27th ABCM International Congress of Mechanical Engineering
December 04-08, 2023, Florianópolis-SC, Brazil

COB-2023-2320 – AEROSTATIC BEARING APPLICATION FOR ROTATING MACHINES – 27th COBEM

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Abstract. *This project aims to develop and test a low-cost air bearing, identifying its load capacity and possible applications in various rotating machines. The intention is to significantly reduce energy dissipation due to friction. Air bearings is considered a promising solution in the current scenario of growth of the sustainable energy sector, more specifically in wind generation. For this, stages of analytical dimensioning and 3D computational. All the steps of the project will be carried out at the teaching institution (CEFET-RJ Campus Nova Iguaçu). Through such analyses, it is expected to obtain a low-cost bearing, but of high durability, which can be safely applied in various rotating machines, thus contributing to the reduction of costs and improvement in energy efficiency. The results of this project will contribute to the technological development of the area of rotating machines, allowing the obtaining of more efficient machines with the use of this new air bearing.*

Keywords: *Wind energy, air bearing, rotating machines, low cost, energy efficiency, durability*

1. INTRODUCTION

The most of rotating machines and machine tools have mechanical components common to each other, known as machine elements, for example, bearings, pulleys and belts, shafts and among other machine elements that make up the various machines already created in the most varied ways functionalities, from aircraft engines to cold storage coolers and large CNC (Computer Numerical Control) lathes to simple vacuum pumps. The proper functioning of these machine elements is directly related to the performance and useful life of each component, ensuring that the machine elements work correctly and with excellent performance, in line with other operating factors, ensuring better operating efficiency and greater longevity.

Owning machines that generate fewer maintenance stops and increase production is essential for the sustainability of any company in the face of the commercial market that every year becomes more competitive. Specifically, bearings and bearings, are present in all rotating machines, despite being well-known and studied machine elements, they still have many opportunities for improvement for various applications, whether critical or not, and using their various configurations.

Improving the operational and performance conditions of these machine elements is of great importance for engineering, companies and the academic community, as the benefit will be mutual between the parties that use these mechanical components.

2. METHODOLOGY

2.1 Context

Aerostatic bearings have an operating principle based on the shaft floating on an air film. Aerostatic bearings can operate at high speeds and at high temperatures. Its operation under normal design conditions means that the component has a long service life, as it has virtually no friction in the system. This condition ensures that the component does not wear out and does not suffer temperature effects. Despite their high cost of implementation, each year aerostatic bearings are more used in industry, where they require high precision and easy maintenance equipment (GAO et al., 2019). In addition to these benefits, these types of bearings are environmentally friendly, as they generate less noise, and their lubricant air, can be disposed of in the environment without negative impacts (BALESTRERO; PURQUERIO, 1991).

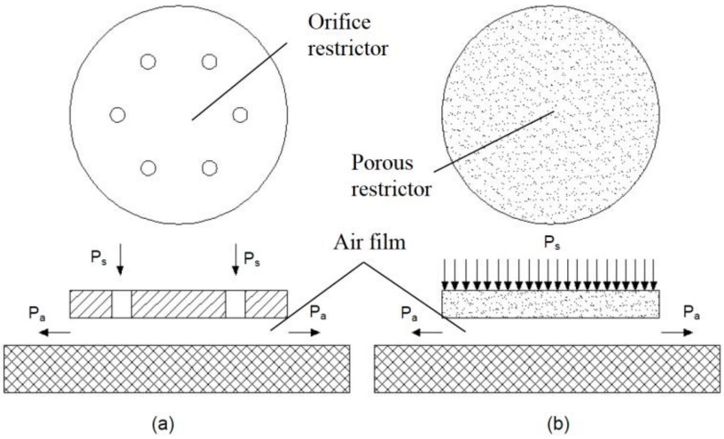

Figure 1 – Basic structure of an axial aerostatic bearing with an orifice restrictor (a) and a porous restrictor (b). Ps = air supply pressure; Pa = atmospheric pressure.

