Evaluating Seize Time of Journal Bearings by Thermal Induced Stresses

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Abstract— Transient thermo-elastic behavior of journal bearing during seizure is very complex and requires careful modeling of the interaction of the surface. In this project work a finite element model is used to describe the thermo-mechanical interactions of journal bearing undergoing thermally Induced Seizure (TIS), two categories of TIS are studied. An extensive set of parametric simulations are performed to study the effect of different parameters on TIS such as load, speed, shaft radius, operating clearance, bearing length, friction coefficient and thermal expansion coefficient. Good agreement between empirical results and the results obtained from this model attests the capability of the model and its potential for predicting thermally induced seizure phenomenon.

Keywords— Friction, Thermo-elastic, Journal Bearings, Seizure.

I. INTRODUCTION

Thermally Induced Seizure in the journal bearing is a mode of failure that occurs quite suddenly and end up causing the catastrophic damage to the system. Even though hydrodynamic bearings are applied in practical applications over a wide range of speeds, loads etc. extensive research efforts are still going on to have better understanding of their behavior. The relative sliding motion between the two contacting solids generally results in loss of mechanical energy due to friction. The power dissipation associated with friction is manifested in the form of heat generation at the contacting surfaces and results in an increase in temperature of sliding bodies. Many widely used mechanical components, such as bearings, seals, brakes and clutches are susceptible to frictional heating. This report investigates the effect of frictional heating on the operating clearance in a journal bearing.

II. ANALYSIS AND MODELING OF THE BEARING

The model consists of a shaft rubbing on the inner surface of the bushing as shown in Figure 4.1. The contact forces results in the generation of frictional heat on the entire surface of the shaft and in the area where it contacts the bushing inner radius. Due to the rise in temperature, the shaft expands and its encroachment to the bushing leads to a loss of clearance. At some point in time, the bearing clearance reduces to a minimum and shaft starts to encroach the bearing. Analysis show that typically during TIS, the following three phenomena occur:

1. The contact forces increase, increasing the heat generated.
2. The contact angle increases causing a higher percentage of heat entering the bush.
3. New areas of contacts are established resulting in a chain reaction of events
   Leading to a rapid loss in the operating clearance.

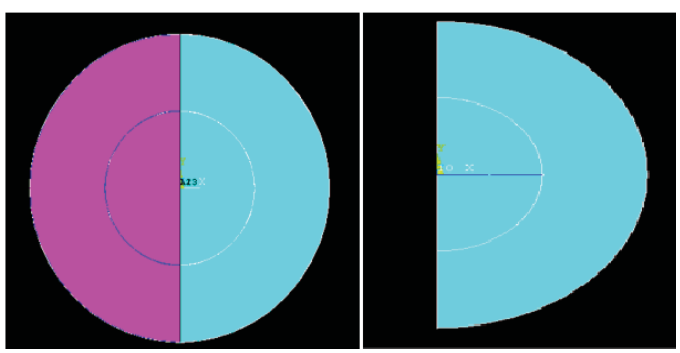
The simulations presented in this work, are implemented by performing a thermal analysis and a thermo-elastic analysis in a stepwise linear fashion. The model utilized for analysis is one-half symmetry and the heat conduction in the axial direction neglected. The operating parameters used for this model are listed below:
W = 4400 N
N = 250 rpm
Rs= 25.5 x 10-3 m
Rb = 51.0 x 10-3 m
C = 0.0125 x 10-3 m
L = 51.0 x 10-3 m

