Frequency Mapping of Square Head Expander for Vibration Testing

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Abstract

The Head expander is a component of an electrodynamic shaker used for vibration tests in the vertical direction for large-size specimens. This study aims to determine the natural frequency distribution of the head expander across a certain number of predetermined points. This distribution map is needed to determine the better placement of future specimens on the head expander. In this study, the determination of natural frequency distribution is done through harmonic analysis (simulation) and experiment to form a contrast between the head expander's ideal condition and the actual condition. The frequency range in the middle of the head expander has almost the same value for both data types at 1550-1650 Hz. These results recommend that the best sample placement is in the middle of the head expander. The difference between the experimental and simulation low points has not too far difference, which is 62.5 Hz. In contrast, at the highest value, the two have a quite far difference, 180.27 Hz. This difference can be caused by the improper installation of sensors on the head expander at specific points.

Keywords: *Resonant frequency, vibration, head expander, simulation, experiment, harmonic analysis*

1. Introduction

Mechanical vibration is one of the main causes of damage to mechanical equipment. A vibration test is performed to confirm the effect of mechanical vibration on the tested equipment. Typically, a vibration test system consists of a dynamic electro-shaker, a power amplifier, a vibration control system, and a data acquisition system (Jeong and Cho 2016). There are a certain number of mounting points on the electrodynamic shaker in a vibration testing system. In many cases, those mounting points are inadequate to accommodate the vibration test specimens. The need to increase the mounting point in a vibration testing system pushes the need of a head expander.

The Head expander is a component of an electrodynamic shaker used for vibration tests in the vertical direction. It is a structure designed to couple the motion from the vibration source to the fixture or the item to be tested without distortion. A head expander is generally required for testing large-size specimens which cannot be directly mounted on the shaker head or armature interface (Kumar, Kumar, and Kumar 2019).

The head expander must be validated before its usage in an experiment. One of the methods of validating head expanders is through vibration tests or experimental data collection. There are a few important parameters in the head expander vibration test. Two of them are resonant frequencies and homogeneity (Ula et al. 2020). Another method to estimate head expander characteristics is through simulation.

A few types of simulation can be used to estimate the vibration characteristics of a specimen. Among them are modal analysis and harmonic analysis. Modal analysis is one of the methods used to evaluate the dynamic characteristics of mechanical components. Moreover, this technique can explain a structure in terms of its natural characteristics. The natural characteristics are natural frequency, damping, and mode shapes (He and Fu 2001; Siva et al. 2021; Wan 2021). However, modal analysis in the simulation study condition is a free vibration without particular direction axes of excitation. Harmonic analysis is performed to complement this weakness in simulation modal analysis. The harmonic analysis was a technique used to determine the steady-state response of a linear structure to loads that vary harmonically with time (Perumal, Swaminathan, and Christensen 2020). The function of excitation is a sine function with constant amplitude

(Tang et al., 2017). The vibration system is often classified as a single degree of freedom (SDOF) in the vibration test environment, as illustrated in Figure 1-1.

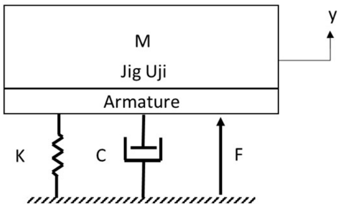

Figure 1-1: Vibration test system with Single Degree of Freedom (SDOF)(Ula et al. 2020)

When an SDOF system is excited by a sine sweep, the response amplitude envelope will deviate from the steady-state amplitude due to the effects of transients, as shown in Figure 1-2. The shape and position of the resonant peak are altered as a function of the sweep rate and direction. Moreover, a beat pattern or "ringing" following the main peak occurs. This ringing results from the system responding at two frequencies of nearly the same value: the transient response at the natural frequency and the harmonic response at the swept excitation frequency. In general, a sine sweep will decrease the amplitude of the peak, shift the position of the peak (along the direction of the sweep), broaden the peak width and distort the shape of the peak. The higher the sweep rate, the more these effects are accentuated (Roy, Violin, and Cavro 2018).

