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Hydrodinamic cylindrical journal bearing for experimental validation of numerical models

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Abstract. *Cylindrical hydrodynamic journal bearings are elements of rotating machines with a wide range of applications, from small engines to large turbo generators. Its operation is based on the principle of a thin film of oil that promotes the separation between a rotating shaft and the bearing, preventing contact between the surfaces. This work aims to present the design and tests of a radial cylindrical bearing used in the experimental validation of a numerical model. This models is capable to estimating the pressure field and temperature field of the oil film subjected to different operating conditions and different lubrication regimes. So, to monitor the oil film temperature along the bearing surface 16 thermocouple sensors distributed equally spaced along its circumferential length were used. This same scheme was also adopted for the acquisition of pressure data, with 16 pressure transducers distributed similarly to the scheme for temperature measurement. Communication between the sensors and the fluid takes place through a small hole in the bearing surface. According to the tests already carried out, it was possible to verify the correct functioning of the bearing and its ability to provide accurate data of the monitored variables.*

Keywords: *Hydrodinamic bearing, test rig, experimental design.*

1. INTRODUCTION

Hydrodynamic bearings are important elements in rotating machines. Its function is to support rotors subjected to different operating conditions in relation to the load and rotational speeds. The main application of hydrodynamic bearings are: turbines, combustion engines, compressors, reduction and amplification boxes, generators and others machines.

Commonly used in large rotary machines, among their main advantages include the high load capacity of hydrodynamic bearings. is important It should be noted that, due to the presence of the oil film, the damping effect on bearings hydrodynamics is more accentuated than in roller bearings, which is beneficial in machines that go through critical speeds during starts and stops (Barbosa, 2018).

Meggiolaro (1996) states that this type of bearing operates in a so-called hydrodynamic regime because there is formation of the lubricant film that separates the shaft from the bearing without depending on the introduction of fluid under pressure. The pressure on the film is obtained by the movement between the two surfaces at a speed sufficient to separate them (Ramos and Daniel, 2021).

The oil film formed in the hydrodynamic bearings creates a separating layer between the shaft and bearing contact surfaces, ensuring friction reduction, minimizing wear and dissipating the heat generated during operation. In this context oil film pressure plays a critical role in this process. The oil film pressure is one of the fundamental parameters influencing the operation of journal bearings and is estimated by theoretical calculations, since the measurement of oil film pressure has been a demanding task in journal bearings, especially in bearings carrying dynamic loads Ronkainen *et al.* (2009). The pressure generated in the oil film during operation results in the sustaining force of the loads applied to the bearing, which reinforces the importance of this parameter.

Measuring the temperature of the oil film in hydrodynamic bearings is extremely important to ensure the correct functioning of these essential components in machines and equipment. The measurement of the oil film temperature allows monitoring the operating conditions of the bearing and identifying possible problems or adverse conditions that may compromise the performance and useful life of the equipment.Temperatures may be measured relatively easily, but unless the proper location is monitored the temperature measurements made will be very poor indicators of overall bearing performance (Glavatskih, 2004).

An experimental test rig is essential role in the study of hydrodynamic bearings, providing a controlled and reproducible environment to investigate the behavior of these components. Through the experimental, it is possible to simulate real operating conditions, apply controlled loads and monitor the relevant parameters, such as temperature, pressure and wear. This allows for detailed analyses, study of variables and evaluation of different bearing configurations. In addition, the experimental test rig offers the opportunity to test new materials, lubricants and design technologies, enabling continuous improvements in hydrodynamic bearings.

A bearing test rig was developed by Flack *et al.* (1993) to characterize the static and dynamic properties of hydrodynamic journal bearings. Static measurement capabilities include operating eccentricity, pressure and thermal boundary conditions, and continuous circumferential pressure and film thickness profiles at multiple axial planes.

Mitsui *et al.* (1983) in a investigation on the cooling effect of supply oil in a circular journal bearing experimentally obtained temperature distributions on axial, radial and circumferential directions for an axial groove bearing, with good agreement between experimental and predicted distributions.

