Studies on load enhancement of Gas Foil Thrust Bearings using copper foils

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Abstract - *Air foil thrust bearing (AFTB) or gas foil thrust bearing(GFTB) works on the principle of hydrodynamic lubrication, load supported here is the axial load or thrust load. These are independent from the conventional bearings because there will be no surface contacts. And in the hydrodynamic lubrication there will be no contact of bearing parts and no damage respectfully. In our experimental procedure the major advantage is the bearing diameter which is 224 mm which is large when compared to other experimental procedure carried out in AFTB. We have studied on the different parameters of the bearing such as foil thickness, sector angle, operating speed and how the wedge film formation takes place in bearing and how the load capacity and stiffness of the bearing can be increased. We have conducted the experiment on copper foil of thickness 0.3, 0.4, 0.5 mm respectively. The operating speed of the AFTB test rig is between 10000 - 20000 rpm. We have carried out the experiment in the two phases that is in first case we have done in the static condition and in the second phase we have done in the dynamic condition. The better possible study has been done to determine the load and stiffness of the bearing.*

Key Words: *AFTB, load, stiffness, operating speed*

1. INTRODUCTION

Bearing is a machine element that restricts the relative motion to only the desired motion, and lowers the friction and wear between the moving parts. The different types of the bearing are plain bearing, rolling element bearing, Jewel bearing, fluid bearing (air), and magnetic bearing. And the AFTB (Air Foil Thrust Bearing) Also Comes under the Category Air bearing and works on the principle of Hydrodynamic lubrication. The term hydrodynamic lubrication can also be coined as fluid film lubrication and the fluid is called air. These are independent from the conventional bearings because there will be no surface contacts. And in the hydrodynamic lubrication there will be no contact of the parts and no damage respectfully. There will be stator and the rotor in AFTB and the foils are attached to the stator. When the power is applied to the rotor, it starts rotating and is set for different rotating speeds. The detailed hydrodynamic film lubrication is seen in figure 2.

It used in the turbo machinery applications, aerospace applications, rotor dynamic applications, food industries, turbo chargers, turbo expanders, coordinate measuring machine, turbo compressors, textile spindles.

Air gap in bearings and there will be no surface contact as in the case of the conventional bearings. So mainly in this kind of the bearings there will be no vibrations, damping, and other vibration related problems.

