Indian National Society for Aerospace and Related Mechanisms
BANGALORE CHAPTER

E-NEWSLETTER

Vol.9, No.1, September 2017

From the Editor

It gives me immense pleasure to place before you this edition of E-newsletter. The first half of this year was a very significant for the members of Spacecraft Mechanisms Group (SMG) at ISAC. SMG witnessed successful deployment and release of mechanisms onboard the remote sensing satellite CAROSAT-2D/2E, Nano-satellite INS-1A/1B and geostationary satellites GSAT-9/17/19. The editorial committee congratulates the past and present members of Spacecraft Mechanisms Group, ISAC for this excellent achievement.

The article titled "*Literature Review on Elasto-Hydrodynamic Lubrication*" presents the literature review on hydrodynamic lubrication and on Rayleigh Step Bearing, which has a variety of industrial applications like turbine bearings, rotor bearings and thrust bearings.

In July 2017, INSARM Bangalore Chapter organized a guest lecture on the topic "*Design of Heading Angle Controller for Non-holonomic Mobile Robot*" at ISRO Satellite Centre, Bangalore by Dr. Shubhashisa Sahoo, from Centre for Artificial Intelligence and Robotics, DRDO, Bangalore. The seminar was well attended and appreciated. The glimpse of this event is also presented in this letter.

This newsletter is intended to be a platform for the exchange of information regarding the current developments, new ideas and novel concepts in the area of mechanisms and related field through active participation of members. I request all INSARM members to actively contribute technical articles related to mechanisms to enhance the technical value of the e-new letter.
With best regards,

Dr. B.P. Nagaraj

Chief Editor

CONTENTS

Quote:

"All knowledge that the world has ever received comes from the mind; the infinite library of the universe is in our own mind"

Swami Vivekananda

FROM INSARM BANGALORE CHAPTER

LITERATURE REVIEW ON ELASTO-HYDRODYNAMIC LUBRICATION

Sisir Kumar Guha, Rahul Ghatak, NarenPatra, DebasishSarkar and **SoumyajitSaha**
Indian Institute of Engineering Science and Technology, Shibpur, P.O. – Botanical Garden, Howrah – 711103
Email id: rahulg@isac.gov.in

1. Introduction

A hydrodynamic lubrication is a type of fluid film lubrication where the load supporting fluid film is generated by the shape and the relative motion between the two contacting surfaces of the bearing. Since the contacting surfaces are elastic, hydrodynamic action will be affected by the elastic deformation. When the contact interface is very small like contact between two gears, cam and follower, rolling contact bearing, machine tool slides, etc. the film pressure of the lubricant becomes very high. This causes the molecules of the lubricant to come closer and thereby increasing the inter-molecular force of attraction. This increases the viscosity of the lubricant. This effect of increase in the lubricant viscosity with the increase in the film pressure is called as piezo-viscous effect. Thus in an elasto-hydrodynamic lubrication (EHL), two conditions prevail simultaneously:

- The contacting surfaces are elastic.
- The lubricant film pressure is very high.

Rayleigh Step Bearing is a type of simple one dimensional sliding contact bearing which has prominent values of the load carrying capacity, lesser frictional parameter and hence lesser frictional loses. It has a large number of industrial applications including turbine bearings, rotor bearings, thrust bearings, etc. Several branches of continuum and discrete mechanics, materials science, lubricant chemistry and rheology, surface physics and topography/metrology, interfacial physics are required for proper analysis. Design and development of advanced interfaces requires knowledge not only in the field of machine design and contact mechanics, but also in several other fields like thermal science, electromagnetic and several other multidisciplinary branches in Engineering.

2. Literature Review

The pressure produced in a lubricant film is transmitted to the boundary surfaces, resulting in elastic deformation of bounding surfaces. The importance of elastic deformation of the bounding surfaces was recognized during the development of the hydrodynamic lubrication theory for non-conformal contact such as that found in gears, rolling contact bearing, cam, and tappets. The first substantial development in case of contact mechanics was on behalf of Hertz[1] based on the assumption of having no lubrication at the interface. The theory became very popular for being able to give simple and satisfactory solution for frictionless elastic contact of dry and smooth surfaces. In practice however most of the power transmitting devices encounter problem due to friction and lubrication found to be an excellent choice for reducing friction and enhancing performance. In 1886 Reynolds published his milestone theoretical lubrication analysis based on Towers journal experiment [2].

Reynolds equation was derived; and it has been the foundation of hydrodynamic lubrication theory since then. One of the remarkable early study was by Martin[3], who publish his hydrodynamic lubrication analysis for line contact in spur gear in 1916 and he found the lubricant film thickness in between gear teeth to be extremely small often in the order of 100 nm. Starting in the 1930, researcher strived to improve the lubrication analysis for counter formal contacts by including the effect of localized elastic deformation of the two surfaces, and that of the lubricant viscosity increases in the contact area due to high pressure.

