IOSR Journal of Mathematics (IOSR-JM)
e-ISSN: 2278-5728, p-ISSN: 2319-765X. Volume 17, Issue 6 Ser. I (Nov. – Dec. 2021), PP 28-34
www.iosrjournals.org

A Study of Longitudinal Surface Roughness Effect on the performance of infinitely short Journal Bearing

P. I. Andharia[1], Hardik M. Pandya[2]
[1] (Associate Professor, *Department of Mathematics, Maharaja Krishnakumarsinhji Bhavnagar University, Bhavnagar, Gujarat, India – 364001).*
[2] (Research Scholar, *Department of Mathematics, Maharaja Krishnakumarsinhji Bhavnagar University, Bhavnagar, Gujarat, India – 364001).*

Abstract:
This paper attempts to study the performance of an infinitely short rough journal bearing. The study has been extracted using the Christenson and Tonder model. The corresponding Reynolds equation has been used to calculate the pressure distribution, which is important for constructing the load-carrying capacity equation. A graphical representation is made to display the calculated value of dimensionless pressure and dimensionless load-carrying capacity. It can be underlined that the standard deviation significantly affects the performance characteristics.
Keywords: *Journal Bearing, Longitudinal surface roughness, Reynolds equation, Pressure, Load carrying capacity.*

Date of Submission: 12-11-2021 Date of Acceptance: 28-11-2021

I. Introduction

In recent decades, hydrodynamic journal bearings have received great attention from practical and analytical point of view. A rapid growth of sleeve bearing technology is mainly due to its wide range of engineering applications such as precision machine tools, nuclear reactors, high-speed aircraft and textile spindles. The development of thin-film lubrication provided a theoretical basis for revealing practical engineering.

Kuzma[1], Lin[2], Nada and Osman[3], Motazeri[4], Patel et al. [5] and Lin et al. [6] have studied on hydrodynamic journal bearings assuming a surface to be smooth. Several works have found on the performance of the journal bearings, such as the works in short bearings by Lin[7], Naduvinamani et al. [8] Patel et al. [9] and Lin et al. [10]; long bearings by Lin[10], Shah and Bhatt[11] and Naduvinamani et al. [12]; infinite bearings by Gururajan and Prakash[13]; narrow bearing by Gururajan and Prakash[13] and finite bearings by Lin[14], Elsharkawy and Guedouar[15] and Elsharkawy[16].

In almost all types of bearing systems, a very important role is played by the roughness of the bearing surface and its roughness pattern. Some investigators (namely Michell[17], Pinkus and Sternlicht[18], Burton[19], Davies[20], Tzeng and Saibel[21] have observed that the performance of the bearing and its life depend on the roughness of the surface, friction, wear and lubricants.

After that, many investigators viz. Andharia et al. [22,23,24], Shah and Bhat[27], Deheri et al. [25, 26, 28], Patel et al. [29, 30], Shukla and Dehari[31], Naduvinamani et al. [34], Andharia and Patel[32,33], Panchal et al. [35,36] have studied and established that the performance of the bearing depends on its roughness and they have also given essential results in terms of the load-carrying capacity of the bearing for various parameters such as the mean, standard deviation and asymmetry of the bearing with and without the use of a magnetic lubricant. In these investigations, Christensen and Tender's[37,38,39] , Christensen[40] role could not be underestimated, who produced a stochastically averaged Reynolds type equation by applying a random averaging process on a Reynolds type equation that gives the mean pressure more readily than local pressure.

Recently, more and more consideration has been given to study the effect of longitudinal surface roughness by Andharia and Deheri[41,42,43], Sharma and Pandey[44], Andharia and Patel[45], Patel and Deheri[46], Lin[47], Shimpi and Deheri[48], Andharia et al.[49], Andharia and Pandya[50,51,52], Adeshara et al.[53] and Patel et al.[54]. All of these observations above clearly show that from a bearing longevity point of view, the effect of the standard deviation remains very crucial.

In this paper, an averaged Reynolds-type stochastic equation for infinitely short journal bearing, and the rough longitudinal bearing surface is solved numerically, and graphical results are produced accordingly.

Indeed, it is revealed that the load-carrying capability of the infinitely short journal bearing can be significantly improved.

II. Analysis:

The pressure distribution along circumference is shown in figure 1. The assumptions of general hydrodynamic lubrication theory are taken into consideration in the development of the analysis.

