FSI and Modal Analysis of Elastic Ring Squeeze Film Damper for Small Gas Turbine Engines

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Abstract: The high speed gas turbine is a power plant developed for modern aircrafts. It is widely used and developed because it can meet the high power to weight ratio. The rotor system of modern small gas turbine works above the critical speeds. Hence, there is a stricter requirement for the control and isolation of vibration magnitude under heavy unbalance load and passing through critical speeds. An advanced oil film damper known as Elastic Ring Squeeze Film Damper (ERSFD) built with orifice pattern has better dynamic characteristics, vibration-isolating effect, simple structure, high reliability, enhanced damping effect when compared with conventional SFD. This ERSFD and rotor components are analyzed using COMSOL to find its mode shapes and ERSFD's profile pressure distribution at orifice under the ring subjected to vibration. These analyses made using COMSOL structural and CFD modules followed by eigenfrequency response and thin film flow. The above study results on ERSFD which enhances the controlled flow at identified locations. It also helps in designing small gas turbine engine high speed rotor system operating at super critical speeds.

Keywords: Elastic Ring Squeeze Film Damper, GT engine, Fluid Structure Interaction and Modal Analysis

Introduction: The Elastic Ring Squeeze film damper (ERSFD) is current interest of study. The Reynolds et al. published the squeeze film effect in his study [8] on lubrication. This effect was an important mechanism for the generation of pressure in a lubricating film together with the wedge effect. The primary goal of a fluid film damping system is to limit the vibration of a given structure by dissipating the energy to the fluid within the film [1-4]. The modelling and numerical simulation of ERSFD have been used in designing and investigating ERSFD systems dynamics to control rotor vibrations and transmitted forces to the base structure [6-8]. The detailed assembly view in aero engine is shown in Fig 1 [a,b]. The modeling, analysis using COMSOL is explained in below chapters.