Aerostatic bearings are not recommended for conditions where there are high loads. The thickness of the air film is responsible for supporting loads, but this same thickness cannot be great due to the escape of air to the external environment and thus requires a greater replacement in the system. In this way, it can be concluded that the mass air flows through the supply holes resulting from the external supply are the only ones responsible for the formation of the lubricating film and the respective load capacity of the bearing (SILVA, 2015a).

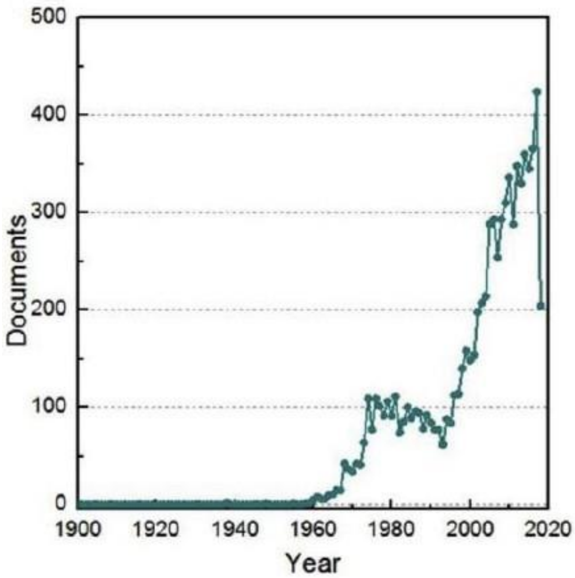

Figure 2 – Journals published vs year.

Although it is still a bearing configuration with a high implementation cost, in recent years the number of publications on the subject has grown exponentially. This data reveals the search for improvement in this type of bearing configuration in recent years.

The discovery of air as a lubricant occurred in 1828 when Willis experimentally verified the flow of air between two flat parallel surfaces (WILLIS, 1828), and at the end of the 19th century, Kingsbury studied the support characteristics of an air-lubricated bearing. Since then, many patents on gas-lubricated bearings were issued in the early 1900s (KINGSBURY, 1897).

2.2 Applications

The rotating machines in their entirety have bearings, whether they are roller bearings, ball bearings, or any other configuration that meets the needs of the operation. Before, processes that were considered complex, today are already well known and controlled. This is how the engineering demand for the various machine designs for the current industry works, the aerostatic bearings appear as an alternative for processes that are considered complex, that have a special of operation and that need superior performance components than those already available.

The segments of mechanical manufacturing, metrology, wind energy and medical equipment are the ones most interested in development and the ones that most use aerostatic bearings in their operations. All these segments have a common factor, they value the quality, efficiency and precision of their processes. The mechanical manufacturing segment is specifically directed at the aerospace industry. Metrology and the medical equipment segment also need more accurate equipment, guaranteeing the quality of their operations and in addition to preventing possible contamination of the process, when compared to bearings lubricated with petroleum products. The wind energy segment increasingly needs components that have a very low maintenance rate and low cost, this condition improves the process, guarantees a better efficiency of its operations and reduces the costs with maintenance stops and other unwanted stops generated due to low-performance component failures.

2.3 Theoretical Basis For Model

The design and modeling of aerostatic bearings requires advanced knowledge in hydrodynamics, fluid mechanics and calculation, in addition to the use of software to aid in simulations and optimizations.

Some theories and equations are addressed for modeling aerostatic bearings. It is necessary to know each of these equations for better use of operational conditions and interpretation of the data obtained.

Bernoulli Equation: The Bernoulli equation describes the relationship between the pressure, velocity, and altitude of a moving fluid. It is used to analyze the fluid flow in the space between the shaft and the aerostatic bearing.

$$\rho V g h_1 + \rho V \frac{v_1^2}{2} + P_1 V = \rho V g h_2 + \rho V \frac{v_2^2}{2} + P_2 V \tag{1}$$

Where ρ, V, g and h are the specific mass, volume, acceleration of gravity and height, respectively, and V, v and P are the volume, velocity and pressure, respectively.

