Determination of Natural Frequency of Vibration and Deformation of Centrifugal Pump Open Impeller for Performance Improvement

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Abstract- The researchers, studied determination of natural frequency of vibration and deformation of centrifugal pump open impeller for performance improvement, using finite element simulation method. Open impeller model was created using Autodesk inventor with assigned material as Stainless Steel to reduce corrosion and peeling effect. Motor shaft hole was created with M24 $\times H200$ ***cylinder having a right hand ANSI metric thread profile. The diameter of the open impeller was 600 mm; impeller hub diameter was 200mm with central shaft hole of 60mm. Impeller model retained 6 blades with a maintained thickness of 6 mm and height of 8 mm. The radius of impeller at inlet and outlet were 12 mm and 24 mm respectively. The vanes have 80 degrees inlet angle and 130 degrees outlet angle respectively. Impeller model was subjected to turning moment of 200 N mm with a victor fluid force of 6 N acting at XYZ directions, angular velocity of 4*** deg/s ***and angular acceleration of 5.4***deg/s^2 ***with fixed rotational constraints. Pump impeller showed high vibration frequency necessary for heavy duty rotor dynamic pumps. Results showed that the values of vibration frequency of the modeled impeller made of Stainless Steel material was found to be 3395.59 Hz by simulation and 7.4312 Hz by computation whereas maximum deformation was found to be 4.5 mm. Hence, to operate pumps within safety limits, the periodic external load of the pump must be lower than 169.78Hz and 6 N in line with the given conditions.***

Indexed Terms- Vibration Frequency, Impeller, Deformation, Finite Element Analysis, Turning Moment, Constraints, Fluid Impact

I. INTRODUCTION

Torsional vibration and deformation of impeller and blades are always a challenging problem for Engineers. According to Khurmi and Gupta (2012) as cited by Onyenobi et al., (2022) explained that centrifugal pump with impeller is widely used in ships, naval vessels, rail coaches and other fluid machineries. Many engineering solutions have been proposed for vibration and deformation of pump impellers, such as the Rayleigh method, lumped mass method (lumped parameter method, LMM), finite element method (FEM), and boundary element method (BEM). In addition, pump rotation beyond normal speed might set up resonance on impeller; vibration is at maximum when speed passes the resonance range. The load on bearings and the lifetime of the pump impeller would be reduced and the likelihood of defects increases (Sztankó, 2005).

According to Rajput (2008) centrifugal pump is a device that impacts energy to a fluid in a fluid system; it increases the fluid flow energy by converting the mechanical energy of a prime mover or electric motor coupled to its input shaft.

Open impeller is a wheel or rotor with a series of backward curved vanes or blades and it is mounted on a shaft which is usually coupled to an electric motor. Mohamed, Moey, Ibrahim, Yazdi, & Merdji (2022) as cited in Onyenobi et al., (2022) opined that the impeller blade is a critical component in a centrifugal pump that determine performance and reliability of the pump, since the fluid bombards it surface. Consequently, impeller demands vibration and deformation evaluations; if reliability and safety are optimal importance.

Khurmi and Gupta (2012) defined frequency as the number of cycles executed by a body in one second. The frequency of free vibration is known as natural frequency. Forced vibration occurs when the shaft is under the influence of a periodic disturbing force. If the frequency of the external force is same as that of the natural frequency of impeller, resonance takes place and impeller blades vibrate with maximum amplitude and eventually deformed. Reviewed literatures revealed that excessive impeller vibration and deformation might ruin pump performance and also lower service life. Hence, the paper aimed at studying the determination of natural frequency of vibration and deformation of centrifugal pump open impeller for performance improvement.

II. METHODOLOGY

The researchers created an open impeller model using Autodesk inventor with assigned material as Stainless Steel to reduce corrosion and peeling effect as shown in Figure 1.0. An open impeller is a type of impeller that has no shrouds to direct the flow of liquid. Motor shaft hole was created with M24$\times H200$ cylinder having a right hand ANSI metric thread profile.

The diameter of the open impeller is 600 mm; impeller hub diameter is 200mm with central shaft hole of 60mm. Impeller model retained 6 blades with a maintained thickness of 6 mm and height of 8 mm. The radius of impeller at inlet and outlet were 12 mm and 24 mm respectively. The vanes have 80 degrees inlet angle and 130 degrees outlet angle respectively. The impeller model was prepared with the aid of inventor software and imported to; Finite Element Analysis software where stress and displacement were predicted. Impeller model was subjected to turning moment of 200 N mm with a victor fluid force of 6N acting at XYZ, angular velocity of 4 deg/s and angular acceleration of $5.4deg/s^2$ with fixed rotational constraints (See Table 1.0).

