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Preliminary studies of Newly Conceptualized Intershaft Squeeze Film Damper (ISSFD) Rings

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Abstract

In modern aircraft gas turbine engines, the use of external damping devices have become inevitable for attenuation of vibrations caused by various reasons. Ultimately the light-weight construction of aircraft engine together with higher efficiency and reduced problems related to vibrations is made possible by careful design of such damping devices. This effort basically concentrates on preliminary studies of a newly conceptualized intershaft squeeze film damper (ISSFD) ring for an intershaft bearing in a two spool configured system.

The conceptualized ISSFD ring is modelled using FEM and tested for its stiffness characteristics and induced Von-Mises stresses. Later, two ISSFD rings having four and three grooves are fabricated and tested on a dedicated static stiffness evaluation test rig fabricated solely for the purpose of evaluating the static stiffness. The experimental results correlate well with the FE results. The newly conceptualized ISSFD ring is ready to be evaluated on a dynamic test rig for its potential of being used as a squeeze film damper in an inter shaft bearing of a typical two spool gas turbine.

Keywords: Inter Shaft Squeeze Film Damper (ISSFD), Gas Turbine Engine, Stiffness, Von-Mises stress, two spools.

INTRODUCTION

The most common problems of high speed rotating machines are excessive steady state vibration levels and rotor instabilities and these problems can be reduced by improved balancing or introducing external damping devices so that the system is operated above the critical speed. Squeeze film dampers (SFD) have become very useful and also their simplicity in design and high potential to deliver desired level of damping fits very well in gas turbine applications.

A squeeze film damper is essentially a simple device consisting of an oil film interposed between the non-rotating outer race (sleeve) of a rolling element bearing and its housing as shown in Fig 1. These are lubricated elements providing viscous damping in mechanical systems. They offer unique advantages of dissipation of vibration energy and isolation of structural components as well as the capability to improve the dynamic stability characteristics of inherently unstable rotor-bearing systems.

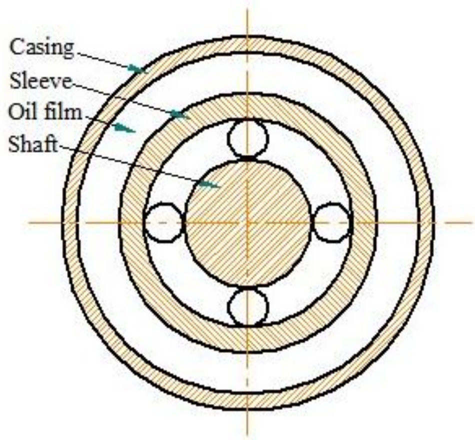

Figure 1: Elements of squeeze film damper.

Luis San Andres [1] has explained the concept of squeeze film damping and the necessity of squeeze film dampers along with its applications. He has tried to elaborate the various models of squeeze film dampers with their design criteria by referring to various papers and the recent developments in this arena. He has observed that the critical design consideration for any SFD is the amount of damping produced in such a design. According to Luis San Andres, when very high level of damping is caused by SFD, it acts as a rigid constraint for the rotor-bearing system and transmits large amount of forces to the supporting structure. He has also observed that when less amount of damping is caused, SFD becomes ineffective and hence permits very high vibration amplitudes. He has reported that the effectiveness of a damper depends on softness and hence will allow for motion at the location of the support. Gupta, et al. tested an improved intershaft squeeze film damper (ISSFD). They have considered two design modifications for analysis and tested them experimentally [2]. Zeidan, et al. highlighted the numerous advantages of Squeeze film dampers and reported that over damped condition of the supports would reduce the effective damping in high speed rotating machinery [3&4]. El-Shafei, et al. showed that the intershaft squeeze film damper is unstable above the engine's first critical speed. They have reported that the intershaft dampers are stable super critically only in a configuration in which the oil film does not rotate [5,6,7&8].

