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On the thermally-induced seizure in bearings: A review

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ABSTRACT

This paper presents a state-of-the-art survey of papers reported on the nature of a troublesome failure mode in bearings known as seizure. This mode of failure is thermally-induced and it occurs in both journal and rolling element bearings. To gain insight, particular attention is given to reported experimental observation, various mechanisms involved, and available prediction methodologies.

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1. Introduction

It is hard to imagine a machine that does not utilize a bearing of some sort, and it is of no surprise that bearings are one considered to be the key component of almost all rotating machinery. Bearings are designed to provide load-carrying capacity that supports the rotation or the sliding motion of one solid body relative to another, typically, stationary body.

Radially-loaded bearings can be broadly grouped into two categories: journal bearings and rolling element bearings; see Fig. 1. In spite of different operational mechanisms and geometrical configurations, both journal bearings and rolling bearings are susceptible to a peculiar form of failure known as seizure whose root cause is thermal effects. When seizure occurs, the bearing cannot support motion and the system totally shuts down.

The key to the safe operation of bearings is a design with an effective thermal management: one that ensures that the heat generation within the system is in balance with heat dissipation. Different types of damage are likely to occur if this balance is disrupted. One class of failure, for example, is a localized surface damage known as thermoelastic instability (TEI) that occurs due to unstable thermal growth that manifests itself in the form of macroscopic hot spots or dark patches on the surface that can be viewed with the naked eye [1–6]. The occurrence of TEI has been widely reported in automatic brakes [4,7,8], clutches [5,9–11] and mechanical seals [12–18]. The underlying cause of TEI is intensive localized frictional heating brought about by concentrated temperatures that create rather large local thermal expansion with significant contact pressure and stress that further aggravates the frictional heating. A succinct history of the early developments on TEI is provided by Burton [19] and with additional details in his book [20].

Scuffing is another type of related damage mode of localized form. It occurs between sliding surfaces that exhibit "welding" without evidence of localized melting. There is typically significant wear associated with scuffing failure. The interested reader is referred to Peterson and Winer [21] and an authoritative review by Dyson [22]. This type of failure is also thought to be caused by abrasive particles that enters a lubrication system and bridges itself across the clearance gap and causes local damage [23–28].

The literature also contains valuable information on the so-called thermal runaway which if not controlled eventually lead to bearing seizure. For example, recent investigations on air-lubricated foil bearings concentrate on thermal runaway caused by high bearing preload that reduces the available clearance to the extent of becoming insufficient with the consequence of increasing frictional heat [29–31].

Having briefly described the different types of thermal failures, we now turn our attention fully to bearing failures with thermally-induced seizure (TIS), as its root cause. TIS can occur in many different operating conditions such as:

- During the start-up period of a journal bearing that have been out of service for a relatively long period of time (e.g., compressor of air conditioning units);
- Due to preload change in rolling bearings (e.g., spindle bearings of high speed machine tools);
- During interruption in the lubricant supply due to contamination or clogging of the filter;
- During temporary interruption in the lubricant supply due to the maneuvering actions in aircrafts;

