Jurnal
Teknologi

Full Paper

EXPERIMENTAL EVALUATION OF THE PERFORMANCE OF DYNAMIC VIBRATION ABSORBERS FOR VIBRATION MITIGATION IN BEAM STRUCTURES

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Article history
Received
5 April 2024
Received in revised form
29 June 2024
Accepted
23 July 2024
Published Online
22 December 2024

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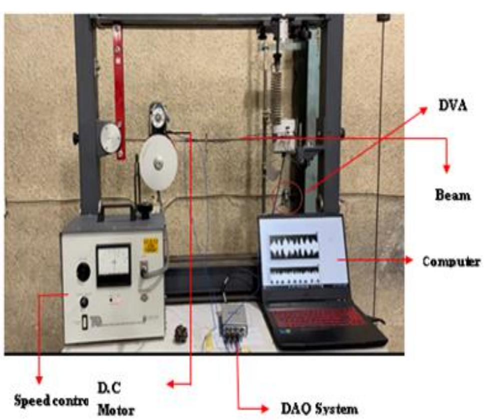
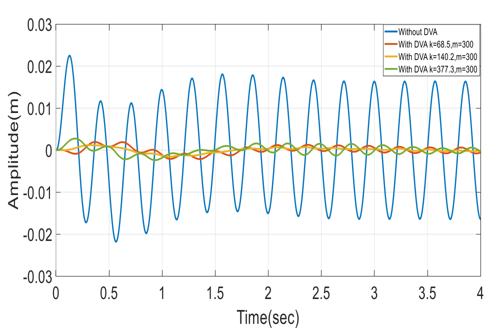
Graphical abstract





Abstract

In this study, experiments are used to evaluate the effectiveness of dynamic vibration absorbers (DVAs) in minimizing vibrations in beam structures. The dynamic vibration absorbers are modest additions to a structure that employ a mass-spring system tuned to the natural frequency of the structure to lower vibration levels. These absorbers were added to a beam construction as part of the experimental investigation, and the vibration levels under various conditions were measured. Under pinned-free boundary, the dynamic behavior of a beam is experimentally investigated with various combinations of the design parameters (mass and spring) and locations of the dynamic vibration absorbers. The beam is subjected to external vibrations, and both with and without the absorbers, its amplitude is measured. According to the results, adding DVAs to the beam structure significantly reduced vibration levels, particularly closer to the natural frequency of the beam. The dynamic response is greatly reduced by mass and stiffness (from, for example, 0.018m to 0.00052m). However, depending on the DVA location, this effect can change. The minimal requirements of the DVA parameters can better reduce the dynamic response if the DVA is positioned at the point of maximum displacement for each corresponding mode.

Keywords: Dynamic vibration absorber, beam, Experimental investigation, dynamic response

