DESIGN AND MODAL ANALYSIS TO CALCULATE CRITICAL SPEED OF SHAFT

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ABSTRACT

Present paper deals with design, analysis and development of critical speed measurement machine for various diameters and lengths of shaft. Everybody has its own frequency it is called natural frequency. When the working frequency matches with natural frequency, resonance will be occurs at certain speed this speed is called 'critical speed'. In general it is very important to determine the critical speed to avoid the breakdown of rotating machine. By knowing the critical speed we run the machine above or below that critical speed. In this project we determine the critical speed of shaft by the experimental analysis. First we calculate the natural frequency of shaft by theoretical and modal analysis (Ansys Software). Natural frequencies at different speed for various diameter of shaft are evaluated and compared in this project.

Keywords: Critical speed, Natural frequency, Modal analysis, Resonance

I INTRODUCTION

All rotating shafts, even in the presence or absence of an external load due to self weight, will cause deflection during the rotation. Due to the combined weight of a shaft and shaft-mountings can cause the deflection which will create or further lead to the resonant vibrations at certain speed. These speeds are generally known as 'critical speed'. Therefore, calculation of critical speed for any shaft is necessary in order to avoid the resonance of shaft [2].

At the critical speed, the shaft is subjected to violent (frequent) vibrations in the 'transverse direction' that of the axis of rotation. These excessive vibrations, associated with the critical speed, may lead or cause the permanent deformation of the shaft. This subjected to structural damage. Also the large shaft deflection at the critical speed, include large bearing reactions and may subjected to bearing failure [1].

The all type of discontinuities are unavoidable, due to assembly, manufacturing and application considerations, which all ensure that the centre of gravity of shaft can't coincides with the axis of rotation.

The main objective of the project is to measure the critical speed with the help of ‘modal analysis’, ‘theoretically’ first and then compare it with the ‘practical’ (experimental) value.

II CRITICAL SPEED

When the working frequency matches with natural frequency, resonance will be occurs at certain speed this speed is called ‘critical speed’.

The fig.1 shows, the shaft vibrates with maximum amplitude that is working frequency matches with first natural frequency at that point we obtained the first mode of whirl at that point we get a ‘first critical speed’ of shaft.

The fig. 2 shows, the working frequency matches with second natural frequency at that point we obtained the second mode of whirl, this means at that point we get ‘second critical speed’ of shaft.

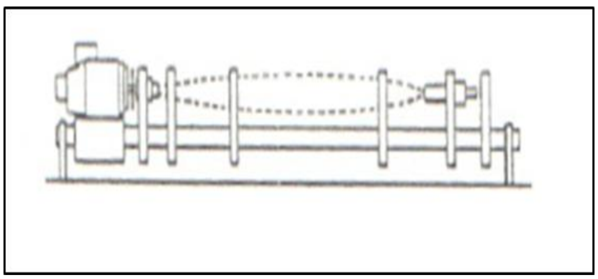

Fig.1: First Mode of Whirl [2]

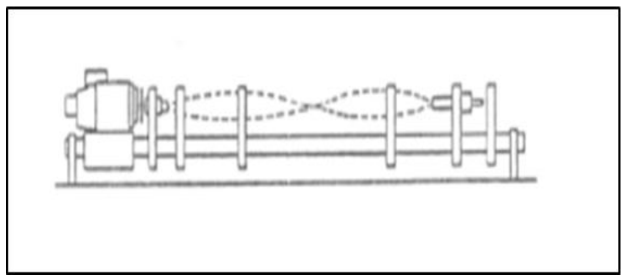

Fig. 2: Second Mode of Whirl [2]

NATURAL FREQUENCY

Natural frequency is the frequency at which a body tends to oscillate (vibrates) in the absence of any external force (example: driving force or damping force).

III CRITICAL SPEED EQUATION

f_n = Natural Frequency, Hz

N = Mode number i.e. 1,2,3…

I = Moment of inertia of shaft

E = Young’s Modulus (GPA)

W = Weight of shaft per meter length

L = Length of shaft (m)

g = Acceleration due Gravity (m/s^2)

Formula for Critical Speed [2],

$$f_n = \frac{\pi}{4}\left[N + \frac{1}{2}\right]^2 \sqrt{\frac{g \times E \times I}{W \times L^4}}$$

IV CALCULATION

Natural Frequency for Diameter (D) =0.004m and Length (L) =1m

We Know the Formula

$$f_n = \frac{\pi}{4}\left[N + \frac{1}{2}\right]^2 \sqrt{\frac{g \times E \times I}{W \times L^4}}$$

i. **For Node one, D= 0.004m, L= 1m**

$$f_n = \frac{\pi}{4}\left[N + \frac{1}{2}\right]^2 \sqrt{\frac{9.81 \times 200 \times 10^9 \times 1.26 \times 10^{-11}}{0.96 \times 1^4}}$$

$f_n = 3.534 \times 5.0745$

$f_n = 17.93$ Hz …………….. For 1st Mode

ii. **For Node Two, D=0.004m, L=1m**

$f_n = 9.817 \times 5.0745$

$f_n = 49.81\ Hz$……………… For 2nd Mode

Similarly by Calculating the Frequencies for D = 6mm, 8mm and Length L= 1m, 0.9m, the values are shown in following table 1.

