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Inspection of Hydrodynamic Lubrication in Infinitely Long Journal Bearing with Oscillating Journal Velocity

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Abstract

Unsteady transient analysis is carried out for hydro-dynamically lubricated journal bearing with infinitely long approximation. The performance characteristics are investigated by oscillating the journal velocity as a 'sine' function of the angle for which the journal rotates with an angular speed. Results comprising of Minimum lubricant film thickness, Dynamic pressure and load, Wall shear stress, Eccentricity, Temperature distribution and heat flux with respect to time are presented in the analysis graphically with the aid of ORIGION PRO 8.

The journal bearing is analyzed in ANSYS 14.0 'Transient Thermal' package. The journal is modeled as a "moving wall" with an absolute rotational speed of 3000 rpm. Appropriate equations and numerical solutions (Simpson's 1/3rd integration rule and Newton-Raphson method) are developed using 'C programming' for solving the Reynolds compressible differential equation. The numerical procedure is fully automated and the scheme converges rapidly. Design parameters are included in the computation taking into account turbulence and gravity.

After carrying out all the above discussed scrutiny, it was observed that minimum oil film thickness is a function of oscillating velocity, pressure is inversely proportional to the minimum oil film thickness, and eccentricity and wall shear stress are also a function of the oscillating journal velocity. While the value of coefficient of friction and coefficient of friction variable are found to be maximum at the maximum velocity, thus leading to its dependency on the oscillating journal velocity. Also, variation of temperature distribution and heat flux with respect to time leads to converging of the results. Validating McKee's investigation leads to completion of the venture.

Keywords: Journal bearing; Newton-Raphson method; Simpson's 1/3rd integration rule; McKee's investigation

Introduction

Today in this technological era, lubrication of journal bearing is an eminent phenomenon for various industries. However, the properties of lubrication may severely exalt or degrade the journal as well as the bearing. Due to the relative motion between the journal and the bearing, a certain amount of power is wasted in overcoming the frictional resistance and if the surfaces are in direct contact, this results in a rapid wear. In order to reduce the frictional resistance and to carry away the heat generated, a layer of fluid (known as lubricant) is provided and is mainly a mineral oil refined from petroleum, vegetable oil, silicon oil, grease etc.

Shaw M.C. [1] has addressed all the suitable properties of the lubricant under different loading conditions. Infinitely long journal bearings are used to support radial loads at extreme operating speeds and conditions where orthodox bearings cannot operate. The load can be supported by the fluid pressure without any actual contact between the journal and the bearing. The load supporting pressure in hydrodynamic bearings arises from either the flow of a viscous fluid in a converging channel (known as wedge film lubrication), or the resistance of a viscous fluid to being squeezed out from the approaching surfaces (known as squeeze film lubrication). Jennifer Egolf et al. [2] had done the analysis on 'air bearings' taking into account the above conditions.

Reynolds Equation for Time Dependent Journal Bearings

In linkage with the time dependency, Cameron A [3] has mentioned load capacity under a time dependent film thickness. Squeeze film denotes a hydrodynamic film that sustains a negative H/t, i.e. when the opposing surfaces are being squeezed together. An extremely beneficial characteristic of squeeze film is that it provides with increased load carrying capacity (although temporary) when a bearing is subjected to an unexpectedly high load. This feature is essential to the reliability of crankcase bearings which must withstand transient combustion forces. A further aspect of squeeze film is that the squeeze film force is always opposite in direction to the motion of bearing surface. Squeeze film forces contribute to the vibration stability of a bearing. To analyze squeeze film forces, the term H/t is kept in the Reynolds equation and is given priority over the film geometry term H/x. The Reynolds equation with the squeeze term is in the form

$$\frac{\partial}{\partial x}\left(\frac{H^3}{\eta}\times\frac{\partial P}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{H^3}{\eta}\times\frac{\partial P}{\partial y}\right)=6U\left(\frac{\partial H}{\partial x}\right)+12\frac{\partial H}{\partial t}$$

This equation defines the hydrodynamic pressure field when the wedge effect is absent. It can be integrated in terms of a specified bearing geometry to provide load capacity, maximum pressure or any other required bearing characteristic in terms of H/t. The 'squeeze time' means the time required for film thickness to decline to some critical minimum value can also be determined by integrating H/t with respect to time.