Du Haut *et al.* (2019) design a test rig suited to investigate the dynamic interaction between rotor and hydrodynamic journal bearings in micro gas turbines. The experimental results are compared with the theoretical results and results are found satisfactorily.

In this work we present an solution to approach for the numerical validation of hydrodynamic bearings using a test rig. Based on solid theoretical foundations, we seek to overcome the limitations of traditional test methods, offering a simple and accurate cylindrical hydrodynamic bearings. Through the development of this test rig, we intend to provide engineers and researchers with a reliable tool to evaluate the performance of hydrodynamic bearings in real operating conditions.

2. Metodology

One of the main requirements for the construction of the radial cylindrical hydrodynamic bearing was a simple design. The ease of manufacturing and assembly is something that directly influences the final product, as one of the limitations found are companies with the knowledge and tools for correct manufacturing. The bearing in question must be split for its complete coupling to the chassis of the workbench. This chassis consists of a rotor mounted on two arms that move longitudinally and pivot at its origin. This configuration guarantees the full control to define the position of the rotor inside the bearing.

Complete assembly of the bearing involve four parts: upper cover, upper pad, base and lower pad. The upper cover and the base are made of steel 1045 and have the structural function of resisting the efforts generated during the operation of the bearing. The upper and the lower pad are the most important parts of the bearing because this pieces are in contact with oil film. They are made of brass, has the groove injection region and inlet holes for the temperature and pressure measurements. The finish for the pad surface is precision ground.

Figure. 1 shows the complete assembly of the bearing. Figure. 2 shows the bearing pad. It is possible to check in detail the inlet holes for temperature and pressure measurement. The holes on the surface are 1mm in diameter and communicate with the side holes of the pad. These side holes are where the thermocouples and pressure sensors will be fitted or connected. One important comment is about the position of surface holes. The centered ones are for pressure measurement because the maximum value of this parameter is located at the center line of the bearing. For temperature measurement there is no necessity to the hole location at the center line because the temperature can be considered constant in axial direction.

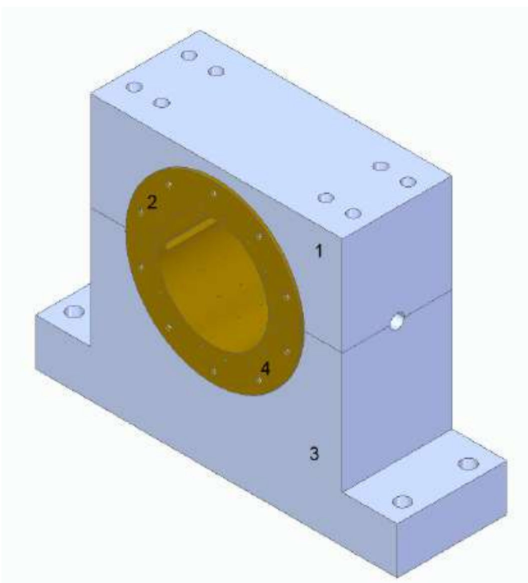


Figure 1. Complete bearing: upper cover (1), upper pad (2), base (3) and lower pad(4).

