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BACHELOR OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
A PROJECT PRESENTATION ON

“EXPERIMENTAL STUDY TO IMPROVE PERFORMANCE OF COMPLIANT FOIL THRUST BEARING”

SUBMITTED BY

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CONTENTS

INTRODUCTION

- The recent development in high-speed turbomachinery requires accurately designed gas bearings.
- To meet the demand of high-speed turbomachinery under different operating conditions, the accurate design of thrust foil bearings and its behavior is a prerequisite for different applications.
- This project mainly focuses on Airfoil Thrust bearing (AFTB).
- These bearings can operate at very high-speed conditions, but the problem is that at low speed the lift is very less because only the pressure of the air has to lift the bearing when loaded axially.
- Historically the study of the theoretical performance of airfoil thrust bearing has been done but it also important to estimate the performance under actual operating conditions.
- It is also important to identify the parameters to be studied under actual operating conditions that affect the performance of AFTB.

THRUST FOIL BEARING

- A thrust foil air bearing has a bump foil arranged on a thrust plate.
- A top foil includes a flat Surface extending along with top bumps of the bump foil, an edge attached to the thrust plate, and a ramp connecting the edge and the flat surface.
- The ramp forms a curvature which has a center located in a Field of Classification Search lower part of the ramp and tangentially contacts the top of a first bump of the bump foil.

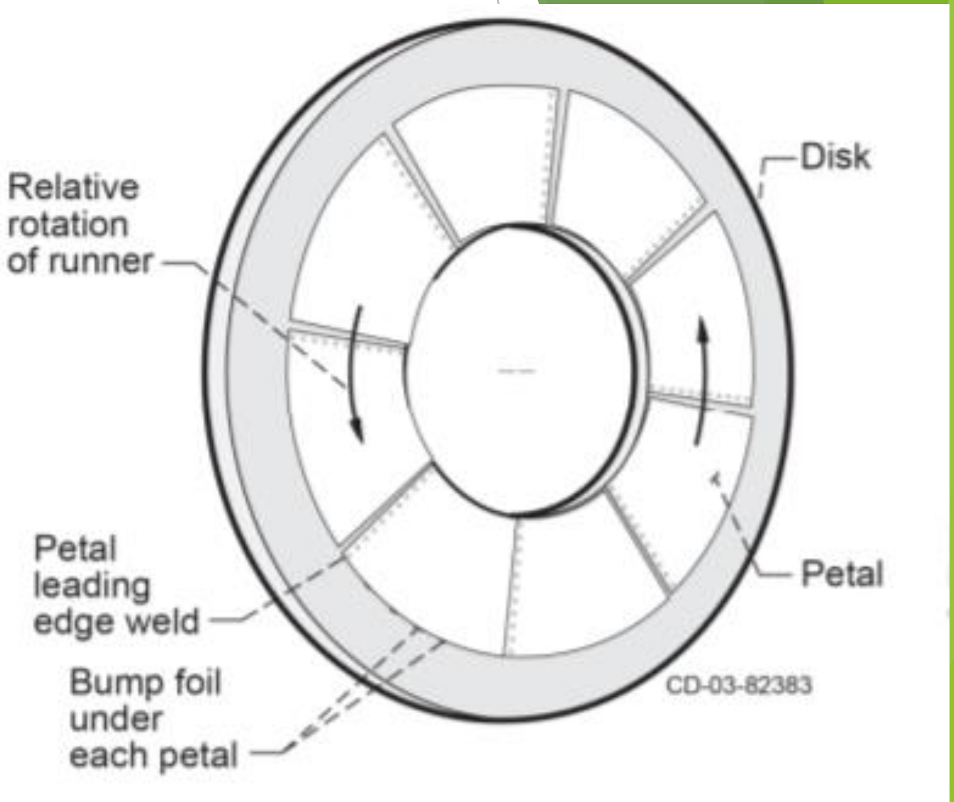


Figure - 1 Thrust Foil Bearing

WORKING OF THRUST FOIL BEARING

- In a thrust foil bearing, the converging film is developed between the foil and the runner due to the axial load.
- The hydrodynamic pressure rise is initially created by the physical contraction of the film thickness between the top foil and the thrust runner.
- The compliant foundation can take any number of styles and forms.

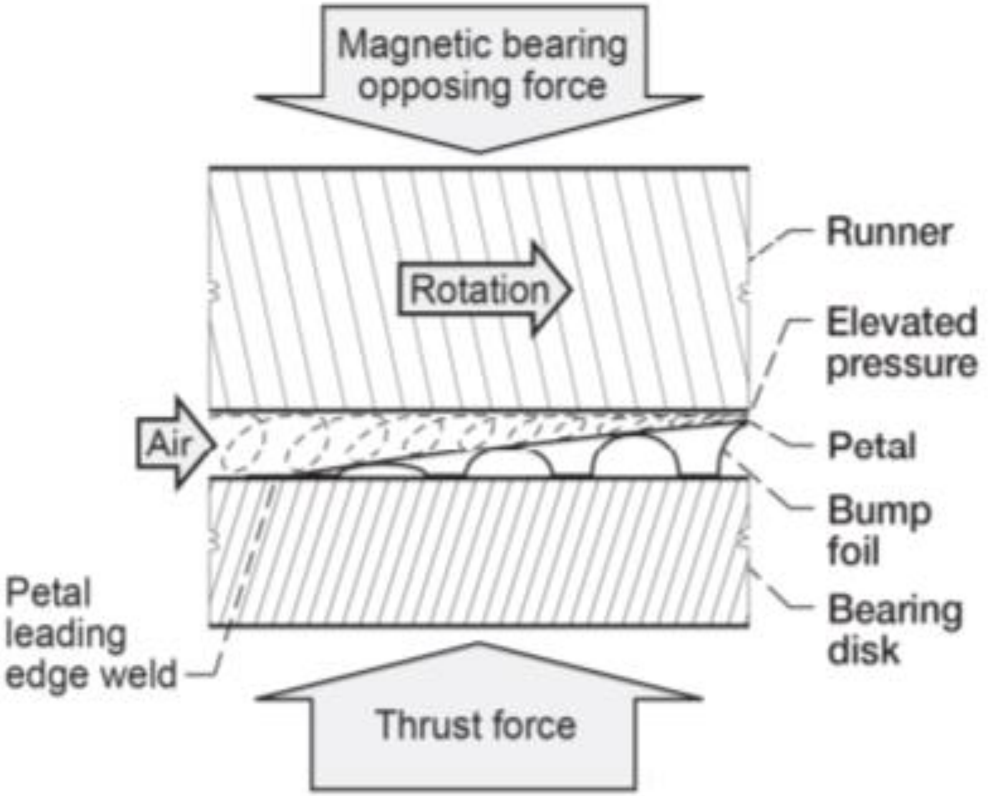


Figure -2 Thrust foil bearing principle of working.

PRESSURE DEVELOPMENT IN AIR FOIL THRUST BEARING

- Once the thrust runner is spinning quickly enough, the working fluid (usually air) pushes the foil away from the runner so that there is no more contact.
- The runner and foil are separated by the air's high pressure which is generated by the rotation which pulls air into the bearing via viscosity effects.
- The high speed of the runner with respect to the foil is required to initiate the air gap and once this has been achieved no wear occurs.
- The top foil provides a smooth flow for the air film to develop onto generate hydrodynamic pressure.
- The airflow in the circumferential direction, as induced by the interaction with the air viscosity and the rotating surfaces, gets compressed into the groove.

ADVANTAGES

- Higher efficiency, due to a lower heat loss to friction.
- Increased reliability.
- Higher speed capability.
- Quieter operation.
- High vibration and shock load capacity.
- No scheduled maintenance.
- Truly oil-free where contamination is an issue.
- Capable of operating above the critical speed

DISADVANTAGES

- Lower capacity than roller or oil bearings.
- Wear during start-up and stopping.
- The high speed required for operation.
- Less load capacity than rolling or oil bearings.
- Thermal management issues.
- A difficulty in modeling complex interaction between film and foil bump's support.

LITERATURE SURVEY

Ref .no	Paper Title	Author	Outcome Of Paper
1	Major Breakthrough In Load Capacity, Speed And Operating Temperature Of Foil Thrust Bearings -2005	**Dr. Hooshang Heshmat**	This paper describes major breakthroughs in foil thrust bearings achieving a thrust load capacity in excess of 570 kPa (83 psi) and temperature capability of 815 °C (1500 °F).
2	Dynamic stability experiments of compliant foil thrust bearing with viscoelastic support- 2008	**YuHou** **Quan Zhou**	Static and stability experiments are conducted on a high-speed gas turbine test rig. The static results indicate that the structural stiffness of test bearing generally increases with the increase in axial load and the decrease in thickness of the bottom foil.
3	Thrust Bump Air Foil Bearings with Variable Axial Load: Theoretical Predictions and Experiments -2011	**Yong-Bok Lee** **Tae Young Kim**	In their A thrust test facility was successfully developed to determine the relationship between load capacity and the deflection of a bearing. From the test results, the model using nonlinear stiffness was in better agreement with the experimental results than the model using linear stiffness
4	Experimental Analysis of the Start-Up Torque of a Mildly Loaded Foil Thrust Bearing-2013	**Franck Balducchi** **Romain Gauthie**	This paper deals with the experimental analysis of the torque and lift-off velocity of a foil thrust bearing. Results are presented for mild static loads ranging from 5 to 60N and rotation speeds comprised between 20 and 35 krpm.

LITERATURE SURVEY

Ref. no	Paper Title	Author	Outcome Of Paper
5	Design Optimization of Gas Foil Thrust Bearings for Maximum Load Capacity-2015	**Tae Ho Kim** **Tae Won Lee**	Their study aimed to develop a design guideline for increasing the load capacity of GFTBs. The drag torque significantly increased only for ramp heights below the optimal value.
6	Parametric study on static and dynamic characteristics of bump-type gas foil thrust bearing for oil-free turbomachinery - 2015	**Kai Feng** **Liang-Jun**	In this paper they theoretically analyzed the static and dynamic characteristics of GFTBs. Both the static load and frictional torque increase considerably at an appropriate small tilting angle.
7	Static characteristics of six pads multilayer protuberant foil thrust bearings -2016	**Yueqing Zheng,** **Tianwei Lai**	In their study they made multilayer protuberant foil thrust bearings with six pads the experimental results show that the variation of the structural stiffness mainly depends on the loading force and the configuration of the bearing.
8	The Limiting Load-Carrying Capacity of Foil Thrust Bearings -2017	**P Samanta** **Mm Khonsari**	In this paper they performed A parametric analysis to examine the role of limiting the load on different geometric parameters for the bearing. A high value of the ramp and compliance yield a large limiting load.

LITERATURE SURVEY OF LOAD CARRYING CAPACITY

Ref. No	Title	Author	Load Obtained in Newton (N)
7	Static characteristics Of six pads Multilayer protuberant foil thrust bearings	**Yueqing Zheng** **Tianwei Lai**	43.9N
4	Experimental analysis of the Dynamic characteristics Of a foil thrust bearing	**Franck Balducchi** **Mihai Arghir**	60N
2	Dynamic stability experiments of compliant foil thrust bearing with viscoelastic support	**Quan Zhou** **YuHou**	22.5N
9	Performance of thrust airfoil bearing for oil-free turbomachinery	**Zbigniew Kozanecki** **Jakub Łagodziński**	55N
10	A high-speed test rig capable of running at 190,000rpm to Characterize gas foil thrust bearings	**Nguyen T. Latray** **Daejong Kim**	65N

OUTCOMES OF LITERATURE SURVEY

From the literature survey, it is observed that at higher speeds the load-carrying capacity is less and deflection if foil is more, we got to know the problems and solutions obtained by the various researcher who researched this field the outcomes of this literature survey is listed below.

- With more layers of the protuberant foils and thinner top foil, the bearing shows a larger maximum load capacity.
- The variation of the structural stiffness mainly depends on the loading force and the configuration of the bearing.
- We got to know Thrust bump foil bearings have high load capacity when the operating speed is high.
- We found that structural stiffness of test bearing generally improves with the increase in axial load and decrease in thickness of bottom foil.

PROBLEM DEFINITION

From the literature survey, we found out various problems faced by the various researcher who researched this field which is listed below.

- The deformation of foil is found to be more due to friction.
- The dynamic stability of the airfoil bearing is low at higher speeds.
- The load-bearing capacity of high-speed bearing is less.
- The efficiency of conventional bearing is less

We are looking towards finding the solution for improvement in the performance of the thrust foil bearing by conducting various analysis and simulations and improvements in design and changing the design configurations trying to increase performance.

OBJECTIVES

This project aims to model and test an efficient thrust foil bearing for better performance over high speeds. The objectives of this project would be to:

- To improve the Load-carrying capability by varying the number of foils in bearing.
- To increase the efficiency by altering foil thickness and improve performance by proper designing of foil shape.
- To reduce the deformation of foil by supporting foil with viscoelastic material.