There is no exact analytical solution for the Reynolds equation for bearings with finite length. Theoretically, exact solution can be obtained if the bearing is assumed to be either infinitely long or

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very short. These two solutions are called Sommerfield's solutions. Approximate solutions using numerical methods are available for bearings with finite length. However, AA Raimondi and John Boyd [4] of Westinghouse Research Laboratory fully solved this equation on computer using the iteration technique. Hasim Khan et al. [5], have developed a simple algorithm for solving thermo-elasto-hydrodynamic lubrication problems of infinite line contacts.

Validation of McKee's Investigation

V. B. Bhandari [6] has explained the McKee's investigation as follows: In hydrodynamic bearings, initially the journal is at rest. There is no relative motion and no hydrodynamic film. Therefore, there is metal to metal contact between the surfaces of the journal and the bearing. As the journal starts to rotate, it takes some time for the hydrodynamic film to build sufficient pressure in the clearance space. During this period, there is partial metal to metal contact and a partial lubricant film. This is thin film lubrication. As the speed increases, more and more lubricant is forced into the wedge-shaped clearance space and sufficient pressure is built up, separating the surfaces of the journal and the bearing. This is thick film lubrication. Therefore, there is a transition from thin film lubrication to thick film lubrication as the speed increases. The transition from thin film lubrication to thick film lubrication can be better visualized by means of a curve called ηN/P curve. The ηN/P curve is an experimental curve developed by McKee brothers. As the McKee investigation curve is fulfilled therefore, it is stated that the numerical solution is thus verified. In connection with McKee's investigation, an exhaustive review was made by Fuller D.D. [7].

Recently, K. M. Panday et al. [8] had carried a Numerical Unsteady Analysis of Thin Film Lubricated Journal bearing which explained that the maximum pressure, the bearing can withstand is increasing with increase in L/D ratio and the maximum pressure is noted at minimum oil film thickness [9,10].

Solution Procedure for Journal Bearing

Take $U = U_0(1+\sin\omega t)$

Take t = 0-12 seconds

$N = N_0\sin(t)$, t-interval of 0.1 seconds

N_o = 3000 rpm or 50rps (industrial constant)

Calculate N at 0 seconds up to 12 seconds

$\omega = 2\Pi N/60$

Calculate ω at 0 seconds up to 12 seconds

$U_0 = \omega_0 \times r$ ($r = 9.75 \times 10^{-3}$m)

$\omega_0 = 2\pi N_0/60$ rps

Find u at 0 seconds up to 12 seconds

η (viscosity of lubricant i.e. water) = 0.001003 kg/m-s

Diameter of bearing = 39 mm and width of bearing = 10 mm

Length of bearing = 1 m or 1000 mm

Pressure (P) = Load (W)/Area (A)

$P_{\text{ON BEARING}} = W/2\pi RL$

Apply Reynolds equation given above

Applying fundamental assumptions: No flow of the boundary surfaces (no slip condition) i.e. U = 0 and No pressure gradients in the direction of gap height (y-direction) i.e. dp/dy = 0

Considering the cylindrical coordinates only, Reynolds equation takes the form: $d/dr(h^3 \times dp/\eta \times dr) = 12 \times dh/dt$

Solving it by Newton-Raphson method and upon integration: $P = 12 \times \eta \times (h_2-h_1) \times r/h^3 \times (t_2-t_1)$

$H = H_0(1+\sin2\pi t)$ – (assumption)

$H_0 = c/4$ and $c = D-d$

Calculate h at 0 seconds up to 12 seconds

Calculate P(Pressure) at 0 seconds up to 12 seconds

$P \times 2\pi rL = W_{\text{ON SHAFT}}$

Calculate W at 0 seconds up to 12 seconds

As our time interval was 0.1 seconds, therefore calculate $W_{\text{at 1 second}}$ (0-0.1-0.2-----1) and similarly $W_{\text{at 2 second}}$ (1.1-1.2-----2) up to 12 seconds

Integrate these W by Simpson's 1/3rd rule to obtain $W_{\text{at 1 second}}$, $W_{\text{at 2 second}}$ and further after

As values of $W_{\text{at 1 second}}$, $W_{\text{at 2 second}}$ and further after are coming just nearly equal, therefore our assumption $h=H_0(1+\sin2\pi t)$ is correct and the journal has a certain static load.