Operating parameters for the finite element model and simulations

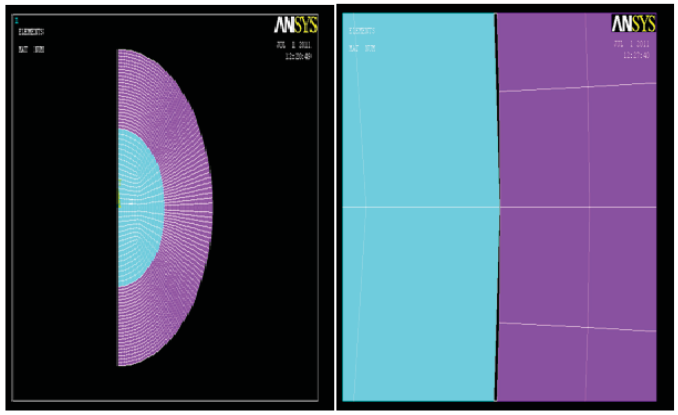
Radius of the Shaft , Rs (m)	0.0255
Radial Clearance between Shaft and Bush Rcl (m)	0.0000125
Inner Radius of the Bush Rib (m)	Rs+Rcl
Outer Radius of the Bush Rob (m)	0.051
Coefficient of Friction FR	0.15
Speed N (rpm)	250
Half of Total Load W	2200
Velocity V in (Radians/Sec)	V=2*pi*Rs*N/60
Length of the Bush L (m)	0.051

III. MATERIAL PROPERTIES

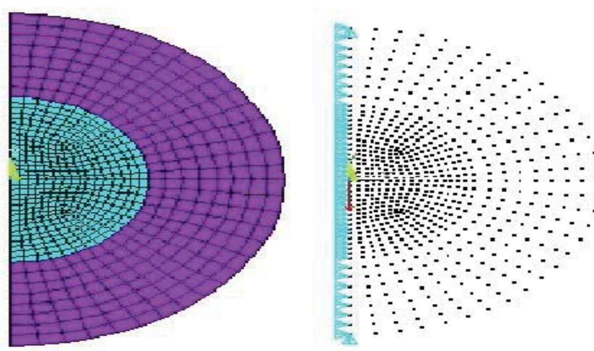
Properties	SHAFT	BUSH
Material Number	1	2
Thermal Co-efficient of expansion(α) m/mK	0.00005	0
Thermal Conductivity (K) W/mk	52	52
Specific Heat (Cp) J/Kg ^{0} C	156	42
Density(kg/m3)	7850	4500
Poisson's ratio	0.3	0.3
Young's Modulus N/mm^2	207e9	110e9



Full sectional and half sectional view of the bearing



Meshing of shaft and bush with clearance

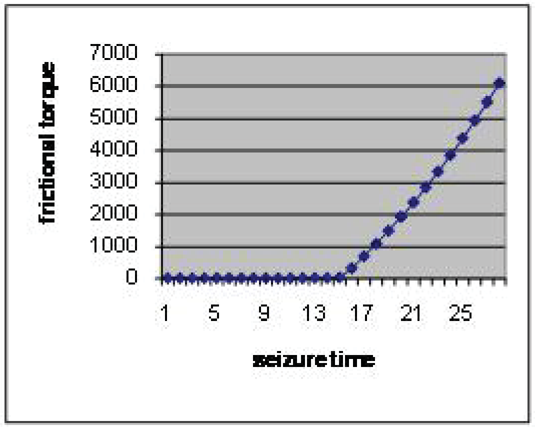


Meshing of the shaft and bush with displacement is constrained

IV. FRICTIONAL TORQUE VERSUS TIME

$$t_{ss} = \frac{C\rho C_p}{2\left(1+\nu\right)\alpha q_s} \bullet \frac{1}{\left[\left(n-1\right)\left(\frac{R_{bo}}{R_s} - \frac{R_s}{R_{bo}}\right)^{-1} + n\right]}$$

For the above given parameters t_s is equal to 15 seconds. However, from Figure 4.8, seizure may not occur until 28seconds into the transient. Therefore, it can be confirmed that the simplified one-dimensional analysis provides a conservative estimate of the seizure time.

