Analysis of the Effect of Rectangular Texture on Performance of Journal Bearings with Water Lubricant Using Computational Fluid Dynamics Method

[1]Mohammad Tauviqirrahman, [2]Muchammad, [3]Syahrul Nur Hidayatulloh

[1,2,3]Mechanical Engineering Department, Faculty of Engineering, Diponegoro University, Jl. Prof. H. Soedarto, SH, Tembalang-Semarang 50275, Indonesia

Abstract - **Journal bearings are one of the machine elements that function to reduce friction that occurs in machine components. Journal bearings are commonly used in industry and power plants because they are capable of working at high shaft rotation and large loads. This research focuses on the effect of providing a surface texture with rectangular geometry on the performance produced using water lubricants. The flow of lubricant in the journal bearing is greatly influenced by the condition of the surface texture provided. These conditions will give different results to the journal bearing performance parameters. Several parameters are analyzed as performance comparisons, namely the value of load carrying capacity (load capacity), friction force (friction force), and acoustic power level (noise). These parameters were generated using the Ansys Fluent 3D simulation model. This research shows the differences in the values of the resulting performance parameters. Providing a rectangular texture has the same effect on lubrication as water fluid. The presence of a rectangular texture has been able to increase the load carrying capacity value but also increases noise emissions and friction force values. This research shows the conclusion that not all parameters of journal performance can be improved as a whole and produce the opposite consequences.**

Keywords: Rectangular texture, load carrying capacity, friction force, acoustic power level.

I. INTODUCTION

Journal bearings are a type of bearing that is widely used in industry and power plants. This type of bearing has a simple construction in the form of a cylindrical sleeve with a hole to enter the lubricant used. Journal bearings work by placing a rotating shaft in the cylindrical shell and then inserting lubricating fluid to form a boundary layer between the inner surface of the bearing and the shaft surface (Satish, 2023). This type of bearing has the advantage of being able to work with large loads at high shaft rotation (Lucassen, 2023).
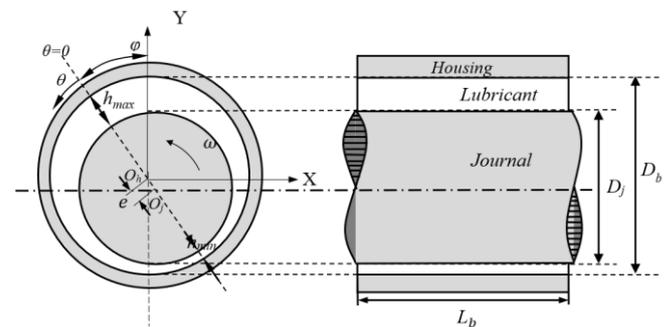

Figure 1: Journal bearing schematic

Figure 1 shows the basic working scheme of a journal bearing where the shaft will rotate in a cylindrical shell which is separated by a lubricant boundary layer. The inclined shaft shifts to the right due to hydrodynamic lubrication.

In journal bearings there is a hydrodynamic lubrication system where there are several stages in journal bearing lubrication. Hydrodynamic lubrication begins when the shaft has not yet rotated, where the shaft does not exert force on the lubricant and is in a position touching the bearing. The next phase is when the new shaft starts to rotate and causes the lubricant layer to move to cover and create a boundary layer between the outer surface of the shaft and the inner surface of the journal bearing. The next phase is that the lubrication has become stable and the shaft tends to shift to the right when the shaft rotates counterclockwise (Ebiefung, 2019). The following is an illustration of the working of hydrodynamic lubrication which can be seen in Figure 2 below:
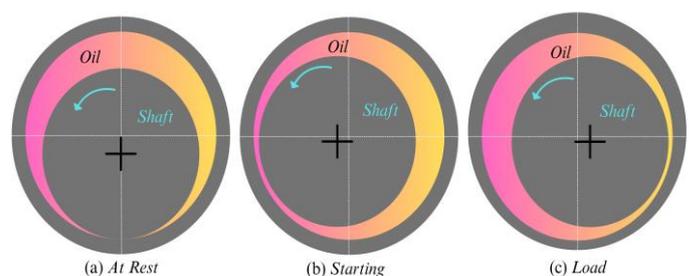