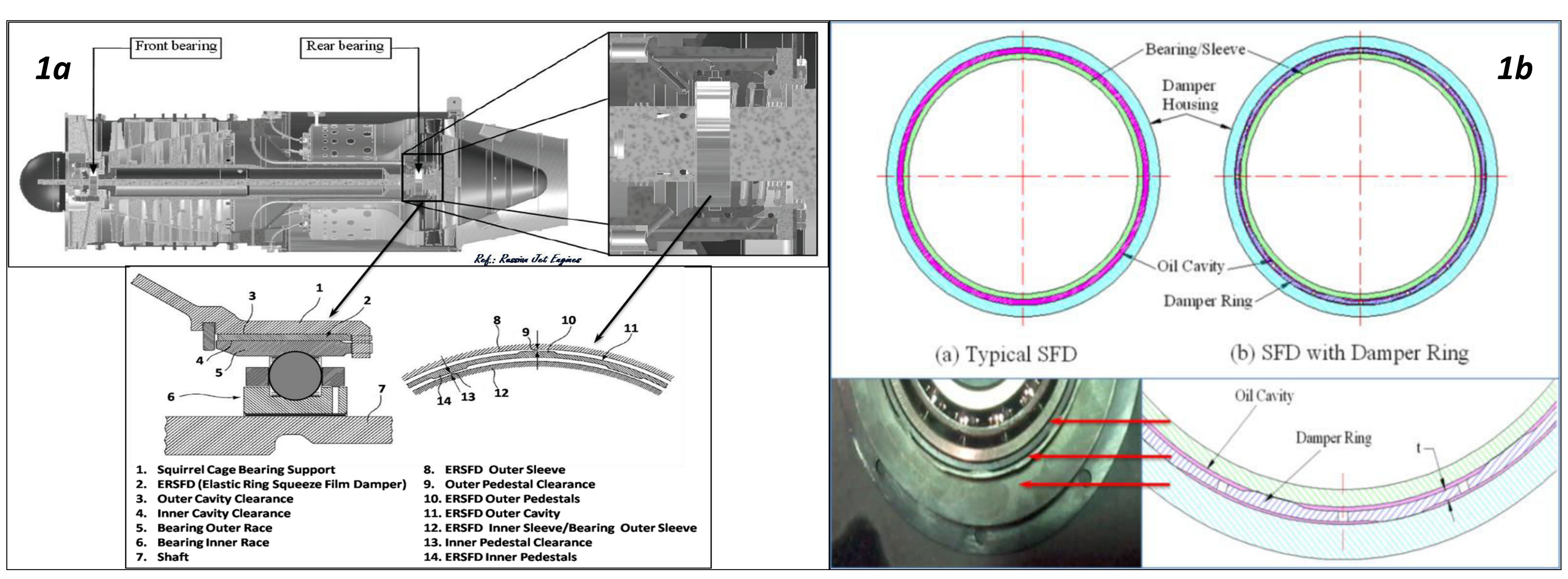


Figure: 1[a, b] Current Technology ERSFD Detailed Assembly View

COMSOL Modal and FSI Analysis: The 3D model of test rig small engine rotor system with dual ERSFD is illustrated in Fig. 2 with an exploded view of ERSFD components for better understanding. The modal based frequency response analysis carried out using structural mechanics for undamped and damped eigenfrequency response of shaft and undamped response of rings. The obtained results are shown in Fig. 4. This FSI model is used to compute the damping force acting on ERSFD ring. Also to compute pressure distribution over the entire ring during high frequency response. These analyses were carried out by interaction between fluid flow and structure via CFD under thin film flow (tffs) between vibrating narrow [5].