1.0 INTRODUCTION

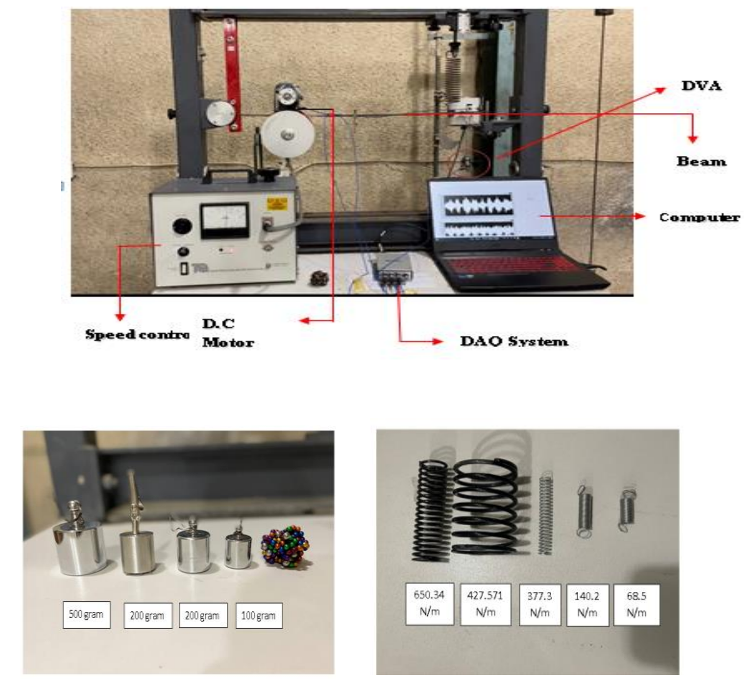
A common occurrence in human activity is vibration. Eardrums vibrate to permit hearing, while light waves vibrate to enable vision. The effects of vibration are taken into account when designing machinery, structures, turbines, and engines in engineering. Due to their detrimental effects, such as increased stress levels, energy loss, weariness, and decreased efficiency, the majority of vibrations are regarded as undesirable. When a system vibrates excessively, it frequently causes interruption, pain, harm, or even destruction. Unwanted vibrations must be managed if such results in machinery or structures are to be avoided. Utilizing what they refer to as Metamaterials for vibration reduction is one efficient remedy [1-3]. Utilizing dynamic vibration absorbers (DVAs), which offer a counter-back motion to remove vibration, is one of the promising methods for vibration attenuation of the structure [4-10]. Systems with a single degree of freedom are the only ones that can use this conventional DVA [11,12]. As a result, its utility is limited. Vibration absorbers were first created in 1909. Den Hartog's first vibration damper is made up of a second mass-spring device that is connected to the first device and prevents it from vibrating at the same frequency as the sinusoidal force acting on the primary device. This well-known vibrational issue has a well-known solution. If damping is added to the absorber, the main mass's vibration amplitude cannot be rendered zero at the driving frequency, but the system's sensitivity to changes in the forcing frequency decreases [13]. Wu investigated the effect of the inertia of the helical spring of an absorber on the dynamic response of a beam to a changing load [14]. Foda and Albassam studied vibration absorbers for beam structures with three different end conditions. Simple support, free, and clamped termination circumstances are applicable[15].

For beam vibration under point or dispersed harmonic stimulation, Wong *et al*. studied a DVA that combines translational and rotational type absorbers [16]. A structure's DVA will react to an external stimulation by applying some force in the opposite direction, limiting the structure's mobility. The study described by [17,18,19] that used the finite element method to examine the use of DVA for vibration reduction in a beam construction revealed that, for some vibration modes, DVA effectively reduces the amplitude of vibration. The findings of employing numerous DVAs attached to a beam structure to reduce vibration indicated that DVA may lower the amplitude of vibration. Ansys APDL was used to analyze the results[18].compared the amplitude before and after installing the DVA in an experiment, which showed that the DVA was successful in absorbing the beam vibration and so reducing the vibration amplitude of a beam construction [20]. [21] demonstrated the ability to use multiple DVAs at different locations on a beam. The results showed that combining DVAs reduced vibrations more effectively than using a single absorber. The ideal position of the DVA linked to a beam was also investigated by [22] using amplitude reduction. The results indicated the that the best location of the DVA is the point that the beam shows the maximum displacement. Active vibration absorber for vibration mitigation is presented by [23]. Anothor interesting work assumes that additions of two types of DVAs can reduce vibration of the beam [24]. The nonlinear dynamics for vibration suppression of a beam accounting for the nonlinear boundary conditions at the absorber location presented theoritically by [25]. According to the current literature, there is a lack in the sensitivity of the beam response to the variation in the DVA parameters. Furthermore, the outcomes of the most of the recent works did not explain the dynamic behaviour of the beam and DVA together and how are they interact each other. As a result, the current work will intorduce a comprehensive experimental evaluation tacking into account all of the previously outlined lacks in the literature.