Reynolds transport theorem: The Reynolds theorem is used to describe the flow behavior of viscous fluids around the shaft and aerostatic bearing. It takes into account the viscosity of the fluid and the geometric characteristics of the bearing to determine the behavior of the air film that supports the shaft.

$$\frac{\partial N}{\partial t} = \frac{\partial}{\partial t} \int_{VC} \eta \rho \partial \forall + \int_{SC} \eta \rho \vec{V} \cdot \partial \vec{A} \tag{2}$$

Where N, t, VC and η are the extensive property, time, volume control and intensive property, respectively, and $\forall$, SC, $\vec{V}$ and $\vec{A}$ are the volume, surface control, velocity and area, respectively.

Navier-Stokes equation: The Navier-Stokes equations are differential equations that describe the motion of viscous fluids. They are used to solve the velocity and pressure profiles of the fluid inside the aerostatic bearing, taking into account the boundary conditions and the physical properties of the fluid.

$$\rho \frac{D\vec{V}}{Dt} = - \nabla p + \rho \vec{g} + \mu \nabla^2 \vec{V} \tag{3}$$

Where ∇ and μ are the pressure gradient and viscosity, respectively.

Reynolds Equations: Reynolds equations are used to estimate the drag forces and support forces acting on the shaft in the aerostatic bearing. These equations consider fluid properties, flow velocity and bearing geometry.

$$Re = \frac{\rho V D}{\mu} \tag{4}$$

Where Re and D are the Reynolds number and diameter, respectively.

2.4 Restrictors

Aerostatic bearings are constructed by airflow restrictors. Restrictors are responsible for forming a thin film of pressurized air over the axle. Just as bearings can have different configurations, restrictors can be manufactured in several other restrictor configurations, but they have two classifications. Restrictors can be classified as orifice or porous restrictors, as seen in Figure 1.

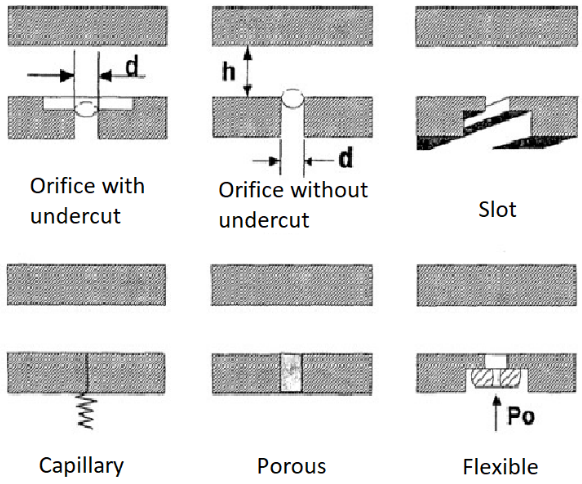

Figure 3 - Types of restrictors

In bearings with orifice restrictors, the airflow runs through holes and/or channels present on the inside of the bushings. Orifice restrictors can still be classified as pocket or capillary (FOURKA; BONIS, 1997). This type of restrictor configuration is the most used, but this type of configuration may present failures in the uniformity of the air film.

Orifice restrictor aerostatic bearings can be plain or cylindrical. This type of configuration is widely used in high-speed and precision machine tools, measuring and laboratory equipment, due to its advantages of being used in clean rooms, with low friction and high efficiency. However, these bearings have some disadvantages in terms of load capacity, rigidity and thermal expansion due to the gap between the surfaces and the compressibility of air. ((CHEN et al., 2010))

In turn, the porous restrictors guarantee the bearing an excellent performance due to the uniformity in the formation of the air film and the stability of the pressure acting in the system, since the porous surface works as several acting holes of smaller diameter. Even though they are more complex to work with, porous restrictors are a great alternative for maximum performance.

