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Rotor Dynamic Analysis of Driving Shaft of Dry Screw Vacuum Pump

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ABSTRACT

Rotor dynamics is the study of vibration behavior in axially symmetric rotating structures. Devices such as engines, motors, disk drives and turbines all develop characteristic inertia effects that can be analyzed to improve the design and decrease the possibility of failure. At higher rotational speeds, such as in a gas pumps, the inertia effects of the rotating parts must be consistently represented in order to accurately predict the rotor behavior. An important part of the inertia effects is the gyroscopic moment introduced by the precession motion of the vibrating rotor as it spins. As spin velocity increases, the gyroscopic moment acting on the rotor becomes critically significant. Not accounting for these effects at the design level can lead to bearing and/or support structure damage. The main objective of this project is to study the Rotor Dynamic behavior of the drive rotor shaft of the Dry screw vacuum pump. The design of the pump is considered from the one of the reputed pump manufacturing industry. The operational speed of the pump is 4500 rpm, whereas the maximum capable speed of the pump is 10,000 rpm. Rotating machinery produces vibrations depending on the unbalanced mass and gyroscopic effects. Thus an investigation is to be made on the rotor dynamic properties of the shaft to find the natural frequencies and critical speed. For this rotor dynamic analysis was carried out in ANSYS APDL and Workbench16 to find the natural frequencies and critical speeds in the range of 0 to 10000 rpm. Thus an effort is made to shift the mass moment of inertia of the shaft by varying the design of the shaft and to shift the critical frequency to the higher speeds of the shaft there by increasing the efficiency. The modal analysis is performed to find the natural frequencies and it is extended to harmonic analysis to plot the stresses and deflections at the critical speeds. The design of the rotor shaft is made in NX-CAD.

Keywords : Dry Screw Vacuum Pump, Rotor Dynamics, Natural Frequencies, Critical Speeds.

I. INTRODUCTION

Dry screw vacuum pumps operate with two screw rotors rotating in opposite directions. This traps the medium to be pumped between the cylinder and the screw chambers and transports it to the gas discharge. Two parallel bearing-supported, intermeshing screw rotors having opposite threads synchronously and contact less counter-rotate in a cylindrical housing that tightly encloses them, and together form a multi-stage Dry Screw Vacuum pump. Due to of the counter-mesh of the two rotors (screws), the volumes sealed in each thread are advanced along the rotors to the outlet. When a displacement volume reaches the outlet opening, the pressure is equalized with the atmosphere. This means that atmospheric air flows into the displacement volume and is then discharged again as the rotor turns. This pulsing gas flow generates a high level of dissipated energy and heats the pump.

The general range of speed of these types of pumps from 4000 to 8000r.p.m. At these speeds the screw and its integrated shaft undergoes vibrations due to its unbalance and gyro effects of rotatating elements. The study to minimize vibrations on these type of pumps are not yet done. Based on the literature of rotodynamic analysis [1],[2]--- [6] , the paper performed Roto dynamic analysis on a shaft of Screw pump. The paper is organized as: After the introduction in Section-1 , modeling and Model Analysis are covered as sections 2 and 3. Section 4 covers Simulation Results and discussions . Finally Conclusions are drawn in section-5.

II. MODELING OF PUMP AND ITS SCREW SHAFT

The development of the required driving shaft is done by NX-CAD. The figure 2.1 shows the assembly model of the screw pump. The internal parts of the pumps are depicted in Fig 2.2.
The screw of shaft is modeled as shown in Fig 2.3. With the help of ANSYS software , the shaft portion is meshed as shown in Fig 2.4.

