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Performance Analysis of Conical Journal Bearing using CFD (Computational Fluid Dynamics)

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Abstract: - Heavy duty applications and precision machines like grinding machines generate radial and axial loads on journal bearings. Instead of using a thrust and cylindrical bearing, a conical journal bearing can be used which can sustain both axial and radial loads. In present work, we analyze the performance of the conical journal bearing using CFD analysis to study effect of change of flow regimes.

1. INTRODUCTION

Hydrodynamic journal bearing is a bearing operating with hydrodynamic lubrication, in which the bearing surfaces are separated from the journal surface by the lubricant film, generated by the journal rotation. The operation of a hydrodynamic journal bearing depends upon the shearing of a film of lubricant in the clearance space between the bearing and the journal load supporting pressure is generated within the film by continuous rotation of the journal. Such journal bearing is used to describe externally pressurized bearings with flow control devices.

Hydrodynamic bearings have found increasing applications in various types of machinery owing to certain favourable characteristics, such as high load-carrying capacity, increased minimum fluid-film thickness, long life, and increased support damping. This makes them attractive for various applications such as high speed turbo machinery, machine tool spindles, reactor coolant pumps, liquid rocket engine turbo-pumps, and precision grinder spindles. In view of their many advantages, hydrodynamic bearings are being considered as alternatives to rolling-element bearings and have been employed very successfully for many years in low-speed machinery that supports high load with low friction.

In plain hybrid bearings recesses in the bearing surfaces are avoided in order to maximize the hydrodynamic effect. There are basically two types of plain hybrid bearing depending upon whether the feed is by slot entry or hole entry. In slot-entry type the restrictors are formed by a slotted shim fabricated into the bearing. A slot-entry bearing needs finer filtration to prevent gradual silting of the slot restrictors. A hole entry bearing may be more prone to complete blockage of a restrictor due to a single particle of debris that was not flushed out of the system on assembly. Slot- and hole entry bearings may be designed in single- and double-row configurations.

Owing to the application of non-recessed hybrid journal bearings in high-speed machinery, it has become important that their transient response should be studied in order to ensure the stability of the systems at the high speeds of operation. Kumar et al. analysed the effect of the rate of acceleration and deceleration on the journal movement during the starting and stopping of a hole-entry journal bearing. It was concluded that the journal centre position after acceleration and deceleration depends on the respective rate of acceleration and deceleration.

Performance analysis of Hydrodynamic journal bearing parameters operating in different flow regimes i.e. Laminar flow, turbulent flow considering static and dynamic parameters of bearing. Analysis of the characteristics of turbulent flow of lubrication in journal bearing, also determination on the load carrying capacity of bearing in turbulent flow regime is done by using different Reynold’s numbers. Reynold’s number decides the flow of lubrication. The variable parameters of lubricant will give different Reynold’s numbers to get the turbulent flow of lubrication while performance of journal bearing. In this paper we find that the effect on pressure, load carrying capacity, coefficient of friction of the Reynold’s number and performance of journal bearing.

2. NEED OF THE STUDY

To carry out Performance analysis of hydrodynamic journal bearing, operating in different flow regimes with considering various parameters of bearing. The bearing geometry parameters affect the maximum static pressure and performance of bearing. Analysis of the characteristics of turbulent flow of lubrication in journal bearing, also determination of the maximum static pressure generated inside the bearing in different flow regime is done by using CFD Analysis. Various values of Reynold's numbers from 800 – 10000 are consider for the analysis of bearing. The variable parameters of lubricant will give different Reynold's numbers to get the turbulent flow of lubrication while performance of journal bearing.

3. OBJECTIVES:-

The objectives set for this study are listed below in step by step manner.

- To study the basics of bearing performance.
- To find various parameters affecting the bearing performance.
- To determine the effect of the eccentricity ratio, Reynold's number, aspect ratio, semi cone angle on static pressure and performance of journal bearing using appropriate analysis software.
- Verification of the simulation results with the experimental results.