Jayaraman and Arunkumar have introduced the concept of flexible supports or flexible mounts which are mounted in between the bearing and the shaft in order to reduce excessive vibration levels in the machinery. They have illustrated the methodology to carry out static testing of ISSFD rings and also done FEM analysis on these mounts with different configurations using suitable element types. They have determined the deflections and found the stiffness of flexible mounts. They have given guidelines and suggestions for the fabrication of the static test rig and the loading procedures to carry out static tests. Hibner, et al. [10&11], Alderson, et al. [12], Qihan Li, et al. [13&14], J.B. Courage [15], Shende, et al. [16] and many more researchers have reported their work related to intershaft squeeze film dampers. Most of the work that is reported in the past doesn't look to be feasible from practical application point of view and the unworkability of SFD as applicable to intershaft bearing plane still continues. Therefore this leads to the necessity of new SFD versions for intershaft bearing applications.

This paper covers preliminary studies involving static stiffness evaluation of a newly conceptualized Inter Shaft Squeeze Film Damper (ISSFD) ring suitable to be accommodated in a typical gas turbine engine. As shown in Figure 2, the gap that is available in the intershaft bearing plane between the inner spool and inner race or the outer spool and the outer race is as low as 3 – 7 mm. The necessity of introduction of very thin oil film needs to be created in the bearing plane to attenuate vibration and at the same time the oil film should not rotate in order to overcome the problem of instability above the first critical speed. Having these points in mind, an idea is conceived to create an ISSFD ring that looked like as shown in Figure 3a. Schematic of a typical conceptualized ISSFD ring having four grooves is shown in Figure 3a and photographs of the same in Figure 3b.The material used for the ring is mild steel.

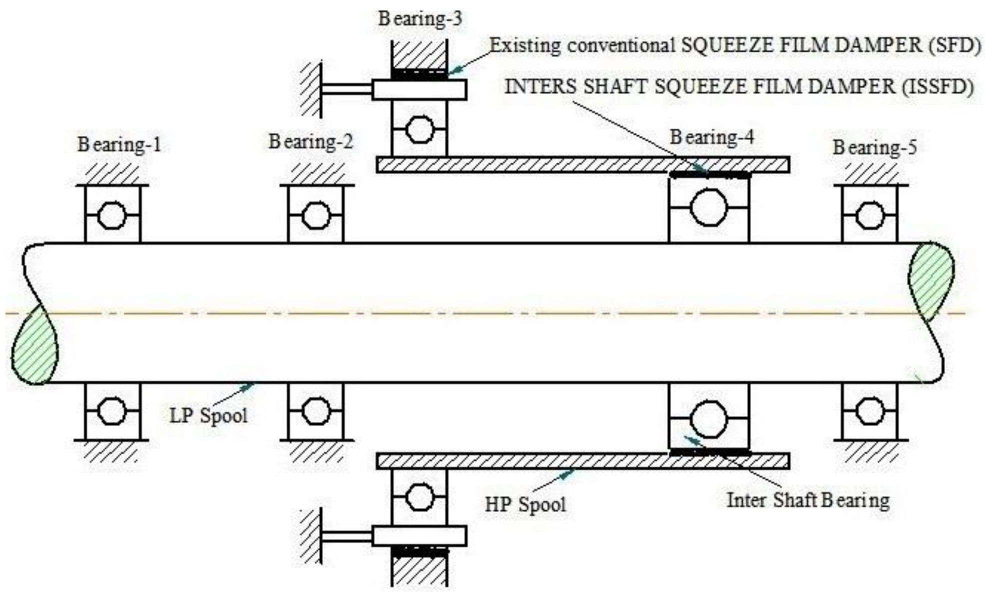

Figure 2: Schematic of two spool test rig

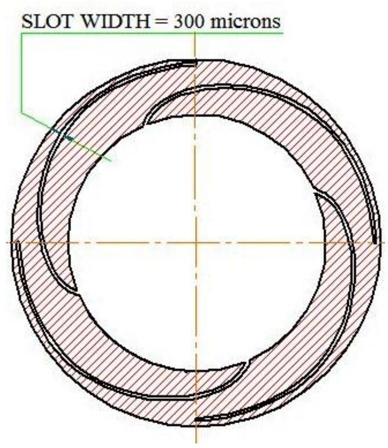

Figure 3a: Schematic of ISSFD Ring.

