Thermal Study of Floating Ring Bearing Sopported Rotors in Turbocharger

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***Abstract*—Present work focuses on computational modeling with coupled field analysis at the floating ring bearing supports for a turbocharger rotor system. Initially, the three-dimensional model of floating ring bearing is developed with important components. The floating ring consists of two fluid films namely inner and outer films, which are separated by the floating ring. Further, coupled field fluid dynamic study is conducted with consideration of fluid film and structural properties of ring, casing and journal. The pressure and temperature distributions in the floating ring bearing is obtained with appropriate boundary conditions. Further, the effect of the speed ratio on the pressure and temperature distribution is evaluated. The interaction between the solid and fluid domain are investigate at different rotor-ring speed ratios. The numerical data is considered from the references and ANSYS Fluent solver is adopted for solving the fluid dynamic equations.**

Keywords—Pressure distributiont; floating ring bearing; ANSYS, Turbocharger; Temperature distribution;

I. INTRODUCTION

A turbocharger works with the help of exhaust gas energy of a diesel engine so as to provide a pressurized air to the engine. Thus, it improves the engine power and reduces the exhaust gas emissions. Turbocharger rotors are high-speed shafts carrying compressor and turbine disks on either end and supported over the floating ring journal bearings. A turbocharger rotor commonly fails by several mechanisms including bearing wear and impeller-casing rub events etc. A reliable design of such rotor bearings is necessary to avoid the vibration-based failure incidents during its operation.

Several earlier works [1–3] focused on the dynamic behaviors of the turbocharger rotor-bearing system. It was found that the outer clearances of floating ring could significantly affect the two sub synchronous frequencies of the rotor. By increasing the feed pressure, the amplitudes in synchronous motions increase tremendously. Zhang et al. [4] explained the stability analysis of the turbocharger rotor supported on the floating ring bearings. Using a flexible multibody rotor /bearing system, numerical run-up simulation were compared with the corresponding experimental test rig measurements proposed by Schweizer [5] Simulation and experimental results show that first two rotor modes were excited in the examined turbocharger system. Qiao et al. [6]described a mathematical model to study the linear stability analysis of a tilting-pad journal bearing system. Some works [7-9] explained the nonlinear modeling of tilting pad journal bearing system based on Taylors series expansion of oil film forces.

The conventional floating ring bearing are having more advantage than the single film journal bearings. The maintenance and manufacturing cost is less for floating ring bearings. The rotating ring decreases the velocity gradient in between housing and shaft. This phenomenon increases the performance of bearing and reduces the frictional losses. The ring speed increases linearly with increasing of the shaft speed when floating ring bearing operates at lower speeds [10]. Hatakenaka and Yanani [11] explained that at lower pressure floating bearings the floating ring speed does not increase further, they illustrated that the speed ratio is less at low pressure floating ring bearings compared to typical oil pressure. San Andres and Kerth [12] explained the effect of temperature on the performance of the floating ring bearings for turbochargers. Porzig et al. [13] explained the influence of the temperature on the parameters of the full floating ring bearings. Song and Gu [14] described the three dimensional computational fluid dynamics (CFD) analysis of the journal bearing with three different cavitation models. They found that for prediction of bearing load and temperature the CFD model with conjugate heat transfer method gives better results compared to traditional Reynolds solution. Huang and Zhuang [15] investigated the cavitation mechanism and temperature influence of cavitation. They found that the temperature drop has been observed when cavitation occurs. Hatakenaka et al. [16] proposed a theoretical analysis of floating ring bush journal bearing with axial oil film rupture being considered. some earlier works [17–19] proposed the stability analysis of turbocharger rotor bearing system and influence of the temperature on the stability also discussed with numerical and experimental analysis. Kohl et al. [20] described the experimental and numerical analysis of an automotive turbocharger with transparent bearing section.

Most of the above works explained the effect of the temperature on journal bearings with a single fluid film. The effect of the temperature, fluid film viscosity and speed ratios on the bearings with two fluid films is still not clear. In the present work, the modelling and CFD analysis of a floating ring radial bearing system is considered. A three dimensional solid model is developed and analyzed using ANSYS software for CFD and static structural analysis. The pressure and temperature distribution in the floating ring bearing is solved with appropriate boundary conditions. Further, the effect of the speed ratio on the pressure and temperature distribution is evaluated. The interaction between the solid and fluid domain is investigated at different rotor-ring speed ratios. The remaining part of the paper organized as follows: section-2 explains the three dimensional modeling of floating ring bearing. Section-3 presents the numerical results and discussion. Conclusions and future scope of the work are presented in section-4.

