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Experimental Investigation of Rubber Damping by Decay Rate Method

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Abstract: In this paper, a research was performed on the manner of determining the vibration properties of rubbers. In the domain of vibration and noise control discussions, amplitude must be reduced for this purpose damping have to be increased. Rubbers increase damping of structures. There are different methods for the determination of the dynamic properties of viscoelastic materials. With regard to the existing facilities, the decay rate method was used for the determination of the dynamic properties of rubber. It is observed that the damping rate of the metal plane is significantly reduced with an increase in natural frequency. Therefore, the use of damping layers is more required for higher frequencies. But by adding a layer of viscoelastic, the natural frequency of the system is reduced. In conclusion the increase of the thickness of the damping layer or installation of the layer in a constrained form causes significant increase in the rate of damping and reduction of vibration damping time.

Keywords: Damping, Damping Layer, Decay Rate, Natural Frequency, Rubber, Vibration

1. Introduction

Vibration suppression of structures is a problem in engineering science that has occupied researchers for a while. The methodology used can be categorized into two groups, namely passive and active controls. In passive control, the material properties of the structure, such as damping and stiffness, are modified so as to change the response of the structure. It was well established that an efficient way to increase passive damping is the use of a sandwich construction with alternating elastic and viscoelastic layers. A typical viscoelastic damper consists of thin layers of viscoelastic material bonded between steel plate [1]. The unconstrained layer damping configuration, also known as free layer damping (FLD), is a technology commonly employed in passive control techniques using viscoelastic materials [2] and [3]. Adding a constraining layer to the viscoelastic material (VEM) enhances the damping capabilities by increasing the shear strain in the VEM. These treatments are called passive constrained layer damping (PCLD) treatments. In constrained damping layer the Vibration energy is damped due to shear deformation in the viscoelastic layer [4] and [5].

Structure with added viscoelastic dampers provided quite accurate results in significantly reduced time and sound radiation, regardless of the plan shape and the location of the viscoelastic dampers [6] and [7]. The characteristics of viscoelastic (VE) and viscous dampers are that they dissipate energy at all levels of deformation and over a broad range of excitation frequencies [8]. The composite material exhibits internal damping, the amount of damping is not sufficient for the leaf spring application. An improvement of the damping properties can be obtained either as an integral part of the composite material [9] improved by changing the lamina lay-up in the composite [10] or by introducing layers of materials with pronounced damping properties such as using a high damping rubber material [11]. High damping rubber (HDR) consists of natural rubber to which black carbon filler is added to increase its damping properties. The use of HDR as a dissipating device in structural systems is very promising in terms of controlling the response under live actions like wind or earthquake [12] and [13]. As a matter of fact, mechanical damping constitutes one of the most uncertain parameters of the analysis. Therefore, Several papers exist which collect experimental measurements and provide damping models [14]. So, these modal parameters can be obtained in different ways, i.e., by the direct frequency response method the complex Eigen value method the modal strain energy method and the nonlinear complex Eigen value techniques. With regard to the existing facilities, the decay rate method was used for the determination of the dynamic properties of rubber. In this paper details and testing process of the decay rate method was described. The damping and the natural frequency of structures is effected by type of viscoelastic and glue, thickness of rubber, free layer and constrained layer. Effect of those element s are measured by different tests.

2. Different Methods for Damping Measurement

There are many methods for measuring damping. One reason for the variety of these methods is the historical record, i.e. a variety of methods have been developed over time, and another is the application of damping in different areas; depending on the requirements of that area, a method is proposed for measuring damping [15], [16] and [17].

In fact, these different methods of measurement should be homogenous and when there is low level damping, the number should be small and when it is great, it should show a greater number. So, there should be a linear equation among the parameters obtained from them. But, in practice it is not always the case and therefore, a similar method and parameter should be used when comparing the damping properties of materials to avoid error in the results. Greater care should be taken with multi-degree freedom systems with high damping and a similar method and uniform parameter should be employed for the comparison of the damping of materials. The basis for measuring damping is the ζ parameter obtained by decay rare measuring method in matter [18].