The bearing consists of a porous insert acting on an impermeable surface. The insert can be built in rectangular, quadrangular, circular or even annular shapes. The impermeable surface is generally the sliding guide, having as requirements an excellent surface finish and flatness, on which the bearing acts reducing friction and, consequently, allowing the smooth and precise movement of the equipment parts.

Gas, usually atmospheric air from a pressurized air supply system, is introduced at constant pressure to the upper surface of the porous insert. As the porous material acts as a restrictor, the pressure drops to the extent that air flows through the pores until it leaves the porous medium and flows through the bearing clearance and the air is expelled to the atmosphere.

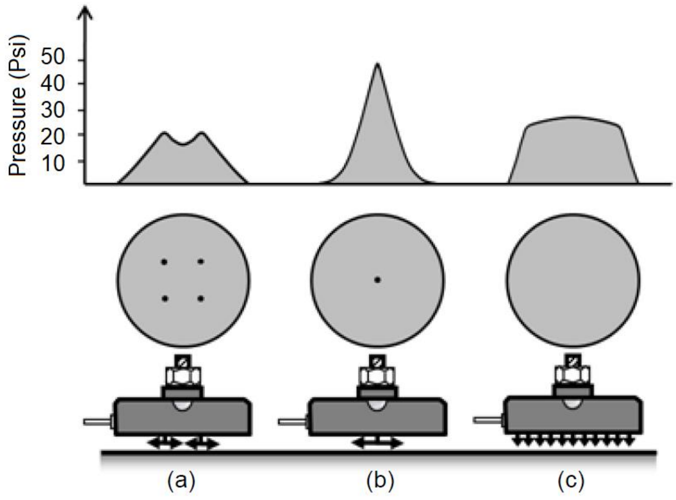

Figure 4 – Restrictors vs Pressure Profile.

As previously mentioned, the use of aerostatic bearings has several points of interest and advantages for engineering, as well as some disadvantages. Some of these advantages and disadvantages are:

Advantages:

- Elimination of contamination commonly caused by lubricating oil;
- Possibility of reducing or eliminating the need for seals in bearings;
- Lubricant stability. No vaporization, cavitation, solidification or decomposition at outside temperatures;
- Low friction and heating, generally no cooling. Allows applications on equipment with very low rotations, or even zero rotation.

Disadvantages:

- Fluid has low viscosity, therefore reduced load capacity;
- Low damping factor of the fluid film;
- The bearing must be manufactured with reduced gaps to allow a satisfactory load capacity;
- The manufacturing process must be precise and with control of manufacturing tolerances, surface finish, alignment, and thermal and elastic distortions.

3. SUGGESTED MODEL

The proposed model will be mounted on a base for a rotating machine already available at the CEFET/RJ (Federal Center for Technological Education Celso Suckow da Fonseca) laboratory. The bearing will be designed for a 10x400 mm shaft for a working pressure between 5-7 bar and rotation between 3000-15000 rpm. These are the operational conditions available in the CEFET/RJ laboratory.

To reduce costs, the project aims to replace the materials of the bearing components with materials of lesser value and greater accessibility, ensuring good efficiency during operation, initially, polymeric materials will be used in manufacturing.

Several studies with test specimens are being developed with the use of polymers in the manufacture of bearings. PTFE (Polytetrafluoroethylene) is one of the materials for this type of project in plain-bearing bushings. According to (SANTIAGO, 2018) for bearings made of PTFE, the ovality results are less than 1% compared to conventional industrial processes. Bushings made from pure PTFE have similar results.

Although several studies are underway for the development of bearings made from polymers, the great challenge is for this material to be able to withstand operating vibrations. The ability to withstand these vibrations depends on several factors such as elasticity, stiffness, density and damping.

The major problem in the use of polymeric materials is the low stiffness. Another material used in the manufacture of bearings is polyurethane. This one has more rigidity.