We have to find an average value of $W_{avg} = W_{\text{at 1 second}} + W_{\text{at 2 second}} +......./12$.

Hence value of W is got, which is the static load of journal.

The slight variation in the value of W was due to the centrifugal forces occurring as a result of journal rotation.

Earlier we have calculated $W_{\text{at 1 second}}$ by multiplying $P_{\text{at 1 second}}$ by 2πrL. So now as we have got the static value of W, the equation changes (due to centrifugal action) as:

$P_{\text{at 1 second}} \times 2\pi(r+e) \times L = W$, where e is the eccentricity due to which centrifugal force factor came into existence.

As the journal shifts by an amount 'e', centrifugal force factor changes the value of W at every instant of time, which we got in the form of $W_{\text{at 1 second}}$, $W_{\text{at 2 second}}$ and further after

Now we can find the value of eccentricity 'e' at every instant of time with the help of corrected value of W by above equation

So we can say that as value of W (load) at every instant was coming nearly same. Therefore, our assumption $h=H_0(1+\sin2\pi t)$ is correct.

ζ (shear wall stress) = $\eta \times du/dh = \eta \times (u_2-u_1)/(h_2-h_1)$

Since u depends on time therefore, ζ also depends on time

Using Petroff's equation: $f = 2\pi^2 \times r \times \eta \times N_0/c \times P$, where f=coefficient of friction at every instant of time and CFV=coefficient of friction variable

CFV= r×f/c

Graph all the variables with respect to time in ORIGION PRO 8.

Analyse them.

Now using ANSYS 14.0 'TRANSIENT THERMAL' Package,

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analyse the temperature distribution, heat flux and directional heat flux.

Plot them with respect to time.

Results and Discussions

Velocity (U) v/s time

Velocity (U) is a function of time change which is an input parameter. This function is taken as a sine function of the angle for which the journal rotates with a constant angular speed. Here, velocity is measured in m/s. It is varied by an instrument known as sinusoidal tachometer (Figure 1).

N rpm and ω (omega) v/s time

Rotational speed (N) and ω (omega) is a function of time change which is an input parameter. This function is taken as a sine function of the angle for which the journal rotates with an angular speed. Here, it is measured in rpm. Negative value indicates the journal is moving in the opposite direction (Figures 2 and 3).

H_{min} v/s time

From the graph formed between H_{min} v/s time, a same curve structure is formed as that of velocity v/s time step curve. This gives rise to a result that the H_{min} is a direct function of oscillating velocity. The gaps in the graph are due to the reason that it is an instantaneous process (Figure 4).

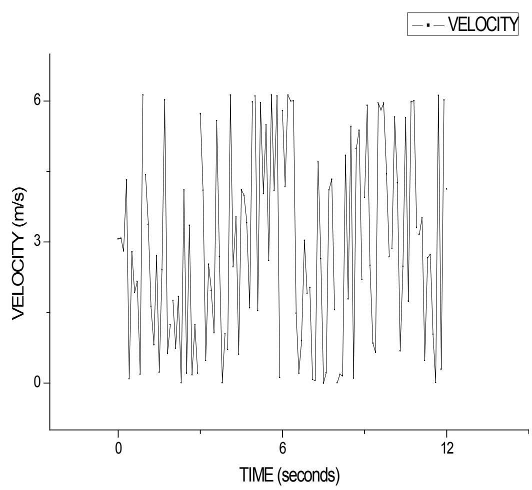

Figure 1: Velocity vs. time.

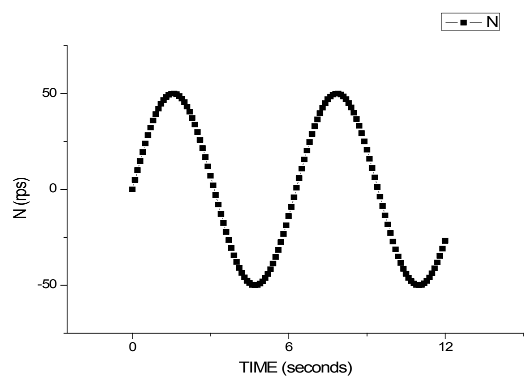

Figure 2: N (rpm) vs. time.

