OPTIMIZING VIBRATION REDUCTION IN 2DOF SYSTEM WITH CHANGE POSITION OF INDEPENDENT TRANSLATIONAL D-DVA

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OPTIMIZING VIBRATION REDUCTION IN 2DOF SYSTEM WITH CHANGE POSITION OF INDEPENDENT TRANSLATIONAL D-DVA

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ABSTRACT

Translation DVA is an additional mass type in which used to reduce the vibration of the translational direction. Research about using translational DVA to reduce rotational and translational vibrations is still very rare. In this study we investigated the process of reducing translational and rotational vibrations in beams using double translational DVA (dDVA). The research begins with a study of literature, then modeling the system into a mathematical equation and simulated with numerical software to find out the characteristics of the system vibration that arises. in this simulation the positions of both dDVA masses in beam are given independent changes. From this research showing that the graph of vibration reduction is symmetry with line $r_{lc} = r_{ld}$. *this condition can occur because the main system is symmetry on both sides. The largest translational vibration reduction is 95.51% which occurs when the system is given the absorber period at position* $r_{lc} = r_{ld}$. *The maximum rotational reduction is 56.62% which occurs when the system is given mass with an arm ratio of 1 and zero.from this research also show that the most effective use of dDVA occurs when the system is given a mass absorber at the center of grafity and the end of the system, with translational vibration reduction of 92.29% and rotation of 56.62%.*

Keywords: double dynamic vibration absorber (dDVA), vibration, modeling, vibration reduction, 2 DOF.

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1. INTRODUCTION

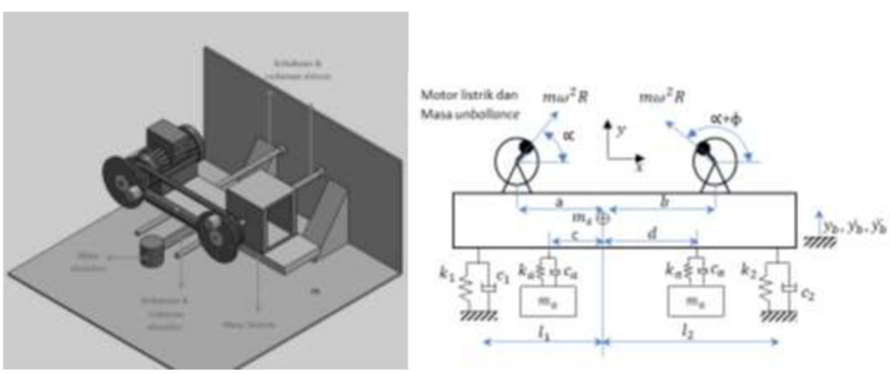
A system such as cars and buses that receive more vibration will be reduce the comfortable level of user'[1]. this condition will be more terrible if the system has a resonance condition, which can make the life of the vehicle becomes shorter. One way to reduce vibration is by adding a dynamic vibration absorber (DVA). In commonly case, DVA is a spring and additional time given to the system to reduce the resonance vibration of the system. There are three types of DVA, namely the DVA and DVA translational translational. Pendulum DVA is used to reduce axial vibration [2], Translational DVA used to reduce translational vibration [3], and rotational DVA is used to reduce rotational vibration [4].

In many cases, vibration in a vehicle is a combination of translational and rotational vibrations together. thus to reduce both types of vibration is required two types of DVA. to know the effect of translational DVA usage in reducing the two types of vibrations above, then conducted a study related to the use of a DVA in reducing the vibration of translations and rotation at once [5-7]. from previous research showing that the use of a DVA at the center of grafity system can reduce the translational vibration optimally, in other side the use of a DVA mass at the end of the system is able to reduce rotational vibrations. In order to reduce vibration better, two translational mass of DVA (dDVA) are given [8], but the moment arm applied to the system is equal, so it is not known how the effect of adding dDVA with the different moments of the arm on the two additional masses.

2. EXPERIMENTAL SETUP

2.1. Generating equation of motion system

Figure 1 (a) is a DVA prototype with two degrees of freedom. The DVA prototype is a beam that is given exciter on both sides. The exciter is a mass placed on a disc and rotated by an electric motor on one side. In order to get the excitation phase difference as desired then one of the beam side is given a ballast box that has a mass equal to the mass of the electric motor. To reduce the vibration of the system due to the excitation that works on it then on both sides of the system are given two dDVA masses.