Iordanoff (1) did a study on the compliant air foil thrust bearing respectively. Here he gave a conclusion that the experimental load calculation and the analytical load calculation As we know in the air foil thrust bearing there will be based on the theory both satisfies. In this study he operated the test rig at 50000 rpm respectively with bearing inner diameter 40mm, outer diameter 80mm. Also in this there is bump foil and top foil, and with the nominal film thickness respectfully of 1.9 micro meter to 2.5 micro meter the load can be observed, finally load is weak when both the rotor and bearing pad touch each other and the top and bump foil touch each other. Bauman (2) conducted the experiment in the air foil test bearing rig and listed the important parameters such as load, speed, torque, temperature but the main parameter is the temperature is the which is almost 650 degree Celsius. Here he explained that the vibrations caused are preliminary due to the shaft and not the foil bearing. Finally the main thing he explained is that the load increases due to the passage of the air film, also we can find that the exact load is the difference of applied load and the load generated between the foil and runner and fixed plate. Brain dykas, Joseph Prahl (3) gave a detailed analysis of heat generation takes places in foil thrust air bearing. As we know in this type of the bearing when rotating at the higher speeds between the air film pressures causes heat on the foil surface we have to counter this type of the problems because it can cause shear on the surface respectfully. Dong Jin Park, Chang Ho Kim (4) have analytical conducted the experiment by keeping the runner in tilted plane in one case and parallel in other case. From all the above cases bearing torque, stiffness, load has been observed. Also the main thing observed is when the bearing pad is tilted the maximum of the load and torques is increased. Also the main thing is the eccentric ratio increases is directly proportional to the load increased. Somaya K (5) In addition, it was found that inserting a metal plate between the top foil and the viscous elastic support at the landing region could improve the load capacity, and that the load capacity of the proposed foil bearing reached 160 N at 20000r/min. Here he conducted series of experiment both experimentally and analytically in one criterion he did sand witch type of experiment with foil, adhesive tape, silicon rubber and in the second case he placed the metal in between the tape and the silicon rubber where load increased significantly. Yonk- Bok lee, Tae-ho kim (6) conducted the experiments by varying the thrust load of bearing. In this experimental results compared with random stiffness of mathematical model gave good output of this bearing. As we know if the rotating speeds of the runner increase air film thickness which corresponds to increase in the load, also in turn corresponds to increase in bearing number. Donghyun lee, Daejong kim (7) conducted the design or synthesis and prediction performance of hybrid air foil thrust bearings respectively. In their design they have created the slots in foil to accommodate orifice. Also they have done the static and dynamic characteristics at different place of orifice in the plate to see pressure film distribution. Tae ho Kim, Yong-bok lee, Tae Young Kim (8) they did a study on the increase of Performance of an Oil-Free Turbo Blower Focusing on Load increases of Gas Foil Thrust Bearings. Here with the increase of the tilting angles of the bearing pad they observed that the load carrying capacity of the bearing was decreased. Robert J Bruckner (9) conducted a study on the enhancement of simplest of the gas foil thrust bearings and he observed the important parameters such as frictional torque, speed, temperature and load. In this with the same foil he conducted the experimental test results with varying rpm he didn't find that load increasing linearly. Ravi Kumar R **N,** Rathanraj K J(10) here there they have made the sector foils where the inner edge and outer edge height decreases and the other is cascading the foils and here they have observed that the load carrying capacity is increased respectfully because the no of the wedges Created are more. Tae ho Kim, Moon Sung Park, Jong Sung Lee, Young Min Kim (11) here they did excitation process by a shaker to induce constant vibrations also they found the dynamic characteristics of the bearing. That is they are increasing frequency which in turn increases the dynamic load. Also the bearing damping coefficient, stiffness increases by the applied frequency respectively. Choong hyun kim, Jisu park (12) designed the rig of foil thrust bearing in the vertical manner as we seen in the many cases it is horizontal manner, by this kind of arrangement of the rig he noticed that the higher amount of friction, frictional torque was noticed. Based on vertical manner of arrangement of rig the air flow between the bearing pad and the thrust pad was seen very well at the higher speed. Tae Ho Kim, Moon sung Park, Tae Won Lee(13) conducted the experiment in the bearing test rig by increasing the ramp height with certain (mm) of increments, also by varying the speed so on by doing this the load was noted. By doing the above experimental results they found that with decreasing ramp height the load increases. The two different variable studied is ramp height, inclination angle. And other different variable discussed here are the drag torque, stiffness which are also inter linkable. Supreeth S (14) it was observed within the increases no of foils, the greater the load speed with the less air gap respectfully. As we know with the lesser the air gap more amount of the load can be withstand and also the main point is inner and the outer edge of the foil are parallel with respect to the back plate. Also it was noted that the foil with less thickness can withstand more amount of the load.

