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Vibration Analysis of Rotating Elements of A Motor

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***Abstract:** With the industrial revolution, the range of applications for rotating machinery in daily life as well as for industrial use in manufacturing and processing, nuclear power plants, automobiles, oil & gas refineries, etc., has greatly expanded. And for all this rotating machinery, the problems brought on by bearing faults significantly contribute to machine failure. Machine Design courses usually teach students how to design a system consisting of a shaft and its bearings under rotating, bending, transverse, axial, and torsional loads. Most textbooks cover Rayleigh's and Holzer's methods, which do not cover other important dynamic effects in shaft and bearing system design. The diameter of the shaft is calculated and then the deflection of the shaft is evaluated by using static deflection formulas. However, this assumption can cause serious errors in shafts' deflection due to eccentric and nonaligned gears mounted on the shaft. The authors addressed this potential manufacturing defect issue in a Machine Design class as a term project, which required students to transfer and apply content knowledge from their dynamics and vibrations' courses. This paper presents all aspects of this successful experience of implementing ABET strategies in the engineering classroom to maximize its reach and potential impact.*

To meet these objectives and, thus, satisfy the ABET requirement to enhance the content knowledge of engineering design courses, the following project was assigned in our senior level machine design class. The main thrust of the work presented here is to show the dynamic effects of load in shaft design and compare it with the case where only static loads are considered.
Keywords: Resonance, Critical Speed, Whirling, Design of shaft, static structure.

I. INTRODUCTION

It has been found out that for various loads and various motor speeds, the selection of material and design keeps changing. So, for a motor running at a desired speed, the loads may vary, and the design of the elements should be made accordingly. So, for 1 such design, say motor running at 'X' rpm, we need to design the system based on this speed i.e., 'X' rpm and then validate the results depending upon the various loads which will come into picture for this system. The design elements would be consisting of shaft, bearings and a gear and the motor would be selected according to the desired speed. Initially, the shaft is designed based on A.S.M.E. Code. Based on this shaft diameter, the further calculations are performed. The Bearings are designed according to SKF Catalogue. The required bearing is selected based on the applications and different load conditions. The Project is concerned with the vibrations of the shaft. The aim of the project is to try to reduce the vibrations of the shaft. These vibrations would be measured by a sensor.

A. *What is Vibration?*

Vibration is a periodic motion of the particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed. In many cases, however, vibration is undesirable, wasting energy and creating unwanted sound. For example, the vibrational motions of engines, electric motors, or any mechanical device in operation are typically unwanted. Such vibrations could be caused by imbalances in the rotating parts, uneven friction, or the meshing of gear teeth. Careful designs usually minimize unwanted vibrations.

Effects of vibration

- It creates excessive stress in machine parts.
- It leads to loosening of assembled parts.
- It may lead to partial or complete failure of machine parts.
- It creates undesirable noise.

B. What is Resonance?

Resonance is the tendency of a mechanical system to respond at a greater amplitude when the frequency of its oscillations matches the frequency of vibration that naturally occurs in the system (its resonance frequency or resonant frequency) than it does at other frequencies. Inadequately built structures, such as bridges, buildings, and aero planes, may experience extreme swaying motions or even catastrophic breakdown. A basic mechanical system with a weight hung by a spring has the following natural frequency:
where *m* is the mass and k are the spring constant.

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

One straightforward illustration of a resonant system that most people are familiar with is a swing set. It resembles a pendulum. The system will swing higher and higher if excited (pushed) with a duration between pushes equal to the inverse of the pendulum's natural frequency, but it will be challenging to move if excited at a different frequency. The equation provides an approximation, for tiny displacements, of the resonance frequency of a pendulum, the only frequency at which it would oscillate.

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$$

C. What is Whirling?

Look at a typical shaft that has a disk-shaped rotor positioned between two bearings, as seen in Fig. Let's assume that the shaft's overall mass is minimal in comparison to the rotor's (or disk's) mass, allowing us to think of it as a straightforward torsional spring. Due to the distribution of the materials, the geometric center of the rotor (disc) section, which is also the mass center, is circular in shape. These two may or may not generally coincide, resulting in eccentricity as seen in Fig. It's possible that the eccentricity is caused by internal material flaws, manufacturing mistakes, etc. The eccentricity of the shaft indicates that the mass of the rotor will produce an in-plane centrifugal force as it revolves. Due of its adaptability the shaft, as shown in the image, the shaft will be dragged away from its center line. Assume that there is little air-friction damping force. As a result, the internal resistance force in the shaft-spring balances the centrifugal force for a certain speed, and the system reaches equilibrium with the shaft bent as shown in the picture. As a result, the shaft rotates around its own axis, while the plane containing the bent shaft and the line of bearings also rotates around an axis that coincides with the line of bearings. Here, we only analyze the synchronous whirl—a situation in which the two rotating speeds are equal.

