Natural Frequency and Deformation Analysis of a Step-Turned Machine Shaft Using Finite Element Method.

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Abstract- The researchers, studied natural frequency and deformation analysis of a step-turned machine shaft using finite element method. The step- turned machine shaft was modeled with inventor, having an assigned material being Austenitic Stainless Steel to reduce deformation and corrosion. The solid cylindrical shaft retained variable cross-sectional diameter of 30mm and 50mm with length of 50mm each. Modeled shaft was imported into Finite Element Analysis Software where deformation was analyzed. In addition, turning moment of 400 N mm and bearing load of 1200N were adopted with fixed constraints. Results from the analysis revealed that the natural frequency was found to be 9801.78 Hz with maximum deformation of 6. 124 mm. Also, the general design information and mechanical properties of the machine shaft were discovered from the study. To avoid failure, the frequency of the periodic external load the shaft would be subjected to must be lower than 490.089Hz and 1200N in line with the given conditions. The researchers made the following recommendations: Machine shaft material must have higher natural frequency greater than periodic load frequency, to avoid failure due to resonance; this research can also be done in future using different shaft geometrical designs such as spindle shaft, square shaft, hollow shaft and other advanced software in computer aided engineering for generalization, etc.

Indexed Terms- Machine Shaft, Deformation, Finite Element Analysis, Bearing Load, Turning Moment, Constraints.

I. INTRODUCTION

Peng and Yan (2022) stated that Shaft is widely used in ships, naval vessels, rail coaches, aircraft, spacecraft, and other machinery. Torsional vibration of shafting is always a most important problem for engineers. Many engineering solutions have been proposed, such as the Rayleigh method, lumped mass method (lumped parameter method, LMM), finite element method (FEM), and boundary element method (BEM). They added that these mentioned methods are “approximate”, the “exact” theoretical solutions are rarely reported.

The shaft of turbine-generators turned over the resonance, vibration is at maximum when speed passes the resonance range. The load on bearings and the lifetime of the equipment will be reduced and the likelihood of defects increases (Sztankó, 2005).

Khurmi and Gupta (2012) stated that the frequency is the number of cycles described in one second. The frequency of free vibration is known as natural frequency. When the shaft is under the influence of a periodic disturbing force, forced vibration occurs. If the frequency of the external force is same as that of the natural frequency of shaft, resonance takes place and shaft vibrates with maximum amplitude or deformation.

Christopher and Michael (as cited in Ugwuegbu and Ewurm, 2022) claimed that a machine shaft of 30 mm diameter constant cross section of the entire shaft will usually experience larger deformation than the similar stepped shaft. They further added that 50 mm diameter shaft will experience smaller displacement or deformation than the similar stepped shaft.

Finite element analysis method here, is a process of simulating the behavior of the helical spring part under given conditions via software so that the effects of real world conditions could be quantify on the part.

There are no doubts that machine shaft excessive vibration increases shaft displacement or deformation and also shaft ability to transmit the required power and work. Reviewed literatures revealed that excessive deformation can ruin machine performance and also lower service life. Hence, the paper aimed at studying the natural frequency and deformation analysis of a step-turned machine shaft using finite element method.

II. STATEMENT OF THE PROBLEM

According to Sztanko (2005) the shaft of turbine-generators turned over the resonance, vibration is at maximum when speed passes the resonance range. The load on bearings and the lifetime of the equipment will be reduced and the likelihood of defects increases.

Crocker (as cited in Fiebig and Wrobel, 2017) the vibration amplitude of a mechanical system depends on the ratio of the driving force frequency and the natural frequency of the system. When the excitation force frequency is equal to the natural frequency of the object, the phenomenon of mechanical resonance occurs, and as a result maximum value can be observed in the vibration deformation.

Khurmi and Gupta (2012) opined that in order to avoid resonance, the natural frequency of the shaft should be at least twenty times the resonance frequency. It is on this note that the researchers aimed at studying the natural frequency and deformation analysis of a step-turned machine shaft using finite element method.

III. PURPOSE OF THE STUDY

The general purpose of the study is to determine the natural frequency and deformation analysis of a step-turned machine shaft using finite element method.

IV. SIGNIFICANCE OF THE STUDY

The result of this study will be beneficial to industrial shaft designers/production engineers in the following ways:

- Production engineers can improve machine shaft safety; reduce operational noise and avoid sudden shaft failure by choosing material whose natural frequency is greater than disturbing periodic force frequency.
- The knowledge of displacement or deformation can be used to improve the design life of machine shaft by making appropriate provisions for accommodation.

