Mohammad E. Alshebani. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 11, Issue 1, (Series-III) January 2021, pp. 42-49

RESEARCH ARTICLE OPEN ACCESS

The validation of centrifugal pumps based on the vibration characteristics

Mohammad E. Alshebani
Public Authority of Applied Education and Training
Kuwait

Date of Submission: 10-01-2021 Date of Acceptance: 25-01-2021

I. INTRODUCTION

Centrifugal pump is a high-speed rotating machine/ equipment that is used in all the major fields. It can be noticed that the forces or the periodic forces within the centrifugal pump for the rotation of impeller may cause fatigue to the bearing, shaft, and different other components. The prime effects of the vibration include the decrease in overall component life that is caused due to the cyclic loads, deformation of the base of the centrifugal pump, a decrease in the life of the bearing, and different seal failures that are primarily due to the vibration as it affects the seal (Wang et al., 2013). On the other hand, the noise of the centrifugal pump is considered to have a negative impact on the working environment and also on the level of comfort for an individual or a group. The exact analysis/ diagnosis of the pump is considered a difficult job as it is noticeable that the noise and vibration can be caused/ generated by the equipment and the system itself. There are many research papers carried out to explore the phenomenon and the prime causes, the possible means of diagnosis and the remedies within the pumps are studied (Ramana et al., 2011).

The vibration is also considered as a crucial to maintain and stabilize the overall working. The vibrations are majorly caused due to the presence of hydraulic and mechanical origins within the centrifugal pump, but there is a need to limit the vibrations and noise in order to maintain efficiency of the centrifugal pump and also to make sure that the pump is kept safe. It can be stated that the maintenance of the pump would help to improve the efficiency of the centrifugal pump as it would help to maintain and sustain the inflow conditions and also the duty points of the pump are effective/ efficient (Ravindra et al., 2009). The prime reasons for the vibration are categorized as the Hydraulic and Mechanical causes.

1.1 Hydraulic Causes

The hydraulic causes that lead to the vibration are as follows;

1) The operating pump may be at the point other than the best efficiency,
2) The running of the impeller vane is too close to the pump's cutwater,
3) The presence of air within the overall system,
4) Water hammer, and
5) Recirculation caused within the system.

1.2 Mechanical causes

The mechanical causes of the vibration caused within the centrifugal pump are as follows;

1) Issues with the shaft (bent or warped),
2) Strain within the pipe,
3) The components within the centrifugal pump are rotating in an unbalanced manner,
4) Poorly designed base or and inadequacy of the foundation,
5) Misalignment of the driver and pump,
6) Concentric shaft and damaged impellers within the centrifugal pump, and
7) various components of the centrifugal pump generate thermal energy growth.

1.3 Aim

The prime objective of the current paper/ study is to explore and evaluate the different vibration characteristics within centrifugal pump and to recommend various means to eliminate or limit the vibrations.

II. LITERATURE REVIEW

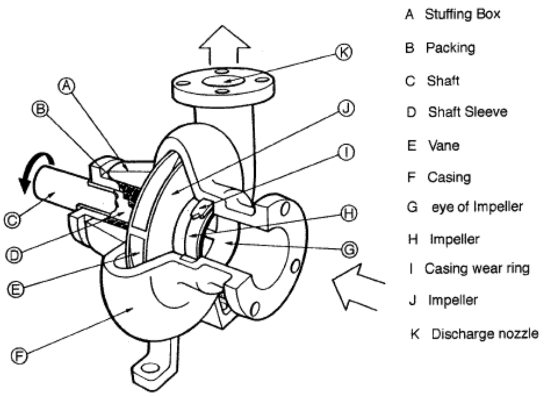

Figure 1: Main parts of the Centrifugal pump (Nuclear Power, 2017)

Naveen Varma et al., (2017) helps to provide a description of the behavior and characteristics of the centrifugal pump. The researchers state that the frequency mode of the centrifugal pump shapes and develops the corresponding frequency along with that, the shock, behavior (harmonic and random) are also shaped by the frequency mode of the pump. The shaft that is already mounted on the rotating impeller that is placed inside of a housing that allows to impart/generate energy and power to move the fluid. The centrifugal force is utilized by the pump right from the initial entry of fluid to the extraction of the fluid through the periphery on the rotating impeller. The whole phenomenon helps to convert the mechanical energy into kinetic energy (resulting from position and motion) that helps to shift the fluid to higher pressure and velocity areas. In the whole process there is a likelihood that vibrations may occur. It is necessary that the vibrations are noticed and concerned about as there are more chances that the vibrations could have a negative impact on the overall performance of the pump. The major effects of the vibration are that it causes the components of the centrifugal pump to get damaged or can even cause a reduction in the overall useful life of the components of the centrifugal pump. Mostly the maintenance of the components is incurred in order to prolong the overall useful life of the components and to manage the conditions in which the pump operates.

