Numerical analysis of some problem on Tribological system

A Synopsis submitted to Gujarat Technological University

for the Award of

Doctor of Philosophy

in

Mathematics

by

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AHMEDABAD

July, 2018

Contents

1 Abstract

The thesis discusses regarding numerical analysis of some problems on Tribological system and their solutions. The mathematical formulation of the physical phenomenon leads to an ordinary differential equation with appropriate boundary conditions whose approximate analytical solutions are obtained and the integrals occurring in these solutions are evaluated by Simpson's 1/3 rule to represent the solutions graphically.

Tribology is one of the formidable engineering discipline which deals with friction, wear and lubrication of interacting surfaces in relative motion. In fact, it comprises the study of the characteristic of films of intervening material between containing surfaces and the fallout of either film failure or absence of a film which are usually manifested by severe friction and wear.

Tribology is yet to find full proof rigorous analytical concepts to provide clear cut guidelines to the complex characterization of wear and friction. For understanding such phenomena, mathematical model based numerical analysis may be helpful to us in the context of statistical development. The prediction of lubricating film characteristic is the crucial factor from application point of view.

Most of the analytical studies relay on understanding of mechanism of friction and wear. After having some run-in invariably the bearing surfaces develop roughness. Sometimes the contaminants of lubricants also contribute to roughness. Hence the roughness induced friction and wear need to be addressed duly. Various methods have been mooted to reduce the adverse effect of roughness in general and the adverse effect of friction in particular. One such method is the use of ferrofluid as the lubricant.

In the thesis, an endeavor is made to evaluate the extent to which a magnetic fluid can go in reducing the adverse effect of roughness induced friction and wear. Measures may be provided to lengthen the life period of the bearing system. The method is based on serving the associated statistically averaged Reynolds' type equation to obtain the pressure distribution which will, in turn, give the Load Carrying Capacity (L.C.C.) resulting in the calculation of friction. The underlying mathematical model is based on the hydrodynamic lubrication in a piston ring-cylinder assembly in an internal-combustion engine (IC engine). Also, a comparative study of various film shapes on the performance of a longitudinal and transverse rough finite hydrodynamic slider bearing through a series of flow factors has been done.

Thus efforts have been made to analyze the influence of roughness parameters on the L.C.C. in rough finite plane, exponential, hyperbolic and secant shaped slider bearings for longitudinal rough surfaces through a series of flow factors. Here, the ferro-lubricant is used instead of conventional lubricant and external magnetic field is used to magnetize the ferro-lubricant which can be produced using permanent magnet or electromagnet by installing it around the cylinder surface. The research work is motivated by the fact that ferrofluid lubrication is extensively used in many engineering applications like in machine tools, gears, sliding contact bearings, clutch plates, etc. The related stochastically averaged Reynolds' type equation is solved by using suitable boundary conditions. Results are obtained for the L.C.C. numerically and presented graphically.

We summarize the work done in the present thesis in the form of various chapters.

In the FIRST chapter, the brief introduction about the present thesis is summarized.

In the SECOND chapter, the prerequisite knowledge about Tribology, its components like friction, wear, lubrication etc., and necessary fundamental governing equations of fluid flow is given.

In the THIRD chapter, an effort has been made to analyze the influence of roughness parameters on the pressure and L.C.C. in a rough finite plane slider bearing (P.S.B.) for longitudinally rough surfaces by taking account of the influence of surface roughness through a series of flow factors and roughness pattern parameter(R.P.P) (Patir [12]).

In the FOURTH chapter, it has been sought to study the effect of longitudinal roughness on the behavior of plane slider bearings with a film formed by a ferro-lubricant instead of the conventional lubricant, by using pressure flow factor-which is strongly dependent on the surface pattern parameter for longitudinally rough finite inclined P.S.B.

In the FIFTH chapter, an analysis of the influence of roughness parameters on the pressure and L.C.C. for a rough finite inclined P.S.B. with transversely rough surfaces has been conducted through a series of empirical pressure and shear flow factors and R.P.P.

