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Vibration Analysis of a Centrifugal Pump

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Abstract - *Centrifugal pumps are among the more versatile and widely used products of rotating mechanical equipment found today. Pumps are essential in almost all utilities services and power generation plants. The basic principal of operation for a centrifugal pump is that a shaft is mounted on a rotating impeller inside a housing (volute) imparts energy to the fluid being moved. Centrifugal pumps utilize centrifugal force (thus their name) to increase the velocity of the fluid as it passes through the impeller and exits at the tip or periphery of the impeller. This action converts mechanical energy (shaft torque) into kinetic energy by acceleration of the fluid to a higher velocity and pressure (potential energy). It is necessary to be concerned about the vibrations because it has a major affect on the performance of Centrifugal pump. This vibration reduces the expected life of the pump components. As maintenance is the art of prolonging the useful operating condition of equipment. The present work identifies the natural frequency, mode shapes to corresponding frequency, shock, random and harmonic behavior of centrifugal pump.*

Key Words: **Centrifugal pump, Modal Analysis, Shock Spectrum Analysis, Random Analysis, Harmonic Analysis, Frequency and Displacement.**

1. INTRODUCTION

Vibration Analysis is applied in an industrial or maintenance environment aims to reduce maintenance costs and equipment downtime by detecting equipment faults. It provides accurate results and produces graphic designs, which is quite helpful for the service operators to detect the faults.

In recent years as observed by R.K BISWAS, [1] states that Condition Monitoring is defined as the collection, Comparison and storage of measurements defining machine condition. Almost everyone will recognize the existence of machine problems sooner or later. The main objective of Condition Monitoring is to recognize the damage that has occurred to the machine so that ample time is available to schedule repairs with minimum disruption to operation and production. Broch [2] states that there has been considerable interest in the maintenance techniques based on condition monitoring, with the analysis of vibration characteristics generated by machines, which makes it possible to determine whether the machinery is in good or bad condition. Simmons [3] opened that vibration from their sources may be small but excite the resonant frequencies of the rotating parts such as the rotor shaft and set-up considerable extra dynamic load on bearings. The cause and effect reinforce each other and the machine reaches towards ultimate break down. As per Gyarmathy [4] there are generally two situations in which vibration measurements are taken. One of them is surveillance mode to check the machinery health on routine basis. The second situation is during an analysis process where the ultimate goal is to tag the problem. In the later case, vibration measurements are taken to understand the cause, so that an appropriate fix can be undertaken. Lingaraju [5] Vibration monitoring which is most frequently used method in condition monitoring provides information about machinery condition as it can reveal the cause of potential problem and provide an early indication of mechanical failure. This gives the possibility for diagnosing and converting malfunctions leading to an optimum management of engine operation.

VIBRATION ANALYSIS PROCEDURE:

- Attach Geometry
- Assign Material Properties
- Define Mesh Controls
- Define Analysis Type
- Include Supports
- Set Frequency Finder Options
- Solve the Model
- Review Result

GEOMETRY MODEL OF CENTRIFUGAL PUMP:

We get this geometry model from Ashlee Terrell who uploaded this model in Autodesk Fusion 360 Gallery

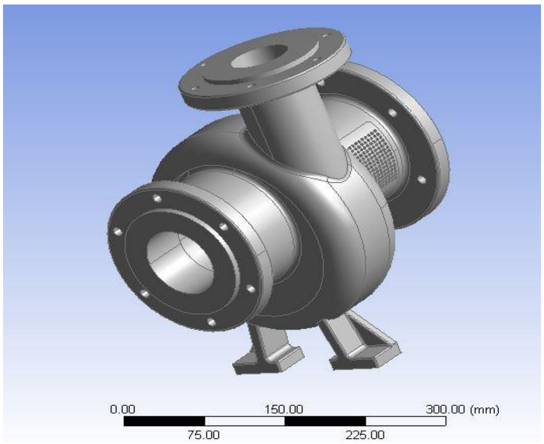

Fig -1 Geometry modal of centrifugal pump

MATERIAL PROPERTIES

	A	B	C
1	Property	Value	Unit
2	Density	7850	kg m^-3
3	Isotropic Secant Coefficient of Thermal Expansion		
6	Isotropic Elasticity		
7	Derive from	Young's...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

