Heat Generation in the Application of Couette Flow– A Numerical Investigation

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Abstract

Heat flux and temperature are the two critical parameters that needs to be examined within the Couette flow. These both the components influence the working of Plain Journal Bearing exceptionally much. Components like rotational speed of the bearing, the geometry and structure of the bearing, consistency, irreversibility etc. are dependable for the variety within the heat flux and temperature with the alter in time. In display think about, alter within the heat flux and temperature change is studied for different mineral oils at distinctive rotational speeds of the shaft. The most point is to choose the leading mineral oil that might exchange the greatest warm flux out of the framework amid the working of plain diary bearing at distinctive rotational speed of the shaft and seem moreover deliver less irreversibility within the framework. Whereas working on the plain diary bearing, a few components such as alter in kinematic consistency with the temperature, Consistency Record, flightiness etc., are considered and examined with regard to the area of investigation.

Keywords: *Heat Generation, Temperature, Couette Flow, Rotational Speed of the Shaft, Viscous Force*

Introduction

The stream of a viscous liquid between one moving and one stationary surface, such stream of lubricating oil in bearing, is categorized as couette stream, as appeared in figure 1. The use of bearings exists in nearly each and each applications of lifestyle, such as the wrist observe, vehicle, disk drive in computers, etc. Orientation are utilized for smooth relative development with as small wear as conceivable between the moving parts, and classified into two essential categories, hydrodynamic diary heading and rolling component orientation. In industry, the diary orientation is utilized for turning apparatus working on the moo and tall speed. Warm exchange and temperature rise are the two imperative components that influence the working of the plain diary bearing, which has been considered broadly. There were many studies that deals with the heat transfer aspects in the journal bearing especially for non-Newtonian fluids and with rpm of greater than 10,000, while few studies have been reported related to investigate the heat transfer aspects in the plain journal bearing with rpm below 10,000 [1].

The liquid within the bearing is displayed as given in figure 1, with two parallel plates out of which one plate is moving with a few consistent speed with regard to the other and the other plate is settled. The liquid is in between the two plates and it acts as a coolant between the two. This course of action of the demonstrate is examined beneath the Couette stream investigation [2], where the space of the consider is the region between the two plates.

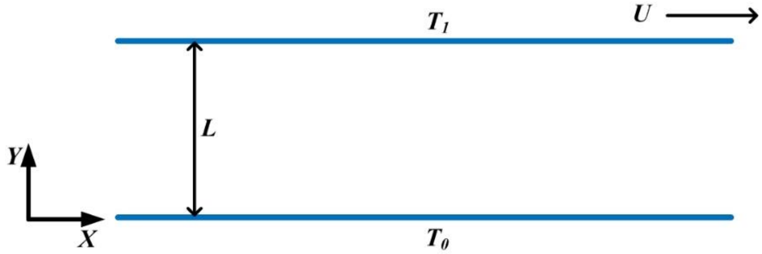

Figure 1: Model of couette flow

The liquid file bearing contains a longer life, as no contact is made between the turning components of get together. Whereas, a metal to metal contact happens for the plain diary bearing at the beginning of operation, and leads to a wear and tear, which present the outside metallic particles within the oil, and can constrain the life of a journal bearing [3]. Hence, the choice and usage of greasing up framework require a prevalent consideration with the effective strategies for the vibration monitoring. In addition, the wellbeing and life span of a liquid film bearing could be a work of the hydrodynamic loads forced on the bearing surface in an alternative manner. Few more points of interest of liquid film orientation are such as less clamor and transmitted vibrations and able to resist the stun loads, too give a separation to power between rotor and ground, long life beneath ordinary stack conditions, etc.

Couette stream gives the best demonstrate for the investigation of warm exchange for stream between two coaxial barrels or parallel plates. The Couette stream is vital in grease, polymer and nourishment processing. The tangential annular stream may be a show for a diary and its bearing in which one surface is stationary whereas the other is turning, and the clearance between the surfaces is filled with a lubricating oil of tall thickness. For such a framework the viscous-energy-dissipation shows up as a warm source term within the vitality condition, which must be illuminated to anticipate the temperature conveyance within the limit hole of a Couette gadget. Warm exchange and friction in a Couette stream are went with by the entropy era that appears the sum of valuable vitality disseminated within the handle.