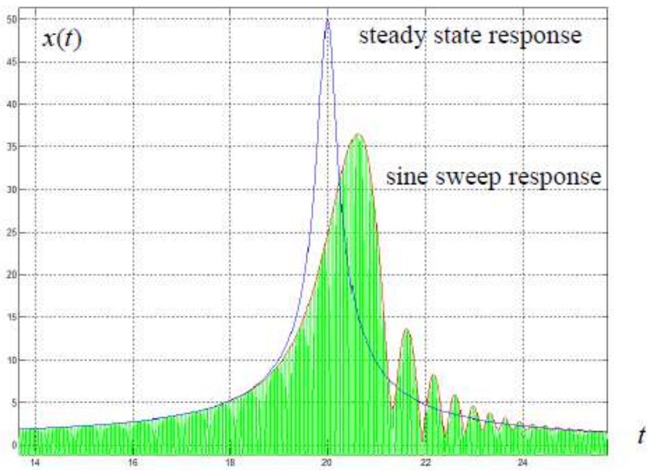

Figure 1-2: Effect of Sine Sweep on SDOF Response (Roy et al. 2018)

This study aims to determine the natural frequency distribution of the head expander across a certain number of predetermined points. This distribution map needs to be known to determine the better placement of future specimens on the head expander. Another importance of the map is determining the stiffness distribution across the surface of the head expander through differences in resonant frequencies. This data can be used as a reference to design a better head expander in the future. In this study, the determination of natural frequency distribution is done through harmonic analysis (simulation) and experiment to form a contrast between the head expander's ideal condition and the actual condition.

2. Methodology

2.1. Related Works

Sujeet Kumar, Neeraj Kumar, and Raman Kumar carried out similar research about a head expander in 2019. In this study, the head expander was designed for a 9000 kgf shaker system with a diameter of 1200 mm. The head expander was subjected to vibration between 5-2000 Hz with several accelerometers installed on radii 250 mm, 350 mm 450 mm, and 550 mm from the centre. (Kumar et al. 2019)

Another similar research has been done by Sentek Dynamics company for a 1200 mm x 1200 mm square head expander. In this study, the square head expander was divided with a seven-by-seven grid for 49 measurement points. (Zhao 2020)

2.2. Problem Definition

When using a fixture in a vibration test, consideration for its natural frequency should be given to avoid resonance between the fixture and test item. Head expander can be considered a type of vibration test fixture; therefore, the same consideration holds. As a head expander have a large surface area, the distribution of resonant frequency needs to be determined; therefore, the following problems were formulated, they are:

A. What is the distribution contour of resonant frequencies across the test item side surface of the head expander?
B. How is the homogeneity of the head expander?

2.3. Method

This research begins with measuring the geometry of the head expander to be tested. The head expander is made of points where the frequency will be measured. The points to be measured are 49, with the distance between the points being 7 cm. 3d model is made based on the shape and size of the head expander. Furthermore, this 3D model is used for FEM harmonic analysis. The simulation results are in the form of the natural frequency of the head expander at each measurement point. In experimental activities, the head expander is drawn with grids, each end of which is the location of the accelerometer sensor. Then, the head expander is vibrated using a vibration tester with a sine swept test profile from 5 -2000 Hz. The frequency at predetermined points in the head expander results from experimental measurements compared with the results of FEM simulations on 3D models. The homogeneity of the head expander and the recommendation for the location of the test object can be concluded based on the test data. The research flow can be seen in Figure 2-1.

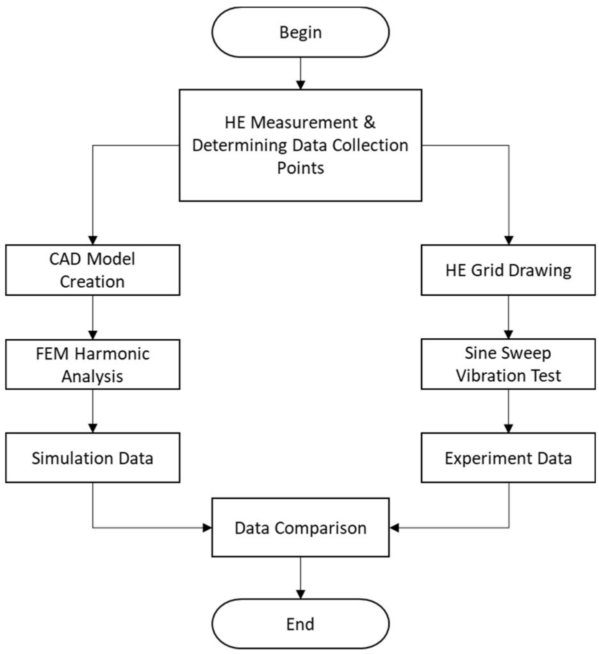

Figure 2-1: Research flowchart

2.4. Head Expander Specification

The head expander that will be tested in this study is square-shaped. This head expander is made of aluminum. The size of this head expander is 600mm X 600mm and weighs 45 Kg. The head expander to be tested can be seen in Figure 2-2.