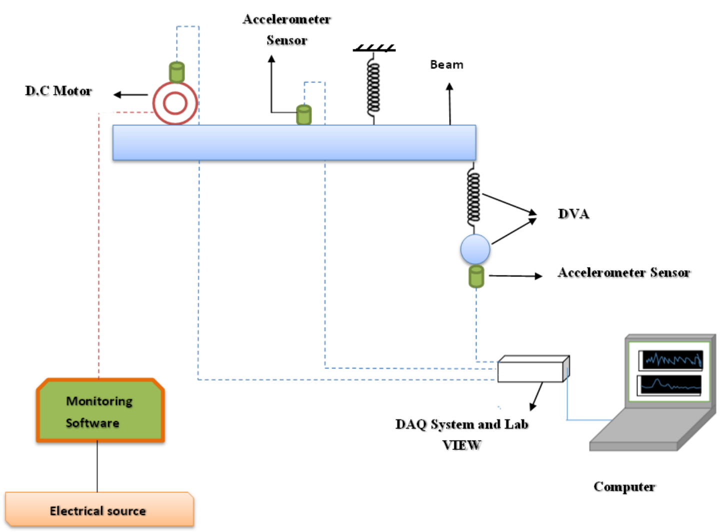
2.0 METHODOLOGY

A physical system is used in an experimental setup to assess the effectiveness of a dynamic vibration absorber (DVA) in reducing vibration and displacement in a beam. The setup generally consists of a beam, a dynamic vibration absorber (DVA), a method of applying a harmonic force or other dynamic inputs to the beam, and measurement equipment to assess the dynamic response. The attachment position of the DVA to the beam is established by considering the properties of both the beam and the DVA. Throughout the experiment, the beam is exposed to dynamic stimuli, and strategically positioned sensors like accelerometers are used to evaluate the beam's response at different locations.

After then, the beam's reaction is contrasted with the response of the beam with the DVA attached. The research of the beam is done for a beam that is 0.74 meters length, 0.012 meters thickness, and 0.025meters width, respectively. The beam is also given consideration for one boundary conditions: pinned-free . Depending on the values needed for the parametric investigation, the mass of the DVA may change. The experimental test rig used in this study was created and developed in the laboratory of University of Babylon for mechanical vibration. The experimental configuration is shown in Figure 1 below for both experimental setup and schematic diagram.



(a)



(b)

Figure 1 Experimental setup

The speed controller shown in Figure 1 can regulate the exciters excitation frequency. The dynamic response of the beam is the primary goal for vibration reduction of the beam, hence it is the only outcome in this work. There are three effective masses for the DVA (100, 200, and 300 grams). However, additional magnetic masses of 1 gram each are utilized to obtain the appropriate values in order to search for the best values of the mass at various excitation frequencies. The effect of mass and stiffness of the DVA and its locations on the dynamic response of the beam, due to harmonic excitation, is investigated in details.

The experimental procedure for the harmonic analysis of the dynamic vibration absorber (DVA) attached to a beam typically involves the following; the beam is mounted on a vibration isolation table or a shaker system that can provide the desired dynamic input. Based on the characteristics of the beam and the DVA, a precise location is chosen for the attachment of the DVA to the beam. To measure the beam, sensors like accelerometers are positioned at various locations along the intended locations. The sensors are calibrated to provide accurate measurement of the beam response. Once the beam is excited by the harmonic force created by the mass eccentricities, the response of the beam with the DVA attached is recorded. The experimental data is evaluated to see if the DVA is successful in reducing the beam vibration and displacement. To improve the DVA's performance for the particular application, parameters like mass, spring stiffness, and position can be changed. Finally, the experiment is repeated with different parameters to examine the impact of various factors on the DVA's performance.

3.0 RESULTS AND DISCUSSION

It is important to note that the beam is examined for pinned-free conditions. The beam measures 0.74 meters in length, 0.012 meters in thickness, and 0.025 meters in width. The dynamic response will be illustrated in the next section.

3.1 Effect of DVA Stiffness

Effects of the DVA stiffness on a beam dynamic response is shown in Figures (2–4) for three different DVA masses. The dynamic response of the beam is significantly influenced by both DVA stiffness and mass variations. The dynamic reaction of the beam is less than its response without DVA, regardless of the stiffness and mass values of the DVA. According to Figure 2, the best reduction in dynamic response is at a stiffness of k=68.5 N/m with a DVA mass of 100 grams. On the other hand, Figure 4 depicts an alternative locally optimal DVA design with k=140.2N/m and m=300 grams for the same reason as earlier. Finally, when the dynamic response is tested at x/l=1, the globally optimal DVA design (for Figures (2-4) that yields the greatest reduction is obtained with k=68.5 N/m and m=200 grams. The main reason for this behavior is that the natural frequency of the attached DVA is closer to the excitation freqwuency of the beam at these values of the DVA parameters and this tunes the DVA to remove higher kinetic energy of the main system by the attached DVA.

