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Static and Modal Analysis of High-Speed Disperser

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Abstract

Shear stress and natural frequency analysis have for a long time been the prime focus for researchers for designing of a safe and functional shaft for a machine. Studies have been conducted to analyse the shear stress with change in geometry such as shaft length and shaft diameter. By the conclusion of this research, the researcher will be able to obtain relation between shaft dia, torque on shaft, shaft length, and weight over the shear stress and natural frequency to find the minimum diameter that is required for safe operation of shaft. This research concluded that with the increase of shaft diameter, there is a reduction of shear stress but there is a decrease in the critical speed of shaft necessary for reducing vibration during operations.

Keywords: Shear Stress, Natural Frequency, Vibration, Static Analysis, Modal Analysis

I. INTRODUCTION

High speed disperser is a kind of mixer where by the application of cowl or saw blade, the liquid-solid mixture agglomeration is reduced to form a homogenous fine dispersion of powder particles in a fluid suspension. A high-speed disperser is often considered as an economical and simple piece of mixing equipment.[1]

When there is a certain amount of torque applied to a shaft, there is an induction of shear stress and vibrations. The geometry under study has a cowl attached at the bottom of shaft which when the shaft rotates, there is a certain deflection observed.[2][3]

The researcher has studied natural frequency and shear stress for different diameter and length of shaft by first calculating the maximum and minimum diameter of shaft by the help of static structural analysis software and validating the same with theoretical result. A relation of shear stress, natural frequency as well as shaft diameter has been established by generation of graphs of the same.

1.2 Recent Works

N. Lenin & Rakesh in 2012 theorised that the effect of centrifugal force on shaft is balanced by inward elastic pulling and also that the deflection obtained in the shaft is a function of shaft speed and it reached its maximum deflection value at a particular angular velocity called as critical speed [4].

The critical speed of shafts depends upon the following main parameters [4]:

1. Mounting of rotors (eccentric or otherwise).
2. Center of Gravity of shaft loaded from any end.
3. Straightness of Shaft.
4. Bending of shaft under action.

Shelar Santosh Ashok et al. in 2018 conducted simulations for 1.0 meters and 0.9-meter-long shaft respectively and found that for 0.04, 0.06 and 0.08 m diameter of shaft, there is an exponential increase in the first natural frequency for both the lengths, and also found the simulation values in conformity with experimental readings [5].

Wang, Cui, & Li in 2004 by their simulations found almost no difference themselves between the values of ANSYS and their own experimental investigations, and also that their geometry results had fallen under safe values similar to ANSYS results [6].

Julie Markee at el. in 2008 concluded that at high shear dispersion rate, the time taken for making of a slurry is reduced and in addition, for optimizing the operation for cost saving, lower the proportion of liquid in a slurry [7].

Vaibhav Ghodge at el. in 2018 stated that for unloaded and simply support sported beam, we observed that material with higher density like structural steel, aluminium alloy has higher natural frequency as compare to material with lower density materials like copper alloy and aluminium alloy due to Young's modulus to density ratio [8].

Takle at el. in 2014 did a validation study of natural frequencies for varying diameters of shaft and concluded that the critical speed should be avoided by a margin of 2.5 for efficient and safe operation of shaft [3].

Desai at el. in 2016 selected different materials with merit to increase in their strength, ductility as well as corrosion resistance and number of impellers concluded that there is no amount of difference in generated shear stress in two impeller system as compared to single impeller system, but the deflection observed is less in two impeller system comparatively [9].

1.3 Problem Definition

This research focuses on change in parameters such as length, diameter, etc. which affect the shear stress as well as natural frequency of the shaft which has not been considered in most previous research papers.

II. STATIC AND MODAL ANALYSIS OF MECHANICAL PARTS

Static and Dynamic analysis is performed to mainly study about the various stresses affecting a mechanical component as well as the amount of vibrations a component exhibits when under operation. Static and Dynamic analysis enable the engineer to enable a mechanical component to undertake various stresses and deflections induced form the operation.

2.1 Static Analysis

Static analysis of a mechanical component enables the engineer to study the effects of loads which are constant in nature such as torque, displacement, forces, self-weight etc. It allows the engineer to determine the effect of these loads in terms of displacements, stresses and strains. Static analysis ignores the effect of inertia and shock that is commonly found when the loads which are applied are changed abruptly.

In this paper, the researcher mainly focuses upon shear stress induced by the effect of Torque applied on assembly of shaft and cowl, which is calculated by **Eqn. 1**.

$$\tau_{max} = \frac{16\,T}{\pi\,D^3} \qquad \ldots 1$$

Where, τ_{max} indicates shear stress MPa, T indicates torque in Nm applied and D indicates diameter in mm of the shaft.