We aim to make a simulation model and test it analytical or by using software to find the maximum best possible results.

METHODOLOGY

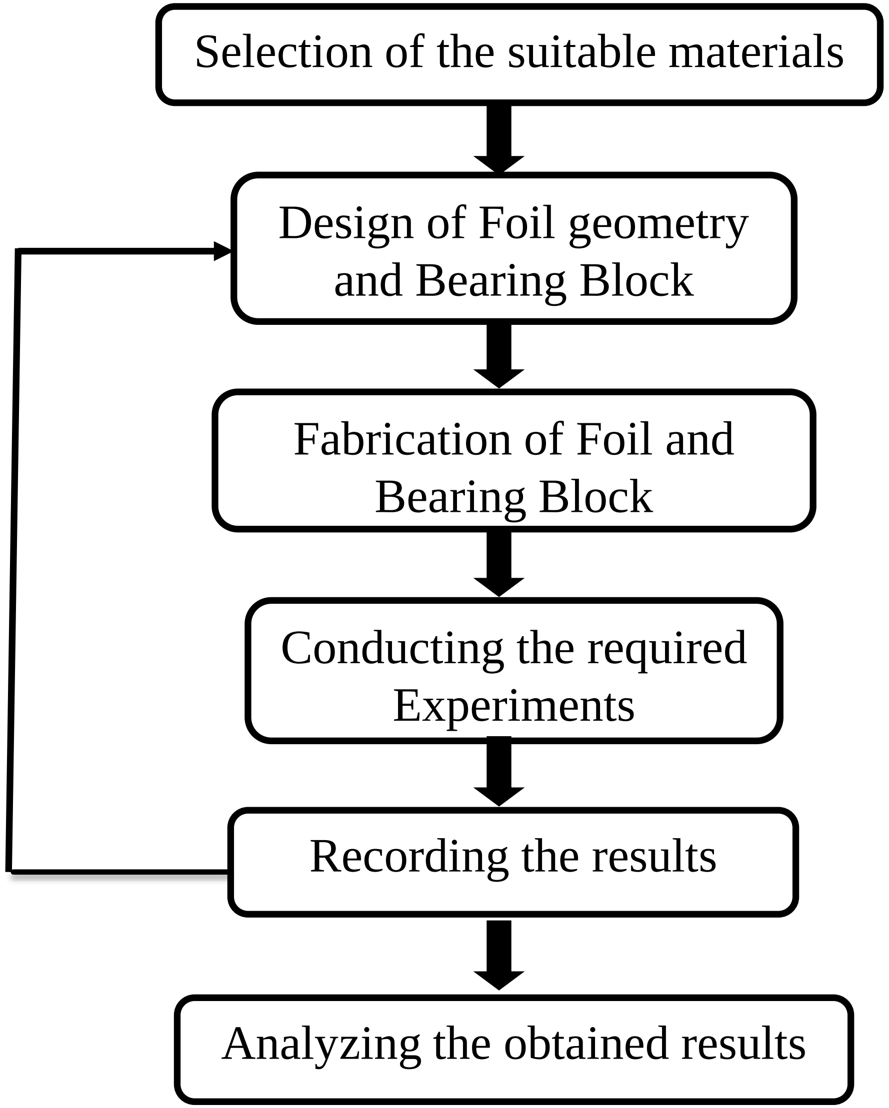


Figure - 3 Methodology Flow Chart

DESIGN ASPECTS AND 2D MODEL OF BEARING AND RUNNER

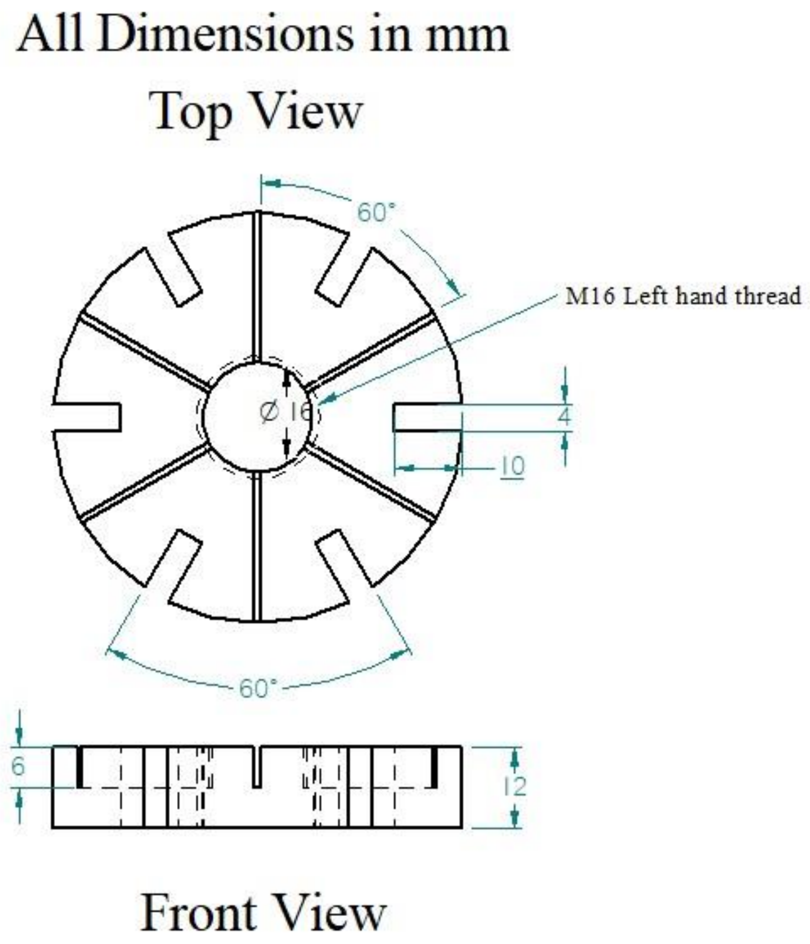


Figure - 4 2D Model of Bearing Block

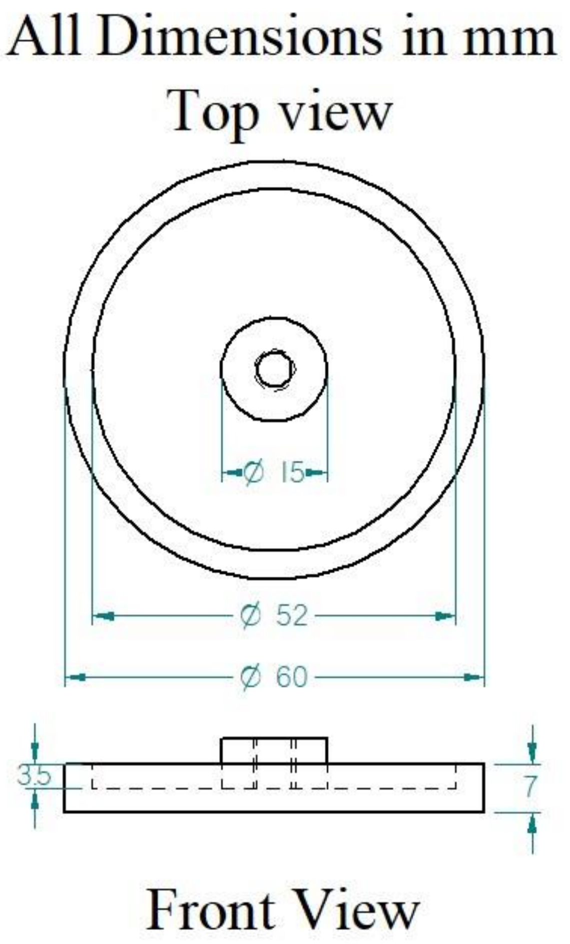


Figure - 5 2D Model of Thrust Runner

2D MODEL OF DIFFFRENT SECTOR ANGLE FOILS AND SHIM ANGLES

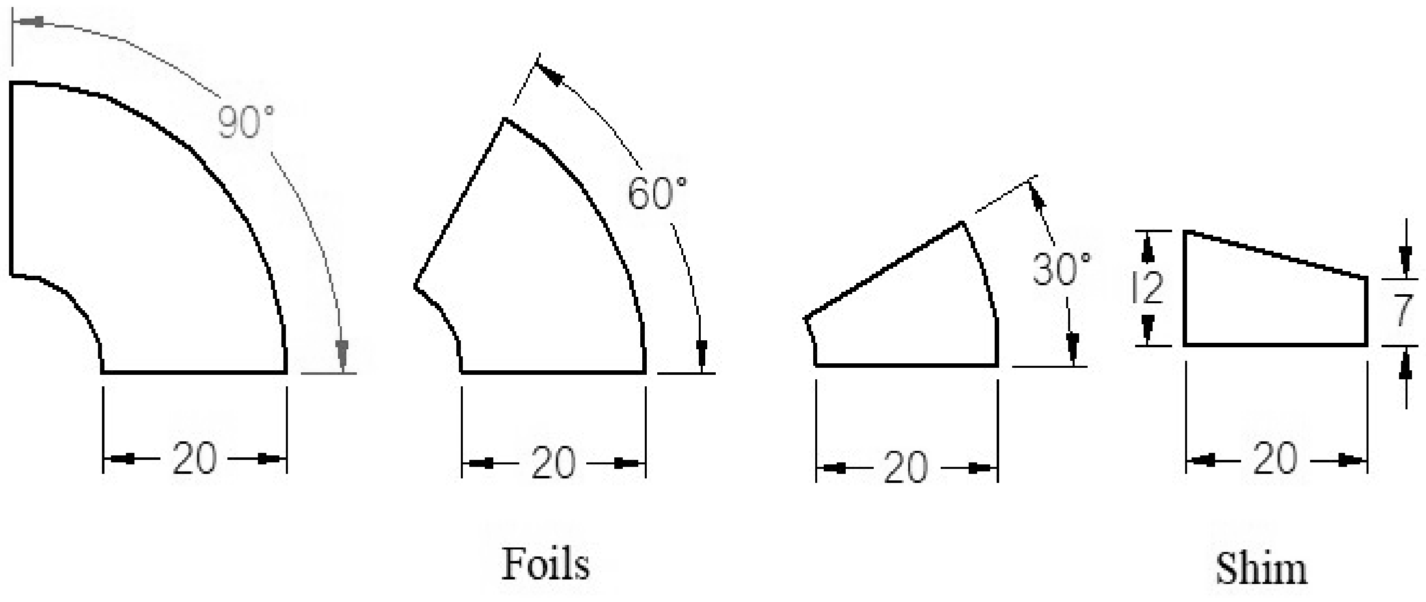


Figure - 6 2D Model of 3 Different Sector Angle of Foils and Different Alpha Angle Foil Shim

- When a circle is divided into four parts we obtain four 90 degree sector parts from the circle
- If we divide a circle into 6 parts we obtain six 60 degree sector parts
- If we divide a circle into 12 parts we get twelve 30 degree parts
- The divided parts of a circle are known as a sector angle.