V. SCOPE OF THE STUDY

This research focused on determining the natural frequency and deformation analysis of a step-turned machine shaft using finite element method. Therefore, all efforts were directed towards the general objective. Natural frequency and deformation evaluations followed Finite Element method. The researchers are members of Federal Polytechnic Nekede, within South East of Nigeria. Results may be subject to variations within other parts of the World.

VI. REVIEW OF RELATED LITERATURE

Peng and Yan (2022) studied torsional vibration analysis of shaft with multi inertias using Hamilton principle, they stated that Shaft is widely used in ships, naval vessels, rail coaches, aircraft, spacecraft, and other machinery. Torsional vibration of shafting is always a most important problem for engineers. Many engineering solutions have been proposed, such as the Rayleigh method, lumped mass method (lumped parameter method, LMM), finite element method (FEM), and boundary element method (BEM). They added that these mentioned methods are “approximate”, the “exact” theoretical solutions are rarely reported. Sztanko(2005) investigated active vibration control in rotating shafts. They formulated a mathematical model describing the motion of the center of a typical cross section of the shaft with and without damping, which can be used to optimize the damping strategy. Finally compared measured results of finite element method and the numeric simulation. Khurmi and Gupta (2012) studied theory of machines, vibrations and stated that the frequency is the number of cycles described in one second. The frequency of free vibration is known as natural frequency. When the spring is under the influence of a periodic disturbing force, forced vibration occurs. If the frequency of the external force is same as that of the natural frequency of spring, resonance takes place and spring vibrates with maximum amplitude or deflection. Fiebig and

Wrobel (2017) conducted simulation and experiment on use of mechanical resonance in machine drive systems. Based on simulation and experimental investigations, the sequential extraction of energy from an oscillator in resonance has been described. Finally, the accumulation of energy at resonance and its use in a prototype of punching press machine and in the crankshaft system was presented. Khurmi and Gupta (2012) studied machine designs, springs and concluded that resonance results in very large deflections of the coils and as well as very high stresses. Under these conditions, it is just possible that the spring may fail. In order to avoid resonance, the natural frequency of the spring should be at least twenty times the resonance frequency.

VII. METHODOLOGY

Researchers considered step turned shaft, with an assigned material being Stainless Steel to minimize deformation and corrosion. The solid cylindrical shaft retained variable cross sectional diameter of 30mm and 50mm with length of 50mm each. Shaft was subjected to turning moment of 400 N mm with bearing load of 1200N representing shaft supported weight with fixed constraints as shown in Fig. 1 and Fig. 2. The machine shaft modeled with inventor was imported to finite element analysis software where natural frequency and deformation were predicted based on the stated conditions.

VIII. DESIGN ANALYSIS

According to Westmann (2004), the stress components in an element are given as below.

$(\sigma_x)_n = \frac{E}{(1+v)(1-2v)}[(1-v)a_n + ve_n] \ldots\ldots(1)$ (as cited in Onyenobi et al, 2022)

$$(\sigma_y)_n = \frac{E}{(1+v)(1-2v)}[va_n + (1-v)e_n] \ldots\ldots(2)$$

$$(\tau_{xy})_n = \frac{E}{2(1+v)}(b_n + d_n) \ldots\ldots(3)$$

$v = Poisson's\ ratio, E = modulus\ of\ elasticity$

The displacement field is shown below.

$$a_n = \frac{\partial u_n}{\partial x} \ \ldots(4)$$

$$e_n = \frac{\partial v_n}{\partial y} \ \ldots(5)$$

$$b_n + d_n = \frac{\partial u_n}{\partial y} + \frac{\partial v_n}{\partial x} \ldots.(6)$$

$v\ and\ u\ are\ velocity\ components\ of\ x\ and\ y$

According to Rajput (200), the principal deformations are given below

$e_x = \frac{1}{E}\left[\sigma_x - \frac{1}{m}(\sigma_y + \sigma_z)\right] \ldots\ldots(7)$ (as cited in Onyenobi et al, 2022).

$$e_y = \frac{1}{E}\left[\sigma_y - \frac{1}{m}(\sigma_x + \sigma_z)\right] \ldots\ldots(8)$$

$$e_z = \frac{1}{E}\left[\sigma_z - \frac{1}{m}(\sigma_x + \sigma_y)\right] \ldots\ldots(9)$$

Von Mises Stress can be given as below.

