A REVIEW ON TURBULENT FLOW ANALYSIS IN THE JOURNAL BEARING AND ITS APPLICATION ON A SIMPLIFIED THD MODEL

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SUMMARY
Turbulence is an irregular fluid motion in which the various flow properties such as velocity and pressure show random variations with time and position. Certain assumptions concerning the character of the flow were made in order to solve the turbulence problem. The theoretical treatment of turbulent flow in fluid film bearing was first attempted by Wilcock in 1950 and then by Constantinescu in 1959. A number of authors proposed different solutions e.g. for pressure distribution, temperature prediction and THD analyses. In the present paper authors developed an empirical relation to determine the viscous sublayer decreases exponentially with increase in Reynolds number. The simplified model decouples the Reynolds and energy equation. Incorporating the supply pressure, recirculation and mixing of fluid at the inlet and assigning the parabolic distribution across film at the inlet boundary lead to a more realistic situation. The predicted results are compared with the experiments.

Keywords: Journal, Bearing, Turbulence, Thermohydrodynamic, Cavitation.

1 INTRODUCTION
Turbulence is an irregular fluid motion in which the various flow properties such as velocity and pressure show random variations with time and position. Because of this randomness the instantaneous value of flow properties has little practical significant and it is the average value of properties that is of interest. In turbulence the number of equations in the system available to characterize mean flow remains the same as the laminar. However, the additional unknown term, Reynolds shear stress, contributed due to mean flow and the turbulent fluctuations makes it difficult to solve purely on theoretical grounds. Thus certain assumptions concerning the character of the flow and an experimental data are essential to solve the turbulence problem.

2 THEORETICAL APPROACHES
In turbulent flow the fluid layer exhibits regular intermixing with each other. In 1904 Prandtl introduced the mixing length theory for the case of thin layer viscous fluid. He demonstrated that a thin layer of fluid exist in the vicinity of solid surface whose velocity is zero at the surface and increases to full stream velocity value at a distance normal to the surface. This retarded layer is called boundary layer. So two distinct region of fluid flow are setup in fluid layer. One where frictional effect is considered and the other layer beyond the boundary layer where shearing stress is small enough to be neglected in mathematical treatment. In the boundary layer the velocity gradient is very large and even the low viscosity of some fluids may make the shear stress appreciably large enough. In last four decades turbulent operation of fluid film bearing has received attention of researchers due to over increasing speed of rotating machinery and the use of low viscous lubricant.

The theoretical treatment of turbulent flow in fluid film bearing was first attempted by Wilcock [1] in 1950 and then by Constantinescu [2] in 1959, who used mixing length theory of Prandtl. Constantinescu assume that the mean fluid inertia stresses are negligible compared to fluctuating inertia forces, know as turbulent stresses. However, at low Reynolds number this argument may not stand because, mean fluid inertia forces may be of the same order as viscous forces. Following Prandtl’s mixing length theory, Constantinescu decoupled the different equation, which can lead to velocity expression for journal bearing. He presented the analytical expression for pressure for turbulent condition. Ng and Pan [3] in 1965 and Elrod and Ng [4] used the concept of eddy or turbulent viscosity which is a functional of the Reynolds number \( R_e = \rho \omega C / \eta \) rather than the molecular viscosity of the lubricant, to represent the turbulent stresses in terms of mean velocity gradient. They proposed a turbulent theory considering the eddy viscosity variation using Reichardt’s formula. This theory is more accurate in predicting the bearing performance for the isoviscous case. The similarity between the approaches followed by Constantinescu 1959 [5] and Ng-Pan-Elrod 1965 is that all of them consider strong Couette flow in pressure and cavitation zones of the journal bearing. Hirs 1974 [7] expressed the view that due availability of only limited experimental data, the range of applicability of theories due to Constantinescu and Ng-Pan-Elrod is uncertain. Hirs observed that for both pressure flow and Couette flow, in the turbulent condition the wall shear stress is dependent on density, viscosity and mean flow velocity. Using the shear stress equation Hirs was able to present equations for shear and pressure flow rate. Taylor and Dowson 1974 [8] document the approaches of Constantinescu, Ng-Pan-Elrod and Hirs in a simplified manner for the ease of...
designers. They point out that the approach of Ng-Pan-Elrod is more promising than that of Constantinescu. They also state that at high Reynolds number and at the transition region between laminar and fully developed turbulent flow, the application of the theories by Ng-Pan-Elrod or Constantinescu would not yield precise results. In such cases Hirs approach may be more suitable and it agrees with the experimental findings. For the values of the Reynolds number \( R_e = \frac{\rho R_0 \omega C}{\eta} \) i.e. between 2000 to 10000, the theories proposed by Constantinescu, Ng-Pan-Elrod and Hirs predict nearly same performance characteristics.