2.2 Modal Analysis

Modal analysis of mechanical parts is mainly used to study the vibrations induced in a structure from loads such as self-weight. It helps the engineer to calculate the critical speed of any rotating body to see weather the body (here shaft) will vibrate under loads. Modal analysis helps the engineer to better design a mechanical component by altering the design geometry for minimal amount of useless vibrations.

The researcher has used modal analysis to calculate the critical speed of shaft. The critical speed of a shaft is found by **Eqn. 2**.

$$f_{natural} = \frac{K}{2\pi L^2}\sqrt{\frac{EI}{m}} \qquad \ldots 2$$

Where, $f_{natural}$ indicates natural frequency in Hz, K indicates a constant value of 3.52 for mode1, E, I and m indicate Youngs modulus Gpa, area moment of inertia m^2 and mass of shaft in Kg.

III. GEOMETRY CALCULATIONS

The researcher focuses on shaft with a cowl attached at the end of shaft with an overhung (distance from bearings to shaft end) distance of 900 mm and total distance of 1300 mm, with a electric motor of 5 Horse Power capacity rotating the shaft at 1450 RPM. The schematic diagram and CAD model of the shaft is shown in **Fig. 1. (a)**

The diameter of shaft was obtained from **Eqn. 1** with the given data as D_{min} as 24.8 mm and D_{max} as 37.2 mm by multiplying the minimum diameter by factor of safety of 1.5. Based on this result, a CAD model was prepared as in **Fig 1. (b).** and geometry information is listed in **Tab. 1**.

Table 1. Geometry Data

Data	Input	Unit
Power	5	HP
Cowl Dimension (D_{Cowl})	140 × 3tk	Mm
Shaft RPM	1450	rev/min
Shaft Length (L)	1200	Mm
Shaft over hung	900	mm

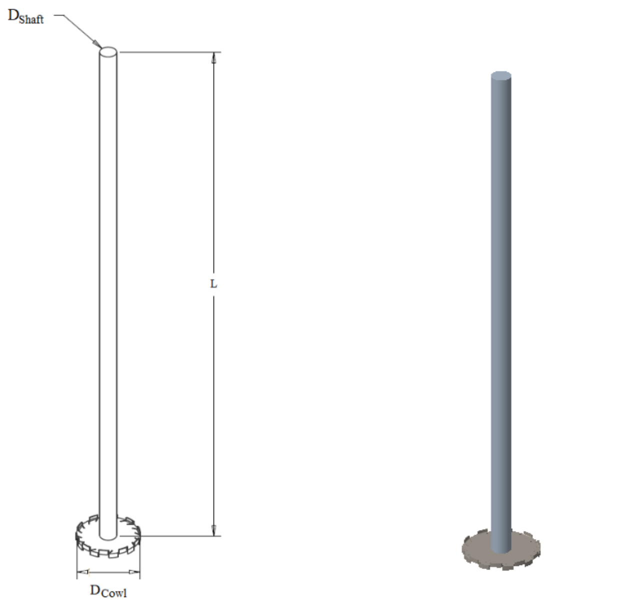

Figure 1. (a) Schematic Diagram (b) CAD Model

The model was loaded in ANSYS Mechanical Static Structural software module, and boundary conditions were given as in Tab. 1.

Table 2. Boundary Conditions

Boundary Condition	Value / Location	Unit
Fixed Support	- /Upper end of Shaft	-
Moment	24.56 / on Cowl	Nm

3.1 Results obtained from Software

The results from the simulation show that the Shear stress acting on the shaft is 9.593 Mpa and the natural frequency is 8.75 Hz. The result can be visualised from **Fig. 2.**

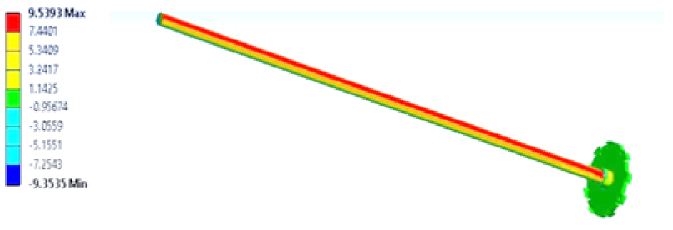

Figure 2. Shear Stress acting on shaft

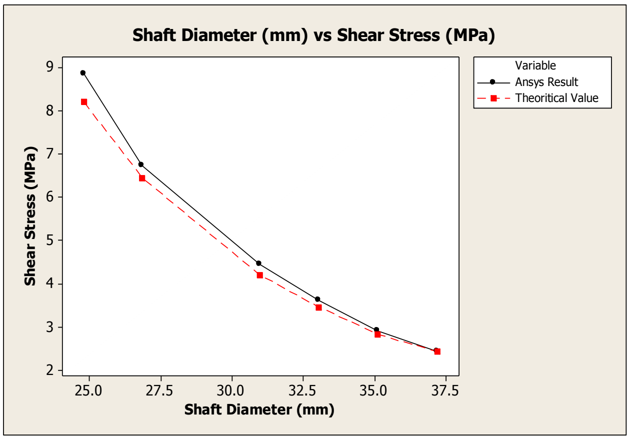

Figure 3. Effect of shaft diameter on shear stress

For obtained results were validated by theoretical calculations by the use of **Eqn. 1** and **Eqn. 2** and found the result for Shear Stress and Natural Frequency to be 8.20 Mpa and 9.22 Hz respectively.