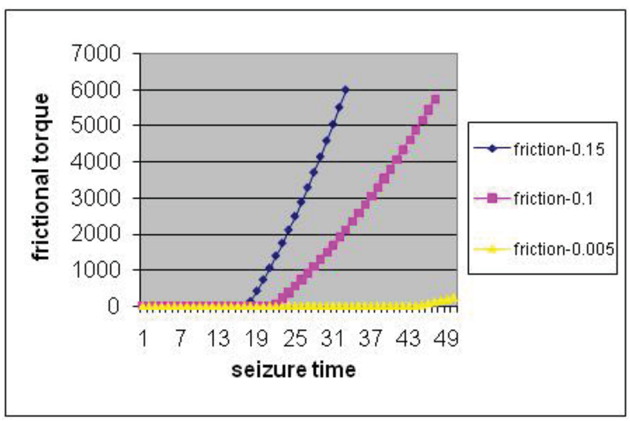


Variation of frictional torque w.r.t. time

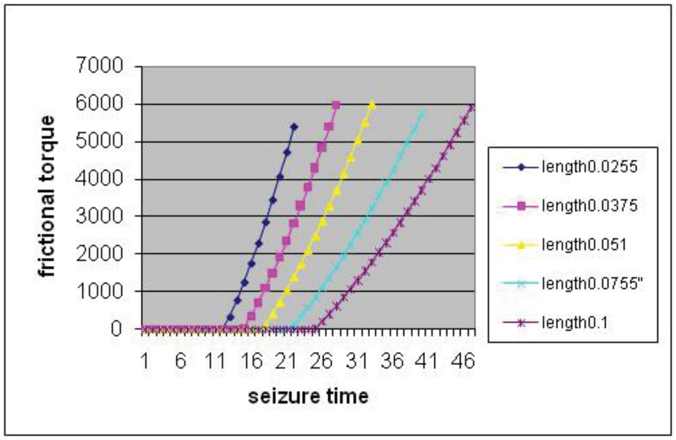
V. LUBRICATED CONTACT

The journal bearing seizure analysis has been performed assuming that dry sliding occurs between the shaft and bushing. In a typical fluid film bearing the surface of the shaft and bushing are completely separated by Film of oil. The major effect of the lubricant is to provide a low friction coefficient and increased internal cooling. The friction coefficient for a lubricated contact is around 0.005 as compared to the value of 0.15 used for the dry sliding case. The heat generated at the rubbing surfaces is directly proportional to the frictional coefficient. Therefore, when the contact is lubricated, the magnitude of the clearance loss would be much less than the dry friction case. In addition, lubricant normally provides some internal cooling.

A plot of the frictional torque versus time is shown in Fig 4.9 for the different frictional coefficient values.