As per Ramana Podugu el al., (2011) the Modal analysis is carried out for the centrifugal pumps and uses the FEM technology to analyze the assembly. The two tests namely the FEA and mathematical model are designed to test the casing of the centrifugal pump and on the other hand, the simulations are carried out to determine the natural frequency of the centrifugal pump. The frequency determination is the first step to know the natural frequencies of the pump whereas, the later the vibration testing is carried out to know whether the centrifugal pump is efficient and in the best conditions. The vibration measurements for the pump are globally evaluated on the bearings on the vertical, horizontal, and axial directions (with the help of BUMP test). The analysis of the resonance is also carried out from the outcomes of the natural frequencies and resonance. Adequate swiftness to the centrifugal pumps is provided in order to ensure that the first or initial frequency is raised / increased. Later the FEA test is applied and the researchers explain that the level of frequencies for the centrifugal pump is visible due to the fact that swiftness of the pump is increased. This results in maintaining and further improving the overall characteristics of the centrifugal pump.

The analysis of the vibration and the noise that is generated by the centrifugal pumps is effectively studied by Ravindra et al., (2009). The researcher also tries to determine and derive the information on determining the causes of the vibration and noise. The researchers determine that there are two main types of causes of vibration in the centrifugal pump known as the mechanical and hydraulic causes. There is a must that the source of the issues or vibration is known prior to evaluating and testing for the measurement of the vibration. It is also important to know the exact location of the vibration in the centrifugal pump. As per the researchers the measurement of vibration data is carried out with the help of vibration spectrum. It is carried out for individual source of vibration and all the sources are analyzed using the vibration spectrum individually. The researchers further state that the overall procedure and process is helpful to ensure higher level of efficiency and performance of the centrifugal pump and therefore, also raise the point of view that effective use of techniques and proper implementation is a must to ensure long lasting and accurate outcomes. The researchers state that the diagnosis analysis can help to provide reliable and long-lasting effectiveness of the components and the overall centrifugal pump.

Michael Tompkins et al., (2016) uses the FEA (Finite Element Analysis) software to determine and evaluate the first natural frequency of the centrifugal pump, further more the researchers make adjustmetns to the overall system and making sure that the modifications are well incorporated to ensure that the resonance is avoided. Tsukamoto & Ohashi, (2000) carried out an experimental as well as theoratical study to determine and analyse the characteristics of the centrifugal pump from the initial rapid acceleration stage to the final speed. The researchers make use of the calcualtions for flow rate, rotataional speed, and total pressure generated from different start up centifugal pumps. The researcher uses the experiments and then compares and contrasts the outcomes of both the analysis to get a more accurate adn knowledgeable outcomes. Sakthivel et al., (2010) study the monoblack pumps (centrifugal pumps) that are purely and globally used in a number of applications (Muralidharana et al., 2014). The researchers state that the monoblack centrifugal pumps are of critical importance and therefore, the analysis and monitoring of its efficiency is highly recommended. The monitoring of the centrifugal pump based on the vibration is essentially required along with that the researchers state that the use of machine learning approaches to monitoring are significantly getting popularity. The researcher highlight the improtance of using C4.5 decision tree algorithm for the analysis and diagnosis of fault with the help of statistics and vibrational signials for both the faulty as well as good conditions.

Ming et al., (2017) highlights the importance of bearing faults and state that these are considered as one of the prime reasons that causes the breakdown of the centrifugal pumps mostly the multistage centrifugal pumps. The researchers contributed to providing a novel method/model for analysing the rolling bearing faults that are primarily based on the decoposition of the variational mode. The analysis of the data for the research that is compared and contrasted helps to determine that The VMD and EMD are compared and the results who that VMD can easily and accurately analyse and predict the bearing fault with the use of modeling simulations and vibrations and also the practical signals for vibrations. The analysis of the overall data helps to confirm that the model develoepd by the researchers is highly effective and can be used to diagnose the rolling bearing faults of the centrifugal pumps.