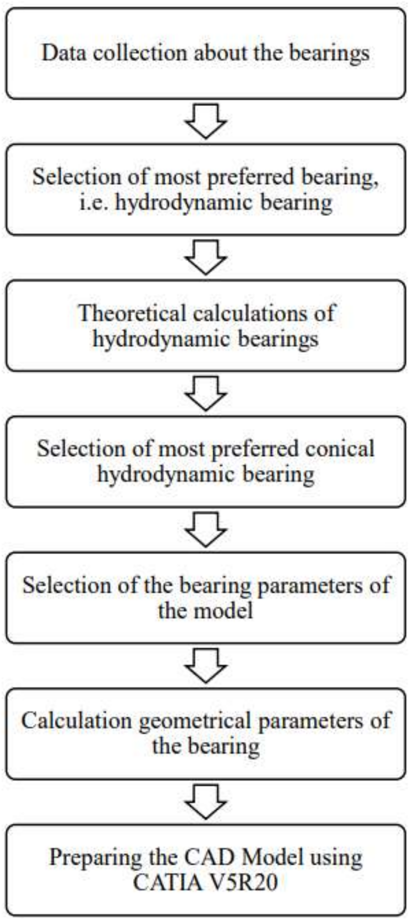
4. DATA AND SOURCES OF DATA

The parameters which are affecting the performance of hydrodynamic journal bearing are:

- Flow Regime
- Non-Newtonian Lubricants
- Bearing Geometry Parameters
- Thermal Effects
- Fluid Inertia
- Supply Pressure
- Flow Control Devices
- Fluid Compressibility
- Journal Misalignment
- Bearing Flexibility
- Surface Roughness

From above parameters, the performance analysis can be carried out using flow regime, bearing geometry parameters, supply pressure and lubrication using CFD analysis and validate it with the experimental results.

5. RESEARCH METHODOLOGY



6. THEORETICAL FRAMEWORK

6.1 Bearing:

A bearing is a machine element that constrains relative motion to only the desired motion, and reduces friction between moving parts. These are mechanical assemblies that consist of rolling elements and usually inner and outer races which are used for rotating or linear shaft applications, the design of the bearing may, for example, provide for free linear movement of the moving part or for free rotation around fixed axis; or, it may prevent a motion by controlling the vectors of normal forces that bear on the moving parts. Most bearings facilitate the desired motion by minimizing friction.