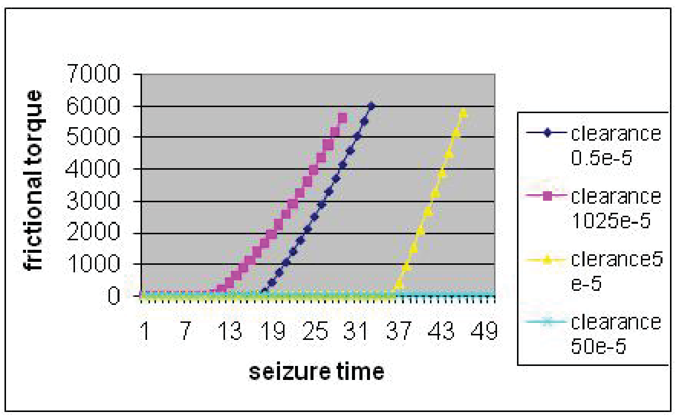


Effect of Friction coefficient on Frictional torque

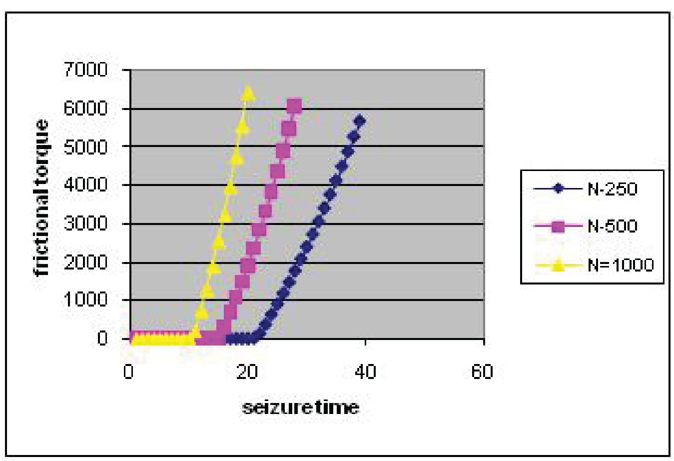


Effect of bearing Length on Frictional torque

Clearance: Operating clearance is one of the important variables in the performance of journal bearing. The variation of clearance with time is of significant practical interest particularly for situations where large frictional heat is produced as result of dry contact. The deformation associated with expansion of the rotating shaft relative to that of the stationary bearing may be quite large, to the extent that a complete loss of clearance may takes place with a catastrophic seizure. Variation of the frictional torque with respect to time for different clearance values is shown in Fig.

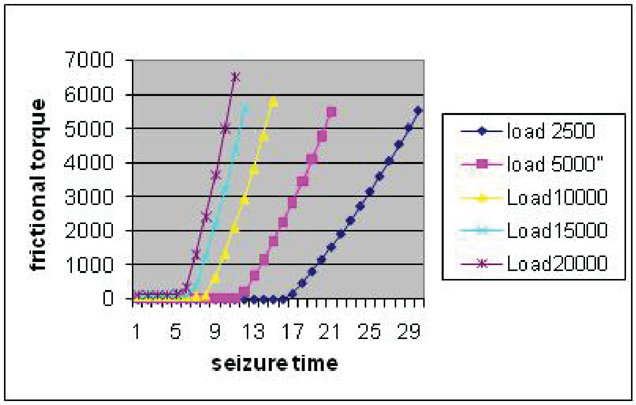


Effect of Clearance on Frictional torque



Effect of Speed on Frictional torque

Load: Frictional torque is greatly influenced by the load. Load must be depends on the operating parameters. We must have some limitation to the load for different operating parameters. For the above given parameters the variation of frictional torque for the different load values are shown in the Figure 4.13



Effect of Load on frictional torque

VI. RESULTS

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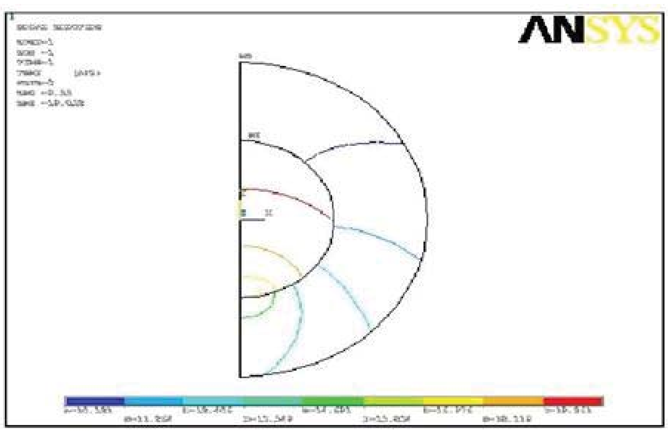
Seizure time: When the frictional torque increases beyond the extent of the driving torque capability, it can be concluded that the journal has seized in the bearing. The present model assumes that TIS is complete when the frictional torque reaches at least 50 times the driving torque. For the following operating parameters the frictional and driving torque values for the first 38 seconds are shown in the Table 5.1.

Operating parameters:

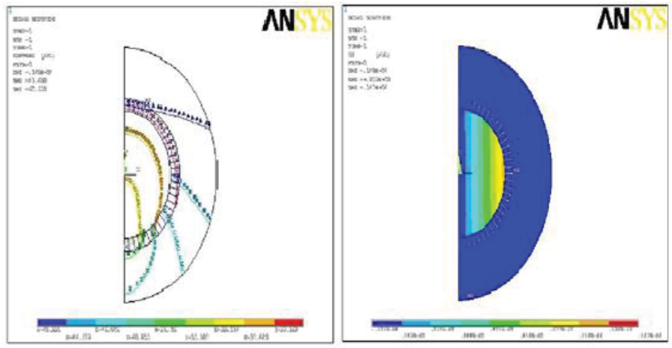
W = 4400 N	*N* = 250 rpm
Rs = 25.5 x 10^{-3} m	*Rb* = 51.0 x 10^{-3} m
C = 0.0125 x 10^{-3} m	*L* = 51.0 x 10^{-3} m

From the above table at 32 seconds of time the frictional torque reached 50 times more than the driving torque. Therefore seizure time for the above given parameters is 32 seconds.