Figure 2: Hydrodynamic lubrication

In journal bearings, cavitation can occur due to a decrease in the static pressure of the lubricant to below its saturated vapor pressure (Lie, 2017). Cavitation appears right when the lubricant comes out of the convergent gap and spreads into the divergent gap of the journal bearing (Sun, 2018). In the cavitation area there are many small bubbles due to the change in the lubricant phase from initially liquid to vapor phase. The size of the cavitation distribution area can affect the pressure and sound acoustics that occur in the bearing (Rasep, 2021). The distribution of cavitation areas can be seen in Figure 3 below:
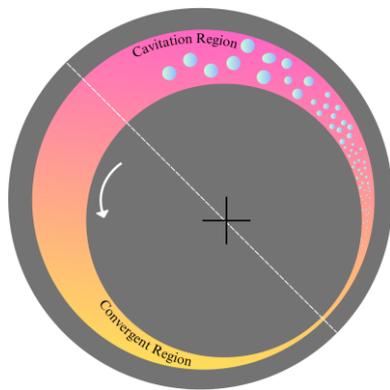

Figure 3: Cavitation region

One of the parameters of journal bearing performance is the load carrying capacity value. Load carrying capacity is the bearing's ability to support a given workload. Various studies have been widely used to increase the value of load carrying capacity, one of which is providing surface texture. Surface texture can increase the load carrying capacity value due to the thickening of the lubricant layer in areas that have the highest fluid pressure (Chen, 2022). The following is the basic load carrying capacity equation used in the Ansys Fluent algorithm:

$$W = \iint_A p\,dx\,dy$$

In research conducted by Tao Nie et.al (2022), partial 2D simulation results of surface texture variations have influenced the performance of a journal bearing. In this simulation, there are several variations in texture geometry, namely rectangular, triangular, trapezoid, and arc. These various variations provide different performance results in each simulation. The highest lubrication performance obtained from the simulation is produced by a surface texture with a rectangular shape. This simulation also produces results from various geometric values of the basic rectangular shape. The parameters used for the geometric values used are the comparison values for the length and depth of the texture. This research is the result of the development of a surface texture simulation in the form of simple roughness with the parameter value Ra (Roughness Average). A simple rough texture on the bearing surface will

basically affect the lubrication performance value of the journal bearing (Tauviqirrahman, 2023). In the construction of bearing surface geometry textures, the placement and number of texture geometries will also change the resulting performance values. This is because the geometric texture in certain areas will have different treatment effects on lubricants that flow hydrodynamically. One of the effects that occur is the thickening of the lubricant film layer. This can increase the collision rate of each fluid particle and increase the resulting pressure value (Arif, 2021). The following are the pressure values resulting from various surface texture models shown in Figure 4 below:
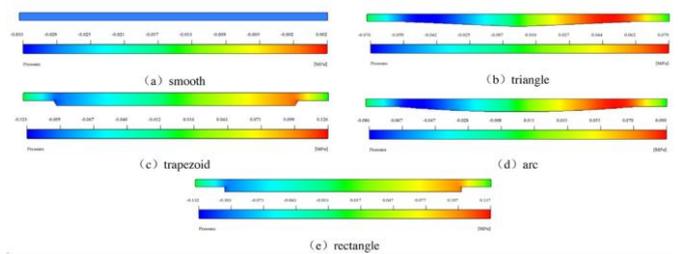

Figure 4: Pressure value on surface texture variations

Figure 4 shows that the pressure value with the rectangular texture model has the largest value. Research conducted by Tao Nie et.al (2022) used oil fluid as a journal bearing lubricant. This is because oil is a fluid commonly used in bearing lubrication systems. Referring to this, the author wants to know whether there are similar changes when using the simulation model with lubricants other than oil. One lubricant that is an alternative and has been widely researched is water fluid (Ganesha, 2023). Water is a fluid substance that is abundant and easy to get almost everywhere. However, when used as a lubricant, water has a much smaller load carrying capacity compared to oil. This is because the viscosity value of water is not as large as that of oil lubricants (Wu, 2023).