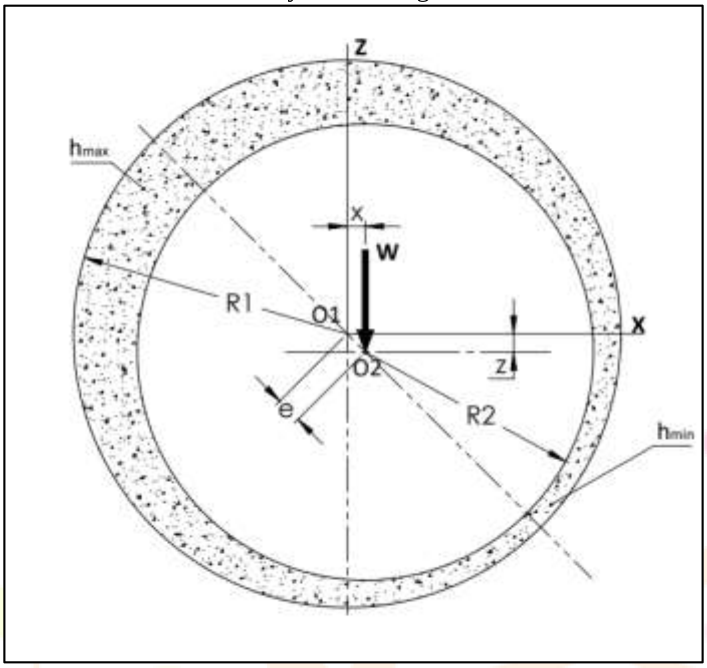


Fig. 6.1.1 Design of Bearing

Bearings are categorized based on their operational type, allowed motions, and the directions of applied loads. There are various types of bearings, including ball and roller bearings, linear bearings, as well as mounted bearings that can use either rolling element bearings or plain bearings. Ball bearings have spherical rolling elements and are suitable for lower load applications, while roller bearings use cylindrical rolling elements to handle heavier load requirements. Linear bearings facilitate linear movements along shafts and may also offer rotational capabilities. Mounted bearings are pre-assembled assemblies that are bolted to frames, stanchions, etc., and are used to support the ends of shafts, conveyor rollers, and similar components. Apart from ball and roller bearings in their radial, linear, and mounted forms, there are also slide bearings for civil engineering applications, jewel bearings used in small instruments, and other specialized frictionless bearings such as air and magnetic bearings. Additionally, sleeve bearings, journal bearings, and other fluid-film bearings are part of the broader category of bushings. Rotary bearings are responsible for holding rotating components like shafts and axles within mechanical systems. They transfer axial and radial loads from the load source to the supporting structure. The simplest form of bearing is the plain bearing, which consists of a shaft rotating in a hole. Lubrication is utilized to reduce friction. In ball bearings and roller bearings, circular cross-sectioned rolling elements like balls or rollers are situated between the races or journals of the bearing assembly to minimize sliding friction. A wide range of bearing designs is available to meet specific application requirements, ensuring maximum efficiency, reliability, durability, and performance. The term bearing is derived from the word to bear, a bearing being a machine element that allows one part to bear another. The simplest bearings are bearing surfaces, cut of formed in to a part, size, roughness, and location of the surface. Other bearings are separate devices installed in a machine or machine part. The most sophisticated bearings for the most demanding applications are very precise components; their manufacture requires some of the highest standards of current technology.

Applications:

Bearing applications span across virtually every industry which employs moving components and equipment. For example:

- Ball and roller bearings are used in machinery of all kinds; from boiler feed pumps to automotive transmissions.
- Mounted bearings are especially common on conveyors, in shaft linkages, and particularly where long lengths of shafting must be supported by housed units where the bearing is not protected by another housing such as a transmission case.
- Linear bearings are used exclusively in linear applications such as slide tables.
- Slide bearings are used primarily for load-bearing application in large civil engineering projects such as bridges where they accommodate a limited range of movement, unlike the other bearings here, where motion—either radial or linear—is the main concern.
- Jewel bearings are restricted to very small devices and movements and do not rely on any rolling elements.
- Frictionless bearings are any of the other special-purpose designs that include air bearings, magnetic bearings, etc.

While bearings are used nearly everywhere, there are some industries that use so many or have specific requirements for durability, cleanliness, etc. that they warrant mentioning here. Some of these industries are:

- Aerospace
- Agricultural
- Automotive
- Machine Tools
- Medical
- Mining

6.2 Conical Journal Bearing:

Journal or plain bearings consist of a shaft or journal which rotates freely in a supporting metal sleeve or shell. There are no rolling elements in these bearings. Their design and construction may be relatively simple, but the theory and operation of these bearings can be complex. This article concentrates on oil and grease-lubricated full fluid film journal bearings; but first a brief discussion of pins and bushings, dry and semi lubricated journal bearings, and tilting-pad bearings.

Low-speed pins and bushings are a form of journal bearing in which the shaft or shell generally does not make a full rotation. The partial rotation at low speed, before typically reversing direction, does not allow for the formation of a full fluid film and thus metal-to-metal contact does occur within the bearing. Pins and bushings continually operate in the boundary lubrication regime. These types of bearings are typically lubricated with extreme pressure (EP) grease to aid in supporting the load. Solid molybdenum disulfide is included in the grease to enhance the load-carrying capability of the lubricant.

Many outdoor construction and mining equipment applications incorporate pins and bushings. Consequently, shock loading and water and dirt contamination are often major factors in their lubrication. Dry journal bearings consist of a shaft rotating in a dry sleeve, usually a polymer, which may be blended with solids such as molybdenum, graphite, PTFE or nylon. These bearings are limited to low-load and low-surface speed applications. Semi-lubricated journal bearings consist of a shaft rotating in a porous metal sleeve of sintered bronze or aluminium in which lubricating oil is contained within the pores of the porous metal. These bearings are restricted to low loads, low-to-medium velocity and temperatures up to 100°C (210°F).Tilting-pad or pivoting-shoe bearings consist of a shaft rotating within a shell made up of curved pads. Each pad is able to pivot independently and align with the curvature of the shaft. A diagram of a tilt pad bearing is presented. The advantage of this design is the more accurate alignment of the supporting shell to the rotating shaft and the increase in shaft stability which is obtained.