MESHING

Meshing was used to divide the centrifugal pump impellers into section with nodes of 10136 and elements of 6030. Increasing the number of elements, means more computations and more mathematical formula for the element. Hence, the more precise the results would be. Mesh settings used is shown below. See Figure 2.0.

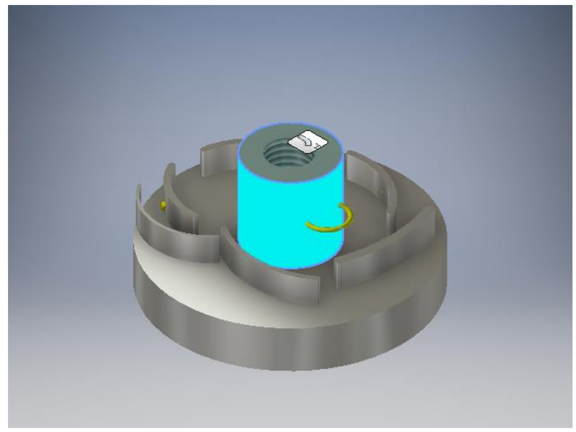

Fig 1.0(a): Open Impeller Model with Moment and Constraints

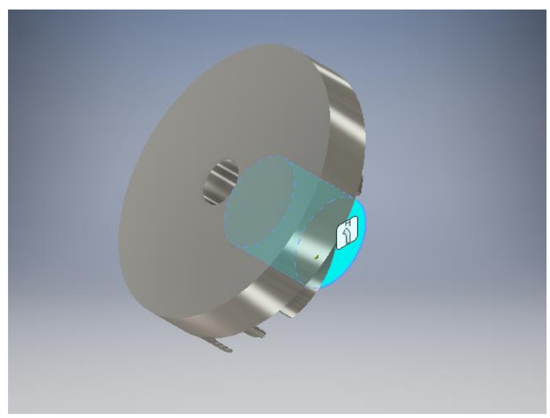

Fig 1.0(b): Open Impeller Model with Moment and Constraints back view

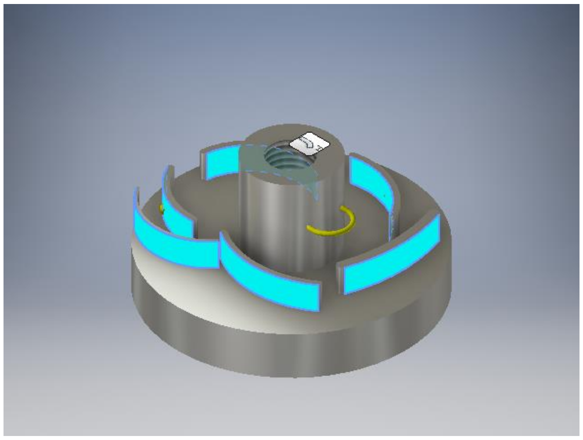

Fig 1.0(c): Open Impeller Model with Load on Blades

Table 1.0: General objective and settings

Design Objective	Parametric Dimension
Study Type	Modal Analysis
Last Modification Date	3/30/2024, 4:15 PM
Number of Modes	8
Frequency Range	500 - 1000
Compute Preloaded Modes	Yes
Enhanced Accuracy	No

Table 2.0: Mesh settings

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 3.0: Material

Name	Stainless Steel	
General	Mass Density	8 g/cm^3
	Yield Strength	250 MPa
	Ultimate Tensile Strength	540 MPa
Stress	Young's Modulus	193 GPa
	Poisson's Ratio	0.3 ul
	Shear Modulus	74.2308 GPa
Part Name(s)	PUMP IMPELLER	

Table 4.0: Operating conditions; Moment

Load Type	Moment
Magnitude	200.000 N mm
Vector X	0.000 N mm
Vector Y	-200.000 N mm
Vector Z	0.000 N mm

Table 5.0: Operating conditions; Force

Load Type	Force
Magnitude	3.464 N
Vector X	2.000 N
Vector Y	2.000 N
Vector Z	2.000 N