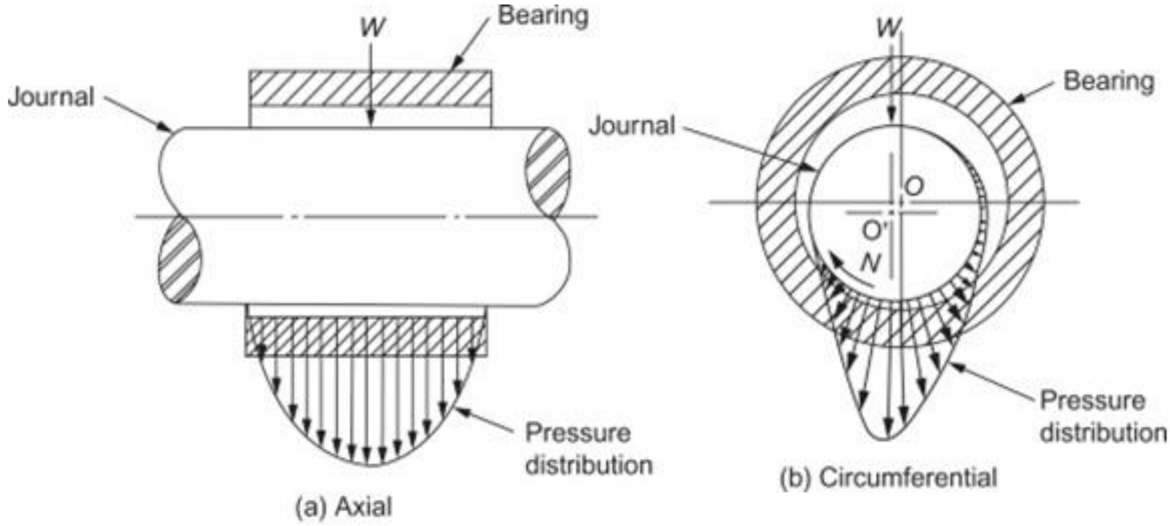

Figure: 1 Physical configuration of a journal bearing

The pressure governing equation is the Reynolds equation in two dimensions for an incompressible fluid, given by

$$\frac{\partial}{\partial x}\left(h^3\,\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(h^3\,\frac{\partial p}{\partial z}\right)=6\,\eta U\frac{dh}{dx}. \qquad (1)$$

The short bearing approximation assumes a sufficiently short bearing in the axial direction and for infinitely short journal bearing

$$\frac{\partial p}{\partial x}=0. \quad (2)$$

Substitute the value of (2) in equation (1), The Reynolds equation for a short journal bearing is obtained as

$$\frac{\partial}{\partial z}\left(h^3\,\frac{\partial p}{\partial z}\right)=6\,\eta U\frac{dh}{dx}. \qquad (3)$$

The bearing surfaces are assumed to be longitudinally rough. Following Christensen and Tonder (1969, 1971 and 1972) the expression for film thickness is considered as

$$h(x)=\bar{h}(x)+\delta_s$$

where h is the mean film thickness, δ_s is the random deviation from the mean film thickness governed by probability density function $f(\delta_s)$, $-\mathrm{c}\le\delta_s\le\mathrm{c}$ [Andharia et al. (1997)]. Here c being the maximum deviation in δ_s.

According to the stochastic averaging method for longitudinal roughness discussed in Christensen and Tonder (1969, 1971, 1972), Andharia et al. (1997) Eq.(3) is transformed to

$$\frac{\partial}{\partial z}\left(\frac{1}{E(h^{-3})}\,\frac{\partial p}{\partial z}\right)=6\,\eta U\frac{d}{dx}\frac{1}{E(h^{-1})} \qquad (4)$$

where, $E(h^{-3})=\bar{h}^{-3}(1+6\bar{h}^{-2}\sigma^2)$

$E(h^{-1})=\bar{h}^{-1}(1+\bar{h}^{-2}\sigma^2).$

Hence,

$$\frac{\partial}{\partial z}\left(\frac{1}{\bar{h}^{-3}(1+6\bar{h}^{-2}\sigma^2)}\,\frac{\partial p}{\partial z}\right)=6\,\eta U\frac{d}{dx}\left(\frac{1}{\bar{h}^{-1}(1+\bar{h}^{-2}\sigma^2)}\right). \qquad (5)$$

Let $x=r\theta$ and hence: $dx=rd\theta$ and the film thickness h is described by the following approximation, which is used in almost all analyses: $\bar{h}=c+ecos\theta=c(1+\varepsilon\,cos\theta)$ that gives $\frac{d\bar{h}}{d\theta}=-\varepsilon\sin\theta,$ where (eccentricity) $E=\frac{e}{c}$. Fluid film thickness $\bar{h}$ is not a function of z; hence equation (5) becomes

$$\frac{d^2p}{dz^2}=6\,\eta U\left\{\bar{h}^{-3}(1+6\bar{h}^{-2}\sigma^2)\right\}\frac{d}{rdx}\left(\bar{h}^{-1}(1+\bar{h}^{-2}\sigma^2)\right)^{-1} \qquad (6)$$

Integrating the above equation twice with respect to z, Eq. (6) takes the form

$$p=3\,\eta U\left\{\bar{h}^{-3}(1+6\bar{h}^{-2}\sigma^2)\right\}\frac{d}{rdx}\left(\bar{h}^{-1}(1+\bar{h}^{-2}\sigma^2)\right)^{-1}z^2+Cz+D \quad (7)$$

where C and D are arbitrary constant.