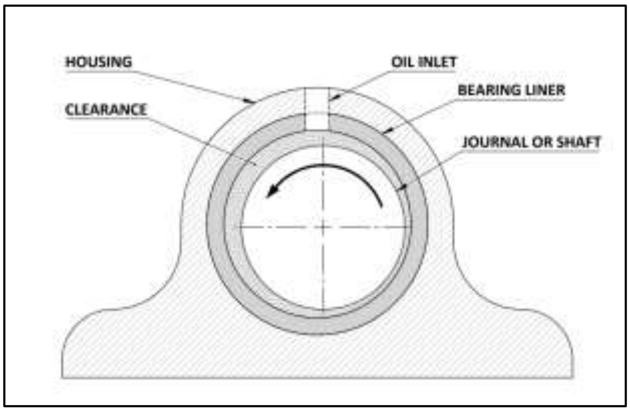


Fig. 6.2.1 Journal Bearing

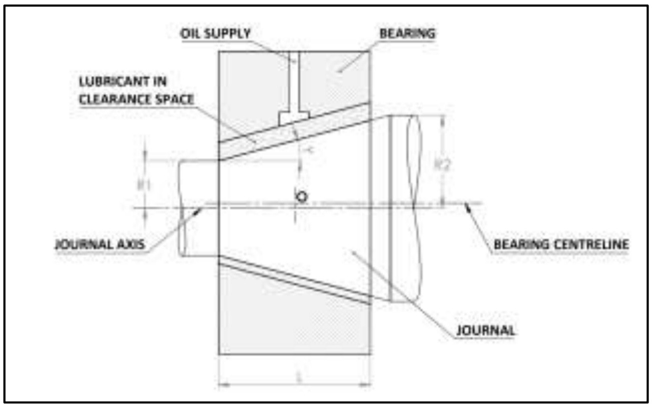


Fig. 6.2.2 Conical Journal Bearing

Journal bearings encompass sleeve, plain, shell, and Babbitt bearings. The term "Babbitt" specifically refers to the layers of softer metals (such as lead, tin, and copper) that constitute the metal contact surface of the bearing shell. During equipment start-up and shutdown, when the rotational speed of the shaft (journal) is insufficient to establish an oil film, journal bearings operate in the boundary regime, resulting in metal-to-metal contact. It is during these periods that the majority of damage to the bearing occurs.
To mitigate such damage, hydrostatic lift can be employed by utilizing an external pressurized oil feed to float large, heavy journals prior to shaft rotation. This prevents direct contact and associated harm. During normal operation, the shaft rotates at a speed that generates sufficient force to create an oil wedge between the curved surfaces of the shaft and shell, resulting in a hydrodynamic oil film. This complete hydrodynamic fluid film enables these bearings to support extremely heavy loads and operate at high rotational speeds. Typical surface speeds range from 175 to 250 meters/second (30,000 to 50,000 feet/minute). Temperature limitations are often dictated by the lubricant used, as the lead and tin Babbitt can withstand temperatures up to 150°C (300°F). It is crucial to note that, during normal operation, the rotating shaft is not centered in the bearing shell. This displacement is known as eccentricity and establishes a specific location for the minimum oil film thickness. In the load zone, the minimum oil film thickness generally ranges from 1.0 to 300 microns, with values of 5 to 75 microns being more common in medium-sized industrial equipment. Larger diameter shafts typically result in greater film thicknesses.

7. GOVERNING EQUATION FOR FINITE ELEMENT ANALYSIS

A modified Reynold's equation governing the flow of lubricant in the radial clearance is used, which is expressed as:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{r}{12\mu}h^3\frac{\partial p}{\partial r}\right)+\frac{1}{\sin^2\alpha}\frac{\partial}{\partial\varphi}\left(\frac{h^3}{12\mu}\frac{1}{r^2}\frac{\partial p}{\partial\varphi}\right)=\frac{\omega}{2}\frac{\partial h}{\partial\varphi}+\frac{\partial h}{\partial t}$$

8. MODELING AND CFD ANALYSIS TOOLS

The geometric modeling of the lubricating film of thickness equal to the radial clearance of the conical journal bearing is done using SOLIDWORKS software. It is imported in Ansys 2019 R3 Workbench as an IGES file, where the CFD analysis is performed using Ansys Fluent.