Journal bearings, especially plain journal bearings, are the most important component to be used in the hydraulic turbines for turbomachinery. Similar to former, study of different aspects such as heat transfer, and type of lubricating oil in the bearing are importance, as these parameters greatly affects the performance of the bearing [4]. There are various mineral oils that are used at different cases in the bearing but to have a best lubricant that can contain all the important characteristic of a good lubricant for the large range of the rotational speed of the shaft must be find out. Another parametric quantity which affects the life of journal bearing, eccentricity is the difference between the radius of the bearing and the radius of the journal (the radial oil clearance) and depends on the revolving speed and applied load. Higher value of eccentricity aids the stability to the hydrodynamic lubrication, especially at high rotation speed. However, a higher possibility of metal to-metal contact at the higher value of eccentricity, imparted higher alternative forces to the bearing metal, leads to premature fatigue failure [3]. While instability occurs at the machine for lower eccentricity value, when journal is nearly centered.

Hydrodynamic Behavior in Couette Flow

Dynamic thickness is a measure of lubricant's inside friction and measured in units called balance (P) or centipoise (1 P = 0.01 cP). Each mineral oil has its claim consistency and it continuously changes with the alter in temperature within the framework. Lubricating characteristics of greasing up oil influences the hydrodynamic behavior of plain diary heading, hence, the consistency review of greasing up oil required depends upon bearing speed, oil temperature and stack. Ahmed and Nassar (2013) reported a common rule to choose the proficient greasing up oil comparing to the rotational speed and temperature [5]. The ISO 68 and 100 Review oils are reasonable for the applications related to the space warming applications, whereas for the high-speed units (10,000 rpm) and lower temperature applications, ISO 32 review oils is appropriate. The greasing up oil of lower consistency is found suitable for the higher speed, though for higher working temperature, profoundly lubricating oil required, as consistency. The lubricating oil having higher viscosity is observed appropriate, where vibration or minor shock loading is possible.

By and large, lubricating oil of less thickness is taken to create a film layer within the plain diary bearing, be that as it may, the thickness ought to not be exceptionally less so that the presence of the oil film layer will be dismissed and friction between two sliding surfaces will take put. It is additionally vital to consider the impact of temperature which increments amid the revolution of diary bearing. The temperature tends to extend interior the plain diary bearing either may be due to viscous warming or any other reason and it comes to up to a greatest esteem of 90℃. Within the handle of selecting fitting greasing up oil for diary bearing, it is required to look at both the parameters, consistency and viscosity file, conversely relative to the consistency alter with temperature, simultaneously. Higher esteem of thickness list implies the less alter within the thickness of the mineral oil with the increment within the temperature.

Heat Generation

A base arrangement is decided by the temperature of the walls, which we hold fixed hereinafter, and either the speed of the moving divider or the shearing stretch required to create it move. In the event that one of these two is set at that point the other is decided, at least locally, and it would appear to create no contrast which is to be the autonomous or the control variable, the other at that point being the subordinate or the reaction variable. When it is the shearing push at the divider a rearrangement is gotten, for this is too the shearing stress over the crevice and the base issue looks similar to the warm start issue in solids. As it were the temperature field is at that point important and the speed of the moving wall is decided by carrying out an integration. This correspondence would proceed to hold on presenting a perturbation in the event that the shearing push over the crevice remained at the divider esteem, but it does not: the liquid nature of the issue does not stay covered up within the confront of a irritation and what we find is that a few, but not all, of the warm start comes about carry over to the frictional warming of temperature touchy fluids in plane Couette stream. The foremost important result is this: on the off chance that the ease could be a solid sufficient work of the temperature there is an upper bound on the divider push and to each divider speed there compares a wall push lying underneath this bound.

The most important factor to be considered in the general case the journal bearings is the generation of heat generation due to metal-to-metal contact and corresponding temperature rise that takes place within the lubricant film [6]. The heat generation is due to the shear in the lubricant film that leads to the friction losses within the lubricant film and hence the heat is generated in the system. The heat generated is called as viscous heating, which is basically a loss in the system and needed to be decreased. The lesser the heat generated, the better will be the operating condition of the plain journal bearing. The temperature rise due to viscous heating, leads to temperature rise and resulted in a reduction of viscosity of the lubricating film and minimize the thickness of lubricating oil film and increases the chance of seizing of the bearing. It reduces the space between the rotating components and affects the performance of the plain journal bearing by deterioration of it.

Another problem causes due to temperature rise is reduction in the boundary lubrication performance and it will be completely missing when the lubricant temperature surpasses a pre-defined temperature. The lubricating film will have a transition temperature and major changes will occur if the temperature of the lubricant will go less or above the transition temperature. If the lubricant temperature is lower than that of transition temperature, the molecules of the lubricating oil will stick to the metal surface strongly and form a strong lubrication film on the metal surface. But if temperature of the lubricant film will go above the critical temperature, then lubrication film loses its strength remarkably which will also pose greater problem for the system and can seize the bearing. Thus, the lubrication temperature must be less than the critical temperature. But, in the case of journal bearing, the transition temperature is very less for the oils.