(a) (b)

Figure 1 Physical form of DVA test prototype (a) and simplification of the model (b)

From the existing prototype then done simplification model as picture 1 (b) and made free body diagram to derive equation of system motion based on Newton law. In this research, there are four equations of motion obtained from the main system and the absorber period, ie the translation of the absorber 1 (Y_{a1}), the translation of the absorber 2 (Y_{a2}), the vertical translation of the main system (Y_s) and the rotation of the main system (θ). From the equations of motion obtained then derived state variable equation which is then used to construct block simulink diagram. The state variable equation is as follows:

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

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

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

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,

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

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

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

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

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

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

In this study it is assumed that horizontal direction (X axis) has little effect, the excitation input used in the simulation is a sinsoidal function acting on the vertical direction (Y axis). Here is an input coming from the motor in the vertical direction.

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

The ballast box has a mass equal to the mass of the electric motor. This box serves to provide different excitation phase of the system. the excitation from the side of the ballast box is given a phase difference of 90 ° to the motor side. The following is a simulated excitation derived from the unbalance period on the sides of the ballast box.

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

2.2. Parameter Simulation

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 Oscilatory Parameter

Parameter	Description	value
k1	Stiffness of cantilever 1	38.800 N/m
k2	Stiffness of cantilever 2	38.800 N/m
c1	Dumping of cantilever 1	49,7 N.s/m
c2	Dumping of cantilever 2	49,7 N.s/m
ca	Duping of cantilever absorber	1,75 N.s/m

Table 2 Geometri Parameter

Parameter	Description	value
ms	System mass	13,88 Kg
mm	Motor mass	5 Kg
mkp	Ballast box mass	5 Kg
m	Unbalance mass	0,14 Kg
I	Inertia of system	0,401 Kg.m2
a	distance center of grafity beam to electric motor	0,06 meter
b	distance center of grafity beam to ballast box	0,06 meter
l1	distance between cantilever 1 to center grafity beam	0,145 meter
l2	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

In this study both mass of absorber is equal to 1/20 of total system time. To produce the natural frequency of the absorber mass equal to the main frequency of the main system, so in this study also given the absorber rigidity of 1/20 of the total system stiffness. This condition applies to both dDVA masses.

2.2. Simulation

All parameters and state variable equations are present, and then simulated using numerical software. The simulation is performed to find out the vibration response that occurs both before and after the addition of double dynamic vibration absorber in all direction of degree of freedom. By knowing the response after and before dDVA, it is also known that the percentage of vibration reduction that occurs after dDVA when the natural frequency of the system occurs.

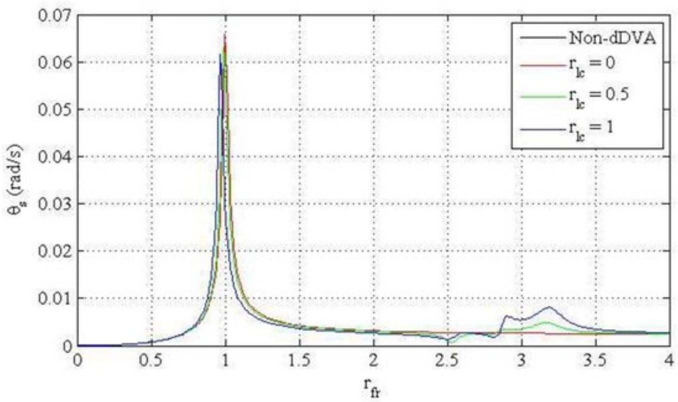
To know the location of the natural frequency of the system then given the frequency changes in the system, while the given frequency is in the range of 0 Hz to 30 Hz which is the vulnerable frequency of the work area of the electric motor. Whereas to know where the best dDVA placement is to dampen the vibration of the translational and rotational direction, we are given momentary momentum changes of the two absorber masses (parameters b and c) independently. The magnitude of the moment arms c and d is varied from 0 m to 0.265 m which is half of the total system length. To vary the frequency value and the absorber moment arm, it is necessary to build a program on numerical software.

In order to obtain the characteristic graph of the system then in the obtained simulation results defined some normalization. The ratio of the translational frequency (r_f) is the result of normalizing the excitation frequency with the natural frequency of the translational direction. The rotation frequency ratio (r_{fr}) is the result of normalization between excitation frequencies to the frequency of rotation of the system. While the arm ratio (r_l) is the result of normalization between the moment arm d or c to the center distance of the beam mass to the absorber mass (l_1). The ratio of arms is divided into two types namely r_{lc} which is the ratio between the moment arms c to l_1, and also r_{ld} which is the normalization between the moment arms d to l_1.