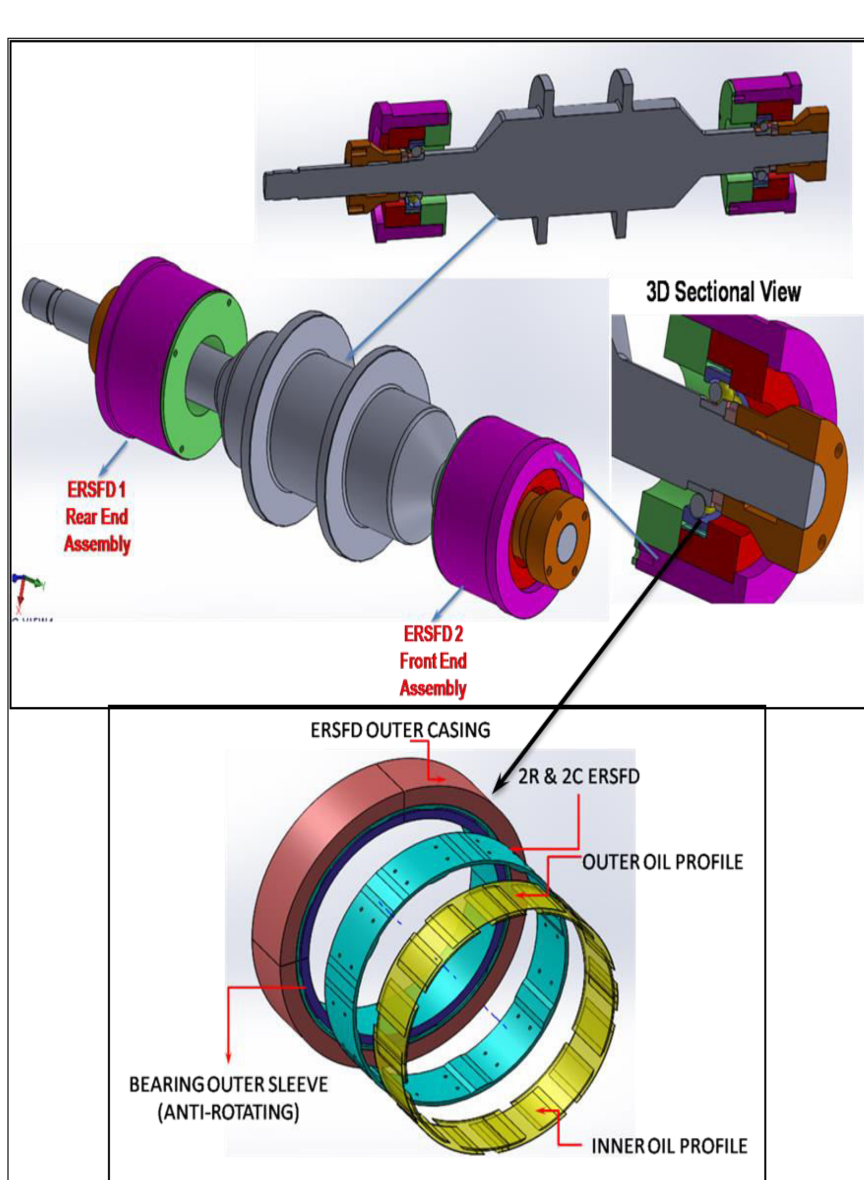


Figure 2. 3D Model of Test Rig Engine Rotor System with an Exploded Dual ERSFD

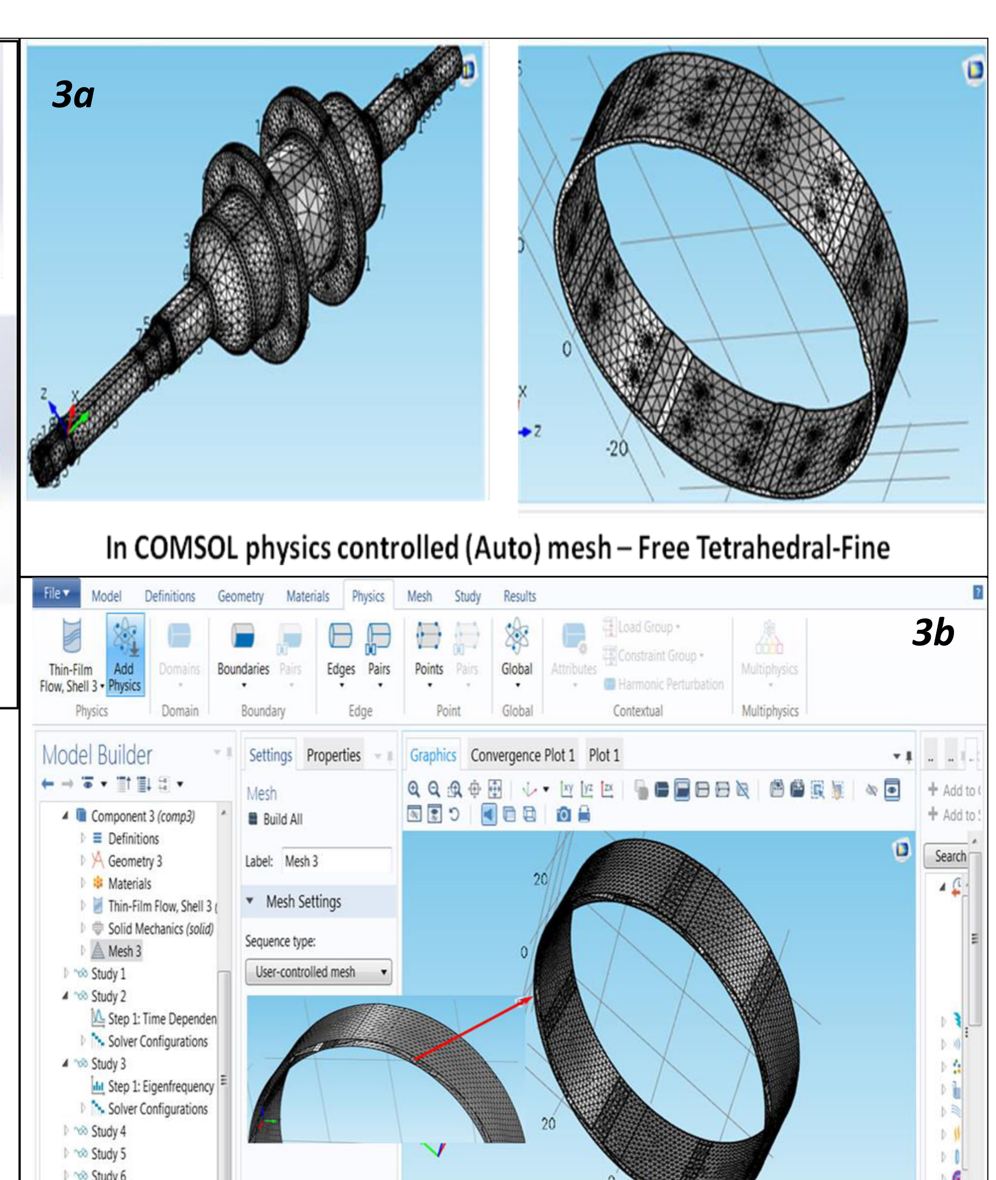


Figure: 3[a,b] Auto Mesh for Modal and FSI Analysis

The Fig. 3a. shows fine mesh modelling in COMSOL for the test shaft and ring