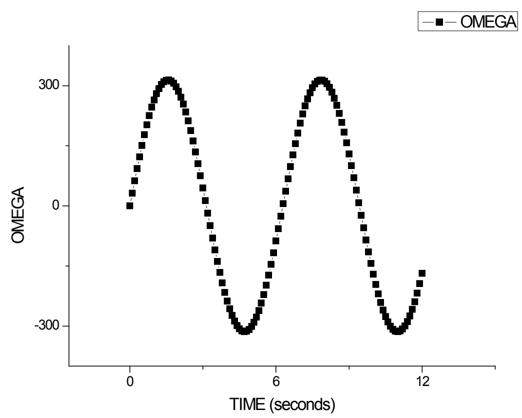

Figure 3: ω (omega) vs. time.

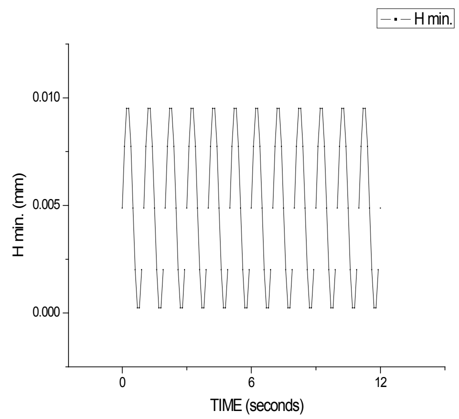

Figure 4: $H_{min.}$ vs. time.

Pressure v/s time

It can be visualised from the graph that the maximum value of pressure is noted at minimum oil film thickness. Hence in case of oscillating velocity the pressure is inversely proportional to the minimum oil film thickness (Figure 5).

Instantaneous and stable weight of journal v/s time

From the graph below it is obvious that the instantaneous weight (weight coefficients) is a direct function of the dynamic pressure, since the graph is almost coming the same.

After integrating the instantaneous weight by Simpson's 1/3rd rule, to get the stable weight of the journal, it can be said that the journal has a certain constant weight, which due to the centrifugal force is getting distracted from the average weight.

As journal has a certain constant weight, hence our assumption $h=H_0$ $(1+\sin 2\pi t)$ is correct and since velocity is also a sine function. Therefore, h is a function of velocity (Figures 6 and 7).

Eccentricity v/s time

From the graph, it can be noticed that the eccentricity is maximum

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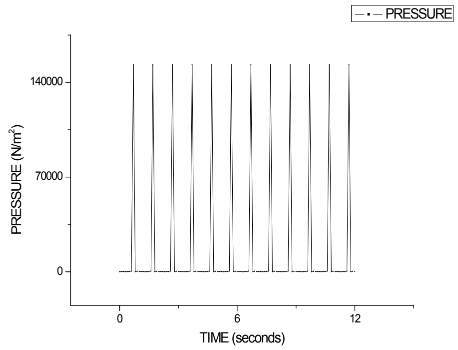

Figure 5: Dynamic pressure vs. time.

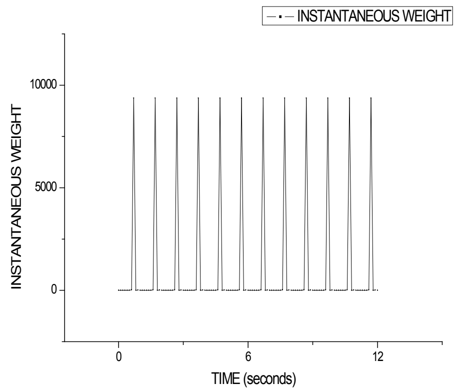

Figure 6: Instantaneous weight vs. time.

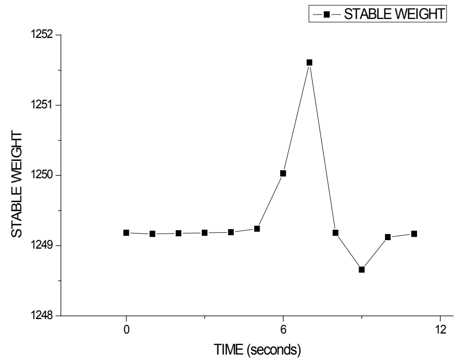

Figure 7: Stable weight vs. time.

at the maximum velocity. Hence the eccentricity is also a function of the oscillating velocity (Figure 8).