In the SIXTH chapter, the analysis consists of the solution of the associated stochastically averaged Reynolds' equation for the underlying problem under various combinations of transverse roughness parameters with magnetization parameter.

In the SEVENTH chapter, a comparative study of various film shapes on the performance of a longitudinal as well as transverse rough finite slider bearing through a series of flow factors has been done. Efforts have been made to analyze the influence of roughness parameters on the L.C.C. in rough finite plane, exponential, hyperbolic and secant shaped slider bearings for longitudinal and transverse rough surfaces through a series of flow factors.

In addition, the graphical results present the friction and load carrying trends with respect to the statistical roughness pattern parameters. The results indicate that the performance of the bearing can be improved through the use of a ferrofluid as the lubricant as compared to the conventional lubricant along with appropriate bearing geometry.

Moreover, the adverse effect of roughness and friction can be minimized by increasing the strength of the magnetic field to a substantial level. The analysis is thus representing a numerical proof of the mathematical soundness of the roughness theory combined with the magnetization effect in a very important mechanical component like a piston ring-cylinder assembly in an IC engine.

The associated stochastically averaged Reynolds' type equation is solved accordingly with suitable boundary conditions. Expressions are obtained for pressure, L.C.C. and friction coefficient. The numerical results are presented graphically.

This Ph.D. Thesis will help in understanding the phenomena of piston-ring assembly and choose a suitable combination of various parameters like type of roughness pattern, roughness parameters, strength of magnetism, bearing geometry etc. to minimize the friction and hence to enhance the performance and life of the bearing system.

2 Brief description on the state of the art of the research topic:

The technical study of tribology also has a long history; Leonardo da' Vinci in the late 15th century developed many of the basic rules of friction, such as the relationship between normal force and limiting friction force (Dowson [7]). There are lot of fine recognized and recorded examples of how ancient civilizations developed bearings and low friction surfaces.

Relatively a very little understanding of tribology was gained until 1886 with the publication of Osborne Reynolds' classical paper on hydrodynamic lubrication. Reynolds [14] proved that the generated hydrodynamic pressure of the fluid (lubricant) between sliding surfaces was adequate to prevent contact between surfaces and therefore friction and wear even at very low sliding speeds.

It has gained an increasing attention after the introduction of stochastic concept and Stochastic Reynolds' equation by Christensen [2, 3], Christensen and Tonder [4, 5] governing the mean pressure in bearings having transverse and longitudinal roughness.

Christensen and Tonder's approach formed the base of the analysis to study the effect of surface roughness in a number of investigations by Prakash and Tiwari [13], Guha [8], Gupta and Deheri [9], Andharia et al. [1].

Patir and Cheng [12] modified the averaged Reynolds' equation for rough surfaces (Equation-3.1). They defined pressure and shear flow factors (ϕ_x, ϕ_y, ϕ_s), which were obtained independently by numerical flow simulation using randomly generated or measured surface roughness profiles.

3 Definition of the problem

The underlying mathematical model is based on the hydrodynamic lubrication in a piston ring-cylinder assembly in an IC engine. In the piston-ring assembly of an IC engine, the cylinder wall is considered as one rough surface and the piston ring is behaving like another rough surface. The movement of the piston is considered linear and so the piston ring slides over the cylinder wall. Also, here it is assumed in the present model that the lubrication is hydrodynamic lubrication. Here, the ferro-lubricant is used instead of conventional lubricant and external magnetic field is used to magnetize the ferro-lubricant which can be produced using permanent magnet or electro-magnet by installing it around the cylinder surface. The research work is motivated by the fact that ferro-fluid lubrication is extensively used in many engineering applications like in machine tools, gears, sliding contact bearings, clutch plates, etc.

