

Study of Noise Annoyance and Vibration of Constructal Designed Window Air Conditioner

Selva Pandian Ebenezer^{1,*}, Achintya Kumar Pramanck²,
KP Ramachandran¹ and Pradeep Kumar Krishnan¹

¹College of Engineering, National University of Science & Technology, Muscat 130, Sultanate of Oman

²Department of Mechanical Engineering, National Institute of Technology, Durgapur,
West Bengal 713209, India

(*Corresponding author email: selvapandiane@gmail.com)

Received: 8 July 2020, Revised: 20 June 2021, Accepted: 17 January 2022

Abstract

Industrial, residential and commercial noise levels are to be maintained for acoustic comfort living conditions. Sound annoyance is a sensation of discontentment linked with any driving force from machines or a circumstance. It is certain that, noise can harm human hearing capacity and brain neuron cells. Novelty of this study was the design of window air conditioner with modified heat exchanger coils with phase change material and water were used as refrigerants. Noise and vibration assessment of the constructal designed window air conditioner (CDWAC) and normal window air conditioner (NWAC) with the conventional vapor compression system was carried out. The noise levels, daily exposure noise level, noise criteria levels of the developed window air conditioner was found to be satisfactory according to the British Standard 4142 and noise at work regulations 1789.

The noise criteria for the CDWAC with phase change material and water exhibited a better performance around 50 dB whereas the NWAC with vapor compression system was around 60 dB.

For normal window AC the RMS value is about 0.62 and constructal window AC is about 0.38. peak amplitude was observed as 0.346 m/s² in the CDWAC whereas it was about 0.512 m/s² for NWAC compressor. The amplitude of vibration is very nominal in between 2 to 2.5 s in CDWAC and the peak variation is same as in 1.5 s. Results reveal that the noise and vibration performance of the construction designed window air conditioner was better than the NWAC.

Keywords: Noise, Window air conditioner, Constructal, Vibration

Introduction

Sound is a source of energy which is in the form of wave motion. Noise is an unwanted sound created in our neighborhood. The term noise is applied to sounds that cause discomfort when hearing. Noise can be caused from a variety of sources such as domestic noise, noise from transport and industrial noise. Machines produce noises which are harmful to the human life. Air conditioning apparatus makes noise during their operation. Compressor and other allied components in vapor compression refrigeration systems are responsible for the noise generation in air conditioners. Window air conditioners are considered to be the basic model and noise generation in window air conditioners range from 60 to 80 dB based on the components used and maintenance of the air conditioning unit[1]. Noise levels of less than 80 dB are considered to be the human comfort level. Any sound source of more than 85 dB will lead to hearing loss.

Air conditioners during their operations create around 20 % of noise in the neighborhood [2]. The maximum noise level generated by a split type air conditioner is around 75 dB (A). The external excitation of noise from a split unit air conditioner is due to fan motor and compressor operation[3]. Absence of annoying noise is essential for every customer or resident who is using air conditioners [4]. Sources of noise in air conditioners are due to the operation of compressors in vapor compression systems, refrigerant flow, fan motor and blower motor. The asymmetrical, refrigerant-induced noise from the refrigerator happens in the area of a 2-phase stream in an evaporator inlet pipe, particularly a perpendicular pipe. An increase of the amplitude can be set up at positive single frequencies of about 280 and 740 Hz as well as in a wide band approximately 2,000 Hz [5]. The vapor compression refrigeration system needs a phase change of the refrigerant inside the heat exchangers such as condenser and

evaporator. The condenser outlet outlines responsively the refrigerant state at the capillary tube inlet through a straight linking of condenser pipe and capillary tube inlet. And this connection leads to the compression of liquid refrigerant in the capillary tube and sudden expansion of liquid refrigerant inside evaporator, and leads to noise generation in the system [5].

Noise emissions from the machines operating in residential areas are to be maintained under the environment protection regulation (1994), and it states that the maximum permissible noise levels from domestic air conditioners is 45 dB (A) [6]. Many past pieces of research show that noise is considered to be a disturbance when it exceeds 55 dB and will be serious problems when it will be over 65 dB [7]. Stress induced by noise in buildings will lead to mental illness [8]. There are several noise criterion systems are used by architects and design engineers[9]. Some of the most commonly used criteria are 1. Noise Criteria (Hansen, 1994), Balanced Noise Criteria (NCB; Beranek 1989), Room Criteria (RC; Blazier 1981), Room Criteria Mark II (RC Mark II; Blazier 1997), and A-weighted Equivalent Sound Pressure Level (Laeq; 1987). A - Weighted sound level was developed and the maximum permissible noise level is up to 48 dB for residential buildings (Bowden and Wang, 2006). As per the study by Zannin and Ferraz [1], A -weighted levels to be considered as a criterion for offices and it correlates with the workers insight and performance [1]. Noise criterion is a popular method used by architects and consultants and it was developed by Leo Beranek in 1950.Noise criterion method has its limitation that, the curves used for the evaluation and design does not extend up to low frequencies. For better comfort conditions, the noise criterion of the air conditioning unit should be kept 5 dB below the noise criterion of the room noise [10]. Most of the heating ventilation air conditioning systems (HVAC) have substantial low-frequency noise levels. Domestic air conditioners produce reverberating noise during their operation in the low-frequency ranges [11]. But a room with a low noise level but with continuous flow or a hissy range can be considered as bad as noise. In 2008 an updated method of noise criterion was published by the American National Standard (ANSI), Acoustical Society of America (ASA). This new standard updated the NC curves down to 16 Hz and relates the noise criterion level to the sound intensity level (SIL). As per previous study conducted by Wagner *et al.* [4], the absence of annoying noise is essential for every customer or resident who are using air conditioners. Han *et al.* concluded in his study that, the asymmetrical, refrigerant-induced noise from the fridge happens at the area of 2-phase stream in an evaporator inlet pipe, particularly a perpendicular pipe [23].

Constructal law of physics states that ‘for a finite-size flow system to persist in time (to live) it must evolve in such a way that it make available greater and greater access to the flow through it’. This law is about the evolution of configuration and design architecture [12]. The design evolution should reduce the imperfections of a system. High energy consumption, noise pollution, harmful to environments are some of the imperfections in an air conditioning system to be focused for better design with least imperfection possible.

The aim of this study was to focus on the noise and vibration analysis of window air conditioners. And the CDWAC performed better in terms of noise and vibration in comparison with NWAC.

To understand the noise as an imperfection in an air conditioning system, the basics of the sound propagation is to be studied. It can be seen that if a point source of sound is radiating in the unobstructed atmosphere then the intensity (I) at a distance (r) is such that,

$$I = W/4\pi r^2. \quad (1)$$

Where W= sound power of the source and

$$4\pi r^2 = \text{surface area of the sphere}$$

written as, $I \propto \frac{P}{4\pi r^2}$ or the intensity is inversely proportional to the square of the distance which is termed to be inverse square law. Flows abound in nature and engineering systems are in general dissipative and thus they generate entropy. Inverse-square law of sound states that, the intensity is inversely proportional to the square of the distance.

$$I = P/4\pi r^2. \quad (2)$$

Intensity is the potential of the sound wave and it is influenced by the distance of the point source.

$$S_{gen} = 4\pi Pr^2/T. \quad (3)$$

$$I = TS_{gen}/4\pi r^2. \quad (4)$$

Considering the Eqs. (1) and (3), minimizing the sound intensity from a particular distance and the point source, corresponds to the minimization of the entropy generation rate. This establishes the link between the minimization in disorder and constructal law. The progress of design is the physics phenomenon and it is potted by constructal law. Constructal law captures the idea of design and evolution in nature and there is no end to evolution [13]. A flow system should evolve in such a way that, disorders can be distributed within the system.

The flow pattern of the disorder is the consequence of constructal law. Here, in this case, a disorder in the system is the noise generation and because of the modification in the design of a window air conditioner. The constructal law of physics is the key to design and technology evolution [14]. Human beings directly recognize only a small range of low-frequency vibrations. Noise is created by the oscillation velocity of vibrations in machines [15]. In domestic air conditioners, vibration and noise increase when the compressor operates at 1,500 RPM[16].

Since the compressor is replaced with a pump in the CDWAC, there is a considerable amount of reduction of vibration and noise. Abnormal noise is created in the domestic air conditioners due to the structure-borne vibration of the compressor [16]. Causes for vibration in compressors is because of the shaft actions and other mechanisms [17].Low-frequency vibration can be a potential problem in any machine [18].

Materials and methods

Compressor was replaced with a pump and water is circulated through the constructal designed window air conditioning system. A double pipe evaporator tube was designed, and phase change material is filled in the outer tube and water is circulated in the outer tube and further gets cooled by the forced air cooled condenser.

This system has advantages of energy efficiency and low noise generation during operation. Thermal comfort achieved by the CDWAC was found to be satisfactory [19].Noise measurements were conducted in the NWAC and CDWAC for a period of 1 month. Noise level analysis was done in both the systems of NWAC and CDWAC and then a comparative study was carried out. Vibration analysis was also conducted in the air conditioners with a virtual instruments using lab VIEW. The schematic diagram of NWAC and CDWAC is shown in the below diagrams 1 and 2. The differences in the design of the CDWAC with the NWAC is shown in the below mentioned **Table 1**.

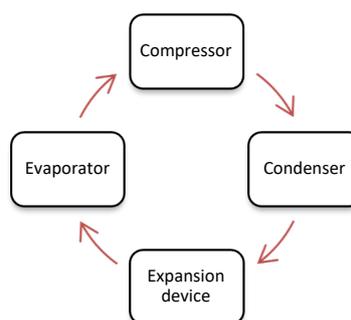


Figure 1 NWAC.