With the known research data, the author tried to carry out research by developing the use of water lubricant on journal bearings that have been given a surface texture. The surface texture used is a rectangular geometric shape. This is because it refers to research conducted by Tao Nie (2022) that the results of the comparison of texture geometry show that rectangular shapes have better performance than triangle, arc, & trapezoid shapes. This research will compare the performance values of journal bearings that are given a rectangular texture with those that are not given a texture (smooth) when using water and oil lubricants as a comparison. Several parameters used to compare performance values are load carrying capacity and friction force. These parameter values are commonly used because they can determine the maximum load value that can be accepted by the journal

bearing and provide an overview of the friction that occurs due to friction between lubricant particles and the shaft and bearing walls.The following is the friction force equation that has been integrated into the ANSYS simulation:

$$F_f \;=\; \iint_A \tau dx dz$$

In this research the author added the acoustic power level parameter as an additional comparison of the performance values produced by journal bearings. Acoustic power level is a parameter that describes the noise level produced by the journal bearing (Poddar, 2019). The sound emissions heard from journal bearings are sound energy produced due to friction between fluid particles and the walls and the bursting of small gas bubbles due to cavitation (Xie, 2023). The following is the acoustic power level equation used in the ANSYS fluent simulation:

$$Lp\,(dB) = 10\log\,(W/W_{ref})$$

$$W \;=\; a_\varepsilon \rho\varepsilon \left(\frac{\sqrt{2k}}{c_0}\right)^5$$

With the load carrying capacity, friction force, & acoustic power level parameters in this journal bearing research, it is hoped that it will be able to provide significant performance comparison results with the help of computational fluid dynamics (CFD).

II. MATERIAL & METHOD

This simulation uses water as a lubrication fluid. This aims to find out whether rectangular texture also affects water fluids apart from using oil in previous research. Water has the advantage that it is abundant on earth and does not cause environmental pollution (Ganesha, 2023).

The meshing used is a method of dividing several layers to produce an accurate lubricant layer. The following meshing is produced in Figure 5 below:
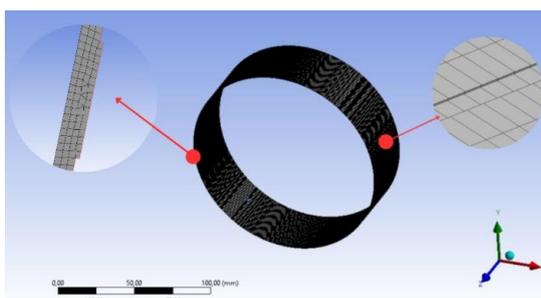

Figure 5: Meshing on rextangular texture

The following is a list of detailed geometric sizes created for this simulation which can be seen in table 1 below:

Table 1: Bearing geometry details

Parameter	Value
Shaft diameter (D_j)	127.716 mm
Inner bearing diameter (D_b)	128 mm
Bearing length (L_b)	42.5 mm
Radial clearance (c)	0.142 mm
Eccentricity ratio (ε)	0.97 mm
Attitude angle (φ)	45°
Shaft speed (ω)	746 rpm

Water fluid has parameters contained according to its type. The following are the water parameters used:

Table 2: Water parameters

Parameter	Value
Density (ρf)	998.2 kg/m³
Viscosity (μo)	0.001003 Pa.s
Density of water vapor (ρv)	0.5542 kg/m
Viscosity of water vapor (μV)	1.34×10^{-5} Pa.s
Vapor saturation pressure (Pv)	4247 Pa

What needs to be attention to in this simulation is the detailed size of the rectangular texture model used. The following is the size of the rectangular texture model as well as the area where it is placed in Figure 6 below:
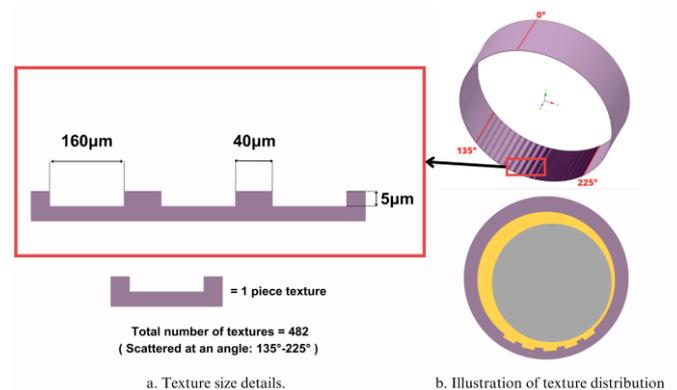

Figure 6. Details of the rectangular texture used

This simulation uses the multiphase method with the Schnerr-Sauer model with the K-Epsilon turbulence model applied to steady conditions. Using the SIMPLE method as an ANSYS calculation method with no-slip boundary conditions and having an inlet and outlet pressure of 0 Pa.