$Von - mises\ stress = \sqrt{\sigma_x{}^2 - \sigma_x\sigma_y + \sigma_y{}^2} \ldots.(10)$

According to Khurmi and Gupta (2012), the natural frequency of shaft is given below.

$f_n = \frac{0.4985}{\sqrt{\delta}}$ ….. (11)

$\delta = static\ deflection$ in mm

IX. RESULTS AND PRESENTATIONS

Table 1: Project Information

Part Name	MACHINE SHAFT
Designer	EWURUM TENNISON
Cost	$100.00
Date Created	6/26/2022
Material	Stainless Steel, Austenitic
Density	8 g/cm^3
Mass	1.06814 kg
Area	16493.4 mm^2
Volume	133518 mm^3

Center of Gravity	x=0.0000000046748 mm y=0 mm z=-11.7647 mm
Avg. Element Size (fraction of model diameter)	0.08
Min. Element Size (fraction of avg. size)	0.2
Grading Factor	1.5
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

Table 2: Material properties

Name	Stainless Steel, Austenitic	
General	Mass Density	8 g/cm^3
	Yield Strength	228 MPa
	Ultimate Tensile Strength	540 MPa
Stress	Young's Modulus	190.3 GPa
	Poisson's Ratio	0.305 ul
	Shear Modulus	72.9119 GPa
Part Name(s)	MACHINE SHAFT	

Table 3: Operating conditions, Moment

Load Type	Moment
Magnitude	400.000 N mm
Vector X	0.000 N mm
Vector Y	0.000 N mm
Vector Z	400.000 N mm

Table 4: Operating conditions, Bearing Load

Load Type	Bearing Load
Magnitude	1200.000 N
Vector X	0.000 N
Vector Y	0.000 N
Vector Z	-1200.000 N

Table 5: Natural Frequency of Vibration

F1	0.00 Hz
F2	0.00 Hz
F3	0.00 Hz
F4	0.00 Hz
F5	0.00 Hz
F6	0.00 Hz
F7	9800.33 Hz
F8	9801.78 Hz