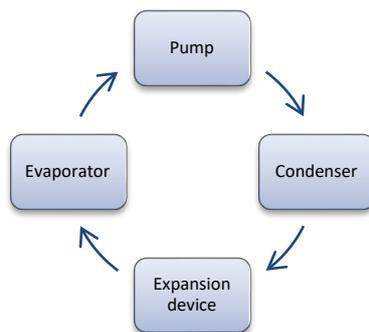


Figure 2 CDWAC.

Table 1 Difference between NWAC and CDWAC.

Normal window air conditioner (NWAC)	Constructural designed window air conditioner (CDWAC)
Compressor	Pump
Forced air cooled condenser	Forced air cooled condenser with water circulation
CFC/HFC refrigerant	Phase change material and water
Evaporator -refrigerant circulating in single pipe	Evaporator - double pipe design (Phase change material inside the inner tube and water circulating in the outer tube)

The schematic diagram of evaporator design in the CDWAC is shown below in the Figure 3.

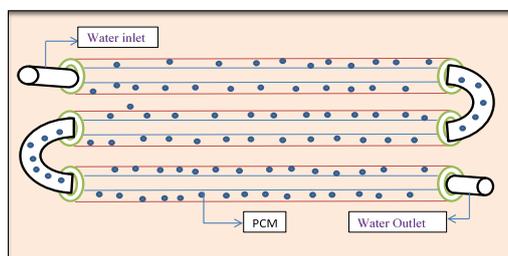


Figure 3 Evaporator design of CDWAC.

Vibration analysis and experimental set up

For conducting vibration analysis, a virtual instrument with lab VIEW was used. Virtual panels in the VI are programmed by the embedded software. Data acquisition, process, analyses are done in the panels in the VI. With the help of lab VIEW, the design of VI accomplishes the analysis of vibration signals.

It can analyze the signals according to the actual requirements. Initial signal-processing methods for machine monitoring have used the FFT to transform the time domain to the frequency domain, for the machine vibration signal analysis [20]. Unlike the earlier vibration measuring instruments, VI can be custom designed according to the need of analysis. VI has advantages like, easy experimental setup, cheap in cost, and lesser maintenance. The measured signals from the compressor and pump were picked up by the sensors and were converted to electrical signals. A digital signal processor was used to acquire data from the sensor.

Sampling and data analysis

Sampling is the process of transforming an input signal which is in the continuous form to an independent form. Conversion of analog signals into digital output is the core function of instrumentation.

The process of data sampling and conversion of the sampled data into digital output is called data acquisition. Sensors, signal conditioning circuits, and analog-to-digital converters makes the complete set of data acquisition system. Personal computer based data acquisition systems has lesser power, high productivity, good display in comparison with the traditional measurement systems. The sampling rate of the data acquisition device is near to the maximum and is made in the software part of the computer.

Vibration data were obtained at the pump provision casing in upright, parallel and pinnacle positions. The key details of DAQ are as mentioned below:

1) Frequency of sampling data: 16 kHz.

2) Number of sampled data: 38,400 & Time of sampling: 2.4 s.

The process of data acquisition and the experimental setups is shown in the **Figures 4 and 5**.

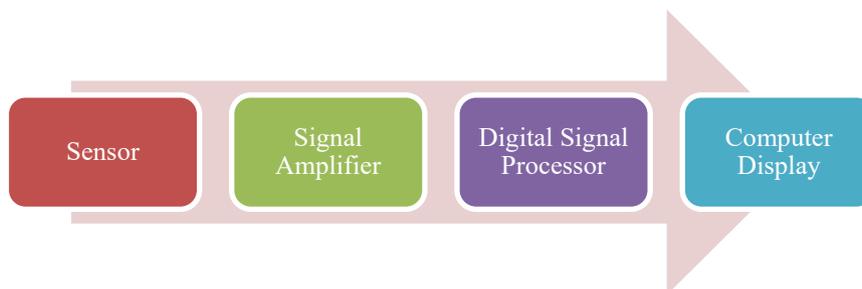


Figure 4 Block diagram of vibration signals measurement.



Figure 5 Data acquisition set up and computer display.

Instrumentation type

LabVIEW-7 application software was developed with fast fourier transform (FFT) analyzer and vibration signals were received through the input module and data acquisition device (NI-DAQ-National Instruments NI SCXI-1000 chassis via SCXI-1530-channel 0, SCXI-1530- channel 1 and SCXI-1530-channel 2). Piezoelectric accelerometers (Model number 600A12, IMI sensors, with a frequency range up to 18 kHz) were used to get vibrations signals in 3 different positions like, vertical, horizontal, and axial positions. Output was displayed with different ranges of frequency and time with the help of lab VIEW software for additional processing, data was fed to MATLAB software.

Vibration analysis

Spectral analysis or frequency analysis is the traditional way used in vibration analysis since it gives an in depth knowledge on the vibration of the machinery. The basic process in frequency analysis is to use FFT to convert signal from time domain to frequency domain. The end use of this conversion is to understand the energy levels of the signal. Spectral analysis is more useful in analyzing the motionless signals with an unchanging frequency levels. Acceleration of the NWAC ranges from 0.8 to -0.5 m/s^2 , whereas in the CDWAC was 0.6 to -0.5 m/s^2 for a time period of 1 s. The speed of the sound waves in the case of the NWAC is higher than the CDWAC.

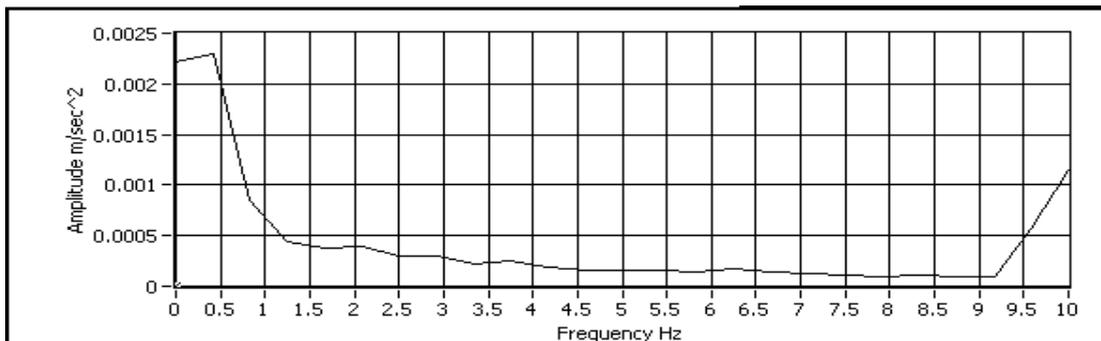
Amplitude is to evaluate of vibration level of the machine and frequency is the measure of amount of oscillations. Frequency domain or spectrum analysis is used for detailed analysis of vibration. In the spectral study, peaks in the frequency curve will be the possible reason for vibration.

The spectral analysis curves for the compressor used in the NWAC and the pump used in the CDWAC are shown in the below **Figures 6 and 7**. It is observed that the severity of the problem in the

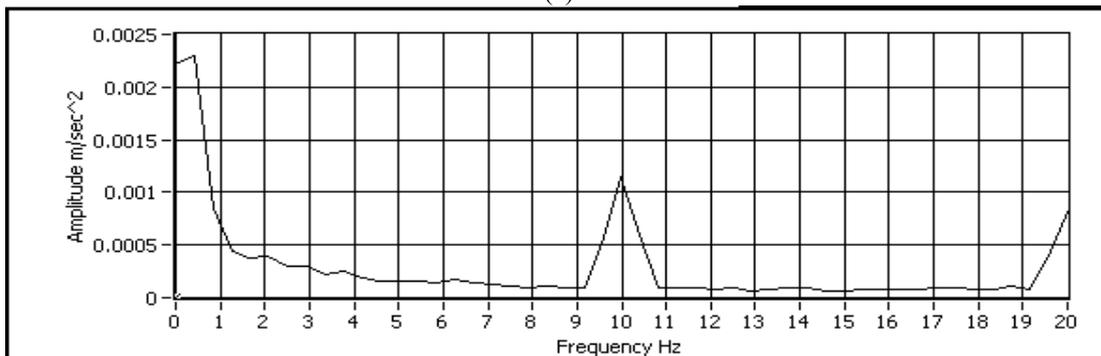
compressor is evident as the amplitude level is 0.2 m/s^2 , whereas in case of pump the amplitude level is almost negligible around 0.001 m/s^2 . The vibration analysis is carried out over the window air conditioner by placing the sensor at top, horizontal, vertical and side position. The vibration over the window air conditioner is observed with respect to frequency and time. The amplitude is measured in terms of acceleration using the sensors.

Top position

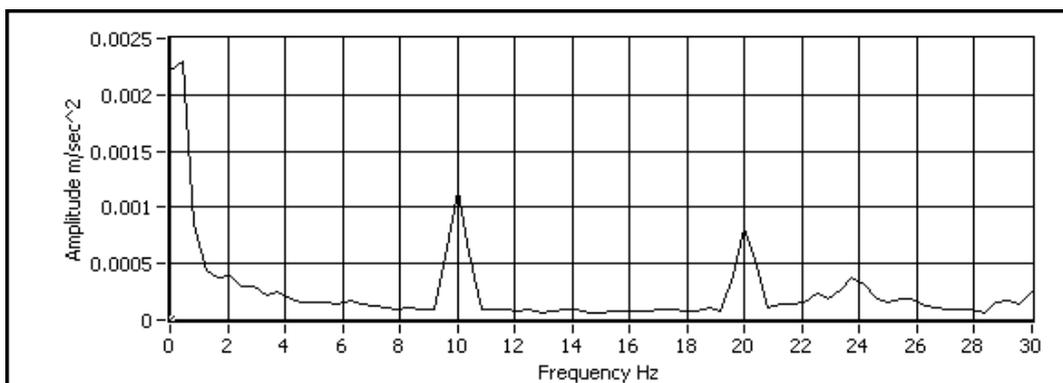
The vibration analyses that are observed in top position over the window air conditioner is given in **Figures 6(a) to 6(h)**.