II. THREE DIMENSIONAL MODEL OF BEARING SYSTEM

The floating ring bearing is one of the hydrodynamic bearing consists of two fluid films which are separated by the floating ring. The fluid dynamic equations describing the pressure and temperature distributions are respectively obtained from Reynold's momentum equation and energy equation given below.

$$\frac{\partial}{\partial x}\left(\frac{h^3}{12\mu}\frac{\partial P}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{h^3}{12\mu}\frac{\partial P}{\partial z}\right)=\frac{R_j\Omega_j+R_r\Omega_r}{2}\frac{\partial h}{\partial x}+\frac{\partial h}{\partial t} \quad (1)$$

The inner film, which lies in between the journal and floating ring whereas the outer film is in between the ring and casing of the bearing. The ring consist of the holes; through these holes, the fluid transfers in-between inner to outer films. *Fig. 1* shows the floating ring bearing structure. It is having two lubricated films and six holes on the ring [11]. Three-dimensional modeling of the floating ring bearing is developed by using Solidworks software.

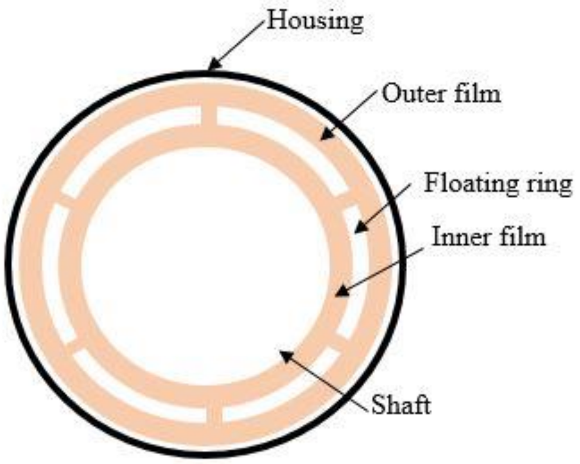


Fig. 1. Floating ring bearing structure

Table 1 shows the geometry of the floating ring bearing used.

TABLE I. GEOMETRY OF THE FLOATING RING BEARING [10]

Parameter	Value
Shaft diameter	11 mm
Ring outer diameter	17 mm
Inner clearance	0.08mm
Outer clearance	0.08mm
Ring width	8 mm
Number of holes on the ring	6
Supplied pressure	3 KPa

Fig. 2 shows the solid model of the floating ring bearing.

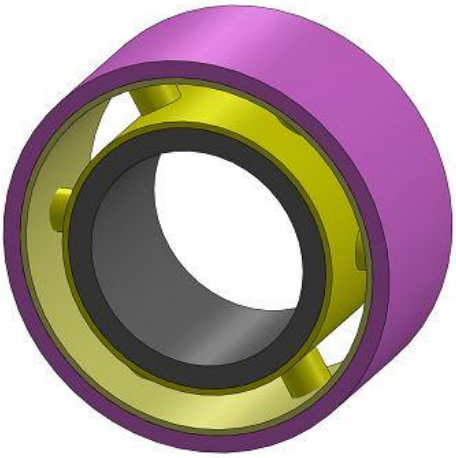


Fig 2. Solid model of the floating ring bearing.

The dynamic load of the rotor (shaft and disk) masses is not considered in the analysis. However, the effect of rotor spin speed and ring speeds on the pressure and temperature distributions are accounted through this model.

III. RESULTS AND DISCUSSION

Initially the three dimensional model of the finite element analysis of floating ring bearing is carried out using ANSYS software. The floating ring bearing consists of two fluid film domains. In this process, the fluid domain is divided in two parts namely inner oil film with ring holes and outer oil film. *Fig. 3* shows the fluid domain meshed model. In the simulation, the boundary conditions are same as that in previous literature [10]. The oil feed pressure and temperature are defined at the inlets as 3000 Pa and 40 ^{0}C respectively. The atmospheric pressure is given at the circumferential outlet for inner and outer oil films. Commercially available SAE 15 W-40 oil is used in the present analysis.

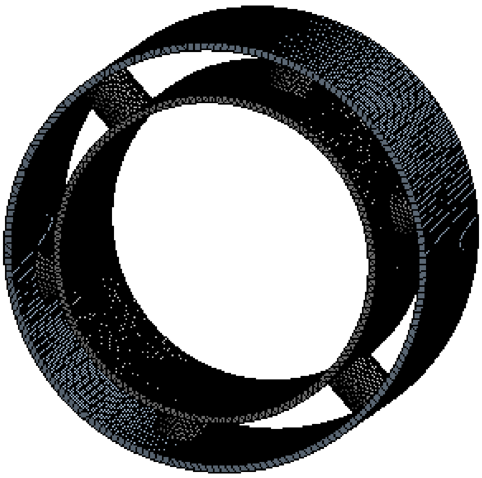


Fig. 3. Fluid domain mesh model

Fig. 4 shows the pressure distribution in the fluid domain.