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Nomenclature

A	total available area for convective heat transfer, $A_s + A_b$
A_b	outside surface area of the bushing
A_f	friction area
A_s	surface area of the shaft
C_p	specific heat
c	operating clearance of journal bearing
c_i	initial clearance of journal bearing
D	shaft diameter
D_p	particle diameter
E	modulus of elasticity
F	contact load between the ball and the raceway
F_0	nominal contact load on the ball at design contact angle
F_I	initial preload on one of the rolling elements
f	friction coefficient
H	overall convective heat transfer, $(A_s h_s + A_b h_{bo} / A_s + A_b)$
h_{bc}	heat convection coefficient from the roller
h_{bi}	heat convection coefficient from inside the bushing/housing
h_{bo}	heat convection coefficient from outside of the bushing/housing
h_s	heat convection coefficient from shaft
k	thermal conductivity
L	length of the bushing
L_b	length of rolling element
L_c	characteristic length (volume/area)
M	system thermal capacity
m_b	mass of rolling element of rolling element
n	heat portioning factor
P	bearing pressure
Pe_D	Peclet number based on the particle diameter (D_p)
Pe_{Dcr}	critical Peclet number
Q_0	initial rate of heat input
q_a	heat flow per unit of surface area
R_b	radius of rolling element
R_i	radius of inner raceway
r_{bi}	inner radius of bushing
r_{bo}	outer radius of bushing
r_s	shaft radius
S_b	outer surface of rolling element
T	temperature
T_0	reference temperature
T_f	average flash temperature
t	time
t_c	time constant
t_{ref}	transition time for bearing to go from fully lubricated to boundary lubrication condition
t_{sp}	seizure-time due to flow disturbance
$\bar{t}_{sp}$	dimensionless seizure-time when flow disturbance occurs
t_{ss}	seizure-time during the start-up
$\bar{t}_{ss}$	dimensionless seizure-time during the start-up
U	linear velocity of slider
V_s	sliding speed
V_s^*	critical sliding speed
W	radial load on the bearing
W_l	load per unit length
α	thermal expansion coefficient
β	hardness ratio
γ	radial expansion or accommodation of roller bearing
ρ	density
δ	net diametral growth of bushing relative to the shaft
ϑ	Poisson's ratio
ϵ	thermal diffusivity
τ	yield shear stress
σ	hardness
δ_c	clearance reduction due to relative thermal expansion
ψ	encroachment factor for lubricated bearing
ϕ	encroachment factor for unlubricated bearing
μ_0	initial lubricant velocity
ω	rotational speed
λ	modified aspect ratio
τ^*	dimensionless seizure-time, $(1/\xi_2) ln(\xi_1 \xi_3 / \xi_1 \xi_3 - \xi_2)$
ΔT	temperature difference
$\sum \zeta$	curvature sum
ξ_1	$A_f r_s^2 \mu_0 \omega / M T_0 c$
ξ_2	$AH/M\omega$
ξ_3	$\alpha r_s T_0 / c$

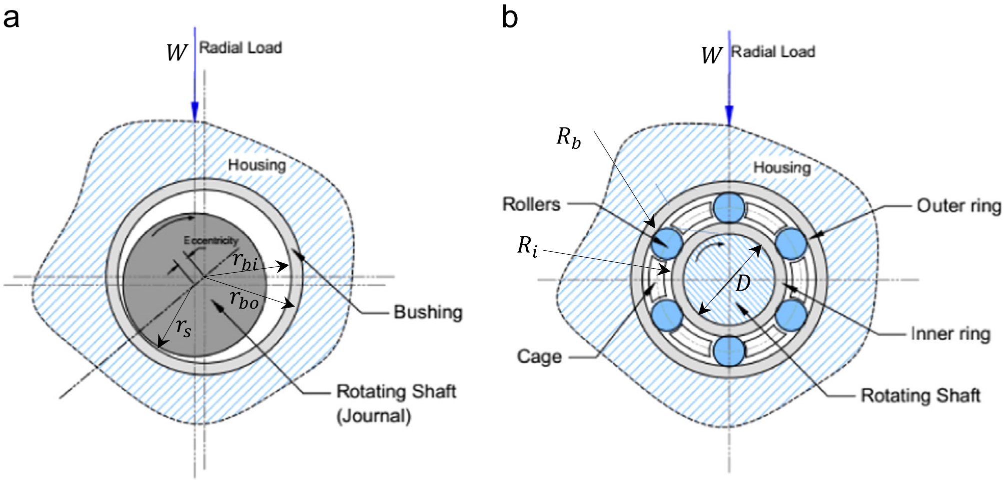

Fig. 1. Schematic of (a) journal bearings (b) rolling element bearings under a radial load.

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