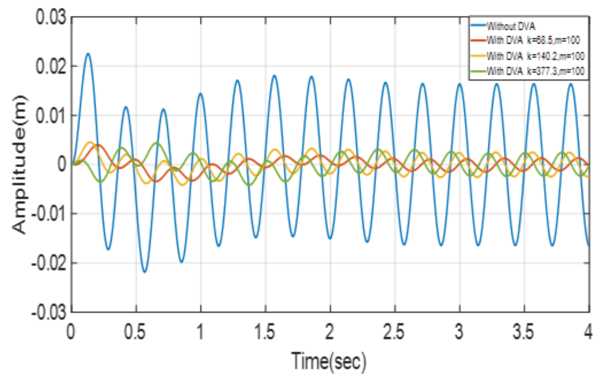


Figure 2 Effect of stiffness with and without DVA at $\omega = 6.75\,\pi\ rad/sec$ at x/l=1

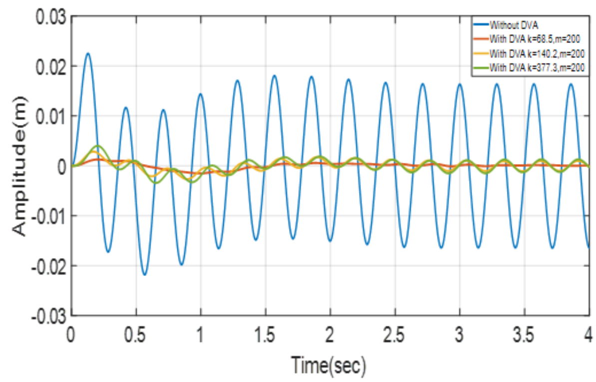


Figure 3 Effect of stiffness with and without DVA at $\omega = 6.75\,\pi\ rad/sec$ at x/l=1

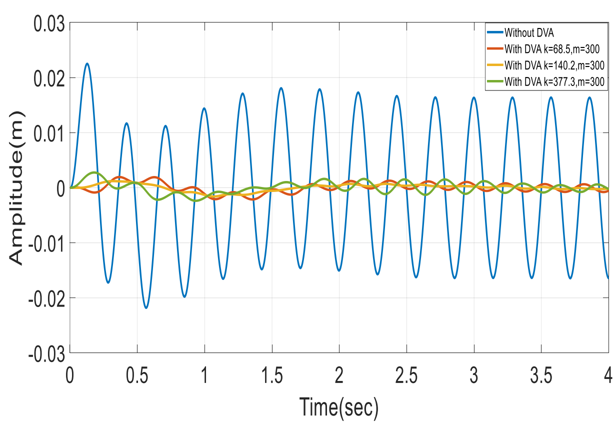


Figure 4 Effect of stiffness with and without DVA at $\omega = 6.75\,\pi\ rad/sec$ at x/l=1

The influence of DVA position will be discussed in the following section using the same stiffness and mass values examined earlier. The dynamic response similar to those observed in Figures (2-4) are depicted in Figures (5–7) when the DVA is placed at the middle (x/l=0.5) rather than at the edge (x/l=1). In comparison to the last three figureures, where the DVA is attached at the free end of the beam, a similar trend of the dynamic response is observed when the DVA is mounted in the middle of the beam. The only difference is that when the DVA is mounted in the middle, the corresponding displacement reaction is larger. However, the combination of k=68.5 N/m and m=100 grams satisfies this requirement (it is the closest one among them) for Figure 5, but k=140.2 N/m and m=300 grams yield the global best combination

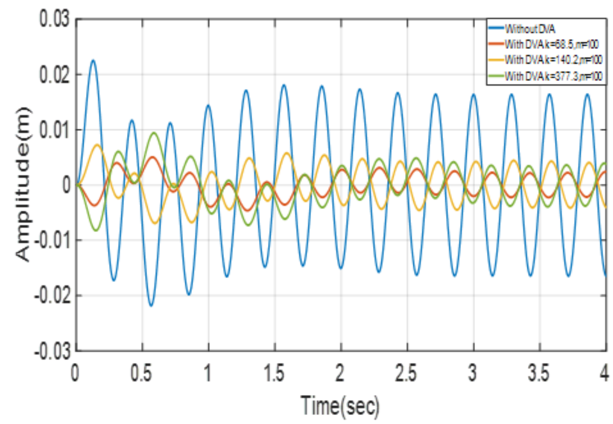


Figure 5 Effect of stiffness with and without DVA at $\omega = 6.75\,\pi\ rad/sec$ at x/l=1