Chart -1 Material properties of the pump

MESHING

A **mesh** is a network of line elements and interconnecting nodes used to model a structural system and numerically solve the system for its simulated behavior under applied loads. The results are calculated by solving the relevant governing equations numerically at each of the nodes of the mesh.

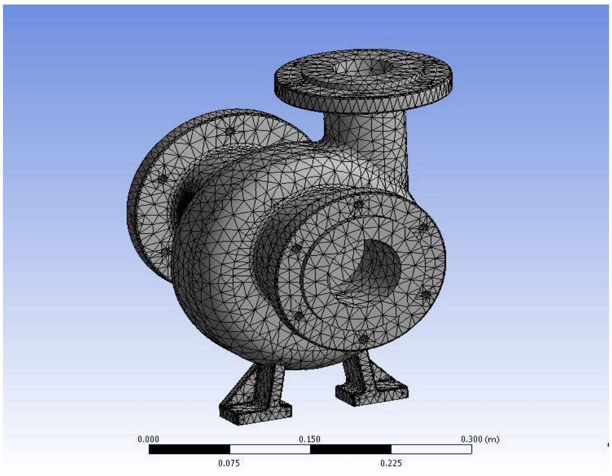

Fig -2 Geometry model after Meshing

For the pump geometry 320764 nodes and 182872 elements are generated.

MODAL ANALYSIS

Modal analysis is used to find the natural or resonant frequencies of a structure and mode shape of the structure at each frequency. Modal analysis assumes that the structure vibrates in the absence of any excitation and damping.

Input Parameters for Modal Analysis

Here we fix the base of the pump and solve the model with predefined engineering data.

Fixing Supports

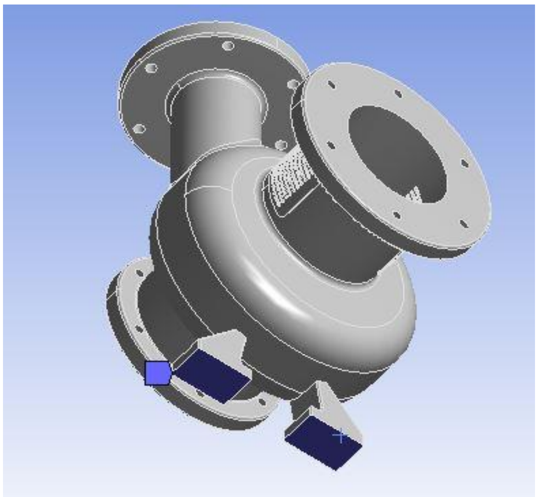

Fig -3 Geometry with fixed supports

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Results from model analysis

The mode shapes of a system are obtained when you calculate its response due to initial conditions only. The natural frequencies are listed below table. The results are compared with theoretical formulas. The corresponding mode shapes are presented in Fig.3-8.

Table-1:

S NO	Frequency from ANSYS	Frequency from Theory	% Error
1	86.5	89	2.8
2	255.5	258.8	1.27
3	342.1	346.4	1.24
4	750.4	759.2	1.15
5	980.8	991.2	1.04
6	1061.6	1101.8	3.64

These are the six mode shapes that are created at six different frequencies.