III. METHODOLOGY

The methodology for the given research is devised to ensure that the aims and objective of the research are kept as the prime focus and methodological underpinnings are used to reach to the desired results and outcomes. The prime aim of the study is to determine and study the different characteristics of the vibration for the centrifugal pump. To study the characteristics of the vibration the researcher builds a methodology in which the researcher can test and examine the parameters of vibration including the acceleration amplitudes and the fundamental frequency with the help of Hammer test. The researcher not only wants to analyze the centrifugal pump but also aims to provide with the possible recommendation on the best possible means to reduce the level of vibration in the short as well as the long run. The researcher aims to use a model that fits the analysis a run the model with the use of CATIA V5 and/or any other relevant software. Finally, the researcher also aims to use ANSYS software to analyze the model that is prepared to test the vibration parameters.

3.1 Basic Measurements for Vibrations

The basic measurement of the vibrations is carried out for a centrifugal pump without any isolator, the details are as follows;

3.1.1 Frequency

The basis for measurement specifically used for the current study firstly, include the frequency as per the direction of the measurement. The results obtained for a base centrifugal pump that is without any isolator helps to develop a base for the current paper. The results for the frequency with respect to direction of measurement helps to identify that the three acceleration measurements include the Vertical acceleration (278.4 Hz), axial acceleration (425 Hz), and the transverse acceleration (277 Hz). The results are shown in the Figure 1 (in appendix 1).

Direction of measurement	Frequency(Hz)
Vertical	278.4
Axial	425
Transverse	277

Table 1: Frequency

The analysis of different isolators and their respective frequencies would be tested against the base frequency and the isolator with highest level of frequency would be highlighted and determined as the best possible fit to maintain and manage the vibration of the centrifugal pump.

3.1.2 Acceleration Amplitude

The other basis for the analysis is the acceleration amplitude for the isolators and the current analysis of the base (i.e. without any isolator) is presented in Figure 2 (in appendix 2). The results of the acceleration amplitude help to provide a detail that a centrifugal pump without any isolator has a vertical acceleration of 10.28 (m/s^2), axial acceleration of 0.432 (m/s^2), and transverse acceleration of 12.5 (m/s^2).

Direction of measurement	Acceleration Amplitude(m/s^2)
Vertical	10.28
Axial	0.43
Transverse	12.5

Table 2: Acceleration Amplitude

The analysis of different types of isolators would be undertaken and the isolator with minimal level of acceleration amplitude would be considered as the most suitable isolator to limit or reduce/avoid the vibration issues within the centrifugal pumps.

3.2 Methodology to Reduce the Vibration

It is known that the vibration issues can be minimized in most of the practical situations and there is no specific measurement or tool to eliminate the level of vibration or the causes behind the initiation of vibrations within the centrifugal pump (Kothale et al., 2018). There are a number of measurements or methods to limit/ reduce the vibrations and the most common and widely used ones are as follows;

- The use of specific measures to limit or control the natural frequencies. It would lead to a possible limit/ reduction of the resonance with respect to the external factors.
- Use of energy or damping dissipating instrument. It would help to prevent too much response of the overall centrifugal pump/ system in presence of resonance.
- The use of vibration isolators is done to ensure that the transmission with respect to excitations can be reduced from a part to another/ different part of the centrifugal pump.
- The use of auxiliary mass neutralizer also known as the vibration absorber is also beneficial to reduce the overall response levels for the mechanism/ system.

From the prime methods used globally to reduce vibrations the researcher aims to use the method in which an isolator is used to limit the transmission or to control the level of vibrations. For that purpose, the researcher uses four (4) different isolators including the 2.5' diameter circular isolator, Grooved isolator, Tapered isolator, and 1.5' diameter circular isolator. The figures of the four isolators used for the analysis are as provided under.

Figure 2: 2.5' diameter circular isolator

Figure 3: Grooved isolator

Figure 4: Tapered isolator

Figure 5: 1.5' diameter circular isolator

3.2.1 Results from the experimentation

The experimentation carried out by the research is beneficial to understand the specification of the system as well as the insights from the system. The researcher aims to test the system with the help of linear parameters, and it is necessary according to the researcher to test and run experiments to analyze the theoretical behavior.