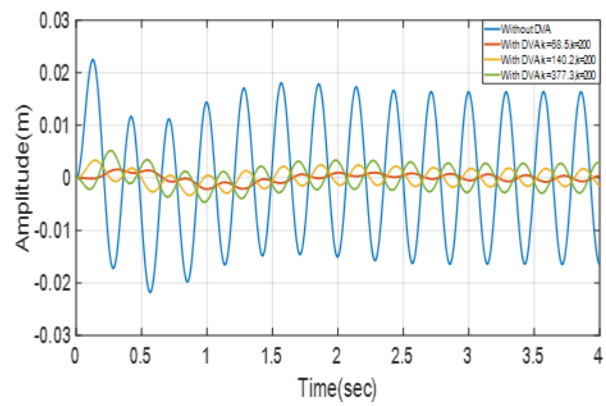


Figure 6 Amplitude response with and without DVA at $\omega = 6.75\pi\ rad/sec\ x/l = 0.5$

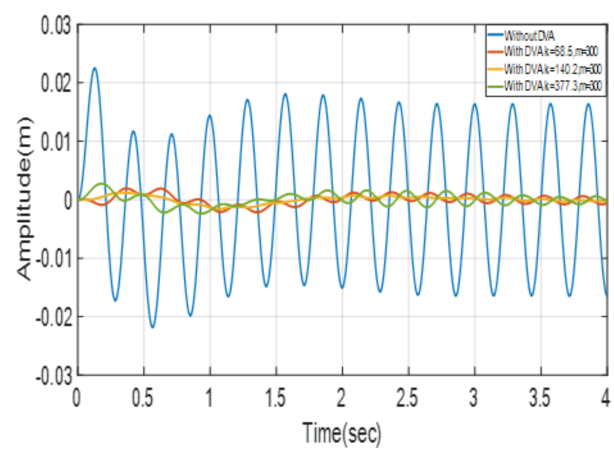


Figure 7 Amplitude response with and without DVA at $\omega = 6.75\pi\ rad/sec\ x/l = 0.5$

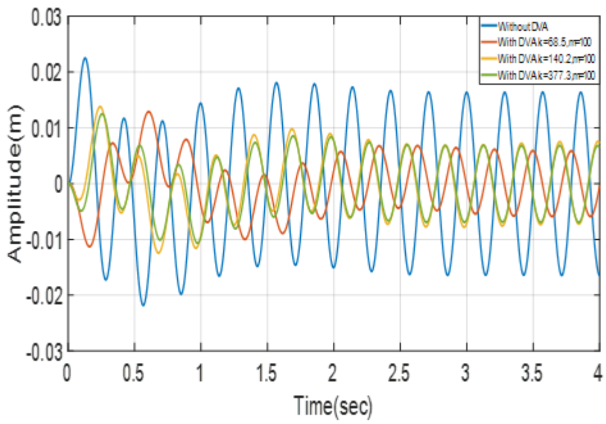


Figure 8 Amplitude response with and without DVA at $\omega = 6.75\pi$ rad/sec $x/l = 0.337$

The DVA is placed at another location (x/l=0.337), and the results are shown in Figures. (8–10) in order to quantify the impact of DVA location on the dynamic response. the last three figures show that, for all DVA stiffness values, the dynamic response of the main system reduces with increasing DVA mass, as seen when k=140.5N/m and m=300 grams are compared to k=140.5N/m and m=100 grams both at x/l=0.337. This behaviour can be linked to the primary system's kinetic energy concept and the DVA location at which this energy is absorbed in accordance with the DVA requirements. The effective mass and velocity of the beam at a particular site determine the kinetic energy of the main system there. As the nodes approach the pinned constraint of the pin-free beam, the nodal velocity (time derivative of the displacement) decreases. This decreasing in velocity at this point must be compensated by increasing the attached mass of the DVA in order to absorb more energy from the main system. This explanation shows how the dynamic response generally behaves at various DVA points on the beam.

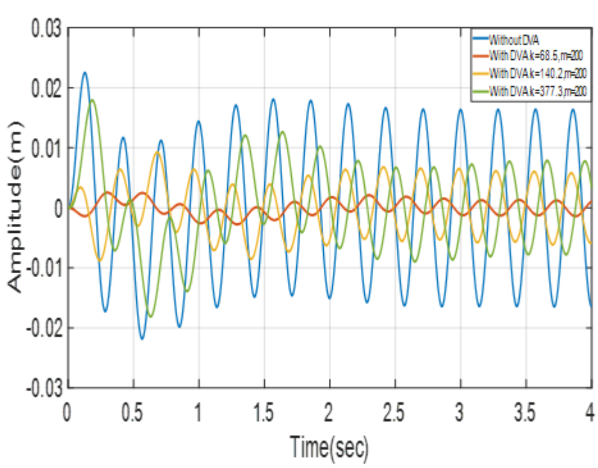


Figure 9 Amplitude response with and without DVA at $\omega = 6.75\pi$ rad/sec $x/l = 0.337$