Table 1: Natural Frequency For different diameter and length

Sr. No.		Length	Diameter	Natural Frequency	Theoretical Value
A	i	1m	0.004m	First Freq.	17.93 Hz
				Second Freq.	49.81 Hz
	ii		0.006m	First Freq.	26.82 Hz
				Second Freq.	74.25 Hz

	iii		0.008m	First Freq.	35.52 Hz
				Second Freq.	98.63 Hz
B	i	**0.9m**	0.004m	First Freq.	22.20 Hz
				Second Freq.	61.24 Hz
	ii		0.006m	First Freq.	33.14 Hz
				Second Freq.	91.42 Hz
	iii		0.008m	First Freq.	44.48 Hz
				Second Freq.	122.21 z

V MODAL ANALYSIS OF SHAFT

For finding the natural frequency we have done the modal analysis of shaft in Ansys (R14.5) By putting the engineering data of shaft and fix the both end of shaft, we have find six modes of vibration the first mode frequency is called natural frequency. Modal Analysis for Various Diameter and Length as Show in Fig 3,4,5,6,7,8,9,10 etc.

The Modal Analysis for various diameter and length of shafts as shown in below table 2.

Table 2: Properties for Spring Steel Material (0.48C, 0.75Mn, 0.40P, 0.40S, 0.20Si, 0.40Ni, 0.40Cr, 0.15Mo) [8]

Sr. No.	Property	Value	Unit
1	Young’s Modulus (E)	207	GPa
2	Density	7860	Kg/m^3
3	Poisson’s Ratio	0.3	-
4	Ultimate Tensile Strength	1350	MPa
5	Yield Strength	1200	MPa

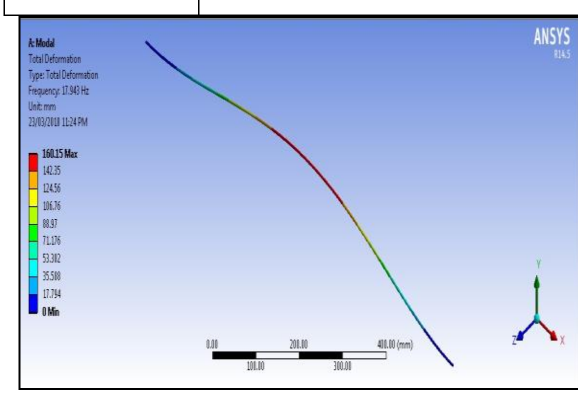

Fig.3 First Mode (D=0.004m, L= 1m, 17.93 Hz)

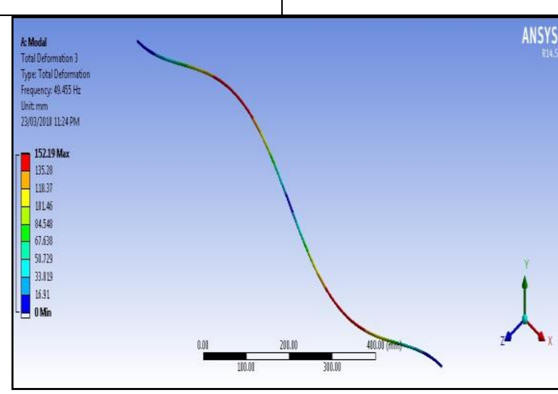

Fig.4 Second Mode (D=0.004m, L=1m, 49.55 Hz)

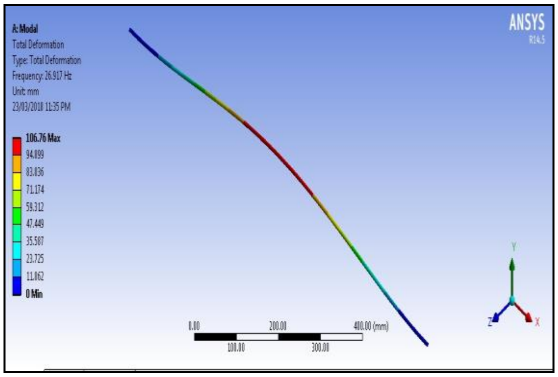

Fig.5 First Mode (D=0.006m, L= 1m, 26.917 Hz)

