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VIBRATION RESPONSE CHARACTERISTICS OF 2 DOF SYSTEMS WITH THE ADDITION OF DUAL TRANSLATIONAL DYNAMIC VIBRATION ABSORBER BY THE EXPERIMENTAL APPROACH

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ABSTRACT

Dual Translational dynamic vibration absorber (d-DVA) is two DVA masses that can move in the translational direction and given into the system to reduce system-translation translational vibrations. . In this research we conducted a study related to the characteristics of 2 DOF system vibration response after the addition of dual translational DVA with an experimental approach and compared the results with simulation results data. The research shows that the addition of dDVA causes the system to have twice natural frequency that occurs at rf = 0.92 and rf = 1.09. The RMS values were 9.81 m / s2 and 15.25 m / s2 respectively. The error between the simulation and experimental results is 8.5% which is caused by the propagation some of the vibrational energy from the system to the surrounding environment.

Keywords: double translation dynamic vibration absorber; DVA; reduce vibration; vibration

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1. INTRODUCTION

The quality of product design as an example in the design of pumps and generators is not only assessed from quality of conformance or operational parameters, but also from noise and vibrations that arise [1]. the excessive vibration will cause a loss to the system, especially for too much noise and a shorter life cycle. Therefore, excessive vibration needs to be reduced. One method of reducing system vibration is by adding dynamc vibrationa bsorber. Dynamic vibration absorber is a mass and spring with certain constants given to the main system to create antiresonance at the operational frequency of the system. This method is first introduced by frahm [2] and watts [3]. The advantage of reducing vibration with DVA is that there don't need to do a major redesign of the main system that has been made [4]. in the absence of a redesign, costs can be reduce.

Several studies related to dynamic vibration absorber have been carried out. Some researchers related to the use of DVA has been focused on magnets as a substitute for absorber mass [5], [6]. To be able reduce the vibration of the 2 DOF system, research has been also conducted regarding the use of dynamic vibration absorber to reduce vibration of 2 DOF [7]–[12]. There are several methods for adding dynamic vibration absorber to reduce vibration in 2 DOF systems, for example by adding an inertia variable [7], using a translational dynamic vibration absorber mass [8], [9], and by providing two translational dynamic vibration absorber then called it dual translational dynamic vibration absorber [10]–[12]. The use of dual translational DVA was carried out by giving two mass translational DVA inwhich the momen arm change are equal to each other [11]. To find out the effect of using dual translational DVA with different moment arm sizes between the two DVA masses, further research was conducted [12]. However, research related to the use of translational independent dual DVA is only limited to simulation so that validation of the truth of the simulation results needs to be done.

In this research we conducted a comparison between the results of simulations and experiments from the effects of using independent dual translational dynamic vibration absorber. Simulation data is obtained by simulating mathematical equations from existing literature into numerical software. While the experimental data is extracted from take experimental date on laboratory.

2. RESEARCH METHOD

2.1. Simulation Setup

The equation used in this study comes from a literature study that has been done. From reference [12] we get 4 equations of motion and 2 equation of excitation. The equation of motion used is shown as 4 equation below

$$\ddot{y_{a2}} = \frac{1}{M_a}\left[C_a\dot{y_s} - C_a d\dot{\theta} + k_a y_s - k_a d\theta - C_a\dot{y_{a2}} - k_a y_{a2}\right]. \quad (1)$$

$$\ddot{y_{a1}} = \frac{1}{M_a}\left[C_a\dot{y_s} + C_a c\dot{\theta} + k_a y_s + k_a c\theta - C_a\dot{y_{a1}} - k_a y_{a1}\right]. \quad (2)$$