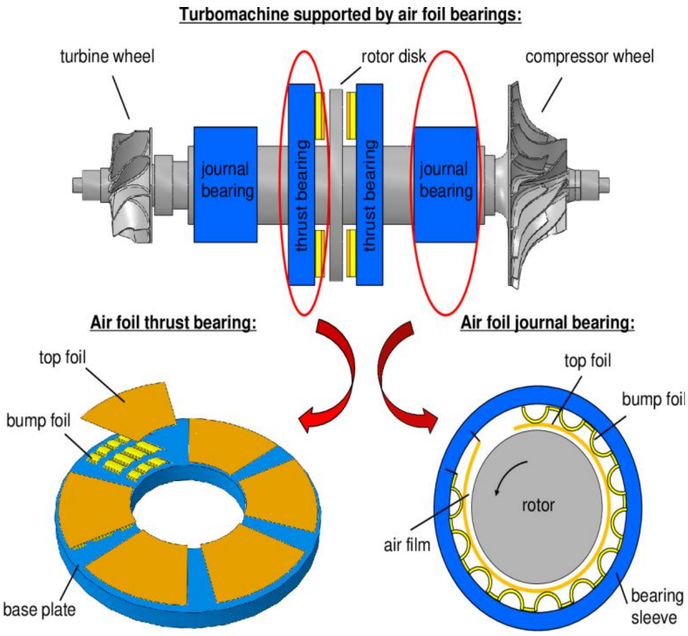

Fig -1: Air Foil Bearings

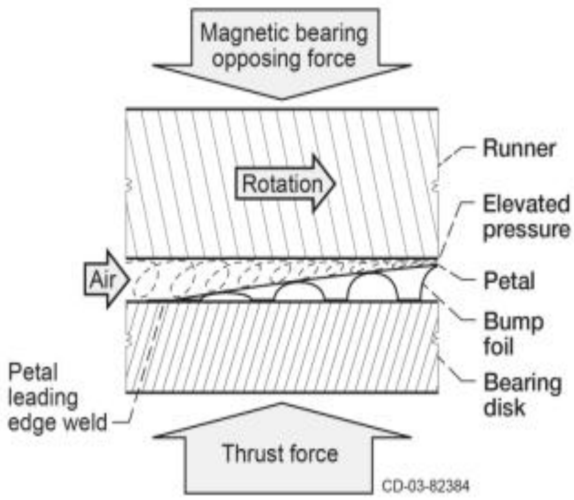

Fig -2: Principle of Foil Thrust Bearing

2. Experimentation

The conduction of the experiment in the AFTB test rig is done using copper foil with thickness of 0.3, 0.4 mm and also by varying the sector angle by 45,60,75,90 degrees. The entire experimentation process is carried out in two stages. In first stage doing the experiment in the dynamic condition and in second stage is static condition in both the stages load, stiffness are measured.

First we are starting with the 0.4mm foil respectively. As we already know there are 4 different sector angles varying from 45-90 degree in increments of 15 degree respectively. We are conducting the experiment for each and every sector angle and noting down the load and stiffness in both static and dynamic condition. And again we are starting with the 0.3 mm foil and doing the same experimentation procedure as we did in the 0.4 mm. In the course of doing the experiment we are also increasing the speed of the rig in the increments of 2000 rpm and it can reach up to speed of 20000 rpm which is maximum and above it can't be reached. The speed of the rig is increased from the beginning till the maximum speed for every sector angle varying from 45,60,75,90 degrees of the corresponding thickness of 0.3,04 mm foil respectively. There is a knob to increase the speed and adjacent to that display is given to note down the speed and adjacent to that load measured display also there where we can take the different readings while performing the experimentation. As in our experiment we are constantly removing the copper foils from the bearing pad and again inserting to it for the various sector angles it is done with help of threads and fasteners for easy removal and performing the experiment. The bearing pad should be almost made exactly parallel to the surface of the rotor which means the outer and inner edge of the free end of the foil should be made parallel to the rotor surface so that very good hydrodynamic film lubrication takes place and the good amount of the load can be with stand. In the course of doing the entire experimentation circulation tank should be on because of the cooling down of the spindle is necessary as more amount of heat generation takes place. While performing the experimentation the bearing pad must be fixed accurately otherwise the rotor which rotates at higher speed may cause damage to the person who's performing the experiment these are safety precautions and measure should be taken. Also while performing the experimentation once used foil cannot be used as the stiffness in the foil will not be retained and good precision and accurate results would not be obtained. The copper foil after being performed experiment in AFTB test rig is shown in figure 4 and7. Also we can see the rig of AFTB in figure 3.

Fig -3: Air foil thrust bearing (AFTB)