The most significant that the scientific community saw regarding the fundamental mechanism of EHL was in 1949, when Grubin[4] based on Ertel's[5] preliminary results obtained in 1939, published his work where he assumed that a flat film was formed in the contact area because the surfaces were elastically deformed by the fluid pressure of several gigapascals and focused on the flow at the inlet zone, taking into consideration the piezoviscous effect of the lubricant. The first successful solution was published in 1951 by Petrusevich[6], who was first to present solution satisfying both Reynold's equation and elastic equation. He presented three cases in detail for different speeds but the same load. In 1959,Dowson and Higginson[7]observed that iterative procedures based upon the successive solution of the elasticity and Reynolds equation could be tedious and only slowly convergent. They therefore developed the inverse solution technique in which the Reynolds equation was used, not to yield a pressure distribution for a specified film shape, but to calculate the film shape associated with a given pressure distribution. As described earlier, the development of the EHL theory and application in earlier years was either based on smooth surfaces or artificial roughness of simple geometry under full film conditions with no surface contact, or through stochastic models that did not directly simulate surface contact and could not handle severe conditions with heavy interaction of rough surface asperities. In mid-1990 mixed lubrication (partial lubrication) was come into the picture. Mixed EHL is the mode in which both EHL films and surface asperity contact coexist and neither can be ignored.

The great achievement of computer technology has fueled significant breakthrough in the thin-film and mixed EHL research and development since mid-1990. First improved optical interferometry has yield fruitful result in the areas of ultrathin film and boundary lubrication as well as mixed lubrication. The thin EHL film measurements can now be done at the nanometer scale, and the transition from full-film EHL to boundary lubrication has been a focus of investigation.

Concurrently, deterministic solution for mixed EHL has achieved significantly progress. Basically there have been two approaches for mixed lubrication simulation: the first is to use a unified equation system method for both the lubrication areas and asperity contact simultaneously, and the second to use separate model for lubrication and contact, respectively. A separate solution with sinusoidal roughness for line contact was presented in 1995 by Chang[8]. The first unified approach for point contact with machined 3 D roughness was published by Zhu[9] in 2011 and by Hsu[10] in 2014.

The authors [11] have evaluated the performance parameters of Rayleigh step bearing like pressure distribution, load carrying capacity, film thickness, and the frictional parameter using power law fluid as the lubricant. It also assumes that the contacting surfaces of the bearings with the fluid are elastic. Thus the regime of the lubrication changes from hydrodynamic lubrication to elasto-hydrodynamic lubrication. Rayleigh step bearing consists of two slides which are parallel to each other. It is shown in the figure 1 below:

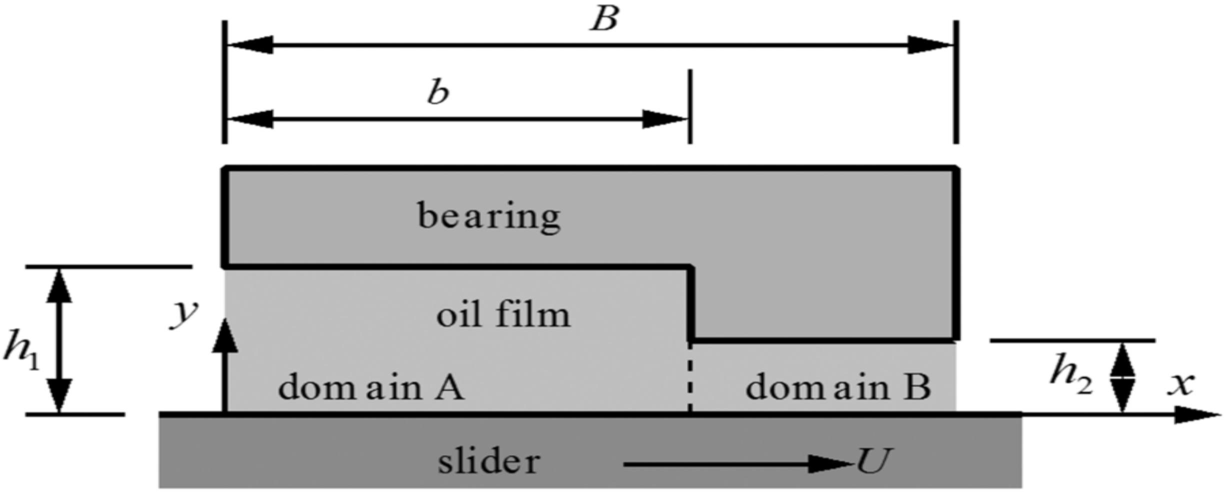

Figure 1 – Rayleigh Step Slider Bearing

In the above figure, B, b, h_1 and h_2 represents overall length, step zone length, step zone film thickness (domain A) and land zone film thickness or initial film thickness (domain B) of the bearing respectively. It can be seen from the above figure that the film thickness is maintained constant in different regions of the bearing. The region of the higher film thickness is called as step zone and the other region is called as the land zone. Due to the abrupt change in the film thickness at some intermediate point along the span of the bearing, hydrodynamic action is generated. Figure 1 shows that the bottom slide is moved towards right with a velocity U m/s and the top slide is fixed.