DESIGN ASPECTS AND FABRICATION

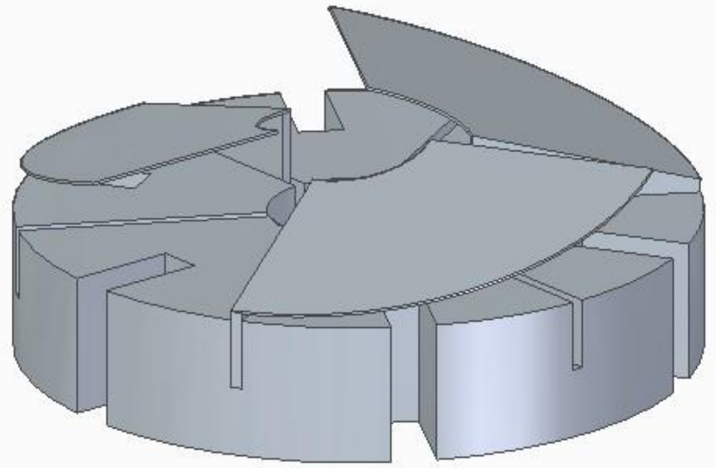


Figure - 7 3D CAD Model and Assembly of Foils to Bearing Block

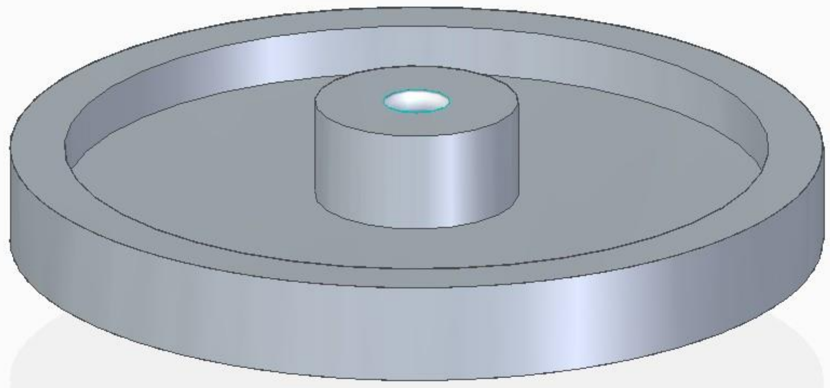


Figure – 8 3D CAD Model of Runner

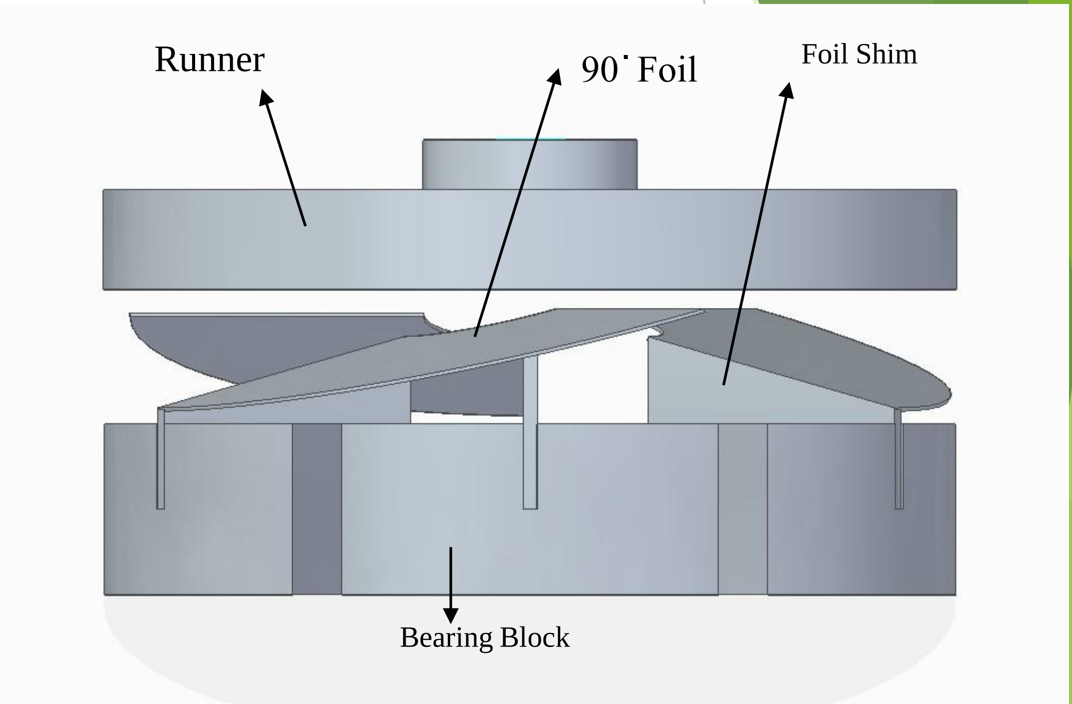


Figure – 9 3D CAD Model Assembly of Bearing Block, Runner and 90 Degree Sector angle Foils

FLUID STRUCTURE INTERACTION ANALYSIS USING COMSOL SOFTWARE

Short Procedure for FSI Simulation in COMSOL 5.0v software

- Defining the required variables and equations and Creating the geometry in model builder.
- Select material and enter material properties like Young's modulus, Poisson's ratio, and Density of the material and fluid.
- Selection fluid structure interaction in the physics enter the required properties and the inlet and outlet Pressure or Velocity.
- Selection of fixed constraints and solid parts and movable parts.
- Select the model and Mesh and give the Mesh size and click ok
- Click on the study and click Compute.
- The results appear after computation is completed then plot the simulation results.

FSI SIMULATION RESULTS

Different Sector Angle Configurations

- ➢ First, we modeled 30-degree sector angle foil and simulated for fluid-structure interaction in COMSOL 5.0v software the results are shown below.

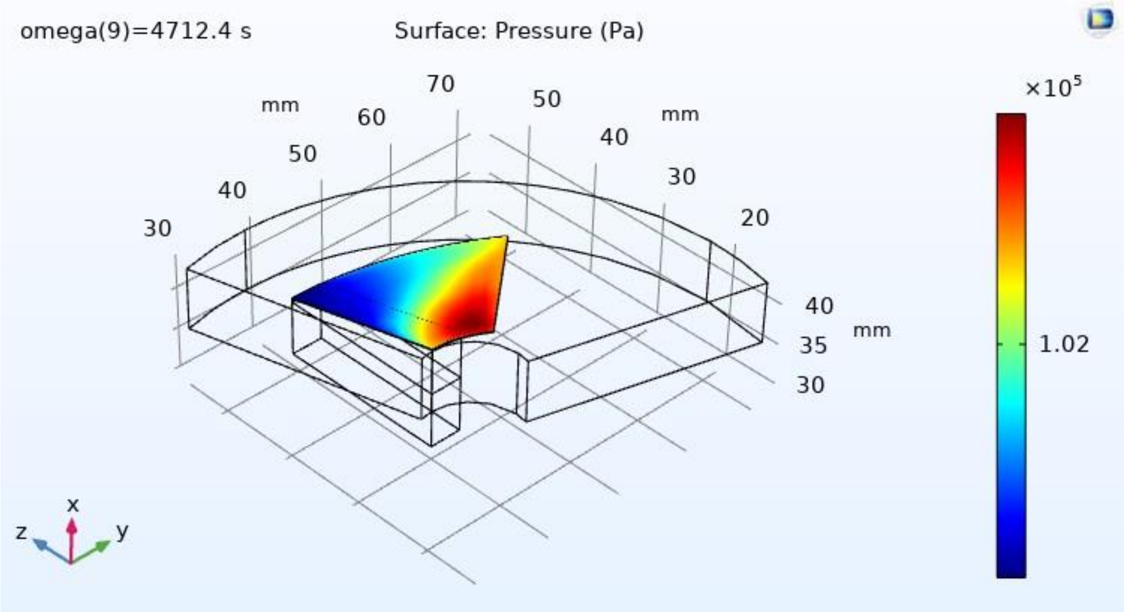


Figure 10 Stress Distribution due to Pressure of 30-degree sector angle foil computed at 10k rpm

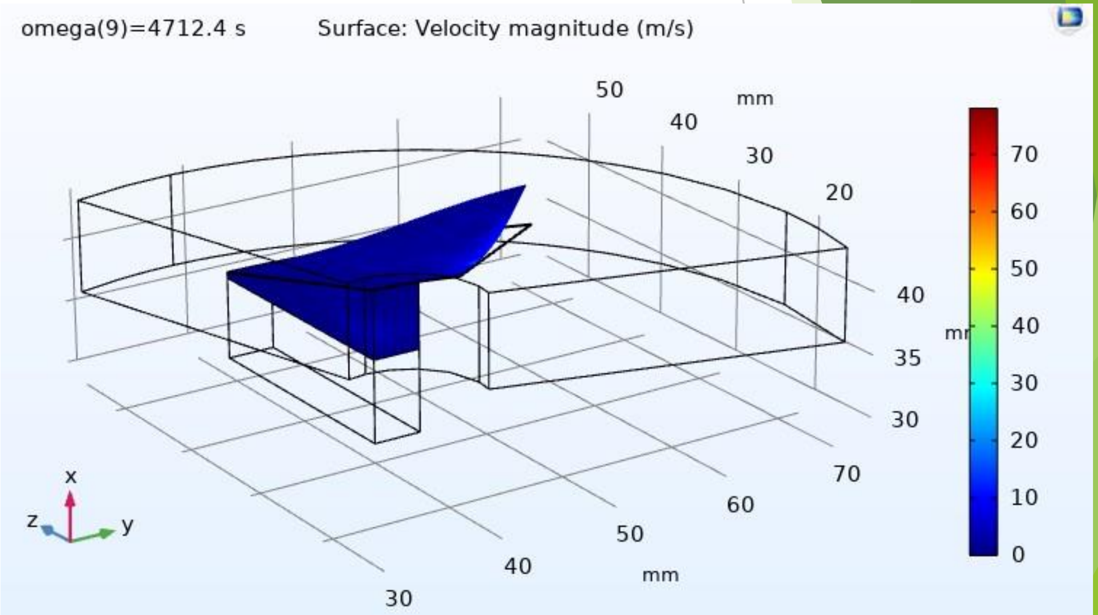


Figure 11 Maximum Foil Deflection of 30-degree sector angle foil computed at 10k rpm

- ➢ The maximum load on foil at 10k rpm is around 34.7595 N and the Deflection is 0.0065 mm.

60-DEGREE SECTOR ANGLE FOIL RESULTS

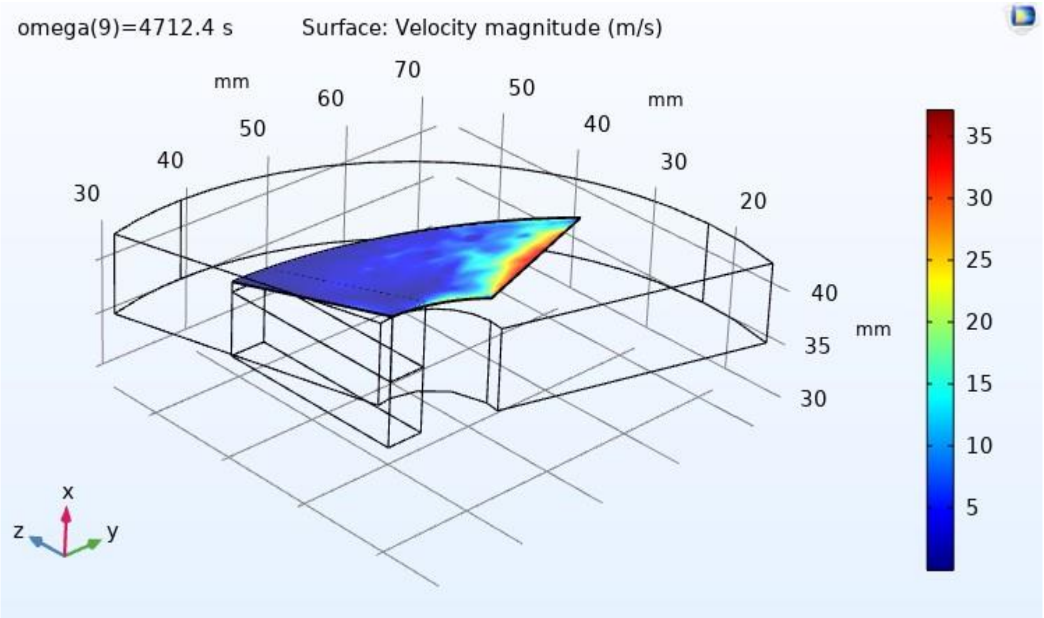


Figure 12 Stress Distribution due to Pressure of 60-degree sector angle foil computed at 10k rpm

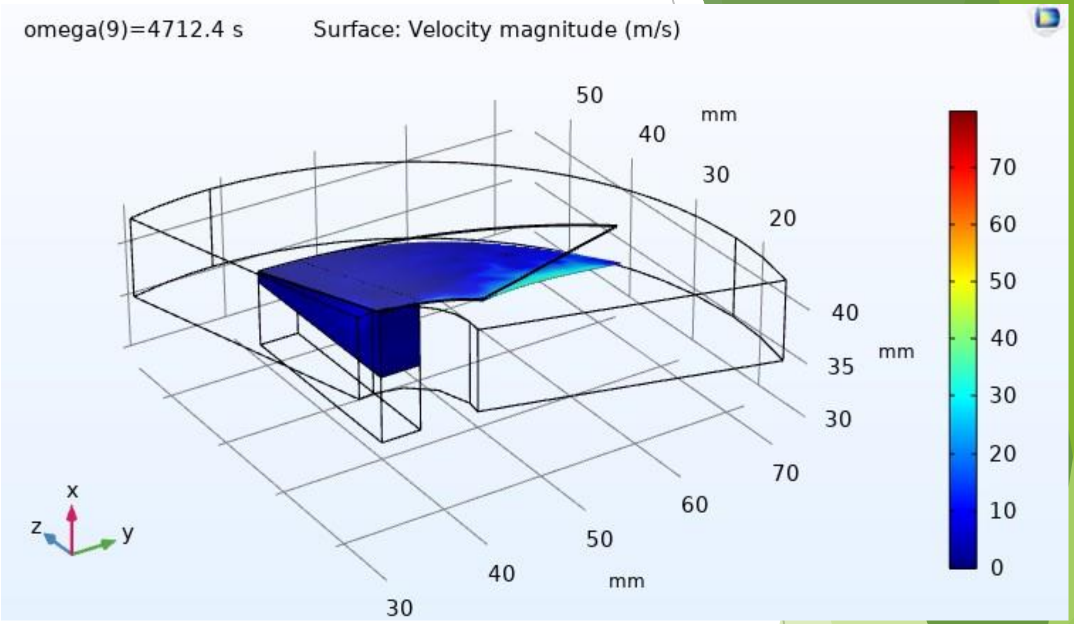


Figure 13 Maximum Foil Deflection of 60-degree sector angle foil computed at 10k rpm

- The maximum load on foil at 10k rpm is around 48.61 N and the Deflection is 0.2179 mm.
- So we decided to make a model of 90-degree sector angle foil and simulated for fluid-structure interaction in software and found results .