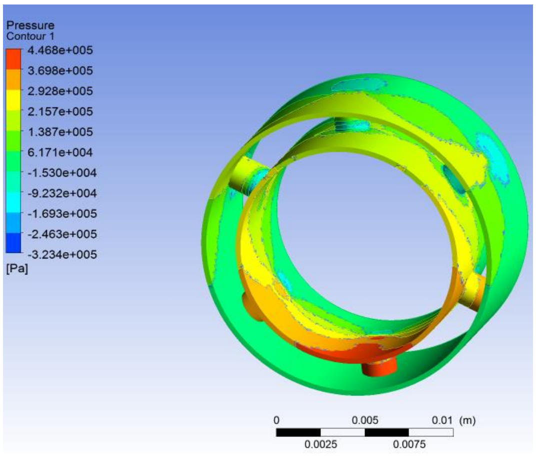


Fig. 4. Pressure distribution in entire domain

It is observed that the maximum pressure distribution occurs within the in oil holes connecting the inner and outer faces of the ring. *Fig. 5* shows the corresponding fluid film temperature contour at 30,000 rpm shaft speed

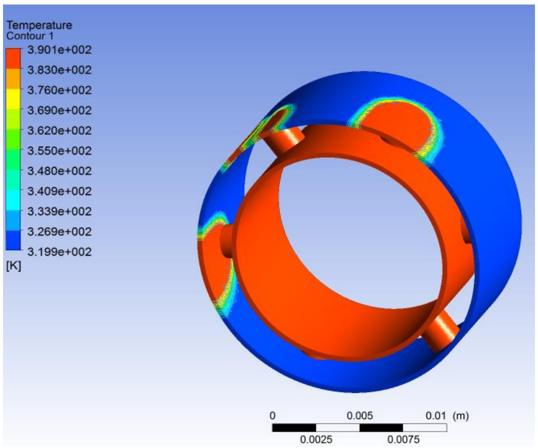


Fig. 5. Temperature distribution in entire domain.

It is observed that the temperature increase in the inner film is more than that of the outer film. The oil exchange between the films can be seen from the temperature distribution. The inner film is the source of high temperature lubricant. *Fig. 6* shows the enlarged view of the temperature distibution in the entire fluid domain.

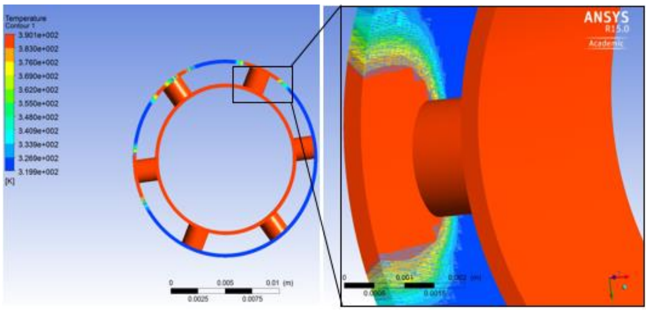
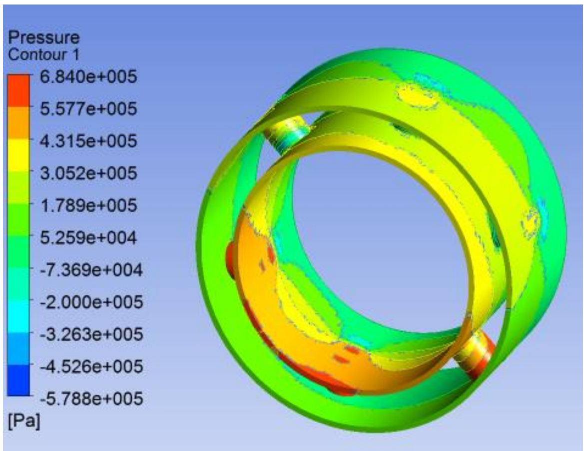


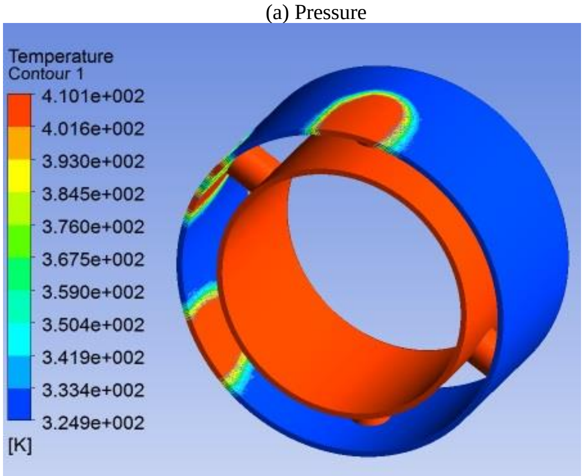
Fig. 6. Enlarged view of temperature distribution.