3.2.1.1 Results for Vibration

The researcher as stated previously uses the three directions of vibration measurements including the vertical, axial, and the transverse. The vibration spectrum is used for the current assessment. The vibration spectrum is a core or basic method used to display and represent the data for vibration in order to reach to specific outcomes, it helps to show the result in frequency domain. The results show the frequency that represents the vibration cycles within the specific period of time of the system. The representation with the help of vibration spectrum is considered effective as there are representations of the vibrations as per the time unit that are hidden, and it is considered as a best tool to monitor the vibrations of the system. There are a number of forms of representing the data using vibration spectrum, but the researcher uses the Fast Fourier Transform to represent the vibration data and outcomes of the analysis.

3.2.1.2 The outcomes of the Hammer Test

The Hammer test is undertaken to determine the natural level for frequencies for all the four isolators individually. The four isolators used by the researcher have their own individual characteristics for the level of vibration, and therefore, individual levels of vibrations are determined to make sure that the outcomes are more relevant and accurate. The test used to analyze the isolators individually is the Hammer test, that is widely used to determine and conclude on the possible frequency for the four isolators one by one. The final outcome of the Hammer test is based on the finding that the isolator with lowest level of acceleration amplitude and highest level of first fundamental frequency would be considered as the most promising isolator to limit the vibration along with improving the overall level of efficiency and limiting or avoiding the resonance for the system. A 10 Kg is suspended on each isolator in order to get the outcomes for the first fundamental frequency and the researcher uses a small test setup to undertake the overall analysis. The outcomes of the analysis and experiment are provided within the results section of the research.

IV. RESULTS

The analysis of the data with the help of vibration measurements (acceleration amplitude for different types of isolators) with respect to the vertical, axial, and transverse acceleration. The baseline isolator that is 2.5' diameter circular isolator shows the minimal level of vibrations whereas, the level of first fundamental frequency is low for the isolator. The values for Groove round isolator for vibration measurements is also low whereas, the total first fundamental frequency for the same isolator remains the highest compared to the rest. On the basis of that it can be stated that the best possible isolator that can help to reduce the vibration levels as well as to improve or accelerate the fundamental frequency for the centrifugal pumps is Groove round isolator.

4.1 Acceleration amplitudes for Types of Isolators

The analysis of the acceleration amplitude for a centrifugal pump without isolator, 2.5' diameter in circular, Groove round, tapered round, and 1.5' diameter in circular is carried out to determine the impact of all mentioned types of isolators on the centrifugal pump's acceleration amplitude. The results are shown in Figure 7 (appendix 3). The analysis of the given types of isolators help to provide with a result that the centrifugal pump without an isolator shows a very high vertical acceleration, a lower axial acceleration, and high transverse acceleration and therefore, it can be stated that the overall acceleration amplitude for the centrifugal pump without an isolator is high which may cause the pump to vibrate and create issues in the later part of its useful life.

On the other hand, the 2.5' diameter circular isolator shows a moderate to high vertical acceleration, a low axial acceleration, and a low transverse acceleration. On the basis of the figures and results it can be stated that the vertical acceleration for the pump is low when compared to the centrifugal pump without isolator. Therefore, overall acceleration amplitudes for the 2.5' diameter circular isolator shows a moderate acceleration and the higher value for vertical acceleration helps to understand that the pump can have vibration issues in the later part of the useful life.

Type of Isolators	Vertical Acceleration	Axial Acceleration	Transverse Acceleration
Without Isolator	10.28	0.43	12.5
2.5" dia. Circular	4.48	1.17	1.67
Grooved Round	3.5	7.33	1.58
Tapered Round	17.8	3.56	6.56
1.5" dia. Circular	10.2	0.88	3.67

Table 3: Acceleration amplitudes for Types of Isolators

The analysis of the figures/ values for acceleration for the Groove round isolator helps to depict that the vertical acceleration of the centrifugal pump remains lower, the axial acceleration is on the higher side which is not as important for the efficiency of the pump, and the transverse acceleration of the pump remains on the lower side. The analysis can help to conclude that the overall acceleration level of the centrifugal pump with the use of Groove isolator is low to medium which is effective.

The Tapered round isolator and the respective values of acceleration (i.e. vertical, axial, and the transverse) help to conclude that the acceleration amplitude is on the higher side as the vertical acceleration is 17.8 and the transverse acceleration for the pump is 6.56 both representing a more likelihood of future vibration issues of the centrifugal pump.

