Failure Analysis Of Journal Bearning During Start Up

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***Abstract*— Thermally induced seizure (TIS) in journal bearings is 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.The finite element modeling is done using ANSYS. A simplified two-dimensional analysis is performed; the analysis assumes that the contact pressure is uniform in axial direction and that no crowning or misalignment is present in the system.

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.

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 a 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 take place with a catastrophic seizure. This seizure phenomenon commonly occurs during the startup process when shaft is in direct contact with bush. Particularly susceptible to seizure are bearings that have not been used for a relatively long period of time or when the lubricant supply to the bearing is blocked thus during the startup process the shaft and the bush are in direct contact with an associated high friction coefficient. Under these circumstances one would like to be able to predict how long it takes before the seizure may set in. The objective of this work is to perform a comprehensive study of seizure in bearings during start up and when a transient flow disturbance is occurred and alive at seizure time which is a function of various parameters. The finite element modeling is done using ANSYS.

The analysis of a bearing undergoing TIS during start up consists of the following steps:

1. A 2-D static contact analysis is to be performed to determine the contact forces and the contact angle.

2. A transient heat transfer analysis is to be performed to model in order to know the thermal effects of dry frictional heating on the journal and the bearing.

3. A transient thermo-elastic analysis is to be 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 are to be studied in this analysis

II. LITERATURE REVIEW

Ling and Saibel [1] performed a study of failure of bearings due to thermal galling of sliding surfaces in contact. The phenomenon of galling or seizing of metals is a function of thermal and mechanical conditions under which the metallic surfaces are rubbed together. Galling was predicted to occur when the sliding surface reached the recrystallization temperature of the metal. For predicting the flash temperature due to the asperity contact the surface temperatures were calculated from Blok's criterion. Galling criteria was expressed as a function of the surface velocity, load and time. This criterion would be more appropriate for high energy sliding, like disc brakes and clutches. This work gave the idea to use a similar failure criterion for bearings.

Gecim and Winer [2] performed a steady-state thermal analysis of a rotating cylinder subjected to heating in a particular region on its surface while the rest of the surface were subjected to convective cooling. The governing partial differential equation and boundary conditions were solved using the Finite Fourier transforms. The boundary conditions are combinations of Neumann and mixed type due to simultaneous heating and cooling on the surface of the cylinder. The analysis on journal bearing undergoing frictional heating is striking. A similar analysis was performed by Patula [3] to determine the steady state temperature of a rotating roller used in rolling of hot ingots in metal forming industry.

. Dufrane and Kannel [6] performed a study on the thermo elastic interactions of a journal bearing undergoing a catastrophic seizure leading to a complete loss in operating clearance. The cause of this type of failure was identified to be dry metal-to-metal contact during the bearing start-up and associated rise in the contact temperature. Bearings that had been out of service for a relatively long time are particularly susceptible due to lack of adequate supply of the lubricant in the contact area. The work is of particular importance as the encroachment of the shaft to the bushing and the concomitant reduction in the operating clearance (in the order of microns) was found to occur rapidly. They performed a series of experiments to determine the effect of dry friction that led to failure by seizure. The experimental results showed that typically seizure occurred within 30 seconds in most journal bearings operating in dry conditions. A one-dimensional thermal and thermo elastic analysis was performed to estimate the seizure time as a function of the operating parameters. The shaft expanded radially outward and seizure was assumed to be complete when the total operating clearance vanished. The bearing thermal expansion was not considered in the theoretical analysis. A linear analytical expression was derived relating the bearing operating conditions and the seizure time. This linear equation holds good only for very short transient times. Although it gave good results that matched experiments, it is somewhat restrictive and does not accurately represent the behavior of the system. The linear variation of seizure time with clearance implies that all bearings irrespective of the operating clearance would eventually seize.

III. FINITE ELEMENT ANALYSIS :OVERVIEW AND PRODECURE

The finite element modeling is done using ANSYS First, the analysis done by Hazlett [8, 9] is 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. A simplified 2-dimensional analysis is performed. The analysis assumes that the contact pressure is uniform in the axial direction and no crowning or misalignment is present in the system. The effect of bearing length is analyzed in the 2-D analysis by taking into account the change in the contact width and change in the heat flux generated with change in bearing length.

The analysis of a bearing undergoing TIS during start up is 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 thermo-elastic 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.

IV. DESCRIPTION OF PROBLEM

The model consists of a shaft rubbing on the inner surface of the bushing as shown in Figure 4.1. Under load, frictional heat is generated at the contact between the rotating shaft and the stationary bearing. A loss of clearance occurs due to relative thermal expansion, as can be seen in the Fig.4.1 the initial cold clearance varies from zero to a maximum. During the thermal transient, the encroachment is a complex function of the various parameters, material properties and boundary conditions.