Table 6.0: Result Summary

Name	Result Value
Volume	34112.5 mm^3
Mass	0.2729 kg
F1	3395.59 Hz

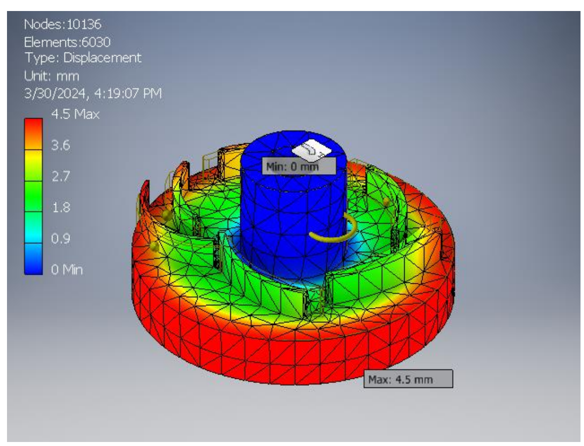

Fig 2.0: Maximum Deformation

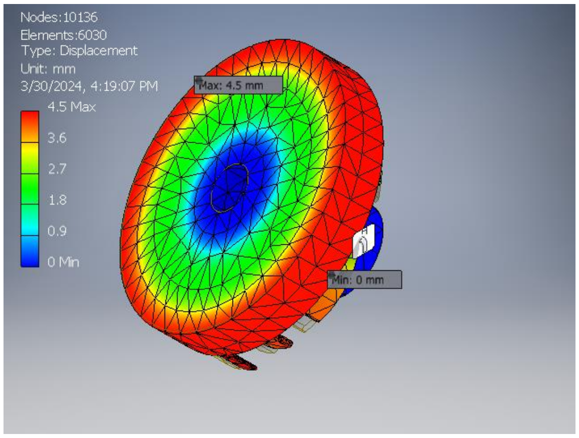

Fig 3.0: Maximum Deformation, F1 3395.59 Hz X

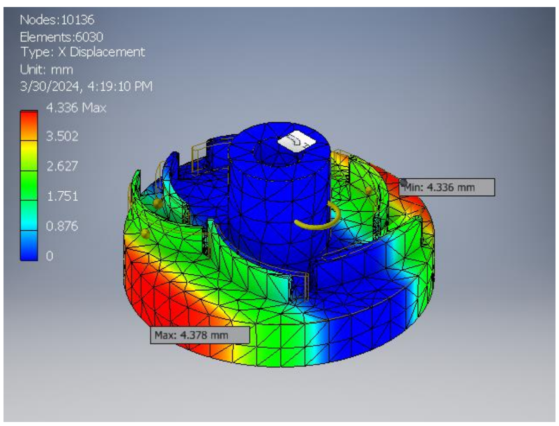

Fig 4.0: Maximum Deformation, F1 3395.59 Hz X

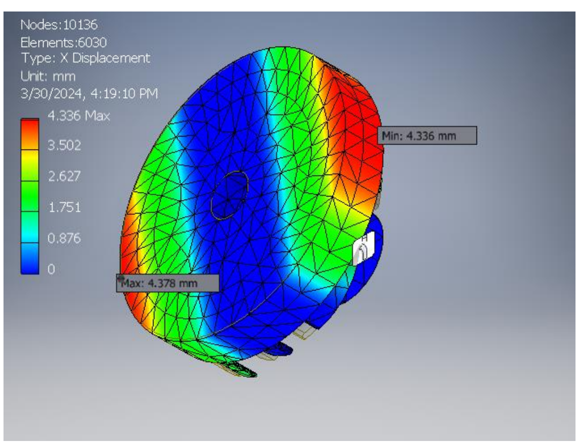

Fig 5.0: Maximum Deformation, F1 3395.59 Hz Y

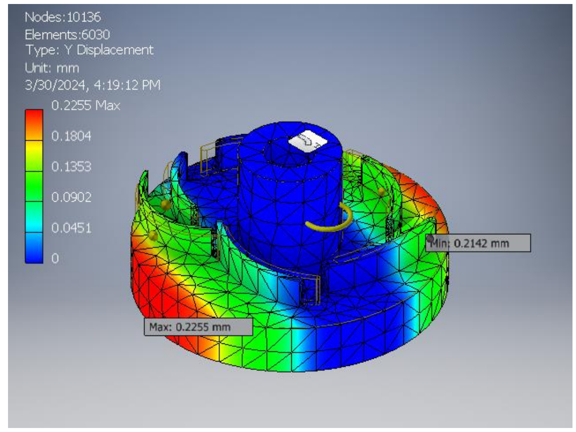

Fig 6.0: Minimum Deformation, F1 3395.59 Hz Y

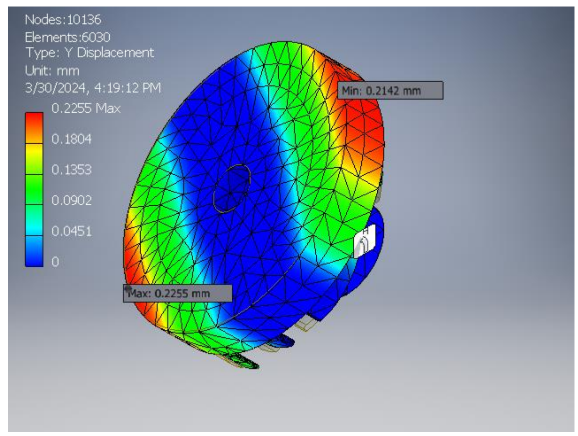

Fig 7.0: Minimum Deformation, F1 3395.59 Hz Z

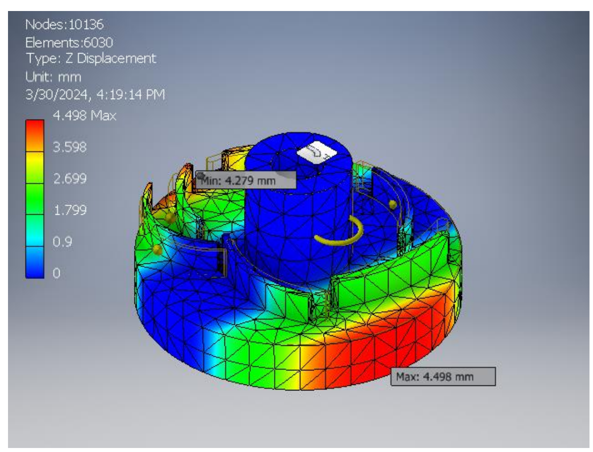

Fig 8.0: Maximum Deformation, F1 3395.59 Hz Z

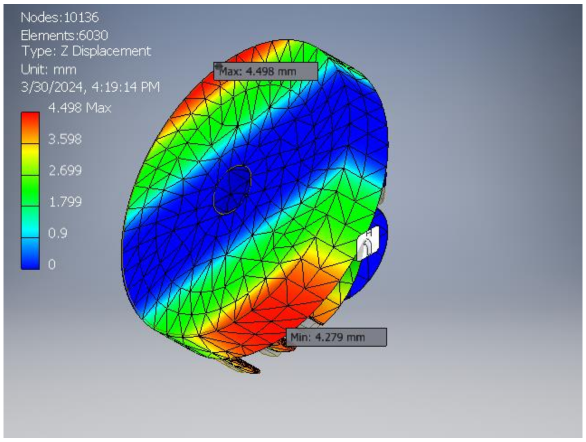

Fig 9.0: Maximum Deformation, F1 3395.59 Hz Z

DISCUSSION

Results from the simulation revealed that the vibration frequency of the designed open centrifugal pump impeller was found to be 3395.59 Hz with maximum deformation of 4.5 mm and more severe along Z axis. These results suggested that high vibration excitation materials are required to achieve a reliable and efficient impeller. To ensure operational safety in centrifugal pumps, the frequency of the periodic external load the pump would be subjected to must be lower than 169.7795.55Hz with fluid impact force of 6 N in line with the given conditions.

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

$$f_n = \frac{0.4985}{\sqrt{\delta}} \quad \text{..... (1.0)}$$

$\delta = deformation$ in mm = 4.5 mm

