MESH INDEPENDENCE AND CONVERGENCE TEST IN THE OIL FILM CHARACTERISTICS OF A TILTING PAD THRUST BEARING

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Abstract: The objective of this paper is to carry out a mesh independence study and ensure the validity of the load and centre of pressure location for a Tilting Pad Thrust Bearing. The computation is done by numerically solving the two dimensional Reynolds' equation at different nodes of the oil film using a finite difference procedure. It is ensured that the solution satisfies: (a) load obtained by integrating pressure values is within ± 5%. (b) radial and angular coordinates of centre of pressure viz. R_{cp} and θ_{cp} lie within ± 3%, and (c) convergence satisfies the ± 1% criteria. The aim is to have simulated output values of integrated load, R_{cp} and θ_{cp} converge to steady specified values corresponding to a pressure distribution with maximum nodal pressure of 4.5 MPa. Finally it is to be ensured that overall domain imbalance is less than 1% for all variables. The approach outlined above results in a unique solution for the given mesh that we have used. Although the solution satisfies the convergence based on load and centre of pressure location values, it has to be made sure that the solution is also independent of the mesh resolution. This check is carried out once to determine right sizing & eliminates erroneous results. This analysis improves the validity of the results.

K**eywords**: Load, pressure, convergence, mesh independence

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1. INTRODUCTION

A thrust bearing is the main component of a hydroelectric installation. The weight of the hydraulic turbine, generator components and the thrust load are all borne by the thrust bearing. The hydroelectric generator rotor moves with low friction and negligible wear. A large sector pad thrust bearing with an outer diameter of over 1 m, provides an important feature. Continuous fluid films are developed over the pad surface. The bearing pads are supported by a pivot or a distributed spring mattress. The support arrangements allow the bearing pad to tilt and produce a favorable geometry for the fluid film formation. Tilting-pad thrust bearings unlike fixed geometry bearings have the ability to self-adjust the tilt to accommodate varying operating conditions. In equalizing tilting pad thrust bearings the thrust-load distribution over the pads is permitted. In this

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paper the importance of using numerical methods and digital computers in developing mathematical methods for any practical problem are discussed. Numerical methods are powerful and versatile because they use algebraic equations in the place of differential equations. In this chapter, the finite difference method used for solving the formulated two dimensional Reynolds' equation for the pressure is described. Integration of the nodal pressure values help in the computation of load.

Hydrodynamic principles were used in the design of tilting pad bearings utilized in mechanisms carrying shaft thrust or radial loads. Optimized pivot positions in the radial and circumferential directions of tilting pad thrust and radial bearings were derived by Ni et al [1]. Hsia- Ming Chu [2] used an inverse method to develop an algorithm for designing the optimum shape and pressure distribution of a slider bearing. The algorithm was developed from the Reynolds' integral, force and moment equations. The load and moment conditions were obtained by the algorithm in order to simultaneously estimate the slider bearing shape and pressure distribution.

2. REYNOLDS' EQUATION

The analysis of hydrodynamic thrust bearings for pressure distribution is based on the Reynolds' equation [3]. With the increasing capacity of computers, numerical models including the pad deformation and influences of viscosity variations along and across the lubricant film have been developed. This is derived through an order of dimension analysis from the Navier-Stokes equations. The lowest order terms are retained and introduced in the continuity equation which is then integrated across the fluid film to give the Reynolds' equation. This was first shown by Reynolds' for a fluid with constant properties. Various researchers have since extended the equation along or across the fluid film to include compressibility and variations in fluid properties. Dowson [4] introduced a general extension of the equation to include varying fluid properties both along and across the fluid film [7-10]. The two dimensional equation Reynolds equation is obtained as follows.

$$\frac{\partial^2}{\partial R^2}\left[\frac{RH^3P}{\bar{\mu}}\right]+\frac{RH^3}{\bar{\mu}}\frac{\partial^2 P}{\partial R^2}-P\frac{\partial^2}{\partial R^2}\left[\frac{RH^3}{\bar{\mu}}\right]+\frac{1}{R\beta^2}\frac{\partial^2}{\partial\theta^2}\left[\frac{H^3P}{\bar{\mu}}\right]$$
$$+\frac{1}{R\beta^2}\frac{H^3}{\bar{\mu}}\frac{\partial^2 p}{\partial\bar{\theta}^2}-\frac{P}{R\beta^2}\frac{\partial^2}{\partial\bar{\theta}^2}\left[\frac{H^3}{\bar{\mu}}\right]=12R\frac{\partial H}{\partial\theta}+24R\beta\frac{\partial H}{\partial\bar{t}} \qquad (1)$$

3. COMPUTATIONAL PROCEDURE

Solution of Reynold's equation using FDM discretization of thrust pad is done by considering a total of 81 nodes in the form of a grid. The Reynold's equation is a non-homogeneous partial differential equation of two variables for which closed form analytical solutions are not available. The use of finite difference methods for a numerical approximation of this type of partial differential equation was discussed in Capitao [5].