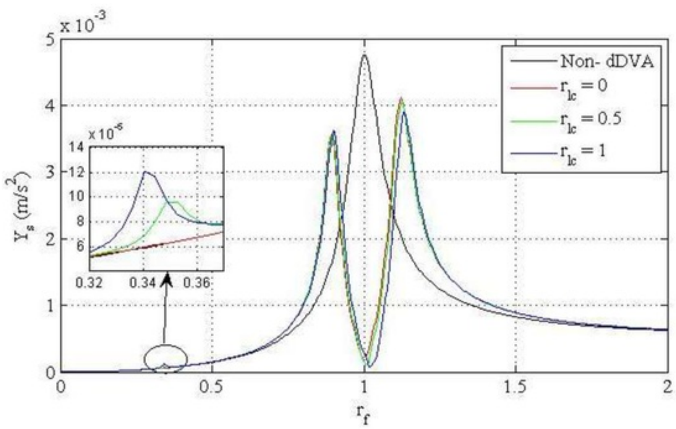
3. RESULTS AND DISCUSSIONS

3.1. RESULTS AND DISCUSSIONS

In this section we examine the effect of changing the position of the first absorber mass without changing the position of the second absorber mass. The second absorber mass is placed exactly at the center of the graph of the main system mass (rld = 0). As for the first absorber mass is placed at the end of the system (r_{lc} = 1), right at the center of the system mass (r_{lc} = 0), and is between the center mass of the system with the tip of the system (r_{lc} = 0.5). The black graph is the RMS graph of vibration for the condition without the DVA grant, the red colored graph is the RMS graph of vibration for the condition r_{lc} = 0, the green graph is the RMS graph of vibration for the condition r_{lc} = 0.5, and the blue graph is the RMS graph of vibration for condition r_{lc} = 1.



(a)



(b)

Figure 2 RMS vibration of the main system with r_{ld} = 0 for (a) translation directionand (b) rotation direction

From Figure 2 it is shown that only one resonance occurs both at the vibration of the translational direction and the direction of rotation. The two resonances occur at different natural frequencies. The difference in the location of natural frequencies that occur between translational vibrations and rotational vibrations occurs because they are not related between the vibration of the translational direction and the rotation of the system. The magnitude of the resonance that occurs in translational vibrations is 0.004 m, while the resonance magnitude that occurs in the vibration of the direction of rotation is 0.06593 rad / s ^{2}.

By giving two mass absorber to the center of mass of the system (r_lc = 0) we can see that the number, location and magnitude of the resonance that occurs in the vibration of the direction of rotation tend to be identical to the conditions without dDVA. This means that the addition of dDVA at the main center of grafity system does not provide a large reduction in the direction of rotation of the vibration. However, the provision of dDVA at this center of graphity system tends to provide significant changes in the vibration of the translation direction. In Figure 2 (b) we can see that in $r_f = 1$ it has antiresonance which makes the RMS displacement value reach the lowest point of 0.000213 m. The existence of this antiresonance is because the two absorber periods have the same frequency as the main system but with a phase difference of 180°. The existence of these two things results in intermittent interference between the absorber mass and the main system, resulting in the emergence of antiresonance at $r_f = 1$.

The change in the change in the position of the first absorber results in a connection between the translational vibration and the rotational vibration, so that the number of resonances that occur in the two directions of freedom of the main system becomes the same and each occurs at the same frequency. Physically the interrelationship of these two degrees of freedom can be seen from the graph, which increases the number of resonances from two to three in Graph 2 (a). While on graph 2 (b) there is also an increase in the number of resonances from one fruit to three. The first resonance in the translational motion is the result of the contribution of the first resonance to the rotational motion, while the second and third resonances of the rotational motion are the transverse from the translational translation.