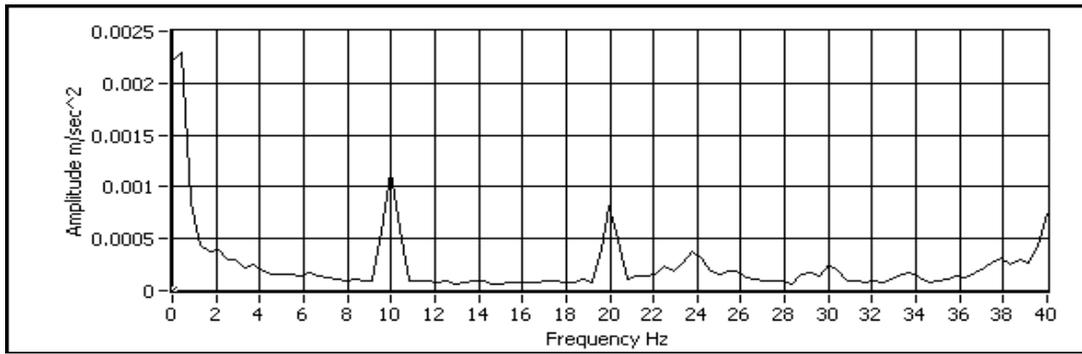
(a)



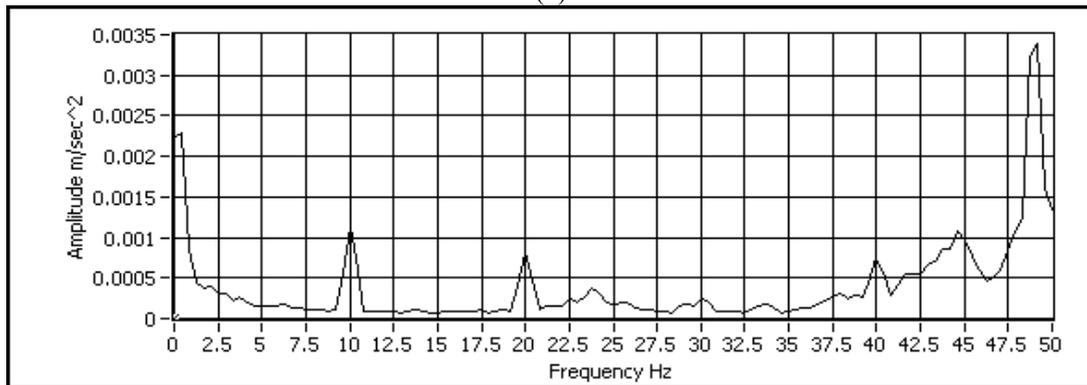
(b)



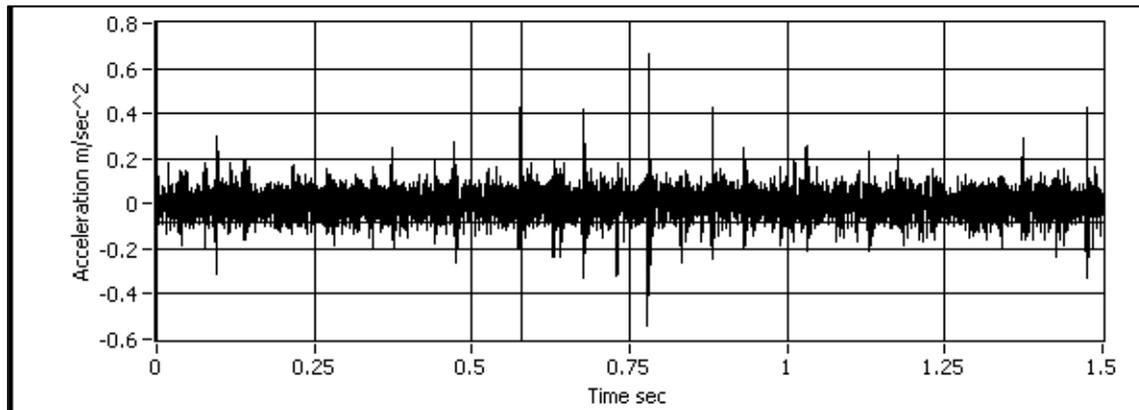
(c)



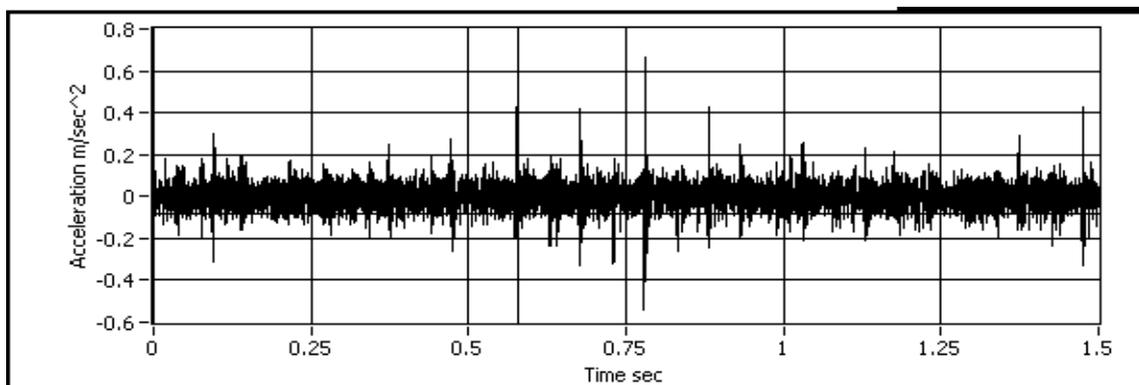
(d)



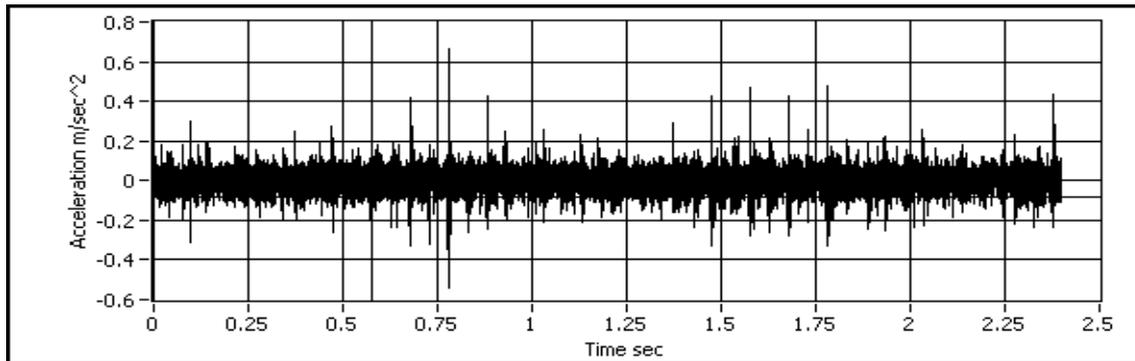
(e)



(f)



(g)



(h)

Figure 6(a) Frequency vs amplitude over 10 Hz.(b)Frequency vs amplitude over 20 Hz.(c)Frequency vs amplitude over 30 Hz.(d)Frequency vs amplitude over 40 Hz.(e)Frequency vs amplitude over 50 Hz.(f)Time vs amplitude for 1.5 s- top position.(g)Time vs amplitude for 2 s- top position.(h)Time vs amplitude for 2.5 s- top position.

The 1st peak over the vibrational amplitude is observed at the frequency of 0.4 Hz with the amplitude of 0.0023 m/s^2 . After the 1st peak, there is a sudden decrease in amplitude of vibration till 1 Hz and then it decreases steadily till 9 Hz. The 2nd peak is observed at 10 Hz with the amplitude of 0.0012 m/s^2 and again it drops symmetrically as it rises. The next peak is observed at 20 Hz with the amplitude of 0.0008 m/s^2 which is similar to that of the peak generated in 10 Hz.

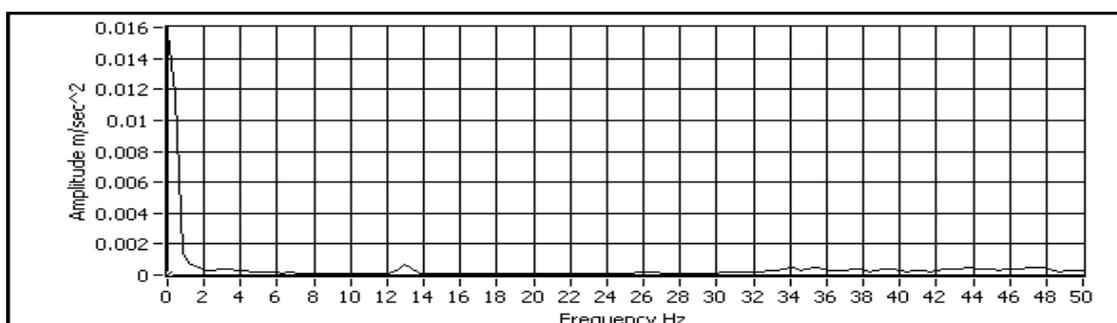
After 20 Hz, the peak is only observed at 48 Hz. The maximum peak is observed at the 48 Hz and the peak amplitude is about 0.0034 m/s^2 .

Similar to the observation of amplitude over different frequencies, the vibrational amplitude is observed over different times as in **Figures 6f - 6h**. The amplitude of the vibration is observed to be in range between 0.64 to -0.53 m/s^2 over the time period of 1.5 s.