Using the boundary conditions at the point $z = \pm\frac{L}{2}$, $p = 0$ and $z = 0$, $\frac{dp}{dz} = 0$ in Eq. (7) and simplifying, one get the expression for pressure distribution in the bearing system as

$$p = \frac{3\,\eta U L^2\,(-E\sin\theta)}{c^2 r(1+E\cos\theta)^3}\left\{\frac{\left(1+3\left(\frac{\sigma}{c}\right)^2\frac{1}{(1+E\cos\theta)^2}\right)}{\left(1+\left(\frac{\sigma}{c}\right)^2\frac{1}{(1+E\cos\theta)^2}\right)^2}\right\}\left(1+6\left(\frac{\sigma}{c}\right)^2\frac{1}{(1+E\cos\theta)^2}\right)\left[\frac{z^2}{L^2}-0.25\right] \quad (8)$$

Introducing of dimensionless quantities

$$\sigma^* = \frac{\sigma}{c}, z^* = \frac{z}{L}, P^* = -\frac{C^2 r p}{\eta U L^2},$$

in Eq. (8) it leads to the expression of the pressure distribution in the dimensionless form as

$$P^* = \frac{3\,(E\sin\theta)}{(1+E\cos\theta)^3}\left\{\frac{\left(1+\frac{3\,(\sigma^*)^2}{(1+E\cos\theta)^2}\right)\left(1+\frac{6\,(\sigma^*)^2}{(1+E\cos\theta)^2}\right)}{\left(1+\frac{(\sigma^*)^2}{(1+E\cos\theta)^2}\right)^2}\right\}[(z^*)^2-0.25]. \quad (9)$$

The component of the total force in the direction of the line of centres is described by,

$$W_N{}^* = \int_0^{\pi}\int_{-\frac{1}{2}}^{\frac{1}{2}} P^*\cos\theta\ d\theta\ dz^*.$$

The component of the total force in the direction of the line of centres is given by,

$$W_T{}^* = \int_0^{\pi}\int_{-\frac{1}{2}}^{\frac{1}{2}} P^*\sin\theta\ d\theta\ dz^*.$$

Load – bearing capacity of the bearing is given by

$$W^* = \sqrt{W_N{}^{*2} + W_T{}^{*2}}. \quad (10)$$

Resulting load-bearing capacity is computed by using Simpson's 1/3 rule.

III. Results and Discussion

The theoretical aspects of the results calculated numerically for various bearing characteristics are explained by figures. In order to study a quantitative behavior of the inconsistency variations of the incompressible lubricant, it is first necessary to calculate the pressure and the load capacity. This is achieved by solving the simultaneous Eq. (5) for the dimensionless pressure P^* and the Eq. (9) for the dimensionless load capacity W^* by the 1/3 method of Simpson. The variation of the pressure distribution (P^*) is shown in Fig. – 2 to Fig. – 6 and the load capacity (W^*) is shown in Fig. – 7 to Fig. – 8.

The pressure distribution P^* versus θ for various values of Z^*, E and σ^* has been depicted in Fig. – 2 to Fig. – 4. The pressure distribution (P^*) decreases continuously as θ increases.

The pressure distribution P^* versus Z^* for various values of E and σ^* has been depicted in fig-5 and fig-6. The pressure distribution(P^*) decreases continuously as Z^* increases.

The load capacity W^* versus σ^* for the variable E has been shown in Fig. – 7. The load capacity is continuously increasing to increase the value of E.

The load capacity W^* versus E for the variable σ^* has been shown in Fig. – 8. The load capacity increases sharply as the value of σ^* increases.

Here, it is depicted that the increasing value of the standard deviation (σ^*) and E increases the load capacity.