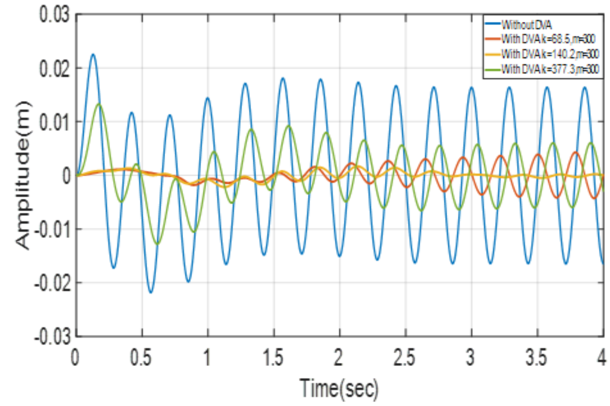
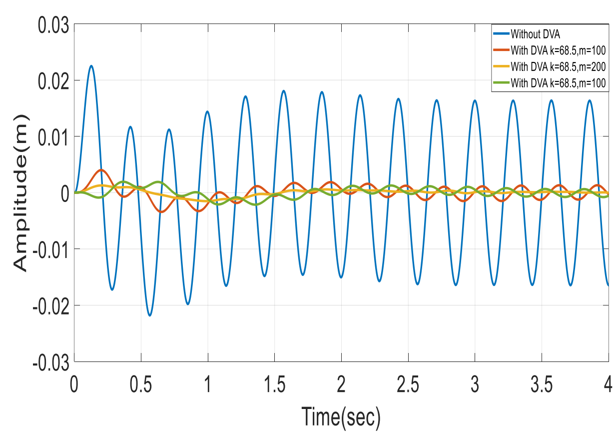


Figure 10 Amplitude response with and without DVA at $\omega = 6.75\pi$ rad/sec $x/l = 0.337$

3.2 Effect of DVA Mass

Figures (11–13) show how, for three distinct DVA stiffnesses, DVA mass impacts a beam's dynamic response. As was already noted, DVA mass and stiffness variations both significantly affect the beam's dynamic response, but only to a certain amount. The dynamic response of the beam is less than its response without the DVA, regardless of the stiffness and mass parameters of the DVA. When the DVA is mounted at the free end of the beam, the least dynamic responses are reached at the smaller values of stiffness and rise with increasing stiffness for all values of the DVA mass, according to a straightforward comparison between these figures. When k=140.5 N/m and m=300 grams, the stiffness and mass are combined in the best manner globally.



Figureure 11 effect of mass with and without DVA at $\omega = 6.75\pi$ rad/sec $x/l = 1$

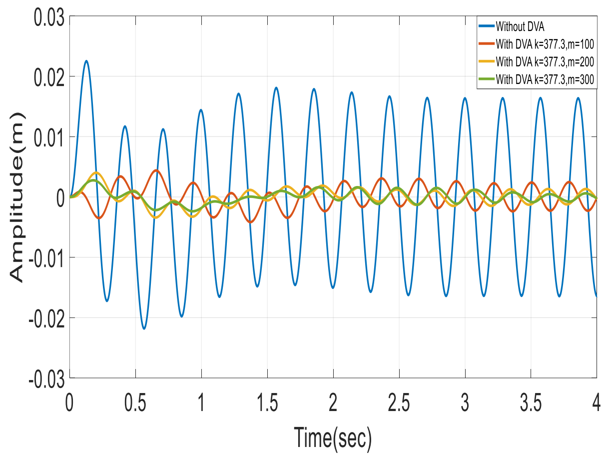


Figure 12 effect of mass with and without DVA at $\omega = 6.75\pi\ \mathrm{rad/sec}\ x/l = 1$