The Finite difference equation is derived by approximating the derivatives in the differential equation via the truncated Taylor series expansion for three successive grid points. The central difference form where in the values of the function at adjacent nodes on either side are required to evaluate the derivatives is used .Writing the Reynold's equation in the above finite difference form results in a set of linear algebraic equations which can be transformed into matrix form and solved simultaneously by available subroutines. This yields the non-dimensional pressure at each node. The computational procedure uses these calculated pressures along with numerical methods for integration to obtain the load capacity, radial and angular location of centre of pressure. To ensure numerical accuracy the pressure distribution satisfied the 0.1 percent convergence limit.

4. RESULTS AND DISCUSSIONS

The mesh independence and convergence test is done taking into consideration the values of load, R_{cp} and θ_{cp} for three different mesh models. The mesh independence study is straight forward and done as follows:

1. The initial simulation is run with 11 × 11 nodal mesh as in figure 1 and the load, R_{cp} and θ_{cp} values are found to be $2.037e^6$, 1.0571 m and 0.2625 radians. The corresponding pressure distribution is given in figure 2.

2. As the above values in step 1 have not converged to required ones, we refine the mesh taking a 10 × 10 nodal matrix as in figure 3. The values obtained for load, R_{cp} and θ_{cp} are 2.0957e6, 1.0565m and 0.2603 radians. The corresponding pressure distribution is shown in figure 4.

3. These are not the same as obtained for the 11× 11 mesh and have also not converged to our prescribed values. This shows that the solution is changing because of the mesh resolution and hence it is not yet independent of the mesh. The mesh is refined further to a 9 × 9 nodal matrix as in figure 5. which yields values of load, R_{cp} and θ_{cp} of $2.1663e^6$, 1.0557 m and 0.2575 radians. These converge within ± 1% of our earlier prescribed values for 4.5 MPa maximum nodal pressure distribution shown in figure 6. This gives the mesh independent solution and is obtained by using the smallest mesh that reduces the simulation time.

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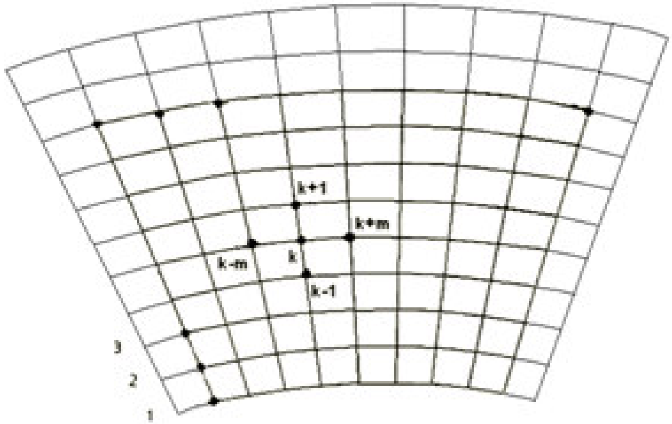

