Effect of Cavitation in Lubricated Sliding Textured Surfaces

Panigrahi D. K. and Sarangi M.
Department of Mechanical Engineering,
Indian Institute of Technology, Kharagpur -721302, India
E-mail: dillip.cetb@gmail.com

Abstract

Surface texturing has been recognized as one of the effective means to improve tribological performance of mechanical components. This technique can have a large variety of industrial applications, such as biomechanical components, solar cells, hydrodynamic bearings, mechanical seals, piston ring, cylinder-liner contacts and magnetic media disks, etc. Under full film lubrication condition, each micro dimple of the textured surface acts as a Rayleigh step, which could develop hydrodynamic pressure and thereby, will enhance the total load carrying capacity. In this situation, pressure in the lubricant may fall below gas saturation pressure or evaporation pressure at the divergent zone (i.e., trailing edge), leading to the occurrence of cavitation. It was found from literature that higher cavitation pressure significantly alters the hydrodynamic (positive) pressure development, so as the load carrying capacity and friction parameter. Therefore, an attempt has been made to investigate the cavitation phenomenon of positive textured surfaces under full film lubrication condition on parallel thrust bearings, where the cavitation zone profile, cavitation pressure, frictional force, load carrying capacity and oil film thickness are determined experimentally. It is found from the experimental results that with increasing speed, both (-ve) cavitation and (+ve) hydrodynamic pressure increases which can be correlated to the observed reduction in recess pressure and increment in film thickness. On the whole, higher cavitation at the trailing edge of the textures helps and/or enhances the (+ve) hydrodynamic pressure development.

Keywords: Surface Texture, Thrust Bearing, Cavitation and hydrodynamic pressure.

1 Introduction

Now–a-days textured surfaces play a vital role in improving the tribological performance between two mating pairs in hydrodynamic lubrication [1]. In 1960s, Hamilton et al. indicated that micro-irregularities are able to generate additional hydrodynamic pressure which increases the overall load carrying capacity of the surfaces. This theory has been well accepted, and micro-hydrodynamic effect is regarded as the most dominant effect of surface texture for high-speed and low-load applications [2]. Here the micro dimples can act as fluid reservoirs which help to retain a thin film of lubricant between two mating pairs [3]. It is also beneficial that

---

Panigrahi D. K. (Corresponding author)
Indian Institute of Technology, Kharagpur, E-mail: dillip.cetb@gmail.com.

Sarangi M.
Indian Institute of Technology, Kharagpur, E-mail: smihir@mech.iitkgp.ernet.in.

the lubricant remaining in the pores can avoid the temperature rise caused by sudden start or stop of a machine [4]. Marian Victor pointed out that surface texturing is a cheaper method to produce load carrying capacity at the surface of the seal, comparing to other methods (i.e. spiral grooves, waviness, etc.) [5]. This phenomenon can have a large variety of industrial applications, such as hydrodynamic bearings, mechanical seals, piston rings and cylinder–liner contacts, etc. Limited literature and research on +ve textures (protrusion) are available, where most of the work concentrate on –ve texture (groove). The –ve textures on thrust pad can trap wear debris and thus reduce the abrasive friction and wear due to the third body[6]. Recent study showed that in all type of texture shapes, +ve textures develops more pressure than –ve textures, because the gap between the mating surfaces reduces with +ve texture [7]. Therefore, present experimental study is aimed to investigate experimentally different tribological parameters between a +ve textured steel plate and a runner, those are parallel to each other.