III. RESULT AND DISCUSSION

In this research, validation was carried out first using the research case of Nie (2022). The following are the validation results in Table 3 below:

Table 3: Validation case

Bearing condition	Parameter	P Max reference article (Nie, 2022)	P Max Study Present	Error (%)
$\varepsilon = 0.97$ with rectangular texture	P Max	150MPa	153.7 MPa	2.4

Table 3 shows that the results of the validation cases produced an error of only 2.4%. In this research, an independent grid test was also carried out on the meshing used. The following are the results of the independent grid test in Figure 7 below:
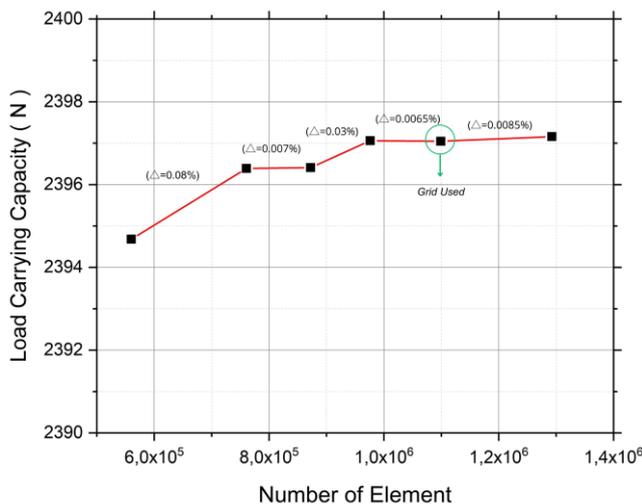

Figure 7: Independent grid test

This simulation compares several parameters that can be used as a basic reference that influence journal bearing performance. The following is a comparison of several resulting parameters. The first parameter to be compared is the resulting pressure distribution contour. The grid test was carried out using variations in the number of elements, around a difference of 150000 elements. The grid test carried out produced the largest error of only 0.008% and the smallest

error difference produced was 0.0065%. The number of elements used in this simulation is 1100000 elements and grid test comparisons were carried out using the number of elements ranging from 600000 to 1400000 with a division of 4 layers in the cross section of the simulated lubricant thickness. The first parameter to be analyzed is the resulting pressure value because it is related to increasing load carrying capacity performance. The greater the pressure generated, the potential load carrying capacity will also be maximized. The following are the results of the comparison of pressure values in Figure 8 below:
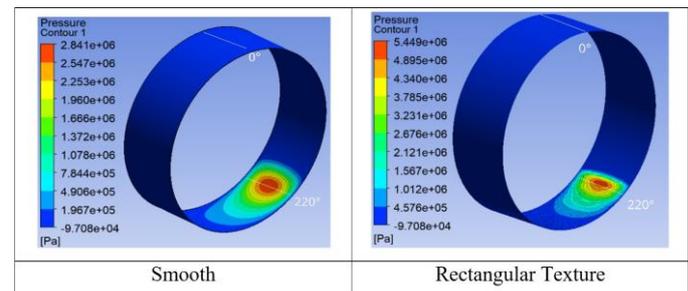

Figure 8: Comparison of pressure values

Figure 8 shows that the pressure generated in the rectangular texture has a greater value compared to the smooth texture. Rectangular textures have narrower and more centralized pressure areas, while smooth pressure areas are wider and more spread out. Rectangular textute has a greater pressure value due to the thickening of the lubricant layer that occurs. The thickening of the lubricant layer can be increased due to the flow of turbulent kinetic energy in the right areas (Harishkumar, 2022). The next parameter that needs to be analyzed is the value of the volume fraction of water vapor. The following is a comparison of the value of the volume fraction of water vapor in Figure 9:
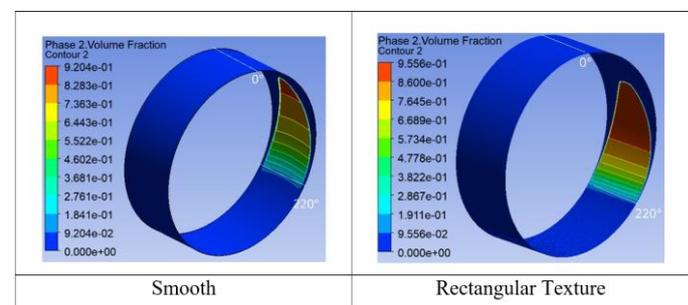