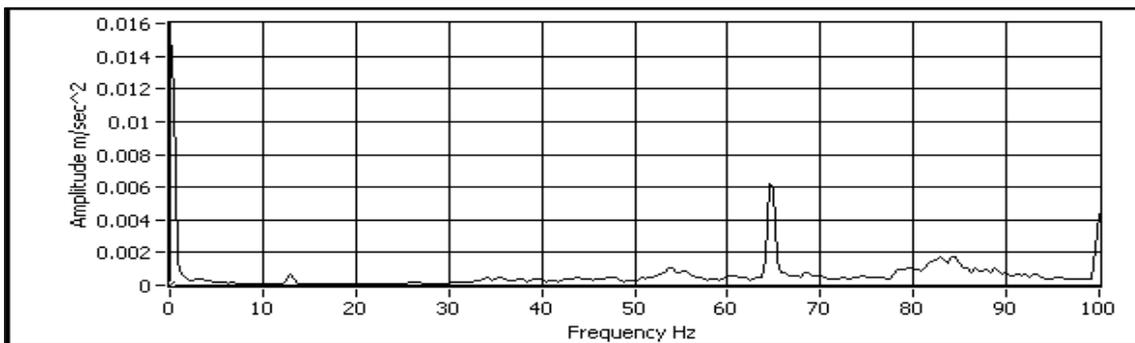
When the time period is extended to about 2 and 2.5 s it was observed that the number of sharp peaks is more in between 1.5 to 2 s. However, the amplitude of vibration is very nominal in between 2 to 2.5 s. In complete analysis, the peak variation is same as analysis in 1.5 s.

Horizontal position

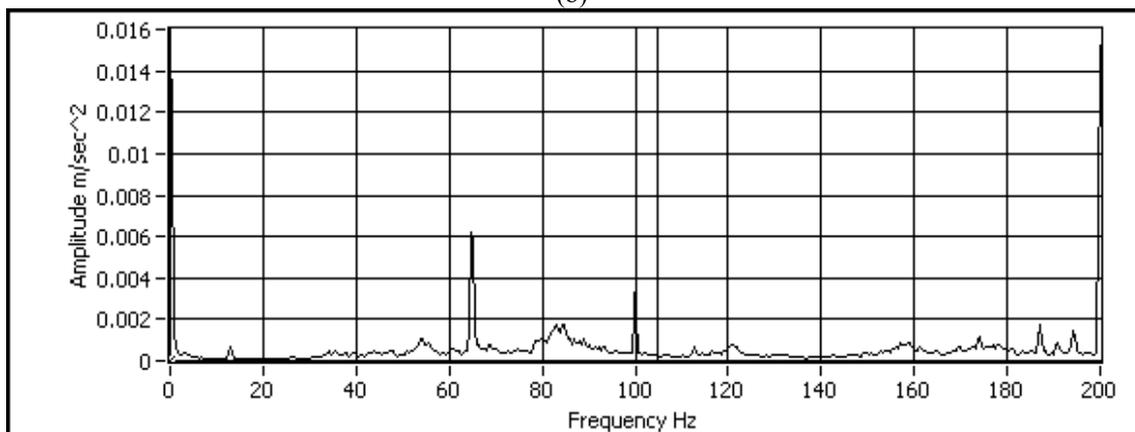
The 2nd experimentation on vibrational analysis is carried out by placing the sensor at the horizontal position and the experimental amplitude values are given based on different frequencies of 50, 100, 200 and 300 Hz as in **Figures 7(a) to 7(d)**. The 1st peak over the vibrational amplitude is observed at the frequency of 0.1 Hz with the amplitude of 0.0015 m/s^2 . After the 1st peak, similar to the sensor at top position there is a sudden decrease in amplitude of vibration till 1 Hz and then it propagates at lower level till 50 Hz. The 2nd peak is observed at 65 Hz with the amplitude of 0.006 m/s^2 which showed sudden increase and decrease in amplitude. The 3rd and 4th peaks are observed at 100 and 200 Hz with the amplitude of 0.0037 m/s^2 and peak amplitude of 0.018 m/s^2 respectively. After the peak at 200 Hz, the next peak is observed at 212 Hz with the amplitude of 0.0082 m/s^2 . The 5th and 6th peak is observed at the 240 and 300 Hz and the amplitude is about 0.004 and 0.006 m/s^2 .



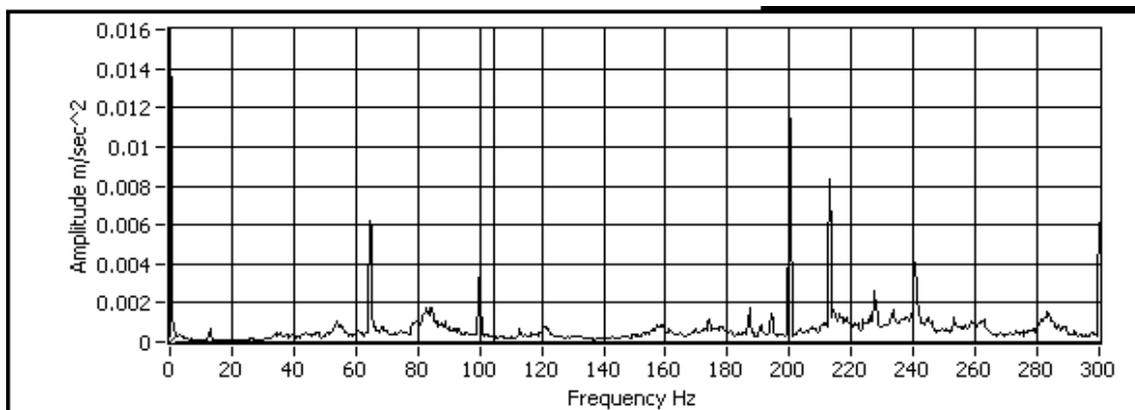
(a)



(b)



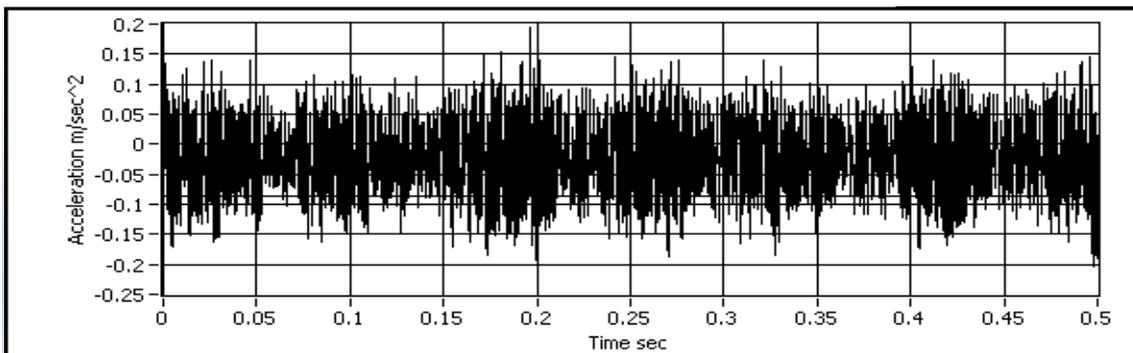
(c)



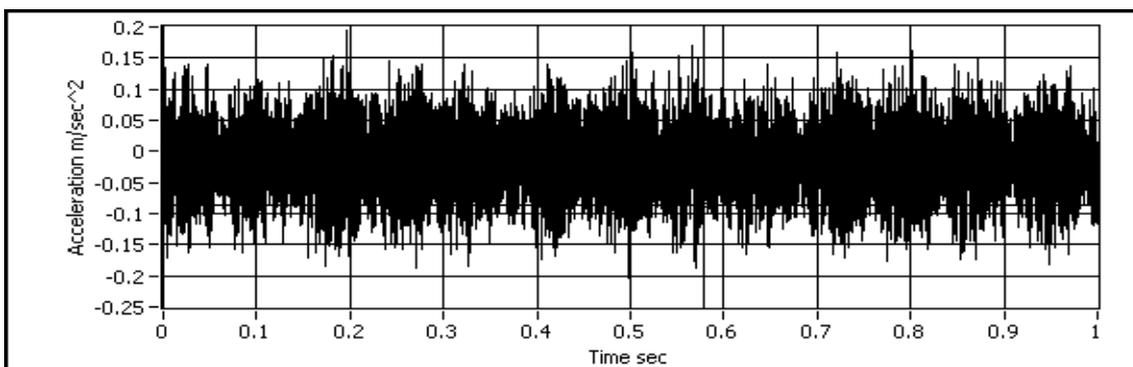
(d)

Figure 7(a) Frequency vs amplitude over 50 Hz- horizontal position. **(b)**Frequency vs amplitude over 100 Hz.**(c)** Frequency vs amplitude over 200 Hz -horizontal position.**(d)** Frequency vs amplitude over 300 Hz -horizontal position.

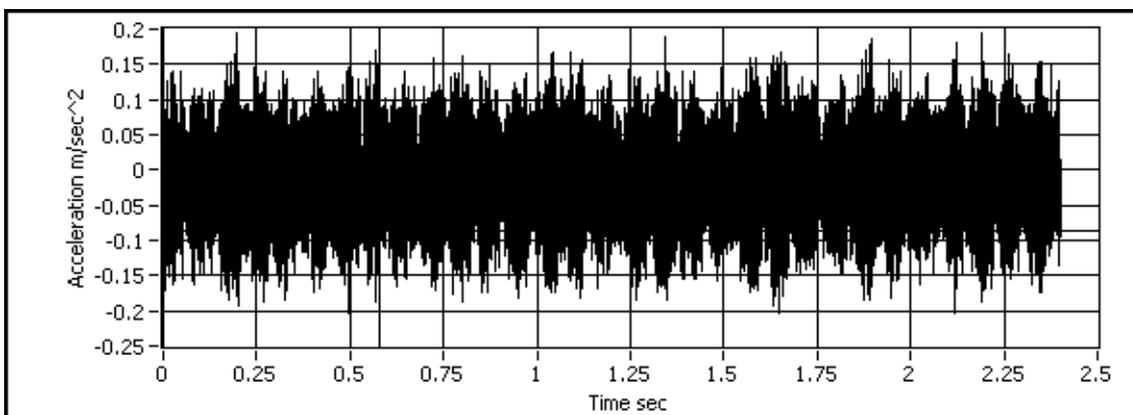
The time domain based vibrational analysis is carried out at different time periods as 0.5, 1 and 2.5 s. The vibration ranged between 0.196 to -0.198 m/s^2 for a time period of 0.5 s. The variation in amplitude along 0.5s to 1s was more than 0.15 m/s^2 at maximum instances and the lower most amplitude value was observed to be -0.2 m/s^2 in the time period of 2.5 to 1.67 s. The time domain based vibrational analysis is given in **Figures 8(a)** to **8(c)**.