The obtained results from simulation are in conformity with theoretical values, and thus validates the simulation model.

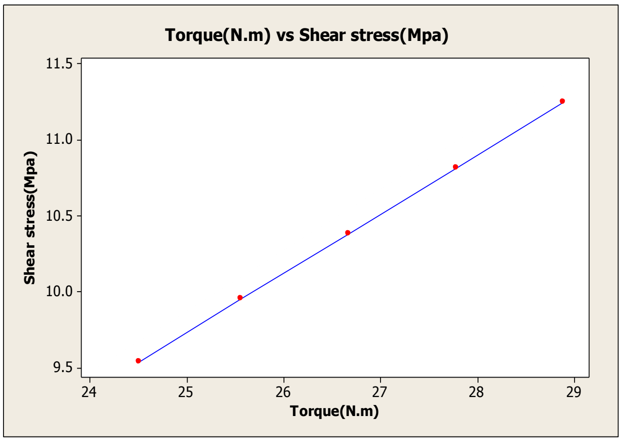

Figure 4. Effect of Torque on Shear Stress

IV. RESULT AND DISCUSSION

To better understand the impact of change in Diameter of shaft, Torque on shear stress and Length of shaft on natural frequency and thus the critical speed. The diameter of shaft was increased with increment of 2.06 mm up to the maximum diameter of 37.2 mm.

4.1 Effect of Shaft Diameter and Torque on Shear Stress

From the obtained results, as seen in **Fig. 3** as the diameter of shaft progresses, there is a decrease in induced shear stress in the shaft by exponential rate because of increase in cross-sectional area resulting in increase in polar moment of inertia and from **Fig. 4** it can be seen as there is an increase of torque, there is a linear increase in induced shear stress.

4.2 Effect of Shaft Diameter and Shaft Length on Natural Frequency

From the obtained modal analysis results, there seems to be a increase in natural frequency with an increase of shaft diameter due to effect of increase in weight of the shaft, indicating increase in stability of the shaft under operation. But for a constant diameter, there is a reduction in natural frequency of the shaft indicating increase in instability under operation.

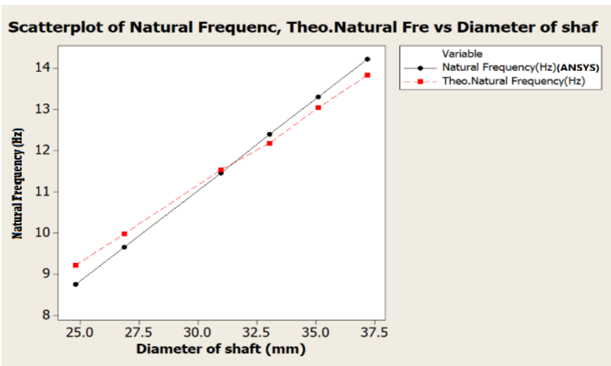

Figure 5. (a) Effect of Shaft Diameter on Natural Frequency

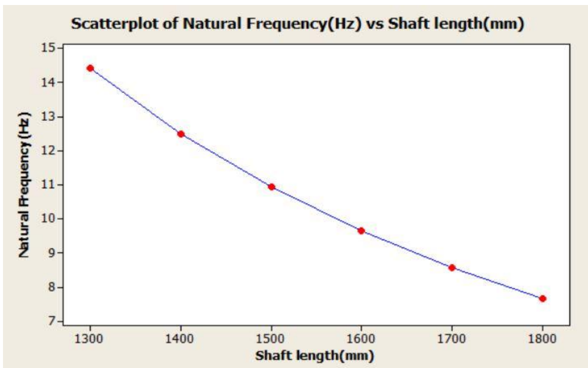

Figure 5. (b) Effect of Shaft length on Natural Frequency

V. CONCLUSIONS

From these observations we can conclude that:

1. Increase in Shaft Diameter results in an decrease in Shear Stress as well as increase in Natural Frequency indicating more stability of the shaft.
2. With increase in Torque acting on the shaft, there is also an increase in Shear Stress induced.
3. With increase in length of shaft, the natural frequency of the shaft decreases with exponential rate which indicates instability and excessive inducement of vibrations in the shaft.

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