Power law fluids are analogous to non Newtonian fluids and don't follow the Newtons law of viscosity. The fluids which don't follow the Newton's law of viscosity are called as non Newtonian fluids or power law fluids. Its viscosity – shear stress relationship can be mathematically expressed as :

$$\tau = m\left(\frac{\partial u}{\partial y}\right)^n + B \qquad (1)$$

In the above equation, τ, Shear stress of the fluid in Pa, u, Local velocity of the flow at y in m/s, y, Distance measured perpendicular to the flow direction in m from the bottom slide, n, Flow index of the fluid, m , Consistency Index and B, Shear stress at zero rate of shear strain in Pa.

For a Newtonian fluid, n is equal to 1 and B is 0.When long chain additives are added to the Newtonian fluids, the fluids essentially become non Newtonian in nature and it changes the performance parameters of bearings in which it is present. Moreover, the load carrying capacity of the Rayleigh step bearing lubricated by power law fluid is found to be more than the bearing with Newtonian fluid. Vice-versa is the situation with the frictional parameter. It has also been found from studies that the performance of Rayleigh step bearing is more than the performance of the conventional journal bearing under the same physical conditions [12]. Our thesis presents evaluates the pressure distribution, load capacity of the bearing, film thickness, flow rate, and, the frictional parameter of a Rayleigh step bearing using power law fluid incorporating the most generalized case of fluid film lubrication, i.e., considering EHL and Piezo-viscous elastic lubrication regime. The analysis also compares the results with Iso-viscous rigid regime of lubrication. The present analysis modifies the Reynolds equation according to the lubrication regime consideration and discritizes it by2^{nd} order central difference scheme. It uses Gauss-Seidel iterative technique with successive over relaxation to obtain the solution of the discritized algebraic equation.

3. Observations

From the literature it can be observed that the development of the lubrication theory and the analysis of the contact mechanics started way back in 1886 from the period of Hertz and Reynolds. Hertz was the first to study the surface contact problem and hence the stress which develops between the two surfaces is referred to as Hertzian contact stress. Lots of research were done between 1930 to 1950 on the lubrication analysis of counter formal contacts which develops between two gear teeths, cam and follower, rolling contact bearings, machine tool slides, etc. From the thesis, authors have concluded that at a particular value of initial film thickness and flow index, the film pressure of the lubricant increases in the step zone, becomes maximum at the step point, and, then decreases in the land zone with step ratio. The load carrying capacity increases with increase in step ratio, becomes maximum at a particular step ratio, and, then decreases with further increase in the step ratio. The step ratio corresponding to maximum load carrying capacity is influenced by the initial film thickness and the flow index. Moreover it increases with increase in the initial film thickness at a particular flow index. The frictional parameter decreases with the increase in the step ratio, becomes minimum at a particular step ratio, and, then increases with further increase in the step ratio. The frictional parameter in step zone is more than the frictional parameter in the land zone. Moreover it has been found that the frictional parameter for a particular step ratio is more for EHL bearing instead of rigid bearing. Researchers were striving to make one unified theory of lubrication which can accommodate from boundary lubrication regime to hydrodynamic lubrication regime. Finally with the development of computer technology along with the numerical techniques, possible solutions were obtained for Reynolds equation which was otherwise difficult to solve analytically. This development started from late 1980's and this continues to be a vast field of research in engineering sciences.

REFERENCES

1. Hertz, H., 1881, "On the Contact of Elastic Solids," J. ReineAngew. Math.
2. Reynolds, O., 1886, "On the Theory of Lubrication and Its Application to Mr. Beauchamp Tower's Experiments, Including an Experimental Determination of the Viscosity of Olive Oil," Philos. Trans. R. Soc. London.
3. Martin, H. M., 1916, "Lubrication of Gear Teeth," Engineering (London).
4. Grubin, A. N., 1949, Fundamentals of the Hydrodynamic Theory of Lubrication of Heavily Loaded Cylindrical Surfaces, Book No. 30, Central Scientific Research Institute for Technology and Mechanical Engineering, Moscow (DSIR Translation).

