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ON THERMALLY INDUCED SEIZURES (TIS) IN JOURNAL BEARINGS

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ABSTRACT

Thermally induced seizure (TIS) in journal bearings is a mode of failure that can occur quite suddenly and end up with a catastrophic damage to the system. A failure, as such, can occur quite suddenly and often the damage to the system is catastrophic. Although it can take place in lubricated bearings, thermally induced seizure is predominant when a hydrodynamic bearing happens to operate in the boundary or mixed lubrication regimes. These conditions occur during start-up or in an event of lubricant supply blockage. The objective of this work is to perform a comprehensive study of seizure in bearings during start-up and arrive at a seizure time evaluation formula that is a function of the various operating parameters. Dufrane and Kannel[1] analyzed the catastrophic seizure of bearings due to dry friction by a simple 1D equation relating the seizure time to the bearing operating parameters and material properties. Hazlett and Khonsari[2] performed a detailed finite element analysis to gain insight into the nature of the contact forces and encroachment of the mating pair leading to TIS of a dry bearing during start up.

The finite element modeling is done using ANSYS 5.7[3]. First, the TIS analysis of Hazlett and Khonsari[2] was recreated. The finite element model of the present work employs a finer mesh than the mesh used by Hazlett and Khonsari to evaluate the contact forces with more accuracy. The analysis of a bearing undergoing TIS during start up was done by the following steps: 1. A 2-D static contact analysis was performed to determine the contact forces and the contact angle. 2. A transient heat transfer analysis was done to model thermal effects of dry frictional heating on the journal and the bearing. 3. A transient thermoelastic analysis was performed to study the interactions of the journal-bearing pair during bearing start-up. The variation of radial clearance, contact forces and ovalization of the bearing were studied in this analysis.

The loading applied in the thermal analysis consists of the heat generated by the frictional contact at the shaft-bushing interface, which is a function of the load, speed and coefficient of friction. The heat generated is applied to the journal and the bushing according to the areas of contact on the shaft and the bushing[2] and cooled convectively at the areas not in contact. The external surface is also cooled by free convection as shown in Fig 2. The loading for the non-linear thermoelastic analysis consists of the thermal loads applied as nodal temperatures and the radial force acting on the journal. The time dependent thermal load is obtained from the results of the transient thermal analysis. The static load, W is applied to act in the negative y-direction on the shaft. As the model utilizes half-symmetry, a load of W/2 is applied. Symmetry boundary conditions are used to model the one-half symmetry as shown in Figure 3. The constraint of the bearing on its outer surface is modeled by fixing the bearing at the node under the shaft on the outer edge of the bearing on the symmetry plane. This constraint approximates the boundary condition on the bottom surface of a pillow block type of bearing as shown in Figures 1 and 3.

Due to the rise in temperature, the encroachment of the shaft on to the bushing with concomitant reduction in the clearance continues until TIS occurs due to the increase in frictional torque. This process is a complex, non-linear phenomenon. Analysis shows that TIS is initiated by the ovalization of the bearing combined with the uniform outward expansion of the shaft yielding contact between the top of the shaft and the inner bushing surface. This leads to an increase in the contact forces and the formation of multiple contact areas. Increase of contact forces raises the frictional heat flux and sets up a positive feedback that accelerates the loss of clearance. Analyses show that the increase in the frictional torque is abrupt once the ovalization of the bearing causes the shaft to encroach the bushing, as there is further loss in the operating clearance.

Seizure Criterion - Frictional torque is the torque resisting the driving torque exerted by the motor. When the frictional torque increases beyond the extent of the driving torque capability, it can be concluded TIS is imminent. The contact forces acting on the gap elements at any instant of time determine the frictional torque at any time. The frictional torque increased to exceedingly large values within typically

3 seconds after the first instance of establishment of new areas of contact immediately after ovalization. See Figure 4.

The seizure time can be written as a function of the speed, load, shaft radius, clearance, friction coefficient and the bearing length. i.e.

$$t_s = g\,(N, W, R_s, C, f, L).$$

The variation of the seizure time during the system start-up is studied when the operating parameters (variables N, W, R_s, C, f, L) are varied. Then a generalized equation is derived depending on the individual relationships of the operating parameters with the seizure time. Using the range of data from 72 sets of simulations and applying a statistical analysis[4], we obtain the following expression for the seizure time.

$$t_s = 1.5\times10^{7}\, e^{62860C}\, e^{14.5L}\,(fN)^{-1.26}\, W^{-1.2}\left(1+5.7\times10^{-17} R_s^{\,-8.74}\right)$$

The empirical relationship is verified for its validity using some of the results published by Hazlett and Khonsari[2] and Wang et.al.[5]. See comparitive results shown in Table 1.

