UNIVERSITI PUTRA MALAYSIA

COMPARATIVE STUDY BETWEEN ANALYTICAL METHOD AND FINITE ELEMENT METHOD OF A CYLINDRICAL BORE JOURNAL BEARING BEHAVIOUR

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By

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Dedicated to

My Parents

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LIST OF ABBREVIATIONS

FDM	:	Finite Difference Method
FEM	:	Finite Element Method
ESDU	:	Engineering Sciences Data Unit
p	:	Film pressure
$\bar{p}$	:	Dimensionless film pressure
h	:	Film thickness
$\bar{h}$	:	Dimensionless film thickness
h_0	:	Minimum film thickness
U	:	Surface speed of shaft
N	:	Rotational speed (rpm)
Re	:	Reynolds number
x	:	Coordinate in circumferential direction
y	:	Coordinate in axial direction
L	:	Bearing axial length
B	:	Circumferential length of bearing
R	:	Journal radius
C	:	Radial clearance
e	:	Eccentricity
ε	:	Eccentricity ratio
θ	:	Angular position of shaft
β	:	Attitude angle

W	:	Load capacity of bearing
$\overline{W}$	:	Dimensionless load capacity
Q	:	Side leakage
$\overline{Q}$	:	Dimensionless side leakage
P	:	Power loss
$\overline{P}$	:	Dimensionless power loss
$\bar{R}$	:	Residual
Ω	:	Domain of calculation
ϕ	:	Weighting function
ξ	:	An isoparametric element coordinate direction
η	:	An isoparametric element coordinate direction
ϕ_j	:	Shape function
$K_{i,j}$	:	Stiffness matrix term at i, j
F_i	:	Load matrix term
$J(\xi,\eta)$	:	Jacobian matrix
μ	:	Lubricant viscosity
τ	:	Shear stress

Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science.

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Chairman: Assoc. Prof. ShahNor Basri, Ph.D., P.Eng.

Faculty: Engineering

This thesis describes a comparative study between analytical method and finite element method of a cylindrical bore journal bearing behaviour. In calculating the performance characteristics of a journal bearing such as pressure distribution, load capacity, flow requirement and power loss, isothermal analysis was carried out. Using both analytical method and finite element method, the effects of variations in operating variables such as eccentricity ratio and shaft speed on the bearing design parameters were calculated. With regard to CPU time, analytical method performs better than finite element method ; but in terms of obtained results, finite element method shows better performance than analytical method. The analytical results and finite element results are compared . In order to check the validity, when these results are compared with the available published results, on the whole, finite element results show better agreement than analytical results.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains.

KAJIAN PERBANDINGAN ANTARA KAEDAH BERANALISIS DAN KAEDAH UNSUR TERHINGGA YANG DIJALANKAN KEATAS KELAKUAN GALAS JURNAL BERGEREK SILINDER

Oleh

DEWAN MUHAMMAD NURUZZAMAN

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Pengerusi : Professor Madya ShahNor Basri, Ph.D., P.Eng.

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Tesis ini menerangkan tentang perbandingan di antara kaedah beranalisis dan kaedah unsur terhingga yang dijalankan dalam kajian kelakuan galas jurnal bergerek silinder. Dalam pengiraan ciri ciri prestasi galas jurnal seperti pengagihan tekanan, keupayaan bebanan, keperluan aliran serta kehilangan kuasa, analisa aliran sesuhu telah dilakukan. Kajian kesan perubahan pembolehubah operasi seperti nisbah kesipian dan halaju aci keatas parameter rekabentuk galas dengan menggunakan kedua dua kaedah beranalisis dan kaedah unsur terhingga telah dijalankan. Berlandaskan kepada masa unit pemprosesan pusat, prestasi kaedah beranalisis didapati adalah lebih baik jika dibandingkan dengan kaedah unsur terhingga, tetapi dari sudut keputusan yang dicapai, sebaliknya didapati prestasi dari penggunaan kaedah unsur terhingga adalah lebih baik dari kaedah beranalisis. Setiap keputusan yang didapati dari kedua dua kaedah beranalisis dan kaedah unsur terhingga dibandingkan. Bagi memeriksa kesahihan keputusan, satu perbandingan dengan keputusan yang telah diterbitkan sebelum ini telah dilakukan. Secara

keseluruhannya, didapati keputusan dari kaedah unsur terhingga mempunyai persamaan yang lebih baik dengan keputusan yang telah diterbitkan, berbandingkan dengan kaedah beranalisis.

CHAPTER I

INTRODUCTION

Wear is the major cause of material wastage and loss of mechanical performance of machine elements, and any reduction in wear can result in considerable savings. The savings can be made by improved friction control. Lubrication is an effective means of controlling wear and reducing friction, and it has wide applications in the operation of machine elements such as bearings. Lubrication problems appear often in engineering design, and it is the mechanism that separates two surfaces moving relative to each other by a fluid film which can be sheared with low resistance without causing any damage to the surfaces (Czichos,1978).

