Experimental and Numerical Analysis of a Laminar Flow between two Planes with variable Slope

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Abstract

The present experimental and numerical investigation deals with problems related to hydrodynamic bearing, machine elements in which a thin film of fluid separates the surfaces in relative motion. The lubricating film is drained in the contact zone which forms a convergent space generating a hydrodynamic pressure. The developed pressure allows the total separation of the surfaces in contact and equilibrates the load. At the bearing the wear and the heat of the components are omnipresent which require the study of the related problems that may arise. The present work considers and treats the parameters which govern the behavior of the hydrodynamic bearings such as the film flow properties: speed, temperature, pressure, the slope of the inclined plane and the friction coefficient between the oil film and the bearing wall. The flow of the fluid in the lubricating film is made in laminar regime. We were able to deduce that an increase in the maximum pressure is observed with increasing speed and slope. The theoretical and numerical results of the pressure distribution show a good agreement with the experimental results.

Keywords: *Two Planes with variable Slope, laminar flow, pressure, lubrication.*

I. Introduction

In the industrial sector it is very important to have reliable machines and equipments with higher performance and possible long life cycle.

The problems that arise in this field for the industrial rotating machineries are numerous and engineers are engaged to solve these problems and find solutions. Among the major problems of the rotating machineries concern the problem of lubrication of parts and bearings. The hydrodynamic lubrication is one of the proposed solutions. It is an important domain of tribology in which a thin film of fluid separates the contact surfaces. It is then necessary to know the temperature and pressure fields in the lubricating fluid between the solids in contact taking into account the change of the slope and the variation of the velocity.

Works have been done on the subject: Boncompain R. et al [1](1987) had treated the thermal effects in hydrodynamic bearings by showing their theoretical and experimental aspects. The effect of viscosity with respect to temperature on the heat transfer on a surface in motion was investigated by Elbashbeshy E. M. A. et al[2] (2000). Technical data on mechanical stops and hydrodynamic bearings have been detailed by J. Frêne[3] (2004). Myers T. G. et al [4] (2006) have analyzed a model that describes the flow of a fluid with variable viscosity in a canal with parallel plates. Makinde O. D. [5] (2006) examined the solutions at the equilibrium state of a liquid film with variable viscosity and a laminar fall along an inclined heating plate. The rheological effect of non Newtonian fluid flow on the history of the film thickness with respect to time between non parallel sliding compressive surfaces had been studied by J.R Lin et al[6] (2006).

Based on the above mentioned investigations, our present work is an experimental and numerical study of flow of an oil film between two planes in which one of them has a variable slope and the other with variable speed.

The main objective of the study is to investigate the effect of variations of the relative velocities, the slope and the lubricant (oil) temperature on the developed pressure. The study is composed of two parts: an experimental part using a Mitchell bearing bench and the second part is a numerical study using a computer commercial code Fluent.

II. Description of the experimental apparatus

The apparatus is mainly composed of a casting aluminum frame in which its position must be accurately adjusted to facilitate the displacement of the band supporting the oil film. The casted aluminum frame supports two cylindrical steel rollers that allow the rolling of the plastic band. One of the rollers is driven by a DC electrical motor with a variable speed. The second roller is mounted on a support with a slot allowing the adjustment of the tensile of the moving plastic band. The surfaces of the rollers are specially designed to avoid sliding of the band and maintain a correct tension. The apparatus is put in a plastic box full with oil at a level that allows the immersion of the lower part of the band. The disposition of the manometric tubes to measure the pressure distribution in the bearing is shown in fig. 1.

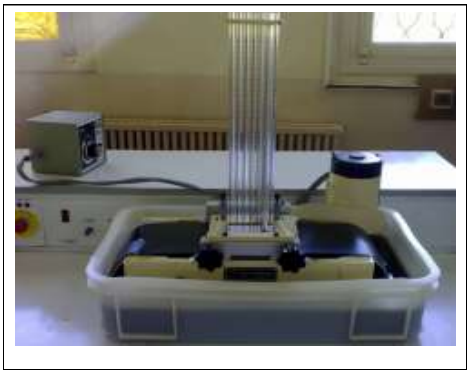


Fig.1. Hydrodynamic bearing apparatus

III. Sketch of the configuration

The Reynolds' lubrication equation can be obtained the continuum mechanics equations and from the law of the Newtonian fluid behavior taking into consideration the particular form of the lubricant film whose thickness is very low with respect to the width and length of the contact surface as shown in fig. 2.

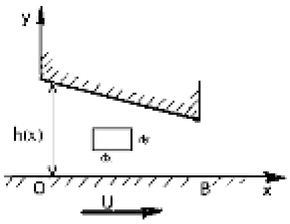


Fig.2. Schematic of the configuration

IV. Results and discussion

IV.1. Variable slope

Fig. 3 shows the variation of the pressure along the bearing at different $a = h_1/h_2$ ratios. In the partially convergent space the pressure is not constant due to the geometric form defined by the two planes and by the relative velocity of the inclined plane.