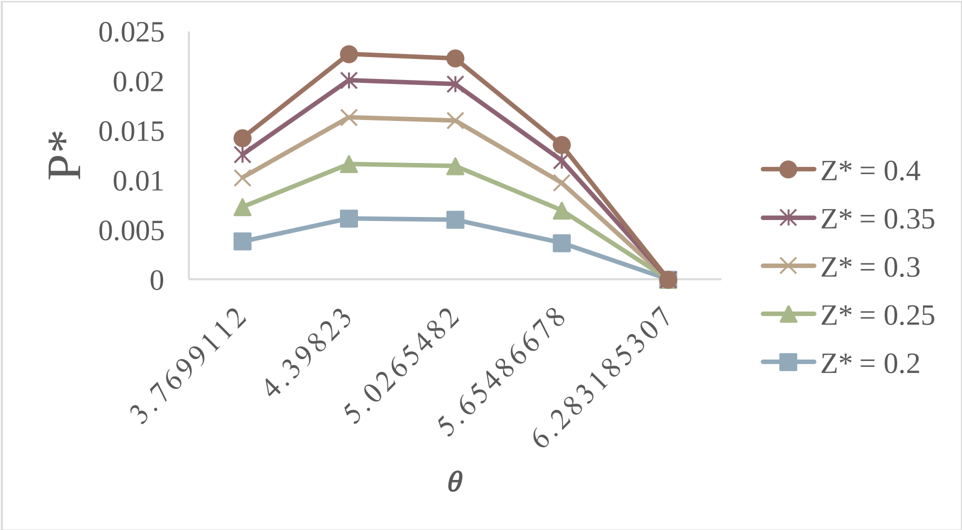

Figure – 2: Effect on pressure distribution with respect to θ for variable Z^*.

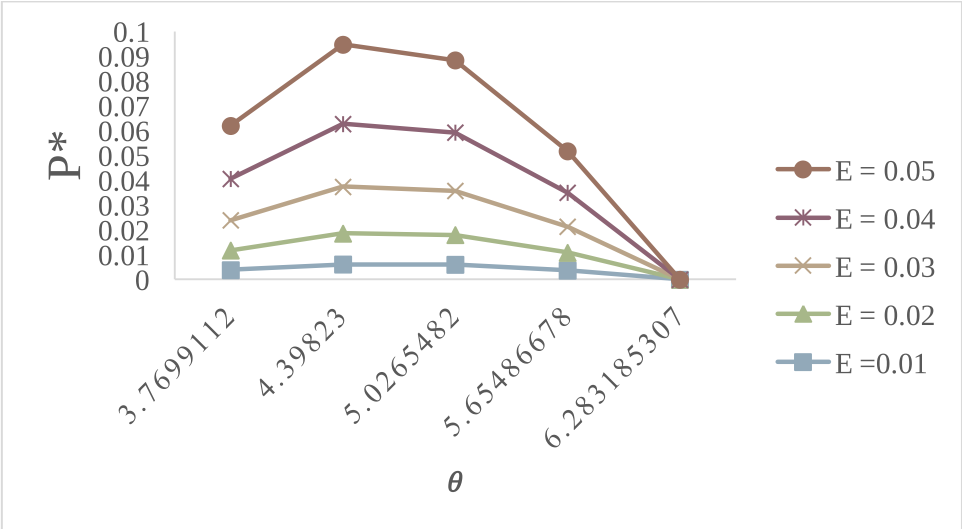

Figure – 3: Effect on pressure distribution with respect to θ for variable E.

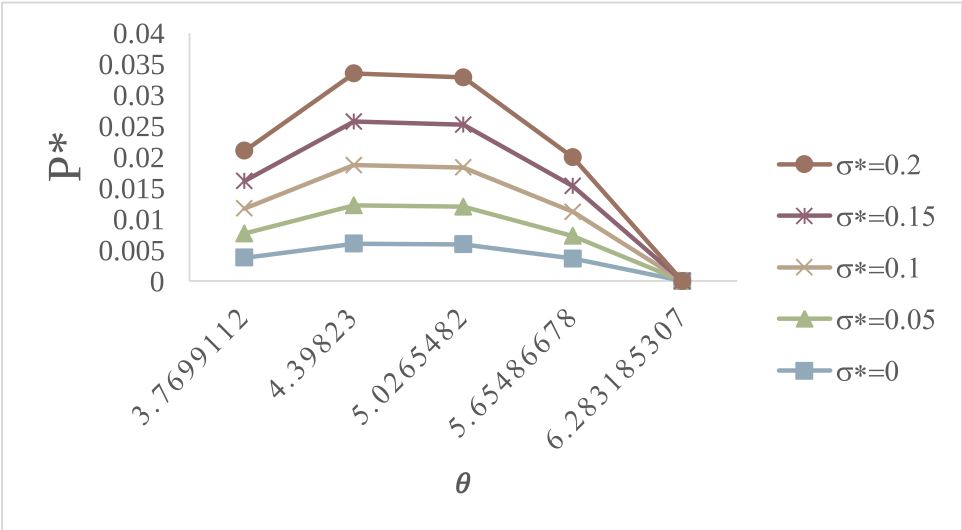

Figure – 4: Effect on pressure distribution with respect to θ for variable σ^*.