1. For low cost oils the transition temperature is 100 ℃
2. For high cost oils the transition temperature is 160 ℃ - 170 ℃

Now if the oil temperature goes beyond 150 ℃ then the degradation of the oil will be there and the rate of oxidation will be increased remarkably. At 100 ℃, the tensile strength of the bearing metal also reduced to one half than that of at room temperature. Therefore, the maximum temperature in the bearing should be less than 100 ℃ - 120 ℃. Thus, to maintain the temperature in a desired limit, the temperature variation in the bearing with the particular type of the lubricant should be known. In the present study, a numerical analysis has been conducted to measure the temperature in a journal bearing in an operation.

Numerical Modelling

Within the show study, certain presumptions are made, such as: relentless state, liquids taking after Newtonian behavior. No impact of outside environment parameters (temperature, weight, speed of the discuss etc.) is considered here. The steady values of thickness and consistent warm conductivity amid the reenactment are utilized. The geometry of the plain journal bearing was planned within the ANSYS 2015 [7], as per the specialized information given within the table 2. Based on the detailed writing, five distinctive geometries were outlined for the different values of flightiness and transformation speed, as specified in table 3. Within the coinciding space, beneath measuring the ‘relevance center’ was kept as medium and ‘smoothing’ was kept as tall. The faces were mapped within the shape of the quadrilaterals and the refinement was kept at 2. The fitting comes about gotten through numerical recreation are appeared from the figure 3.

Following the ASTM D2422-97 [8] and ISO 3448 method [9], authors have taken some mineral oils for the analysis of the couette flow in the application of plain journal bearings which are used in the low speed hydraulic turbines. The mineral oils that authors are using are ISO 32, ISO 46, ISO 68 and ISO 100. The properties of the above stated mineral oils are tabulated below.

Table 1: Technical Data used for the Numerical Simulation

Shaft Radius	$R_S = 0.05m$
Journal Radius	$R_B = 0.1m$
Radial Clearance	$C = 0.05m$
Reference Temperature	$T0 = 303\ K$
Reference Pressure	$P = 1\ atm$
Initial Temperature of the lubrication	$TL = 303\ K$
Lubrication Density	$\rho = 827.1\ kg/m^3$
Lubrication Specific Heat	Cp = 1942.67 J/Kg-K
Lubrication Thermal Conductivity	K = 0.128 W/m-k
Lubrication Viscosity	μ = 0.013 Pa-s
Bearing Thermal Conductivity	k_b = 54 W/m-k
Bearing Density	$\rho = 7833\ kg/m^3$
Bearing Specific Heat	C_p = 465 J/Kg-K
Bearing Convective Heat Transfer Coefficient	$h_B = 80\ W/m^2 - k$
Shaft Convective Heat Transfer Coefficient	$h_S = 100\ W/m^2 - k$
Revolution Speed	N = 1000 to 2000 rpm

Table 2: Eccentricity values at various RPM for plain journal bearing [3]

RPM	e/H	e (mm)
1000	0.35	17.5
1250	032	16
1500	0.3	15
1750	0.29	14.5
2000	0.27	13.5

Table 3: Thermo-physical properties of selected lubricating oils

Mineral Oil	ρ @ 15^0C (kg/l)	ρ @ 60^0C (kg/l)	v @ 60^0C (cSt)	μ @ 60^0C (kg/m-s)	K @ 60^0C (w/m-k)	C_p@ 60^0C (J/kg-k)
ISO 32	0.854	0.827	15.9	0.013	0.128	1942.67
ISO 46	0.865	0.837	21.5	0.018	0.129	1942.67
ISO 68	0.867	0.839	29.5	0.024	0.128	1934.3
ISO 100	0.868	0.840	40.7	0.034	0.0106	1934.3

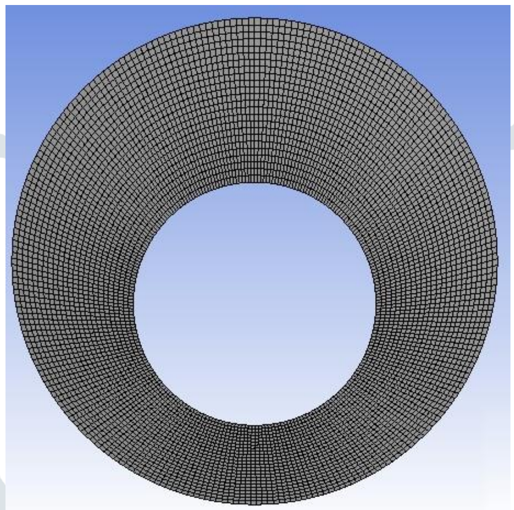

Figure 2: Meshed model of the plain journal bearing geometry for eccentricity = 17.5 mm and e/H ratio = 0.35 for the revolution speed of 100 rpm

