wind turbine gearboxes, and the other a new lead-free bronze alloy called InnoAlloy - compared against a standard CuSn12Ni2 alloy. The results demonstrate that the required performance criteria can be met with a crimped bearing solution and that Miba's bearing materials outperform the standard alloy significantly. Figure 6 presents a comparison between the Miba AlSn25 alloy and the standard CuSn12Ni2 alloy based on the visual assessment

of the running surface. Both test specimens were subjected to identical tribological tests, allowing for a direct evaluation of wear characteristics.



Figure 6: Optical appearance of AlSn20 (left) and CuSn12 (right) specimen after load limit identification at 0.5m/s in comparison with untested specimens.

This innovative solution has also been successfully qualified under real operating conditions. Three demonstrator components have successfully completed a validation test on a real size gearbox, confirming the reliability of tribological performance. This step is crucial, because it introduces additional influences such as geometry, assembly conditions, and real operating environments. Figure 7 shows the contact surface of an actual crimped pin for a Wind GBX after successful validation.



Figure 7: Crimped pin after GBX validation test

Characterization of the contact zone

Customer feedback and internal development initiatives prompted further investigation into the behavior of the contact zone between the bearing material and the substrate. To verify the load-carrying capacity of the crimped interface and support further validation and optimization, a physical qualification method was developed.

The methodology for characterizing the crimp connection is based on a two-part test pin with a structured surface, as illustrated in Figure 8. The two halves of the pin are joined by crimping with a bearing sleeve, forming the final test specimen. By applying axial forces or moments to the ends of the specimen and recording the displacement, the connection can be analyzed using a stress-displacement diagram.



Figure 8: Split-shaft setup for mechanical characterization

The investigations include both static and dynamic tests at room and elevated temperatures. Additionally, a simulation model is being developed in collaboration with the Institute of Technical Mechanics at Johannes Kepler University. An overview of all the tests performed is shown in Figure 9.

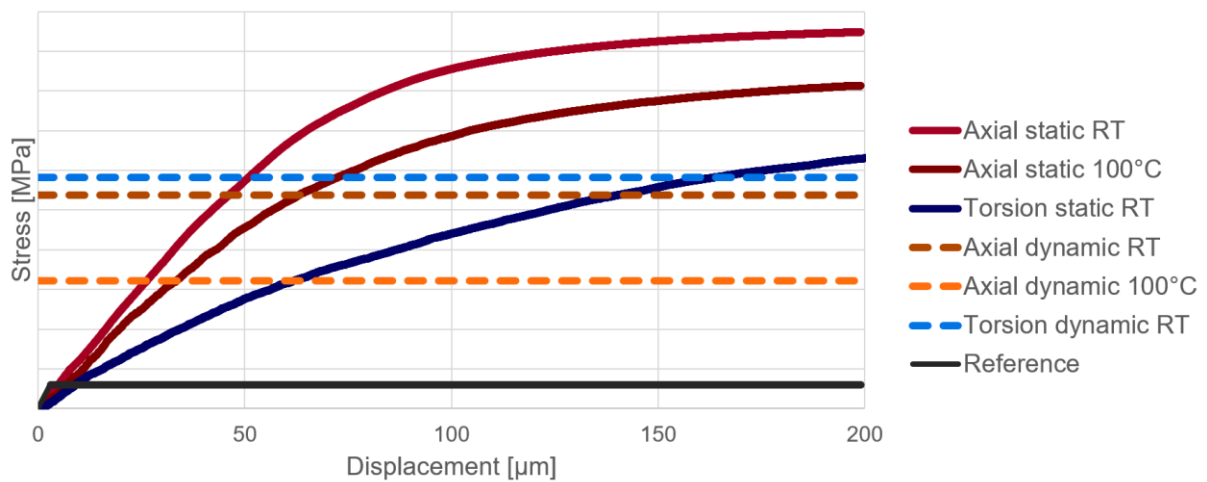


Figure 9: Overview of the test results

For the purpose of comparability, reference measurements were conducted on a thermally assembled press fit (steel–steel), representative of configurations commonly used in the assembly of rolling bearings or bushings. The results from the quasi-static tests indicate that the crimped joint is capable of sustaining significantly higher load levels compared to the current standard solution. Even at an elevated operating temperature of 100 °C, only a moderate reduction in load-bearing capacity of approximately 10 % is observed.

The outcomes of the dynamic tests are illustrated by the horizontal lines in the diagram. These lines denote the maximum load level at which continuous cyclic loading was successfully maintained while exhibiting a stable stress–strain response. Notably, even under the most demanding conditions, including dynamic loading and elevated temperature, the crimp connection demonstrates the ability to transmit loads several times greater than those achieved by the reference system. This clearly highlights the superior performance and robustness of the crimped joint under highly demanding operational conditions.