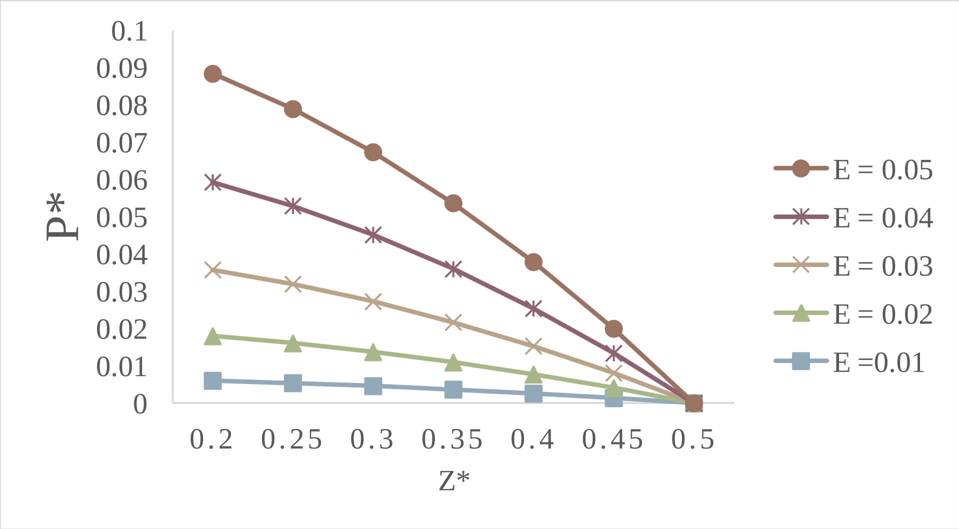

Figure – 5: Effect on pressure distribution with respect to Z^* for variable E.

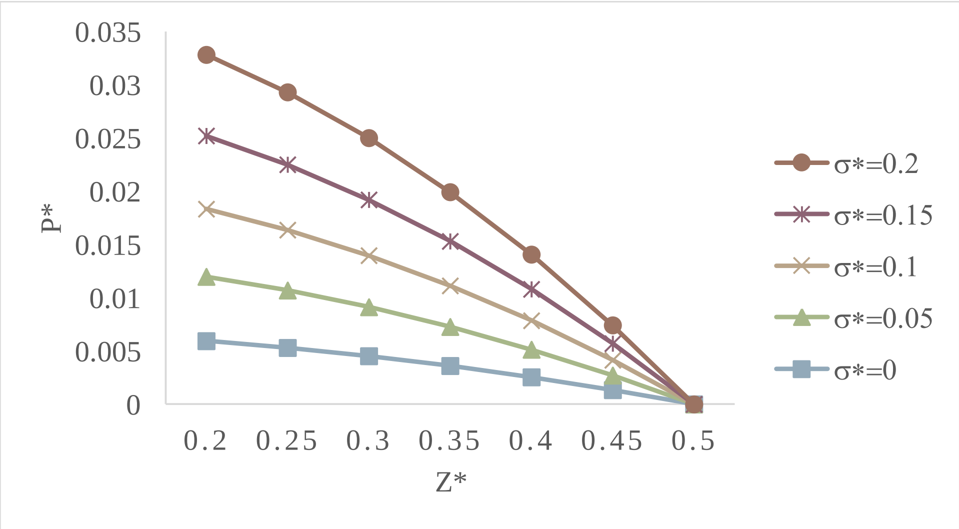

Figure – 6: Effect on pressure distribution with respect to Z^* for variable σ^*.

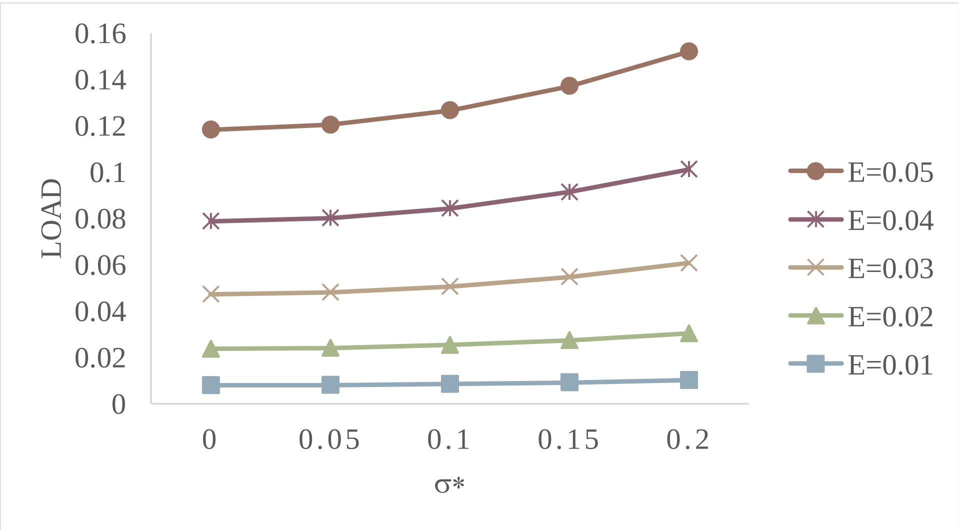

Figure – 7: Effect on load-carrying capacity with respect to σ^* for variable E.