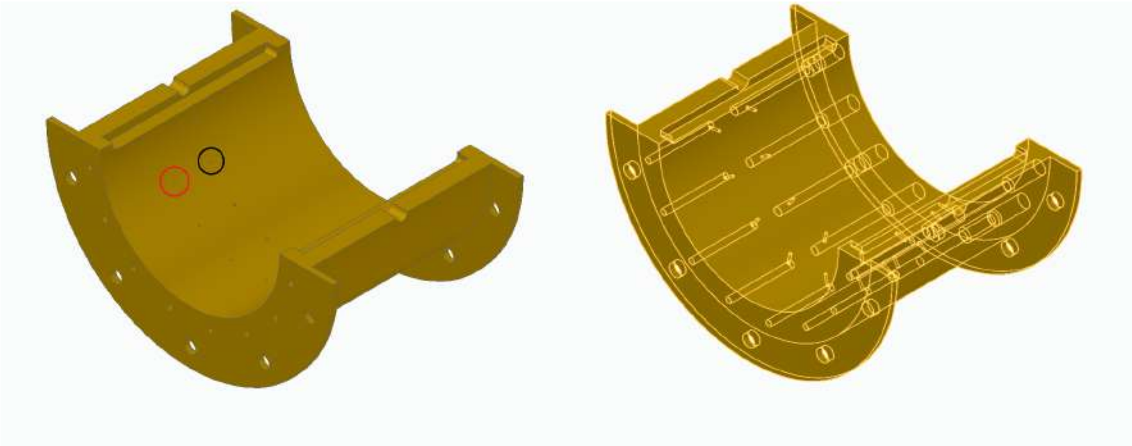


Figure 2. Lef: Red circle shows the inlet for temperature measurement, black circle pressure measurement; Right: communication of surface holes and side holes

The geometric dimensions of the bearing were adjusted for the rotor present in the chassis of the test rig. Through numerical simulation, the radial clearance for the bearing was defined at 0.15 mm, thus, the bearing has a diameter of 100.3 mm. The axial length is 100 mm (L/D ratio = 1). The bearing is a leading edge groove type, the bearing surface was developed with a groove region to agree with this characteristic.

Lubricating oil is supplied to the bearing through a hydraulic unit. The equipment provides two lines with hydraulic hoses that are connected to the bearing. Figure. 3 shows the half of the bearing where it is possible to visualize the injection channels as well as the groove region on the surface of the bearing.

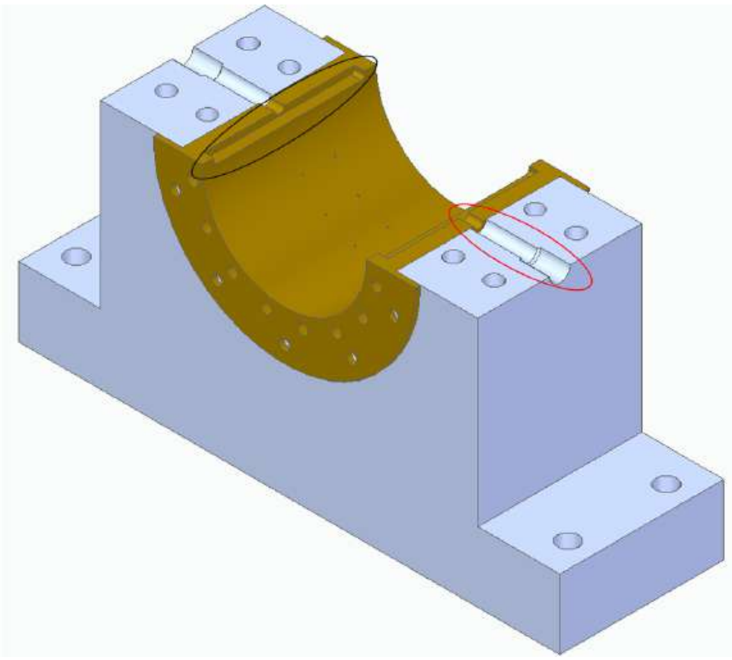


Figure 3. Red circle shows the inlet oil to feed the bearing; black circle points the geometry of the groove region

The sensors used are shown in figure 4. To measure the pressure, a pressure transducer capable of operating in a range of 0 to 40 bar was the choosen, which is sufficient for the proposed validation. A type K thermocouple was used to measure the temperature. The geometric dimensions of the thermocouple allow it to fit with a gap in the lateral holes of the bearing, which allows the flow of the circulating oil that was in the bearing surface.

