EFFECTS OF GROOVING IN A CIRCULAR STEP THRUST BEARING
M. Mahbub Razzaque and M. Zakir Hossain
Department of Mechanical Engineering
Bangladesh University of Engineering & Technology
Dhaka-1000, Bangladesh

ABSTRACT
Assuming narrow grooves and considering inertia effect, an equation for the pressure distribution in a grooved circular step thrust bearing has been derived. A parametric study has been performed to investigate the effects of step and groove geometry on pressure distribution, load capacity and lubricant flow rate. Three arrangements of the bearing surface have been studied and it has been found that the maximum load capacity is obtained by putting grooves only on the step. Inertia significantly affects the load capacity. To get increased load capacity with increase of inertia, the step inner radius should be larger than 0.45 times of the outer radius. For the most enhancement of hydrodynamic load, the groove inclination angle should be 135° with the direction of rotation and the depth should be twice the minimum film thickness.

INTRODUCTION
In high load applications, hydrostatic circular step thrust bearings are often preferred. Though a number of studies have been performed in the seventies to investigate the effects of grooves in various types of bearings, seals and clutches, none of them considered how grooves might modify the load capacity of a circular step thrust bearing. This paper looks into the effect of grooves on the surface of a hydrostatic circular step thrust bearing as shown in Fig. 1.

MODELING
The thrust bearing under consideration has a circular step of outer radius \( r_o \) and inner radius \( r_i \). A shaft having a flat circular end and rotating at a constant speed, \( \Omega \) rad/s is supported by pressurized fluid supplied at pressure \( p_s \) to the gap through a concentric hole of radius \( r_h \). The minimum film thickness over the annular region of the step (i.e. for \( r_l < r < r_o \)) is \( h_l \) and that over the annular region of the recess (i.e. for \( r_s < r < r_l \)) is \( h_r \), where \( c > 1 \). Three arrangements of the bearing surface have been studied: (a) only the step is grooved, (b) only the recess is grooved and (c) both the step and the recess are grooved.

Starting from the equations of motion and the equation of continuity and assuming that the grooves are extremely narrow, the governing equations are established and solved to obtain the average pressure distribution through a procedure described in Razzaque and Kato [1,2] for squeeze film problems. Among the inertia forces, only the centrifugal force is considered. Load capacity, flow-rate, viscous torque and power loss are consequently obtained from the pressure distribution. Neglecting grooving effects, these equations can be reduced to the analytical results for nongrooved circular step thrust bearings, derived by Dowson [3].

RESULTS AND DISCUSSION
The derived equations are tedious but simple, containing mostly the dimensions of grooves and the bearing as shown in Eq. (1).

\[
\frac{L}{m_s p_s} = -\frac{1}{2} \left[ G + S \left( 1 - R_s^2 \right) \left( 1 + R_i^2 + G + \frac{1}{Re_s} - \frac{1}{Re_o} \right) \right] \approx 1 - \frac{1}{Re_s} - \frac{1}{Re_o} \quad (1)
\]

Where, \( G = \frac{R_r^2}{R_s^2} - \frac{R_i^2}{R_s^2} + K \left( 1 - R_i^2 \right) \left( \ln R_i - \ln R_s \right) \), where the function of groove geometry, \( L \) is load and \( R_s \) and \( R_i \) are, respectively, dimensionless step and supply hole radii.

Parameter \( S \), defined as \( (3/20) \rho \Omega r_h^2 / p_s \), represents the ratio of dynamic pressure to the reference pressure. It depends on the centrifugal force acting on the fluid and, therefore, is termed as inertia parameter. The remaining parameter \( Re_s \) is a modified Reynolds number defined as \( \rho \Omega h_l^2 / \mu \), where the minimum film thickness, \( h_l \) is used as the characteristic length. The magnitude of inertia parameter \( S \) may be as high as 2 at a moderate speed of 3600 rpm if a lubricating oil of density 800 kg/m³ is pumped at a pressure of 1.2 atm's into a circular step thrust bearing of outer radius 0.30 m.

Figure 2 shows the radial pressure distribution for the three arrangements of groove and two geometries of the step, namely \( (r_s-r_t) / r_0 = 0.3 \) and 0.5, where \( (r_s-r_t) \) is the width of the step. It is evident that in both cases, the pressure distribution is most significantly affected when the step is grooved (case a). The grooving effect is more pronounced in the wide step i.e. \( (r_s-r_t) / r_0 < 0.45 \), which is consistent with the results of Dowson [3] for nongrooved bearings. If the step is located at this radius, load capacity is not affected by the change of inertia or the operating speed. If the step is located at a larger radius, load capacity increases with inertia. For \( r_s / r_0 < 0.45 \), inertia reduces the load capacity. In all cases, increase in load capacity is possible through suitable orientation of grooves on the step. It is evident from Fig. 4 that at \( r_s / r_0 \approx 0.45 \), nearly 50% load capacity increment is possible by grooves with inclination angle \( \beta = 135° \) with the direction of rotation. It is found that for any step location, the load capacity is the maximum at this groove inclination angle. Influence of grooves diminishes with the decrease of step width.

As \( r_s \) is increased the step becomes narrower and acts like a dam against the outward flow. Outward flow-rate increases with the increase of speed and the presence of step causes an increase in load capacity. With a decrease in \( r_s \), the step becomes wider and acts as the actual load bearing surface as well as a viscous pump without any dam at its outer periphery. In this case, the net outward flow is decreased due to less
available passage for flow. As before, the outward flow-rate is increased with the increase of speed. It reduces the pressure at the step (see Fig. 2) and thus the load capacity is decreased. However, with grooves this outward pumping may be reduced to some extent by designing the grooves to act like an inward pump. The effects of grooves on the step surface become insignificant for narrow steps, which occurs at a large \( r_i \). In such a case, the outward pumping action of the viscous pump over the recess outweighs the inward pumping action of the grooves on the step surface.

Figure 5 shows the effect of groove depth on load capacity. It is evident that load capacity increases with groove depth but making grooves more than 2 times deep compared to the minimum film thickness is not useful. It is also found that half of the step surface area should be grooved into narrow grooves to obtain maximum load capacity.

CONCLUSIONS
A simple analytical equation is presented for estimating the pressure distribution in a grooved circular step thrust bearing. A parametric analysis shows that grooving increases load capacity and the bearing with grooved step gives the maximum load capacity. With an increase in inertia, load capacity increases only if the step radius is larger than 0.45 times of the bearing radius. In a wider step, no increase in load capacity is possible with increase of inertia. Load capacity depends on groove depth and inclination. For the maximum load capacity, the groove depth should be twice the minimum film thickness and the inclination angle should be 135° with the direction of rotation.

REFERENCES

FIGURES

Figure 1. Model of the grooved circular step thrust bearing.