The condition of the coupled system can also prove mathematically using the eigen value matrix of the system. In this case the moment arm value c is not zero, so the value of $k_a. c$ is not zero. For $k_a. c$ with nonzero values in the eigen value matrix can be interpreted that the main system translation motion is influenced by the translational motion of the dDVA and the main system rotation motion. Likewise, the opposite applies to the main system rotation motion which is also influenced by the translation of the main system and the translational motion of the two dDVA periods, so that the number of resonances that occur in the two graphs above are equal.

when viewed in detail there are some changes in RMS displacement values that appear because of changes in the c arm moment value (r_{lc}) given, such as: changing the RMS displacement value when antiresonance occurs, shifting the resonance location occurs, changing the antiresonance location occurs, and also changing the value RMS vibration when resonance occurs. From Figure 2 (a) shows that with the increasing value of r_{lc}, the large RMS displacement for the first and second resonances tends to be higher, whereas the large RMS displacement for the third resonance tends to decrease. The RMS displacement at the first resonance for r_lc = 0.5 and $r_{lc} = 1$ is 0.0000957 m and 0.000012 m respectively. The second resonance for $r_{lc} = 0$, r_lc = 0.5 and $r_{lc} = 1$ occurs at 0.00355 m, 0.003585 m and 0.003621 m, respectively. Whereas the third resonance for $r_{lc} = 0$, $r_{lc} = 0.5$ and $r_{lc} = 1$ occurs at 0.004112 m, 0.004047 m and 0.003898 m.

Another thing that is not less interesting than the discussion of the times is the change in location and the magnitude of the antiresonance that occurs with the change in the dDVA moment arm. As previously explained, this antiresonance is the result of destructive interference between the vibrations that occur in the mass of dDVA and vibrations in the main system. This interference arises because of the 180 beda phase difference between the system period and the dDVA period, so that the vibration from the main system becomes reduced. From Figure 2 (a) it is also shown that most of the r_{lc} given to the system, the translational RMS value of the vibration becomes lower and lies in the much higher r_{lc}. The large RMS displacement that occurs is equal to 0.000213 m, 0.000087 m, and 0.000072 m, each of which occurs at $r_f = 1$, $r_f = 1.008$, and $r_f = 1.021$.

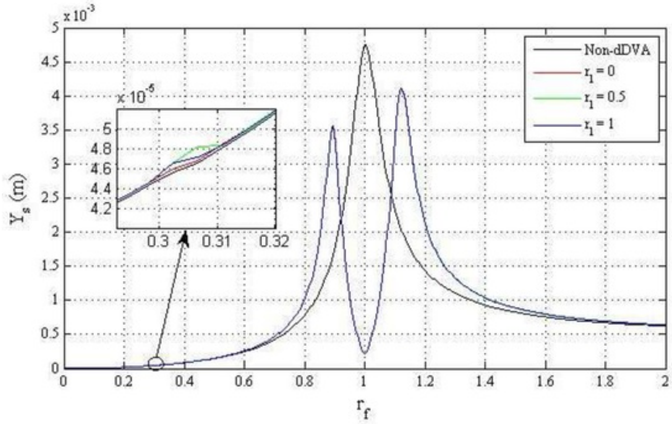
The change in the ratio of the moment arm c also gives a change in RMS angular displacement as shown in Figure 2 (b). with the greater r_{lc} value given, the RMS value of the angular displacement of the first resonance will be lower and lie on the lower r_{fr}. The large RMS displacement of this first resonance is 0.06593; 0.06307; and 0.06157 which each occurs for arm ratio 0; 0.5; and 1. Besides changes in angular displacement RMS, the addition of the moment arm ratio also makes the frequency ratio shift where resonance occurs. As the larger arm of the given moment, the first resonance of the system will be further away from $r_{fr} = 1$. this condition is the cause of reduced vibration that occurs in the area of rotation frequency ratio 1.

3.2. RESULTS AND DISCUSSIONS

To determine the effect of giving the moment arm to the two dDVA masses to the change of RMS of the system vibration, in this discussion is shown RMS displacement graph and RMS angular displacement system with $r_{ld} = r_{lc}$ as in Figures 3 (a) and 3 (b). In large amounts there are some differences that occur when both dDVA masses are given the moment arm. Among them such as increasing the number of resonances that occur both the direction of translation and rotation, the occurrence of antiresonance in $r_f = 1$ translational motion, and coupled between translational vibrations and system rotation.

When both dDVA masses are placed at the center of the system mass ($r_l = 0$), no changes occur when the system is not given dDVA mass. While changes actually appear in translational vibrations as shown in Figure 3 (a). The system that originally only experienced one resonance then changed to having two resonances. All of this happens because the mass of dDVA at the center of the main system mass still does not result in the coupling between the translation vibration and the system rotation. This can be proved mathematically using the eigen value system equation. In this case the moment arm values (c and d) are zero, so the value of $k_a.c$ and $k_a.d$ becomes zero too. For $k_a.c$ and $k_a.d$ equal to zero in the eigen matrix value it can be interpreted that the main system translation movement is only affected by the translational motion of the absorber period, but not affected by the rotational motion of the main system. Thus there is no connection between translational vibration and rotation of the main system.