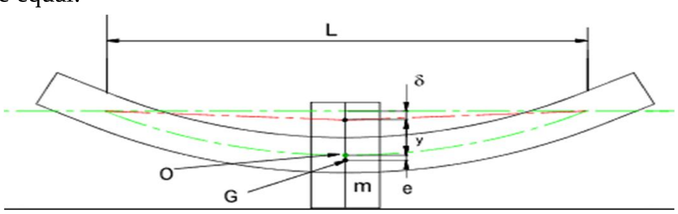

Fig 1. Whirling

D. What is Damping?

A damping influence is one that has the power to lessen, restrict, or even stop oscillations in an oscillatory system. Physical systems experience damping because of processes that release the oscillation's stored energy. Examples include resistance in electronic oscillators, viscous drag in mechanical systems, and light absorption and scattering in optical oscillators. In other oscillating systems, such as those that occur in biological systems and bicycles, damping that is not based on energy loss can be crucial.

The decay of oscillations in a system following a disturbance is described by the dimensionless quantity known as the damping ratio. When perturbed from their state of static equilibrium, many systems display oscillatory behavior. For instance, a mass suspended from a spring might bounce up and down if it is pulled and released. The system generally tries to return to its equilibrium position after each bounce but overshoots it. When losses (such as frictional ones) dampen the system, the oscillations may occasionally attenuate or progressively decrease in magnitude. The oscillations' rate of decay between each bounce is measured by the damping ratio. The damping ratio is a system parameter, denoted by ζ (zeta), that can vary from undamped ($\zeta=0$), underdamped ($\zeta<1$) through critically damped ($\zeta=1$) to over damped ($\zeta>1$).

A wide number of fields, including control engineering, chemical engineering, mechanical engineering, structural engineering, and electrical engineering, are frequently interested in the behavior of oscillating systems. An electric motor's speed or the sway of a tall building in the wind are two examples of physical quantities that oscillate; however, it might be useful to describe common elements of behavior using a normalized or non-dimensional zed approach.

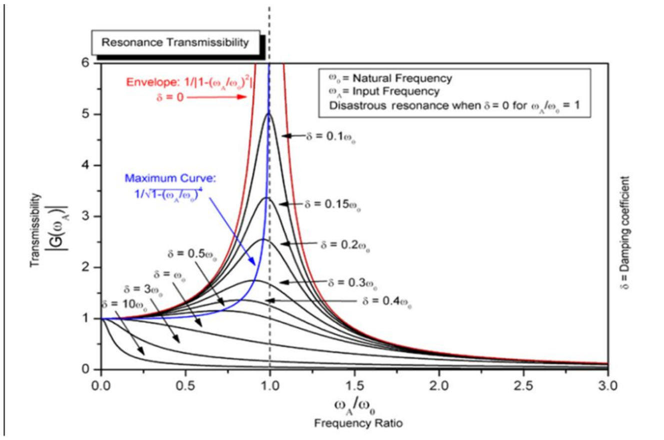

Fig 2. Frequency Ratio vs Transmissibility

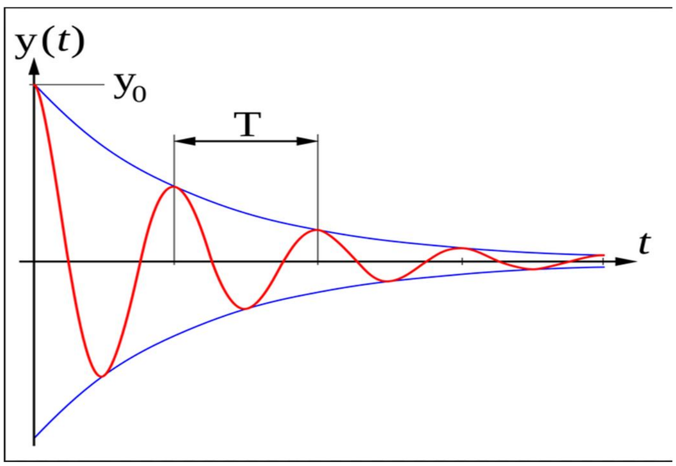

Fig 3. Damped oscillation graph

II. DESIGN OF SHAFT

A. Design of SHAFT

The design of shaft based on strength can be divided into Three categories: -

1) Design of shaft by Theories of Failure.
2) Design of solid shaft by maximum principal stress theory.
3) Design of shaft by A.S.M.E Code.