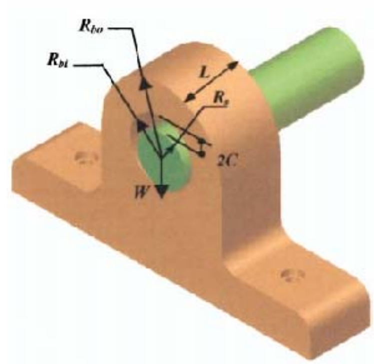

Fig. 1 – Schematic of a journal supported on a pillow block

The total heat generated in the contact region is partitioned between the journal and bushing. When the shaft expands relative to the bushing, the increase in the frictional torque leads to an increase in the frictional heat generated at the contact. As the clearance loss progresses, a larger percentage of the total frictional heat enters the bushing due to increased area of contact and the contact conductance with the shaft.

V. ANALYSIS MODEL

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 = 1000 N; N = 500 rpm

R_s= 25.5 x 10^{-3} m; R_b = 51.0 x 10^{-3} m

C = 0.0125 x 10^{-3} m; L = 51.0 x 10^{-3} m; $\mu=0.3$

VI 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 16 seconds

TABLE: 1 Frictional Torque and driving torque values for first 16 seconds

TIME	FRICTIONAL TORQUE	DRIVING TORQUE
1	15.387	51.0
2	15.388	51.0
3	15.903	51.0
4	15.548	51.0
5	15.405	51.0
6	15.427	51.0
7	17.048	51.0
8	15.989	51.0
9	15.556	51.0
10	15.688	51.0
11	19.37	51.0
12	18.953	51.0
13	313.307	51.0
14	1125.219	51.0
15	1991.784	51.0
16	**2912.57**	**51.0**

From the above table at 16 seconds of time the frictional torque reached 50 times more than the driving torque. Therefore seizure time for the above given parameters is 16 seconds.

VII PARAMETRIC STUDY

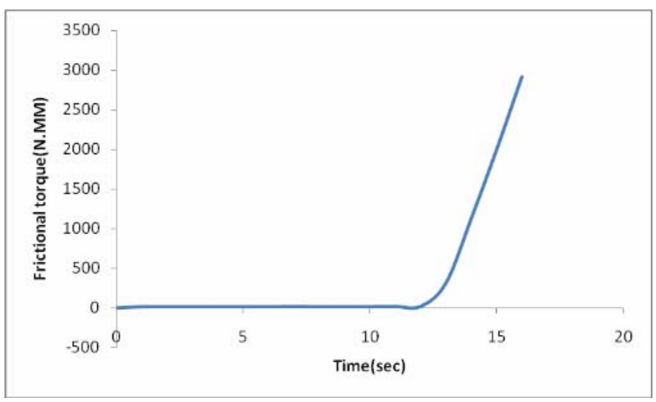

Fig. 2 Variation of frictional torque w.r.t. time.

LUBRICATED CONTACT:

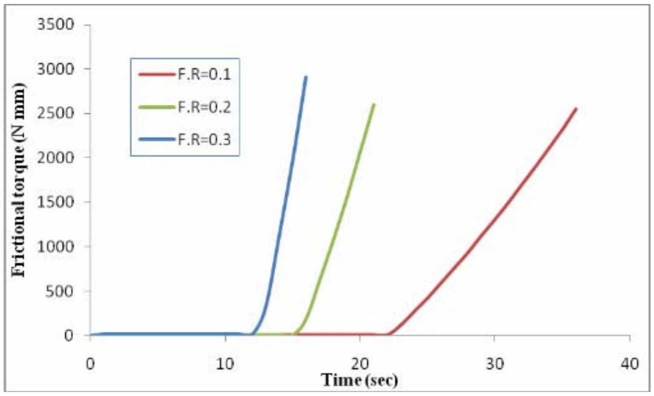

Fig. 3 Effect of Friction coefficient on Frictional torque

BUSHING LENGTH:

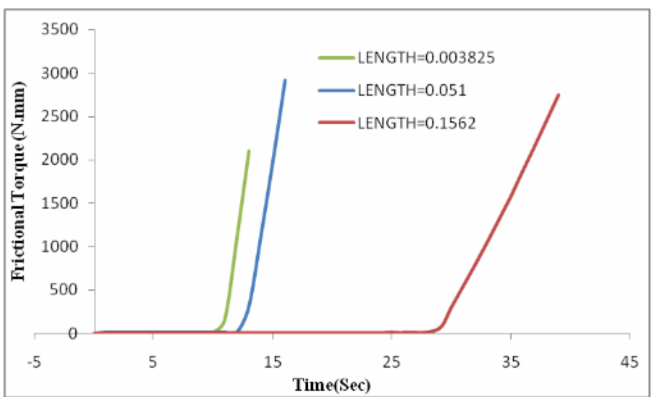

Fig. 4 Effect of bearing Length on Frictional torque

CLEARANCE:

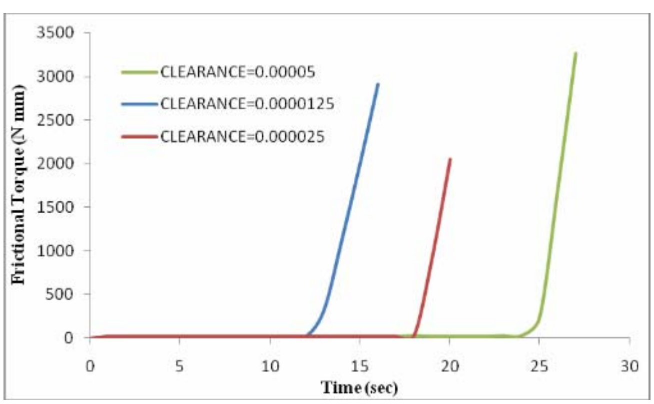

Fig. 5 Effect of Clearance on Frictional torque

SPEED:

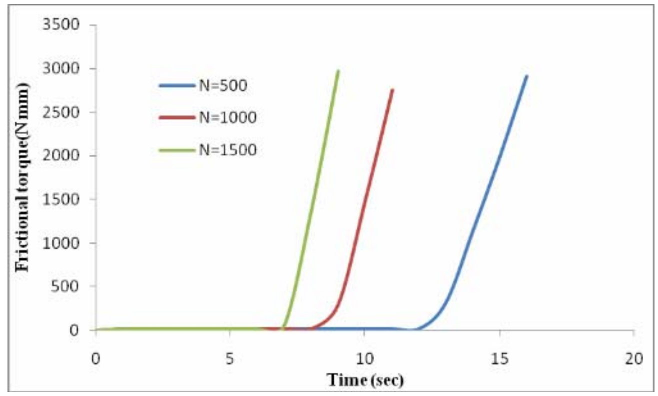

Fig. 6 Effect of Speed on Frictional torque

LOAD:

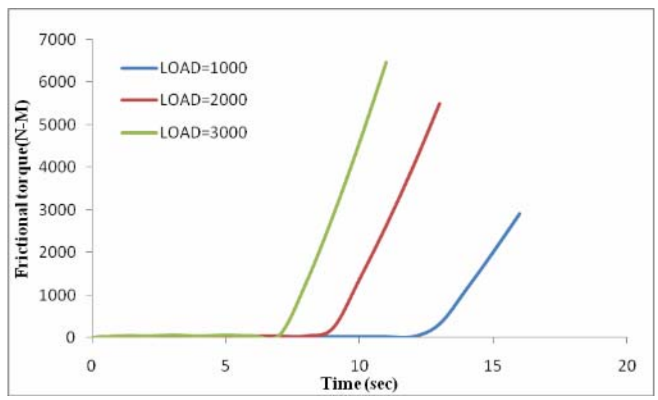

Fig. 7 Effect of Load on frictional torque

VIII Results and Discussion

The encroachment of the shaft on to the bushing with concomitant reduction in the clearance continues until the seizure is complete. The process is a complex, nonlinear 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 an extra contact area. Increase of contact forces raises the frictional heat flux and sets up a positive feedback that accelerates the loss of clearance. 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. The frictional torque increased to exceedingly large values within few seconds after the first instance of establishment of new areas of contact.

The reasons for such an abrupt increase in frictional torque are:

(I) As explained previously, the increase in contact forces increases the frictional heat generated and the increase in frictional heat means that the shaft would expand more increasing the contact forces and establishing more area of contact. This process leads to a positive feedback loop and a chain reaction leading to a rapid failure due to TIS.

(II) The operating clearance of the bearing just before seizure is reduced to a significantly lower value compared to the steady-state operating clearance. This is due to the thermal expansion of the journal and the bearing into the operating clearance area. The available clearance just before the extra contact occurs has already reduced to an exceedingly small value.

IX CONCLUSION

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 behaviors of journal bearing undergoing TIS were studied for the different operating parameters to gain insight in .

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