Figure 3b: Photographs of ISSFD Ring.

3D Modelling of ISSFD ring

Using CatiaV5Modelling software, an ISSFD ring with such dimensions that would fit a typical gas turbine engine is modelled. The dimensions taken are; Outer diameter 155 mm, Inner diameter 145 mm, Width 40 mm and Groove thickness 0.3 mm. While creating the grooves, enough care was taken so that creation of sharp corner between the two lines is eliminated to avoid stress concentration. Figure 4a shows the photograph of the ISSFD ring model and Figure 4b shows the zoomed view of a groove.

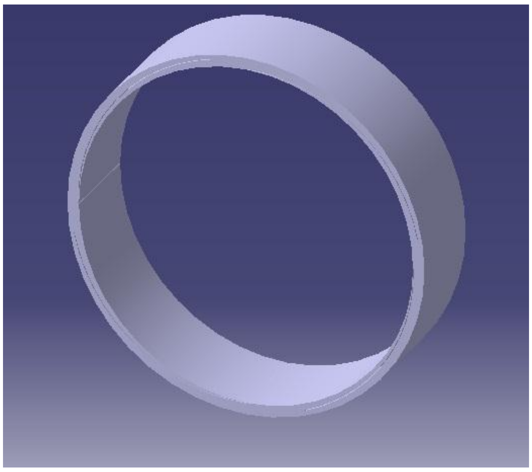

Figure 4a: 3D Model of ISSFD Ring

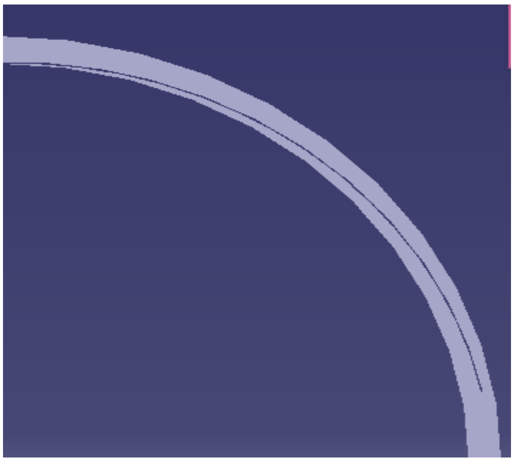

Figure 4b: Zoomed view of spiral Groove

FE ANALYSIS

When cosine load is applied on the inner half surface of the ring, the deflection and also the corresponding Von-Mises stress induced are noted. The load is applied in terms of pressure that varies from zero to maximum value and maximum value to zero on the inner bottom half of the ring. On application of load, the groove would act as a cantilever beam in which the maximum deflection occurs at the tip of the beam and maximum stress would be induced at the fixed end. The model with plane stress with thickness element was found to be adequate to obtain a solution and that matched well with experimental result.

A common simple approach is to assume that the surface pressure on 180° portion of the hole is in compression and follows the equation P = A cos (θ), $0 \leq \theta \leq \pi$, else P=0. On diametrically opposite ends, the loads are zero and the same is indicated in Figure 5.

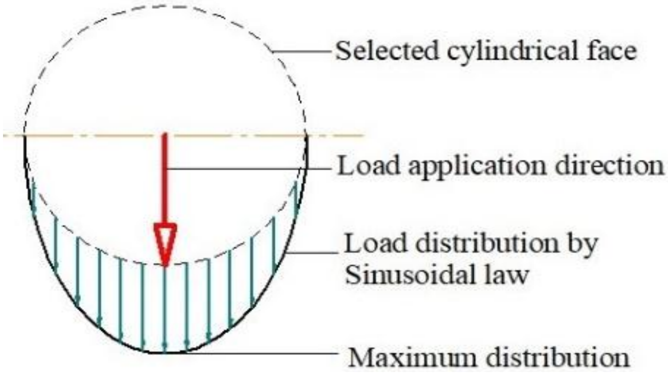

Figure 5: Cosine load distribution.