$$\ddot{\theta} = \frac{1}{I}[N_1 + N_2 + N_3 + N_4 - N_5 - N_6]. \quad (3)$$

With,

$N_1 = (-C_1 l_1 + C_2 l_2 + C_a d + C_a c)\dot{y_s}$

$N_1 = (-k_1 l_1 + k_2 l_2 + k_a d + k_a c)y_s$

$N_3 = -C_a d\dot{y_a} - C_a c\dot{y_b} - k_a d y_a - k_a c y_b$

$N_4 = -mb\omega^2 R\sin(\alpha + 90) + ma\omega^2 R\sin(\alpha)$

$N_5 = \left(C_1 {l_1}^2 + C_2 {l_2}^2 + C_a d^2 - C_a c^2\right)\dot{\theta}$

$N_6 = \left(k_1 {l_1}^2 + k_2 {l_2}^2 + k_a d^2 - k_a c^2\right)\theta$

$$\ddot{y_s} = \frac{1}{m_s}[P_1 + P_2 - P_3 - P_4 - P_5 - P_6]. \quad (4)$$

With,

$P_1 = m\omega^2 R\sin\alpha + m\omega^2 R\sin(\alpha + 90)$

$P_2 = C_a\dot{y_a} + C_a\dot{y_b} + k_a y_a + k_a y_b$

$P_3 = (C_1 + C_2 + 2C_a)\dot{y_s}$

$P_4 = (k_1 + k_2 + 2k_a)y_s$

$P_5 = (C_1 l_1 - C_2 l_2 - C_a d + C_a c)\dot{\theta}$

$P_6 = (k_1 l_1 - k_2 l_2 - k_a d + k_a c)\theta$

From reffernce [12], we find 2 excitation equation as in equations (5) and (6). The excitation equation that works in the simulation is a sinusoidal equation with a 90◦ difference phase. this condition occurs because the exciter is a rotated mass with a phase difference between excitation of 90◦.

$$F = m.\omega^2.R.\sin(\omega.t). \quad (5)$$

$$F_2 = m\omega^2 R \sin(\alpha + 90). \quad (6)$$

The parameter values used in the simulation come from previous research. Based on the literature study [12], the simulation parameters are obtained as table 1.

In order to obtain the same results between simulation and experiment, the absorber mass parameters used in the experiment are given as large as those in the simulation as in reference [12]. Thus in this research the magnitude of the two mass absorber is equal, inwhich is equal to 1/40 of the total mass system. with this condition, then absorber stiffness used is also 1/40 of the total system stiffness. with this condition we can conclude that the absorber stiffness used is 1/40of the total mass of the system.

2.2. Simulation Parameter

The parameter values used in this simulation are parameters derived from previous research. Based on previous research, geometry and oscilatory parameters were obtained. The two groups of parameters used in this study are shown in table 1 and table 2.

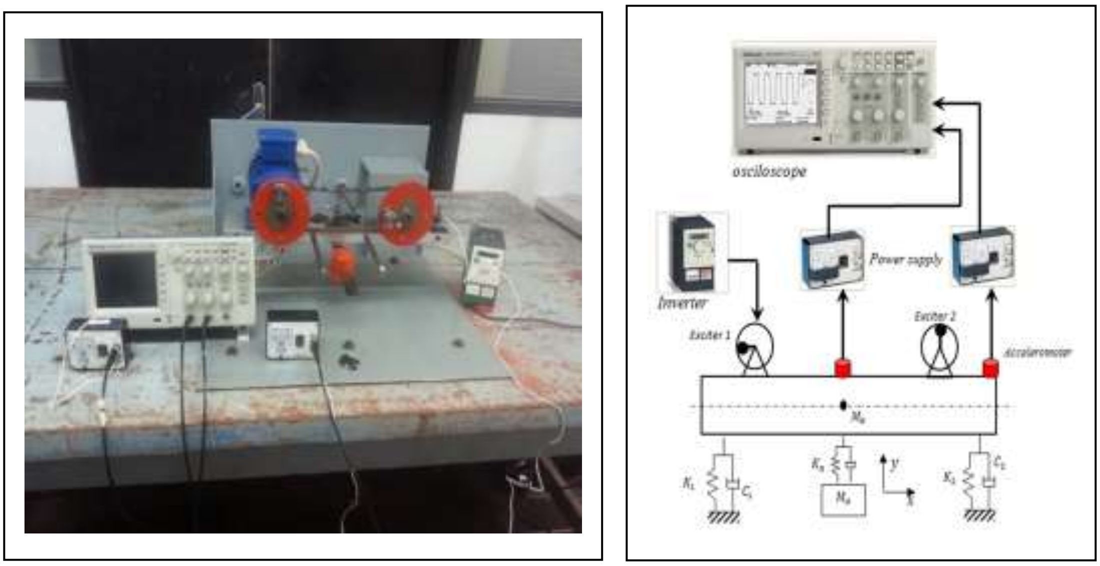
Table 1 Simulation Parameter

Parameter	Description	value
k_1	Stiffness of cantilever 1	38.800 N/m
k_2	Stiffness of cantilever 2	38.800 N/m
c_1	Dumping of cantilever 1	49,7 N.s/m
c_2	Dumping of cantilever 2	49,7 N.s/m
c_a	Duping of cantilever absorber	1,75 N.s/m
m_s	System mass	13,88 Kg
m_m	Motor mass	5 Kg
m_{kp}	Ballast box mass	5 Kg
m	Unbalance mass	0,14 Kg
I	Inertia of system	0,401 Kg.m^2
a	distance center of grafity *beam* to electric motor	0,06 meter
b	distance center of grafity *beam* to ballast box	0,06 meter
l_1	distance between cantilever 1 to center grafity *beam*	0,145 meter
l_2	distance between cantilever 2 to center grafity *beam*	0,145 meter
R	the rotational radius of the unbalance mass	0,045 meter
L	beam length	0,530 Meter