components of modal analysis. These are physics controlled (auto) - free tetrahedral mesh which are used in order to obtain efficient simulations when investigating different setups. Fig. 3b. shown, also physics controlled (auto) - free triangular mesh generated for FSI analysis.

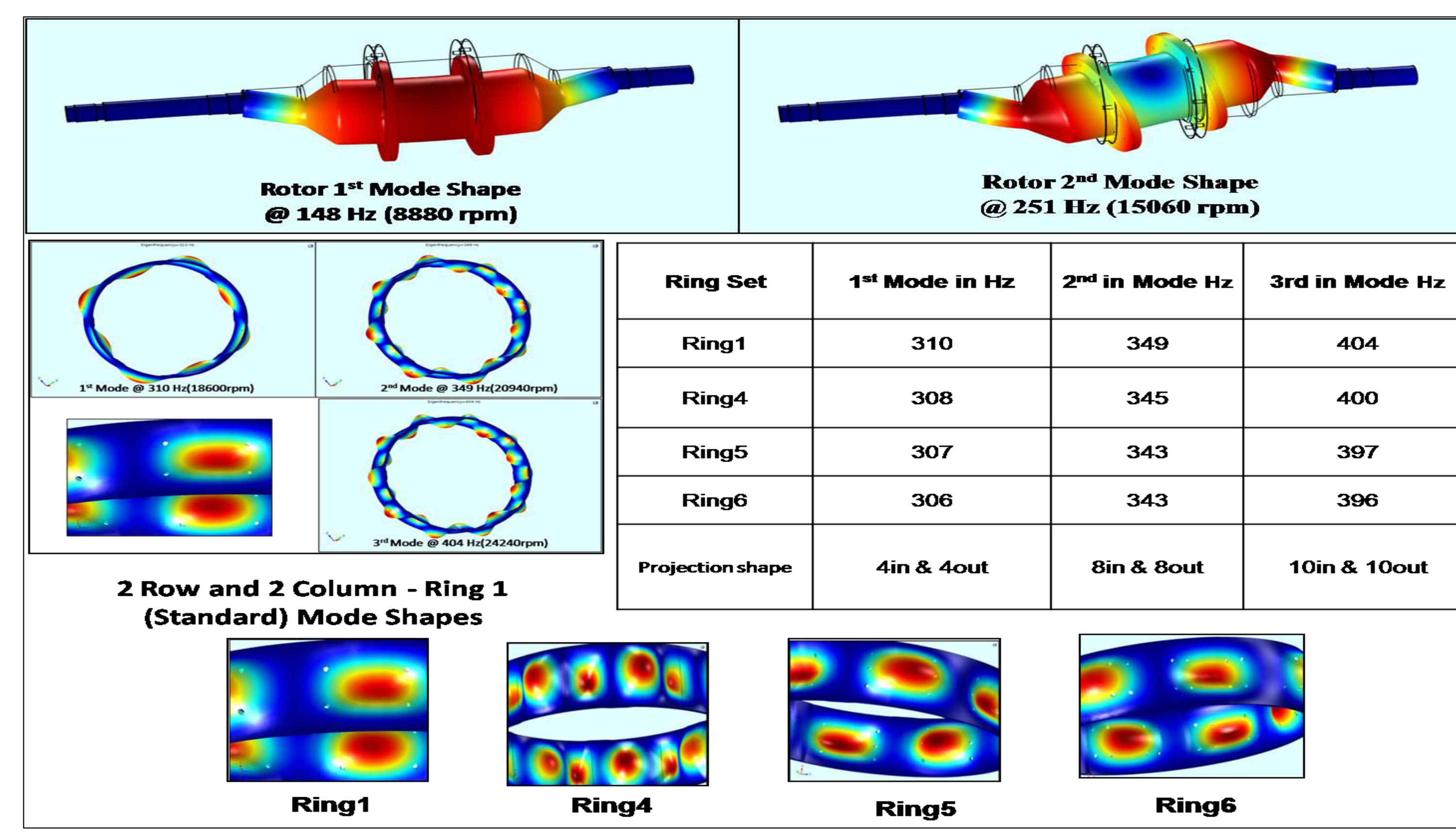
Computational Methods: In modal analysis an eigenfrequency analysis finds the eigenfrequencies and modes of deformation of test rotor and ring components. The eigenfrequencies f in the structural mechanics field are related to the eigenvalues $\boldsymbol{\lambda}$ solved through