Wall shear stress v/s time

Since the value of wall shear stress is coming maximum at the maximum value of the velocity, therefore wall shear stress is also a function of the oscillating velocity (Figure 9).

Coefficient of friction v/s time

Value of Coefficient of friction is found to be maximum at the maximum velocity (Figure 10).

Coefficient of friction variable (CFV) v/s Time

Since CFV is directly proportional to coefficient of friction, therefore they get nearly the same curve (Figure 11).

Validation of McKee's Investigation

Since the problem defined by us is very much validating the McKee's investigation, hence the purpose of solving the problem is justified and our assumptions are correct at every step (Figures 12 and 13).

Thermal Considerations

Minimum temperature is at the surface of the journal due to the

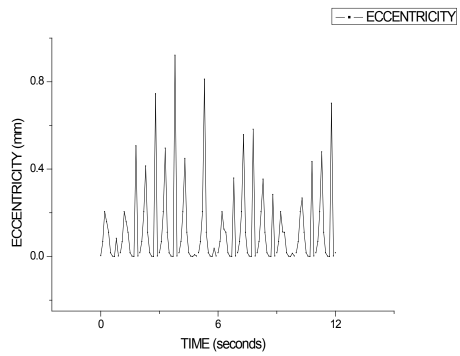

Figure 8: Eccentricity vs. time.

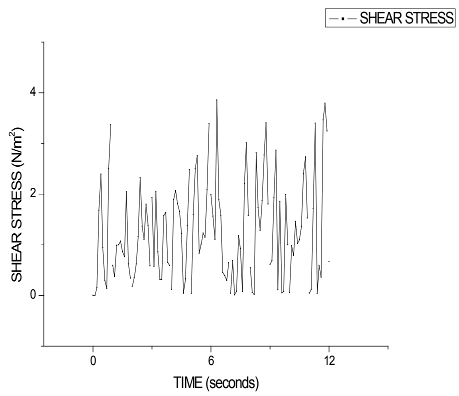

Figure 9: Wall Shear Stress vs. time.

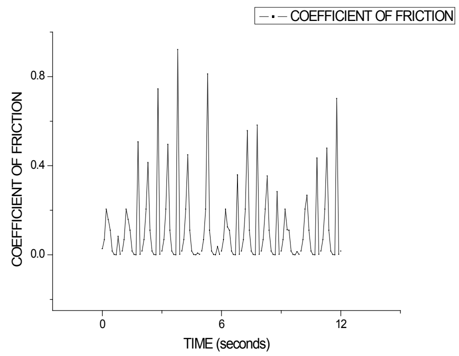

Figure 10: Coefficient of friction vs. time.

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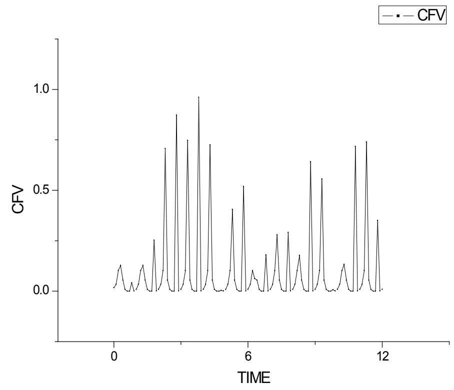

Figure 11: CFV vs. time.

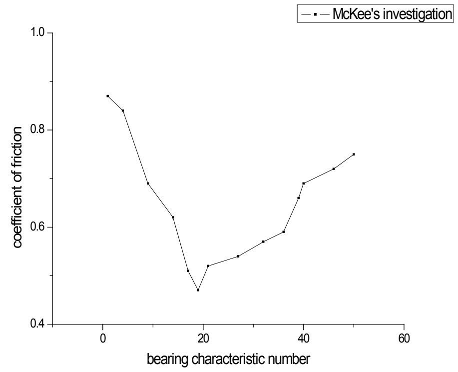

Figure 12: McKee's investigation.