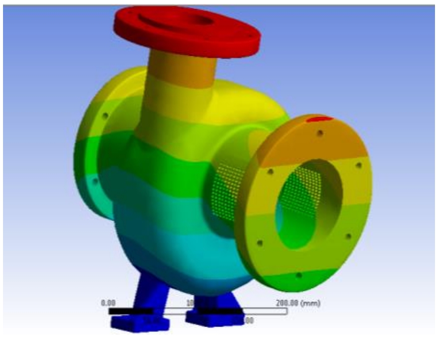

Fig -4 Mode-1

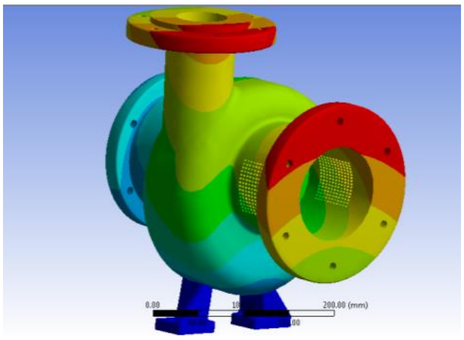

Fig -5 Mode-2

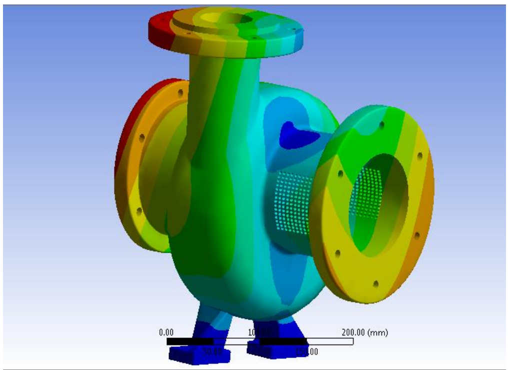

Fig -6 Mode-3

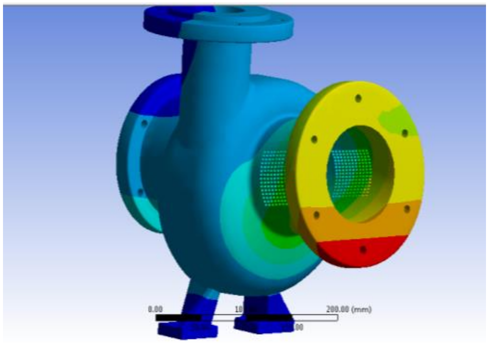

Fig -7 Mode-4

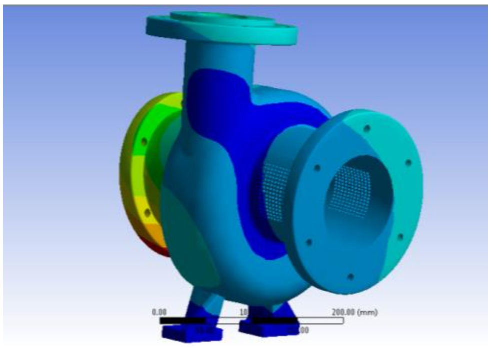

Fig -8 Mode-5

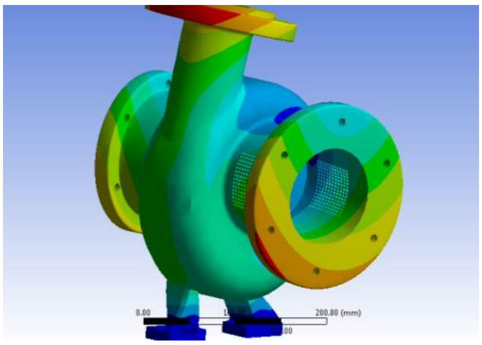

Fig -9 Mode-6

SHOCK SPECTRUM ANALYSIS

Shock Spectrum Analysis is mainly used in place of a time-history analysis to determine the response of structures to random or time-dependent loading conditions such as earthquakes, wind loads, ocean wave loads, jet engine thrust, rocket motor vibrations, etc. Spectrum analysis is a type of vibration analysis in which the results of a modal analysis are used to calculate displacements and stresses in the model.