Finally, the analysis of the 1.5' diameter circular isolator helps to provide with a detail that the vertical acceleration is 10.2 (i.e. high) whereas, the values for axial acceleration (0.88) is considered low, and the transverse acceleration for the centrifugal pump is low to moderate (i.e. 3.67). The results of the overall analysis help to predict that the use of Groove round isolator is most beneficial for the centrifugal pump in order to limit the acceleration amplitude which may eventually lead to less likelihood of issues of vibration.

4.2 First Fundamental Frequency Hz

The analysis of the first fundamental frequency in Hz for the centrifugal pumps with different types of isolators help to provide with a description of the efficiency of the isolators in generating power that can lead to higher performance. The value for 2.5' diameter circular isolator, Groove round isolator, Tapered round isolator, and 1.5' diameter circular isolator. The graphical representation of the analysis is in Figure 8 (appendix 4). The analysis is beneficial to highlight the individual first fundamental frequencies and based on the values presented in Table 2 it can be stated that the highest value for the first fundamental frequency for the Groove round isolator is higher as compared to the three other isolator types (i.e. 134.27 Hz). The values for 2.5' diameter circular isolator are 62.25, for Groove round isolator 134.27, Tapered round isolator shows a value of 68.35, and the value of first frequency for 1.5' diameter circular isolator is 113.52 respectively.

Types of Isolator	First Fundamental Frequency Hz
2.5" dia. Circular	62.25
Grooved Round	134.27
Tapered Round	68.35
1.5" dia. Circular	113.52

Table 4: First Fundamental Frequency Hz

The analysis helps to provide a conclusion that Groove round isolator is highly preferable when it comes to first fundamental frequency in Hz followed by 1.5' diameter circular isolator, tapered round isolator, and 2.5' diameter circular isolator.

V. CONCLUSION

- The analysis of the data with the help of specified data analysis techniques say for, the study of different types of mechanical/ industrial isolators that are used to limit the centrifugal pumps vibrations. The isolators studied within the study are circular and are analyzed with two different diameters, these include the Groove and tapered isolators. The analysis of the two types of isolators help to provide with a conclusion that the use of Groove isolators provides with a better outcome. The use of Groove isolators helps to limit the vibration acceleration amplitude, the vibration acceleration without the use of isolators is higher as compared to the same centrifugal pumps with Groove isolators.
- The use of the hammer test for centrifugal pump and specifically for the Groove isolators help to identify that the use of Groove pump helps to improve the fundamental frequency of the pump that results in ensuring that the resonance condition in the later stages can be avoided.
- The overall analysis of the data and the isolators help to identify that the use of Groove isolators help to limit the resonance conditions and also the vibration acceleration amplitude and therefore, these must be used to reduce the overall level of vibration in the centrifugal pump.

REFERENCES

[1]. Kothale, S.S., Joshi, P.G.S. & Naik, P.D.V.R., 2018. Experimental validation of vibration characteristics of selected centrifugal pump. International Research Journal of Engineering and Technology (IRJET), 05(01), pp.1312-15.

[2]. Michael Tompkins, Robert Stakenborghs & Gregory Kramer, 2016. Use of FEA software in evaluating pump vibration and potential remedial actions to abate resonance in industrial vertical pump/motor combinations. Charlotte, North Carolina: 24th International Conference on Nuclear Engineering.

[3]. Ming, Z., Zhinong, J. & Kun, F., 2017. Research on variational mode decomposition in rolling bearings fault diagnosis of the multistage centrifugal pump. Mechanical Systems and Signal Processing, 93(1), pp.460-93.

[4]. Muralidharana, V., Sugumaran, V. & Indira, V., 2014. Fault diagnosis of monoblock centrifugal pump using SVM. Engineering Science and Technology, an International Journal, 17(3), pp.152-57.

[5]. Naveen Varma, K. et al., 2017. Vibration Analysis of a Centrifugal Pump. International Research Journal of Engineering and Technology (IRJET), 4(3), pp.1582-88.

[6]. Nuclear Power, 2017. Main Parts of a Centrifugal Pump - Nuclear Power. [Online] Available at: https://www.nuclear-power.net/nuclear-engineering/fluid-dynamics/centrifugal-pumps/parts-of-centrifugal-pump/ [Accessed 26 August 2019].