5. Ertel, A. M., 1939, "Hydrodynamic Lubrication Based on New Principles,"Akad. Nauk. SSSR, Prikladnaya Matematikai Mekhanika, 3(2).
6. Petrusevich, A. I., 1951, "Fundamental Conclusions from the Contact-Hydrodynamic Theory of Lubrication," Izv. Akad. NaukSSR.Otd. Tekh. Nauk.
7. Dowson, D., and Higginson, G. R., 1959, "A Numerical Solution to the Elasto-hydrodynamic Problem," J. Eng. Sci.
8. Chang L, 1995, "Deterministic modeling and Numerical Simulation of lubrication between rough surfaces – a review of recent developments".
9. Dong Zhu, Q. Jane Wang- Elasto-hydrodynamic Lubrication: A Gateway to Interfacial Mechanics –Review and Prospect (Copyright: 2011 by ASME).
10. Li-Ming Chu, Hsiang-Chen Hsu, and Jiann-Lin Chen-An Analytical Approach for Analysis of Slider Bearings with Non-Newtonian Lubricants (Hindwai Publishing Corporations,16th January,2014).
11. Guha S.K., Ghatak R., Patra N., Sarkar D., Saha S., 2015, "Analysis of Elasto-Hydrodynamic Step Bearing Using Power Law Fluid", Indian Institute of Engineering Science and Technology, Shibpur, Howrah – 711103, West Bengal.
12. Hamrock B.J. and Anderson W.J., 1968, " Incompressibly Lubricated Rayleigh Step Journal Bearing with Zero Order Perturbation Solution".

ABOUT AUTHORS

Prof. Sisir Kumar Guha is currently working as Professor in department of Mechanical Engineering, IIEST Shibpur, Howrah, West Bengal. He obtained his B.E. in Mechanical Engineering from IIEST Shibpur in 1978, MTech from IIT Kharagpur in 1980 and PhD from IIT Kharagpur in 1989. His technical interest lies in Tribology, Elasto-Hydrodynamic lubrication in bearings and slider bearings with surface textures (dimples) effect.

Mr. Rahul Ghatak is currently working as Engineer in Spacecraft Mechanisms Group, ISRO Satellite Centre, Bengaluru. He obtained his B.E. degree in Mechanical Engineering from IIEST Shibpur in 2015.

Mr. Naren Patra is currently working as Engineer in M.N. Dastur Pvt. Ltd., Kolkata. He obtained his B.E. degree in Mechanical Engineering from IIEST Shibpur in 2015.

Mr. Debasish Sarkar obtained his B.E. degree in Mechanical Engineering from IIEST Shibpur in 2015.

Mr. Soumyajit Saha obtained his B.E. degree in Mechanical Engineering from IIEST Shibpur in 2015.

INSARM LECTURE

on

DESIGN OF HEADING ANGLE CONTROLLER FOR NON-HOLONOMIC MOBILE ROBOT

On 7th July 2017, INSARM Bangalore Chapter organized a guest lecture at ISRO Satellite Centre, Bangalore by **Dr. Shubhashisa Sahoo**, Scientist-E**,** from Centre for Artificial Intelligence and Robotics, DRDO, Bangalore. The abstract and the glimpse of this event are presented.

Abstract: This study describes the mathematical model of a Non-holonomic Mobile Robot for designing the heading angle controller. In analyzing the robot handling performance, a critical aspect is the use of an appropriate tire model that can accurately characterize the ground-wheel interaction. Another associated challenge is to obtain the corresponding model parameters. The novelty of this work includes the proposal of estimation of model parameters using the experimental data. The performance of the controller was evaluated experimentally at different speeds using a battery operated test platform. A wide range of experiments such as lane change and double lane change have been conducted for comparison with the simulation results. It was found that gain scheduling helped in tracking the desired heading angles of the vehicle at various speeds.

Felicitation of **Dr. Shubhashisa Sahoo**

Presentation by **Dr. Shubhashisa Sahoo**

Participating Audience

FORTH COMING SEMINARS

\

3rd ISSC National Conference on ***Complex Engineering Systems of National Importance: Current Trends and Future Prospectus*** **(INaC-03)**

Organised by ISSE Chandigarh Chapter and Semi-Conductor Laboratory, Department of Space on October 12th and 13th , 2017 at Indian School of Business, Chandigarh. 273010, (UP) India

Website: ***www.scl.gov.in***

INVITATION FOR ACTIVE PARTICIPATION

We invite you to send technology news, technical articles, members' news and suggestions/comments on e-newsletter and the web contents to Chief Editor to improve the newsletter. The technical articles may be limited to 400 words only in MS Word format with two photographs. The direct extracts from references may be avoided. Kindly provide your e-mail & mail address to enable us to contact you.

enewsletter@insarm-bangalore.org

www.insarm-bangalore.org