90-DEGREE SECTOR ANGLE FOIL RESULTS

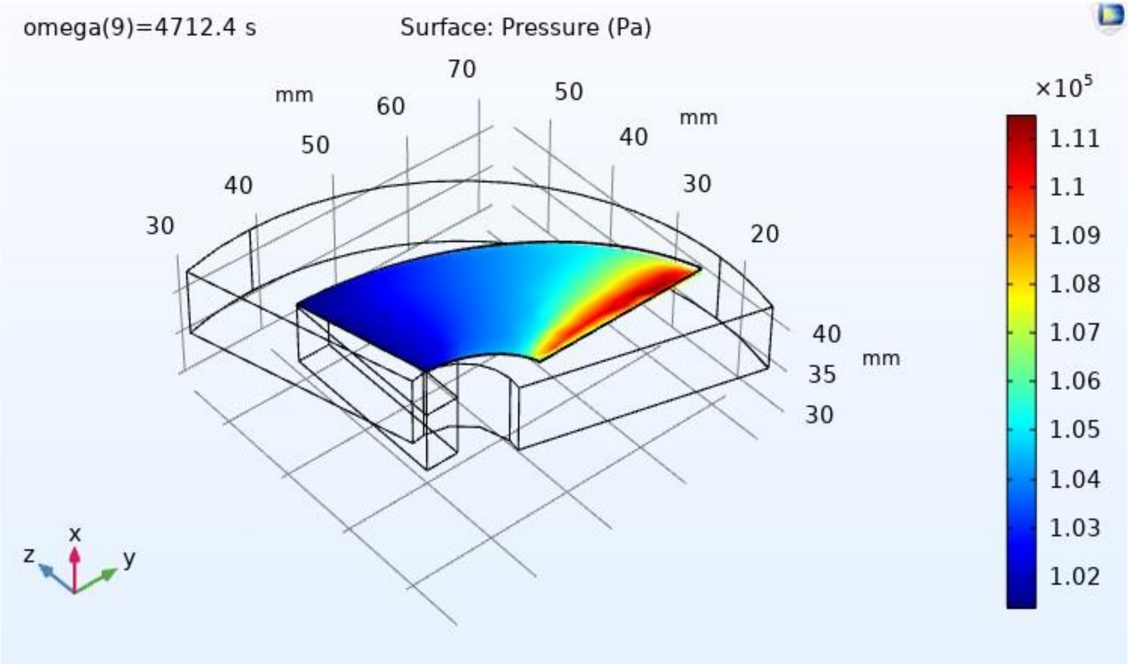


Figure 13 Stress Distribution due to Pressure of 90-degree sector angle foil computed at 10k rpm

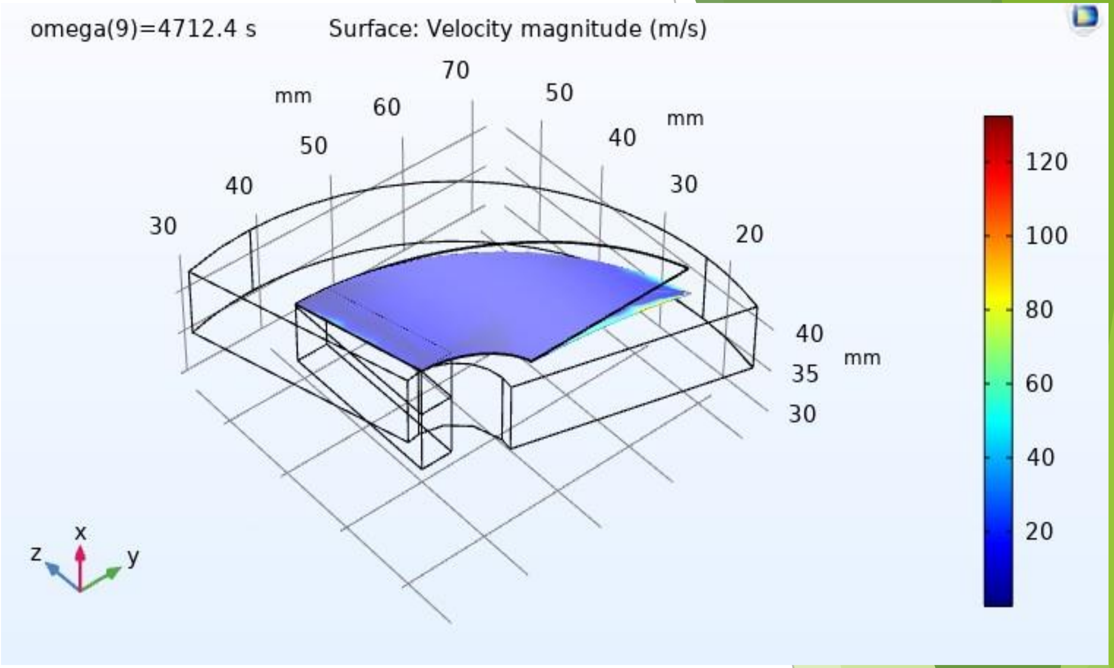


Figure 14 Maximum Foil Deflection of 90-degree sector angle foil computed at 10k rpm

- We found that the maximum load on foil at 10k rpm is around 65.2041 N and the Deflection is 0.0285mm.
- We can see an increase in load-carrying capacity when compared to a 30-degree sector angle and 60-degree sector angle.

DIFFERENT FOIL THICKNESS CONFIGURATIONS

- After changing the sector angle configuration and Simulating we found out a 90-degree sector angle gives maximum load and less deflection when compared with another sector angles configuration.
- So now we change the model by increasing the thickness of foil to 0.1mm,0.15mm,0.2mm,0.3mm,0.4mm, and 0.5mm the simulation results are shown below.

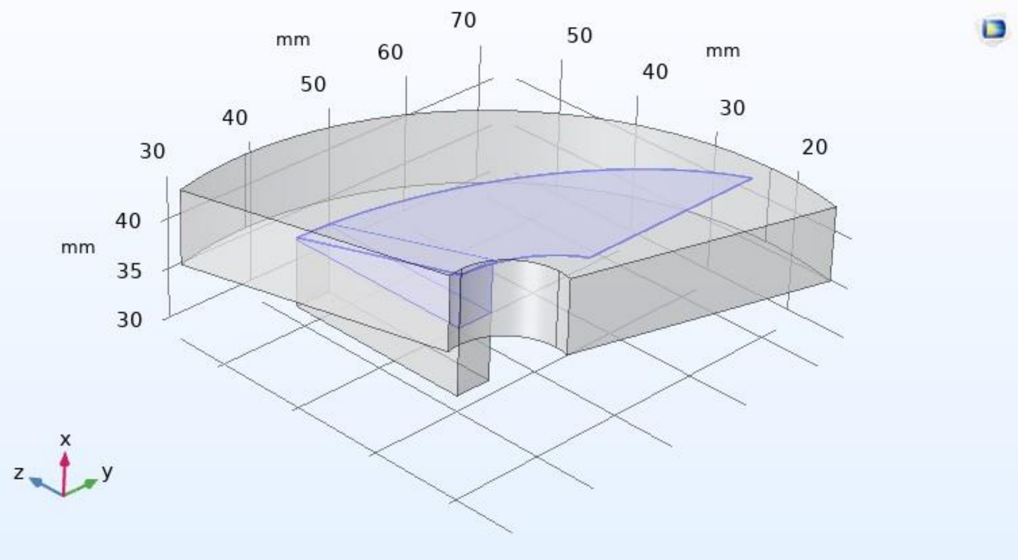


Figure 15 Model of 90-degree sector angle foil with 0.1mm thickness

- We found the maximum load on foil at 50k rpm is around 67.1952N and the Deflection is 0.5301mm
- Then we again changed the thickness of foil to 0.15mm as shown in figure 16.

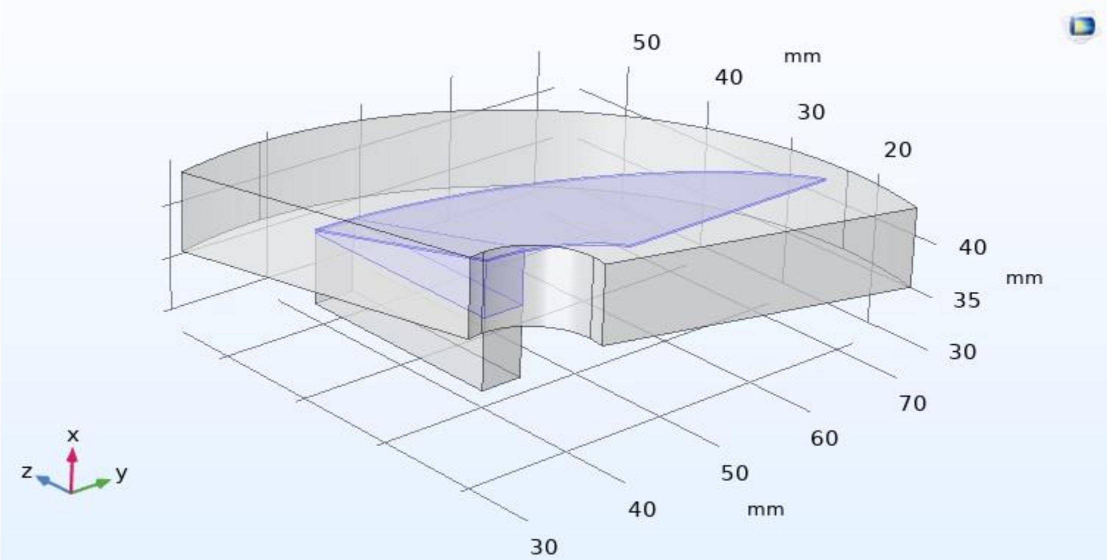


Figure 16 Model of 90-degree sector angle foil with 0.15mm thickness

- We found that the maximum load on foil at 50k rpm is around 67.2754N and the Deflection is 0.7068mm.

90-DEGREE SECTOR ANGLE FOIL WITH 0.2MM AND 0.3MM THICKNESS RESULTS

- We then again changed the thickness of foil to 0.2mm

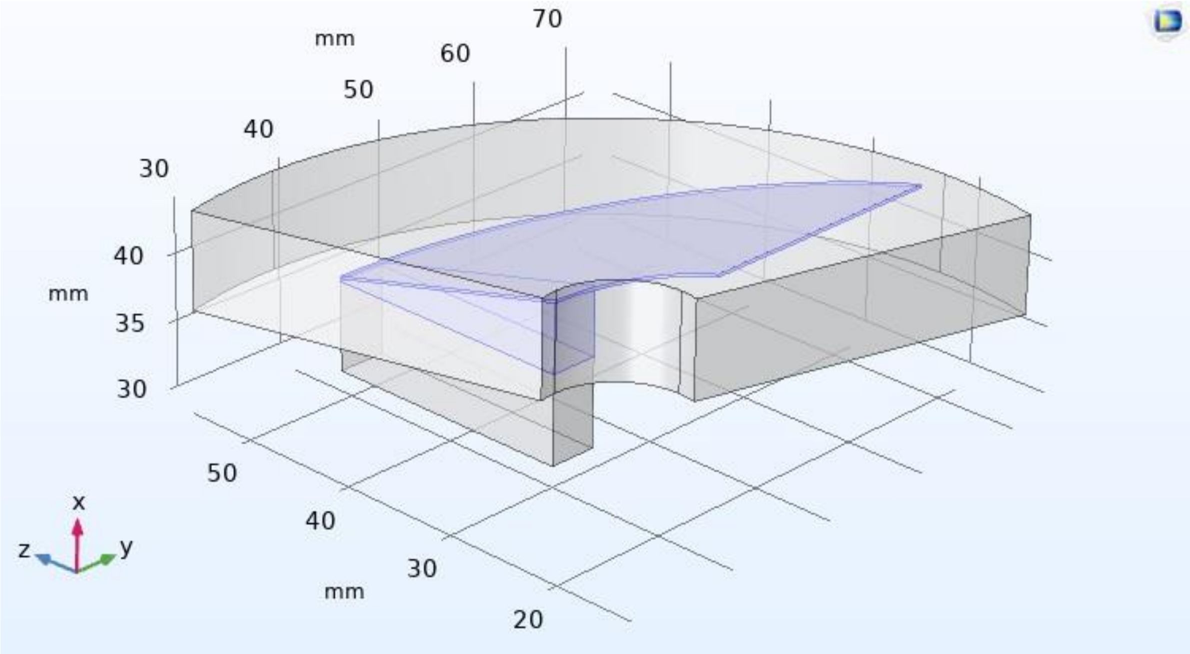


Figure 17 Model of 90-degree sector angle foil with 0.2mm thickness

- We found that the maximum load on foil at 50k rpm is around 67.4255N and the Deflection is 0.5152mm of 90-degree sector angle foil with 0.2mm thickness.