The stiffness of the material is related to its resistance to deformation. Rigid materials have a more rigid molecular structure, that is, these materials do not easily deform when subjected to external forces. Therefore, they tend to have lower vibrations.

Combining the characteristics of the two materials mentioned above, the bearing structure will be made of polyurethane and the bushing will be made of PTFE. These components will be manufactured in a 3D printer and their structure and molecular organization will also be evaluated as performance criteria for the project.

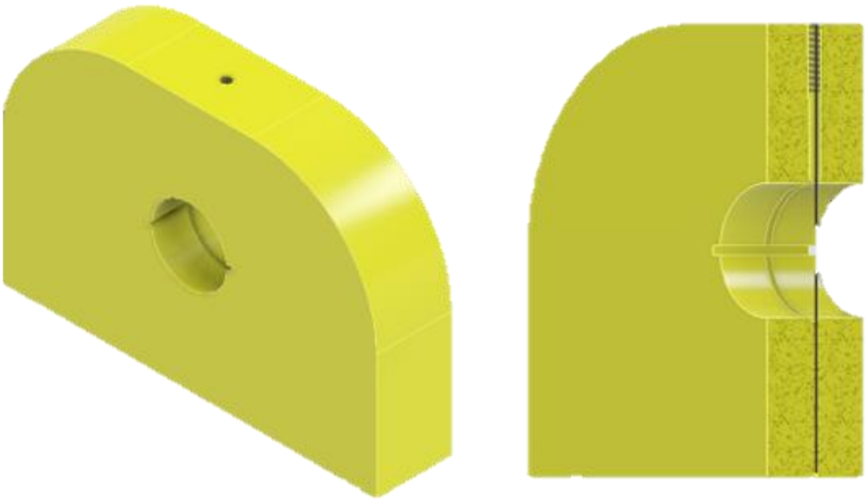

Figure 5 - Bearing polymeric structure.

The bearing bushing will have a cylindrical geometry, aiming at a better performance in view of its characteristics. Cylindrical bushings are the most used because they are more practical for installation. This type of bushing provides a greater contact area, providing a more uniform air film, but greater precision is required in its manufacture. Spherical bushings allow conditions of axial movement and misalignment, but have a smaller contact surface. A smaller contact surface does not guarantee a uniform air film, but this configuration does guarantee a lower wear rate.

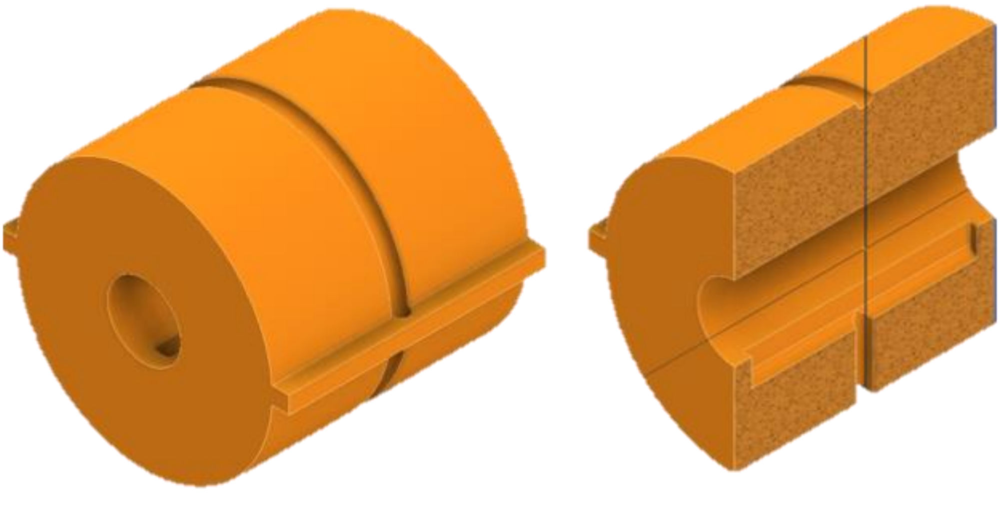

Figure 6 – Polymeric cylindrical restrictor.