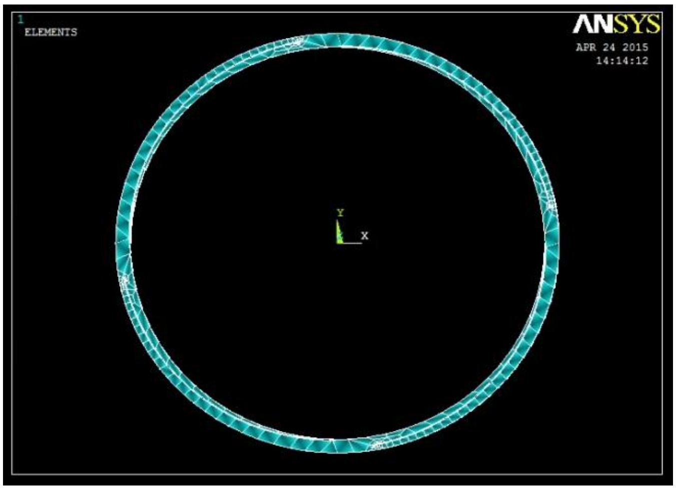

Figure 6: Finite elemental model of four grooves ISSFD ring with solid element

FE model of ISSFD ring with four grooves configuration is created using solid Quad 4 node 182 elements as shown in Figure 6. Plane182 is used for 2D modelling of solid structures. The contact wizard provides a useful means of generating pair of contact element between the target and contact surfaces. The properties of air are assigned for the contact wizard element.

Static test rig

The static test rig is a compact rigid set up and it consists of two rectangular plates which are attached on either ends of two columnar bars. The rectangular plate at the bottom holds two V- blocks in position holding a solid mandrel mounted with ISSFD ring. The rectangular plate at the top supports a loading wheel. The loading unit includes screw rod arrangement and it is manually operated by rotating the loading wheel. The load cell connected to the loading unit measures the load applied on the ISSFD ring. The schematic of static test rig is shown in

Figure 7a and photograph of the same in Figure 7b.