By shifting the position of both sides of the dDVA mass moment ($r_{ld} = r_{lc} \neq 0$), the initially unpaired system changes into a coupling. Graphically this can be shown as in Figure 3 for both $r_{ld} = 0.5$ and $r_{ld} = 1$. In both pictures it is shown that the number of resonances that occur for translational vibrations and rotations is the same. The first resonance in the translational vibration is the result of the contribution of the first frequency of the rotational vibration, while the second and third resonances in the rotational vibrations are the result of the contribution of the second and third resonances of the translation direction vibrations.



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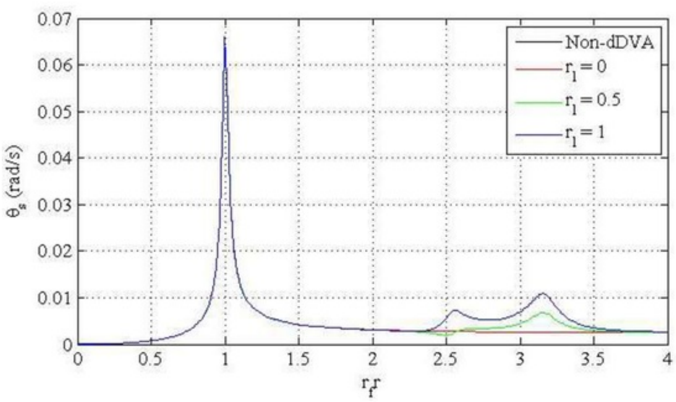


(b)

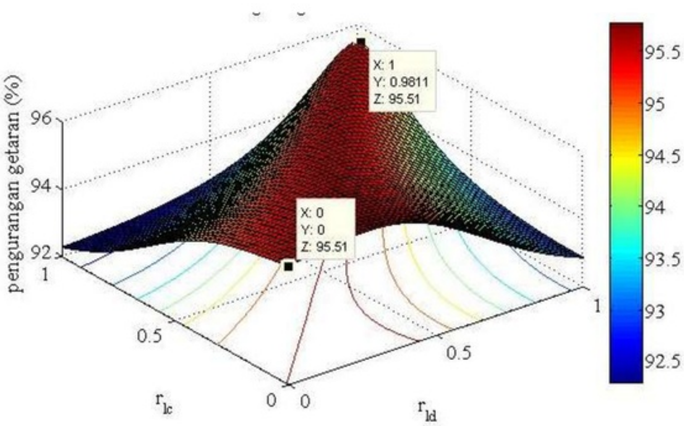
Figure 3 grafik (a) RMS *displacement* dan (b) RMS *angular displacement* untuk sistem dengan dengan $r_{ld} = r_{lc}$

The RMS angular displacement at the first resonance does not change either before or after the addition of dDVA mass. This shows that there is no vibration reduction in the rotation direction. While in the direction of translation, giving dDVA mass to all arm ratios resulting an antiresonance area at $r_f = 1$. The large RMS displacement when antiresonansi occurs is 0.0002589 m. The same RMS displacement value for all arm ratios shows that the magnitude of the translation vibration reduction will be equal to all arm ratios given. antiresonance is actually the result of destructive interference from both dDVA masses to the major system mass. Destructive interference arises because both dDVA masses have the same frequency with fequency of major system mass, but with a phase difference of 180°. With the existing conditions, the inertia of vibrations stored in both dDVA masses will work against the vibration inertia of the main system, resulting a significant reduction vibration from the main system.

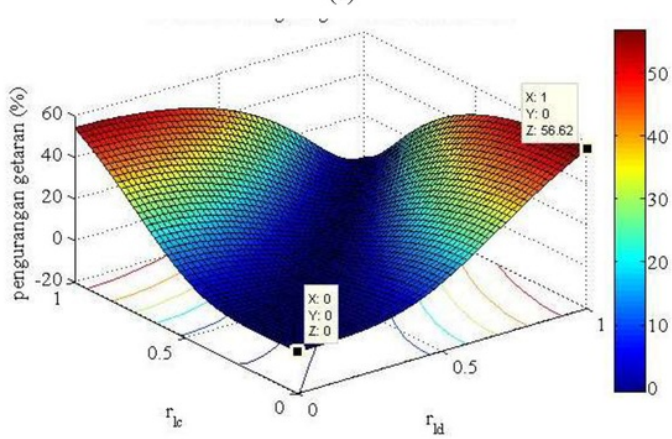
The change in the moment arm ratio (r_l) also does not give a significant change in the RMS displacement of the second and third resonances in translational motion. The RMS displacement of the second and third resonances for each is 0.003546 and 0.004144, respectively, at r_f = 0.8949 and r_f = 1.122 respectively. As for the rotation direction, the greater arm ratio given in both dDVAs results in higher RMS angular displacement values. The angular displacement RMS value for the third resonance at r_l = 0,5 and r_l = 1 are 0.006725 and 0.01084 respectively.