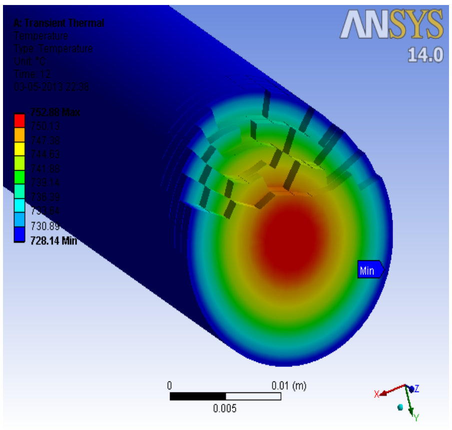

Figure 13: Temperature distribution on the journal.

presence of the lubricant on the surface of journal. After 12 seconds, it starts to converge (Figure 14).

Green colour defines the global maximum temperature while the red colour determines the global minimum temperature. These two temperatures defines the range of temperature at which the journal will be oscillating (Figure 15).

Due to the temperature gradient, there is a heat flux from the surface of the journal towards the inner side of the journal (Figure 16).

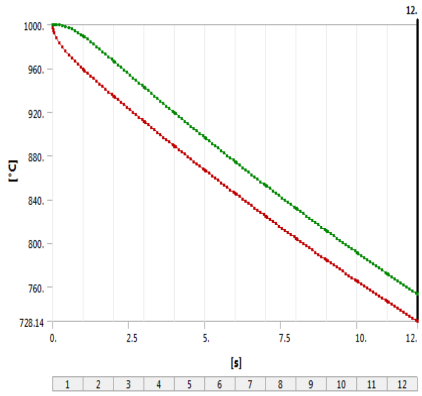

Figure 14: Temperature on the journal vs. time.

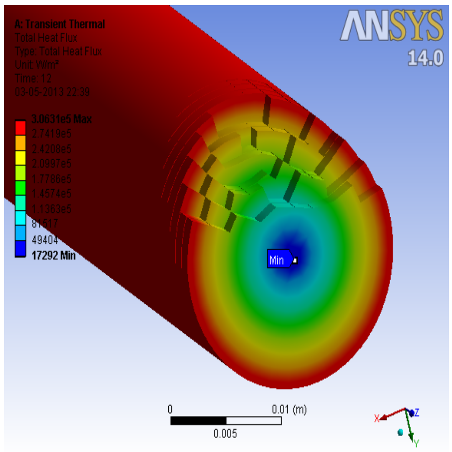

Figure 15: Heat flux distribution on the journal.

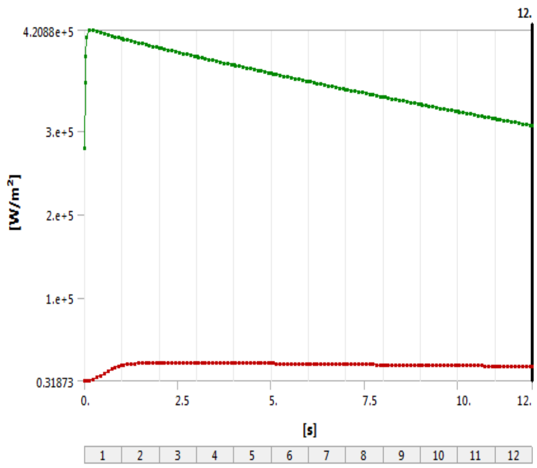

Figure 16: Heat flux on the journal vs. time.

Green colour defines the global maximum heat flux while the red colour determines the global minimum heat flux (Figure 17).

Minimum temperature is at the inner surface of the bearing due to

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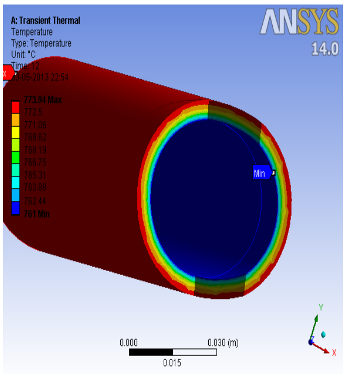

Figure 17: Temperature distribution on the bearing.

