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The role of lubricant feeding conditions on the performance improvement and friction reduction of journal bearings

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ABSTRACT

Most conventional hydrodynamic journal bearing performance tools cannot suitably assess the effect of lubricant feeding conditions on bearing performance, even though these conditions are known to affect important performance parameters such as eccentricity and power loss.

A thermohydrodynamic analysis suitable to deal with realistic feeding conditions has been proposed. Special attention was given to the treatment of phenomena taking place within grooves and their vicinity, as well as to the ruptured film region.

The effect of lubricant feeding pressure and temperature, groove length ratio, width ratio and number (single/twin) on bearing performance has been analyzed for a broad range of conditions. It was found that a careful tuning of the feeding conditions may indeed improve bearing performance.

1. Introduction

The accurate prediction of hydrodynamic journal bearing behavior is far more complex than what their simple geometry might initially suggest. In fact, the simultaneous pressure, flow and heat transfer calculations need to include the treatment of phenomena such as film rupture, dual phase flow, film reformation, forced and free heat convection and conduction, viscous dissipation, inner groove lubricant flow mixing and thermo-elastic distortion. The integrated modeling of these phenomena in a single algorithm displaying acceptable computation times does not seem to be a straightforward task.

The complexity of the problem has frequently led to the use of oversimplified models. Particularly, the incorporation of lubricant feeding conditions was normally made in an oversimplified way in most theoretical approaches or inclusively altogether disregarded. In fact, neglecting the effect of lubricant feeding pressure, feeding temperature or the actual geometry of grooves might explain some of the notable discrepancies found between many theoretical predictions and experimental measurements. These discrepancies seem to be especially acute in the case of twin groove journal bearings. The lack of comprehensive experimental data focusing on these issues might have also contributed for the lack of awareness on the important role which lubricant feeding conditions play on bearing performance.

The inclusion of realistic lubricant feeding conditions in journal bearing analyses might raise some theoretical difficulties, depending on the model used. That is why some models neglect the influence of feeding conditions altogether, while others have used simplified approaches such as the consideration of:

- Full film reformation at the maximum film thickness position or the groove position [1].
- Grooves of infinitesimal width (no circumferential extension) [2,3].
- Grooves of finite width but extending them to the full length of the bush body [4–6].
- Finite size grooves but imposing flow rate or no feeding pressure (ambient) [5].
- Negligible or oversimplified thermal phenomena occurring at the groove region, such as the effect of recirculated hot oil, feeding temperature, reverse flow (oil that re-enters the groove from downstream) or back flow (fresh oil that flows upstream from the groove).

An analysis of the influence of feeding pressure in the performance of twin groove journal bearings through Finite Element

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Nomenclature

A	groove length (axial direction) (m)
b	bush length (axial direction) (m)
c_r	radial clearance (m)
c_{mix}	mixing coefficient used to obtain the leading edge temperature, T_{le}^{+} (dimensionless)
c_p	specific heat at constant pressure (W/kg K)
d	nominal bearing diameter (m)
e_s	thickness of the layer of lubricant adhered to the shaft (Modified Effective Length model) (m)
e_{s0}	fraction of the film height filled with the layer of lubricant adhered to the shaft (Modified Effective Length model) (dimensionless)
$\overline{EL}$	effective length ratio (fraction of the bearing length filled with liquid streamers for a given circumferential coordinate) (dimensionless)
$\overline{EL}_m$	modified effective length ratio (same as EL but corrected for the modified effective length model) (dimensionless)
h	local film thickness (m)
h_{min}	minimum film thickness (m)
K	thermal conductivity (W/m K)
N	shaft rotational speed (rpm)
P	hydrodynamic pressure within the film (relative to ambient pressure) (Pa)
P_f	lubricant feeding pressure (relative to ambient pressure) (Pa)
q	heat transfer rate (W)
Q_f	lubricant feeding flow rate (l/min)
r	radial coordinate (bush body domain)/nominal bearing radius (m)
T_{amb}	ambient temperature – the average temperature of the bearing system environment (°C)
T_b	bush body temperature field variable (°C)
T_f	lubricant feeding temperature (°C)
T_{max}	maximum bush temperature (°C)
u	fluid velocity field variable (m/s)
U	tangential velocity of the shaft surface (m/s)
W	applied load/load carrying capacity (N)
W_s	specific load (the load divided by the projected area of the bush ($b \bullet d$)) (Pa)
w	groove width (circumferential direction) (m)
x	circumferential coordinate of the unwrapped geometry (m)
y	radial coordinate (fluid domain) (m)
z	axial coordinate (m)

Greek symbols

α	circumferential coordinate – angle measured from the centre of the $+90^\circ$ groove (deg)
ε	eccentricity ratio (dimensionless)
ϕ	attitude angle (deg)
θ'	liquid fraction (volumetric) (dimensionless)
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)

Subscripts

axial	corresponding to the lateral edges of the groove or to the lubricant crossing them
bkf	corresponding to back flow (oil leaving the groove through the trailing edge, in the upstream direction)
eq	corresponding to the equivalent property of the flowing mixture (gaseous + liquid)
g	corresponding to the gaseous portion of the flowing mixture
f	corresponding to feeding conditions
gr	corresponding to a groove
is	corresponding to the inlet section of a bearing land (the whole bush section at the coordinate of the leading edge of the groove)
H	corresponding to convective heat transfer inside the groove regions
l	corresponding to the liquid portion (lubricant) of the flowing mixture
le	corresponding to the leading edge of a groove (downstream edge)
out	corresponding to outlet flow rate leaking from the bearing through its edges
rvf	corresponding to reverse flow (oil entering the leading edge of the groove coming from downstream)
te	corresponding to the trailing edge of a groove (upstream edge)

Abbreviations

CFD	Computational Fluid Dynamics
EL	Effective Length model
EL_m	Modified Effective Length model
GRE	Generalized Reynolds Equation
RPM	Revolutions Per Minute
TEHD	Thermoelastohydrodynamic
THD	Thermohydrodynamic

Methods was performed by Knight et al. [7]. A 1D energy equation was used and the axial pressure profile described through second order polynomials. It was shown that the feeding pressure affects the maximum temperature decreasing it, especially at low Sommerfeld numbers. The increase in feeding pressure was found to increase significantly the flow rate and slightly the power loss.

A series of theoretical and experimental studies on high speed twin groove journal bearings were carried out by Gethin and El-Deihi [8,9] in order to assess the influence of the position of the two diametrically opposed axial grooves relatively to the load direction. In this last work a more rigorous THD approach was used, in comparison to the former works. Viscosity and temperature were allowed to vary along the thickness and heat conduction through the solid bodies was considered. The shaft temperature was imposed as being equal to the mean film temperature, while at the leading edge of the groove the inlet temperature was calculated through a heat balance. The use of such a groove mixing model proved to be determinant for the improvement of the results. With this new model a much better agreement with experiment was found for the temperature profile. However, huge differences between theory and experiment continued to be detected in flow rate.

Attention to film reformation and the use of mass conserving algorithms for treating feeding conditions was highlighted by Dowson et al. [10]. A thorough theoretical and experimental assessment of the influence of lubricant feeding conditions on the performance of circular journal bearings with several groove configurations was made by Claro and Miranda [11], including twin axial groove journal