Under full film lubrication condition, each micro dimple of the textured surface acts as a Rayleigh step, which could develop hydrodynamic pressure and thereby, will enhance the total load carrying capacity. The mechanism for this performance enhancement is thought to be related to the formation of cavitation generated inside the dimples. In this situation, pressure in the lubricant may fall below gas saturation pressure or evaporation pressure at the divergent zone (i.e., trailing edge), leading to the occurrence of cavitation[2]. In dealing with the cavitation problem in lubrication theory, there exist two well-known models. The first one is the Reynolds model that does not treat the film reformation boundary, where the cavitation ends and full-film begins; hence, it does not enforce mass-conservation. The other one is the Jakobsson–Floberg–Olsson (JFO) model [10] that formulates the boundary conditions of both film rupture and reformation, and meets the requirement of mass conservation. In principle, the JFO model is more rigorous than the Reynolds model. In contrast, the Reynolds model is much easier for implement in numerical calculation. In 1981, Elrod proposed a computational algorithm that incorporates the JFO boundary condition in the form of a single equation for both the full-film and cavitated regions by the aid of a single parameter known as the switch function. Using the switch function, the Elrod algorithm automatically predicts the cavitated and full-film regions, conserves mass continuity, and predicts the hydrodynamic pressure distribution. Ausas et al. [8] pointed out that when dealing with a micro-textured journal bearing, the Reynolds model is neglected in the cavitation area comparing with the JFO model in which the massconserving models could be used. Qiu and Khonsari [9] found that in mechanical seal-like structures, the JFO model could predict cavitation in dimples and give more realistic performance predictions than the Reynolds model. Although Qiu and Khonsari have also published their experiment results of cavitation observation, they did not compare their simulation results with the experimental ones. So far, for lack of reliable experimental evidence, there still exists a controversy over which cavitation model is more credible for the lubrication analysis of surface textures.

It was found from literature that higher cavitation pressure significantly alters the hydrodynamic (positive) pressure development, so as the load carrying capacity and friction parameter. Therefore, an attempt has been made to investigate the cavitation phenomenon of positive textured surfaces under full film lubrication condition on parallel thrust bearings, where the cavitation zone profile, cavitation pressure, frictional force, load carrying capacity and oil film thickness are determined both experimentally and theoretically.

2 Experimental Study

The experiment is conducted using the in-house developed test rig. Figure 1 shows the in-house developed test rig designed for this purpose. A series of experiments are conducted for the purpose of visualizing the formation of cavitation in a thrust pad having two rectangular shaped textures. The size of the thrust pad (or disc) is having inner and outer radius 25mm and 50mm, respectively. The textures is a rectangular prism of $12\text{mm} \times 10\text{mm}$ base with height 180 μm. The textures are fabricated diagonally opposite to each other at an angle of 180° apart on the pad as shown in figure 2.