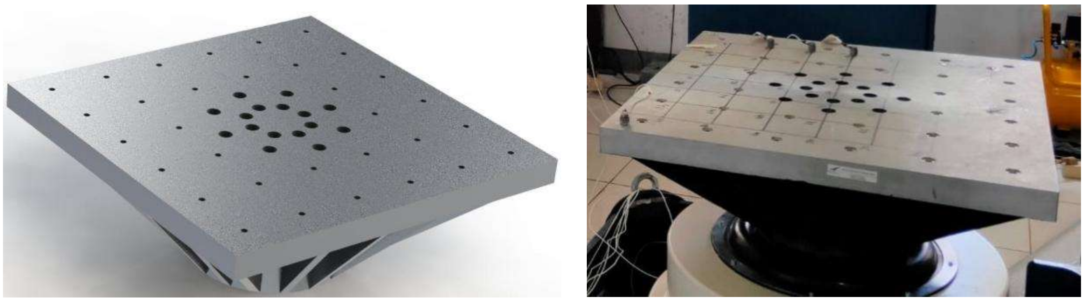

Figure 2-2 Head expander illustration; CAD model (left) and actual (right)

2.5. Experimental Set-Up

The vibration test device is used to measure the natural frequency of the head expander. The vibration test equipment used consists of a shaker that serves to provide vibrations to the test object. The vibration control module functions as a signal generator to drive the shaker and a data acquisition system. The amplifier will amplify the signal generated from the vibration control module to turn on the shaker according to the desired signal conditions. The diagram of the vibration testing system can be seen in Figure 2-3.

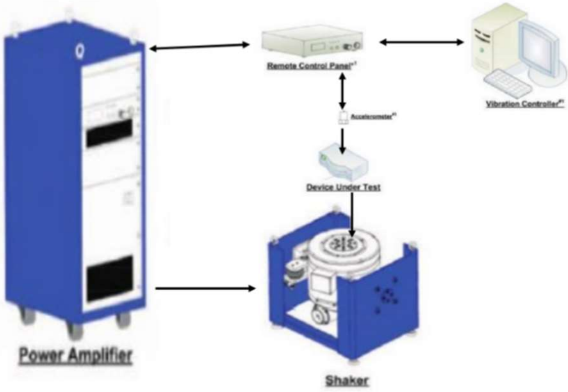

Figure 2-3: Vibration testing system diagram

The vibration control module used has four input channels for the IEPE type accelerometer sensor. Due to the limited input channels, testing activities are repeated until all the specified points are met with frequency data. The accelerometer sensor used as a fixed control is located at the end of the head expander. Meanwhile, the three sensors used in response to their positions are moved at predetermined points in sequence. The installation of the sensor position can be seen in Figure 2-4.

Figure 2-4: Accelerometer sensors set-up

2.6. FEM Harmonic Analysis Set-Up

The model of the square head expander is made with CAD software according to the actual dimensions, and its top surface is divided into 49 data capture points, as seen in Figure 2-5. FEM harmonic analysis on square head expander CAD model is then conducted. The support boundary condition used is the fixed type. This boundary condition is given to the bolt holes at the base of the head expander to represent the bolt connection with the shaker, as seen in Figure 2-6. Base Excitation of 1 G is given to those boundary conditions to simulate the output of the shaker. A natural frequency contour map was made based on the data collected at the nearest nodes from 49 previously determined points.