Results and Discussion

The numerical simulation of the journal bearing is done for ISO 32 in Ansys Workbench. The temperature ranges are observed for different rotational speeds of the journal bearing for ISO 32 that are shown in the table 4. The least and the most extreme temperature values are imperative to check within the plain diary bearing since the mineral oil (ISO 32) utilized can be worked at the temperature contrast of as it were $600C$ and subsequently it gets to be essential to check that whether amid the operation of the plain diary bearing the temperature contrast does not exceed $600C$, particularly within the plain diary heading where the peril of the breakage of the atoms is continuously there that can essentially increment the temperature inside the framework. As the over organized values of the temperature distinction are all less than $600C$, thus ISO 32 can be utilized within the plain diary bearing. The visuals (pictures) gotten within the Ansys for the ISO 32 at distinctive rotational speeds of the shaft are appeared.

Table 4: Temperature Difference at Different RPM for ISO 32

RPM	T_{min} (k)	T_{max} (k)	ΔT (K)
1000	282.6	296.99	14.39
1500	292.3	298.65	6.35
1750	293.3	299.9	7.6
2000	291.9	300.13	8.23

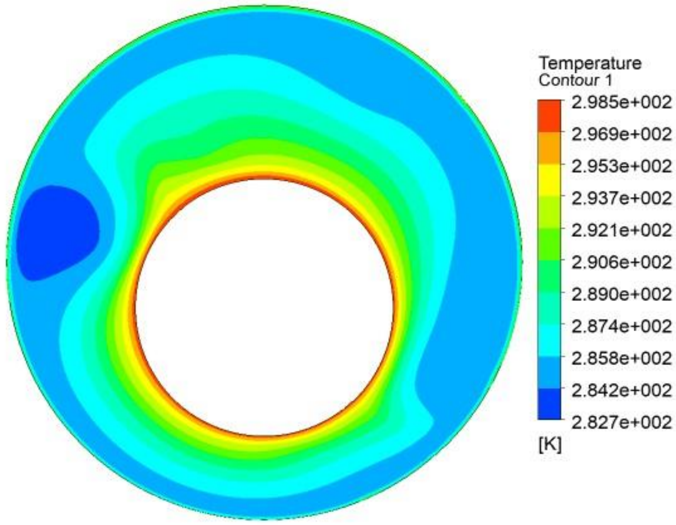

Figure 3: Temperature Contour of ISO 32 at N=1000 rpm

Temperature contours of ISO 32 at the rotational speed of the shaft of 1000 rpm is shown in fig. 3. It is observed that the temperature variation for the above model is about 14.39 K, with the maximum temperature occurring at the shaft and the minimum temperature occurring at the location around the journal. There is a thin film of maximum temperature around the shaft and the thickness of the film is very small. This may be due to the low rotational speed of the shaft. The heat must be transferred from the shaft to the journal.

The fig. 4 shows the temperature contours of ISO 32 at the rotational speed of the shaft of 1500 rpm. It is observed that the temperature variation for the above model will be 6.35 K, with the maximum temperature occurring at the shaft and the minimum temperature occurring at the location around the journal. There is a film of maximum temperature around the shaft and the thickness of the film is some large as compared to the thickness of the film observed at N=1000 rpm.

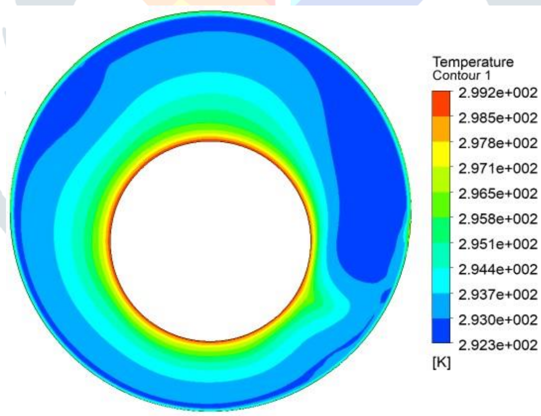

Figure 4: Temperature Contour of ISO 32 at N=1500 rpm

The fig. 5 shows the temperature contours of ISO 32 at the rotational speed of the shaft of 1750 rpm. The observed temperature variation for the N = 1750 rom is about 7.6 K, where the maximum temperature occurring at the shaft and the minimum temperature occurring at the location around the journal. There is a film of maximum temperature around the shaft and the thickness of the film very large as compared to the other thickness of the film that were observed at N= 1000 and N=1500.