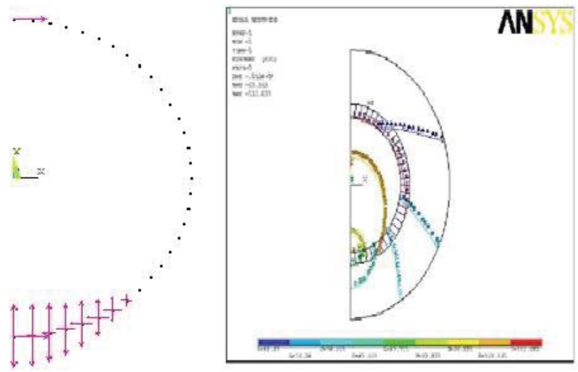
Temperature distribution, Contact force reactions and Deformation of shaft at 12 & 32 seconds during the analysis are shown below in the Figures 4.8 & 4.9. Contact forces list at 12 & 32 seconds are shown in the Tables 5.3 & 5.4. During this, it is observed that temperature rise is the function of time and those plots illustrate the onset and completion of seizure for a journal bearing during start-up.



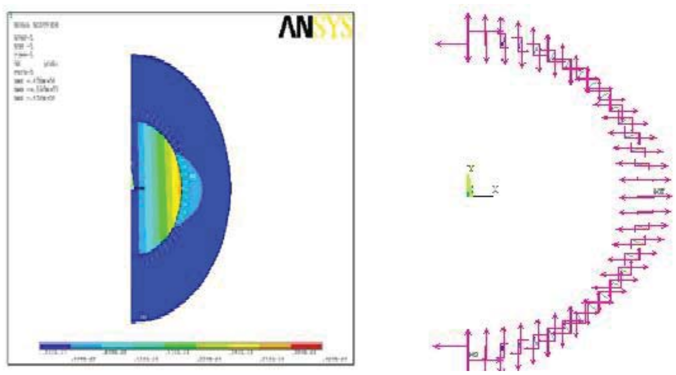
Steady state temperature distribution



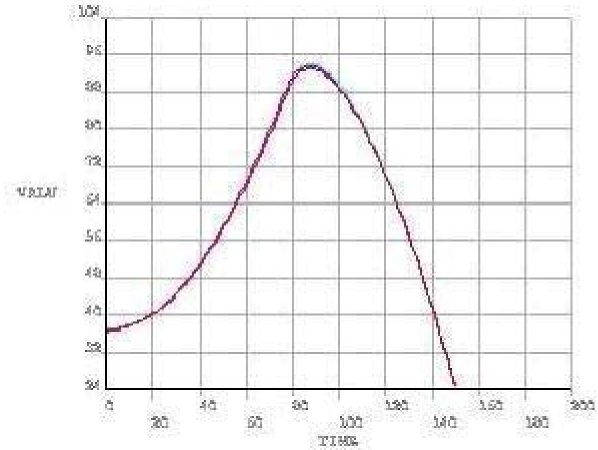
Temperature Distribution and Deformation of the shaft



Contact forces reactions and Temperature distribution



Deformation of the shaft and Contact forces reactions


Temperature variation during transition period

Verification and Analysis

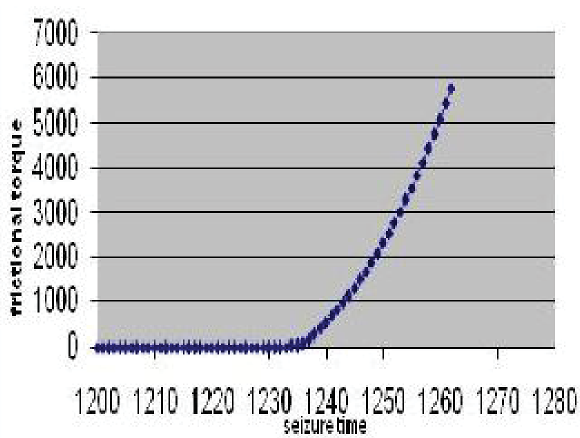
The simulated results, verified for its validity using some of the published results, are shown in the table.