(a)



(b)

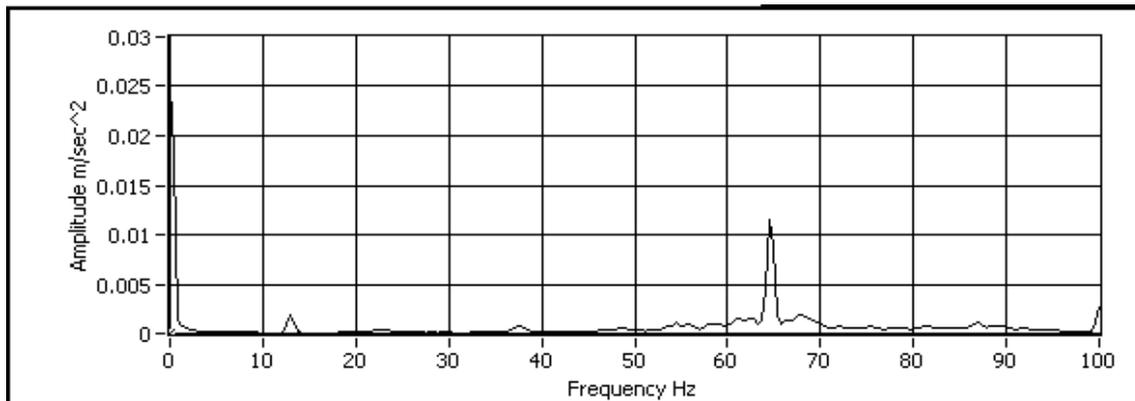


(c)

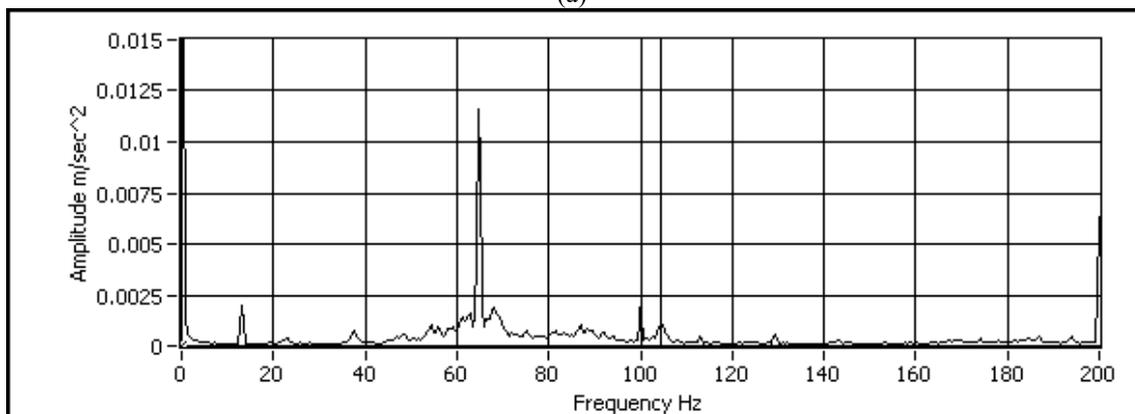
Figure 8 (a) Time vs amplitude for 0.5 s- horizontal position. (b)Time vs amplitude for 1 s- horizontal position.(c)Time vs amplitude for 2.5 s- horizontal position.

Vertical position

The 3rd set of experimentation on vibrational analysis is carried out by placing the sensor at the vertical position and the experimental amplitude values are given based on different frequencies of 100 and 200 Hz (Figures 9a and b).



(a)

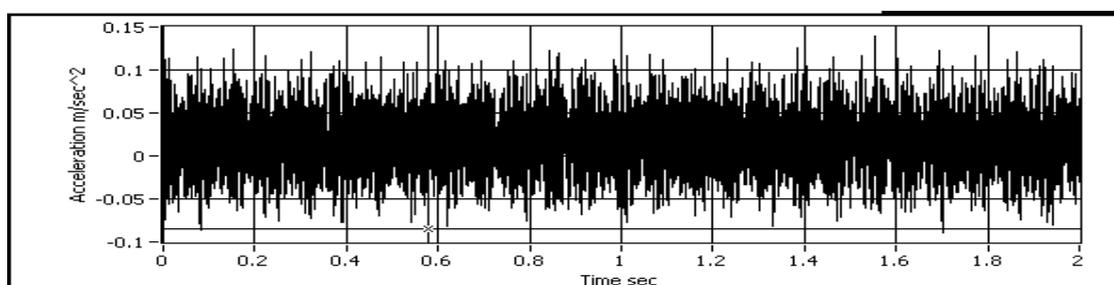


(b)

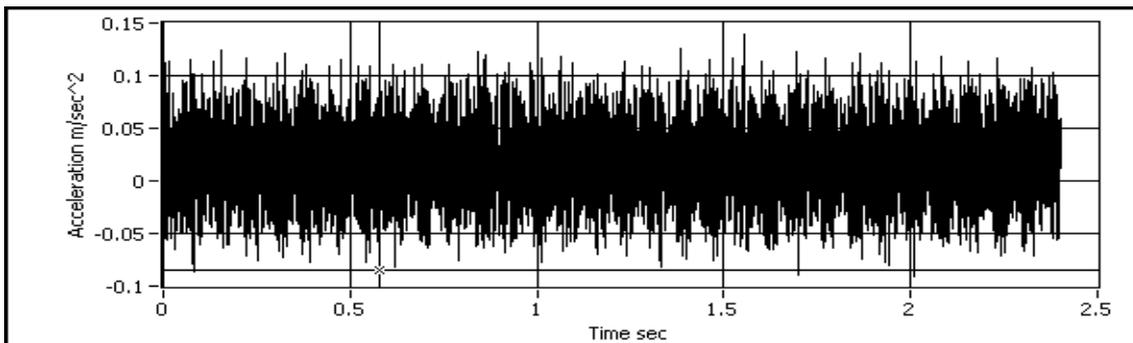
Figure 9 (a) Frequency vs amplitude over 100 Hz.(b)Frequency vs amplitude over 200 Hz.

The 1st peak over the vibrational amplitude is observed at the frequency of 0.1 Hz with the amplitude of 0.023 m/s². After the 1st peak, similar to the sensor at Vertical position there is a sudden decrease in amplitude of vibration till 2 Hz and then it propagates at lower level till 15 Hz. The 2nd peak is observed at 65 Hz with the amplitude of 0.012 m/s² which showed sudden increase and decrease in amplitude. The 3rd and 4th peaks are observed at 100 and 200 Hz with the amplitude of 0.0021 m/s² and amplitude of 0.0068 m/s² respectively.

The time domain analysis is carried out over 2 time period of 2 and 2.5s. It was observed that the range of amplitude is about 0.15 to -0.1 m/s² over the time period of 2 s. The deviation in the amplitude with respect to time decreases towards the time period of 2.5 s. The amplitude pattern obtained for the time periods of 2 and 2.5 s are given in **Figures 10(a)** and **10(b)**.



(a)

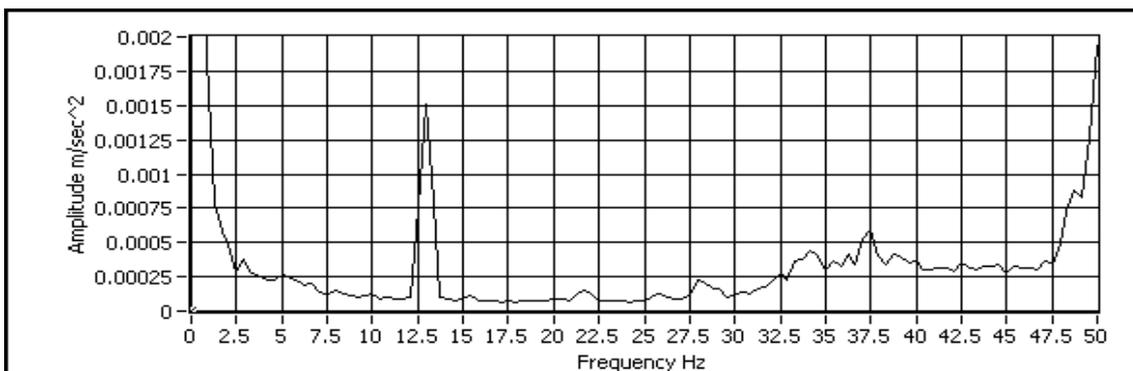


(b)

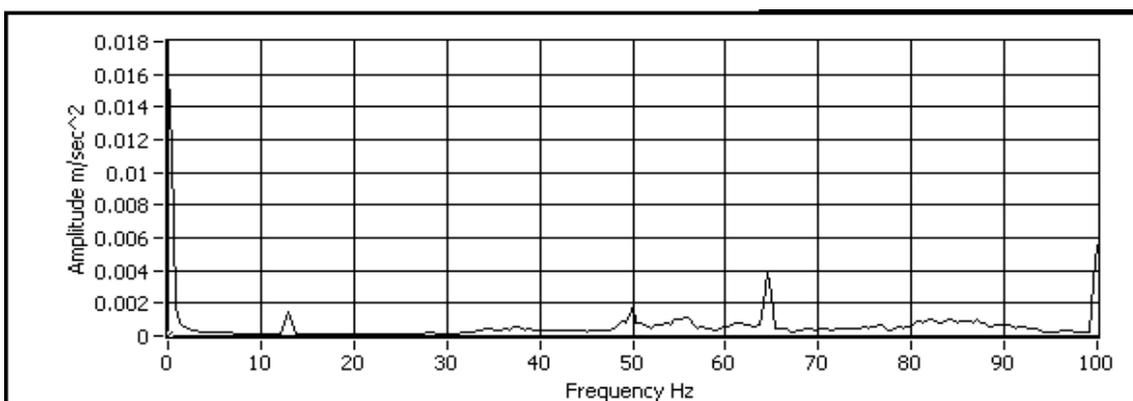
Figure 10 (a) Time vs amplitude for 2s - vertical position. (b) Time vs amplitude for 2.5s - vertical position.