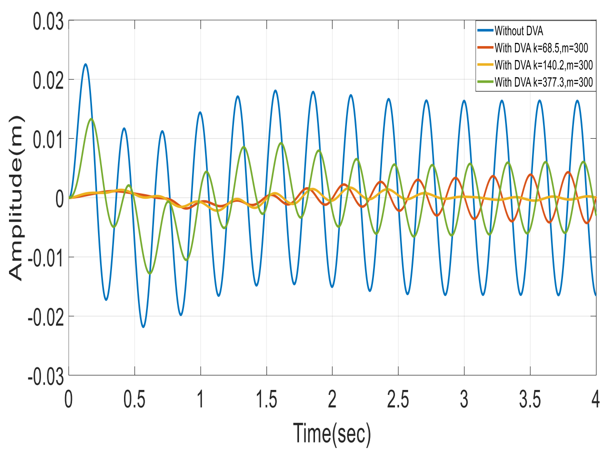


Figure 13 effect of mass with and without DVA at $\omega = 6.75\pi\ \mathrm{rad/sec}\ x/l = 1$

As previously stated, the DVA position is an essential factor that should be investigated in terms of the impact of mass. Effect of DVA location will be covered in the following section. The dynamic response equivalent to Figures 11–13 is shown in Figures 14–16 and 17–19, respectively, when the DVA is situated at the midway (x/l=0.5) and (x/l=0..337) rather than (x/l=1).

Comparing the behavior when DVA is positioned at the free end of the beam to the behavior seen in Figures 14-16, there is a small shift. However. The dynamic response has been considerably diminished. The local and global combinations, however, are (68.5N/m, m=200grams) and (k=140.2N/m, m=300grams), respectively, for the local and global optimal values. The only discernible variation is the dynamic response's amplitude, which increases when the DVA is not intended to be placed at the beam's free end (maximum deflection). Similar results can be reached when the DVA is positioned farther from the beam's free end or closer to the beam's pinned point, as shown in Figures (17-19) when the DVA is positioned at x/l=0.337. These results show a higher dynamic responsiveness for the beam. The amplitude of the response increases dramatically as the mass of the DVA increases at higher stiffness levels, as seen in Figure 17, where the DAV is regarded as an inadequate design and neither locally or globally optimal design has been achieved.

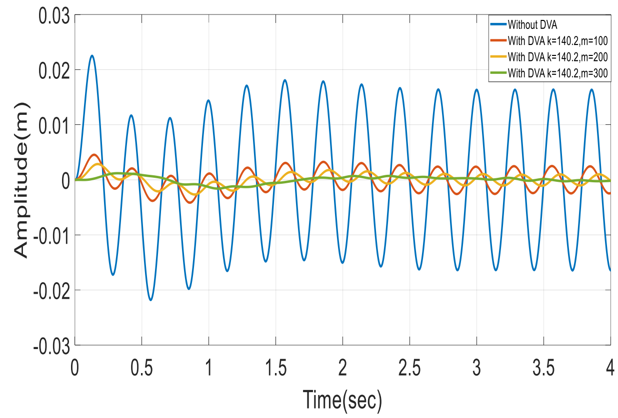


Figure 14 effect of mass with and without DVA at $\omega = 6.75\pi\ \mathrm{rad/sec}\ x/l = 0.5$

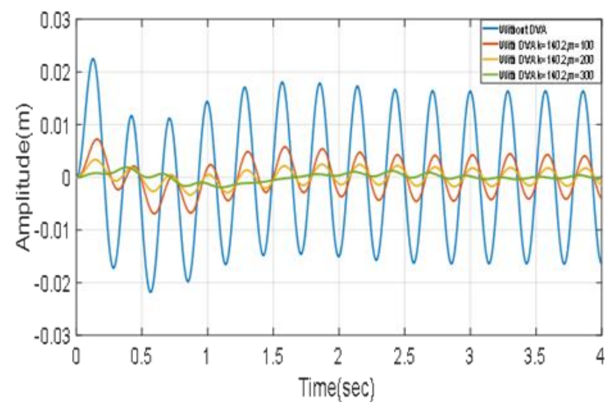


Figure 15 effect of mass with and without DVA at $\omega = 6.75\pi\ \mathrm{rad/sec}\ x/l = 0.5$