Figure 1: Discretization of pad for Reynold's equation 11× 11 matrix

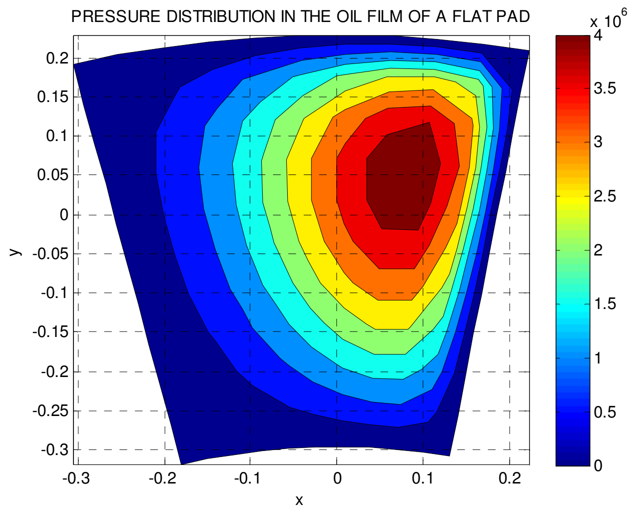

Figure 2: Pressure distribution for 11 × 11 nodal matrix mesh

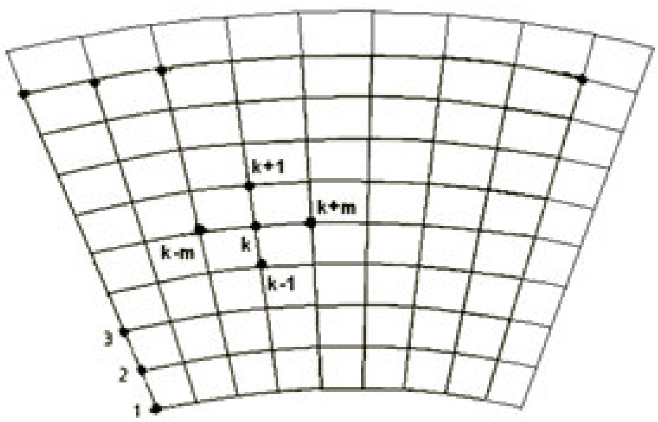

Figure 3: Discretization of pad for Reynold's equation 10× 10 matrix

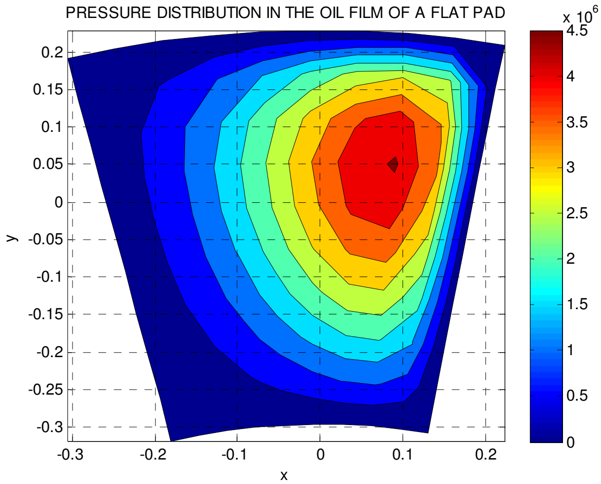

Figure 4: Pressure distribution for 10 × 10 nodal matrix mesh

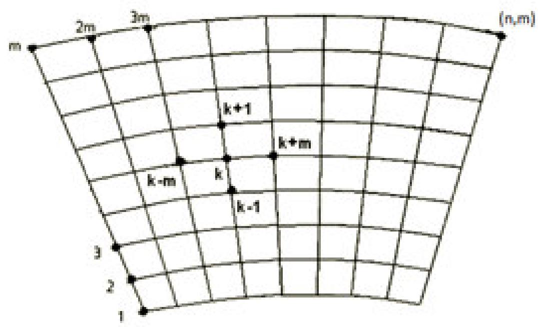

Figure 5: Discretization of pad for Reynold's equation 9× 9 matrix

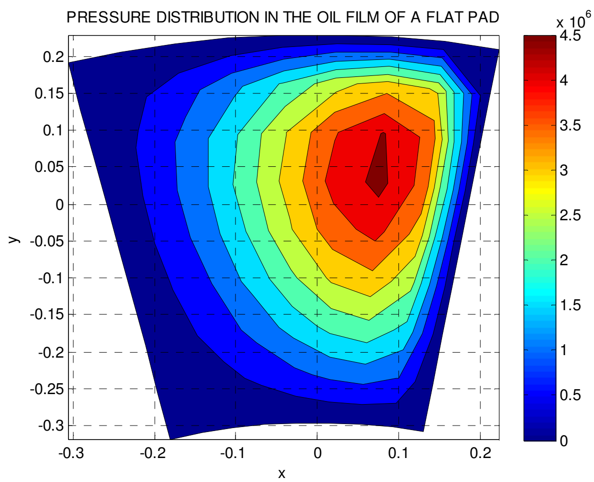

Figure 6: Pressure distribution for 9 × 9 nodal matrix mesh5.

5. CONCLUSION

For a given mesh the convergence ensured that the simulation values of interest viz. steady pressure that were monitored matched the values that were set prior to starting the simulation. In addition the mesh independence test ensured that the results obtained are due to the boundary conditions and physics used and not the mesh resolution. The mesh independent solution corresponds to the smallest mesh size with 81 nodes and that which reduces simulation run time. This confidently proves the validity of our results and theoretical model.

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