The modal governing the mean pressure in a rough slider bearing is the following averaged Reynolds' type equation is introduced by Patir and Cheng [12].

$$\frac{\partial}{\partial x}\left[\phi_x \frac{h^3}{12\mu}\frac{\partial \bar{p}}{\partial x}\right] + \frac{\partial}{\partial y}\left[\phi_y \frac{h^3}{12\mu}\frac{\partial \bar{p}}{\partial y}\right] = \frac{U}{2}\frac{\partial \bar{h_T}}{\partial x} + \frac{U\sigma}{2}\frac{\partial \phi_s}{\partial x} \tag{3.1}$$

4 Objective and Scope of work

The principal objective behind the present work is to understand the performance of the finite inclined plane slider bearing with respect to various statistical roughness parameters (mean, standard deviation, skewness etc.) and physical roughness pattern parameter which represents whether the roughness is longitudinal or transverse.

In addition, it is aimed to analyze the behavior of present mathematical model in terms of pressure, friction coefficient and load carrying capacity in presence of ferro-lubricant in compared to the conventional lubricant.

Further, our goal in the last chapter is to compare the performance of the present bearing system through different geometries of the slider bearing.

Here, the results are obtained for one dimensional mathematical model that can be extended for two dimensional models. It can be seen overall performance on the whole two dimensional region of the bearing surface. The effect of temperature on the performance of the bearing system can be measured and analyzed, because the change in temperature can affect the viscosity of the lubricant.

5 Original contribution by the thesis

The original contribution by the thesis is modified mathematical model which analyzes:

- The effect of roughness parameters on the performance of inclines plane slider bearing in case of longitudinal and transverse roughness.
- The effect of magnetic fluid as a lubricant equipped with the roughness parameters on the performance of inclined plane slider bearing in case of longitudinal and transverse roughness.

- The effect of bearing geometry of slider on the performance of slider bearings of the various shapes and observed that choosing suitable bearing geometry the performance of the bearing system can be enriched.

The results of such problems are obtained graphically and compared as well to know the criteria for betterment of the bearing's performance.

6 Methodology of Research and Results/Comparisons

The following assumptions were considered in the model:

- Body forces are neglected i.e there are no extra fields of forces acting on the lubricant.
- The lubricant is considered as Newtonian (i.e stress is proportional to rate of shear).
- The viscosity is constant throughout film thickness.
- The Reynolds hydrodynamic lubrication concept is applicable to lubrication in piston ring assembly.
- Piston ring dimensions are assumed to be constant for width, axial height, length, outer and inner diameter, clearance between the ring and piston etc.
- Piston - cylinder assumed to be perfect concentric assembly.
- The flow is assumed to be steady in X- direction and the surface roughness is considered either longitudinal or transverse.

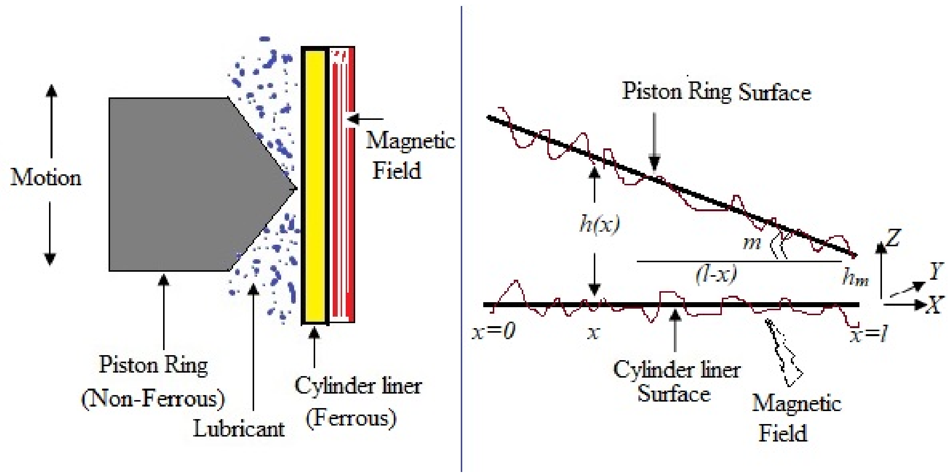

Figure 6.1: P.S.B. geometry in Piston ring-cylinder assembly

Hence the problem (Equation 3.1) is considered as a one dimensional problem. Various roughness parameters, like mean, standard deviation and skewness, roughness pattern parameter for longitudinality and transversness of the rough surface and magnetization parameters are introduced at various stages and then solved the one dimensional differential equation for the mean pressure at the contact zone of the bearing system with appropriate boundary conditions. The Load carrying capacity and the friction coefficient are obtained. Also the comparison is made with previous research work to justify the present work.

