Review on Hydrodynamic Analysis of Journal Bearing using Computational Fluid Dynamics

Dharani kumar S, , Kavya L, Arthur Adaikalaraj J, Ajay Richard J

Abstract: ***Hydrodynamic journal bearings are preferred in various industries and sectors due to its medium load application and cost. The total load of the shaft is handled by the bearing in the oil film layer which has a thickness of several microns. This produces a pressure that is distributed on the surface of the bearing and the load is bared without any metal to metal contact. Since the rotational velocity is high, the metal surfaces and lubricant get heated up which may produce cavitation effects due to wedging action. Ansys Fluent is used for solving numerical equations and the obtained value is imported to Static Structural for FSI approach. The approach of Computational Fluid Dynamics (CFD) is applied to infer Navier-Stokes equation to obtain the pressure distribution for the corresponding boundary conditions. Therefore, analyzing the bearing using hydrodynamic analysis method and obtaining the Fluid-Structure Interaction (FSI) model can unveil the deformation occurred in the bearing housing. Most of the analysis done has been performed with an assumption of steady-state flow condition. However, it is not applicable for validation purposes.***

Keywords: Boundary condition, Cavitation, Computational Fluid Dynamics, Fluid-Structure Interaction, Fluid structure interface, Pressure distribution, Turbulent effects.

I. INTRODUCTION

Journal bearings of hydrodynamic type are given due contemplation as it is a prominent member of various machinery that rotates. The purpose of hydrodynamic journal bearing is to support a load. The friction between relatively moving surfaces is to be decreased to achieve the purpose. A bearing of journal type comprises of a journal which is a circular shaft that rotates in a bearing which is a fixed sleeve [1]. The external load(W) is supported by the bearing and at the clearance(c) space, the existence of lubricant between the journal and the bearing as a thick film avoids the metal with the surface of the bearing and the rotating part of machinery [2]. With accession journal speed, more fluid is forced into clearance space that is wedge-shaped which begins to exert pressure [3]. Energy dissipation is required for the operation of any journal bearing. The determination of overall system characteristics is pretentious by several parameters especially thermal conditions and the material properties that depend on these thermal conditions [4].

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Mr.S.Dharani kumar M.E.,(PhD) Department of Mechanical Engineering in Sri Eshwar College of Engineering .

Ajay Richard J Department of Engineering in Sri Eshwar college of Engineering .

Arthur Adaikalaraj J Department of Engineering in Sri Eshwar college .

Kavya L Department of Engineering in Sri Eshwar college.

The bearing performance is feigned by rise in temperature. Considerable rise in temperature of the lubricant is caused due to high speed of rotation [2]. The oil film thickness becomes smallest(minimum), that is, the closest approach of the journal and the bearing, when the load is supported by enough pressure. If film thickness – minimum of the oil is extensive to the quantity liable on the characteristics of the deformities of the surfaces that are in contact, a condition of perfect lubrication will exist. The important contemplations in journal bearing lubrication is the distinction of oil film thickness that is minimum, the altitude angle (angle between the line of center with the vertical) and the maximum film pressure location [3]. Journal bearing's load carrying capacity is reliant on pressure in lubricant layer when the shaft rotates [5]. In recent trends, the researches cynosure on the internal combustion engine output which is to be maximized and their weights that is to be pared. Hence the main bearing's housing and the connecting rod big end bearing's housing are subjected to operating conditions that are severe [3]. There are substantial elastic deformations in the main bearing and the connecting rod causes bearing loads to increase leading to the impulsion to downscale the dimensions and component masses in modern combustion engines. The set-up and condition of the bearing gap to feed the lubrication, also influences the performance of the journal bearing. The placement of axial groove apposite to load line intervenes the thermal behavior and the hydro-dynamic pressure generation [6]. This may affect the properties of lubricating fluid which in turn affects the performance. The progress of computer technology has led to the use of commercial computational fluid dynamics (CFD) for solving complex equations [7]. The use of CFD codes with provide the results of flow equations by solving Navier-Stokes equations rather than Reynold's equation [8]. In the thermo hydrodynamic analysis, the temperature variations in the lubricant was found by solving energy equations that are two-dimensional and the pressure variation was found by solving Reynolds equation(two-dimensional) by forsaking the film thickness variations, can now be done by using energy equations that are three-dimensional to anticipate the fluid film's the temperature distribution in CFD software [7]. The increase in the journal speed during the rotation of the journal inside the bearing, forces the fluid into the wedge-shaped region. Therefore, it is likely to investigate the lubricant's fluid film with the forte of commercial CFD code amalgamating the FSI.