Figure 4. Left: pressure transducer; Right: thermocouple type K

Temperature measurement in bearings is not trivial. As the numerical models use discretization for the solution of the differential equations involved, it is interesting for the validation to measure the temperature referring to a point. Obtaining a variable in this way would not be possible with a thermocouple attached to the bearing surface, as in this way the measurement would correspond to the temperature of a region of the surface, not a specific point. Glavatskih (2004) proposed a way around this problem. It basically consists of creating a channel allowing the flow of oil from the bearing surface (Fig. 6). The numerical analysis condition assumes steady state, so the oil flow passing through the sensor ensures a more accurate measurement of the temperature at the point.

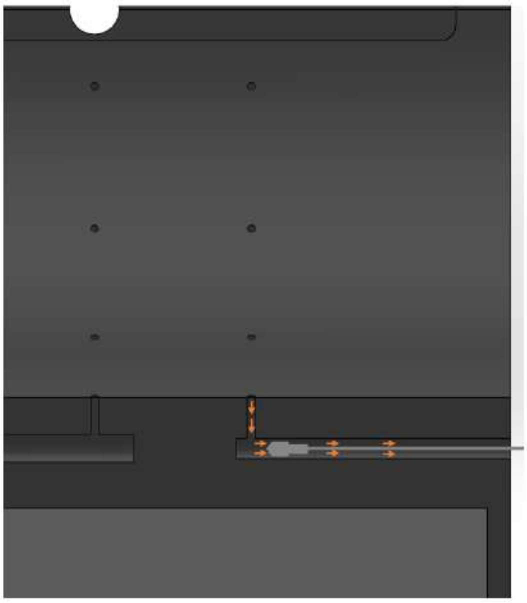
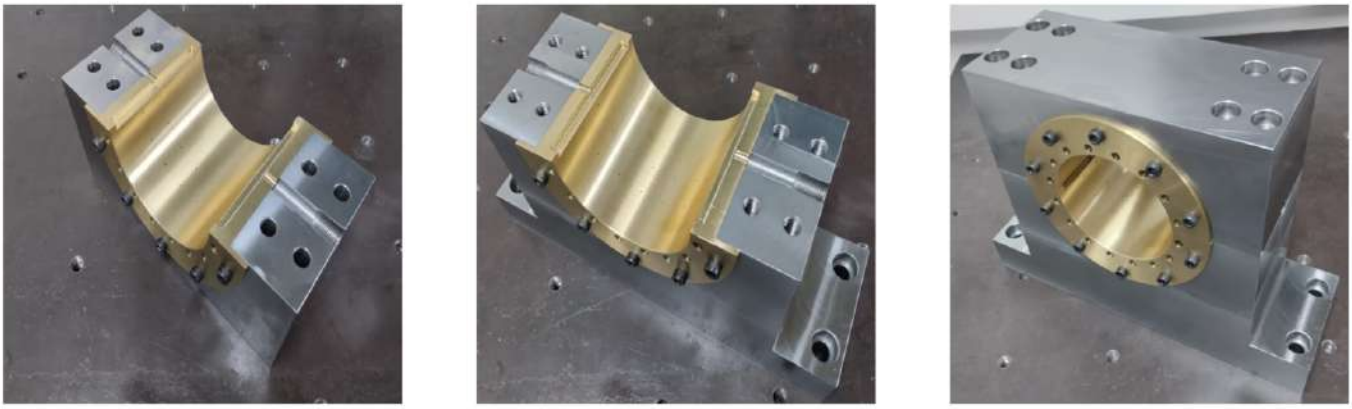


Figure 5. Continuous oil flow coming from bearing surface through thermocouple.

3. Results

After the design and manufacturing stage, the result obtained is shown in the figure. The manufactured bearing fully met our expectations, even providing a good look. The meticulous and precise manufacturing of the ground pad surface resulted in a perfect assembly without corners and burrs, the machining and grinding ensured a precise geometry, reducing any excessive wear and avoiding internal friction.



A B C

Figure 6. A: upper pad fixed to the upper cover; B: lower pad fixed to base; C: complete bearing

The coupling of the bearing to the experimental test rig was carried out without major difficulties. As the entire bearing project was based on its insertion in this chassis, the geometric dimensions were established for this purpose. Figure. 7 shows the bearing mounted on the chassis ready for operation.