The relative pressure of the oil increases from the bearing inlet up to a maximum value where the pressure gradient is null then it decreases to reach a value up to an important value than that of the inlet. The value of the maximum pressure is a function of the ratio a, its point of application shifts towards the flow exit when increases. The maximum pressure value is reached for a=2.

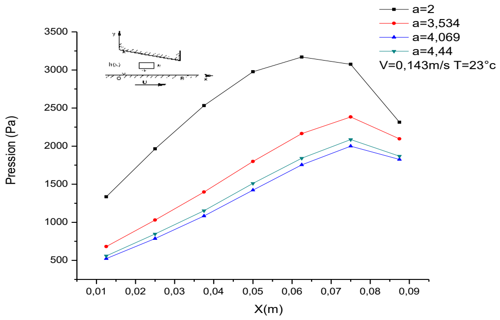


Fig.3. Variation of the pressure along the two non-parallel planes with variable slope (With fixed velocity and temperature)

IV.2. Variable velocity

Fig. 4 illustrates the pressure variations along the partially convergent space at different relative velocities.

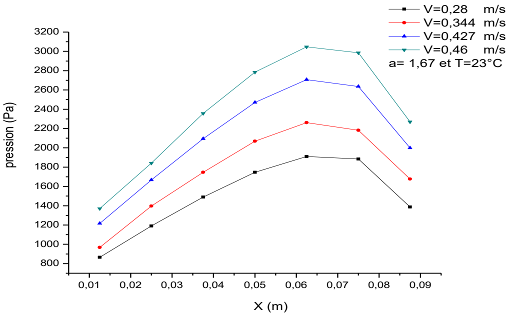


Fig.4. Variation of the pressure along the two non-parallel planes with variable velocity (With fixed slope and temperature)

At a constant slope the maximum pressure increases with the increase of the plane (band) translation speed.

The profiles of the pressure distribution are not influenced by the variation of the velocity.

The point of application of the maximum pressure is at the same position in all the graphs. However the profiles are not similar for the case of variable slope as shown fig. 3.

IV.3. Variable temperature

Fig.5 shows the pressure variations at different oil temperatures. It is observed that the pressure in the bearing increases with decreasing temperature at a given velocity and slope.

The pressure behavior obtained under the effect of temperature is explained by the variation of the viscosity. Since at low temperatures the oil becomes more fluid thus generating low pressures.

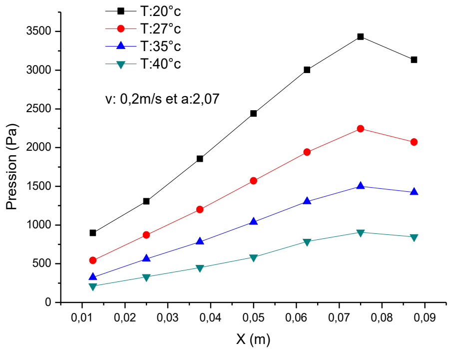


Fig.5. Variation of the pressure along the two non-parallel planes with variable temperature (With fixed velocity and slope)

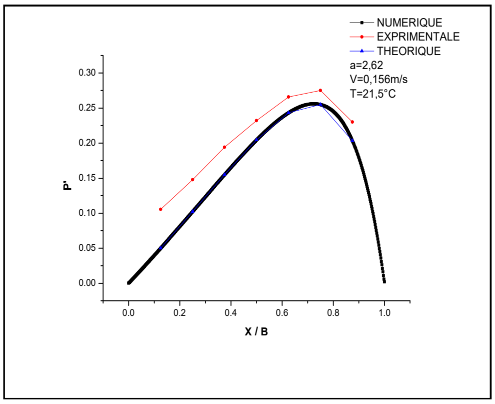
The gap between the pressures at different temperatures is less important at the bearing inlet and is more important at points of maximum pressures.

V. Numerical results for theoretical and experimental validation

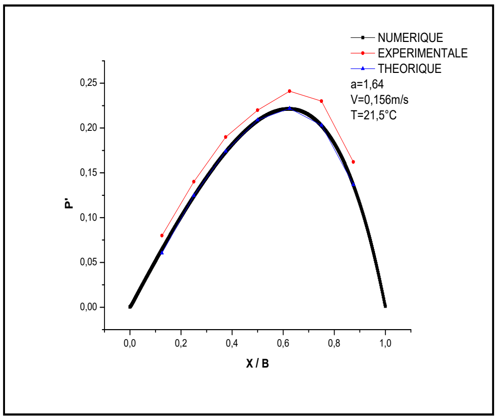
The obtained numerical results have been validated by the experimental results. In the following the experimental, theoretical and numerical results are illustrated in the same graph and examined for each case.

V.1. At constant velocity

In fig. 6, the variation of the dimensionless experimental pressure, theoretical and numerical are illustrated. The relative velocity for both cases is the same however the slope is different for one case to the other. It can be observed a good agreement between the experimental, theoretical and numerical pressure results in both figures. Moreover, the effect of the slope on the displacement of the point of application of the pressure is clearer in this part.