Simulation is done using a program on numerical software. In the simulation several normalities were made, as example translation frequency ratio (r_f) and rotational frequency ratio (r_{fr}). The translation frequency ratio (r_f) is the result of the normalization between excitation frequency with translational natural frequency. The rotation frequency ratio (r_{fr}) is the result of normalization between the excitation frequency and rotational natural frequency.

To simplify the comparison process with the experimental results, the moment arm of the two absorber masses is zero, which means that the two absorber masses are located at the center of grafity of the main system. The frequency of excitation is varied from 0 Hz to 30 Hz.

2.2. Experimental Setup



(a) (b)

Figure 1. Taking experimental date (a) Schematic diagram setup taking experimental data (b)

The experiment was carried out by taking vibration acceleration response data in the translational Dual Test - DVA as shown in Figure 1. data is taken at a frequency of 7 Hz to 21 Hz. The data obtained is then processed to obtain acceleration RMS data at each set point frequency. The RMS data acceleration of the experiment is then compared with the RMS data acceleration of the simulation for further analysis.

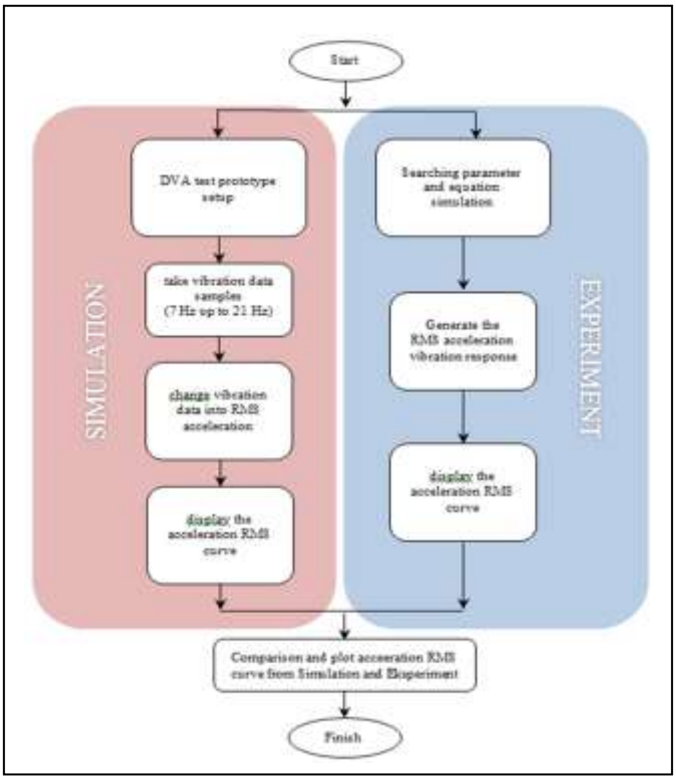


Figure 2. Research metodologycal

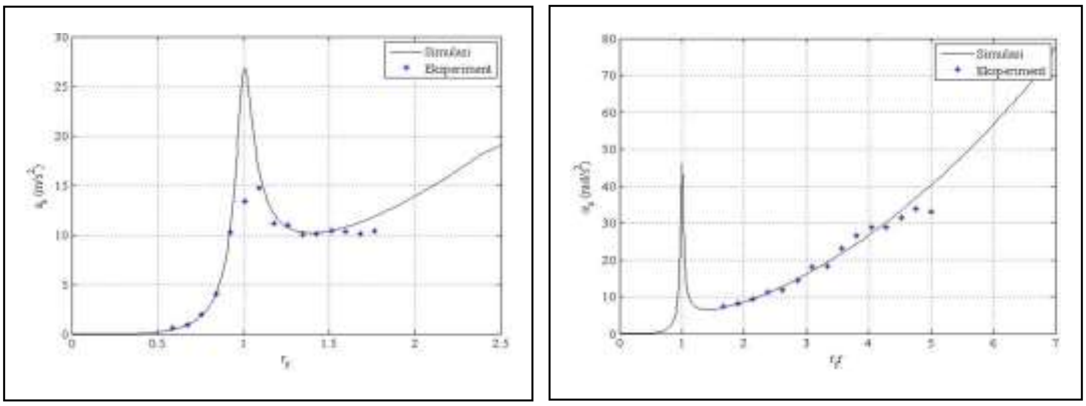
3. RESULTS AND DISCUSSIONS

3.1. Comparison Characteristics of Vibration Response without Dual Dynamic Vibration Absorber

In this sub-section discussed comparison is obtained from the RMS of the vibration system of the simulation results against the experiment. In this sub-section, we discuss the comparison between RMS system vibration simulation results with RMS vibration system results from the experiment. The system vibration RMS discussed is when the system is not given a dual dynamic vibration absorber. Comparisons are made on both directions of the system's motion axis, namely in the direction of translation and rotation. the graph results of the comparison is shown as in figure 3.