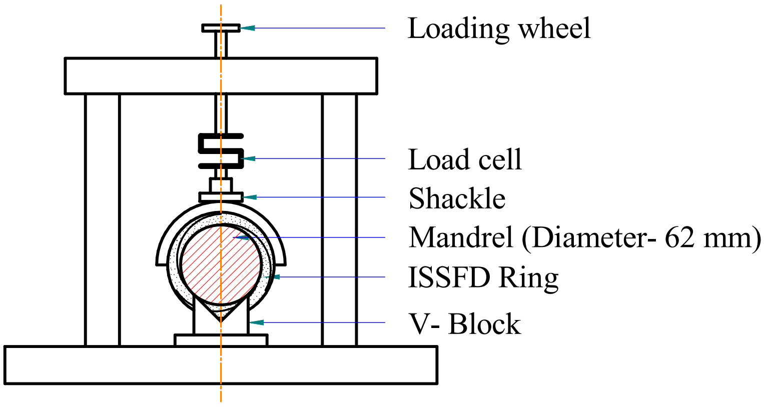

Figure 7a: Schematic of Static test rig

Figure 7b: Photograph of Static test rig

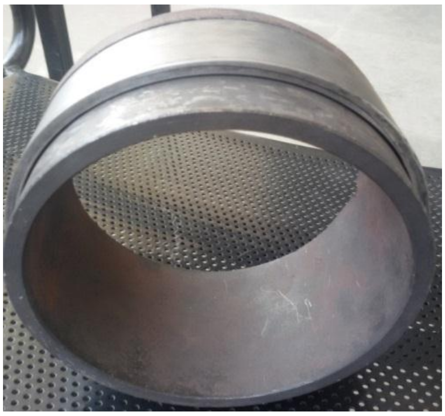

Figure 8a: ISSFD Ring on a hollow mandrel

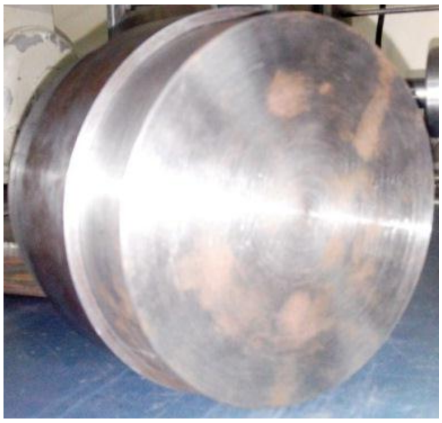

Figure 8b: ISSFD Ring on a solid mandrel

Two ISSFD rings, one of them with four grooves and another with three grooves, suitable for a typical gas turbine engine, having 155 mm outer diameter, 145 mm inner diameter and width (along the axis) 40 mm were fabricated using wire EDM process. Stress relieving is done in order to relieve the internal residual stresses developed during the machining process. During stress relieving, no undesired change in shape of ISSFD ring is ensured by mounting it on a hollow mandrel and a collar as shown in Figure 8a. Figure 8b shows the Photograph of ISSFD ring mounted on a solid mandrel.

RESULTS AND DISCUSSIONS.

Results of FE analysis

Table 1 below shows the values of deflections of the groove and Von-Mises stress induced for various values of pressure/load on a four grooves ISSFD ring model. Figure 9 shows a plot of Load Vs deflection and Figure 10 shows a plot of Load Vs Von-Mises stress induced. From the plots, one can observe that the response is more or less linear for different loads leading to a linear system. Using the tabulated values of load and deflection, stiffness of the ISSFD ring with four grooves is found to be 2.6MN/m.

Table 1: Deflection and stress predicted using FE model for a ring with 4 grooves

Sl no	Load (N)	Pressure (M Pa)	Deflection (mm)	Von-Mises stress (M Pa)
1	100	0.011	0.039	15.35
2	200	0.022	0.079	30.71
3	300	0.033	0.119	40.32
4	400	0.044	0.159	60.42
5	500	0.055	0.199	76.77
6	600	0.066	0.230	98.13
7	700	0.077	0.278	107.5
8	800	0.088	0.318	122.8