- We then again changed the thickness of foil to 0.3mm

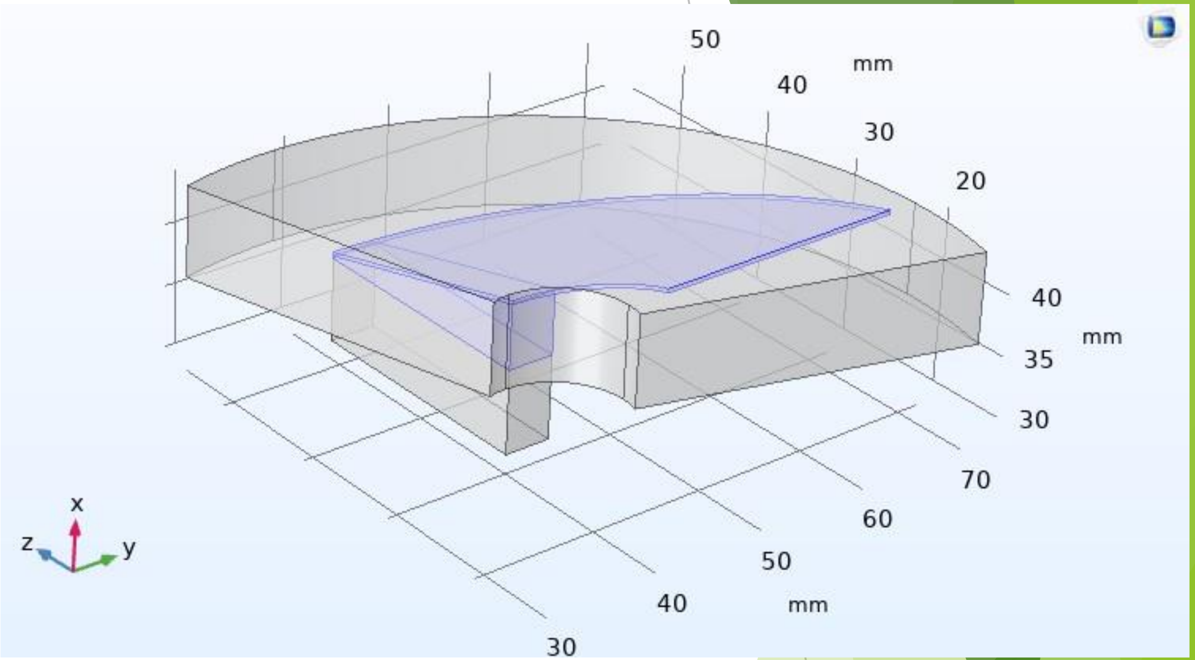


Figure 18 Model of 90-degree sector angle foil with 0.3mm thickness

- We found that the maximum load on foil at 50k rpm is around 67.5790N and the deflection is 0.4475mm of 90-degree sector angle foil with 0.3mm thickness.

90-DEGREE SECTOR ANGLE FOIL WITH 0.4MM AND 0.5MM THICKNESS RESULTS

- We then again changed the thickness of foil to 0.4mm

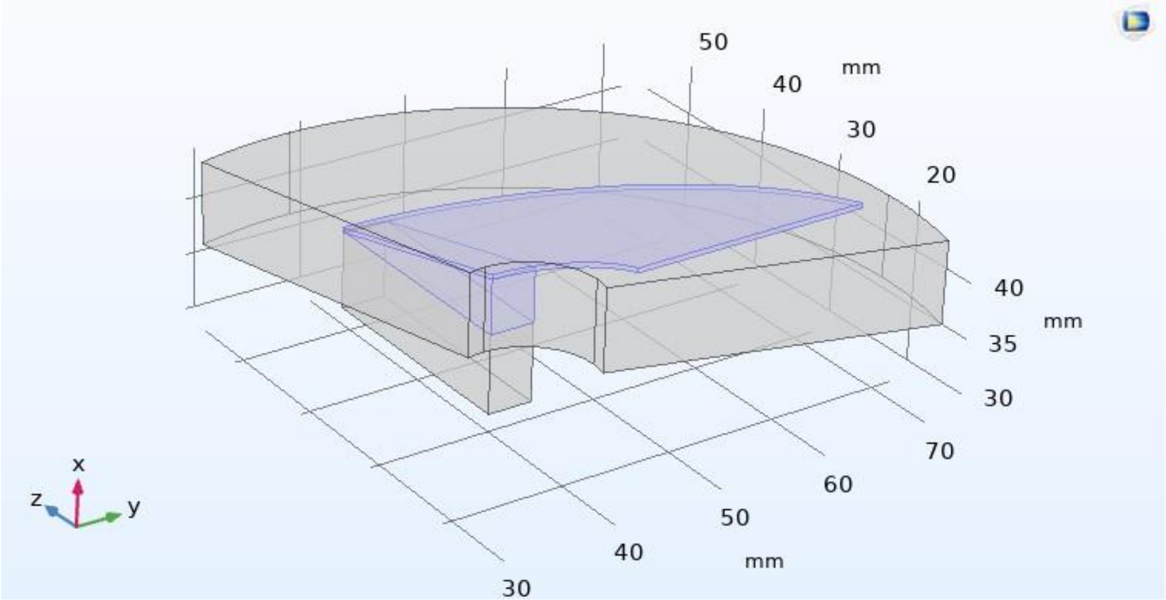


Figure 19 Model of 90-degree sector angle foil with 0.4mm thickness

- We found that the maximum load on foil at 50k rpm is around 68.5936N and the Deflection is 0.4215mm in 90-degree sector angle foil with 0.4mm thickness configuration.

- We then again changed the thickness of foil to 0.5mm

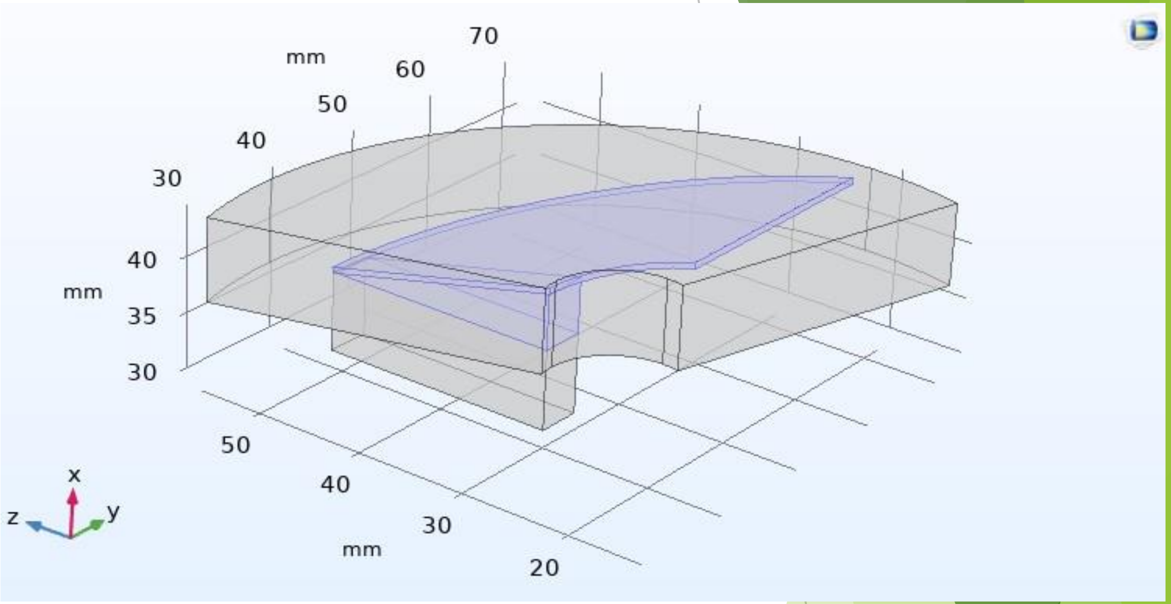


Figure 20 Model of 90-degree sector angle foil with 0.5mm thickness

- We found that the maximum load on foil at 50k rpm is around 67.8318N and the Deflection is 0.1594mm in 90-degree sector angle foil with 0.5mm thickness configuration

STRESS DISTRIBUTION & MAXIMUM DEFLECTION PLOT RESULTS

- Stress Distribution of 90-degree sector angle foil of 0.5mm thickness

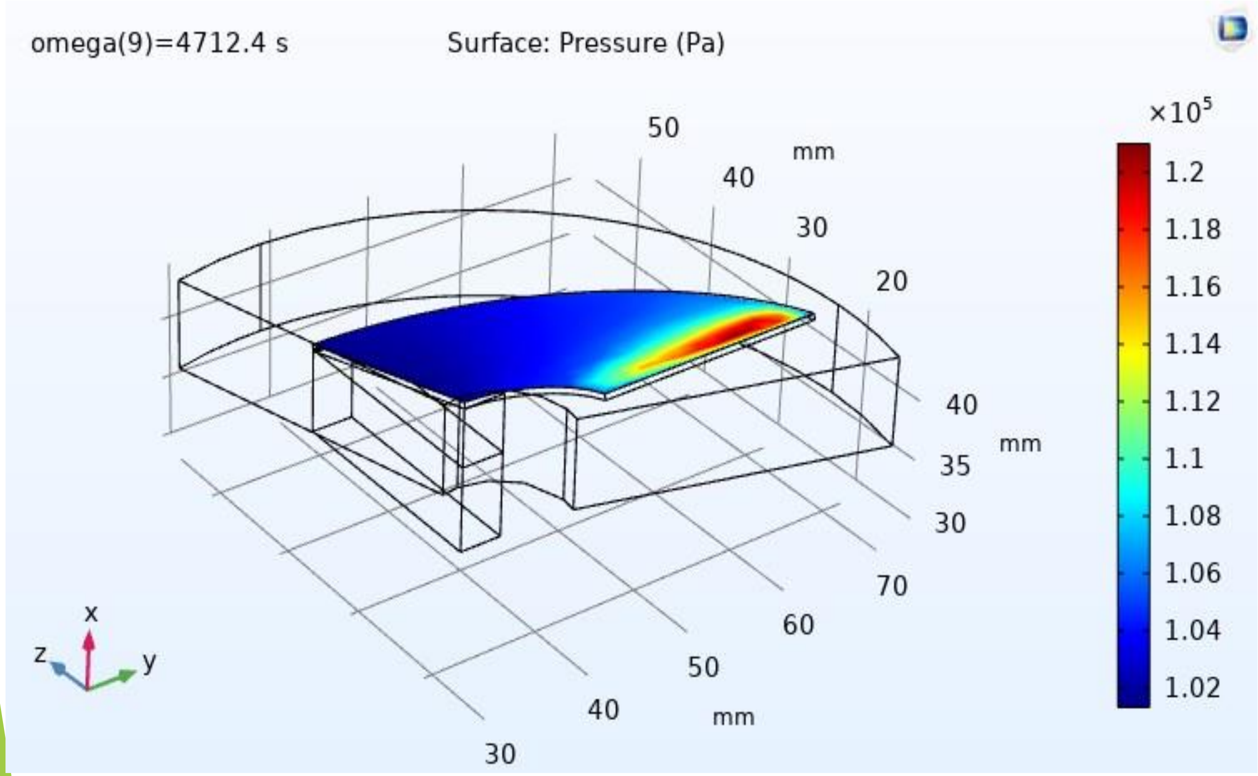


Figure 21 Stress Distribution due to Pressure of 90-degree sector angle foil of 0.5mm thickness computed for 50k rpm