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The use of CFD with laminar flow regime for the operation of full journal bearing with various L/D ratios would give the pressure field of journal bearing(full) [9]. The denouement obtained are validated and analyzed

A. Nomenclature:

S.no	Notation	Parameter	Unit
1	D	Journal diameter	m
2	Db	Bearing diameter	m
3	C	Clearance	m
4	h min	Film thickness - Minimum	Micrometer
5	h max	Film thickness - Maximum	Micrometer
6	Vm	Peripheral velocity of journal	m/s
7	L	Length of the Journal	m
8	Ƞ	Viscosity of the oil	Pa-s
9	N	Speed of the journal	rpm
10	ϵ	Eccentricity ratio	No unit
11	ϕ	Altitude angle	°
12	W	Safe working load	N
13	ΔT	Temperature rise	°C
14	ψ	Relative clearance	No unit

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II. LITERATURE SURVEY

The study of various works done earlier shows the following analytic and numerical techniques. The three-dimensional computational fluid dynamic analysis is used to derive hydrodynamic journal bearing’s (lubricated with a Bingham fluid) characteristic performance with the help of dynamic mesh technique. Design parameters that are considered for analysis are eccentricity preferably relative, and the two dimensionless parameters - load carrying capacity and wall shear stress, Sommerfeld number, strain rate, pressure distribution, temperature distribution, friction coefficient, Reynolds number, and flow properties of lubricant like viscosity(turbulent), and velocity magnitude. This analysis lead to charts that help in smart analysis [10]. A new transient analysis method was applied rather than the conventional method for the delve of fluid-structure interaction in the rotor bearing system using the combination of CFD and FSI. Cavitation and thermal influence are studied on the actual physical model. The grooves of different types on the rotor bearing were studied and the theoretical and experimental results were matched [11]. For the load and operating speed of the journal bearing the solution of eccentricity and altitude angle is obtained by optimization using the design optimization module. ANSYS Workbench was used to carry out the simulations with consideration of realistic bearing deformation along with cavitation. The magnitude of pressure built in the bearing becomes lower due to increase in shaft speed and risen oil vapor distribution is found. The numerical evaluation of bearing deformation shows that with the increase in shaft speed, there is an increase of the deformation [12]. The elasto-hydrodynamic lubrication of a full journal bearing is simulated and modelled using CFD and CSD with a sequential application. Using various L/D ratios in CFD, under laminar flow a full journal bearing’s pressure field is obtained. The pressure force that is obtained from the deformation and distribution of stress on the bearing liner are evaluated using Finite Element Method by satisfying the boundary conditions. The critical points are indicated by the stress distribution in the bearing structure [9]. Further studies indicated the importance of partial groove in the bearing. The pressure distribution on the lining is split up by the grooves. Therefore, the wear is depleted on the area of the groove. The use of groove increases the amount of lubricating oil contained between the journal and the bearing which drops the possibility of metal-to-metal contact [13]. Then assumptions that Reynolds equation fails to hold for computing performance predictions were overcame using the CFD techniques. The shaft length is usually longer than that of the bearing. When cavitation effects are studied, constant wall temperature cannot be applied. The vapor pressure at various temperatures of the corresponding liquid is used to obtain the values for cavitation. Cavitation is the direct cause of change in pressure, which is caused by temperature and density changes [14]. In the lubricant oil film, there is a high temperature rise due to the heavy loads that affects the performance of journal bearing. Thermo-hydrodynamic analysis is done to obtain the realistic performance parameters. The parameters along the profile of the journal bearing like pressure and temperature of the lubricant is predicted using the CFD approach that solves the Navier-Stokes equation that is three-dimensional [2]. The structural deformations and the hydrodynamic pressures where estimated and computed using structural module and CFD respectively. In-built transfer interface in the software were used to transfer the displacement and the fluid pressure forces. Response Surface Optimization in Central Composite Method using DOE was carried out for the journal bearing position [15]