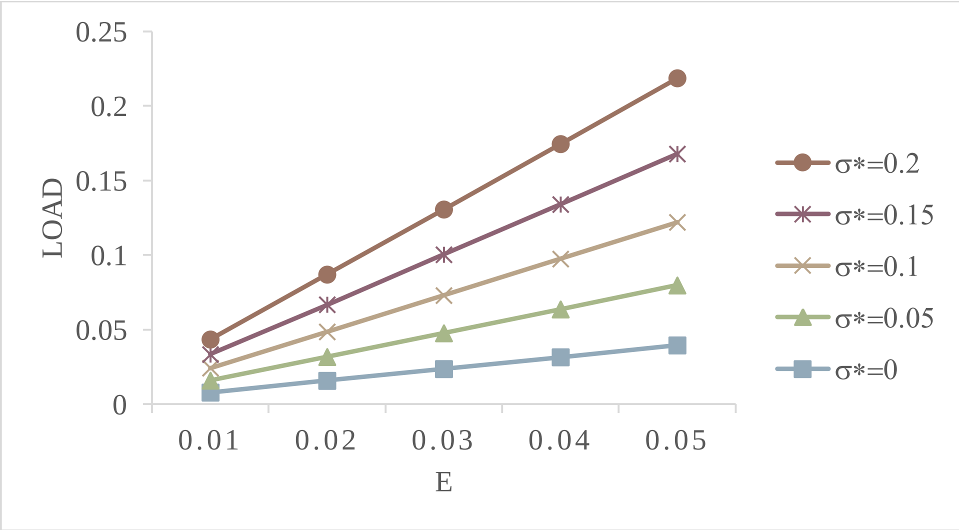

Figure – 8: Effect on load-carrying capacity with respect to E for variable σ^*.

IV. Conclusions:

This study emphasizes that roughness aspects must be evaluated when designing this type of bearing system which is important from bearing life. It is often observed that the standard deviation and eccentricity greatly improve load-carrying capacity.