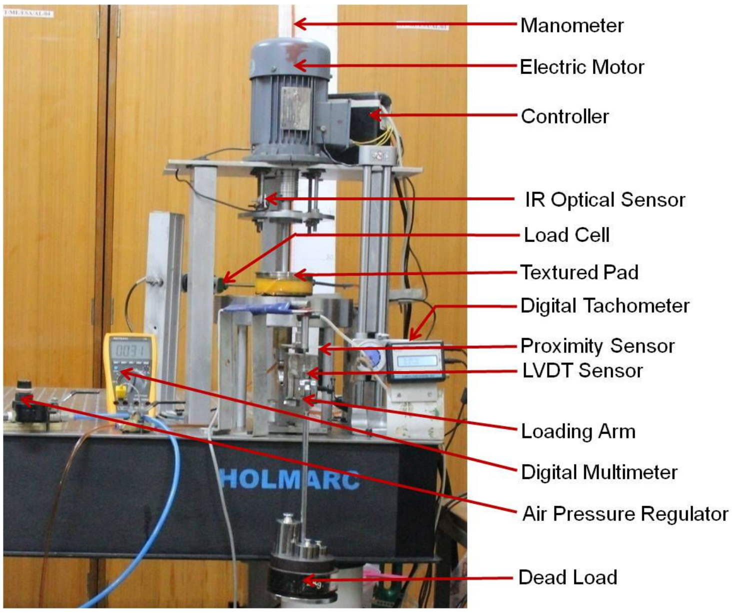


Figure 1: In-house developed Test Rig

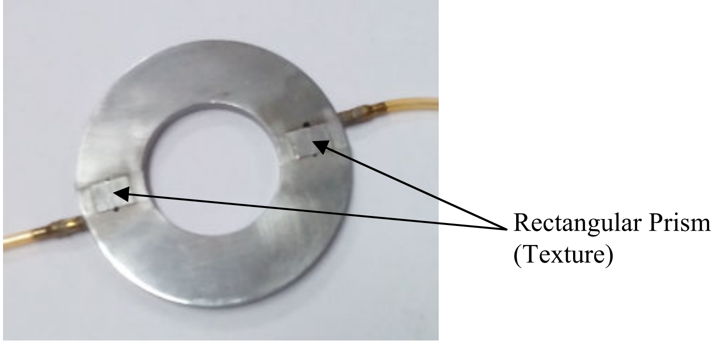
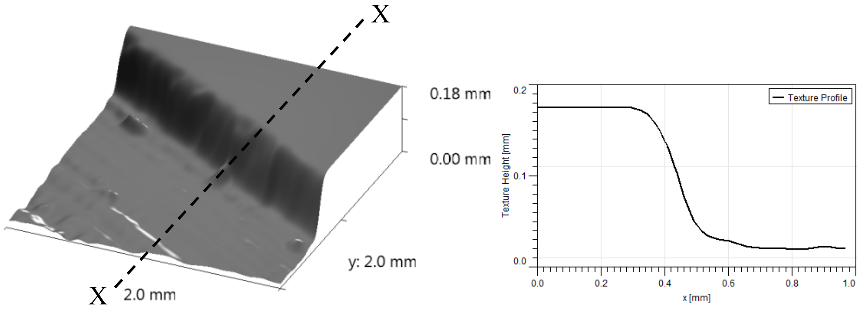


Figure 2: Thrust Pad with two Rectangular textures
(Approx. Texture Height = 180 μm)

The height of the textures are measured with 3-D profilometer. A small portion of the texture as captured under 3-D profilometer is shown in figure 3(a), whereas the line drawing in figure 3(b) shows the distribution of surface height across the line X-X marked in figure 3(a). The load cell, proximity sensor and the manometer is mounted on the test rig as shown in figure 1 to measure the frictional load, oil film thickness and recess pressure, respectively. The cavitation pressure is measured with a pipe connected to the thrust pad in the cavitation zone through oil suction from a container.



(a) 3-D Profile (b) 2-D Profile across line X-X

Figure 3: Measurement of Texture Height with 3-D Profilometer (Texture Height= 180 µm Approx.)

3 Test Procedure

Castrol CRB Plus (SAE 20W40) oil having density 0.884 kg/l and viscosity 0.09pa-s is used for present experimental study. The texture pad is mounted on a disc with the help of locating pins and not allowed to rotate with the runner while in operation. The lubricant is supplied from a oil tank, which is maintained at a constant pressure of 0.5 bar. The oil flows uniformly and continously over the textured pad.This is the case of a constant flow system as there is no restrictor used in the supply line. This effect has also been verified during the subsequent experiments, that the flow rate always remain constant. The runner, which connected to the electric motor, is rotated at different controllable speeds with the help of controller as shown in figure 1. The runner is made of perspex manufactured from methyl methacrylate monomer which is clearly transparent and also highly resistant to variations in temperature. The cavitation profile is clearly visible through the runner during its motion which is recorded with a high speed camera. The load is applied by means of dead weights on a lever.The experiment is conducted at different loads and different speeds in regulated stepwise manner. For a particular load, the speed is varied from 0 to 300 rpm stepwise. At a particular speed the experiment continues for 5 minutes to attain steady state and then it is shifted to the next speed after the readings were taken. The experiment continues from the first speed to the last speed for all loading conditions following the prescribed manner. The cavitation zone profile is formed at the trailing edge of the textures as shown in figure 4.The size of the cavitation profile increases with increase in speed.