The lubricant film carries part of the total load on the bearing. The mechanism which does this is varied. In some cases, the mating parts are specially designed to ensure it, as in journal bearings. The full load may not be carried by the oil film, but it relieves the material by carrying most of it. Pressure in the lubricant film is generated by 'wedge action', the relative movement of the surfaces dragging the lubricant into a decreasing space (Summers-Smith,1994). When the surfaces in relative motion are so oriented that the motion causes the fluid pressure to support the load without metal-to-metal contact, the lubrication phenomenon is known as hydrodynamic lubrication . A common engineering component which exploits this principle is the cylindrical bore journal bearing in which a loaded shaft (or journal) rotates in a metallic bush that is fed continuously by a lubricating fluid. Under ideal operating conditions the longitudinal axes of both shaft and bush are parallel, although displaced eccentrically. This gives rise to a thin converging fluid film which generates a pressure field and forms the load carrying portion of the bearing .

In hydrodynamic lubrication, several simplifying assumptions are made before a mathematical description of the fundamental underlying mechanisms can be derived. The principles of hydrodynamic lubrication were first established by a well known scientist Osborne Reynolds in 1886 (Welsh,1983). Reynolds explains the mechanism of hydrodynamic lubrication through the generation of a viscous liquid film between the moving surfaces. Reynolds equation is derived from the full Navier-Stokes equation. More often it is derived by simply applying a typical engineering approach and considering the equilibrium of an element of liquid subjected to viscous shear and applying the continuity of flow principle. It is assumed that the lubricant is incompressible and that the viscosity is constant throughout the film. This approach is known as isoviscous model where the thermal effects in hydrodynamic film are neglected. From a practical point of view, Reynolds most important conclusions were that the formation of an oil wedge was essential, a thin oil film could carry a greater load than a thick film, the load carrying capacity of an oil film increased directly in proportion to its dynamic viscosity, and under most normal conditions, it also increased directly in proportion to the relative velocity between the two opposing surfaces (Welsh,1983). The entire process of hydrodynamic pressure generation can be described mathematically to enable accurate prediction of bearing characteristics. The journal bearing design parameters such as load carrying ability, flow requirement and power loss are determined from Reynolds equation both analytically and numerically.

For many years, attempts were made to solve the differential equations which arose from the theories of Reynolds using specialized mathematical functions. But this analytical solution process was very tedious and the range of solutions was very limited. Discrepancy always existed between what was required in the engineering solutions to hydrodynamic problems and the solutions available. For quick engineering analysis, nowadays the application of analytical method determines two types of journal bearing solutions (i) Long bearing solution (side leakage neglected) and (ii) Narrow bearing solution (Hamrock, 1994).

Numerical analysis has allowed models of hydrodynamic lubrication to describe the characteristics of real bearings. To analyse the bearing design parameters, various approximate numerical methods have evolved over the years such as the finite difference method (FDM), finite element method (FEM) etc. It is very difficult to use the finite difference method when irregular geometries are encountered because it only approximates the region of interest with a grid of uniformly spaced nodes (Nicholas,1977). Conversely, one of the latest and most popular numerical technique, the finite element method is attractive in the situations when curved or abnormally shaped boundaries are encountered. In the finite element method the solution region is divided into elements giving a piecewise approximation to the governing equations. Since these elements can be assembled in a variety of ways, they can be used to represent complex geometries or irregular boundaries. Use of elements and interpolation functions ensure continuity of pressure and mass flow rate across inter-element boundaries (Nicholas,1977). The finite element method now has a wide range of applications particularly in engineering. It was first used in the structural engineering. More recently however, it has been developed for solution of viscous flow and plasticity problems.

Objective of Study

Currently, there is very little information about the comparison between the analytical method and the finite element method of a journal bearing behaviour. Thus to understand this issue more clearly, a research study has been carried out to compare analytical method and finite element method in the design parameters of a journal bearing. The analytical method and finite element method solution procedures, the results of these analyses, and their comparisons with published results form the major part of this thesis.

Structure of the Thesis

In this thesis a review of pertinent literature is presented in chapter II. Chapter III discusses all the related theories that account for the design parameters in hydrodynamic lubrication for a cylindrical bore journal bearing. Chapter IV outlines the numerical computation procedure. In this chapter, the related theories for the finite element method are described for solving the design parameters of a journal bearing. Chapter V describes the most pertinent theories for the analytical method for solving the design parameters of a journal bearing.

The results of this research work i.e. the effects of operating variables such as eccentricity ratio and shaft speed on the various design parameters are outlined in chapter VI. The FEM results are compared with analytical results. These results are also compared with the published results to verify the present study. Chapter VII concludes the work described in preceding chapters. It also includes recommendations for further work.