Side position

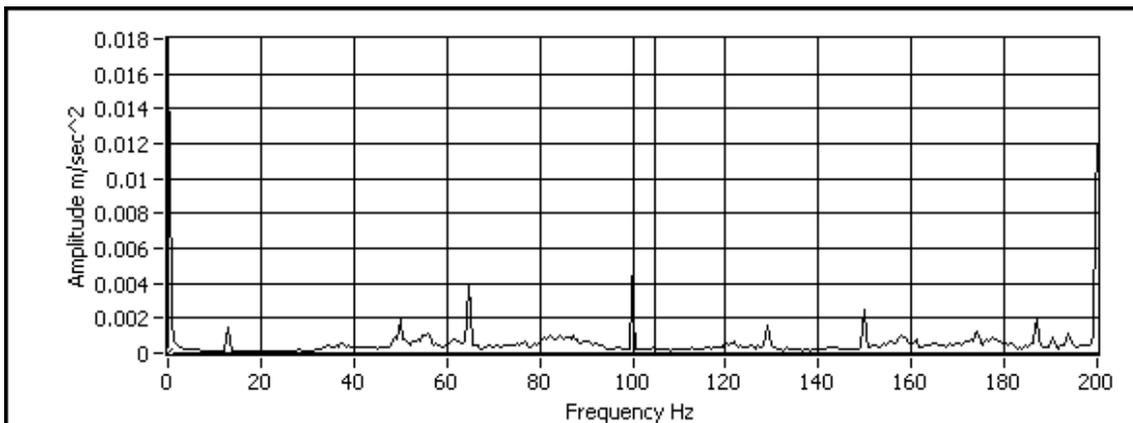
The final experimentation on vibrational analysis is carried out by placing the sensor at the side position and the experimental amplitude values are given based on different frequencies of 50, 100 and 200 Hz as in Figures 11(a) to 11(c).



(a)



(b)



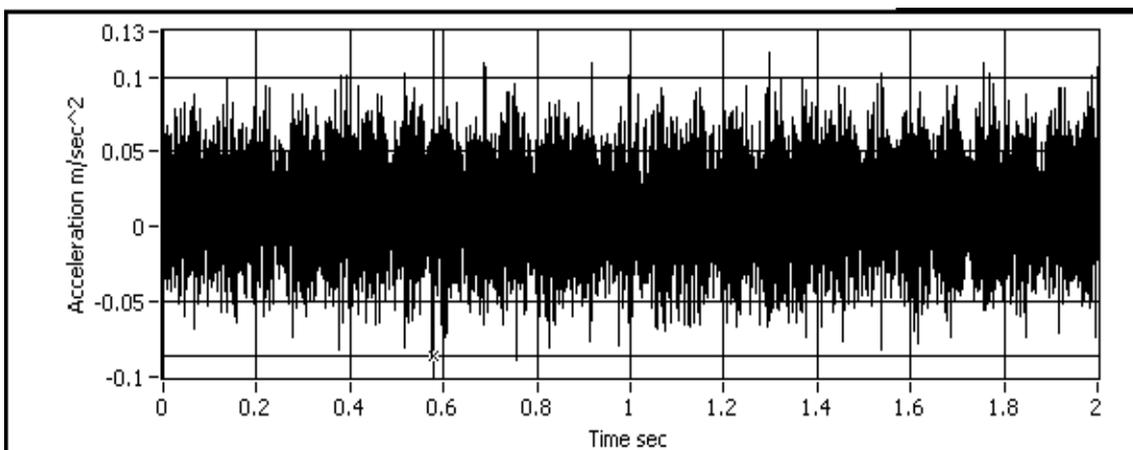
(c)

Figure 11 (a) Frequency vs amplitude over 50 Hz.(b) Frequency vs amplitude over 100 Hz. (c) Frequency vs amplitude over 200 Hz.

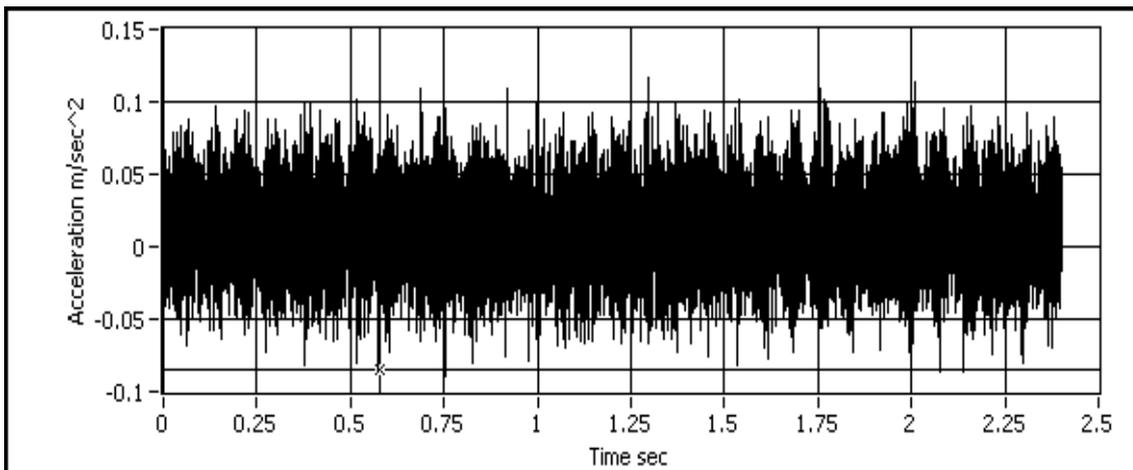
The 1st peak over the vibrational amplitude is observed at the frequency of 0.1 Hz with the amplitude of 0.0018 m/s² and sudden decrease in amplitude is observed till 2 Hz and then it propagates with small peak at 13 Hz.

The 3rd peak is observed at 65 Hz with the amplitude of 0.004 m/s². The 4th peak is observed at 100Hz with amplitude of 0.044 m/s² and at 130 Hz the 5th peak which is similar to the 2nd peak with amplitude of 0.0018 m/s². After 130 Hz,the next peak is observed at 150 Hz with amplitude of 0.0022 m/s². Another peak occurs at 187 Hz that is similar to the 2nd and 5th peak. The final peak occurs at 200 Hz with the amplitude of 0.012 m/s².

The time domain analysis is performed over the 2 different time periods of 2 and 2.5s respectively and the corresponding outcomes on vibrational amplitudes are obtained in **Figures 12(a)** to **12(b)**. The range of amplitude is observed to be maximum of 0.15 m/s² and minimum of -0.08 m/s².



(a)



(b)

Figure 12 (a) Time vs amplitude for 2.5 s- side position. (b) Time vs amplitude for 2.5 s - side position.

The peak amplitude is observed to be about 0.346 m/s^2 for the evaporator in the CDWAC and it is observed to be about 0.512 m/s^2 for NWAC compressor. The corresponding figures for both the air conditioner is given in Figures 13 and 14.

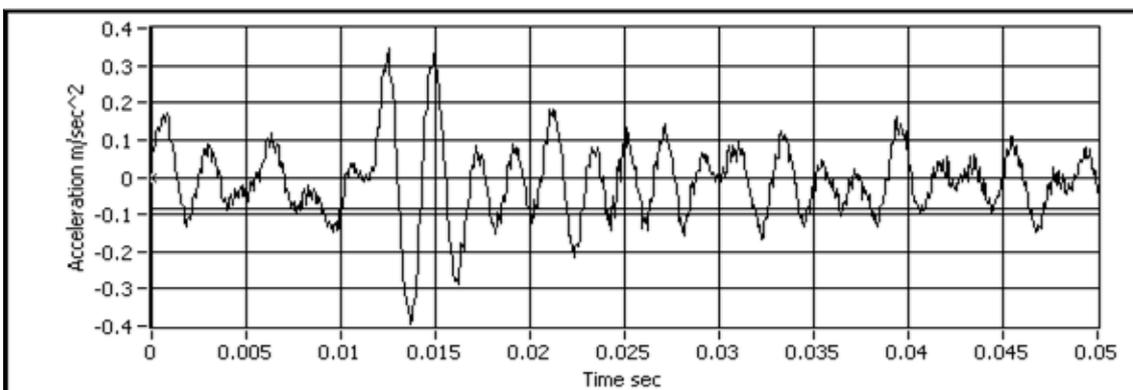


Figure 13 Acceleration vs time curve (Pump - PCMWAC).

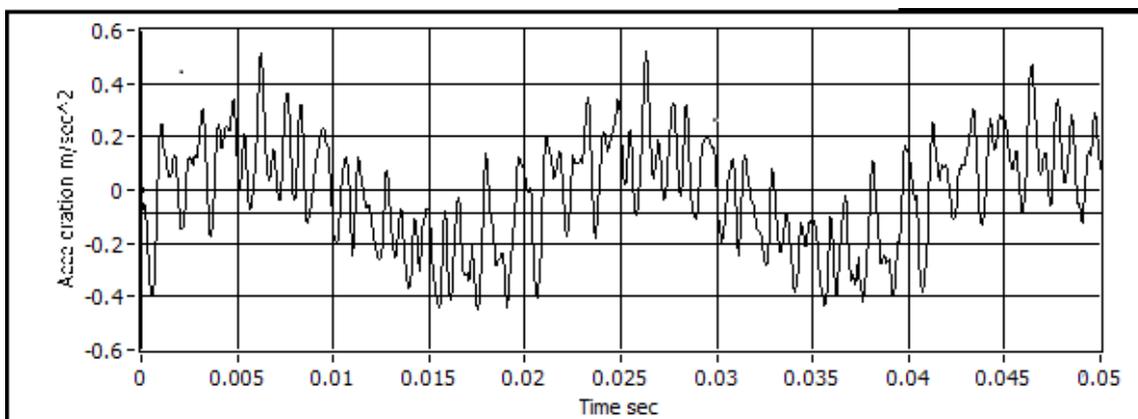


Figure 14 Acceleration vs time curve (Compressor - NWAC).