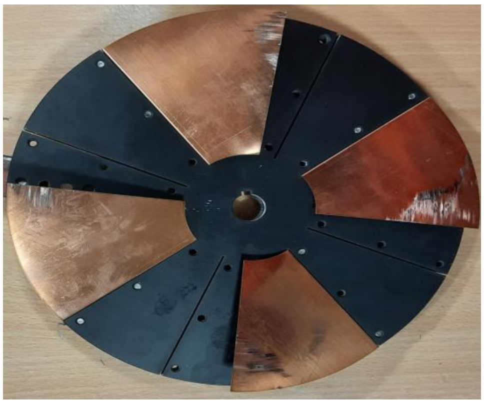

Fig -4: Copper foil with bearing pad

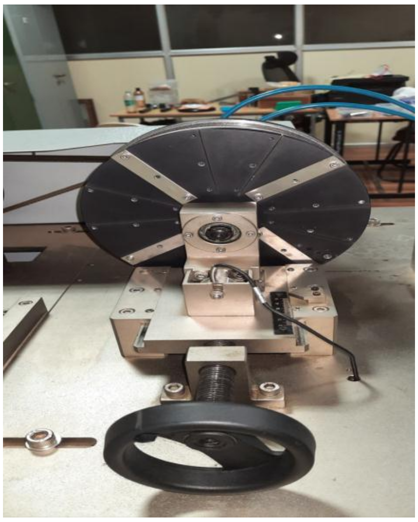

Fig -5: Side view of air foil bearing thrust rig

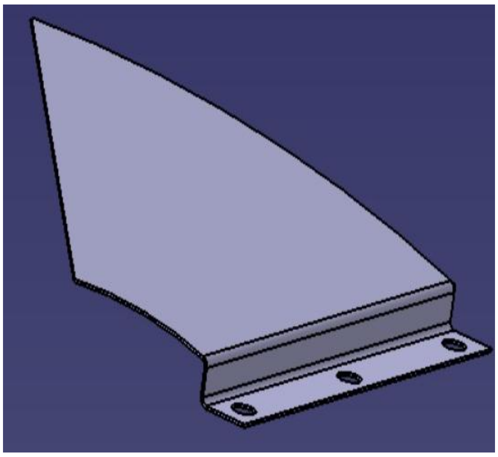

Fig -6: 45 Degree copper foil

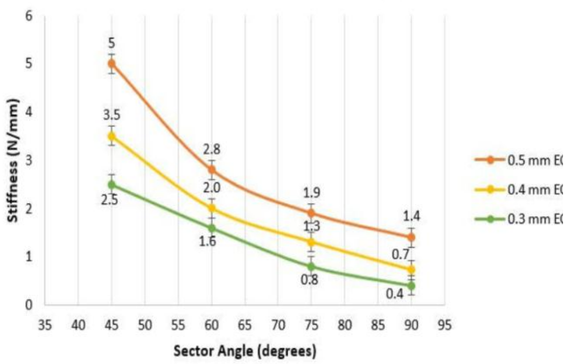

Fig -7: Static stiffness of AFTB with 4 copper foils

3. RESULTS

The results have found out in two criteria based on the experimentation procedure

1. Static Conditions

Now let us discuss the results of static conditions. Here we are discussing the different parameters in the AFTB test rig by not increasing the speed of the rotor, mean to say that in standstill condition. As we already know that by the basic common sense and elementary level science that the element with the higher thickness will be stiffer and this result may also be observed from the graph by plotting graph of stiffness (N/mm) versus various sectors angles (degrees) for the various thicknesses of the copper foils. From the above **figure 7** we may notice that even though stiffness is higher in 0.5 mm it is particularly observed in the sector angle of 45 degree and it is much higher than 60,75,90 degree. As earlier explained in the dynamic condition in 0.5mm foil thickness of sector angle 60, 75, 90 circumferential areas or foil area is more and according to our experimental validation we may observe that is easily deflected and having the less stiffness.

The maximum stiffness value obtained is 5(N/mm), the above criteria discussed also holds good in the case of 0.3, 0.4 mm respectively. In the case of 0.3, 0.4mm the stiffness value obtained is 3.5 (N/mm) and 2.5 (N/mm).

$$\delta = \frac{W\ L^3}{3EI}$$

W= load (N)

L=length of the foil (mm)

E= modulus of elasticity (N/mm^2)

I=moment of inertia (Kg.m^2)

δ = deflection (mm)

From the above equation it may be noted that the as length on the foil goes on increasing deflection delta goes on increases by this analogy one can understand that why the stiffness in 0.5 mm copper foil is greater than compared to other foils.

2. Dynamic Conditions

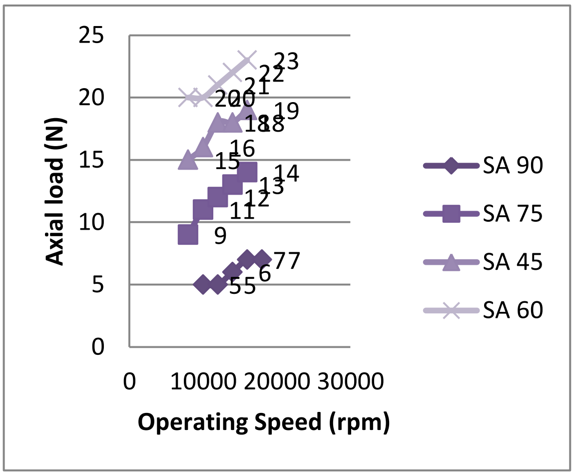

Fig -8: Load capacity of AFTB 0.3 mm copper foils

We may observe from the above figure 8, 9 that for the thickness of 0.3, 0.4mm of copper foil a graph of load versus the operating or the running speed were plotted and different parameters were measured. We have conducted the experiments for all the three thicknesses of foil which are 0.3, 0.4 and 0.5mm.

But we observed that the foil thickness of 0.5 mm supposed to have very high stiffer and rubbing occurs between the rotor and copper foil which results in the bearing failure. It may be observed that one of the reasons behind the failure is the operating speed which needs to be higher than our speed that is 20000 rpm.