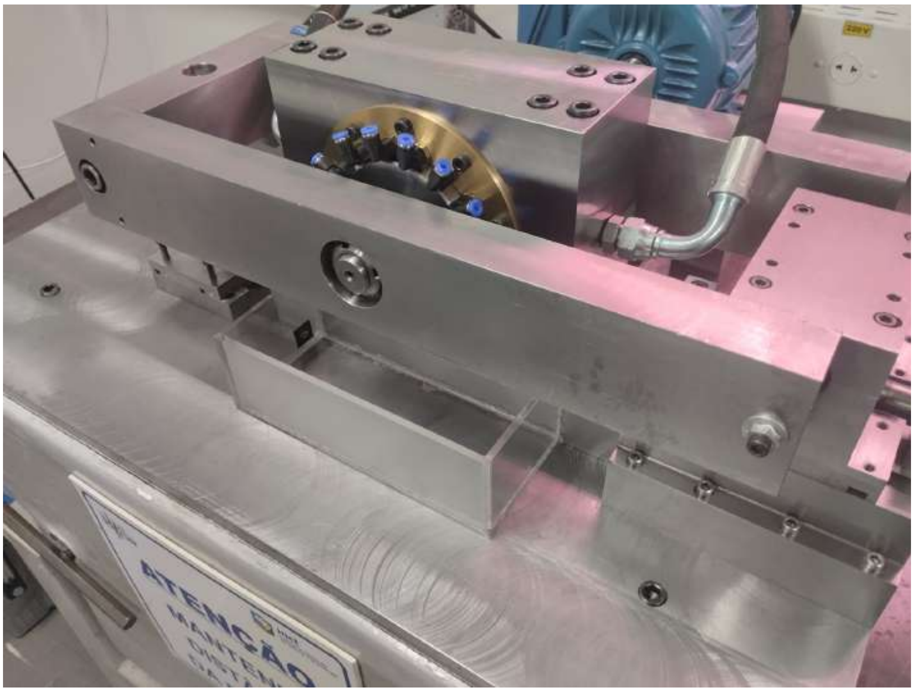
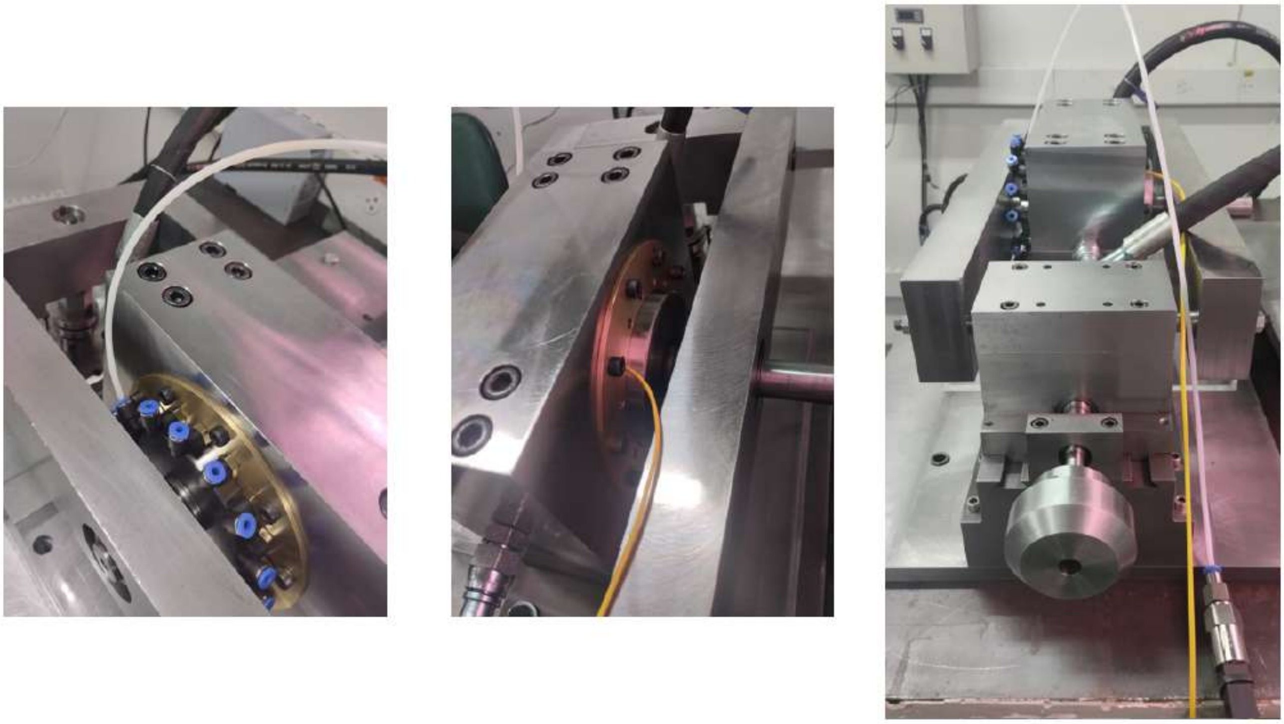


