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A simplified thermoelastohydrodynamic model for a parallel surface slider

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Abstract

The present paper presents an original, quasi-analytical, thermoelastohydrodynamic (TEHD) model for a fluid film, parallel surface, elastic slider. Temperature variation along the slider is included in a simplified manner, based on Tipei assumption (viscosity variation along the pad is proportional to film thickness variation) [Tipei N. Theory of lubrication. Stanford, CA: Stanford University; 1962]. The elastic deformation of the slider, due to film pressure, is estimated using a simplified 1D elastic beam model. A simple, closed-form equation is proposed for load capacity–film thickness relationship. Parametric analysis performed with this quasi-analytical model shows optimal values for the most important design parameters. It is shown that suitable pad geometry can generate important load-carrying effects.

Keywords: Lubrication; TEHD analysis; Parallel slider; Elastic beam

1. Introduction

The use of compliant components to increase the overall performances of fluid-film pairs is a modern solution, in continuous development, with successful applications in bearings or seals. It is well known that elastic deformations due to temperature gradients or film pressures, although small, can be comparable with typical film thicknesses and hence, can be used to control and/or improve film performances.

One should recall that elasticity has been used since the 1960s as a solution for thrust bearing performance improver, through the elastic support of the pads [1]. However, creating lift-off effects in a tapered pad thrust bearing requires adequate shaping of the pads' surfaces by difficult, expensive and relatively precisionless manufacturing processes.

The present paper deals with a relatively new solution to generate load-carrying capacity in thrust bearings, based on controlled elasticity of the pad, which is nominally flat and parallel to the mating runner. This alternative can substitute the traditional technology for creating the convergent gap (tilting-pad or tapered land configurations).

The first studies of lift-off effects for flat and parallel surfaces were conducted by Fogg, Cameron and Wood (see [2]) in 1946 (thermal wedge effect). Later, after the report of Ettles and Cameron [3], the effect of thermal distortion of solids on pressure distribution was recognized as important and a great amount of work has been dedicated to the study of thermoelastic effects in typical bearing configurations.

The study of hydrodynamic (HD) effects generated in thrust bearings by using elastic pads, has been initiated at the Technical University of Gdansk (Poland) in the 1980s and published in a series of papers starting from 1985 [4,5]. The experimental results reported in [6] demonstrate not only the capacity of these bearings to generate HD effects but also their superiority with respect to similar tilting-pad thrust bearings. However, theoretical modeling of these bearings has been presented in an extremely synthetic manner, without any details regarding the assumptions and the mathematical model solved for.

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Notation

B	width of the slider, m
E	Young's modulus, Pa
F	load capacity, N
$\bar{F}$	dimensionless load capacity $(= Fh_o^2/(\mu_i UBL^2))$
g_e	slider thickness in the elastic zone, m
h	film thickness, m
$\bar{h}$	dimensionless film thickness $(= h/h_o)$
H	film thickness ratio $(= h_i/h_o)$
I_z	second moment of inertia, m^4
L	total length, m
ℓ	length of the elastic zone, m
p	pressure, Pa
$\bar{p}$	dimensionless pressure $(= ph_o^2/(6\mu_i UL))$
R	radius, m
U	velocity, m/s
v	deflection, m
x, y	coordinates, m
X	dimensionless coordinate $(= x/\ell)$

Greek symbols

γ	slider relative thickness $(= g_e/L)$
λ	slider length parameter $(= \ell/L)$
Γ	combined parameter $(= \mu_i UL^2/(Eh_o^3))$
μ	viscosity, Pa s

Subscripts

i	inlet
o	outlet

Approximately in the same period, an important bearing producer deposed a patent for a flexure-pivot tilt pad for journal and thrust bearings and reported experimental results [7], but related theoretical models published after that are scarce.

These elastic pads have been recently modified and patented for thrust bearings by KALSI Inc. [8]. KALSI solution, named *load responsive hydrodynamic bearing* is primary intended for highly loaded thrust bearings operating at high speeds and severe environmental conditions (high shocks, vibrations).

Kucinschi et al. [9] have recently published an important theoretical study on thermoelastohydrodynamic (TEHD) effects of grooved elastic thrust washers using a 2D finite-element model.

The main goal of the present paper is to develop a simple, easy to use TEHD model for an elastic, parallel slider. The model includes two modules: a *flow module* based on a simplified 1D non-isothermal flow model and an *elastic module* that counts for slider pressure-induced deformation. Thermoelastic deformations of the slider are neglected.

2. The model

The main dimensions of the elastic slider are illustrated schematically in Fig. 1. As can be seen, the slider consists of two distinct zones: the *elastic zone* (*inlet zone*), elastically deformed under the effect of pressure distribution and the so-called *flat zone* (*outlet zone*), corresponding to the rigid part of the pad (pillar). For the sake of simplicity, the origin of x-axis is taken at the boundary between elastic and flat zones.

2.1. Fluid-film model

The present analysis is based on the following assumptions:

(1) The fluid is Newtonian, incompressible, in laminar flow, without slip at solid boundaries.

(2) Constant pressure and temperature across the film thickness.

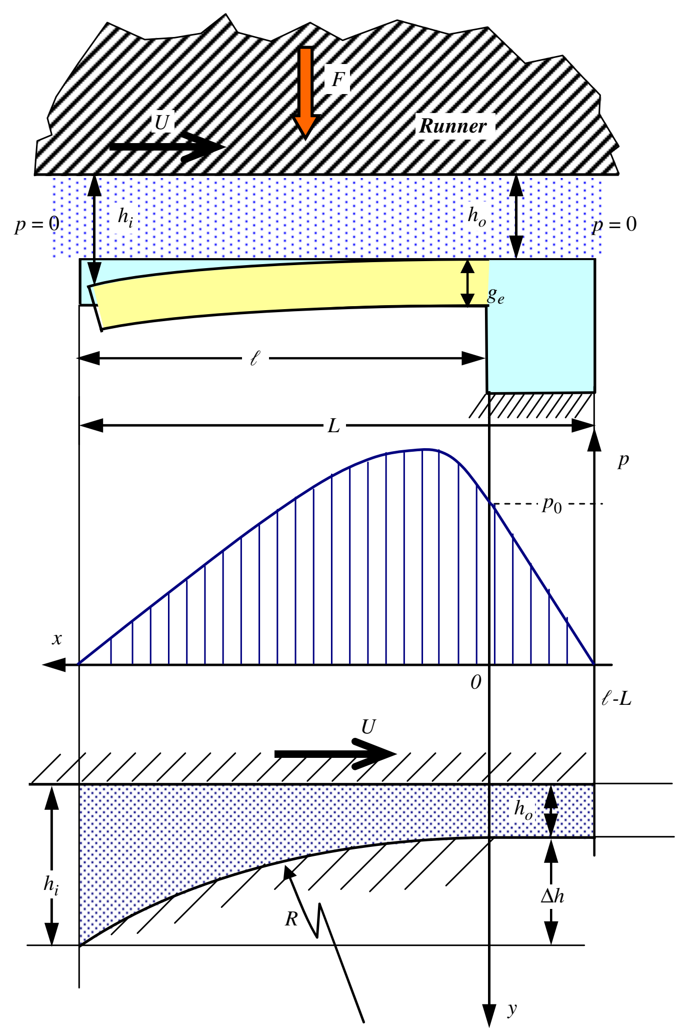

Fig. 1. Schematic of the slider and film geometry.