III. ANALYSIS

The observation of various methods of analysis made from different analysis approach is described. The journal is in equilibrium when the applied load W is external. The pressure of the lubricant in the clearance acts upon it as it rotates with an angular velocity. The film thickness varies from its maximum value to minimum value at the bearing angle range of 0 to 180. The thickness is maximum when bearing angle is 0 and the film thickness is minimum when the bearing angle is 180. The shear stress and shear rate relation of lubrication is achieved with a few assumptions as an isothermal operation at steady state where the flow considered to be laminar and solved using conservations equations for laminar flow [10]. The performance of fluid domain is proclaimed using energy conservations, continuity and full Navier-Stokes equations for incompressible continuous isoviscous fluids.

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In the fluid domain, the cavitation was modelled with phase change boundary condition [11]. Bearing deformations becomes higher with the increment in speed which leads to the change of fluid film sway in the bearing and hence the geometry is remodeled dynamically. A fraction of oil vaporizes due to increase in speed. The flow becomes two-phase. In plain journal bearing lower pressure is built up with cavitation due to the wide distribution of vapor. The solution to three dimensional Navier-Stokes and momentum equations gives the pressure distribution in journal bearing of hydrodynamic type. The mass and momentum is obtained for all types of flow in FLUENT by solving these equations [12]. In Fluid Structure Interaction the initial fluid flow is altered as the solid structure deforms due to the pressure exerted by the fluid flow. The boundary condition of the fluid flow changes due to deformation of the solid structure [9]. The approach of analysis flexible modelling approach in numerical CFD is used. A complete analysis of the journal bearing behavior is done with consideration of rotational effects. The procedure used is general transport equation formulation [14]. Thermo hydrodynamic analysis is the simultaneous solution of equations for lubricant, bearing, shaft. CFD codes are used to provide solution to flow issues by full Naiver – Stokes equation, an alternative to Reynold's equation. Temperature distribution is foretold by the solution of three-dimensional energy equation instead of conventional two-dimensional equations. The pressure and velocity of the fluid is computed using conservation equation of mass and momentum. Along or from the fluid to bearing surface either the heat transfer or temperature is computed and solution is obtained using equation of energy[2]. The equations that are most commonly used are mentioned below.

Mass conservation equation:

$$\frac{\partial P}{\partial t} + \nabla\left(\rho\overrightarrow{v}\right) = 0$$

Momentum Conservation equation:

$$\frac{\partial}{\partial t}\left(\rho\vec{v}\right) + \nabla\left(\rho\vec{v}\vec{v}\right) = -\nabla p + \rho\vec{g} + \overrightarrow{F}$$

Steady state, incompressible flow equation:

$$\frac{\partial}{\partial t}\left(\rho C_p T\right) + \nabla\left(\rho\vec{v}C_p T\right) =$$
$$\nabla(K.\ \nabla T) + Q_v$$

Pressure and Temperature variation on lubricant viscosity:

$$\mu = \mu_0\, e^{\alpha(P-P_0)} e^{-\beta(T-T_0)}$$

IV. MODELLING

The different modelling methods based on the analysis methods are explored. The problem of small clearance value compared to journal diameter was examined with the CFD model by using hexahedral cells. The divisions used for analysis are 8 for journal-bearing film, 360 for circumferential direction and 25 for axial direction with 72000 number of cells [10]. Three dimensional numerical models were analyzed. Two pairs of fluid structure interface were used to hitch the lubricant with the journal and bearing which are taken as the fluid domain and solid domain (two domains). For the fluid domain different mesh numbers, here eight, were chosen from 15k to 30 k. And the mesh number total was 53k for both domains together [11]. The numerical model is presumed to be in steady state and the laminar flow with isothermal condition is assumed as the Reynolds number is low. Design explorer approach is used. In CFD modelling the lubricant was meshed using hexahedral elements in six layers in radial direction and the journal and the bearing (solid domain) was meshed as tetrahedral element s [12]. In FSI coupled field analysis is used to yield significant structural deflections. The structure and the fluid flow are evolved as coupled system in every computational step of CFD. The entire model is analyzed with some nodes and elements [9]. The continuity equation for momentum and transforming equations are untangled to acquire the numerical CFD results. Near the journal and bearing surfaces, the control volume width is reduced radially to obtain increased resolution of thermal boundary conditions and velocity[14]. Laminar flow is assumed. The bearing shell is analyzed with stationary wall condition. The journal is analyzed with moving wall condition at a specified rotational speed. Eccentricity value is taken as rotational axis origin[2]..