Wave form analysis

The RMS value of the wave form obtained from the positioning of sensor in the top position is observed to be 0.4 and it is estimated through the equation:

$$\text{RMS} = \frac{1}{N} (\sum_{i=1}^N (X_i)^2). \quad (5)$$

Where N is the number of test carried out and i is the specific test number.

Similarly, the RMS value for the waveform obtained at the horizontal, vertical and side position is about 0.308, 0.224 and 0.239 respectively. **Table 2** and **Figure 15** shows the comparison among the RMS Value obtained from the waveforms from the sensor placed at various location.

Table 2 Comparison on RMS value at different location.

Position	RMS Value (m/s ²)
Top position	0.4
Horizontal position	0.308
Vertical position	0.224
Side position	0.239

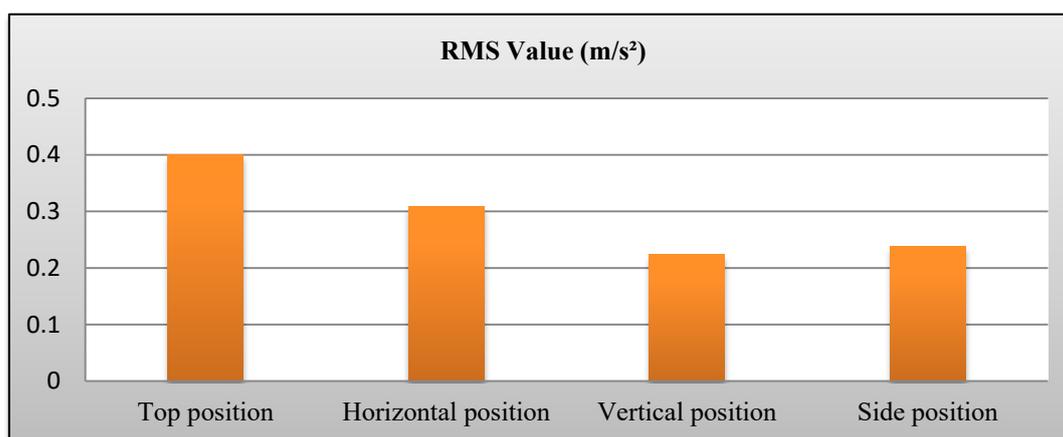


Figure 15 Comparison on RMS value at different locations.

The RMS value of the compressor over the pump in the constructal design and compressor in the normal design is given in **Table 3** and **Figure 16**. For normal window AC the RMS value is about 0.62 and constructal window AC is about 0.38.

Table 3 Comparison between normal and constructal window AC.

Unit	RMS Value (m/s ²)
Normal window AC	0.62
Constructal window AC	0.38

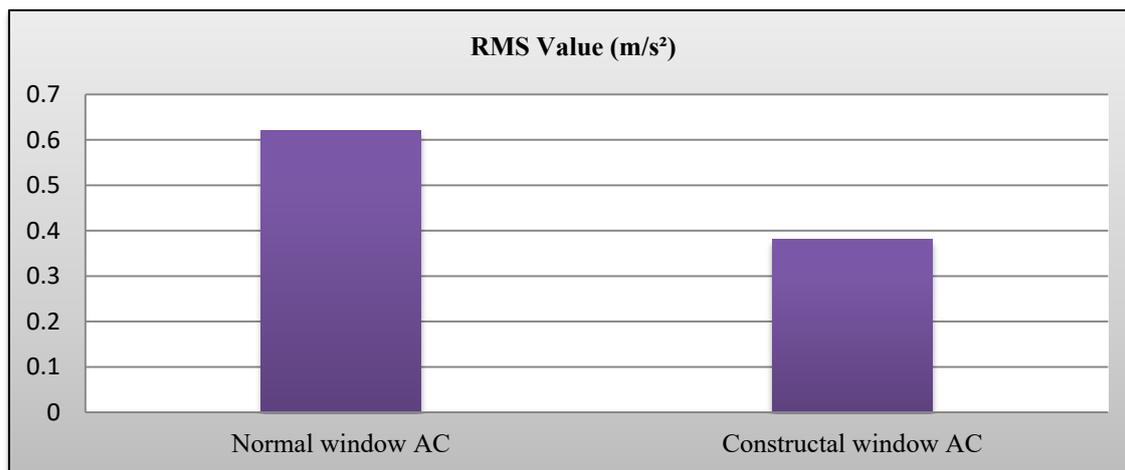


Figure 16 RMS value for normal and constructal AC.

Noise analysis

Measured values of noise levels in the normal and CDWAC are shown in the below Figure 17.

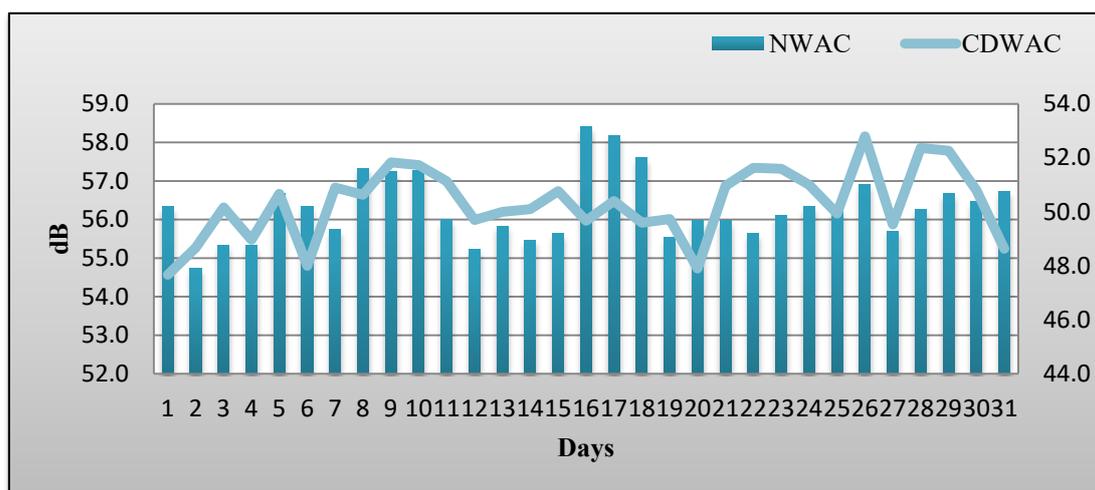


Figure 17 RMS value for normal and constructal AC.

The noise levels of the air conditioners were measured under normal operating conditions for the day and an average for the day was taken for the calculations. Through Figure 10, it is evident that the noise levels measured in the NWAC were higher than the CDWAC and it is evident that it operates noiselessly which is a good sign under noise at work regulations and environmental comfort conditions.

The below mentioned Figure 18 shows the line fit t curve for the noise levels of CDWAC. The data is distributed linearly. Regression equation is given by the equation $y = mx + b$. The linear regression equation for the noise levels and Laeq values are given by the equation $1.384x_1 + 1.0039x_2$. Sound level varies over time is assessed by the method of equivalent continuous sound level (Laeq).

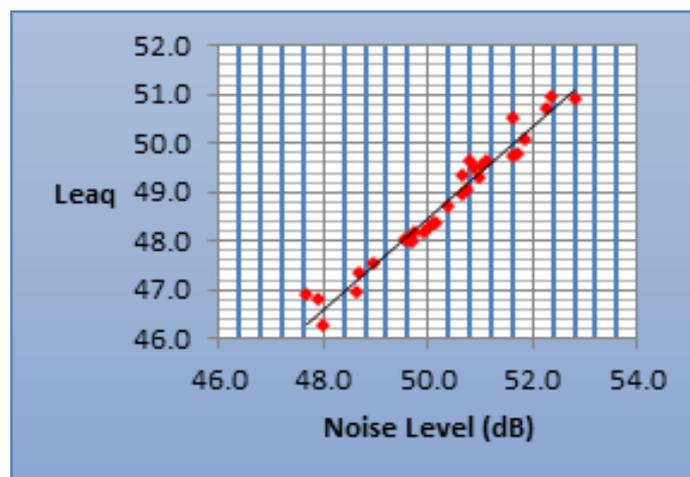


Figure 18 Line fit plot Laeq and noise levels in CDWAC.

The Laeq measurement correlates with the annoyance to the occupants and possible hearing problems. Noise level of Laeq =55 dB is suggested by the World Health Organization (WHO) as an annoyance during the day hours. The below mentioned **Table 1** shows the regression statistics for Laeq and sound levels in CDWAC.

Table 4 Regression statistics.

RegressionStatistics	
Multiple R	0.983871852
R Square	0.96800382
Adjusted R Square	0.9668611
Standard Error	0.227694658
Observations	30

In regression analysis, R^2 value indicates the amount of variables explained in the model. In this particular analysis, the R^2 value is 0.9, so 96 % of variance is explained in the model. The multiple R value is near to 1, and so we can conclude that the model has a strong linear relationship between the variables. That is the Laeq value highly depend on the noise annoyance created by the air conditioner.