Figure 9: The volume fraction of water vapor

Figure 9 shows that the fraction of water vapor value in the rectangular texture is higher than the smooth texture. This can be caused by an increase in pressure in the convergent area so that when the divergent gap exits there is a sudden increase in speed.

The next parameter analyzed is the turbulent kinetic energy value. According to Harishkumar (2022), increasing turbulent energy in the right areas will be able to increase the resulting pressure value. However, turbulent kinetic energy has consequences in the form of increased noise in the form of an increase in the acoustic power level value which is also proportional to the turbulent eddy dissipation parameter. The following is a comparison of the values of turbulent kinetic energy and turbulent eddy dissipation in Figures 10 and 11 below:
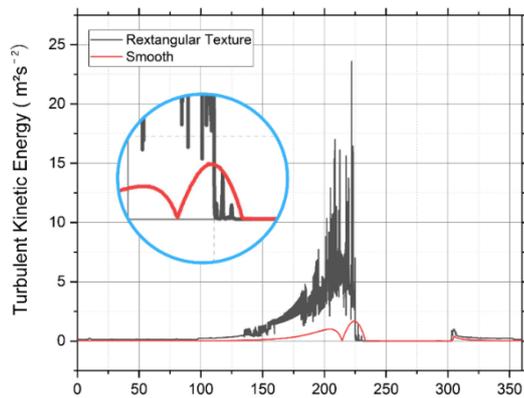

Figure 10: Turbulent kinetic energy value

Figure 10 shows that the turbulent kinetic energy value in the rectangular texture is higher than the smooth texture. This is one of the parameters that influences the increase in the resulting pressure value. The following are the comparison results of turbulent eddy dissipation which are comparable to the turbulent kinetic energy values shown in Figure 11 below:
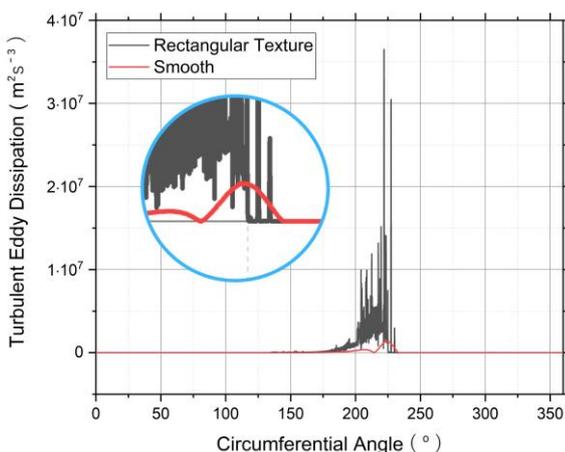

Figure 11: Turbulent eddy dissipation

The parameters above are several parameters that influence the main parameters used to analyze journal bearing performance. In this research, performance parameters include load carrying capacity, friction force, and acoustic power level. The following is a comparison of the total performance

parameters of journal bearings starting with the load carrying capacity value shown in Figure 12 below:
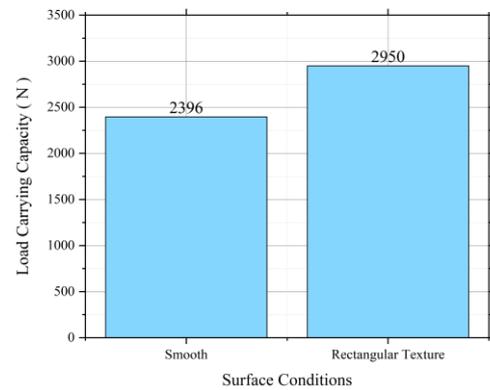