A.S.M.E Code for Design of Shaft

- American Society of Mechanical Engineers (A.S.M.E) established a code for the design of transmission shaft. This code for the design of shafts is based on the maximum shear stress theory.
- According to A.S.M.E code, the maximum shear stress induced in a solid shaft, subjected to the fatigue loading of combined torque and bending moment, given by,

$$\zeta_{max} = \frac{16T}{\pi d^3}.$$

T = Equivalent Twisting Moment
= [(KbM)2 + (KtT)2]0.5
* Allowable shear stress as per A.S.M.E. code (without keyway):

According to A.S.M.E. code, the values of allowable shear stress are as follows: -
ζper = 0.75 x 0.3 Syt or 0.75 x 0.18 Sut

whichever is minimum.
We have designed the shaft based on A.S.M.E. Code:
Power = 20 kW.

Speed of Motor = 300 r.p.m.

Thus, using the relation

$$P = \frac{2\pi NT}{60000} (kW).$$

Thus, we get
T = 954.93 x 103 N mm.
We know that Maximum Bending Moment is given by

$$M = \frac{FL}{4}.$$

M = 625 x 103 N mm.

Based on these values of T and M, we determine the value of equivalent torque on the shaft.

The equivalent torque is given by
Te = [(KBMY)2 + (KtT)2]0.5.
For Mild Steel,
Kb = Shock Factor for bending = 1.5 and
Kt = Fatigue Factor for torsion = 1
Using this above equation, we evaluate The and we get,
Te = 1338.2 x 103 N mm.

Diameter of Shaft is given by

$$\zeta_{max} = \frac{16Te}{\pi d^3}.$$

and ζmax = 42 MPa.
Thus, Diameter of Shaft = 54.54 mm ≈ 55 mm.

B. Design of Bearings

A bearing is a component of a machine that limits relative motion to only that motion that is intended and lessens friction between moving elements. The bearing's design may, for instance, permit free rotation around a fixed axis or free linear movement of the moving part.
It may also serve to prohibit motion by managing the vectors of normal forces acting on the moving parts. Most bearings reduce friction to enable the desired motion. According to the type of operation, the motions permitted, or the directions of the loads (forces) applied to the parts, bearings can be generically categorized.
Our system has shaft diameter = 55 mm. So according to SKF Catalogue we must select bearing number as 11. Also, the bearing series selected is of extra light series. Also, bearing type is selected as deep groove ball bearing. Thus, we select the bearing as 6011.

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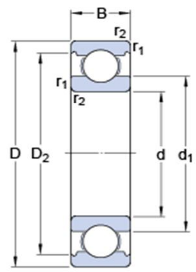
III. BEARING: 6011.