The temperature prediction across and along the film was carried out by Constantinescu 1973 [9] for turbulent fluid in a journal bearing. He used empirical constants to modify the pressure and viscous shear terms due to inertia effects, for a specified range of the Reynolds number. He states that in a high speed bearing a considerable amount of heat is produced in the film and thus temperature rise may exist along the surface and across the film thickness. In turbulent flow the eddy viscosity and Prandtl number appear in the energy equation as a product in the condition term across the film thickness. This causes difficulty in the solution of the energy equation, which he overcame by assuming an average eddy viscosity, and determined the mean temperature in the film.

Safar and Szeri 1974 [10] have used Reichardt’s viscosity expression and iterated the pressure and viscosity equation until the convergence on shear stress is achieved. This approach is very accurate but very fine grid for the finite difference formulation, depending on the values of Reynolds number and eccentricity ratio. Therefore, they have presented results only for a few eccentricity values. They reported that for the case of low eccentricity ratio the predicted temperature in the cavitation zone does not agree with the experimental findings. They also reported that the inclusion of the cross heat transfer through conduction in the energy equation causes numerical instability in the computation, when the value of eccentricity ratio exceeds 0.5. Suganami and Szeri 1979 [11] extended the work of Safar and Szeri by incorporating the additional term of heat conduction along the circumference. This is more effective when the reserve flow also exists.

The THD analyses presented by Constantinescu 1973 [12], Safar and Szeri 1974 [10] and Suganami and Szeri 1979 [11] consider the viscosity variation due to temperature in the fluid, but the effect of recirculation and mixing of lubricant at the supply groove is not dealt with. Cowking 1985 [12] reported that when recalculation and mixing of lubricant at supply groove are taken into account in the energy equation, the predicted temperature distribution agrees with the experimental findings. He also reported that the temperature variation in the lubricant film under turbulent flow is small compared to the laminar flow. This is mainly because of the high eddy diffusivity of heat in the turbulent film.

Hashimoto et al. 1984 [13] presented a simplified analytical model to predict the average film temperature distribution along the circumference. They used the concept proposed by Constantinescu 1974 [9] to modify the pressure and viscous shear terms. Neglecting the cross heat transfer through conduction simplifies the energy equation and does not pose any difficulty in obtaining the numerical solution. Ignoring the pressure induced flow in calculating viscous shear and heat transfer, permits the decoupling of the Reynolds and energy equation, similar to the approach due to McCallion et al. 1970 [14] for laminar flow. Since the major portion of the heat diffuses across film due to intermixing of lubricant molecules their overestimates the temperature in the lubricant film.

There is not much experimental work on temperature profile in a journal bearing under turbulent flow reported in literature. Gardner Ulschmid 1974 [15] and Cowking 1981 [12] presented the temperature distribution in a journal bearing. In both the studies the value of Reynolds number does not exceed 2000. This value of Reynolds indicates the transition from laminar to turbulent flow. Hence it is difficult to compare the turbulent flow model with their experimental results.

3 IMPROVED MODEL

In the present paper authors developed an empirical relation to determine the viscous sublayer decreases exponentially with increase in Reynolds number. For theoretical analysis viscous layer is treated by using the molecular viscosity of the fluid and turbulent core is treated by an average eddy viscosity based on Constantinescu is [9] empirical relationship. The effect of pressure induced flow on temperature is assumed to be small and therefore ignored. The energy equation in cavitation zone is treated by considering and empirical constant for heat dissipation through conduction and convection and the viscous heat generation is neglected [16, 17]. Thus the simplified model decouples the Reynolds and energy equation. Incorporating the supply pressure, recirculation and mixing of fluid at the inlet and assigning the parabolic distribution across film at the inlet boundary lead to a more realistic situation. The predicted results are compared with the experiments.

4 REFERENCES