Figure 12: Load carrying capacity value

Figure 12 shows that the load carrying capacity value for rectangular texture is greater than smooth. Rectangular texture has a load carrying capacity value of 2950 N while smooth is 2396 N. This proves that the rectangular texture can thicken the lubricant layer on the journal bearing. The greater the load carrying capacity value, the greater the shaft load that the bearing can support. The next parameter that needs to be analyzed is the friction force value. Friction force can occur due to friction between fluid particles and the bearing walls. The smaller the friction force value, the smaller the resistance acting on the shaft and this will make the bearing performance more optimal. The following is the resulting friction force seen in Figure 13 below:
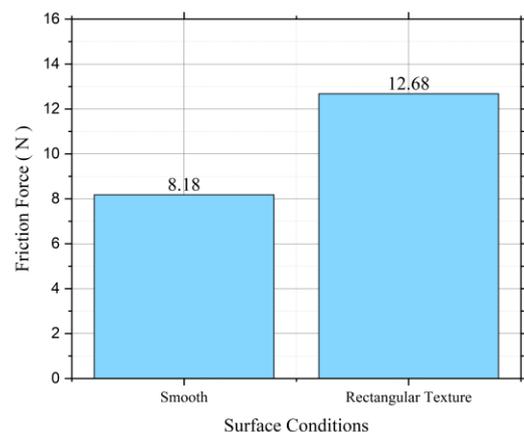

Figure 13: Friction Force

Figure 13 shows an increase in the friction force value resulting from the rectangular texture. This shows that although rectangular texture is able to increase the value of load carrying capacity, the presence of rectangular texture also causes the consequence of increasing the friction force produced. The final parameter that influences journal bearing performance is the noise level produced by the journal

bearing. The noise level is represented by the acoustic power level value resulting from the simulation. The following are the results of the comparison of acoustic power levels in Figure 14 below:
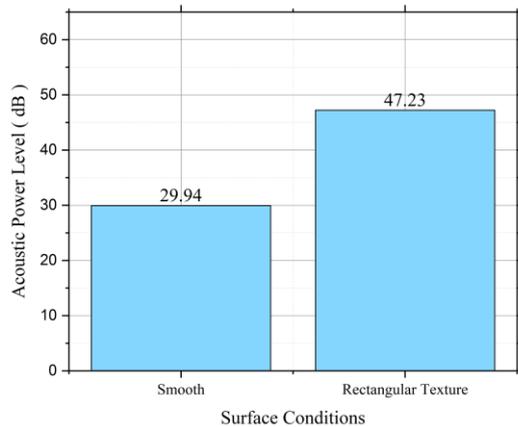

Figure 14: Friction Force

Figure 14 shows that rectangular texture can increase noise in the form of acoustic power level values. In the rectangular texture the average acoustic power level produced is 47.23 dB, while the average acoustic power level in the smooth is 29.94 dB. In accordance with the acoustic power equation applied in the ANYS fluent simulation, the noise level is directly proportional to the turbulent kinetic energy produced. This is because the turbulent kinetic energy value in the rectangular texture is also greater than the smooth one.

All these parameters are analyzed in total in order to find out the overall performance comparison. The following are the results of a comparison of total journal performance due to the influence of rectangular texture which is shown in table4 below:

Table 4: Total performance comparison

Performance Parameters	Smooth	Rectangular Texture
Load Carrying Capacity	2396 N	2950 N
Friction Force	8.18 N	12.68 N
Acoustic Power Level	29.94 dB	47.23 dB
% Change in Load Carrying Capacity	+23.1 %	
% Change Friction Force	+55.1 %	
% Change in Average Acoustic Power Level	+57.7 %	

Table 3 shows the comparison results of the overall journal bearing performance where rectangular texture has had a significant influence. Rectangular texture is able to increase the load carrying capacity value by 23.3% but has consequences in the form of an increase in friction force by 55.1% and an increase in noise value by 57.7%. This shows that rectangular apart from oil lubricants (previous research) can also have an influence on lubrication with water fluids.

IV. CONCLUSION

With the overall simulation results, this research can draw the following conclusions:

1) The influence of rectangular texture, apart from having an influence on oil lubricants, also has an influence on lubricants with water fluids.
2) The influence of rectangular texture can improve one of the journal bearing performances but has the consequence of reducing other performance parameters.
3) The 3D simulation in this research shows that there is an increase in the load carrying capacity value of 23.1%, namely from a smooth texture of 2396 N to 2950 N in a rectangular texture. There is an increase in friction force of 55.1% from smooth which is 8.18 N to 12.68 N in rectangular texture. And the noise level increased by 57.7% from smooth 29.94 dB to 47.23 dB.