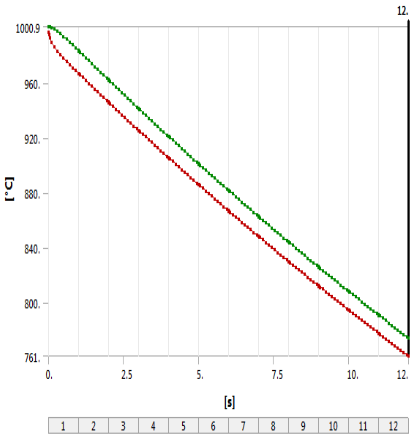

Figure 18: Temperature on the bearing vs. time.

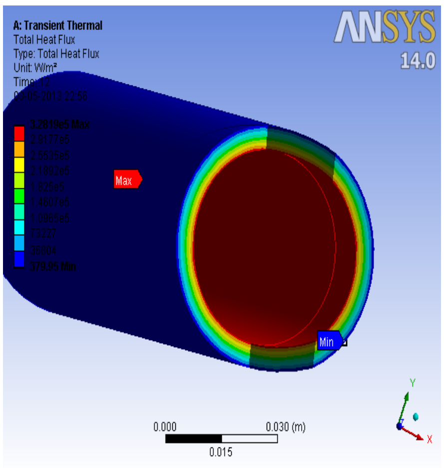

Figure 19: Heat flux distribution on the bearing.

the presence of the lubricant on the inner surface of bearing. After 12 seconds, it starts to converge (Figure 18).

Green colour defines the global maximum temperature while the red colour determines the global minimum temperature. These two

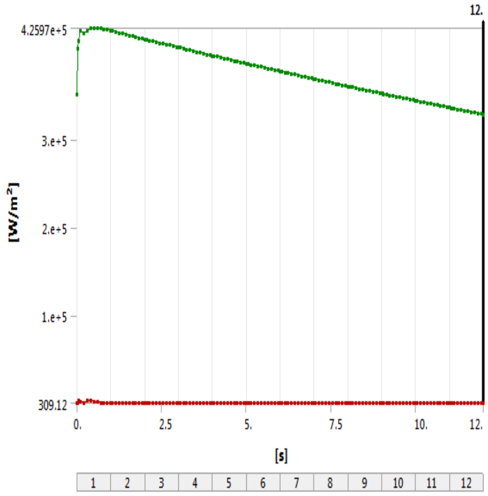

Figure 20: Heat flux on the bearing vs. time.

temperatures defines the range of temperature at which the bearing will be oscillating (Figure 19).

Due to the temperature gradient, there is a heat flux generating from the inner surface of the bearing towards the outer side of the bearing (Figure 20).

Green colour defines the global maximum heat flux while the red colour determines the global minimum heat flux.

Conclusions

Based on the above results and discussions following conclusions are made:

1. Dimensionless H_{min} is a function of oscillating velocity.

2. Dimensionless H_{min} gets nearly the same curve as oscillating velocity.

3. In case of oscillating velocity, the pressure is inversely proportional to the minimum oil film thickness.

4. Eccentricity is also a function of the oscillating velocity.

5. Wall shear stress is also a function of the oscillating velocity.

6. Coefficient of friction and CFV is found to be maximum at the maximum velocity.

7. McKee's investigation is justified.

References

1. Shaw MC, Macks EF (2001) Analysis and lubrication of bearings. McGraw-Hill.
2. Egolf J, Swaminathan S, Spence K Air Bearing Optimization.
3. Cameron A (1996) Principles of lubrication. Longman.
4. Raimondi AA, Boyd J (1958) A solution for the finite journal bearing and its application to analysis and design. ASLE Transactions 1: 159-174.
5. Khan H, Sinha P, Saxena A (2009) A simple algorithm for thermo-elasto-hydrodynamic lubrication problem. Int J Research and Reviews in Applied Sciences.
6. Bhandari VB (2010) Design of machine elements (3rdedn), Tata McGraw Hill Education Private Limited, New Delhi.
7. Fuller DD (1984) Theory and practice of lubrication. John Wiley.

8. Panday KM, Choudhary PL, Kumar NP (2012) Numerical unsteady analysis of thin film lubricated journal bearing. IACSIT Int J Engineering and Technology.
9. Hanumappa Reddy A (2005) Hydrodynamic analysis of compliant journal bearings.
10. Gunther RC (1971) Lubrication. Bailey Brothers.