[7]. Ramana Podugu, J., Suresh Kumar, B.V.M. & Syam Kumar, N., 2011. A modal approach for vibration analysis and condition monitoring of a centrifugal pump. International Journal of Engineering Science and Technology (IJEST), 10(2011).

[8]. Ramana, P., Suresh, K., Murthy, R.B.V. & Syam, K.N., 2011. A modal approach for vibration analysis and condition monitoring of a centrifugal pump. International Journal of Engineering Science and Technology (IJEST), 3(8), pp.6335-44.

[9]. Ravindra, B., Rajashri, P. & Kedar, K., 2009. Vibration and Noise in Centrifugal Pumps - Sources and Diagnosis Methods. Paper Ref: S1163_P0437. Portuga: International Conference on Integrity, Reliability and Failure, Porto/Portuga.

[10]. Ravindra, B., Rajashri, P., Khanzode, K. & Ltd., K.B., 2009. Vibration and noise in centrifugal pumps-sources and diagnosis methods. Porto: Paper Ref: S1163_P0437 20-24 3rd International Conference on Integrity, Reliability and Failure.

[11]. Sakthivel, N.R., Sugumaran, V. & Babudevasenapati, S., 2010. Vibration based fault diagnosis of monoblock centrifugal pump using decision tree. Expert Systems with Applications, 37(6), pp.4040-49.

[12]. Tsukamoto, H. & Ohashi, H., 2000. Transient Characteristics of a Centrifugal Pump During Starting Period. Journal of Fluids Engineering, 104(1), pp.6-13.

[13]. Wang, Y. et al., 2013. Effects of vane wrap angle on flow induced vibration and noise of centrifugal pumps. Transactions of the Chinese Society of Agricultural Engineering, 29(1), pp.72-77.

Appendices

Appendix 1 - Frequency

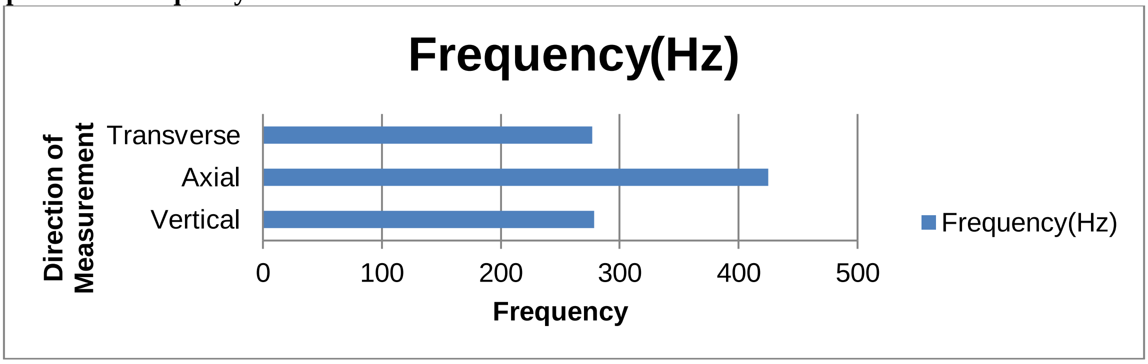

Figure 6: Frequency

Appendix 2 - Acceleration Amplitude(m/s^2)

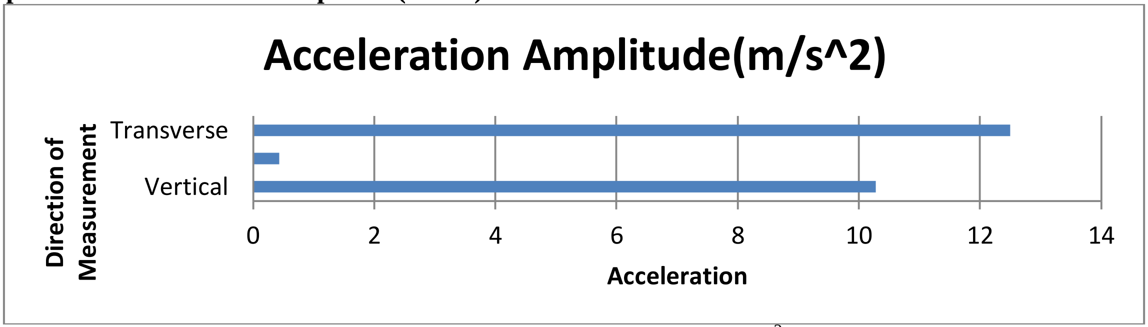

Figure 7: Acceleration Amplitude(m/s^2)