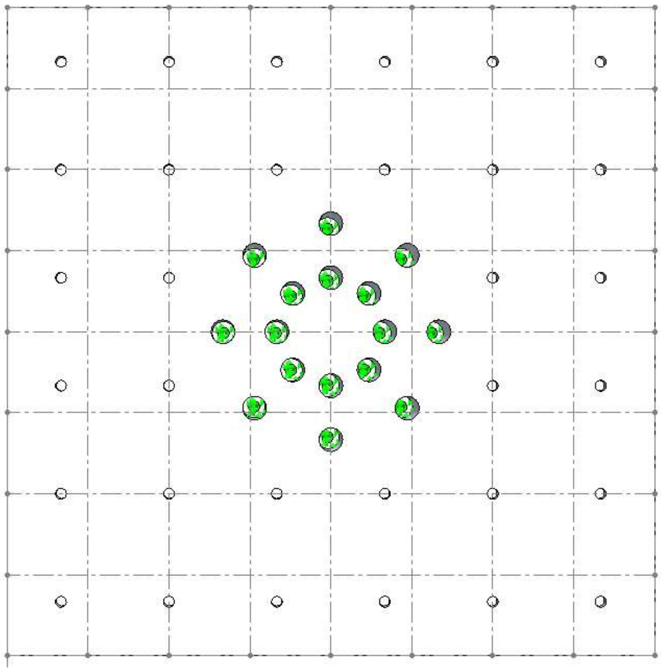

Figure 2-5: The 49 data collection points based of line intersections

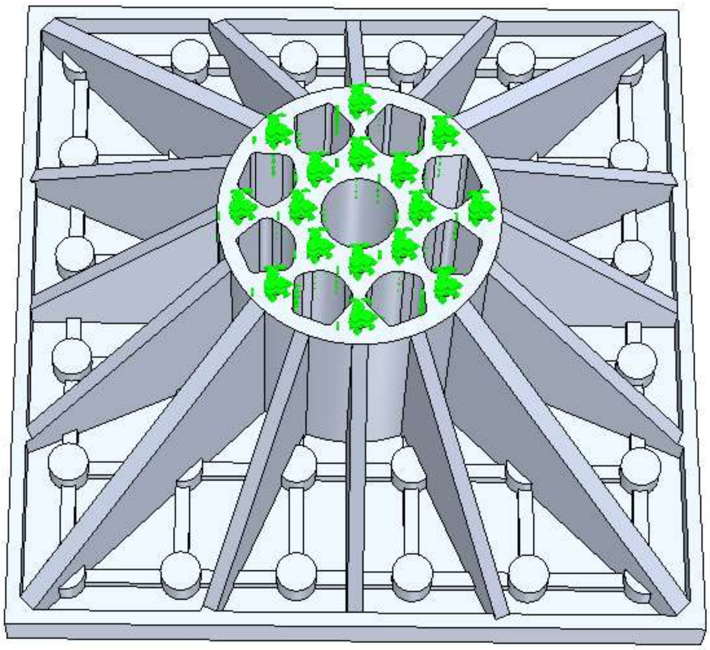

Figure 2-6: Fixed boundary condition on bolt holes

3. Result and Analysis

The results of the head expander simulation using FEM in the form of frequencies at predetermined points are summarized in Table 3-1 and visualized in Figure 3-1. The head expander has a different resonant frequency for each point. The lowest resonant frequency is 1424 Hz, and the highest resonant frequency is 1558.2 Hz. The simulation results show no significant difference in the frequency value that occurs in the head expander. The test result data in frequency is made into a contour image, as shown in Figure 3-2 and elaborated in Table 3-2.

Table 3-1: Simulation resonant frequencies

Coordinate (cm)	Resonant Frequencies (Hz)						
	7.5	15	22.5	30	37.5	45	52.5
7.5	1550.6	1537.3	1480.6	1480.6	1480.6	1546.4	1554.5
15	1542	1532.1	1480.6	1424	1480.6	1532.1	1542
22.5	1532.1	1480.6	1480.6	1424	1480.6	1480.6	1532.1
30	1480.6	1480.6	1424	1424	1480.6	1480.6	1480.6
37.5	1532.1	1480.6	1480.6	1480.6	1480.6	1480.6	1532.1
45	1542	1532.1	1480.6	1480.6	1480.6	1532.1	1546.4
52.5	1554.5	1542	1532.1	1480.6	1532.1	1546.4	1558.2