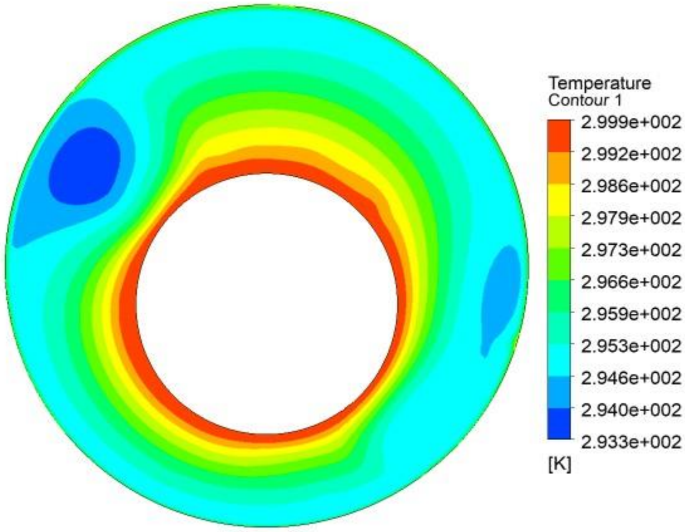

Figure 5: Temperature Contour of ISO 32 at N=1750 rpm

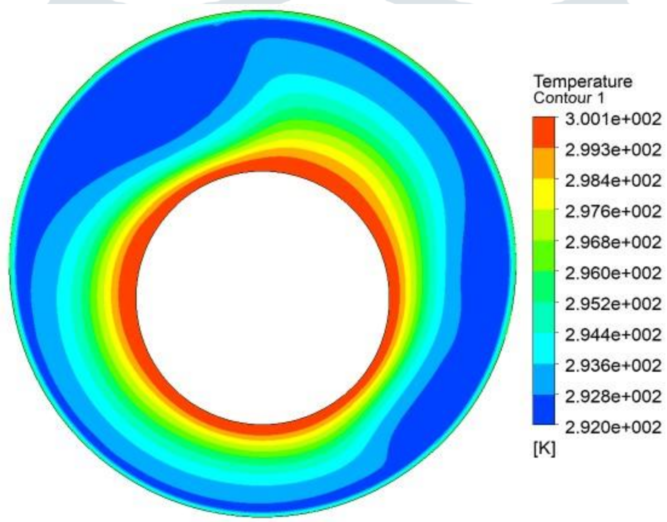

Figure 6: Temperature Contour of ISO 32 at N=2000 rpm

Fig. 6 shows the temperature contours of ISO 32 at the rotational speed of the shaft of 2000 rpm. It is observed that the temperature variation for the above model will be 7.6 K, with the maximum temperature occurring at the shaft and the minimum temperature occurring at the location around the journal. There is a film of maximum temperature around the shaft and the thickness of the film is very large as compared to the other thickness of the film that were observed at N= 1000, N=1500 and N=1750. This shows that as the rotational speed of the shaft increases, the temperature increases in the plain journal bearing and the heat should be dissipated form the shaft to the outside area.

Conclusions

The model of the couette stream can be utilized for the consider of the plain diary which comprises a turning component, shaft and the settled component, diary. Essentially, within the couette stream there are two parallel plates out of which one is moving and the other one is settled. The crevice between the diary and the shaft is exceptionally less and thus the ebb and flow impacts can be disregarded. Consequently, the plain diary bearing can be examined as a classical case of the Couette stream. The Thickness Index was found greatest for the ISO 32 among all the mineral oils which shows very less alter within the consistency with the increment within the temperature.

Among the all mineral oils (ISO 32, ISO 46, ISO 68 and ISO 100), warm flux within the show is most extreme for the ISO 32 at all the expressed rotational speeds. Subsequently, ISO 32 is demonstrated to be the ideal mineral oil among all the mineral oils and giving best comes about at each rotational speed of the shaft i.e. 1000 to 2000 rpm. For the further accuracy and real-life simulation, transient state also can be considered during the study with Non-Newtonian fluids. External environment effect and Vogel equation, Arrhenius equation etc. can also can be considered during the working of the plain journal bearing. In the present study, constant value of thermal conductivity and viscosity was assumed, however, both changes with the temperature. Therefore, varying viscosity and thermal conductivity also can be considered during the simulation.

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