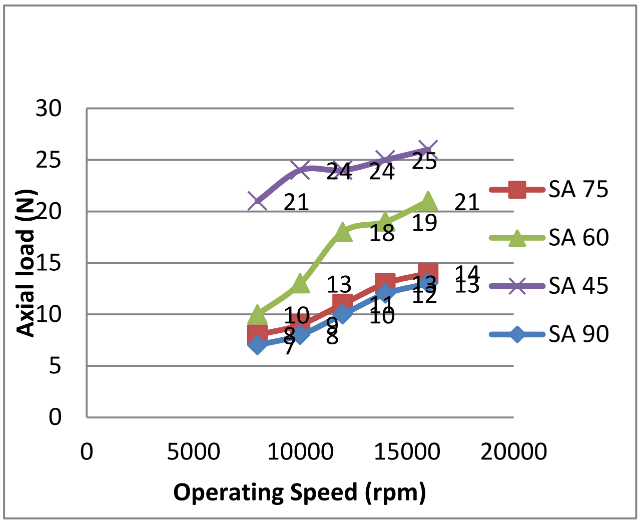

Fig -9: Load capacity of AFTB 0.4 mm copper foils

Because if the speed is very high say supposed to be greater than 20000rpm or still very high the foil may deflect easily. Also we must note that for this thickness of 0.5 mm of foil we have done for various sector angles that is 45,60,75,90 degrees but no improvements or satisfied result are not observed. For the foil of thickness 0.5 mm speed may not only be the valid reason it might depends on the material or the foil geometry. And basically why we are stressing on the operating parameter because based on that hydrodynamic lubrication or wedge formation takes place and it may result load withstanding or it may not be higher stiffer.

Now let us investigate the parameters of 0.3mm, 0.4mm foil of the AFTB test rig respectively. We may see that from the above plotted graph for various sectors angles a plot of load versus rpm is plotted. Also it is clearly indicated that the load holding capacity of the foil with sector angle 45, 60 degrees have shown the better results compared to the foil of 75, 90 degree respectively. The above load holding capacity of foil with sector angle 45, 60 degree is true in both the cases that are 0.3, 0.4 mm copper foil which can be observed from the above plotted graphs. The main reasons behind the foils of sector angle 75, 90 degrees are not showing good load holding capacity because they are having the larger circumferential area can be easily deflected, in other words the foils touches the rotor as soon as the rotor achieves the desirable speed. Even though according to our experimentation process the circumferential or sector area is of foil is large, wedge film formation is not possible up to the greater extent and neither good load holding capacity may be observed. The above cited reason for the 75, 90 degree sector angle of foil holds reasonably well because for both 0.3, 0.4 mm of copper foil 45, 60 degree angle the load holding capacity up to 25 Newton that is equal 2.5 kg.

After performing the series of the experiment in AFTB test rig the above following graphs were obtained from the experimental data obtained from the rig. We conducted the experiment in the two ways one is in the dynamic and other is in static condition. We plotted the graph of load versus speed (rpm) for the different thickness of the copper foils. And the thicknesses are 0.3, 0.4mm respectively. We came to know about the different parameters such as stiffness, load, speed, and thickness and sector angle how all these parameters are correlated.

$$F = K\delta$$

F=load (N)

K=Stiffness (N/mm)

δ= Deflection (mm)

From the above equation it may be known that stiffness (K) is inversely proportional to the delta (δ) means as the stiffness increases the deflection delta (δ) decreases. Also coming to discuss another parameter that is the load (F) which is directly proportional to the stiffness means as the load increases stiffness also increases.

4. CONCLUSIONS

After conducting the series of experiments in the AFTB test rig different parameters were study and observed. The parameters are thickness of the foil, sector angle, ramp height and finally operating speed. The main thing in our experimentation procedure and the conduction of our experiment is that we have done the experiment in two criteria that is first is in the dynamic condition and the second in the static condition. In the static condition we have observed that stiffness parameter is one of the main parametric studies and in dynamic condition load is most discussed parameter. In both criteria parameters were observed for the different thickness of the foils. Also sector angle 45, 60 degree has been shown promising developments. In case of stiffness parameter measured in the static condition 0.5mm copper foil shown good stiffness but it does not shown better load holding capacity in the dynamic condition, but finally if the operating parameter of the rig is greater we can ensure that 0.5mm copper foil can also hold better load holding capacity. Finally in our test rig the bearing diameters are larger compared to other research work done on the AFTB or GFTB so by increasing operating speed the bearing might show good load holding capacity.

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