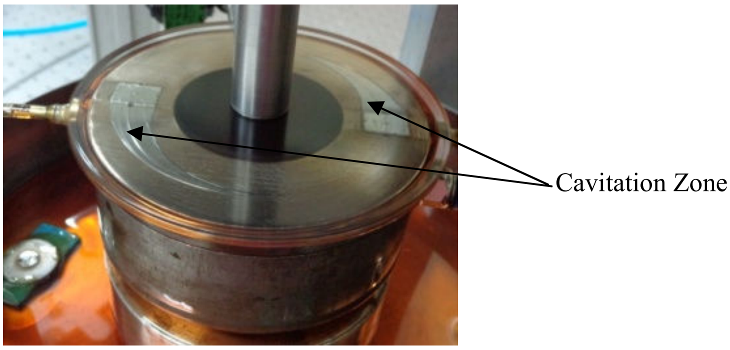


Figure 4: Cavitation Zone Profile on Textured Pad
(Load = 2 kg and Speed = 100 rpm)

4 Results and Discussion

In this experiment the textured pad is tested for 2 kg, 3 kg and 4 kg by varying the speed from 0 to 300 rpm in stepwise manner. The variation of frictional load, cavitation pressure, film thickness and recess pressure with varying speed at different loading conditions are plotted from the experimental data.

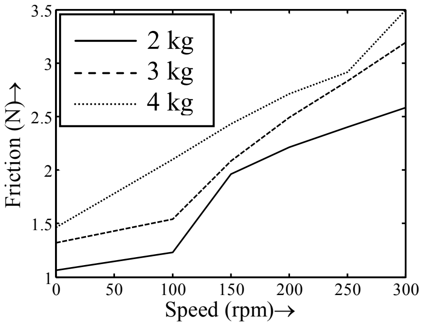


Figure 5: Variation of Friction Force with Speed

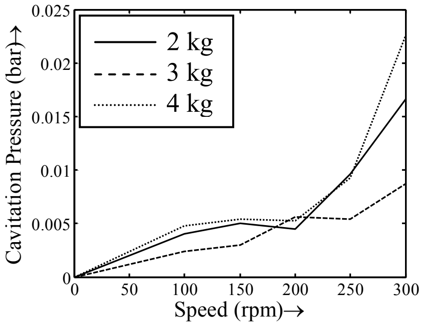


Figure 6: Variation of Cavitation Pressure with Speed

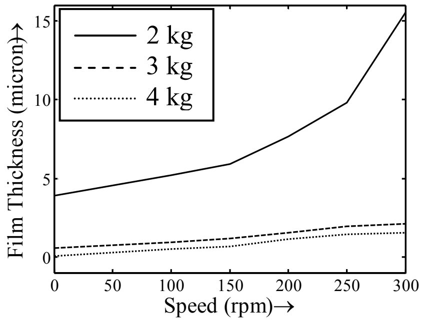


Figure 7: Variation of Film Thickness with Speed

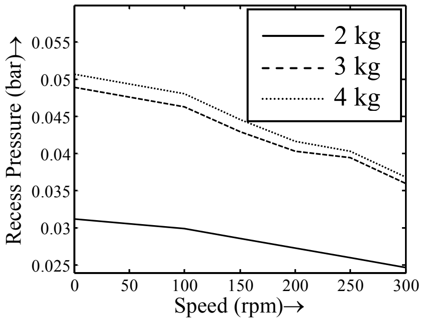


Figure 8: Variation of Recess Pressure with Speed

It is observed from the experimental results that the friction force increases with both load and speed as shown in figure 5. At a particular speed, hydrodynamic peak pressure increases with increasing load. When the condition at the boundary remains same, the pressure gradient in the oil film increases due to rise in the peak pressure. Therefore friction force increases as it is dependent on both pressure gradient and velocity of flow. For a particular load, when speed increases, the local peak pressure over the texture increases leading to higher cavitation pressure. This can be noticed in figure 6, where it also gets higher amount of flow obstruction with increasing speed.

Figure 7 depicts that the film thickness increases with increase in speed and decreases with increase in load. It is obvious that at higher load, more pressure has to develop in the lubricant film in order to support the load. Therefore, film thickness reduces in order to facilitate the increase in the recess pressure and also the hydrodynamic pressure in the land portion. On the other hand, at a given load, the hydrodynamic pressure increases in the land portion with increasing speed. When load is kept constant, the recess pressure has to reduce in order to compensate the increase in the hydrodynamic pressure in the land portion. This reduction in recess pressure as shown in figure 8 and increase in hydrodynamic pressure in land portion ultimately cause the increase in the film thickness as shown in figure 7. In this present experimental analysis, there are only two textures, where overall hydrodynamic pressure development in the land portion is very low as compared to the recess pressure. This recess pressure carries major part of the applied load, therefore, it increases with increasing load as shown in figure 8.