Input Parameters for shock spectrum analysis

RS Displacement graph is given as input along with modal analysis results. Following Fig.10 shows the input parameters to quantify the shock spectrum analysis.

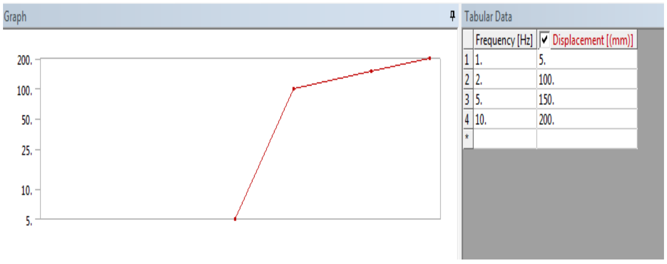

Fig -10 RS Displacement Graph

Results for shock spectrum analysis

The Range of Deformation of the pump can be observed from the Fig.11

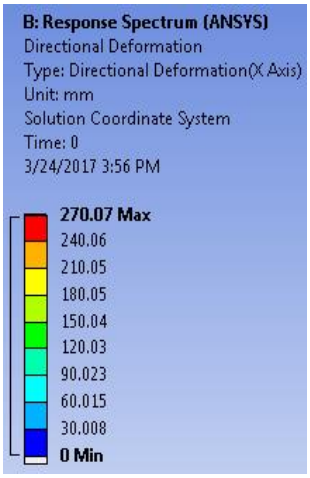

Fig.11 Range of Deformation

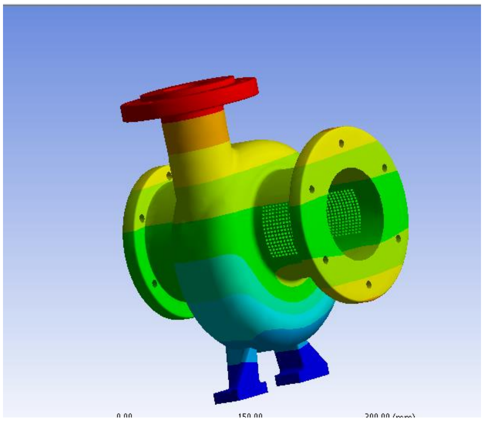

Fig -12 Directional deformation along X axis

The Range of Equivalent stress can be observed from Fig.13

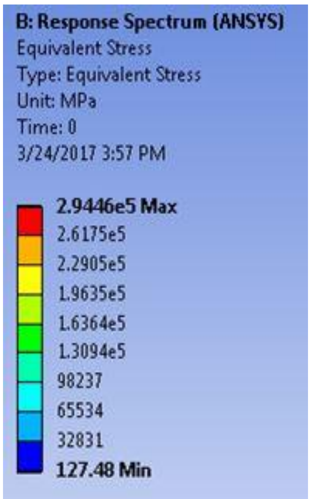

Fig -13 Range of Equivalent Stress

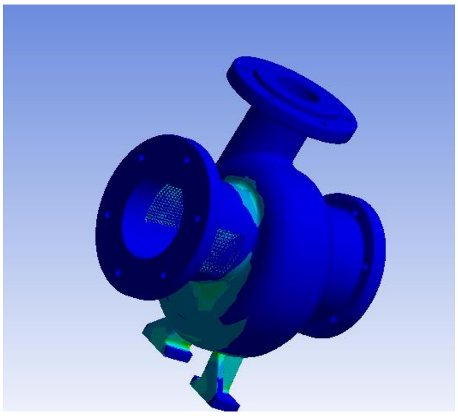

Fig -14 Equivalent Stress

RANDOM ANALYSIS

A random vibration analysis provides the likely structural response to a spectrum of random excitations. The modal analysis is required to initiate the Random analysis since it provides the dynamic characteristics required for the analysis. In a random vibration study, loads are described statistically by power spectral density (PSD) functions. PSD function is a statistical representation of the load time history.