- Maximum Foil Deflection of 90-degree sector angle foil of 0.5mm thickness

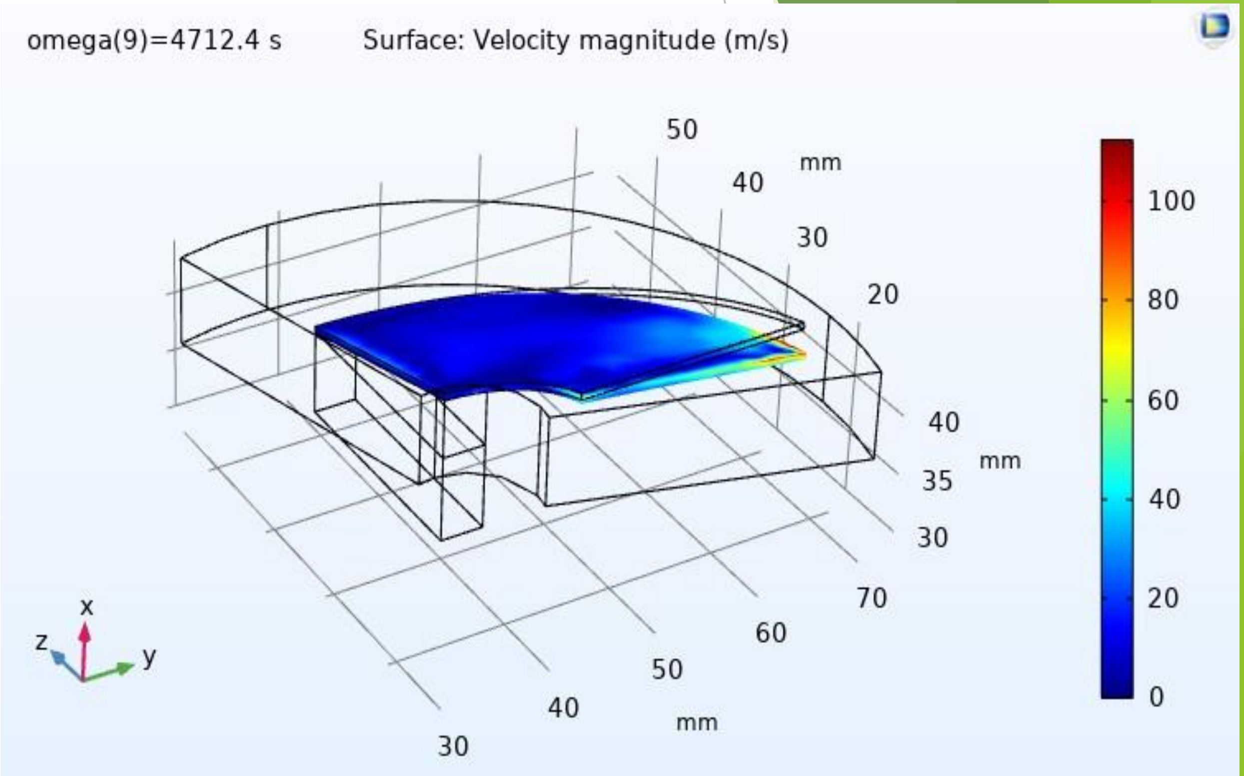


Figure 22 Maximum Foil Deflection of 90-degree sector angle foil of 0.5mm thickness computed for 50k rpm

DIFFERENT FOIL THICKNESS RESULTS PLOTTED AS GRAPH

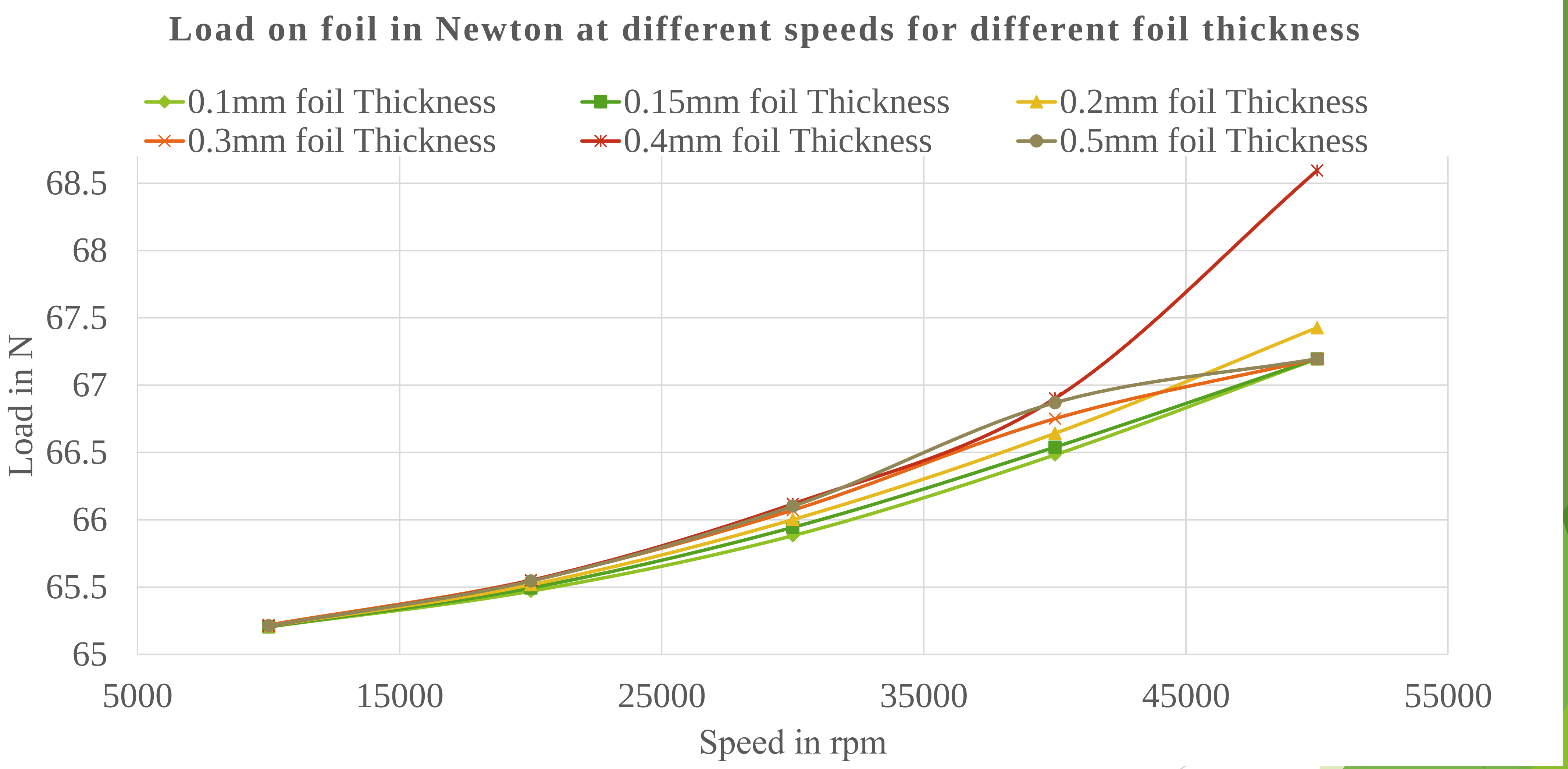


Figure 23 Load on 90-degree sector angle foil computed for different foil thickness and speeds

DIFFERENT FOIL THICKNESS RESULTS PLOTTED AS GRAPH

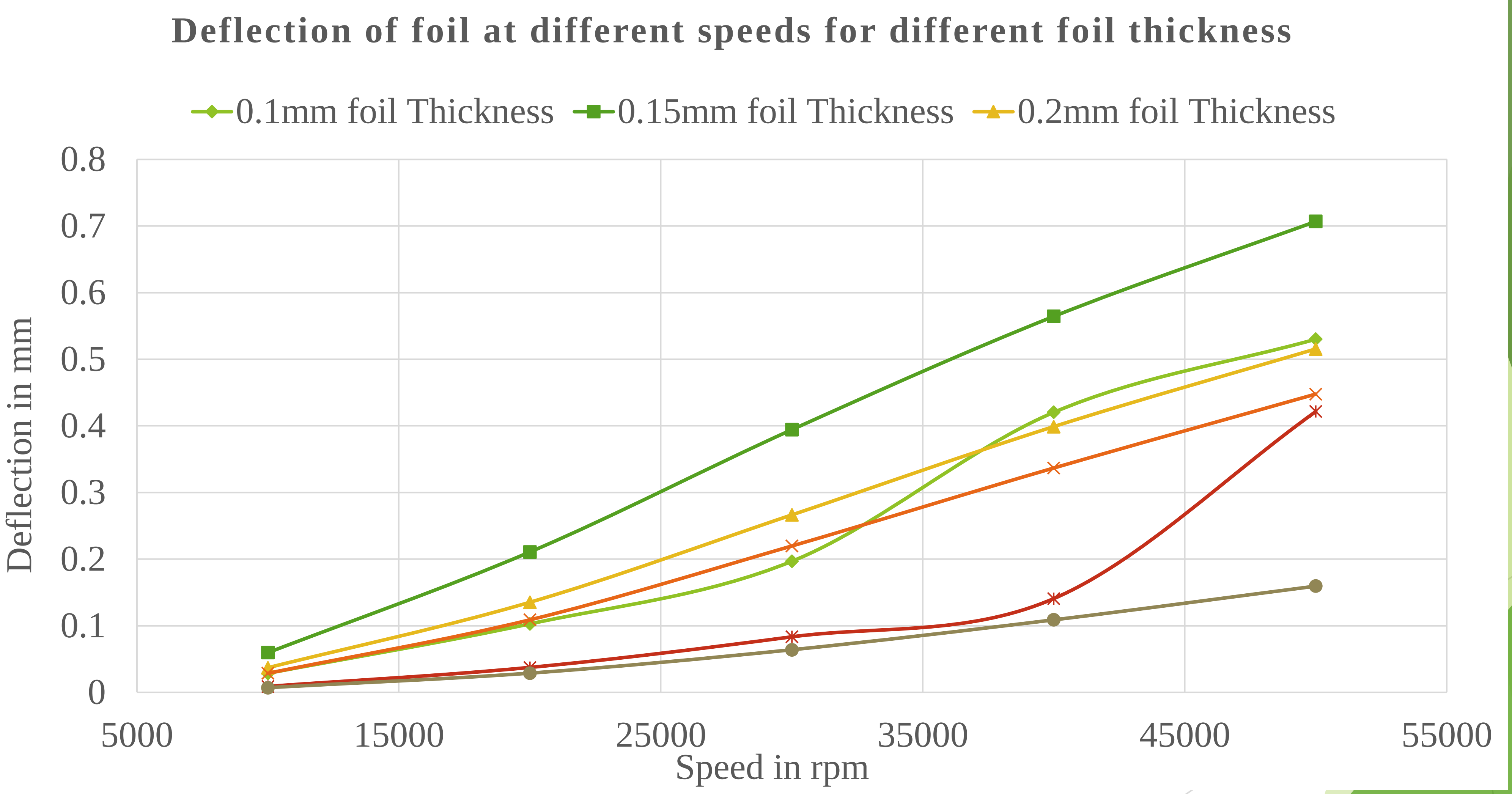


Figure 24 Deflection of 90-degree sector angle foil computed for different foil thickness and speeds

VISCOELASTIC SUPPORT CONFIGURATION

- After changing the thickness, we found that increasing the thickness decreases the deflection of foil and the foil deforms less when the thickness is more and found little bit improvement in load-carrying capacity.
- We modeled viscoelastic support for the 90-degree sector angle single foil with Viscoelastic support (Single Air Bubble from bubble wrap) in the corner of the foil as shown below.

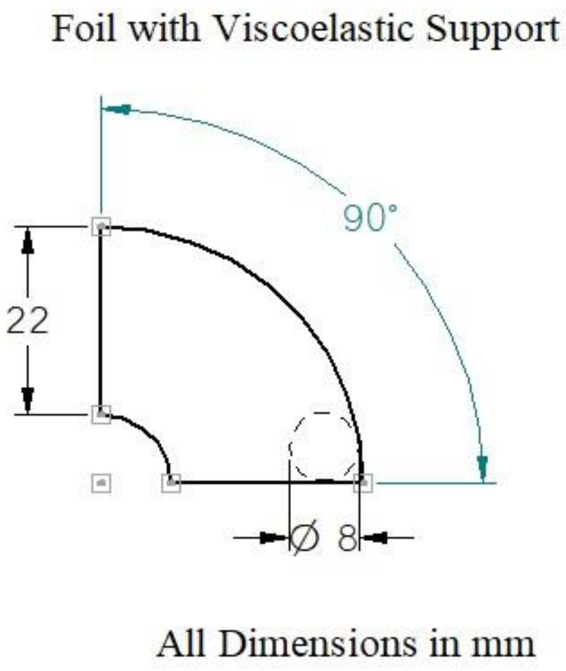


Figure 25 2D drawing of 90-degree sector angle foil with viscoelastic support (Air bubble) in corner