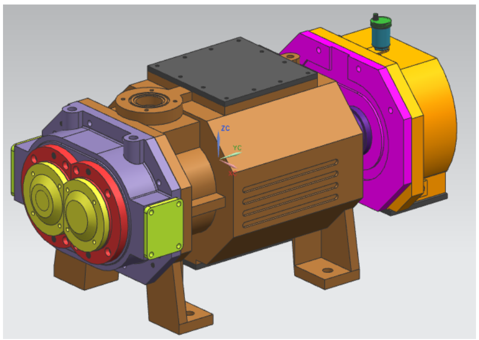

Figure 2.1-D model of the pump

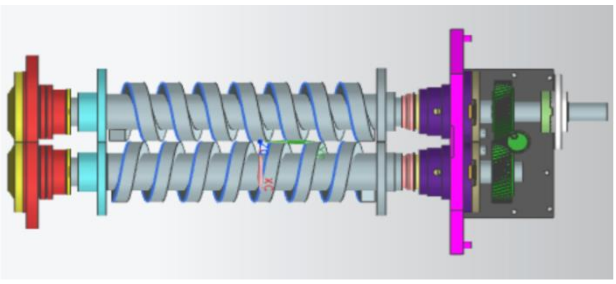

Figure 2.2 Internal structure of the pump

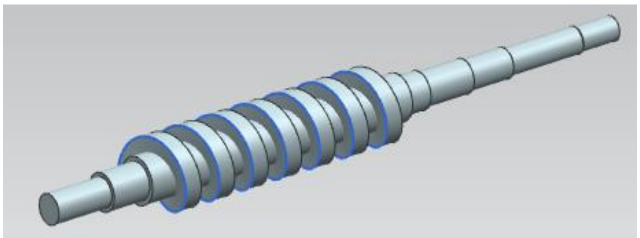

Figure 2.3 : 3-D model of the helical shaft

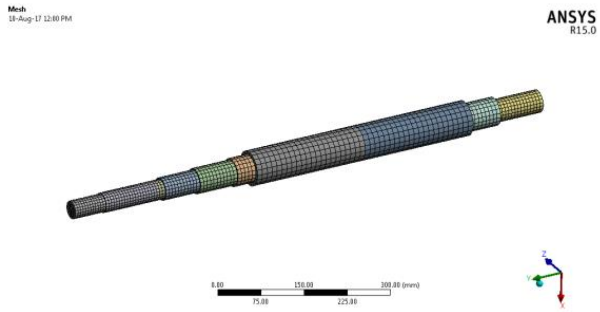

Figure 2.4 : Finite element model

III. MODEL ANALYSIS OF SCREW SHAFT

The modal analysis of the vacuum pump is performed using following properties:
Young's modulus: 200GPa, Poisson's ratio : 0.3,Density: 7850kg/m^3 Yield stress: 248MPa.
The final axis symmetrical model for rotor dynamic analysis is shown in the Fig. 3.1 .It is discredited into large number of elements by meshing it with the solid 186 and above mentioned material properties. The following conditions are imposed during the analysis:

- Bearing elements are created at their respective positions on the shaft with bearing 214 elements and with the stiffness of 10^4 N/mm.
- As the mass is unsymmetrical along the axis, it is converted to a point mass located at the position of the center of mass. There are two point masses created i.e. at the location of the center of mass of the gear and at the location of the center of mass of the spherical part of the shaft.
- The gyroscopic effect is turned on insoftware.
- In order to obtain the Campbell diagram, there should be multiple load steps. Thus angular

velocity is applied as two load steps i.e. as 0 rpm and 20,000 rpm. (0 rad/s and 2095 rad/s).

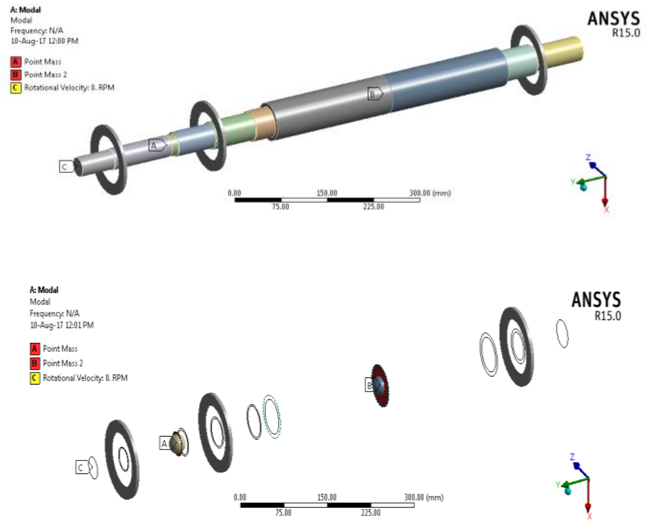

Figure 3.1 : Finite element model with bearings stiffness

IV. SIMULATION RESULTS & DISCUSSIONS

The modal analysis is carried out for the shaft initially (termed as case-1), then the shift mass centre of shaft is made and the extracted the responses (termed as case-2). The results are obtained for the both models. The natural frequencies obtained from both cases. The Campbell diagram is generated for case-1 is in Fig 4.1. The Campbell diagram locates the positions of the obtained critical speeds. There are two critical speeds obtained as 7381.4 and 7394.7r.p.m.

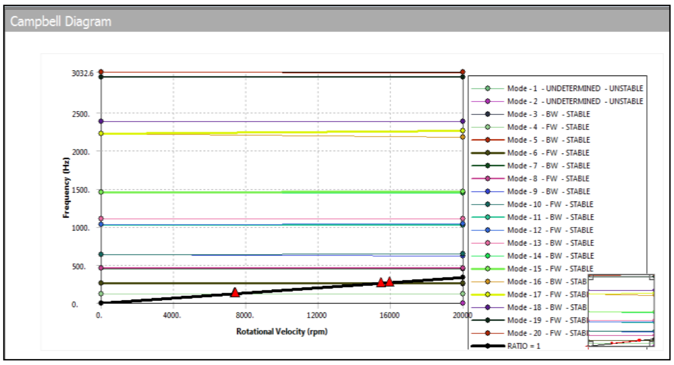

Figure 4.1: Frequency Response of the shaft (Case-1)

The Centre of mass of shaft is modified by altering the design considerations(It is termed as case-2) and the campbell diagram is extracted as shown in Fig 4.2.The critical speeds obtained in this case are 15459 and 15922.