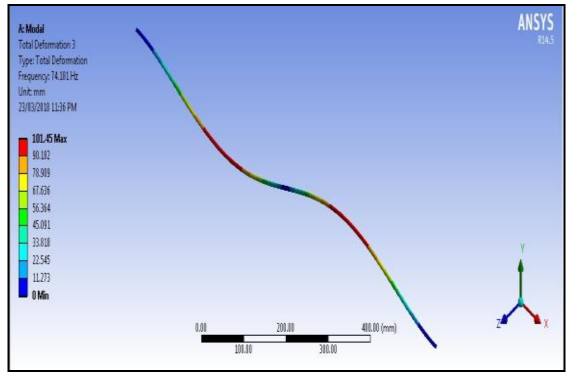

Fig.6 Second Mode (D=0.006m, L=1m, 74.181 Hz)

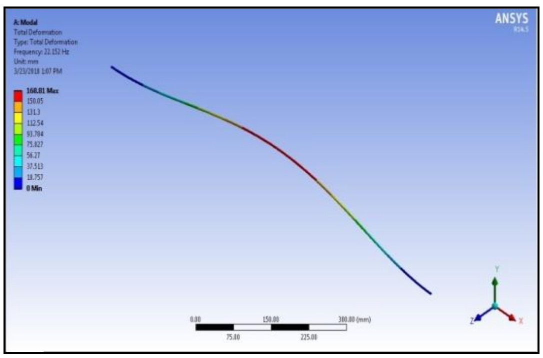

Fig.7 First Mode (D=0.004m, L= 0.9m, 22.152 Hz)

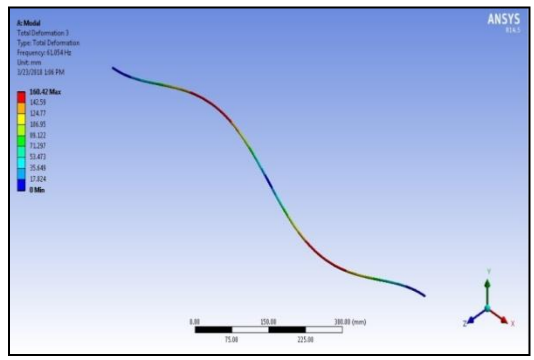

Fig.8 Second Mode (D=0.004m, L=0.9m, 61.054 Hz)

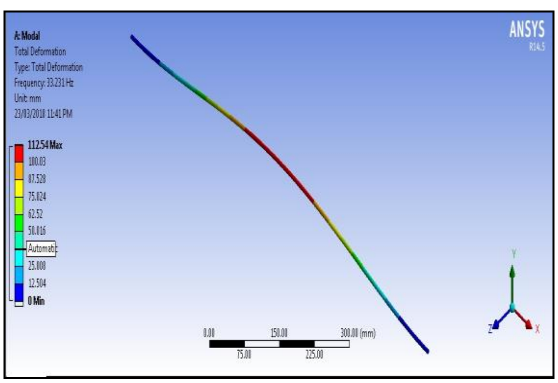

Fig.9 First Mode (D=0.006m, L= 0.9m, 33.230 Hz)

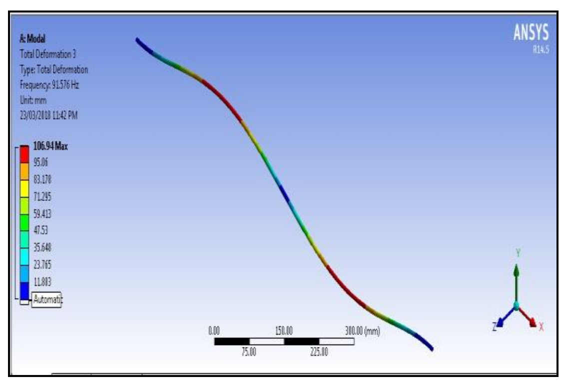

Fig.10 Second Mode (D=0.006m, L=0.9m, 91.576 Hz)

Table 3: Modal Frequency For different diameter and length by Modal Analysis

Sr. No.		Length	Diameter	Modal Frequency	Modal Analysis Value
A	i	**1m**	0.004m	First Mode	17.943 Hz
				Second Mode	49.455 Hz
	ii		0.006m	First Mode	26.917 Hz
				Second Mode	74.180 Hz
	iii		0.008m	First Mode	35.880 Hz
				Second Mode	98.880 Hz
B	i	**0.9m**	0.004m	First Mode	22.152 Hz
				Second Mode	61.054 Hz
	ii		0.006m	First Mode	33.230 Hz
				Second Mode	91.576 Hz
	iii		0.008m	First Mode	44.302 Hz
				Second Mode	122.06Hz

VI CONCLUSION

From table 1 and table 3 the theoretical values as well as modal analysis values of natural frequency are approximately equal.

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