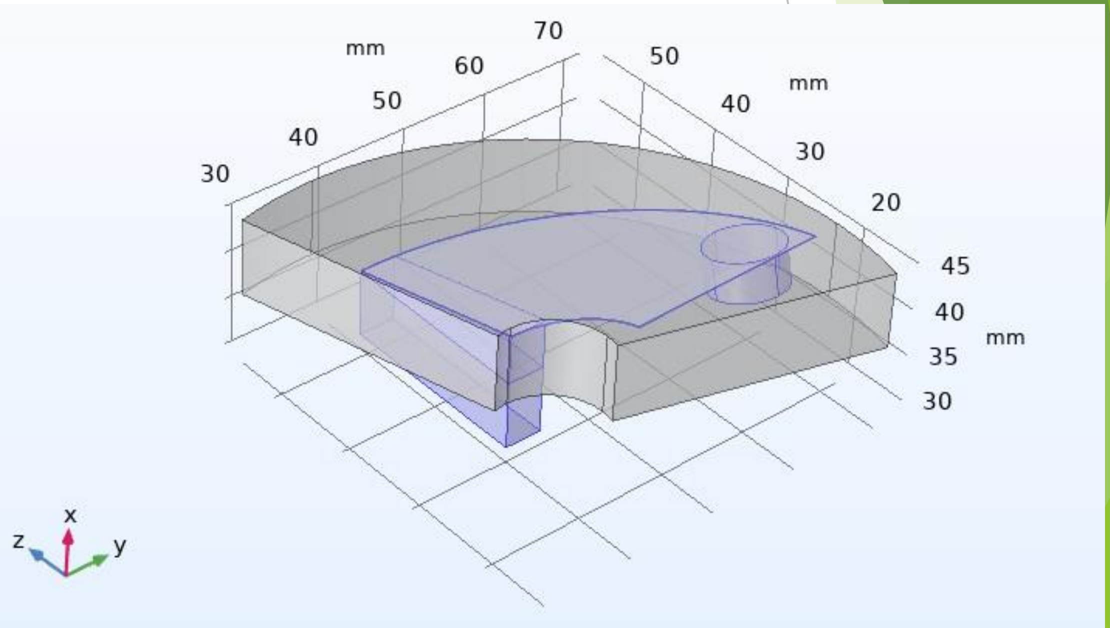


Figure 26 Model of 90-degree sector angle foil with viscoelastic support (Air Bubble)

VISCOELASTIC SUPPORT CONFIGURATION RESULTS

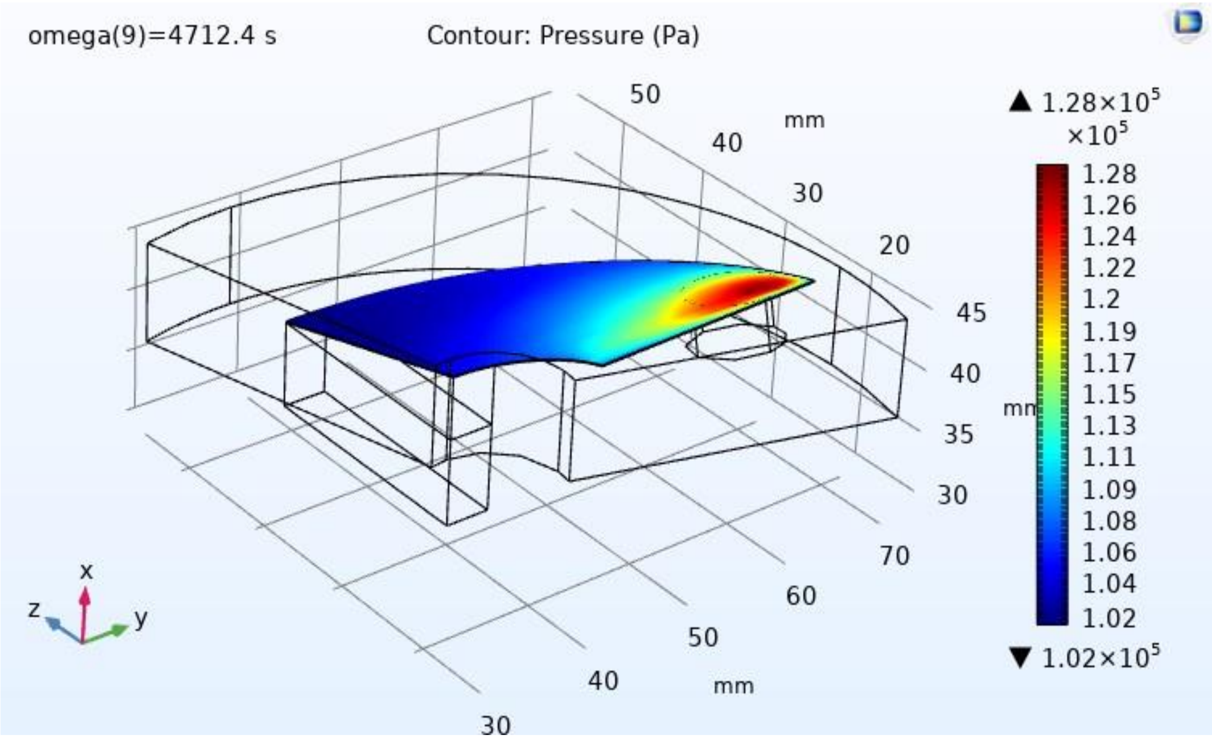


Figure 27 Stress Distribution due to Pressure of 90-degree sector angle foil with viscoelastic support (Air Bubble) computed at 30k rpm

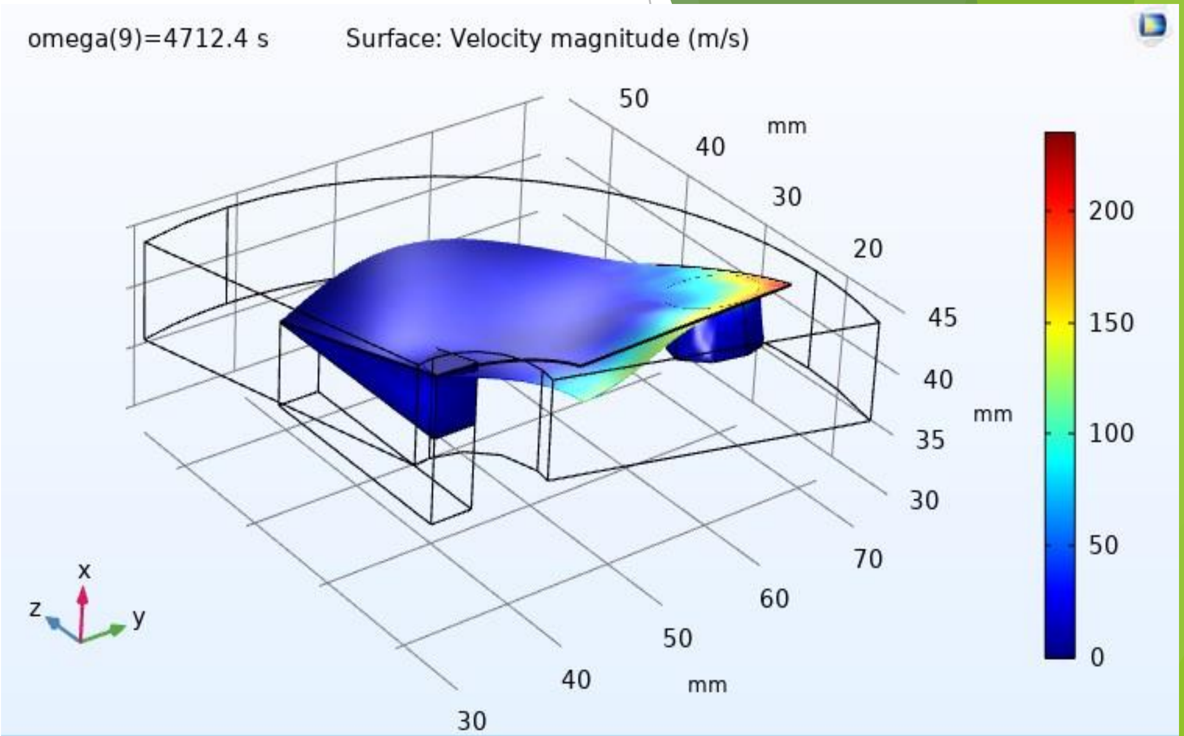
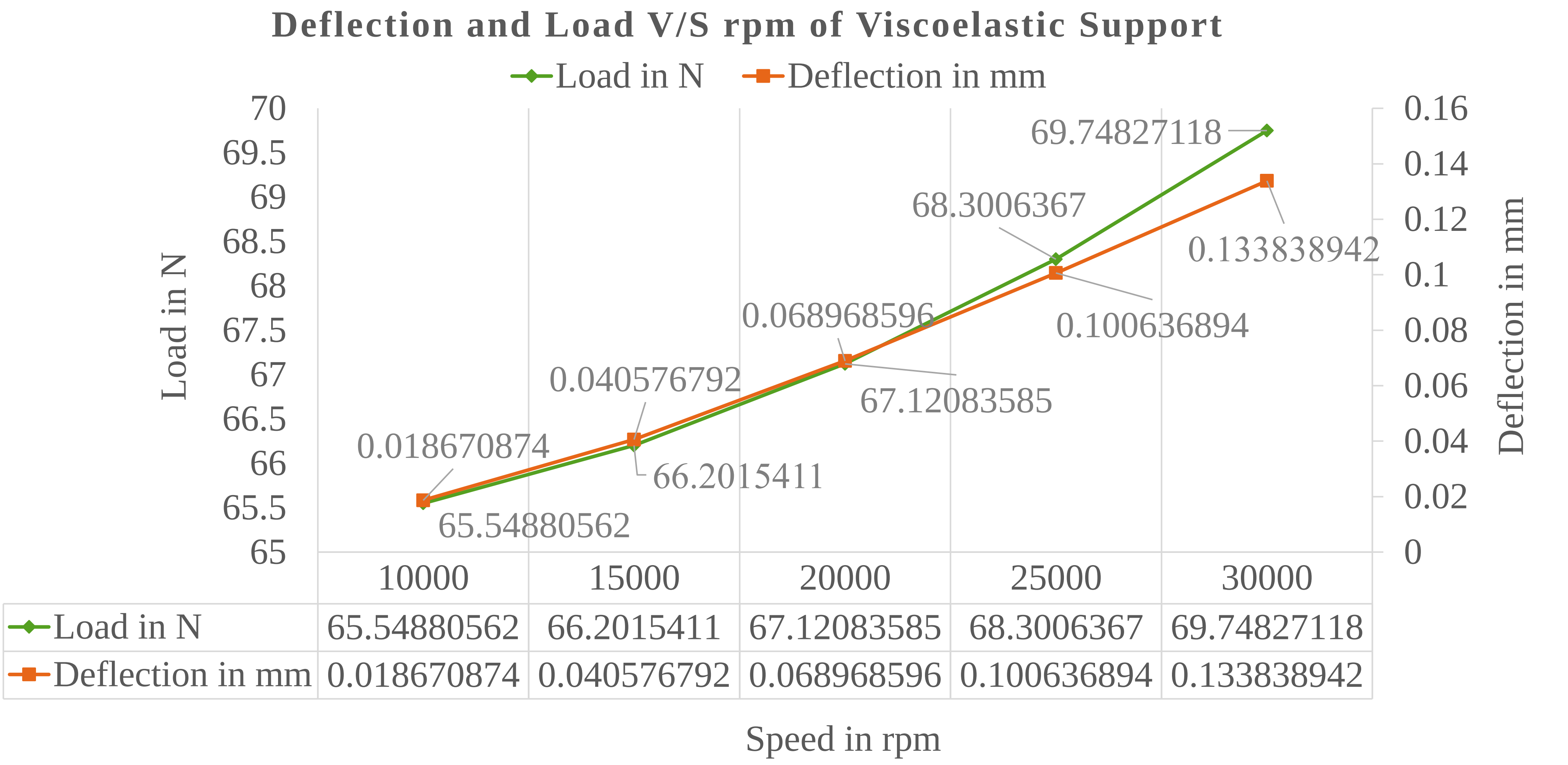


Figure 28 Maximum Foil Deflection of 90-degree sector angle foil with viscoelastic support (Air Bubble) computed at 30k rpm

- We found that the maximum load on foil at 30k rpm is around 69.74N and the Deflection is 0.13 mm.
- Due to support, there is an improvement in load and the deflection also reduced when compared to previous models with no support.