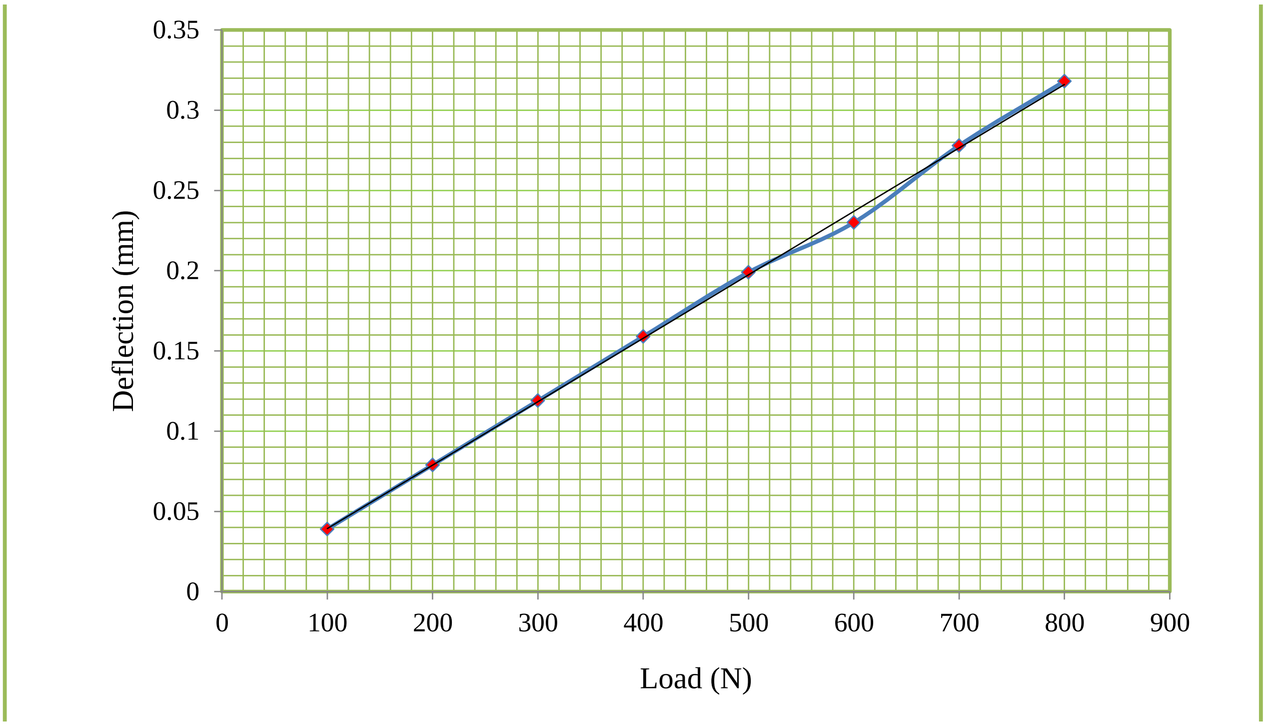

Figure 9: Load Vs deflection for four grooves ISSFD model

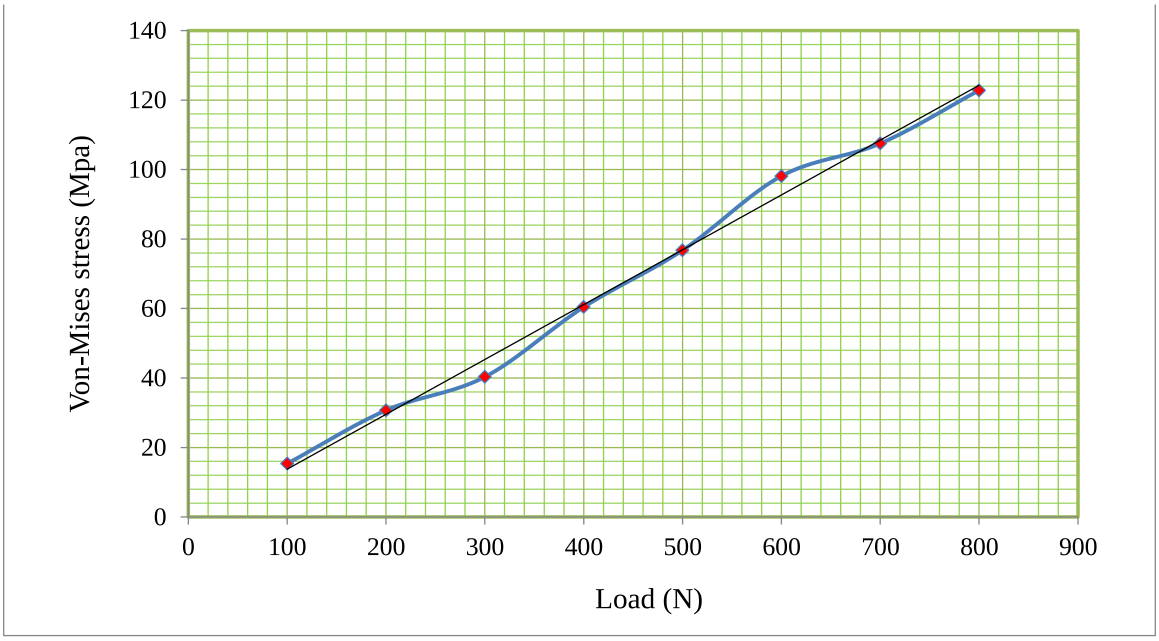

Figure 10: Load Vs Von-Mises stress for four grooves ISSFD model

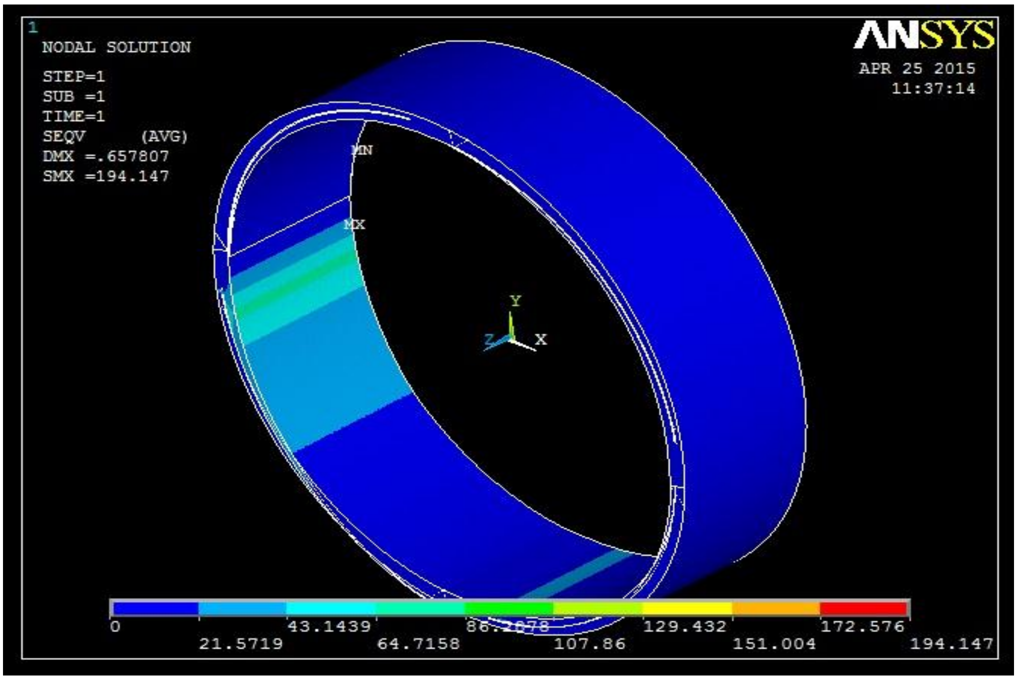

Figure 11: Von- Mises stress distribution for a four groove model.

Figure 11 shows distribution of Von-Mises stress on a four grooves ISSFD ring model under maximum loading condition.

Static stiffness evaluation results of ISSFD rings

ISSFD rings having four and three grooves were tested in the static test rig to evaluate the stiffness of the rings under static condition. Tables 2 and 3 show the relevant load values for loading up to the closure of the groove for the experiments conducted on four and three grooves ISSFD rings. The stiffness of all the grooves for each of the ring is more or less constant leading to a linear system. It is found that the Static stiffness of ISSFD ring with four grooves is 2.44 MN/m and that with three grooves is 1.60 MN/m.

Table 2: Load values of groove closure on four grooves ISSFD ring.

Load (kg)						Load (N)
Trail no	1st groove	2nd groove	3rd groove	4th groove	Overall average	Overall average
1	73.4	75.0	74.5	74.3	74.53	731.14