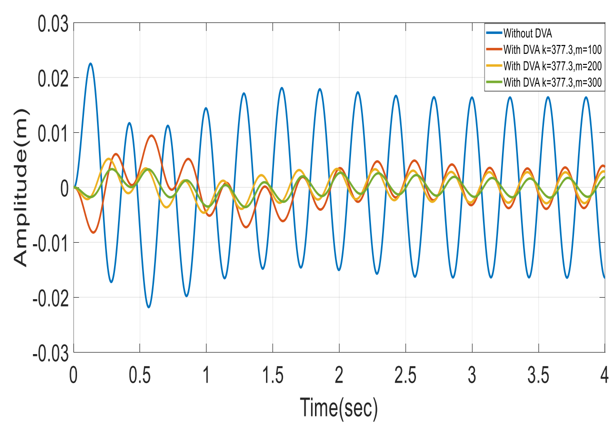


Figure 16 effect of mass with and without DVA at $\omega = 6.75\pi\ \mathrm{rad/sec}\ x/l = 0.5$

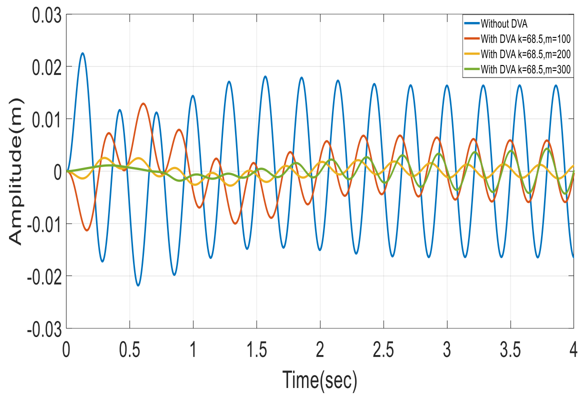


Figure 17 effect of mass with and without DVA at $\omega = 6.75\pi$ rad/sec x/l =0.337

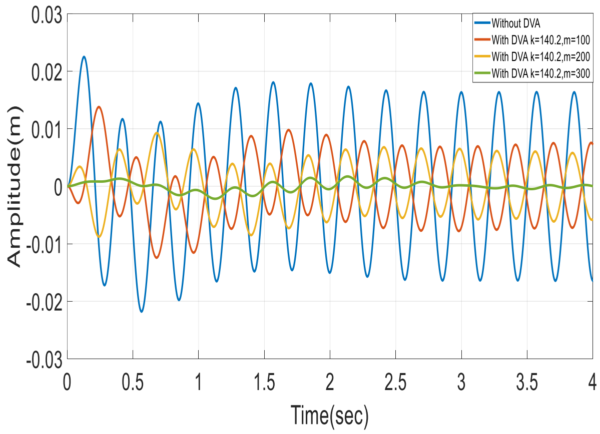


Figure 18 effect of mass with and without DVA at $\omega = 6.75\pi$ rad/sec x/l =0.337

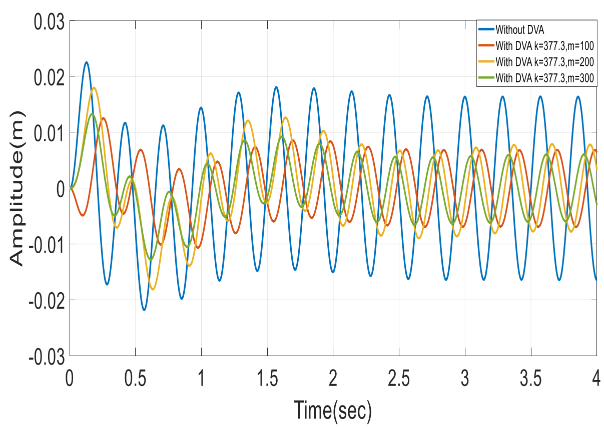


Figure 19 effect of mass with and without DVA at $\omega = 6.75\pi$ rad/sec x/l =0.337

4.0 CONCLUSION

The investigation has led to several conclusions. A major effect in lowering the dynamic response of the beams to an external dynamic input is noticed due to the addition of the dynamic vibration absorber. The dynamic response can be decreased significantly (from 0.018m to 0.0018m, for example) by suitable selection of the values of both mass and stiffness. If the absorber is situated at the point of maximum beam displacement, the minimal requirements of the DVA parameters can better reduce the dynamic response. For an ideal DVA that dissipates the main system's kinetic energy at a specific point, the DVA location changes must align with adjustments in its characteristics. The dynamic response's amplification decreases with increasing constraint.

Acknowledgement

We would like to thank Al-Mustaqbal University/Babylon/Iraq and University of Babylon/Babylon/Iraq for their valuable support and helpful feedback.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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