VISCOELASTIC SUPPORT CONFIGURATION RESULTS PLOTTED AS GRAPH



	10000	15000	20000	25000	30000
Load in N	65.54880562	66.2015411	67.12083585	68.3006367	69.74827118
Deflection in mm	0.018670874	0.040576792	0.068968596	0.100636894	0.133838942

Figure 29 Sector angle 90-degree foil computed for viscoelastic support (Air Bubble)

VISCOELASTIC SUPPORT CASE 1 AND 2 RESULTS

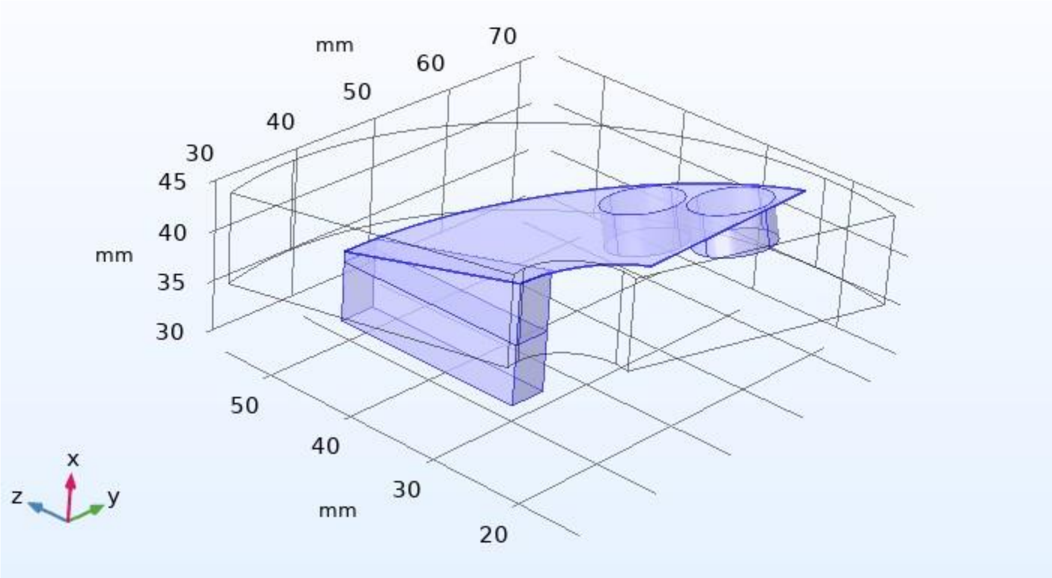


Figure 30 Model of 90-degree sector angle foil with 2 viscoelastic support (Air Bubble) Case 1

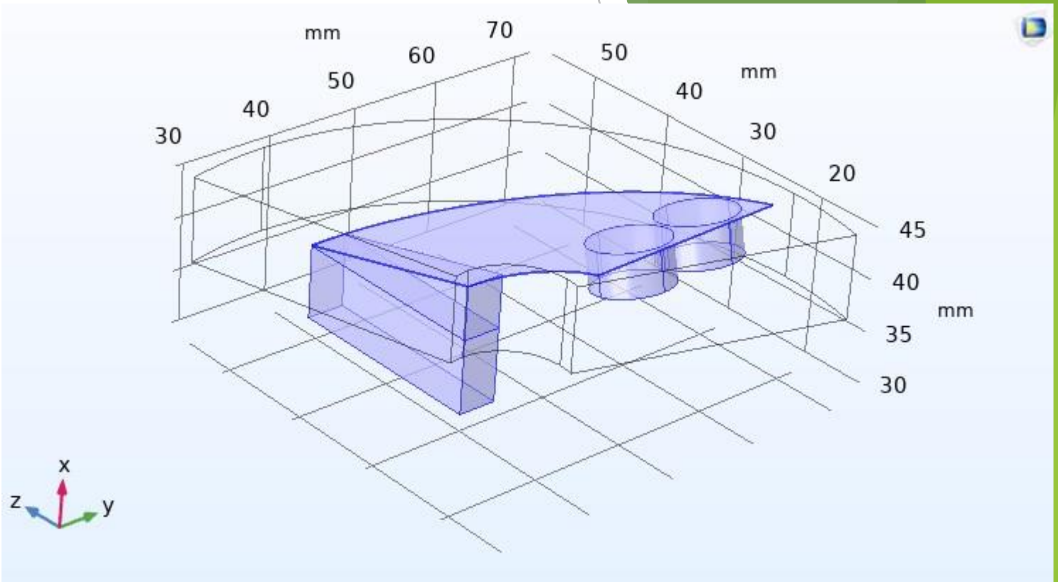


Figure 31 Model of 90-degree sector angle foil with 2 viscoelastic support (Air Bubble) Case 2

- We found that the maximum load on foil at 30k rpm is around 70.12N and Deflection is 0.1186mm.
- Then we again changed the position of the viscoelastic supports as shown in figure 31.

- We found that the maximum load on foil at 30k rpm is around 70.13N and Deflection is 0.1048mm

VISCOELASTIC SUPPORT CASE 3 AND 4 RESULTS

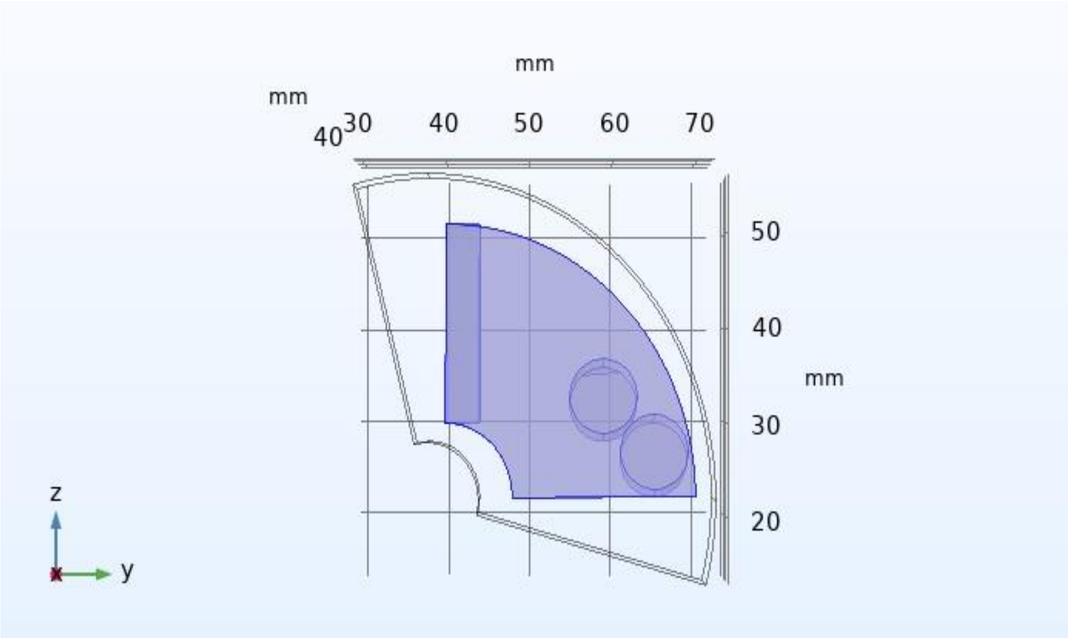


Figure 32 Model of 90-degree sector angle foil with 2 viscoelastic support (Air Bubble) Case 3

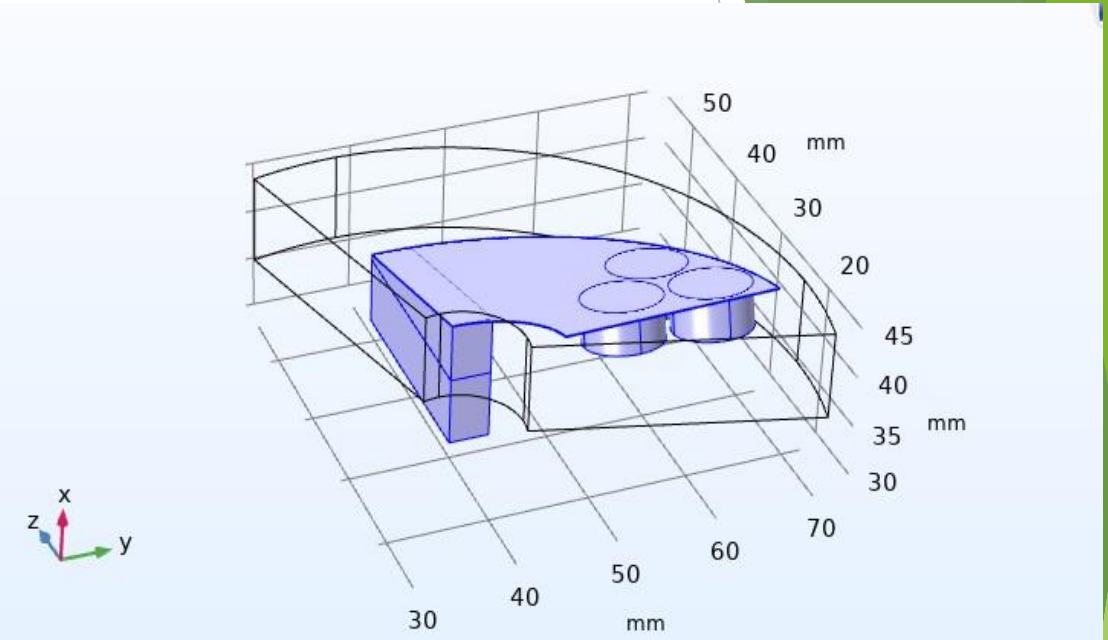


Figure 47 Model of 90-degree sector angle foil with 3 viscoelastic support (Air Bubble) Case 4

- We found that the maximum load on foil at 30k rpm is around 69.66N and Deflection is 0.07896mm in 90-degree sector angle foil with 2 viscoelastic support (Air Bubble) Case 3 configuration.

- We found that the max load on foil at 30k rpm is around 69.9712N and the Deflection is 0.08024mm in 90-degree sector angle foil with 3 viscoelastic support (Air Bubble) Case 4 configuration.

RESULTS AND DISCUSSION

- The simulation of thrust foil bearing and its analysis was done. The designed model of a thrust foil bearing with 90-degree sector angle foil with 2 viscoelastic support (Air Bubble) Case 2 configuration gives maximum load-carrying capacity when compared with all other configurations we did before.
- Testing and simulations of thrust foil bearing were done by using COMSOL 5.0v Multiphysics software and the design was seen to be safe for running at **30k rpm** with no problems.
- The maximum load-carrying capacity was around **70.13N**. Stress distribution on foil shows stress concentration towards the trailing edge of the foil. The best results that we got from all configurations are shown below.

Sl.no	Configuration	Load in N	Deflection in mm
1	Viscoelastic Support Case 2	70.13N	0.1048mm
2	Foil Thickness 0.5mm	67.19N	0.1594mm
3	90 Degree Sector Angle	65.20N	0.0285mm
4	60 Degree Sector Angle	48.61N	0.2179 mm
5	30 Degree Sector Angle	34.75N	0.0065 mm

CONCLUSION

- This project has succeeded in its goal by providing a simulation model to facilitate the design of thrust foil bearing.
- The conclusions of this preliminary work emphasize the importance of foil thickness, the number of foils, angle of foil, and foil supports.
- An attempt has been made to conduct simulation analysis in nature to obtain quantitative values of load carrying capabilities of thrust foil bearings as a function of different geometric and operating parameters.
- Detailed analysis and simulations were studied and were conducted to evaluate the quantitative values of the load carried by the foil thrust bearing under dynamic conditions.
- Higher load carrying capabilities have been observed for the foil thrust bearing with support to foil .

REFERENCES

1. **Dr. Hooshang Heshmat** "Major Breakthrough In Load Capacity, Speed And Operating Temperature Of Foil Thrust Bearings" World Tribology Congress September 12-16, 2005, Washington, D.
2. **Quan Zhou, YuHou, Chunzheng Chen** "Dynamic stability experiments of compliant foil thrust bearing with viscoelastic support" Tribology International 42 (2008) 662–665
3. **Yong-Bok Lee, Tae Young Kim, Chang Ho Kim & Tae Ho Kim**" Thrust Bump Air Foil Bearings with Variable Axial Load: Theoretical Predictions and Experiments" Tribology Transactions, 54: 902-910, 2011Copyright C _ 2011 KIST.
4. **Franck Balducchi, Mihaı¨ Arghir, Romain Gauthier, Emelyne Renard** "Experimental Analysis of the Start-Up Torque of a Mildly Loaded Foil Thrust Bearing" Journal of Tribology 2013 by ASME JULY 2013, Vol. 135 / 031702-1
5. **Tae Ho Kim, Tae Won Lee** "Design Optimization of Gas Foil Thrust Bearings for Maximum Load Capacity" Proceedings of ASME Turbo Expo 2015: Turbine Technical Conference and Exposition GT 2015 June 15 – 19.
6. **Kai Feng, Liang-Jun Liu, Zhi-Yang Guo, and Xue-Yuan Zhao**." Parametric study on static and dynamic characteristics of bump-type gas foil thrust bearing for oil-free turbomachinery" Proc IMechE Part J: J Engineering Tribology0(0) 1–18! IMechE 2015.

7. Yueqing Zheng, Tianwei Lai, Shuangtao Chen, Liang Chen, Liqiang Liu, and Yu Hou, “Static characteristics of six pads multilayer protuberant foil thrust bearings” Proc IMechE Part J: J Engineering Tribology0(0) 1–7! IMechE 2016

8. P Samanta1 And Mm Khonsari,” The Limiting Load-Carrying Capacity of Foil Thrust Bearings,” Department of Mechanical and Industrial Engineering, Louisiana State University, Patrick Taylor Hall, Baton Rouge, La 70803, USA- 2017.

9. Zbigniew Kozanecki, Jakub Łagodziński, Eliza Tkacz, Kacper Miazga, “Performance Of Thrust Airfoil Bearing For Oil-Free Turbomachinery,” Institute Of Turbomachinery, Lodz University Of Technology, 219/223 Wólczańska Str., 90-924 Lodz, Poland.

10. Nguyen T. LaTray and Daejong Kim “A HIGH-SPEED TEST RIG CAPABLE OF RUNNING AT 190,000RPM TO CHARACTERIZE GAS FOIL THRUST BEARINGS” Proceedings of ASME Turbo Expo 2018 Turbomachinery Technical Conference and Exposition GT2018 June 11-15, 2018, Oslo, Norway.

Thank You..