In figure 3 (a) showing the comparison of translational vibration RMS graph when dual dynamic vibration absorber not given to the system. From this figure the highest translational vibration RMS value occurs when the system is given a frequency close to $r_f = 1$, while the maximum RMS value is 13,745 m/s^2 which occurs when $r_f = 1.0924$. we can find out the comparison of experimental and simulation results By combining graphs of simulation results with graphs of experimental results. trend graphs obtained from experimental and simulation results are the same.

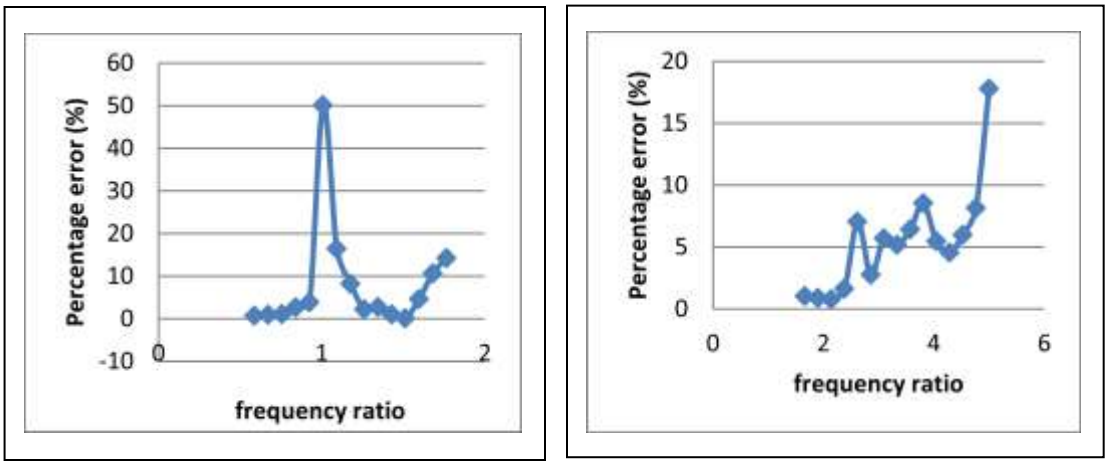
Although it has the same trend between the results of the simulation and experiment, but the results of the analysis show that the average deviation of data is quite large between the results of the experiment and simulation. The large of average date deviation obtained between the vibration of the simulation results and the experimental results is 7.96%. The magnitude of this deviation is due to the presence of some vibrations from the main system which spread to the environment around the DVA dual-test equipment, especially in this is the table where the dual-DVA test equipment is placed.



(a) (b)

Figure 3. RMS system vibration comparison chart from simulation and experiment results (a) translation without dual DVA and (b) rotation without dual DVA

When the system is given a low frequency ratio we can see that the deviation values that occur between the translation RMS vibration simulation and experiment results are very small. The small amount of deviation is because when given a low frequency, all vibrational energy is still focused on the main system so that there is no vibration energy that spreads out to the environment. But when the system is given a frequencies ratio that are almost same with translation natural frequency ($r_f = 1$), very large deviation between the RMS translation vibration simulation and RMS translation vibration experiment results will be occurs. The biggest deviation that occurs is equal to 50.11% as shown in figure 4 (a).



(a) (b)

Figure 4. Percentage difference chart between simulation and experiment results (a) translation without dual DVA and (b) rotation without dual DVA.