Comparisons of results

Speed	Seizure time published	Simulated seizure time
250	100	96
500	68	62
750	58	56
100	50	48
1200	46	43
1500	42	40
1800	34	32
2000	30	30
2200	30	28
2400	26	24

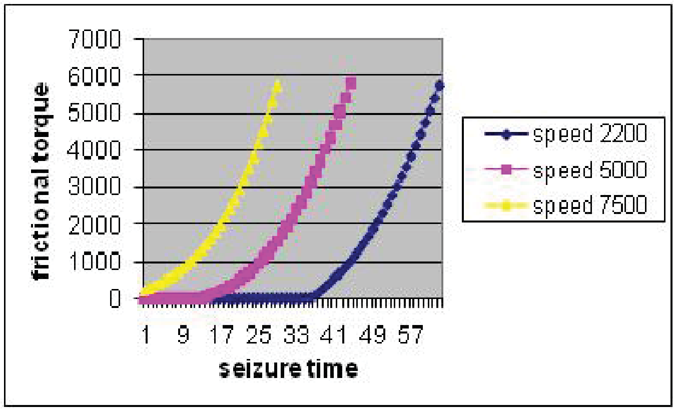
Thermo-elastic behavior of journal bearings undergoing seizure

(1) *Variation of frictional torque w.r.t time:* during the transition period the variation of frictional torque with respect to time is shown in Figure 5.8. In this figure we can observe that the frictional torque reached 50 times more than the driving torque at 62 seconds of time.



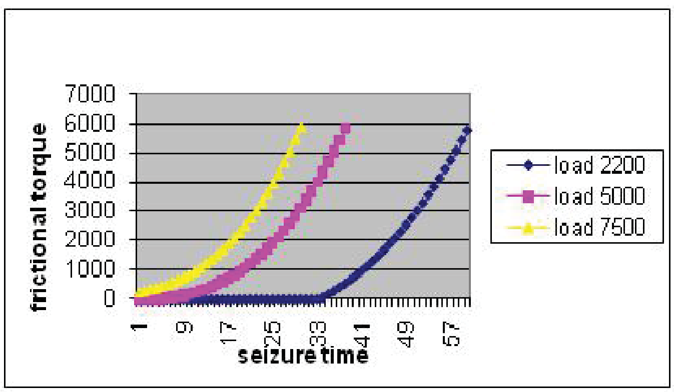
Variation of frictional torque w.r.t time

Speed: The frictional heat is proportional to N, high operating speeds will have a significant impact on the time to seizure. For the above given parameters the variation of frictional torque for the different speed values are shown in the Figure 5.9



Effect of Speed on frictional torque

Load: frictional torque is greatly influenced by the load. The load depends on the operating parameters. We must have some limitation to the load for different operating parameters. For the above given parameters the variation of frictional torque for the different load values are shown in the Figure 5.10 At 32 seconds of time the frictional torque reached 50 times more than the driving torque (112.200). Therefore seizure time for the above given parameters is 32 seconds i.e.5502.313.



Effect of Load on frictional torque

VII. CONCLUSIONS

When rotating machinery that is supported on fully lubricated bearings are started up from rest, the lubrication flow may not have been established and there would be metal-to-metal contact. The effect of the dry sliding during start-up was analyzed by studying the effect of start-up friction on the bearing operating parameters such as clearance loss and frictional torque by a thermo elastic finite element model. A series of simulations were performed by varying the operating parameters to give insight in to the system. The 1D Equation predicts a linear relation between the seizure time and the operating clearance. This means that the bearing will seize even if the clearance is very large and it gives the conservative results. This 2D analysis gives 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. Thermo elastic behavior of journal bearing undergoing TIS were studied for the different operating parameters to gain insight in to the system.

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