2	75.4	74.0	75.1	74.9		
3	74.5	74.5	74.4	75.1		
4	74.3	74.2	74.6	74.3		
Avg.	74.4	74.425	74.65	74.65		

Table 3: Load values of groove closure on three grooves ISSFD ring.

Load (kg)					Load (N)
Trial no	1st groove	2nd groove	3rd groove	Overall average	Overall average
1	49.5	48.7	49.1	48.96	480.30
2	49.2	48.9	48.9		
3	48.9	48.8	49.0		
4	48.8	48.9	48.8		
Avg.	49.1	48.82	48.95		

CONCLUSIONS

A newly conceptualized four grooves ISSFD ring suitable to be used on an intershaft bearing as squeeze film damper has been tested analytically and experimentally from the point of evaluating the static stiffness value. Stiffness value of ISSFD ring with four grooves by FE method is found to be 2.60 MN/m and by experimental method is found to be 2.44 MN/m. One can observe that FE result and experimental result of stiffness for four grooves ISSFD ring correlate well. A second ISSFD ring with three grooves is evaluated experimentally for its stiffness value and is found to be 1.60MN/m. The newly conceptualized ISSFD ring is ready to be evaluated on a single spool dynamic test rig for its potential of being used as a squeeze film damper in an inter shaft bearing of a typical two spool gas turbine.

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