9. BEARING GEOMETRIC AND OPERATING PARAMETERS

The conical hydrodynamic journal bearing used for current analysis has the following parameters:

Sr. No.	Parameter	Notation	Values
1	Aspect Ratio	λ	1.0
2	Semi-cone Angle	α	10°
3	Eccentricity Ratio	ε	0.1-0.9
4	Reynolds Number	Re	780, 1300, 2200
5	Radial Clearance (Micron)	C	50
6	Supply Pressure (MPa)	Ps	0.5
7	Operating Temperature (°C)	Ts	40
8	Mean Diameter (mm)	d	100
9	Length (mm)	L	100
10	. Journal minimum diameter (mm)	$\boldsymbol{d_1}$	82.3674
11	Journal maximum diameter (mm)	$\boldsymbol{d_2}$	117.6326
121	Bearing minimum diameter (mm)	$\boldsymbol{D_1}$	82.4674
13	Bearing maximum diameter (mm)	$\boldsymbol{D_2}$	117.7326

Properties of Lubricant for CFD analysis of Conical Hydrodynamic Journal Bearing:

Sr. No.	Properties	Oil
1	Mass Density (kg/m³)	860
2	Fluid Viscosity (Pa-s) (Kg/m. s)	0.0277
3	Specific Heat (J/Kg ^{0}C)	2000
4	Thermal Conductivity (W/m ^{0}C)	0.13

10. MODELING AND SIMULATION

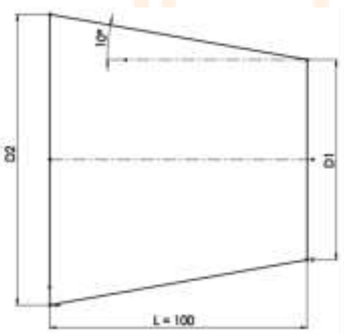


Fig 10.1 2D sketch for modeling

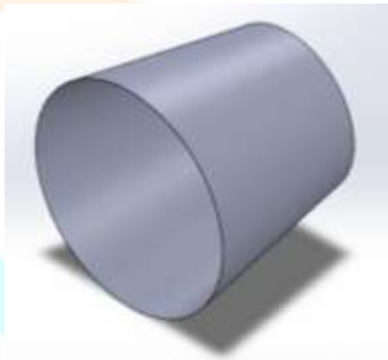


Fig 10.2 3-D CAD Model

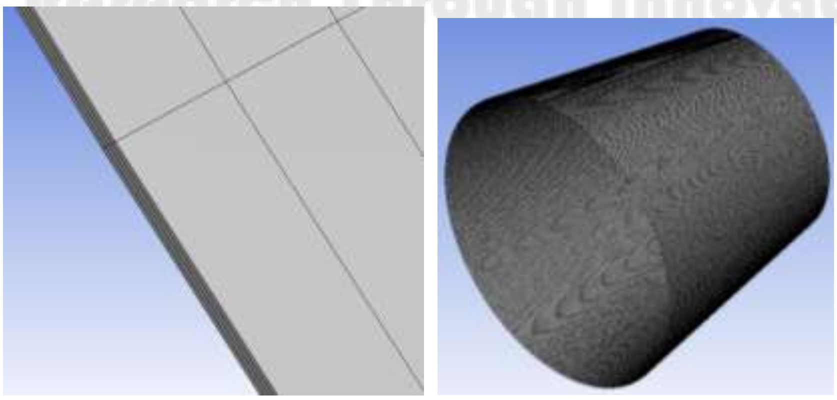


Fig 10.3 Ansys Meshing

11. RESULTS AND DISCUSSION

In this study, we analyze the performance of the conical journal bearing under different parameters of Reynold's number. The analysis is done across laminar (Re=780), transition (Re=1300) and turbulent (Re=2200) flow regimes.

Using Ansys Fluent Software, we find the effect of change in Reynold's number on the maximum static pressure using the above mentioned oil as lubricant. The results obtained from the simulation are plotted for comparison.

The maximum static pressure results for three flow regimes are presented in the table. To further analyze the data, the percentage increase in static pressure between laminar to transition flow, transition flow to turbulent flow and laminar to turbulent flow regimes are calculated for each eccentricity ratio.