The integrals occurring in the calculation throughout the work is carried out by Simpson's 1/3-rule. And the results and mutual relations between two parameters are shown graphically and in tabular form. Various film shapes are taken in account for comparing the corresponding load carrying capacity and obtained favorable results with the secant shape slider bearing.

7 Achievements with respect to objectives

The mathematical model given in equation-3.1 by Patir and Cheng [12] is modified accordingly to achieve our goal and :

- Solved the modified mathematical model with respect to suitable boundary conditions for getting relation among various parameters like roughness parameters (e.g. mean, standard deviation, skewness) , pattern of roughness (e.g. longitudinal or transverse), type of lubricant (e.g. magnetic lubricant or conventional lubricant), magnetic parameter, shape of bearing geometry etc.

- Achieved satisfactory results as desired and obtained suitable combinations of such kind of parameters that may enhance the performance and life period of the bearing system.

8 Conclusion

- The effect of roughness parameters on the pressure, L.C.C. and friction coefficient for a rough finite inclined P.S.B. with longitudinal as well as transverse rough surface has been analyzed. The results obtained here are compared with those of [6, 11, 10]. It is observed that the L.C.C. can be increased by decreasing the value of the roughness pattern parameter and decreased by increasing the value of the roughness pattern parameter (R.P.P).

- The comparative study among plane, hyperbolic, exponential and secant shape slider bearing systems justifies that the trio-negatively skewed roughness, standard deviation and mean negative may result in a better performance of the bearing system irrespective of the value of R.P.P. and vice versa. The secant shape slider bearing gives better performance than plane slider, hyperbolic slider and exponential slider bearing. It is also clear that the performance and life of the bearing system can be enhanced by choosing proper bearing geometry with other suitable parameters like mean, standard deviation, skewness and R.P.P. However, from longevity point of view, the roughness aspect needs to be evaluated while designing the bearing system.

9 List of Publications

List of Publications Arising From the Thesis

- Influence of magnetic fluid through a series of flow factors on the performance of a longitudinally rough finite slider bearing. *Global Journal of Pure and Applied Mathematics*, 12(1),(2016): 783-796.
(Available online: http://www.ripublication.com/gjpam16/gjpamv12n1_69.pdf)

- Influence of surface roughness through a series of flow factors on the performance of a longitudinally rough finite slider bearing, *Annals of the Faculty of Engineering Hunedoara*, 14.2 (2016): 227.
(Available online: http://annals.fih.upt.ro/pdf-full/2016/ANNALS-2016-2-36.pdf)

- Influence of transverse surface roughness through a series of flow factors

on the performance of a rough finite plane slider bearing, *PRAJNA - Journal of Pure and Applied Sciences*, ISSN- 0975 - 2595, Vol 24-25, (2017):1-6
(Available online: http://spuvvn.edu/academics/publications/prajna_2017/mathematics/1.pdf)

- Comparative study of various film shapes on the performance of a longitudinal rough finite slider bearing through a series of flow factors, *Mathematics Today, An International Journal for Mathematical Sciences*, ISSN 0976-3228, e-ISSN 2455-9601, Vol.34(A), (2018): 40-52
(Available online: http://mathematicstoday.org/currentisue/V34(A)_2018_5.pdf)

List of Accepted Article

- The effect of magnetic fluid together with transverse roughness pattern parameters on the performance of a plane slider bearing, *Lecture Notes in Mechanical Engineering (Springer): Proceedings of the 1st International Conference on Numerical Modelling in Engineering-2018*, ISSN-2195-4356 accepted for presentation and publication.

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