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ISOTHERMAL AND THERMAL ANALYSES OF ELASTOHYDRODYNAMIC LUBRICATION OF HARD ROLLING CONTACT

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ISOTHERMAL AND THERMAL ANALYSES OF ELASTOHYDRODYNAMIC LUBRICATION OF HARD ROLLING CONTACT

By

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UPM

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LIST OF ABBREVIATIONS

D_{ij}	Influence Coefficients to Calculate Elastic Deformation of Node I due to p_j
E	Elasticity Modulus
E′	Effective Elastic Modulus
E_o	Initial Elastic Modulus of Material in Contact
F_x	Force in x Direction
F_y	Force in y Direction
G	Shear Modulus
g	Acceleration of Gravity
h	Lubricant Film Thickness
h_c	Film Thickness at Maximum Pressure
h_s	Inlet Film Profile
H	Dimesionless Film Thickness, h/R
h_m	Film Thickness at Point of Maximum Pressure
H_{min}	Minimum Film Thickness
h_o	Film Thickness on Line of Centres
K	Lubricant Conductivity, W/(m°c)
m_x, m_y	Mass Flow per unit Width, x and y Direction
p	Pressure
Q_{gen}	Rate of Generation of Heat per unit Volume
Q_{out}	Amount of Heat Flow out Oil Film
Q_{in}	Amount of Heat Flow into Oil Film
Q_{R1}	Amount of Heat loss via Roller1

Q_{R2} Amount of Heat loss via Roller2

q Reduced Pressure, $q = (1-e^{-\alpha P})/\alpha$

R Equivalent Radius of Roller, $1/R = 1/R_1 + 1/R_2$

R_1 Radius of upper Roller

R_2 Radius of Lower Roller

R′ Radius of Curvature

T Dimensionless Temperature, t/t_o

t Time

U Dimensionless Speed Parameter, $\eta_o u/E'R$

u Mean Surface Velocity in x direction, $1/2(u_1+u_2)$

u_1, u_2 Surface Velocities of Solids in x-direction

V1,V2 Surface Velocities, y direction

w_z Load per unit Length of Roller

W Dimensionless Load Parameter, $w_z/E'R$

x_E Any value at the Inlet Region

x_1 Unknown Value in the Inlet Line Contact

x_o Unknown Value in the Outlet Line Contact

x, y, z Coordinates Axes

Greek Symbols

α Pressure Exponent of Viscosity

τ Shear Stress

γ Shear Strain Rate

τ_{zx}	Lubricant Shear Stress in x direction in Plan whose Normal is z
τ_{zy}	Lubricant Shear Stress in y direction in plan whose Normal is z
η	Dynamic Viscosity Coefficient
η_o	Viscosity at Atmospheric Pressure
ρ	Lubricant Density
ν	Kinematic Viscosity
ς	Combined Displacement of Two Solids

Subscript

E	Related to Value in the Outlet Line Contact
EHD	Elastohydrodynamic
EHL	Elastohydrodynamic Lubrication
i	Related to Value in the Inlet Line Contact
inlet	Related to Lubricant Inlet Position
out	Related to Lubricant Outlet Position

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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MARCH 1997

Chairman: Assoc. Prof. Ir. Dr. SHAH NOR BASRI

Faculty: Engineering

In the field of industrial tribology, elastohydrodynamic lubrication (EHL) is a comparatively recent area of research. It only became properly established in the early 1960s. EHL of rolling contact is mainly divided to two phases (soft and hard), depending on the elasticity modulus of the material in contact. Hard rolling which relates to materials of high modulus of elasticity e.g. metal, is the part of interest in the present study.

The first objective of the research is to study the elastohydrodynamic lubrication problem of hard rolling line contact. Second is to investigate the isothermal and thermal conditions for EHL in hard rolling system. The contact geometry of the rolling process was specified as a line contact. An incompressible fluid flows in to the system. Under both isothermal and thermal conditions, a Newtonian lubricant was described. Two different widely used lubricants were tested. First, is a mineral Naphthenic (TN22) and the second is a synthetic Cycloaliphatic (ST40).

It is assumed that two rollers of equal radius are moving relatively with same speed on a plane of different velocity. Two coordinate axes were considered (x and y). The parameters and conditions of controlling the system of contact are theoretically selected to match the practical field situations. Newton-Raphson and the finite difference methods were represented in the mathematical technique used for computations.

Two isothermal models and another two of thermal conditions were developed. The analysis for the isothermal and thermal models did not show any obvious

difference between the mineral and synthetic oil film used. The results of pressure distribution and film thickness for the two thermal models under isoviscous and viscous conditions did not show any change in pattern. The comparison between isothermal and thermal behaviour has shown that the thermal effects have a strong influence on the pressure spike amplitude. The present results were compared and discussed with other earlier published results.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi syarat ijazah Sarjana Sains.