A. Features of 6011 Bearing

▶ 6011

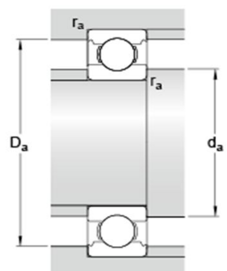
Popular item
SKF Explorer

Dimensions



d		55	mm
D		90	mm
B		18	mm
d_1	≈	66.3	mm
D_2	≈	81.5	mm
$r_{1,2}$	min.	1.1	mm

Abutment dimensions



d_a	min.	61	mm
D_a	max.	84	mm
r_a	max.	1	mm

Wednesda
Local time
DUBAI

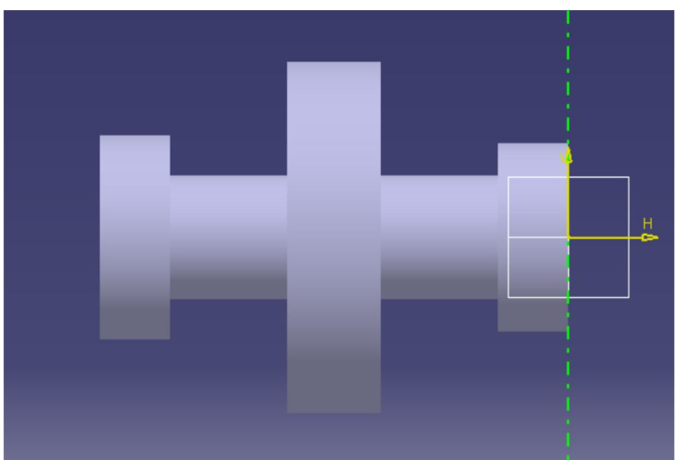


Fig 4. General CAD model

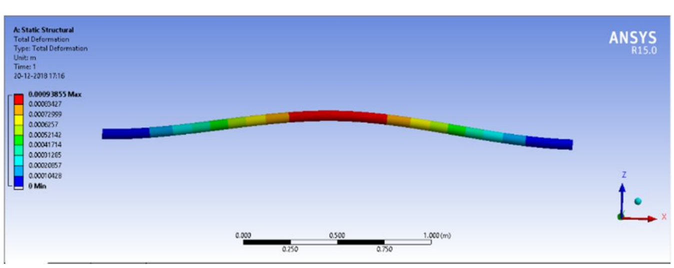


Fig 5. Deflection on shaft (on ANSYS)

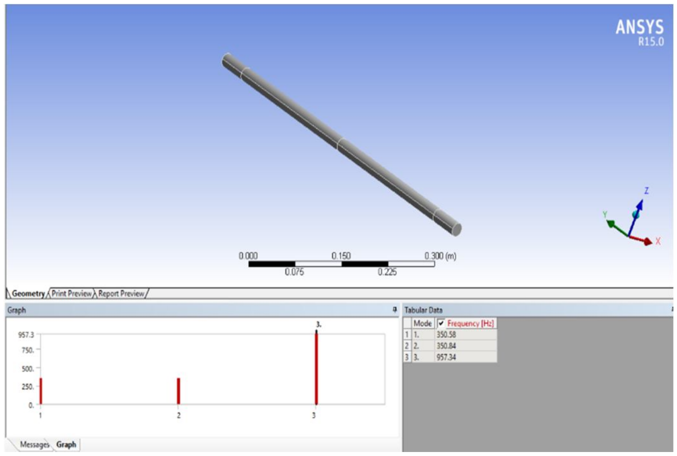


Fig 6. Nodal analysis (on ANSYS)

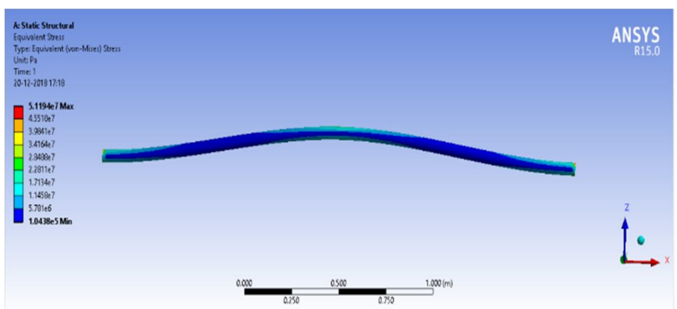


Fig 7. Stress in the system (on ANSYS)

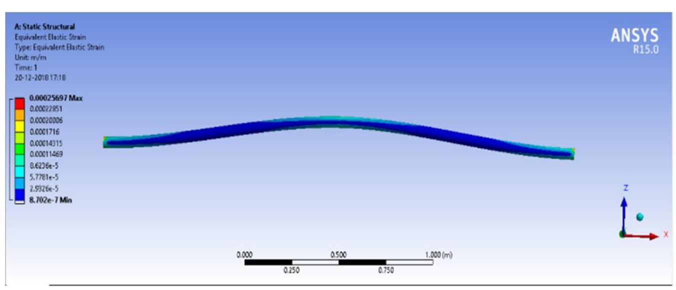


Fig 8. Strain in system (on ANSYS)

IV. CONCLUSION AND SCOPE

Thus, from above study, to prevent resonance the natural frequency of the system should not be equal to excitation frequency which will further reduce the vibrations in the system.

In today's world of mechanical engineering, vibration analysis has become essential. Vibration analysis is applicable to practically all areas of mechanical engineering.