Input Parameters for Random Analysis

Here we give PSD function as input along with the results from Modal Analysis.

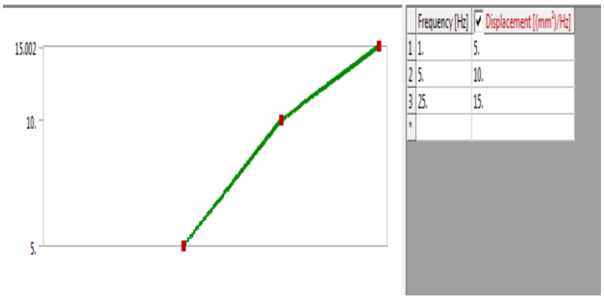

Fig -15 shows the PSD Function Graph

Results for Random Analysis

The Range of Deformation along x axis of pump can be observed from Fig.16

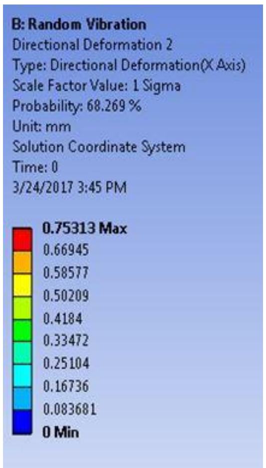

Fig -16 Range of Directional Deformation along X axis

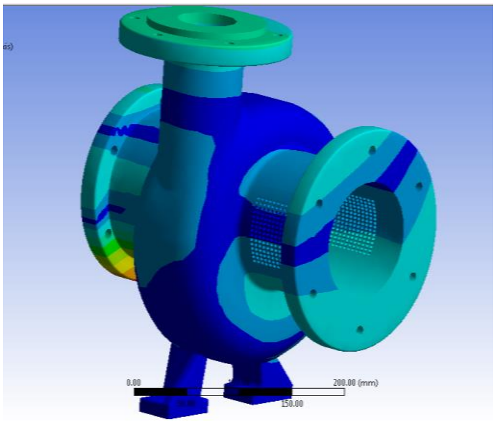

Fig -17 Deformation along X axis

The Range of Deformation along y axis of pump can be observed from Fig.18

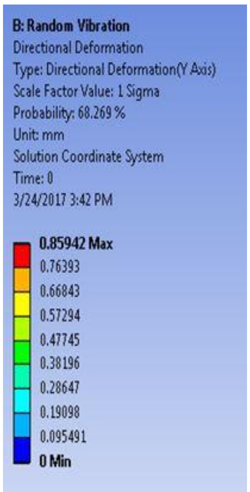

Fig -18 Range of Directional Deformation along Y axis

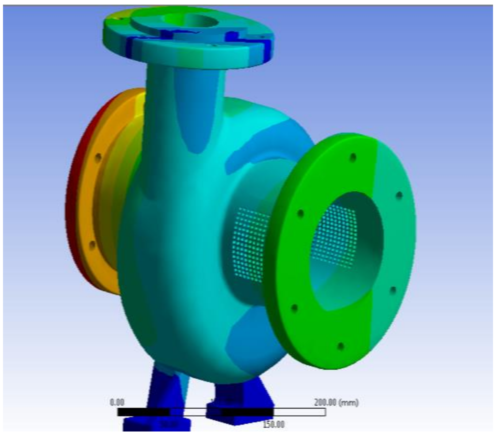

Fig -19 Deformation along Y axis

The Range of Deformation along z axis of pump can be observed from Fig.20

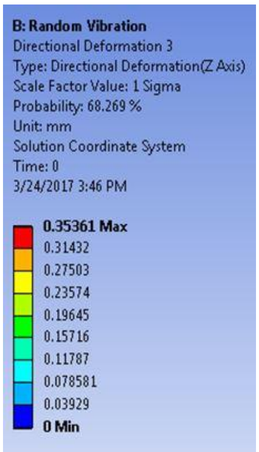

Fig -20 Range of Directional Deformation along Y axis