The restrictor will be of the pocket type with a recessed hole. The air inlet will be through the upper part of the bearing and the air distribution through internal side cavities in the bushing.

To reduce vibration, the bearing will have a rounded steel casing for better fixation. This shape provides a more uniform pressure distribution, reducing pressure spikes, vibration and improving bearing stability.

Elastic rings will be used in the inputs and outputs of the bearings for axial locking to avoid misalignment and risks under operating conditions. More details of the model can be seen in the fabrication drawings in the Appendix.

The great difference of this project is the use of polymeric materials for both the bushing and the bearing structure. As previously mentioned, several studies with test specimens were carried out using polymeric materials for bearings, but this project aims to apply polymeric materials in practice and for aerostatic bearings.

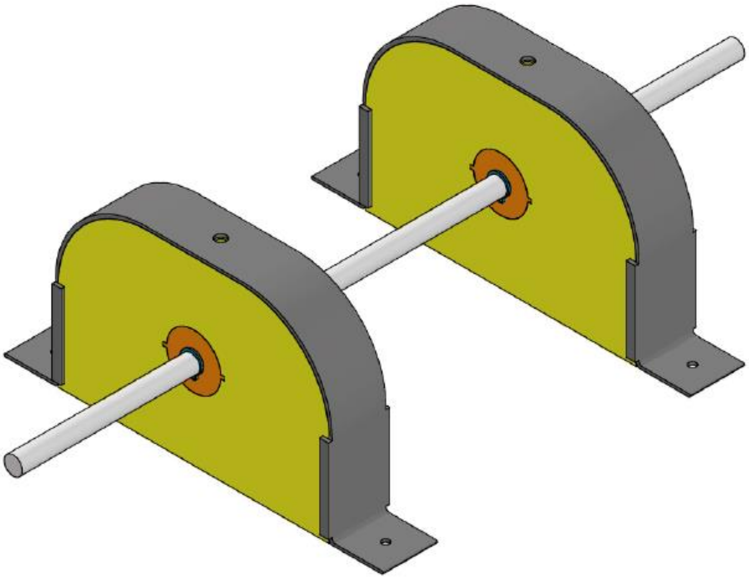

Figure 7 – The proposal model.

4. COST

The use of 3D printers in industry has grown exponentially, precisely due to their low production cost and quick project delivery. Although 3D printers still have a high acquisition cost, with values of around R$ 1.000,00 for home use and R$ 500.000,00 for professional use, 3D printed projects are still more economically advantageous, since, when compared for machining machines these values are more attractive.

The cost of 3D printing using PLA (Polactic acid) is on average R$ 40,00 per gram. This value may vary depending on the type of material chosen for printing, the form of material, which can be filament or resin, and the percentage of completion of the project.

The use of 3D designs for this type of project is very important, as we are making the transition from a metal machine element to plastic. It is important that the model will have to undergo some changes during the development of the prototype and several impressions will be necessary until a satisfactory result is achieved.

5. CONCLUSION

The industry is always looking for better results in the short term. The development of innovative projects that bring cost reduction results to companies is essential for market competitiveness and the quality of the service/product offered.

The use of aerostatic bearings has several benefits, but their implementation still requires a high investment. The proposed model aims to considerably reduce the high cost and complexity of implementing this bearing configuration.

The assistance of the 3D printer is of great importance for the reduce cost of developing the project and for the production of the proposed model. 3D printers are fundamental tools for the industry 4.0 project journey, where it is necessary to connect machines and deliver better and faster results.

Finally, cost reduction projects will always be attractive to the industry and research in this area is fundamental for market competitiveness and quality of company delivery.

6. ACKNOWLEDGMENTS

The authors would like to thank CEFET/RJ - UNED Nova Iguaçu for their support and resources.

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