References

[1]. Kuzma, D. C. (1963). The magnetohydrodynamic journal bearing, Transaction of the ASME, pp. 424–428.
[2]. Lin, J. R. (1998). Squeeze film characteristics of finite journal bearings: couple stress fluid model, Tribology International, vol. 31, no. 4, pp. 201–207.
[3]. Nada, G. S. and Osman, T. A. (2007). Static performance of finite hydrodynamic journal bearings lubricated by magnetic fluids with couple stresses, Tribology Letters, vol. 27, no. 3, pp. 261– 268.
[4]. Montazeri, H. (2008). Numerical analysis of hydrodynamic journal bearings lubricated with ferrofluid. Journal of Engineering Tribology 222, 51-60.
[5]. Patel, N. S., Vakharia, D. P. and Deheri, G. M., (2012). A study on the performance of a magnetic-fluid-based hydrodynamic short journal bearing, ISRN Mechanical Engineering, vol. 2012, Article ID 603460, 7 pages.
[6]. Lin, J. R., P. J. Li and T. C. Hung (2013). Lubrication performances of short journal bearings operating with non-Newtonian ferrofluids. Zeitschrift fuer Naturforschung A 68a, 249-254.
[7]. Lin, J. R. (1997a). Static characteristics of rotor bearing system lubricated with couple stress fluids. Computer & Structure, vol. 62, pp. 175-184.
[8]. Naduvinamani, N. B., Hiremath, P. S., Gurubasavaraj, G. (2002). Squeeze film lubrication of a short porous journal bearing with couple stress fluids. Industrial Lubrication and Tribology, vol. 54, pp. 739-747.
[9]. Patel, R. M., G. M. Deheri and P. A. Vadher (2010). Performance of a magnetic fluid-based short bearing. Acta Polytechnica Hungarica 7, 63-78.
[10]. Lin, J. R. (1997b). Squeeze film characteristics of long partial journal bearings lubricated with couple stress fluids. Tribology International, vol. 30, pp. 53-58.
[11]. Shah, R. C., Bhat, M. V. (2004). Ferrofluid squeeze film in a long journal bearing. Tribology International, vol. 37, pp. 441-446.
[12]. Naduvinamani, N. B., Hiremath, P. S., Fathima, S. T. (2005). On the squeeze film lubrication of a long porous journal bearing with couple stress fluids. Tribology International, vol. 34, pp. 12-20.
[13]. Gururajan, K. and Prakash, J. (1999). Surface - roughness effects in infinitely long porous journal bearings. Journal of Tribology 121, 139-147.
[14]. Lin, J. R. (1997c). Effects of couple stresses on lubrication of finite journal bearings. Wear, vol. 206, pp. 171-178.
[15]. Elsharkawy, A. A. and Guedouar, L. H. (2001). An inverse solution for finite journal bearings lubricated with couple stress fluids. Tribology International, vol. 34, pp. 107-118.
[16]. Elsharkawy, A. A. (2005). Effects of lubricant additives on the performance hydrodynamically lubricated journal bearings. Tribology Letters, vol. 18, pp. 63- 73.
[17]. Michell, A.G.M. (1950). Lubrication - Its Principles and Practice, London, Blackie.
[18]. Pinkus, O., Sternlicht, B. (1961). Theory of Hydrodynamic Lubrication. McGraw-Hill Book Co. Inc., New York.
[19]. Burton, R. A. (1963). Effects of two-dimensional sinusoidal roughness on the load support characteristics of a lubricant film, J Fluids Eng. 85(2): 258-262. doi: 10.1115/1.3656572
[20]. Davies, M. G. (1963). The generation of pressure between rough-fluid lubricated moving, deformable surfaces, Lubr. Eng. 19: 246-252.
[21]. Tzeng, S.T., Saibel, E. (1967). Surface roughness effect on slider bearing lubrication, ASLE Transactions, 10(3): 334-348.
[22]. Andharia, P. I., Gupta, J. L., Deheri, G. M. (1997). Effect of longitudinal surface roughness on hydrodynamic lubrication of slider bearings, Book - Institute of Materials, 668: 872-880.
[23]. Andharia, P. I., Gupta, J. L., Deheri, G. M. (1999). Effects of transverse surface roughness on the behaviour of squeeze film in a spherical bearing. Journal of Applied Mechanics and Engineering; 4: 19-24.
[24]. Andharia, P. I., Gupta, J. L., Deheri, G. M. (2001). Effect of surface roughness on hydrodynamic lubrication of slider bearings, Tribol. Trans. 44(2): 291-297. doi: 10.1080/10402000108982461

[25]. Deheri, G. M., Andharia, P. I., Patel, R.M. (2004). Longitudinally rough slider bearings with squeeze film formed by a magnetic fluid, Indust. Lubric. Trib. 56(3): 177-187.

[26]. Deheri, G. M., Andharia, P. I., Patel, R. M. (2005), Transversely rough slider bearings with squeeze film formed by a magnetic fluid, Int. J Appl. Mech. Eng. 10(1): 53-76.

[27]. Shah, R. C. and Bhat, M. V. (2003). Effect of slip velocity in a porous secant shaped slider bearing with a Ferrofluid lubricant. FIZIKAA; 12: 1-8.

[28]. Deheri, G. M., Patel, H. C. and Patel, R. M. (2006). Performance of magnetic fluid based circular step bearings, Mechanika, vol.57, no.1, pp. 22–27.

[29]. Patel, R. M., Deheri, G. M. and Patel, H. C. (2010). Effect of transverse roughness on the performance of a circular step bearing lubricated with magnetic fluid, Annals, vol.8, no.2, pp.23–30.

[30]. Patel, R. M., Deheri, G. M. and Vadher, P. A. (2015) Hydromagnetic rough porous circular step bearing, East. Acad. J., vol.3, pp.71–87.

[31]. Shukla, S. D. and Deheri, G.M. (2013). Effect of slip velocity on magnetic fluid lubrication of rough porous Rayleigh step bearing, JMES, vol. 4, pp. 532-547.

[32]. Andharia, P. I. and Patel, M. (2015). The Surface Roughness Effect of Transverse Patterns on the Performance of Short Bearing. International Journal of Scientific & Engineering Research, 6: 82-87.

[33]. Andharia, P. I. and Patel, M. (2017). Performance of a Transversely Rough Long Bearing. Journal of Environmental Science, Computer Science and Engineering & Technology. Sec. C, 6(4): 511-522.

[34]. Naduvinamani, N. B., Siddangouda, A., Siddharam, P. (2017). A comparative study of static and dynamic characteristics of parabolic and plane inclined slider bearings lubricated with MHD couple stress fluids, Tribol. Trans. 60(1): 1-11. doi: 10.1 080/10402004.2016.1141446

[35]. Panchal, G. C., Patel, H. C., Deheri, G. M. (2016). Influence of magnetic fluid through a series of flow factors on the performance of a longitudinally rough finite slider bearing, Global J Pure Appl. Math. 12(1): 783-796.