Table 11.1: Results for Aspect Ratio = 1.0, Semi-cone Angle=10˚, Reynold's Number = 900, 1300, 2200 and Lubrication = Oil

Sr. No.	Oil				% Increase in 900 and 1300 Re	% Increase in 1300 and 2200 Re	% Increase in 900 and 2200 Re
	Re-	900	1300	2200			
	RPM	111000	160000	271000			
	Eccentricity Ratio	Maximum Static Pressure (MPa)					
1	0.1	96.28	141.48	296.05	46.95	109.25	207.49
2	0.2	207.06	297.25	631.48	43.56	112.44	204.97
3	0.3	340.56	510.29	1051.36	49.84	106.03	208.72
4	0.4	529.65	809.88	1582.84	52.91	95.44	198.85
5	0.5	795.96	1239.46	2333.17	55.72	88.24	193.13
6	0.6	1221.23	1908.53	3590.34	56.28	88.12	193.99
7	0.7	1962.15	3091.75	5889.49	57.57	90.49	200.15
8	0.8	3630.08	5650.21	11020.75	55.65	95.05	203.60

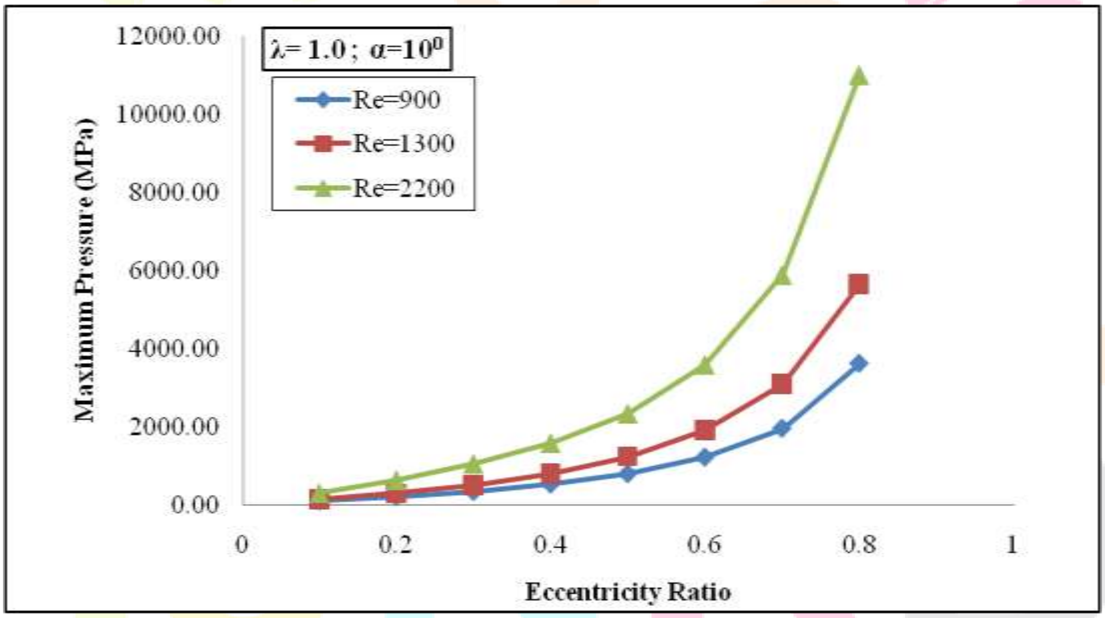


Fig. 11.1 Maximum static pressure v/s Eccentricity Ratio plot for Aspect Ratio = 1.0, Semi-cone Angle=10˚, Reynold's Number = 900, 1300, 2200 and Lubrication = Oil

12. CONCLUSION

Fig. 11.1 shows the plot of maximum static pressure Vs eccentricity ratio for oil lubricated conical hydrodynamic journal bearing having semi-cone angle 10° and aspect ratio is 1.0. Reynold's number value for laminar flow 900, for transition 1300 and for turbulent 2200 is taken to performance analysis. The percentage increase of maximum static pressure generated in conical hydrodynamic journal bearing for eccentricity ratio from 0.1 to 0.7 is less as compare to percentage increase for eccentricity ratio 0.7 to 0.8.The load-carrying capacity for turbulent flow regime is 3 times greater than the laminar flow regime using oil as lubrication.

From the results table and the plot, it can be concluded that the maximum static pressure increases with the increase in eccentricity ratio, as well as Reynold's number; and the pressure is highest in turbulent regime.

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