5 Conclusion

From the experimental study of thrust pad bearing with two rectangular shaped textures considering constant flow system, it can be concluded that the tribological performance characteristics such as friction force, cavitation pressure, oil film thickness and recess pressure are quite sensitive with hydrodynamic pressure development. The hydrodynamic pressure development is completely influenced by cavitation pressure that occurs due to presence of deterministic textures on a plane surface. The friction force increases with increase in speed at a particular load. The cavitaion pressure increases with increase in speed leading to hydrodynamic pressure development. Hence, the film thickness increases and the recess pressure decreases with the increase in speed at a particular load

6 References

[1] Wang, X., Yu, H. and Huang, W. (2010), “Surface Texture Design for Different Circumstances”, TriboBR, pp. 97-107.

[2] Zhang, J. and Meng, Y. (2012), “Direct Observation of Cavitation Phenomenon and Hydrodynamic Lubrication Analysis of Textured Surfaces”, Tribol Lett, Vol. 46, pp. 147–158.

[3] Wakuda, M.,Yamuchi, Y.,Kanzaki, S. and Yasuda, Y. (2003), “Effect of surface texturing on friction reduction between ceramic and steel materials under lubricated sliding contact”, Elsevier Science, pp. 356-363.

[4 Wang, W. Z., Huang, Z., Shen, D., Kong, L. and Li, S. (2013), "The Effect of Triangle-Shaped Surface Textures on the Performance of the Lubricated Point-Contacts", Journal of Tribology, Vol. 135, pp. 1-10.
[5] Victor, M., "Lubrication of textured surfaces", ing., University Politehnica of Bucharest, pp. 1-4.
[6] Suh, N.P., Mosleh, M., Howard, P.S. (1994), "Control of friction", Wear, Vol. 175, pp. 151-158.
[7] Ismail, S. and Sarangi, M. (2012), "Effects of texture shape and fluid-solid Interfacial slip on the hydrodynamic lubrication performance of parallel sliding contacts, ImechE, Part J:Journal of Tribology".
[8] Ausas, R., Ragot, P., Leiva, J., Jai, M., Bayada, G., Buscaglia, G.C., (2007), "The impact of the cavitation model in the analysis of microtextured lubricated journal bearings", J. Tribol. Trans. ASME, Vol. 129, pp. 868–875.
[9] Qiu, Y., Khonsari, M.M., (2009), "On the prediction of cavitation in dimples using a mass-conservative algorithm", . J. Tribol. Trans. ASME, Vol. 131, pp.
[10] Olsson, K.O.,(1965), "Cavitation in dynamically loaded journal bearings", Chalmers University of Technology, Goteborg, Sweden, Report No. 308.
[11] Braun, M.J., Hannon, W.M., (2010), "Cavitation formation and modelling for fluid film bearings: a review", Proc. Inst. Mech. Eng., Vol. J 224, pp. 839–863.
[12] Heshmat, H., (1991), "The mechanism of cavitation in hydrodynamic lubrication", Tribol. Trans., Vol. 34, pp. 177-186.
[13] Hupp, S.J., (2008), "Defining the Role of Elastic Lubricants and Micro Textured Surfaces in Lubricated, Sliding Friction", pp.11-151.
[14] Marian, V.G., Kilian, M. and Scholz, W. (2007), "Theoretical and experimental analysis of a partially textured thrust bearing with square dimples", IMechE Vol. 221 Part J, pp. 771-778.
[15] Meng, F., Zhou, R., Davis, T., Cao, J., Wang, Q.J., Hua, D. and Liu, J., (2009), "Study on effect of dimples on friction of parallel surfaces under different sliding conditions", Elsevier Science, pp. 2863-2875.
[16] Scaraggi, M., (2012), "Textured Surface Hydrodynamic Lubrication: Discussion", Springer, pp. 1-16.