It is observed that the enlarged hole is the hole with a considerable amount of fluid flowing from inner film to outer film. The temperature is shown in colors. The major heat source is the inner film, and the rise of temperature in outer film due to friction can be neglected relative to the inner film; thus, the temperature increase in outer film is mainly caused by the flowing of the high temperature lubricant from inner film to the outer film. The viscous heating effect plays an important role in the floating ring bearings. *Fig. 7* show the pressure and temperature distribution at 40,000 rpm shaft speed.

It is observed that there is a significant change in the pressure and temperature distribution when the speed ratio changes. So the speed ratio influences the pressure and temperature distribution. Further static structural analysis is carried out to investigate the interaction between the fluid and solid domain in the floating ring bearing. *Fig. 8* shows the total displacement in the floating ring bearing.



(a) Pressure



(b) Temperature

Fig. 7. Pressure and temperature distribution

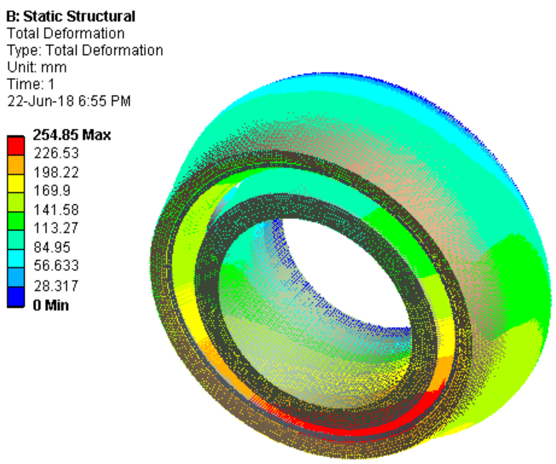


Fig. 8. Total deformation in floating ring bearing

It is observed that the interaction between the fluid domain and solid is clearly identified. The interaction between the inner film and ring as well as ring and outer film are also observed. The largest displacement is observed at the inner face of the ring because the heat transfer is taking place between inner film and outer film via ring holes. *Fig. 9* shows the equivalent stress distributions.

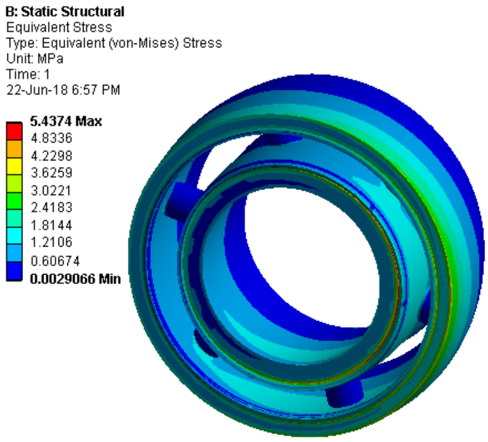


Fig. 9. Equivalent stress distribution

It is observed that the maximum stresses are well below the material strength.

IV. CONCLUSIONS

In this paper, the CFD analysis of the floating ring bearing used to support the turbocharger rotor system has been illustrated. The three-dimensional model of floating ring was analyzed in ANSYS workbench 15 software for CFD and static structural analysis. Further, the effect of the speed ratio on the pressure and temperature distribution was evaluated. The interaction between the solid and fluid domain are investigate at different rotor speed ratios. The conclusions from the work are summarized as follows.

- From pressure distribution, the low and high-pressure zones were identified. The pressure distribution in the inner and outer films were predicted.
- From temperature distribution, it was identified that the inner film was having more temperature compared to outer film due to the fluid flow taking place from inner film to outer film.
- It can be concluded that the effect of viscous heating plays an important role in floating ring bearings. the speed ratio also influence the pressure and temperature distribution
- Next, by considering the static structural analysis to know the interaction between the fluid domain and solid the displacement, stress plots were obtained. It can be concluded that the floating ring was having more displacement.

As a future scope of the present work, the thermal analysis of the entire turbocharger rotor bearing system may studied. An experimental work can be conducted with surrounding temperature effects to support the studies obtained in the present analysis.

ACKNOWLEDGMENT

The authors are grateful to the National Institute of Technology, Rourkela, Odisha, India for extending their facilities to carry out the research work.

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