REFERENCES

[1] Arif, M., Kango, S., & Shukla, D.K. 2021. Investigasing the Effect of Different Slip Zone Locations on The Lubrication Perfomance of Textured Journal Bearings. Industrial Lubrication and Tribology. 73(6): 872-881.

[2] Chen, S., Xiang, G., Filon, M., Guo, J., Wang, J., & Cai, J. 2022. On the tribo-dynamic behaviors during start-up of water lubricated bearing considering imperfect journal. Tribology Internasional. 174.

[3] Ebiefung, A. 2019. The Vertical Generalized Complementarity Problem: Mixed Lubrication and Choice of Technology Models. Mathematics and Statistics. 1:45-53.

[4] Ganesha, A., Joseph, A., Pai, R., Khader, S.M.A., Kumar, N. & Kumar, S. 2023. Performance Optimization of a Multi-groove Water Lubricated Journal Bearing with Partial Slip by Taguchi Analysis. Arabian Journal for Science and Engineering.

[5] Harishkumar, Kini, C. R., Shenoy S. B. 2022. Effect of Cavitation and Temperature on Fluid Film Bearing Using CFD and FSI Technique: A review. Archives of Computational Methods in Engineering. 30: 1623-1636.

[6] Li, Q., Zhang, S., Ma, L., Xu, W., & Zheng, S. 2017. Stiffness and damping coefficients for journal bearing using the 3D transient flow calculation. Journal of Mechanical Science and Technology. 31(5): 2083-2091.

[7] Lucassen, M., Decker, T., Guzman, F. G., Lehmanm, B., Bosse, D., & Jacobs, G. 2023. Simulation methodology for the identification of critical operating conditions of planetary journal bearings in wind turbines. Forsc Ingenieurwes. 87:147-157.

[8] Nie, T., Yang, K., Zhou, L., Wu, X., & Wang, Y. 2022. CFD Analysis of Load Capacity of Journal Bearing with Surface Texture. Energy Report. 8: 327-334.

[9] Poddar, S., & Tandon, N. 2019. Detection of particle contamination in journal bearing using acoustic emission and vibration monitoring techniques. Tribology Internasional. 134: 154-164.

[10] Rasep, Z., Yazid, M.N.A.W.M., Samion, S. 2021. A study of cavitation effect in a journal bearing using CFD: A case study of engine oil, palm oil and water. Jurnal Tribologi. 28: 48-62.

[11] Satish, C., Singh, A. 2023. A Study of Double Layer Conical Porous Hybrid Journal Bearing Operated with Non-Newtonian Lubricaant. Tribology Internasional. 179:121-130.

[12] Sun, D., Li, S., Fei, C., Ai, Y., & Liem, R.P. 2018. Investigation of the effect of cavitation and journal whirl on static and dynamic characteristics of journal bearing. Journal of Mechanical Science and Technology. 33(1): 77-86.

[13] Tauviqirrahman, M., Yohana, E., Paryanto, Jamari, Muslim, F.Z. 2023. Investigation on acoustic, thermal, and tribological properties of hydrodynamic journal bearing with heterogeneous rough/smooth surface. Result in Engineering. 18: 1-22.

[14] Wu, Z., Qingyuan, C., Guo, Z., & Huang. 2023. Pengaruh parameter alur pada kinerja pelumasan bantalan berpelumas air pada kecepatan rendah. Wear. 552.

[15] Xie, Z., Jiao, J., & Yang, K. 2023. Theoretical and experimental study on the fluid-structure-acoustic coupling dynamics of a new water lubricated bearing. Tribology Internasional. 177.

Citation of this Article:

Mohammad Tauviqirrahman, Muchammad, Syahrul Nur Hidayatulloh, "Analysis of the Effect of Rectangular Texture on Performance of Journal Bearings with Water Lubricant Using Computational Fluid Dynamics Method" Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET,* Volume 7, Issue 11, pp 356-362, November 2023. Article DOI https://doi.org/10.47001/IRJIET/2023.711048

****