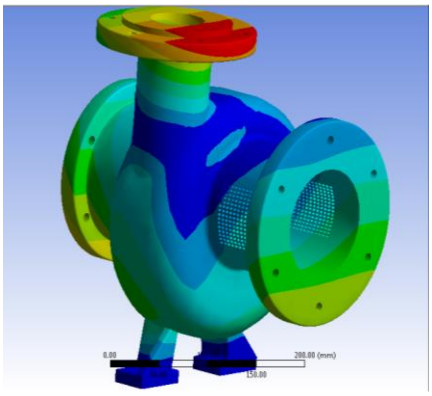

Fig -21 Deformation along Z axis

The Range of Equivalent stress of pump can be observed from Fig.22

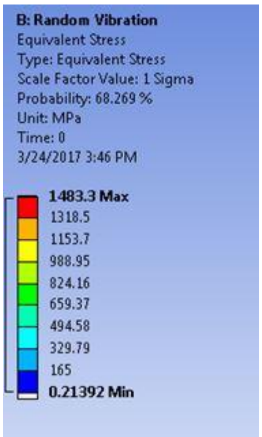

Fig -22 Range of Equivalent Stress

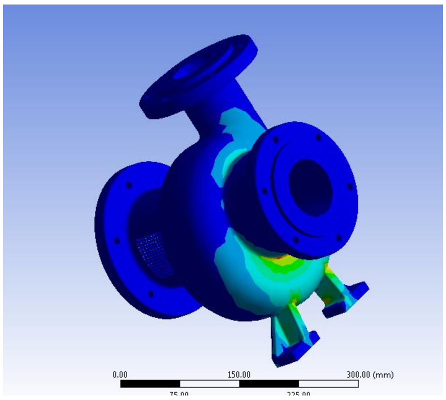

Fig -23 Equivalent stress

HARMONIC ANALYSIS

Harmonic analysis calculates the response of the structure to cyclic loads over a frequency range (a sine sweep) and obtain a graph of some response quantity usually displacement versus frequency. The Peak responses are then identified from graphs of response vs frequency and stresses are then reviewed at those peak frequencies.

Input Parameters for harmonic analysis:

The results of modal analysis are used as input along with the frequency range.

Minimum frequency: 20 Hz.

Maximum frequency: 2000 Hz.

Results for Harmonic Analysis:

The Range of Total Deformation along y axis of pump can be observed from Fig.24

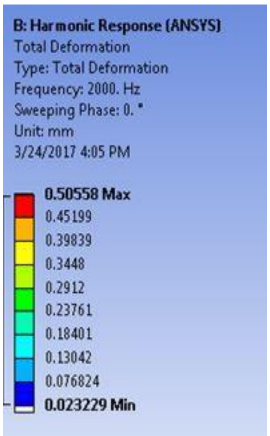

Fig -24 Range of Total Deformation

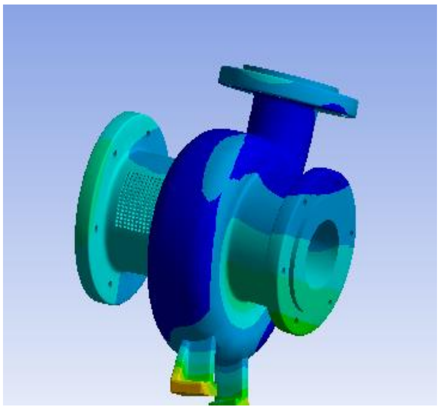

Fig -25 Total Deformation

The Range of Equivalent stress of pump can be observed from Fig.26

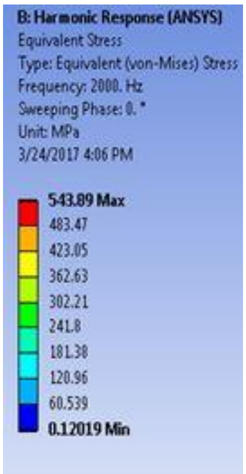

Fig -26 Range of Equivalent stress

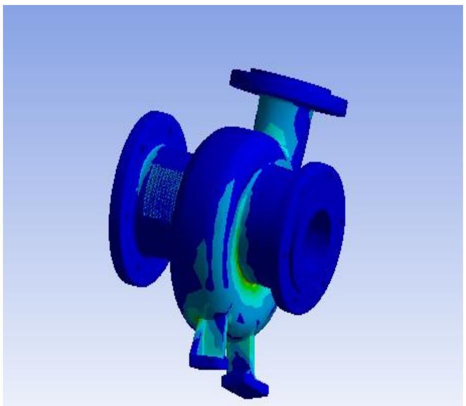

Fig -27 Equivalent stress

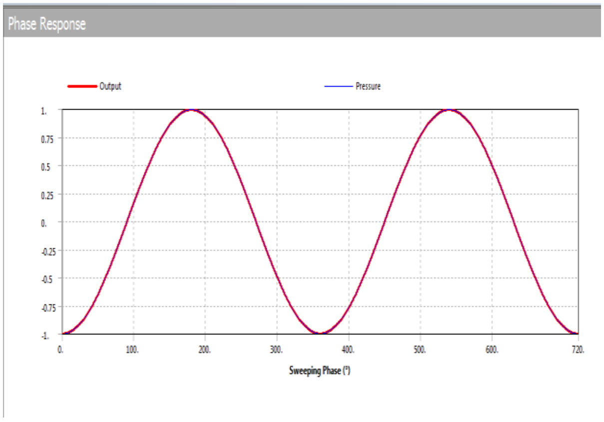

Fig -28 Phase Response Curve

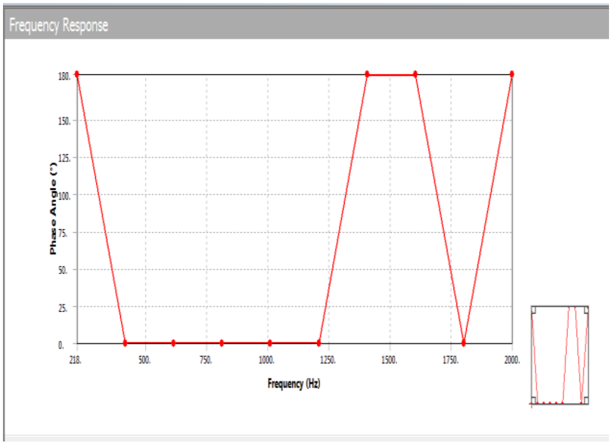

Fig.29 Frequency Response Curve

CONCLUSION

This paper investigated the centrifugal pump geometry using vibration analysis in frequency domain.

- Modal analysis finds the natural frequencies of a structure and the mode shape of the structure at each frequency. The frequency ranges between 86.5 Hz - 1061.6 Hz
- Shock spectrum analysis determines the response of Centrifugal pump to random or time-dependent loading. The Directional displacement ranges between 0 mm – 270 mm.
  Equivalent Stress ranges between 127.4 Mpa - 2.94e5 Mpa.
- Random vibration analysis provides the structural response to a spectrum of random excitations. The direction of the vibration measurement or plane of measurement also determines the Centrifugal pump vibratory problem. So we determine deformation along different axis.

Equivalent Stress ranges between 0.213 Mpa - 1483.3 Mpa

- Harmonic analysis calculates the response of the structure to cyclic loads over a frequency range and obtain a graph of some response quantity is obtained. Peak responses are then identified from graphs of response vs frequency and stresses are then reviewed at those peak frequencies
  Total Deformation ranges between 0.023 mm – 0.505 mm
  Equivalent stress ranges between 0.12 Mpa - 543.09 Mpa

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