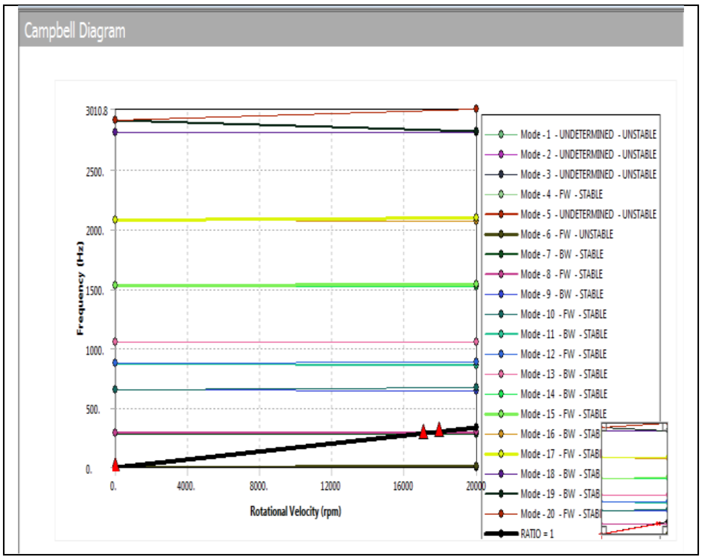

Figure 4.2 : Frequency Response of the shaft (Case-2)

After obtaining the critical speeds from the modal analysis, harmonic analysis is performed with an unbalanced mass of 10.272Kg applied in spherical and hallow rings shapes from the axis as shown in Fig 4.3.

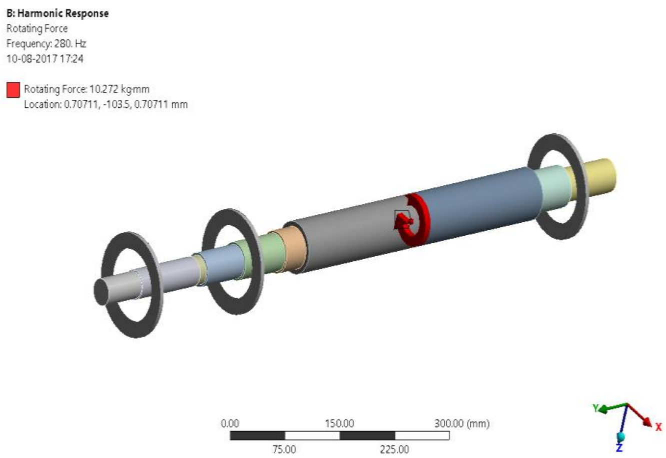

Figure 4.3 : Dynamic model of shaft for harmonic Analysis

The harmonic analysis results of the shaft at four critical speeds (7381, 7394,15459,15922) are analyzed and the stress contours corresponding speeds are respectively shown in Fig 4.4

The values stresses developed at critical speeds of the shaft (7381, 7394,15459,15922) r.p.m are respectively 361.6,234.9,376 and 261MPa.

V. CONCLUSIONS

In this paper, the rotor dynamic analysis of the driving shaft of the dry screw Vacuum pump is performed by introducing both shift of centre of mass and Gyroscopic effects. The simulation studies are made for the range of speed 10 to 20000r,p.m. The paper investigates the critical speeds and corresponding stresses. Two conditions have been imposed : gyro effect and shift of mass of system . As a result rotor dynamic analysis two critical speeds are obtained nearer to 7000r.p.m when centre of mass is not shifted and two more critical speeds

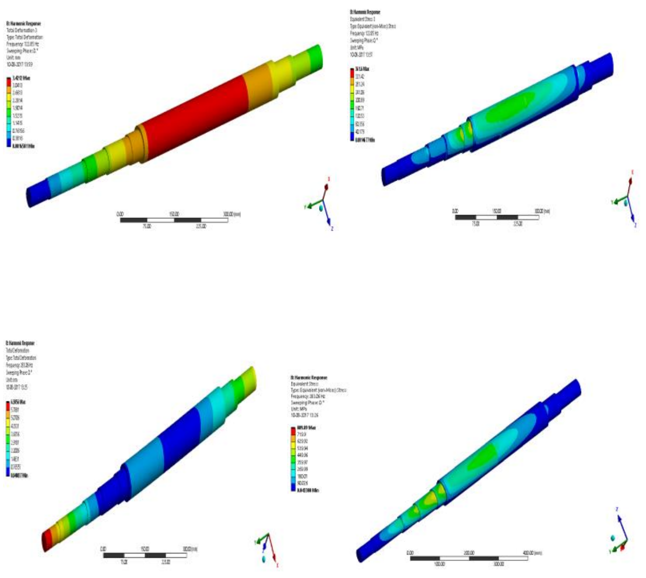

Figure 4.4. Stress contours at critical speeds

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