$$f_n = \frac{0.4985}{\sqrt{3.016}} = \frac{0.4985}{0.067082} = 7.4312\text{Hz}$$

CONCLUSION

The created centrifugal pump impeller showed high vibration frequency necessary for heavy duty rotor dynamic pump. Study showed that the values of vibration frequency of the modeled impeller made of Stainless-Steel material was found to be 3395.59 Hz by simulation and 7.4312 Hz by computation whereas maximum deformation was found to be 4.5 mm. Hence, to operate pumps within safety limits, the periodic external load of the pump must be lower than 169.78Hz and 6 N in line with the given conditions.

RECOMMENDATIONS

The following recommendations are suggested based on the study:

1) Excessive loading of impeller along Z axis must be avoided to reduce stress and deformation within permissible limit.
2) Impeller material must have higher excitation frequency for avoid sudden failure of pumps.
3) This research can also be done in future using different impeller designs and other advanced software for generalization.

LIMITATION OF THE STUDY

In the course of carrying out this research, determination of natural frequency of vibration and deformation of centrifugal pump open impeller for performance improvement, using finite element simulation method, the researchers encountered many hindrances which might cause deviations from actual results. Some of the hindrances includes: design difficulties, cost of FEA analysis, lack of electricity, material sourcing, etc.

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