Noise rating and noise criterion curve

The noise criteria curve was developed in 1957 in the objective to produce comfortable living environments in buildings. Noise Criteria is defined as a single number noise rating system generally used to degree the steady-state noise levels in a room [21]. Noise criteria level is a standard describing the relative noise of space with a range of frequencies. Noise rating is frequently used in the measurement of noise from air conditioning systems.

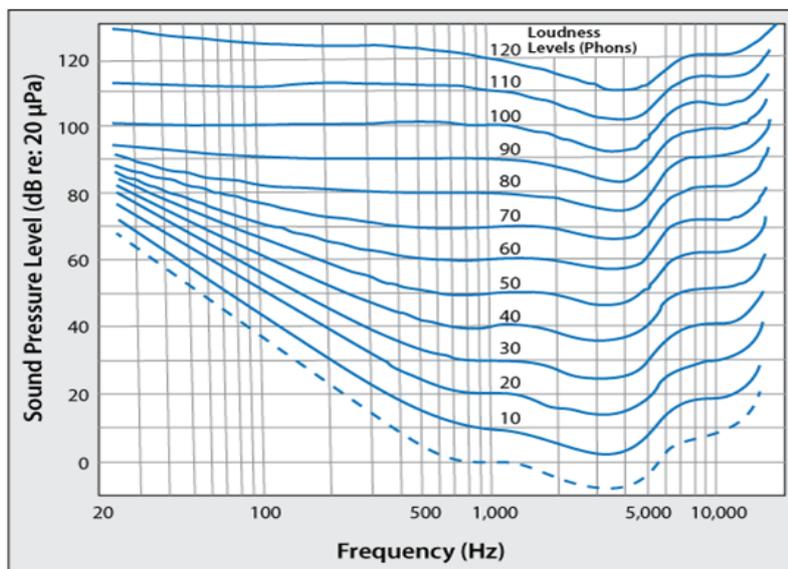


Figure 19 Noise criteria standard.

Figure 19 shows the change of sound pressure level according to the change in frequency of the noise generated. The noise rating and noise criteria curves have been devised to analyze the interfering noise. BS 4142 suggests the following method for the corrected noise level.

- 1) Locate the noise level in 50 dB (A).
- 2) Apply the total character adjustment of +5 dB (A) where the noise has a definite continuous.
- 3) Add 5 dB (A) if the sound is impulsive.
- 4) Apply a correction to let for the discontinuous character of the sound. This is by finding the percentage of the time the noise is formed and applying a correction from the chart, depending upon day or night.

The corrected noise levels calculated for the NWAC and with phase change material, the corrected noise level is calculated as shown below in Table 5.

Table 5 Noise criteria levels of the air conditioners.

	NWAC	CDWAC
Measured noise level	56.2	50.3
Total character correction	5	5
Impulsive character	Nil	Nil
Corrected Noise Level	61.2	55.3

Based on the standard British Standard (BS) 4142, the corrected noise level of the NWAC with vapor compression systems was found to be high and can be a hazard to the acoustic comfort.

Conclusions

Noise and vibration analysis of CDWAC was studied in comparison with the NWAC.

The design of constructural window air conditioner was an attempt to minimize one of the disorders or imperfection in the system (noise level created by the air conditioner during its operation). Since the compressor in the conventional window air conditioner is replaced with a pump to circulate water through the system, it was observed a significant amount of noise reduction in the system during its operation.

Noise criteria level of NWA is 61 dB; where as in CDWA is 55 dB. Noise measurement and daily noise exposure level (Laeq) for the CDWA was measured and it was compared with NWAC.

The comparative results of Laeq expose that, the CDWAC performs better with noise criteria around 44 dB, whereas the NWAC has 60 dB which is considered to be an annoyance in the occupied space according to the world health organization standards. Previous study by Wu and Leishow around 10 dB reduction in the operation of residential air conditioners, whereas the designed constructal window air conditioner exhibits a reduction in noise during operation around 14 dB [22]. Vibration analysis of both the air conditioners was done by the experimental investigation. The source of vibration is because of the compressor in NWAC and this was replaced with a pump in CDWAC. Time domain analysis and spectral analysis of both the air conditioners were done and the curves were plotted for better understanding of the performance of both the air conditioners in connection with vibration during operation. The peak amplitude of compressor in NWAC is 0.18 m/s^2 ; whereas in the CDWAC where a pump was used, a pump was used were 0.01 m/s^2 . Acceleration is the varying rate of velocity with time. The acceleration observed in NWAC is 0.6 m/s^2 and in CDWAC is 0.3 m/s^2 , which is a satisfactory result which indicates, minimized the abnormal machinery noise and vibration.

Time domain analysis is carried out over 2 time periods of 2 and 2.5 s. It was observed that the range of amplitude is about 0.15 to -0.1 m/s^2 over the time period of 2 s. The deviation in the amplitude with respect to time decreases towards the time period of 2.5 s. The amplitude pattern obtained for the time periods of 2 and 2.5 s. The time domain analysis is performed over the 2 different time periods of 2 and 2.5 s respectively and the range of amplitude is observed to be a maximum of 0.15 m/s^2 and minimum of -0.08 m/s^2 .

From this study, the attempt made to minimize the imperfections during operation of the window air conditioner was found to be satisfactory. Noise and vibration of the CDWAC was performing better in comparison with NWAC.

Acknowledgements

Authors would like to express their sincere gratitude and thanks to the College of Engineering, National University of Science and Technology, Muscat, Sultanate of Oman for the opportunity provided to carry out the study.

References

- [1] PHT Zannin and F Ferraz. Assessment of indoor and outdoor noise pollution at a university hospital based on acoustic measurements and noise mapping. *Open J. Acoust.* 2016; **6**, 71-85.
- [2] SP Huang and RP Lai. Frequency characteristics of interior noises in houses. *In: Proceedings of the 2005 World Sustainable Building Conference, Tokyo, Japan. 2005*, p. 1503-8.
- [3] HM Shivraj and N Kapilan. Analysis of domestic split unit air conditioning system of outdoor unit. *Int. J. Eng. Res. Gen. Sci.* 2016; **4**, 128-34.
- [4] V Wagner, H Enigk, T Beitz and KW Kallus. Subjective and objective evaluation of the air conditioning sound. *J. Ergonomics* 2014; **4**, 131.
- [5] T Tannert and U Hesse. Noise effects in capillary tubes caused by refrigerant flow. *In: Proceedings of the International Refrigeration and Air conditioning Conference, West Lafayette, Indiana. 2016*, p. 1562.
- [6] Fact Sheet and Acoustic Terminology. Noise technical fact sheet 7: Sound insulation for air conditioners and other noise from residential machines, The City of Adelaide, 2004.
- [7] GZ Gedik, NY Akdag, F Kiraz, B Sener and R Cacan. Evaluation of mass housing settlements in terms of wind and noise control: Istanbul and Diyarbakir as a case. *J. Environ. Eng. Landsc. Manag.* 2017; **25**, 389-401.
- [8] E Sellappan and K Janakiraman. Environmental noise from construction site power systems and its mitigation. *Noise Vib. Worldw.* 2014; **45**, 14-20.
- [9] SK Tang. Noise indices for assessing domestic air conditioner noise. *Noise Vib. Worldw.* 2006; **37**, 10-4.
- [10] B Hay and MF Kemp. Frequency analysis of air conditioning noise in landscaped offices. *J. Sound Vib.* 1972; **23**, 375-81.
- [11] S Jachimowicz and K Gładyszewska-Fiedoruk. The noise produced by the air handling units depending on the type of engine. *In: Proceedings of the 10th International Conference on Environmental Engineering, Vilnius, Lithuania. 2017*, p. 20.
- [12] A Bejan and S Lorente. The constructal law of design and evolution in nature. *Philos. Trans. R. Soc.*

- B: Biol. Sci.* 2010; **365**, 1335-47.
- [13] A Bejan and MR Errera. Complexity, organization, evolution, and constructal law. *J. Appl. Phys.* 2016; **119**, 074901.
- [14] AF Miguel. Natural flow systems: Acquiring their constructal morphology. *Int. J. Des. Nat. Ecodyn.* 2010; **5**, 230-41.
- [15] M Lorgulescu and R Beloie. Vibration and current monitoring for Fault's diagnosis of induction motors. *Ann. Univ. Craiova Electr. Eng. Ser.* 2008; **57**, 102-7.
- [16] Z Wen, Y Zhang, Y Hu, R Zhang, H Gu and J Zhang. Research on low frequency vibration of rotary compressor. *In: Proceedings of the 23rd International Compressor Engineering Conference, West Lafayette, Indiana.* 2016, p. 1424.
- [17] MK Amirnejhad, MRanjbar and MKarimkhany. Effects of impeller gap on rotor vibration in a highspeed centrifugal compressor: A numerical and experimental analysis. *Int. J. Eng.* 2017; **30**, 814-20.
- [18] OKavianipour and AM Khoshnood. Vibration suppression of fuel sloshing using sub band adaptive filtering. *Int. J. Eng.* 2015; **28**, 1507-14.
- [19] SP Ebenezer, AK Pramanick and KP Ramachandran. Window air conditioner with orthodox refrigerants. *Int. J. Eng.* 2020; **32**, 322-7.
- [20] G Zaza, AD Hammou, A Benchatti and H Saiah. Fault detection method on a compressor rotor using the phase variation of the vibration signal. *Int. J. Eng.* 2017; **30**, 1176-81.
- [21] C Bujoreanu and M Benchea. Experimental study on HVAC sound parameters. *In: Proceedings of the 7th International Conference on Advanced Concepts in Mechanical Engineering, Iasi, Romania.* 2016, p. 012051.
- [22] C Wu and X Lei. Noise control and sound quality evaluation of outdoor unit of split air-conditioner. *J. Meas. Eng.* 2016; **4**, 58-69.
- [23] HS Han, WB Jeong, S Aoyama and JY Mo. Experimental analysis for reducing refrigerant-induced noise of 4-way cassette type air conditioner. *J. Mech. Sci. Tech.* 2009; **23**, 1456.