ANALISIS ISOTERMA DAN TERMA PELINCIRAN ELASTOHIDRODINAMIK SENTUHAN GULINGAN KERAS

oleh

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MARCH 1997

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Didalam bidang tribologi industri, pelinciran elastohydrodynamic (EHL) adalah merupakan suatu yang agak baru kepada dunia penyelidikan. Ianya hanya menjadi satu kenyataan yang berasas pada sekitar awal tahun enampuluhan. EHL yang berhubung dengan penggulingan bersentuh (rolling contact) telah terbahagi kepada dua fasa (lembut dan keras) yang bergantung kepada modulus keanjalan sesuatu bahan yang bersentuh. Penggulingan keras merupakan sesuatu yang berkait rapat dengan bahan yang mempunyai modulus keanjalan yang tinggi bahan logam, yang mana didalam penulisan ini ianya menjadi sebahagian dari kajian.

Objektif pertama daripada kajian ini adalah untuk mendapatkan pemahaman yang mendalam terhadap permasalahan sistem pelinciran EHL keatas gulingan keras. Kedua, adalah untuk mengkaji syarat isothermal dan terma terhadap EHL didalam sistem penggulingan keras apabila dua bahan pelincir dari jenis berlainan digunakan.

Persentuhan jometri didalam proses gulingan ini telah dispesifikasikan sebagai garis sentuh. Bendalir yang tidak mampat dialirkan didalam sistem ini. Didalam dua keadaan, iaitu isoterma dan terma, pelincir Newtonian dapat diandaikan. Dua bahan pelincir yang luas penggunaannya dari jenis yang berlainan telah diuji. Bahan itu adalah Mineral Naphthenic (TN22) dan Synthetic Cycloaliphatics (ST40).

Diandaikan dua pengguling yang berjejari sama berpusing pada halaju yang sama diatas satah kelajuan berbeza pada dua paksi koordinat X dan Y. Parameter dan syarat pengawalan sistem sentuhan secara teorinya dipilih untuk menyamai keadaan sebenar. Pada peringkat awal Kaedah Newton-Raphson dan kaedah perbezaan terhingga telah digunakan didalam teknik matematik untuk tujuan pengiraan.

Analisis untuk model isoterma dan terma tidak menunjukkan sebarang perbezaan yang ketara diantara

bahan lapisan mineral dan sintatik yang digunakan. Dua model isoterma dan dua model terma telah terbentuk. Keputusan pengagihan tekanan dan ketebalan lapisan untuk kedua-dua model tidak menunjukkan sebarang perubahan dari segi corak. Perbandingan diantara perlakuan isoterma dan terma telah menunjukkan bahawa kesan terma mempunyai pengaruh yang kuat terhadap amplitud pepaku tekanan.

Keputusan yang telah didapati mempunyai persamaan amat memuaskan dengan keputusan ujikaji yang sebelumnya.

Chapter I

Introduction

Background Overview

Lubrication is an essential feature of most modern machinery and has wide applications in the operation of many industrial processes such as forming, forging, drawing, extrusion, and rolling. There is a great body of technological experience in the production and application of lubricants, but the scientific study of lubrication and associated problems of friction and wear is comparatively a recent development.

Nowadays the area of contact mechanics has become a very important topic for so many researchers in the field of industrial tribology. In many modern industrial applications, the contact action is unavoidable and without it the manufacturing of so many parts will be

relatively impossible, because usually deformation of product takes place due to the force of contact action exerted by another part. Friction is usually present at these contacts by which heat is generated and wear occurs, leading to a highly significant loss of energy. It is estimated that one third of the world's energy resources in present use is needed to overcome friction in one form or another. Analysis of machine break-downs also shows that majority of cases of failures and stoppages are associated with interacting moving parts such as gears, bearings, couplings, sealings, cams, clutches and other machine elements (Stachowiak and Batchelor, 1993).

Recently the elastohydrodynamic lubrication (EHL) has become an effective means of controlling wear and reducing friction. In this system, lubricant is introduced at the local contact and is designed to prevent direct contact between the surfaces in relative motion. The first notable breakthrough occurred by Grubin (1949) when he managed to incorporate both the elastic deformation of the solid and the viscosity-pressure characteristics of the lubricant in analyzing

the inlet region of lubricated non-conformal machine elements.

EHL of hard rolling or sliding systems can be briefly described as a form of hydrodynamic lubrication where elastic deformation of the lubricated surfaces becomes significant (Hamrock, 1994). It relates to materials of high modulus of elasticity and is usually associated with highly stressed machine elements, such as rolling element bearings and gears. The contact conditions and the controlling parameters of EHL systems for hard contact are now being investigated leading to the development of power transmission techniques which are expected to take the advantage of the system concept in a rolling configuration.

In a fully developed EHL, the elastic deformation of the solids is often significant relative to the thickness of the fluid film separating them and the contact pressure is high enough to significantly increase the lubricant viscosity within the junction. In this research the pressure distribution and film thickness in EHL for hard rolling contact will be

expressed in terms of isothermal and thermal analysis under various conditions. Since pressure and film thickness both are the most significant factors in EHL system.

Aims of Current Research

The main aims of this study are:

1) to study the elastohydrodynamic lubrication problem of hard rolling line contact,
2) to investigate the isothermal and thermal conditions for EHL in hard rolling system.

Thesis Layout

In this thesis, Chapter II includes a literature review in the field of elastohydrodynamic lubrication, theoretical and experimental investigations and explanations for the EHL system process covering the principles of line and point contact. Also given is a general description of dry and lubricant contact. Isothermal and thermal EHL are also included.