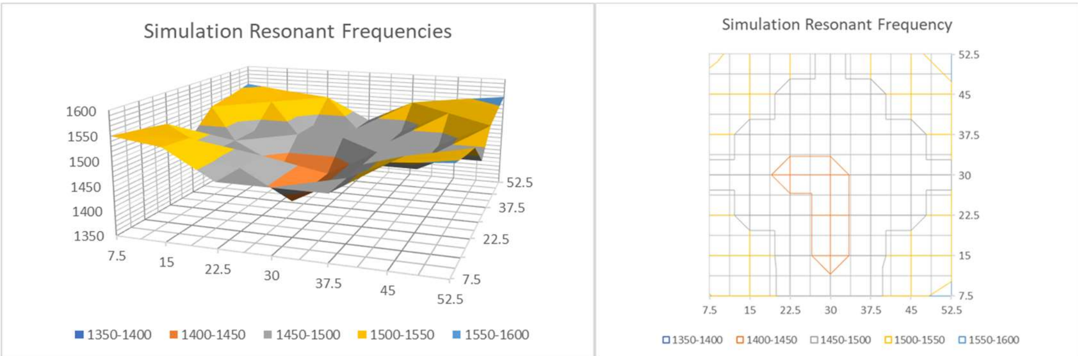

Figure 3-1: Simulation resonant frequencies contour map

Experimental testing of the head expander resulted in the lowest resonant frequency being 1486.5 Hz, and the highest resonant frequency was 1958.48 Hz. The X contour image is made to show the distribution of the frequency values in the head expander resulting from the experimental test. The resonant frequency in the center is between 1450-1500Hz. In comparison, the resonant frequency at the corner shows a significant difference around 1900 Hz.

Table 3-2: Experimental resonant frequencies

Coordinate (cm)	Resonant Frequencies (Hz)						
	7.5	15	22.5	30	37.5	45	52.5
7.5	1923.57	1490.96	1670.82	1606.97	1675.83	1490.96	1958.48
15	1490.96	1486.5	1680.86	1602.16	1670.82	1828.01	1490.96
22.5	1721.65	1685.91	1626.35	1578.33	1621.48	1690.97	1670.82
30	1650.91	1631.23	1587.82	1573.6	1587.82	1597.36	1611.79
37.5	1732.01	1711.36	1631.23	1583.07	1631.23	1660.83	1675.83
45	1490.96	1844.53	1675.83	1606.97	1690.97	1490.96	1490.96
52.5	1923.57	1490.96	1665.82	1616.63	1690.97	1490.96	1923.57

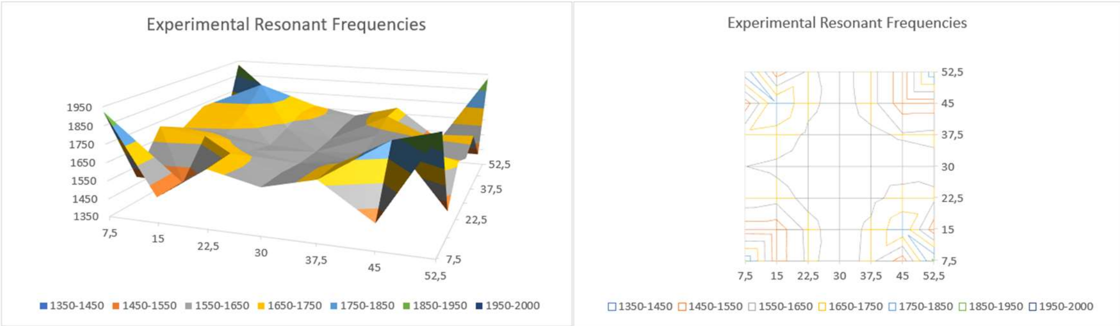

Figure 3-2: Experimental resonant frequencies contour map

The position of placing the test object is recommended in the middle because the frequency value in the middle has almost the same value in the range of 1550-1650 Hz. The simulation results with experimental results show a significant difference in values in the corners of the head expander. This difference is due to the improper installation of the accelerometer sensor on the head expander.

4. Conclusions

Data from experiments and simulations have been compared. The frequency range in the middle of the head expander has almost the same value for both data types at 1550-1650 Hz. These results recommend that the best sample placement is in the middle of the head expander. The difference between the experimental and simulation low points has a not too far difference, which is 62.5 Hz. In contrast, at the highest value, the two have a quite far difference, which is 180.27 Hz. this difference can be caused by the improper installation of sensors on the head expander at certain points.

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Contributorship Statement

The main contributors to this paper are Mikhael Gilang P.P.P and Muksin, who carried out data collection, data analysis, simulation, and set the test equipment. The conceptual research was carried out by Yusuf Giri Wijaya and Nur Mufidatul Ula. Mr.Agus Harno Nurdin Syah has carried out the supervision and final edit of this paper.

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