V. RESULTS AND INFERENCE

The analysis and the corresponding modelling methods provided the following results that are inferred by contrast and validation as annotated. With comparison and scrutiny of different fluids, it was found that the Bingham fluids have larger load carrying capacity, frictional force than Newtonian fluids. By varying the electric and magnetic fields in the fluid film the yield stress increases [10]. With the increase in external exerted load, there was a decrement in the film thickness- minimum, which in turn increased the eccentricity. It is also found that there is an increase in temperature rise with increasing load[11]. This is the study of hydrodynamic journal bearing with multiphase flow. The increase in eccentricity ratio and speed increases the peak pressure. It was found that the eccentricity ratio change is more sensitive. At lower eccentricity ratio values the hydrodynamic force developed is insufficient to support the external load and thus the pressure distribution is high at these values. It is necessary to consider the increased bearing deformation with speed and increased significant hydrodynamic pressure forces at higher speed to anticipate the precise bearing performance characteristics.[12]. In FSI, the influence of eccentricity ratio on pressure is greater than the L/D ratios. There is a predominant increase in displacement vector of bearing when the eccentricity ratio increases [9]. The interaction that occurs thermally between the shaft and lubricant is obtained by flexible modelling approach and accurate modelling of backflow is possible. The shaft does not circumambulate the bearing in steady flow validation of this model approach. The temperature is localized on the surface of the shaft and it does not affect the performance characteristics of the bearing due to fixed shaft position. Under unsteady flow temperature differentials on shaft can be used to forecast cavitation [14].

The maximum pressure obtained is high and the rise of temperature in the lubricant is elevated if the viscosity is constant. But practically, the rise in temperature decreases the viscosity which in turn influences the capacity of load carrying, reducing the life of the journal bearing. Thus, the prediction of performance of the bearing is wrong when there is constant viscosity [2].

VI. CONCLUSION

The conclusion drawn from the investigation of hydrodynamic analysis of journal bearing are elucidated. The sensitivity of eccentricity ratio is higher on the journal bearing. The pressure distribution on the bearing shell is higher when the eccentricity value is low, due to insufficient hydrodynamic force. The rotating velocity and external load decide the total pressure on the bearing housing. A favorable oil film thickness layer should be maintained in order to obtain an opposing oil film pressure to support the load. Moreover, the analysis should be performed under transient condition including thermal and turbulent effects. Thermo-hydrodynamic analysis is done to consider the change in viscosity of lubricant and the softening of the material at high temperatures. The use of accurate cavitation model may produce more accurate real-time results. Considering values obtained from steady-state equations are not suitable for validation.

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AUTHORS PROFILE

Mr.S.Dharani kumar M.E.,(PhD) working as Assistant Professor Department of Mechanical Engineering in Sri Eshwar College of Engineering obtained BE (Mechanical Engineering) in 2012 with First class with Distinction, CSI college of Engineering , Ooty . I got PG degree under specialization of CAD/CAM from Dr.Mahalingam College of Engineering. I received gold medal for my academic performance during the year of 2013-15. Also received best outgoing student during my PG. I have published 6 papers in Scopus indexed journal.

Ajay Richard J pursuing bachelor's degree in Sri Eshwar college of Engineering has strong academic background with practical experience through internship, has won many awards for the project works and guiding my juniors and fellow-mates about technology, Vision and Growth through Coders Club and Product Development Clubs.

Arthur Adaikalaraj J pursuing bachelor's degree in Sri Eshwar college of engineering is well equipped with technical skills and good theoretical knowledge in Strength of Materials and is currently focusing on the application side of Computational Fluid Dynamics.

Kavya L pursuing bachelor's degree in Sri Eshwar college of engineering has an excellent academic record and exhibits masterful management skills. She's currently on to Newtonian Fluid Mechanics and Thermodynamics.