Figure 7. Complete bearing mounted into test rig

The connection of the bearing instrumentation was also carried out without major difficulties. Figure. 8 shows the result of connecting the sensors to the channels designed in the bearing. For a better visualization, only a thermocouple sensor and a pressure transducer were connected. Some tests have already been carried out and the acquisition of signals showed rapid stability, a characteristic that stands out in experiments with hydrodynamic bearings.



A B C

Figure 8. Bearing mounted for measurement with 2 sensors only. A: Pressure point in the bearing. B: Thermocouple location in the bearing. C: side view of the bearing.

The final configuration with all sensors mounted on the bearing is shown in Figure 9. The acquisition of all pressure sensors was done manually using a multimeter (4 to 20 mA signal). The multimeter used was a Tektronix DMM914, professional equipment with adequate resolution for this measurement. The thermocouples were connected to a dedicated acquisition system (Agilent 34970A), where the temperature values are shown on a digital display.

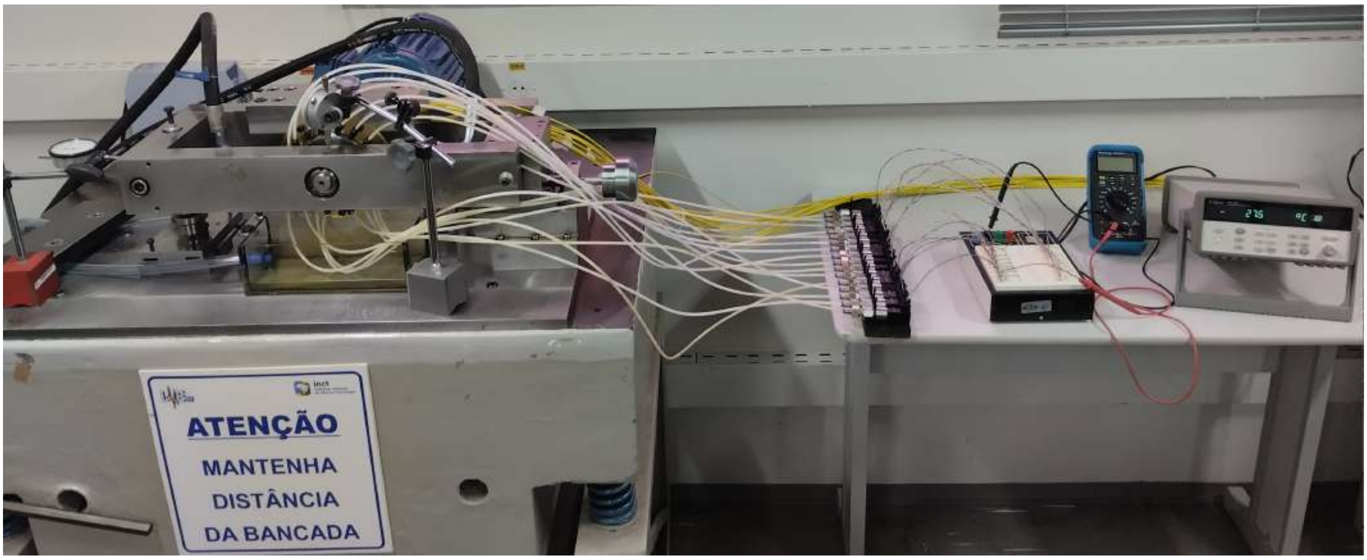


Figure 9. Bearing assembled with all sensors and respective acquisition systems

The results obtained in experiments are shown in the figure. The eccentricity applied to the journal in relation to the bearing was 45%, with an attitude angle of 270° in relation to the origin and the shaft has a speed of 1200 rpm. The position of journal was controlled and measured with a pair of dial gauges mounted in horizontal and vertical position. The oil flow rate for each injection groove was 2L/min and oil pressure was 10 bar. The data was acquired after 2 hours of machine running to ensure a condition close to steady state.