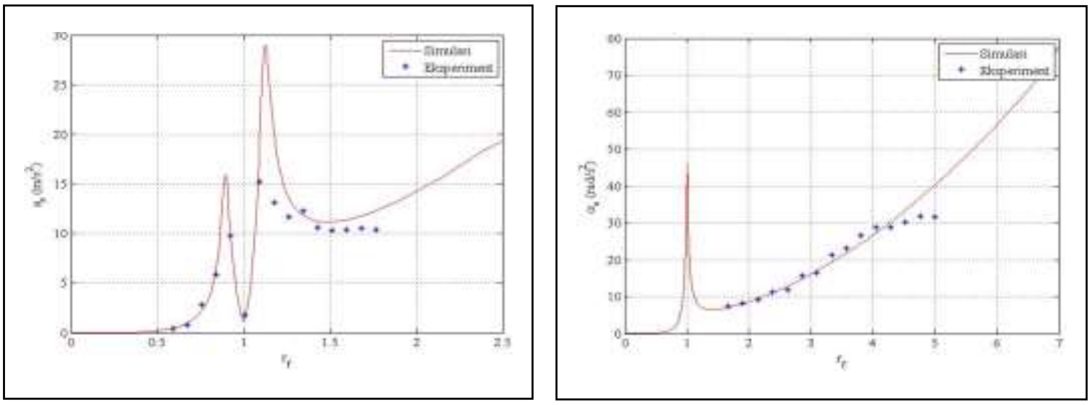
Figure 3 (b) shows a graphical comparison of RMS rotation vibrations without the dual dynamic vibrtion absorber on the system. The black graph shows the simulation results, while the blue dots are graphs of experimental retrieval results. From the graph shown that the highest rotational vibration RMS value is equal to 17,784 m/s^2 obtained when r_{fr} = 5. we can find out the comparison of experimental and simulation results By combining graphs of simulation results with graphs of experimental results. trend graphs obtained from experimental and simulation results are the same.

Although it has the same trend form between the simulation results and experiment results, but based on the results of analysis shows an error that occurs between the simulation data and experimental data.The percentage errors that occur for each sample of data is shown in Figure 4 (b). Based on the figure, the percentage errors that occur in systems without DVA is ranging from 0.77% to 17.78% and the average error is 5.45%.

When the system is given a low frequency ratio we can see that the error percentage is very small as in figure 4 (b). The small deviation caused by focus all of vibration energy into the main system so that no vibrational energy spread out to the environment. if the frequency ratio increases, in general the value of the error percentage that occurs will increase. this condition occurs because the vibration is spread to the environment around of prototype DVA test. For this case is the table where the Prototype DVA test is placed. With the spread some of vibration energy system to the environment, resulting in reduced total vibration inside the main system. So that the large RMS rotational vibration of the experiment becomes much smaller than the RMS vibration rotation simulation as in Figure 4 (b). The biggest error that occurs between the results of the smulation and experiment in this case is 17.78%.

3.2. Comparison Characteristics of Vibration Response With Dual Dynamic Vibration Absorber

In this sub-chapter, we discuss comparisons obtained from systems vibration RMS generated from simulations with system vibration RMS generated from experimental data. The system vibration RMS discussed is when the system has been given a dual dynamic vibration absorber. Comparisons are made on both directions of the system's motion axis, namely in the direction of translation and rotation. The graph of the comparison results is shown as in Figure 5.