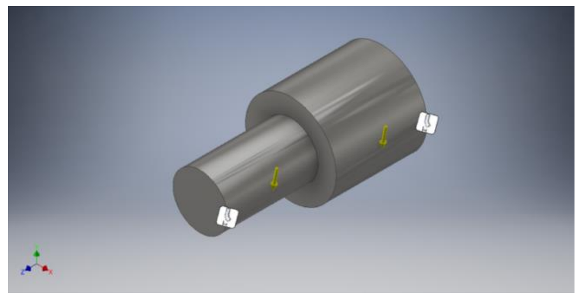

Fig.1: Machine Shaft Model

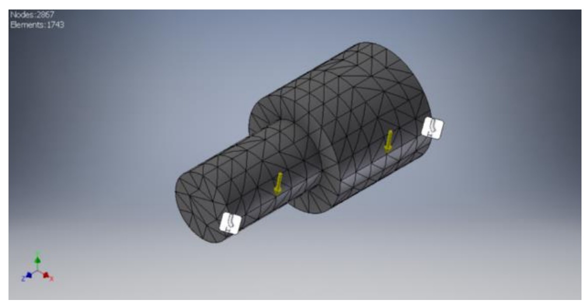

Fig.2: Load, Mesh and Constraints on Shaft Model

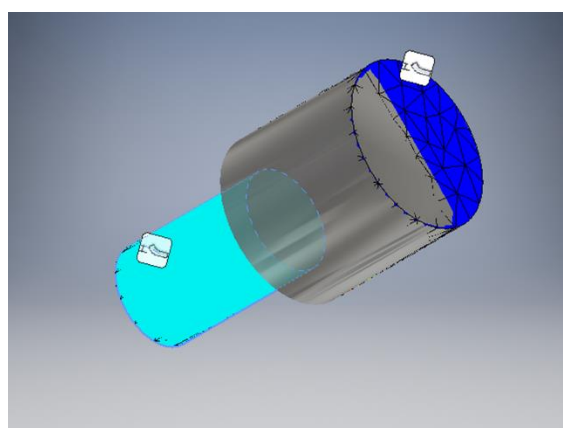

Fig.3: Mesh and Constraints on Shaft Model

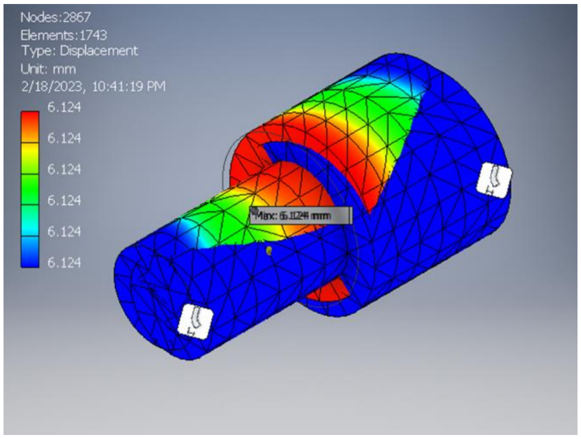

Fig.4: Displacement on Shaft Model

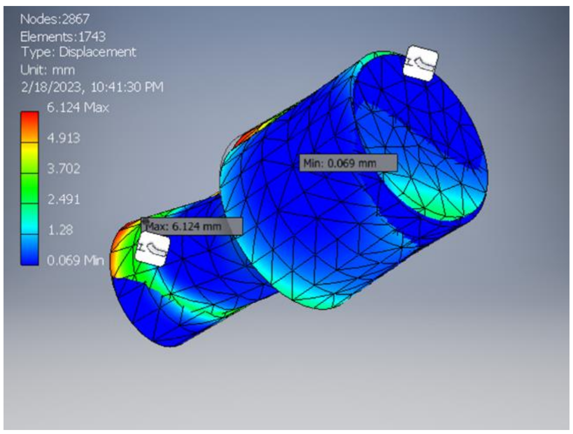

Fig.5: Displacement on Shaft Model
F7 9800.33 Hz

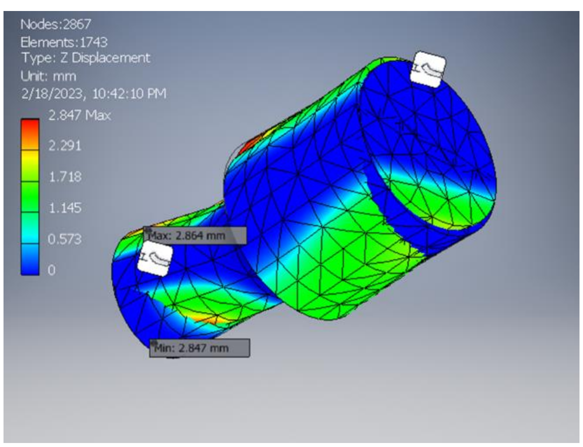

Fig.6: Displacement on Shaft Model
F7 9801.78 Hz

X. DISCUSSION

Natural frequency and deformation analysis of a step-turned machine shaft were studied using finite element method. The study considered step turned machine shaft, having an assigned material being Stainless Steel to minimize deformation and corrosion. The solid cylindrical shaft retained variable cross-sectional diameter of 30mm and 50mm with length of 50mm each according to Fig. 1. Turning moment of 400 N mm and bearing load of 1200N was adopted with fixed constraints as shown in Fig. 2, Table 3 and Table 4 respectively. Natural frequency and deformation analysis was achieved using finite element analysis software according to Fig. 3 to Fig. 6. Also, the general design information and mechanical properties of the machine shaft were found from the study according to Table 1 and Table 3 respectively. Results from the analysis revealed that the natural frequency was found to be 9801.78 Hz with maximum deformation of 6.124 mm. To ensure operational safety, the frequency of the periodic external load the shaft would be subjected to must be lower than 490.089Hz and 1200N in line with the given conditions.

CONCLUSION

The study showed that the values of natural frequency and deformation of the modeled step-turned machine shaft were found to be 9801.78 Hz and 6.124 mm respectively.

RECOMMENDATIONS

The following recommendations are suggested based on the study:

1) To ensure operational safety, the frequency of the periodic external load the shaft would be subjected to must be lower than 490.089Hz and 1200N.
2) Machine shaft material must have higher natural frequency greater than periodic load frequency, to avoid failure due to resonance.
3) This research can also be done in future using different shaft geometrical designs such as spindle shaft, square shaft, hollow shaft and other advanced software in computer aided engineering for generalization.

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