$$f = \frac{-\lambda}{2\pi i} \quad .....1$$

CFD/FSI(tffs) : The following modified Reynold's equation, pressure difference and the forces on the noncontact/contact surfaces due to excitations are analytically found using below mentioned simplified equation in COMSOL solver.

modified Reynold's equation

$$\frac{1}{r}\frac{d}{dr}\left(\frac{r h_0^3}{12\mu}\frac{dp_f}{dr}\right) = V_\omega \quad .....2$$



Ring Set	1st Mode in Hz	2nd in Mode Hz	3rd in Mode Hz
Ring1	310	349	404
Ring4	308	345	400
Ring5	307	343	397
Ring6	306	343	396
Projection shape	4in & 4out	8in & 8out	10in & 10out

Figure 4. Modal Analysis Results of Shaft and Different ERSFD Ring

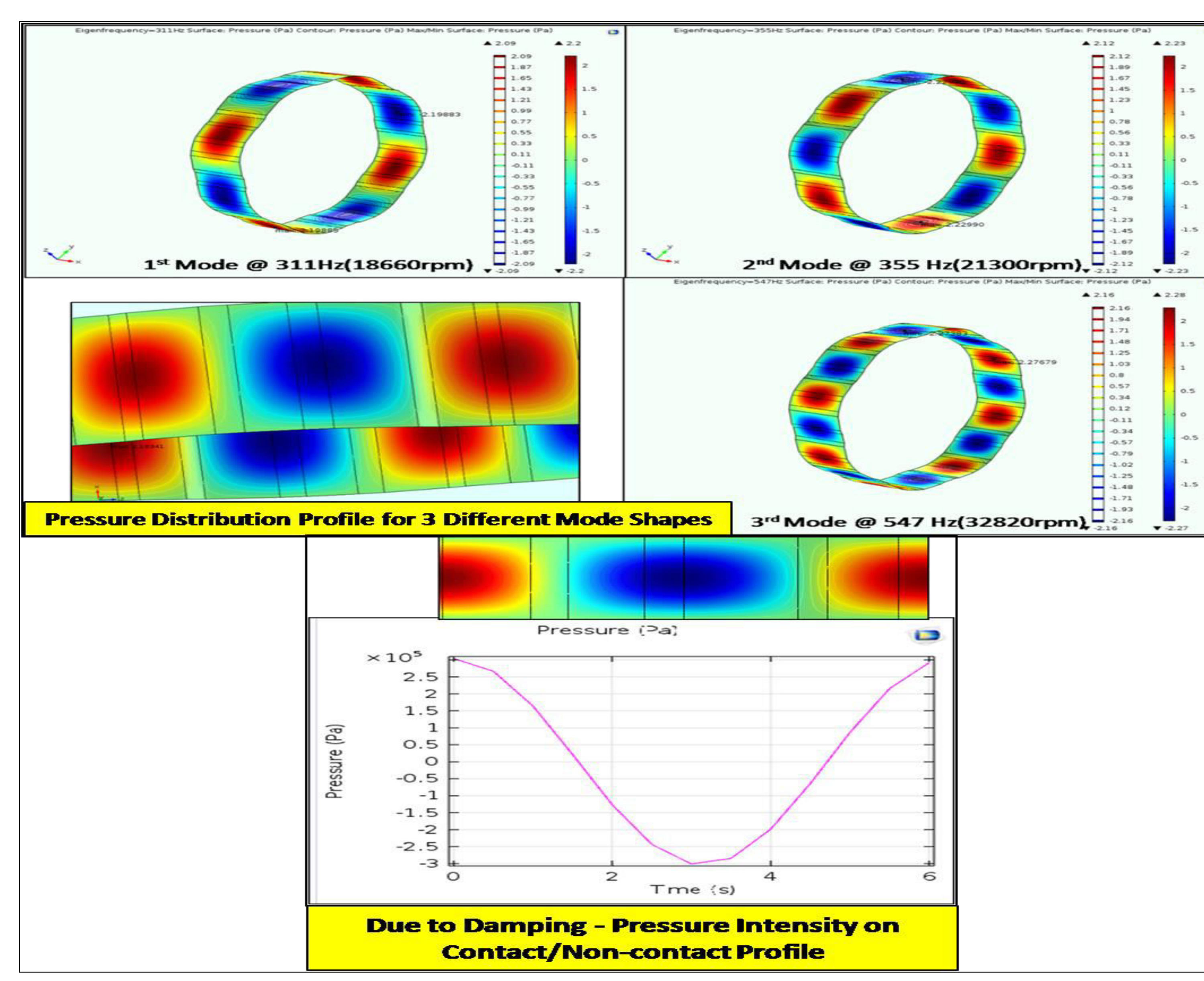


Figure 5. FSI Analysis Result of ERSFD Ring

Conclusions: In this work using a COMSOL multi physics solver, the modal and FSI on rotor and ERSFD effects was investigated. To determining the mode shapes on the test shaft and ERSFD's. The values of the alternate pressure intensity profile are shown in Fig. 5. This FEM analysis using COMSOL provides eigenfrequencies and locations to give flow through openings. These are the essential basic inputs to design multi configured ERSFD's to enhance damping effects.

References:

1. Wei Zhang et al. "Elastic ring deformation and pedestal contact status analysis of elastic ring squeeze film damper", Journal of Sound and Vibration 346 (2015) 314–327.
2. Thennavarajan et al. "Dynamic Analysis of Multi Mass Counter Rotor System with Integral S-shaped Squeeze Film Damper", Int. Advanced Research Journal in Science, Engineering and Technology, Vol .4(6), pp.123-128 (2015).
3. Xu et al. "Influence of orifice distribution on the characteristics of elastic ring squeeze film dampers for flywheel energy storage system", IEEE Transactions on Plasma Science 41 (5) (2013) 1272–1279.
4. Hong et al. "Dynamic design method of elastic ring squeeze film damper", Journal of Beijing University of Aeronautics and Astronautics 32 (6) (2006) 649–653.
5. Hamrock et al. "Fundamental s of Fluid Film Lubrication", Marcel Dekker, 2004.
6. L. San Andrés, "Theoretical and Experimental Comparisons for Damping Coefficients of a Short Length Open-End Squeeze Film Damper", ASME Journal of Engineering for Gas Turbines and Power, 118 (1996) 810-815.
7. Gunter et al. "Design of non-linear squeeze film dampers for aircraft engines" Journal of Lubrication Technology, 99(1) (1977) 57-64.
8. Reynolds et al, "On the theory of Lubrication and its Application to Mr. Beauchamp Tower's experiments, including an Experimental Determination of the Viscosity of Olive Oil", Philosophical Transactions of the Royal Society, Part I, 177 (1886) 157–234.