Appendix 3 - Acceleration Amplitude for types of Isolators

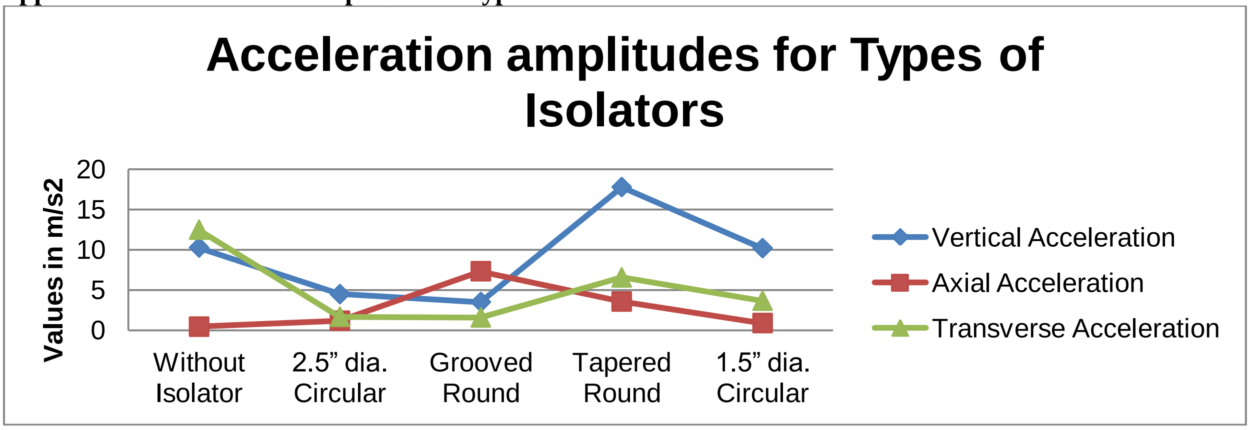

Figure 8: Acceleration amplitudes for Types of Isolators

Appendix 4 - First Fundamental Frequency

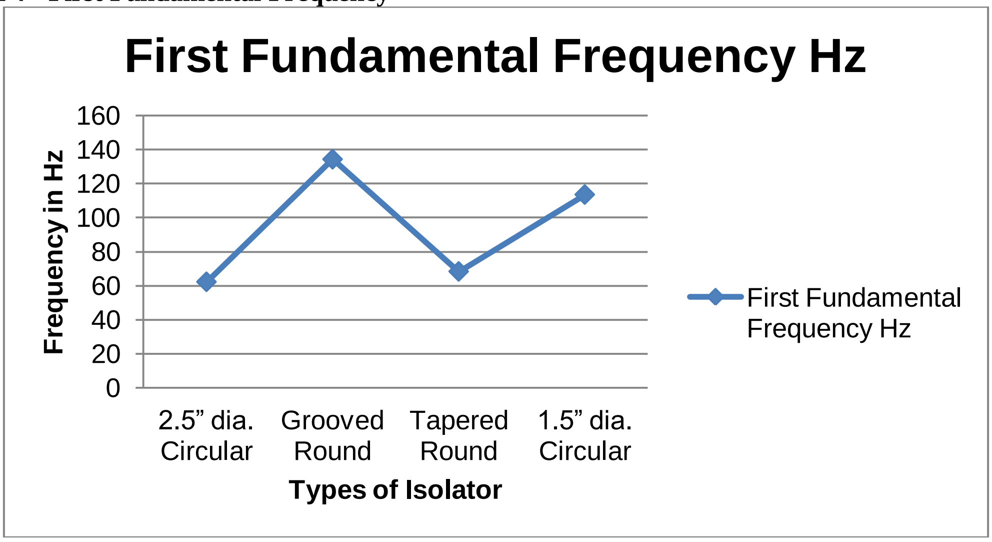

Figure 9: First Fundamental Frequency Hz

Mohammad E. Alshebani. "The validation of centrifugal pumps based on the vibration characteristics." *International Journal of Engineering Research and Applications (IJERA)*, vol.11 (1), 2021, pp 42-49.