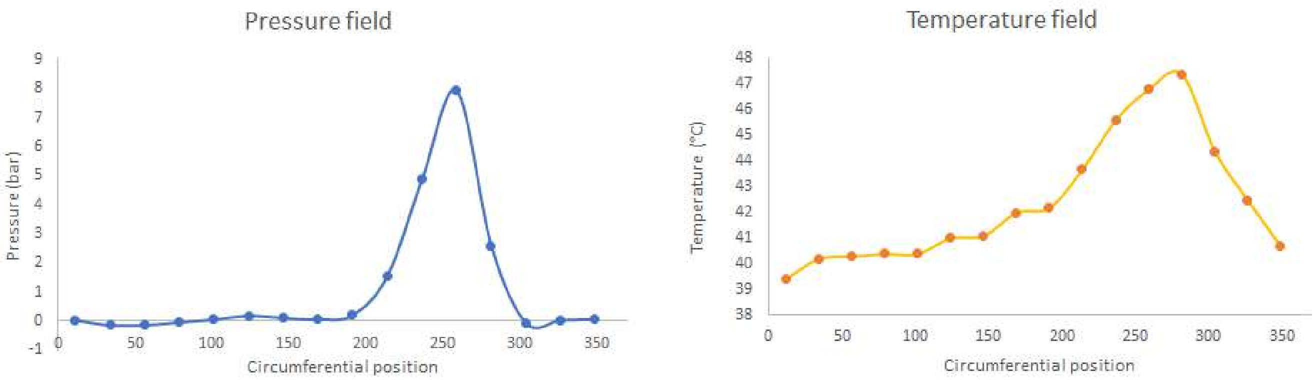


Figure 10. Results of data acquisition of hydrodynamic cylindrical bearing

Data acquisition in the experiment was carried out successfully. Measuring the pressure reading through the multimeter was surprisingly simple and reliable, the sensors have good precision and factory calibration, which made the acquisition of pressure data a step without many problems. Checking the measured values was easy if necessary, just by loosening the sensor and installing a calibrated pointer pressure gauge. The solution used of maintaining an oil flow passing through the thermocouple to temperature measurement was a correct decision. Analyzing the temperature curve, an expected behavior was found, with an increasing temperature gradient in the region of thinnest oil film thickness and its subsequent decrease as this region is surpassed.

4. CONCLUSION

Through a design and manufacturing approach, several technical challenges were overcome, resulting in a high quality hydrodynamic cylindrical bearing with satisfactory performance. The bearing has made it possible to obtain precise experimental data, allowing a detailed comparison between numerical results and those observed in practice.

Its use in numerical model validation experiments contributes to the advancement of knowledge in the area, providing valuable information that can be applied in the design of more efficient and reliable mechanical systems.

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6. REFERENCES

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