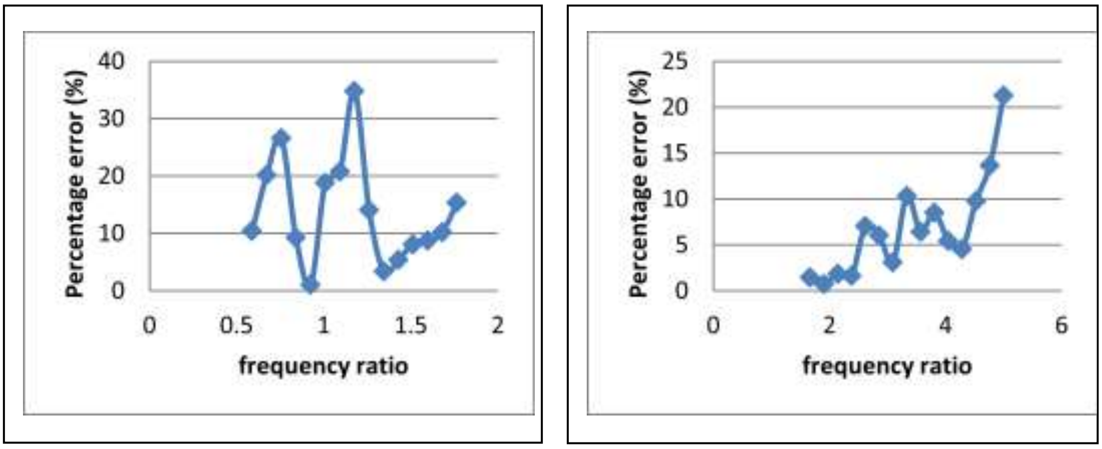


(a) (b)

Figure 5. RMS system vibration comparison chart from simulation and experiment results (a) translation with dual DVA and (b) rotation with dual DVA

In figure 5 (a) showing the comparison of translational vibration RMS graph when dual dynamic vibration absorber given to the system. The continues line in the graph interpret the simulation results, while the blue dots in the graphs are interprate the experimental data retrieval. the graph shows that the system has twice the natural frequency. Experimental results show that natural frequencies occur at r_f = 0.92 and r_f = 1.09, with RMS values of 9.81 m/s^2 and 15.25 m/s^2 respectively.

Although it has the same trend between the results of the simulation and experiment, but the results of the analysis show that the average deviation of data is quite large between the results of the experiment and simulation. The large deviation of the average data obtained between the vibration of the simulation results and the experimental results is 13.38%, with error values ranging from 3.37% to 34.82 %. The large value of deviation value caused by exixtance some of vibration energy from the main system that is spread to the environment around the dual-DVA test equipment, especially in this is the table where the dual-DVA prototype test is placed.



(a) (b)

Figure 6. Percentage difference chart between simulation and experiment results (a) translation with dual DVA and (b) rotation with dual DVA

When the low ratio frequency given into the system, we can see that the deviations value that occur between the RMS translation vibration simulation and experimental results are very small. The small amount of deviation is due to all vibrational energy still focused on the main system so that no vibrational energy is spread out to the environment.

Giving dual translational dynamic vibration absorber at the center position of the beam caused increase the number of system natural frequencies. systems that formerly only have one natural frequency change to twice the natural frequency. If we look again at Figure 6 it is shown that when the system is given a frequency that is close to natural frequency it results in an increase in the error that occurs. This condition exists because when the natural frequency is reached in the system, the vibrational energy that occurs is very high. The amount of vibration energy in the system is not perfectly stored in the system, but is spread to the surrounding environment of the system. for example, it is spread to the table where the DVA test equipment is placed. This is what causes high errors when natural frequencies. The highest error rate based on experimental data was 34.82%.

An error increase when the system natural frequency reach may also occur in the vibration of the rotation direction, but in this research taking experimental data was carried out above the rotational natural frequency as shown in figure 6. In general, from the figure, it can be seen that the experimental results graph has the same trend as the graph of the simulation results. When the frequency is high we can see that the deviation between the simulation results and experiments is increasing, this is confirmed by the error graph as shown in figure 7. The biggest error that occurred was 21.26%. The magnitude of this deviation occurs because all the vibrational energy of the system is not perfectly stored into the mass of the main system, but some spread in the environment around the system, resulting in reduced vibration of the experimental results.

although it has a very high deviation when given a high frequency of excitation, in general, the large average deviation that occurs between the curve of the simulation results and the experiment is still quite low. The value of deviation between the simulation results data is equal to 6.78% which indicates that the simulation results can be said to be the same as the results of the experiment.

5. CONCLUSION

From the research it can be concluded that:

- for conditions without dual-DVA, the system has the highest translational vibration RMS of 13.74 m/s^2 and occurs when r_f = 1,0924
- From the range of experimental test, systems without dual-DVA have a maximum rotational vibration RMS of 17,784 m/s^2 and occur at the highest frequency.
- The addition of Dual-DVA to the system causes the system to have two translation natural frequencies. First natural frequency occurs when r_f = 0.92 with falue RMS 9,81 m/s^2. Second natural frequency occur for r_f = 1.09 with RMS value 15.25 m/s^2.
- The average error between the simulation and experimental data of the four test conditions is 8.5%. Thus it can also be interpreted that the level of significance between the simulation data and the experimental data is 91.5%. The error that occurs between the results of simulation and experiment is more due to the channeling of some vibrations from the main system to the environment around the system, resulting in differences in the results of simulation and experiment.

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