[36]. Panchal, G. C., Deheri, G. M., Patel, H. C. (2018). Comparative study of various film shapes on the performance of a longitudinal rough finite slider bearing through a series of flow factors, Math. Today: An Int. J Math. Sci. 34(A): 40-52.

[37]. Christensen, H. (1969). Stochastic models for hydrodynamic lubrication of rough surfaces, Proc. Instit. Mech. Eng. 184(1): 1013-1026.

[38]. Christensen, H., Tonder, K. (1971). The hydrodynamic lubrication of rough bearing surfaces of finite width, J Lubric. Tech. 93(3): 324-329.

[39]. Tonder, K., Christensen, H. (1972). Waviness and roughness in hydrodynamic lubrication, Proc. Instit. Mech. Eng. 186(1): 807-812.

[40]. Christensen, H. (1972). A theory of mixed lubrication, Proc. Instit. Mech. Eng. 186(1): 421-430.

[41]. Andharia, P. I. and Deheri, G. M.(2001). Effect of longitudinal surface roughness on the behaviour of squeeze film in a spherical bearing, International Journal of Applied Mechanics and Engineering, vol. 6, no. 4, pp. 885–897.

[42]. Andharia, P. I. and Deheri, G. M.(2010). Longitudinal roughness effect on magnetic fluid-based squeeze film between conical plates, Industrial Lubrication and Tribology, vol. 62, no. 5, pp. 285–291.

[43]. Andharia, P. I. and Deheri, G. M.(2013). Performance of magnetic fluid-based squeeze film between longitudinally rough elliptical plates, ISRN Tribology, vol. 2013, Article ID 482604, 6 pages.

[44]. Sharma, R. K. and Pandey, R. K. (2005). Effect of Longitudinal Surface Roughness on The Performance of Thermo Hydrodynamically Lubricated Slider Bearing– A Stochastic Roughness Model, 12th National conference on Machines and Mechanisms (NaCoMM), pp 269-275.

[45]. Andharia, P. I. and Patel, M. (2015). Longitudinally Rough Short Bearing. International Journal of Science and Research; 4: 2497-2502.

[46]. Patel, J. R. and Deheri, G. M. (2016). The effect of slip velocity on the ferrofluid-based squeeze film in longitudinally rough conical plates, J. of the Serb. Soc. for Comp. Mechanics, vol. 10, no. 2, pp. 18-29.

[47]. Lin, J. R. (2016). Longitudinal Surface Roughness Effects In Magnetic Fluid Lubricated Journal Bearings", J. of Marine Sci. and Tec., vol. 24, no. 4, pp. 711-716.

[48]. Shimpi, M. E. and Deheri, G. M. (2016). Combine effect of bearing deformation and longitudinal roughness on the performance of a ferrofluid-based squeeze film together with velocity slip in truncated conical plates, Imperial J. of Interdisciplinary Research, vol.2, no.8, pp.1423–1430.

[49]. Andharia, P. I., Patel, M. and Trivedi, M. M. (2018). Performance of a Magnetic Fluid Based Longitudinally Rough Long Bearing, IJSRR, 7(3), 462-475.

[50]. Andharia, P. I., Pandya, H. M.(2018). Effect of Longitudinal Surface Roughness on the Performance of Rayleigh Step Bearing, IJAER, vol. 13, no. 21, pp. 14935-14941.

[51]. Andharia, P. I., Pandya, H. M.(2019). The Behaviour of Longitudinal Roughness in Hydrostatic Circular Footstep Bearing, JASC, Vol 6, Iss. 4, pp. 802-811.

[52]. Andharia, P. I., Pandya, H. M.(2020). A Study of a Longitudinally Rough Hydromagnetic Squeeze Film in Infinitely Long Rectangular Plates, Studies in Indian Place, Vol 40, Iss. 56, pp., 1249-1259.

[53]. Adeshara, J. V., Prajapati, M. B., Deheri, G.M. and Patel, R.M.,(2018). A Study of Hydromagnetic Longitudinal Rough Circular Step Bearing. Advances in Tribology, Article ID 3981087, 7 pages.

[54]. Patel, H. P., Deheri, G. M. and Patel, R. M. (2019). Numerical modelling of hydromagnetic squeeze film in Conducting longitudinally rough annular plates. International Journal of Research and Analytical Reviews, Vol 6, Issue 2, 220-228.

P. I. Andharia, et. al. "A Study of Longitudinal Surface Roughness Effect on the performance of infinitely short Journal Bearing." *IOSR Journal of Mathematics (IOSR-JM)*, 17(6), (2021): pp. 28-34.