FIGURES AND TABLES

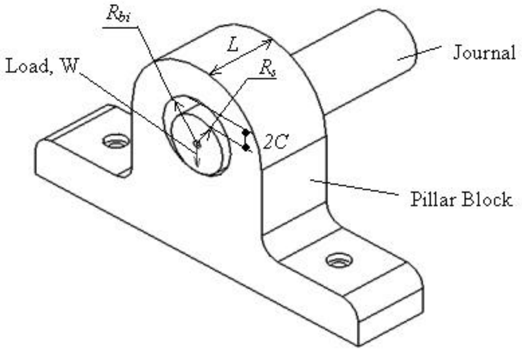

Figure 1 – Schematic of a journal supported on a pillar block

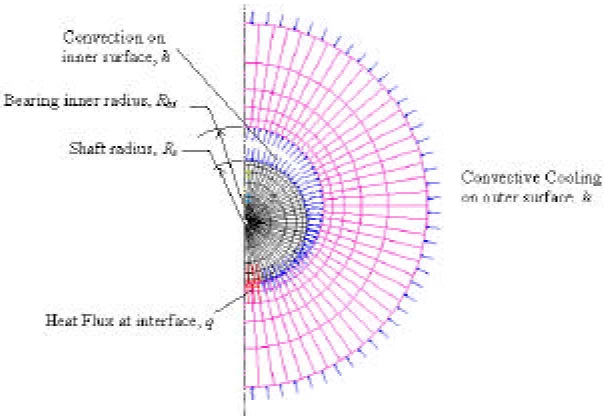

Figure 2 - Finite Element Model for Thermal Analysis, with loads and boundary conditions. (Not to scale)

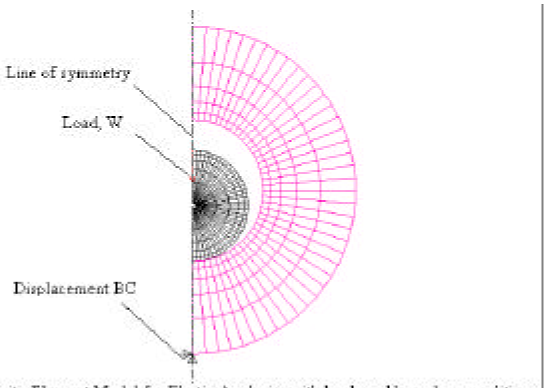

Figure 3 - Finite Element Model for Elastic Analysis, with loads and boundary conditions

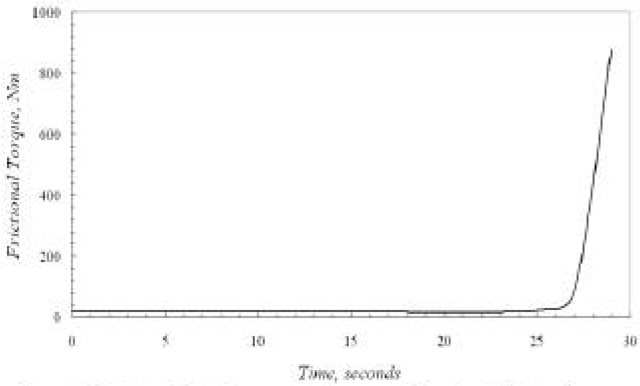

Figure 4 Variation of frictional torque during start-up – Note that the frictional torque increased to 50 times the initial frictional torque to indicate seizure

Table 1 - Comparison of Empirical results with published results

No.	Speed	Load	Clearance	Shaft Radius	Bearing Length	Coefficient of friction	Seizure time, published	Seizure time, calculated
1	250	4400	1.25E-05	0.0255	0.051	0.15	28	28
2	1800	4400	1.25E-05	0.0255	0.051	0.15	2	2.4
3	250	4400	1.25E-05	0.0255	0.03825	0.15	21	23.6
4	250	4400	1.25E-05	0.0255	0.0256	0.15	16	19
5	560	160000	5.00E-05	0.0781	0.0781	0.15	3	2.1

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