CHAPTER II

LITERATURE REVIEW

Introduction

Although the study of friction and wear attracted the attention of many scientists during the past few centuries, the scientific investigation into friction and wear is a relatively recent phenomenon. Much of the tribological research is commercially oriented and a wide range of wear resistant or friction resisting materials have already been developed. Lubrication is an effective means of controlling wear and reducing friction in bearings. This chapter presents a review of the most pertinent background work, experimental and theoretical studies in the fluid film lubrication. To establish a comprehensive background literature, the review firstly focuses on some of the general research carried out in the field of friction, wear and lubrication. Subsequent sections review the experimental and theoretical work carried out in hydrodynamic bearings, particularly the cylindrical bore journal bearing. The review covers aspects associated with Newtonian fluids and isothermal effects.

Background

Lubrication is the mechanism that reduces friction between two surfaces in relative motion. Power loss, excessive temperature rise and consequent wear are the problems associated with friction. The study of the nature of friction was undertaken by Leonardo da Vinci in the late 15th century (Stachowiac and Batchelor,1993). He concluded that the static and low speed frictional resistance of two surfaces was proportional to their weights and independent of the area of contact, and that smoothing or lubricating the surfaces reduced the frictional drag (Ezzat,1971). However, the understanding of friction and wear languished for several centuries with only fancy concepts. For example, it was proposed by Amonton in 1699 that when surfaces were covered by small spheres, and the friction coefficient was a result of the angle of contact between spheres of contacting surfaces then a value of friction coefficient close to 0.3 was found (Stachowiac and Batchelor,1993).

At the end of the eighteenth century, Coulomb observed that kinetic friction was less than static friction and that frictional resistance is proportional to the load and unaffected by area or speed (Ezzat,1971). Although these early studies were on plane surfaces, the longest history of scientific study of contact surfaces is concerned with the journal bearing (Ezzat,1971). In 1848, Von Pauli investigated the effect of bearing metals on the frictional behaviour of oil lubricated journal bearings. He was able to achieve a coefficient of friction of 0.0033. The frictional resistance increased tenfold when he applied the same load to a smaller bearing increasing the specific load by 36% (Cameron,1966) Hirn was the first to report the importance of the lubricant viscosity in friction in 1854 (Ezzat,1971) He reported that the frictional resistance in a journal bearing was proportional to the load, speed and lubricant viscosity. Later, his work, which lacked theoretical backing, was used by Petroff as a foundation for the hydrodynamic theory of friction (Cameron,1966). Goodman explained the theory of friction in lubricated surfaces by the interference of surface asperities (Cameron,1966). During that time, Petroff worked on the analysis of the existing information and devoted himself in finding the frictional resistance of lubricated bearings. In 1883, Petroff gave the results of experimental work on viscous friction in a hydrodynamic bearing. He correlated friction with the lubricant viscosity. He concluded that between two coaxial cylinders i.e. for the 'ideal' case of no eccentricity between bearing and journal, there was no 'wedging action' and hence no ability of the oil film to support a load , and no lubricant flowed in the axial direction (Juvinall and Marshek,1991).

Experimental Studies

The serious appreciation of hydrodynamic lubrication started towards the end of the 19th century. Among all the early investigations in lubrication, Beauchamp Tower's experiments represented a breakthrough that led to the development of lubrication theory. In 1883, Tower reported the results of a series of experiments which investigated the friction between solid bodies at high velocities (Cameron,1966). Tower observed that oil in a journal bearing always leaked out of a hole beneath the load. He tried to block this flow by pounding cork and wooden stoppers into the hole, but the hydrodynamic pressure forced them out. Tower connected a pressure gauge to the oil hole, and subsequently made experimental measurements of the oil film pressures at various locations. He then discovered that the summation of local hydrodynamic pressure times differential projected bearing area was equal to the load supported by the bearing (Stachowiac and Batchelor,1993). The analysis of this work carried out by Stokes and later Reynolds led to a theoretical explanation of Tower's results and on this the theory of fluid film lubrication has been based.

In 1886, with the publication of classical paper on hydrodynamic lubrication, Reynolds proved that hydrodynamic pressure of liquid entrained between sliding surfaces was sufficient to prevent contact between surfaces even at very low sliding speeds (Stachowiac and Batchelor,1993). His research findings had immediate practical application and led to the removal of an oil hole from the load line of railway axle bearings. The oil, instead of being drained away by the hole, was able to generate a hydrodynamic film and much lower friction resulted (Stachowiac and Batchelor,1993). The work of Reynolds initiated many other research efforts aimed at improving the interaction between two contacting surfaces, and which continue up till today. As a result, journal bearings are now designed to high levels of sophistication (Stachowiac and Batchelor,1993).