(a)

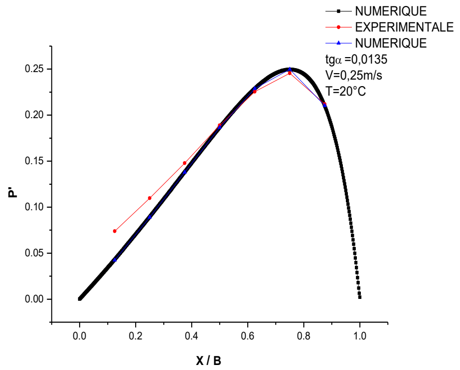


(b)

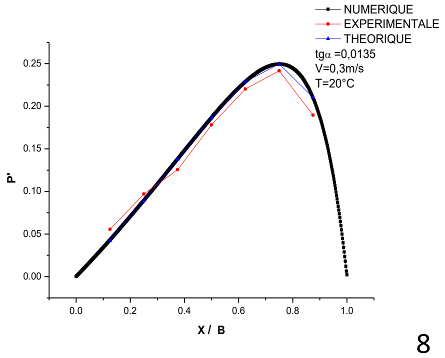
Fig.6. Variation of the dimensionless pressure with constant speed :(a)a=2.62;(b)a=1.64

V.2. At fixed slope

Both figures 7 show the variation of the experimental, theoretical and numerical pressures with fixed slope and variable relative velocity.



(a)



(b)

Fig.7. Variation of the dimensionless pressure with fixed slope :(a) v =0.25 m/s;(b)v=0.3m/s

Similarly it is noticed a good correlation between the experimental, theoretical and numerical pressure results in both figures. The maximum pressures in both figures are shifted towards the bearing outlet due to the slope effect which is quite important. The obtained results allow to validating the 2D numerical model and give the possibility to examine the cases where there are difficulties in carrying out experiments.

V.3. The load

Fig. 8 shows the variations of the experimental, theoretical and numerical load with respect to the ratio " a ". The obtained results show a good agreement between the numerical and theoretical values which are acceptable with those of the experiment. In the three illustrated plots the reaches a maximum value for a ratio a=2.2 above which it decreases. Between the experimental and theoretical variations, a maximum difference of about 17% is noticed at the point of the maximum load, this difference decreases when the slope increases.

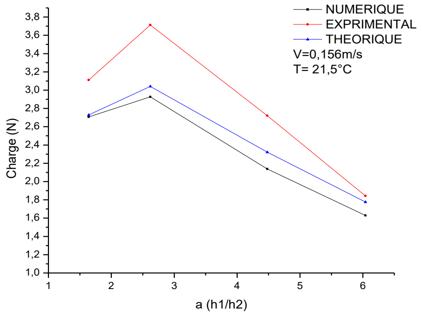
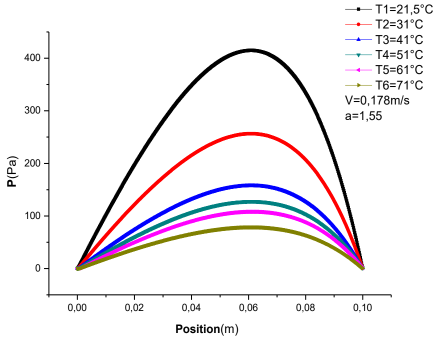


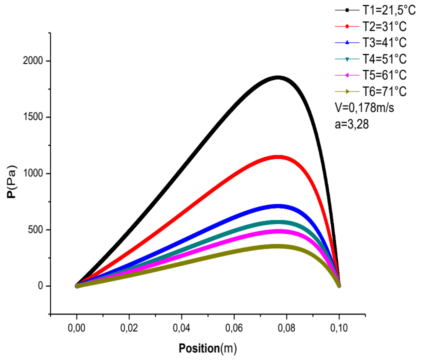
Fig.8. Variation of the load with respect to the ratio.

V.4. At variable temperature

Fig. 9 shows the variation of pressure as a function of temperature with fixed relative velocity and variable slope.



(a)



(b)

Fig.9. Pressure variation with respect to Temperature:(a)a=1.55;(b)a=3.28

The obtained results clearly show the significant effect of the temperature on the pressure. The pressure generated in the film is inversely proportional to the temperature. At elevated temperatures the maximum pressure has lower values because the oil is more fluid thus less viscous. From the figure , when the temperature is tripled from 20.1°C to 71°C the generated pressure decreases 5 times in the same temperature interval. Although the resistant of the lubricant and the sliding velocity make increase the temperature of film and lower the generated pressure. This requires the control of the temperature variations of the film in order to assure a good operational service of the bearings.

VI. Conclusions

In the case of a hydrodynamic mechanical stop (inclined patens type) operating in laminar regime, the comparative simulation, theoretical and experimental study has been carried out along a canal with inclined planes. The study put into evidence the effect of the variation of pressure for different values of temperatures, velocity with variable slope and then the load variations with respect to the ratio $a = h_1/ h_2$. It can be concluded that the value of the pressure in the film is highly influenced by the geometry of the contact, by its kinematics and by the temperature. We can draw from this study the good agreement between the experimental, theoretical and numerical found results.

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