3.3. RESULTS AND DISCUSSIONS

In the previous discussion showed that giving dDVA mass is able to reduce the vibration of the direction of translation on the system, especially when the system reaches r_f = 1. This translation vibration reduction is due to the emergence of antiresonansi in the frequency region. Basically the dDVA used in this study is DVA translational, which should only be used to reduce the vibration of the system translation. However, in this study showed that giving the moment arm to the dDVA mass can reduce the rotational vibration of the system especially in the area of r_{fr} = 1. This rotational vibration reduction is more due to the shift of resonance system to the lower rfr, so there is a reduction of vibration at r_{fr} = 1. Giving Different arm moments will also give a different level of translation and rotation vibration reduction.



(a)



(b)

Figure 4 reduction vibration (a) translation direction and (b) rotation direction

Figure 4 (a) is a translation vibration reduction graph at the translation frequency ratio 1, with a change in the ratio of the moment arm of the first absorber base (r_{lc}) and the second absorber period (r_{ld}). From this figure it can be seen that the maximum reduction in system translation vibration is 95.5%. This decrease is obtained if the system is given r_lc and r_ld which is the same size. Thus the value obtained from this simulation is a graph that is symmetric to the line $r_{lc} = r_{ld}$. This symmetry surface graph occurs because the main system is a symmetrical system with the center of mass of the system located at half of the beam length. The lowest percentage of vibration decrease occurs at 92.29% which occurs when given r_{lc} = 1 and $r_{lc} = 0$ or the opposite.

Giving the same arm ratio in both dDVA masses was able to reduce translational vibrations better than when both dDVA masses were given different arm ratios. This is because giving the same arm ratio can also be equivalent to placing both dDVA masses at the time center of the main system, so that the dDVA given is only focused to dampen vibrations in the translational direction without giving a damping effect on the rotation direction. This is also the cause of the absence of a reduction in the vibration of the rotation direction during both periods dDVA is given the same arm ratio ($r_{lc} = r_{ld}$), as in figure 4 (b).

In Figure 4 (b) shown that the value of the minimum rotational vibration reduction is zero percent which occurs when both dDVA masses are given the same arm ratio. The biggest vibration decrease occurs when one mass of dDVA is given an arm ratio of one, while the other dDVA mass is given an arm ratio of zero. Physically this means that the dDVa mass is placed at the center of the mass of the main system and one is placed at the end of the main system. As for the large reduction in the maximum rotation vibration is 56.62%.

4. VIBRATION REDUCTION OPTIMIZATION

From above result shown that when main system give two dDVA masses with the same arm ratio ($r_{lc} = r_{ld}$), the reduction of translation vibration become very maximum. But in this condition rotational vibration doesn't decrease. By placing one of the absorber periods at the endpoint of the main system ($r_l = 1$) and one other absorber period at the time center of the main system ($r_l = 1$), we can see a decrease in translational vibration reduction although not as significant, ie from 95, 5% to 92.29%. however, the change placing position of two absorber masses gives a segnificant change in the percentage of rotation vibration reduction. In this condition the percentage of vibration reduction which was initially 0% changed to 56.62%.

5. CONCLUSION

The maximum translational vibration reduction is 95.51% obtained when the system is given two absorber masses with the same arm ratio ($r_{lc} = r_{ld}$). Maximum rotation vibration reduction is 56.62% and is obtained when one of the absorber masses is placed at the center of graphity of the main system ($r_l = 0$), and the other mass is placed at the end of the system ($r_l =$ 1). The most effective use of dDVA is obtained when one of the absorber masses is placed at the center of mass of the main system ($r_l = 0$), and the other mass is placed at the end of the system ($r_l = 1$). The decrease in translational vibration obtained in this condition is 92.29% and 56.62% in the rotation direction.

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