All forms of rotating machinery can benefit from vibration analysis, including the following:

Generators, Compressors, Pumps, Fans, and Turbines

Vibrations in IC engines are caused by uneven reciprocating masses, high gas pressure, and mount structural features.

Vibration in I.D. fans is brought on by rotating machinery. High vibration levels are the main sign of rotor mass unbalance. Our goal is to minimize these vibrations as much as we can.

The system's efficiency and the component life both increase with lower vibrations.

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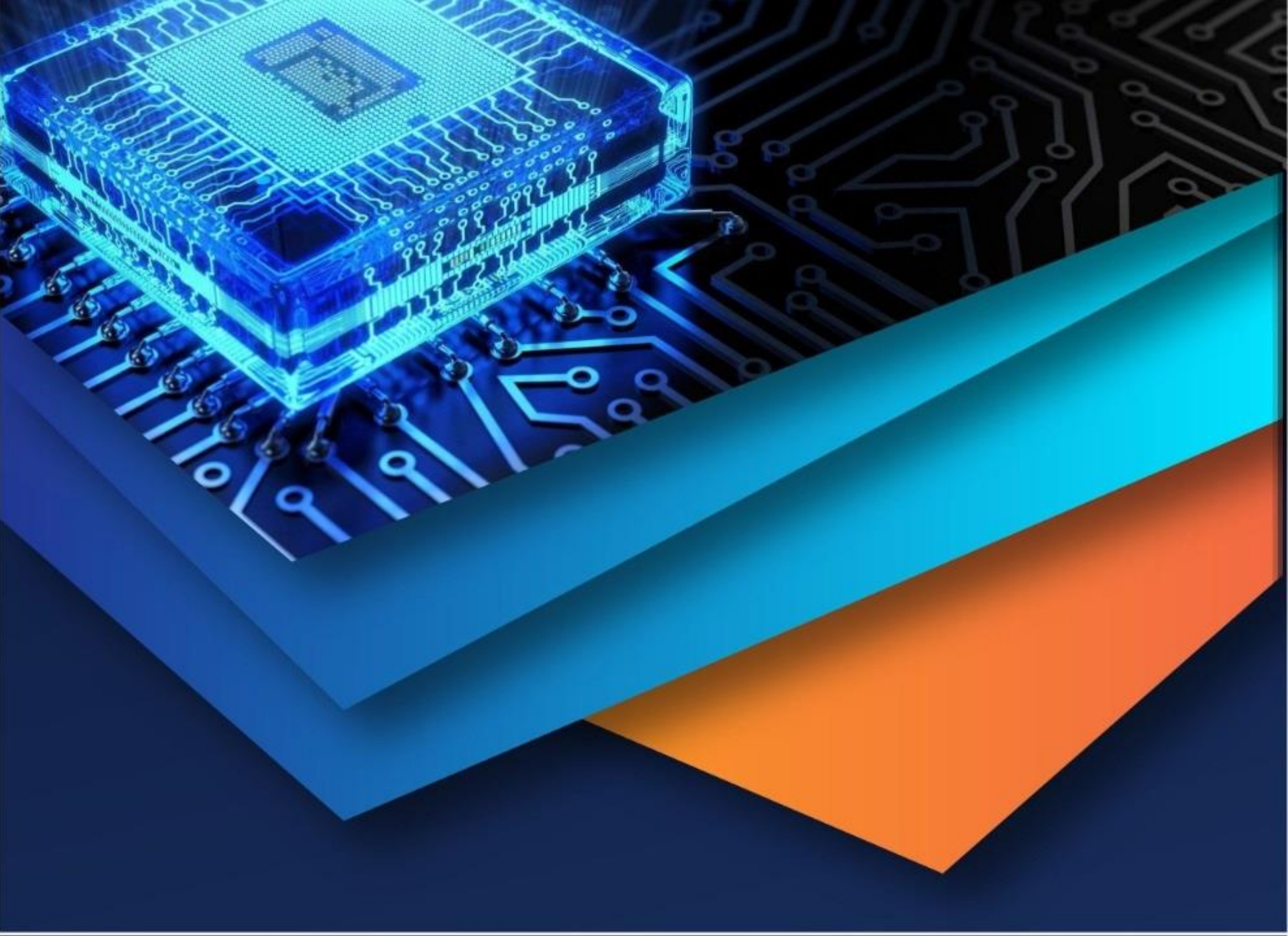

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