2.1. Damping Ratio or Fraction of Critical Damping (ζ)

The fraction of critical damping (damping ratio) is a measure of one very specific mechanism of damping, i.e., viscous damping which is proportional to velocity. If the damping forces acting on a single degree-of-freedom mass-spring system, illustrated in Figure 1 B, satisfy this type of relationship, then the equation of motion for harmonic excitation is

$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F_0\cos(\omega t) \quad (1)$$

The response depends on m, k, and a parameter $(C/2\sqrt{km})$ which involves c, k, and mand is known as the fraction of critical damping (damping ratio). This parameter, labeled ζ , controls the peak amplitude, the half-power bandwidth, and the resonance frequency ω_r

$$x_{max} = \frac{F_0}{2k\zeta\sqrt{1-\zeta^2}}\, x(0) = \frac{F_0}{k}\,\omega_r = \sqrt{(k/m)(1-\zeta^2)}\,\frac{\Delta\omega}{\omega_r} = 2\zeta \quad (2)$$

The plot of $x(\omega)$ versus frequency ω, for specific values of m and k is very similar tothose for the viscoelastic damping, provided that. $\eta \div 2\zeta$ the distinction between viscous and hysteretic damping (constant k, and η) is not at once apparent. Figure 2 shows the frequency response diagram for both states of viscous damping and viscoelastic. As it is observed, the difference in low frequencies and especially in damping is very high.

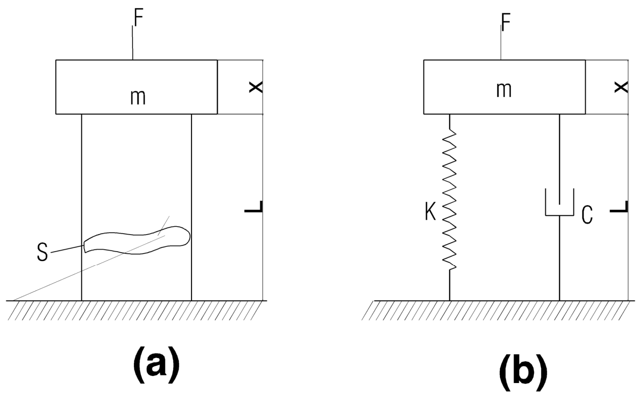

Figure 1. Single degree-of-freedom system with: (A) viscoelastic damping; (B) viscous damping.

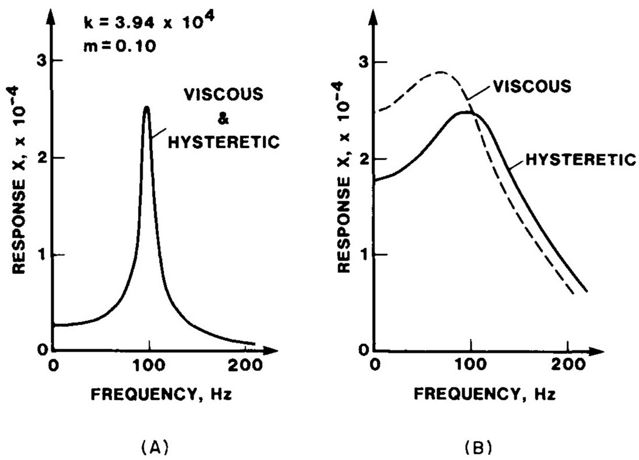

Figure 2. Comparison of viscous and hysteretic damping of a single degree-of-freedom system with (A) low damping (η=0.1, ζ= 0.05); (B) high damping (η=1, ζ= 0.5) (Harris. 2002).

2.2. Method of Measuring Decay Rate for Obtaining Damping Ratio

The free decay rate was determined by digitizing the transient vibration signal in a data-logger, performing time-frequency analysis on it", and best-fitting an exponential decay rate to the time-varying amplitude of the relevant spectral peak (as described in [19] and [20].

If a system with damping is actuated by an initial force and is then released or is imbalanced and released again as shown in Figure 3, it oscillates sinusoidally and its vibration amplitude is reduced in each oscillation period until it returns to its equilibrium state. The amplitude reduction rate of vibrations is an exponential curve (Figure 3, left) and equation (3) shows its mathematical relation.

If the f(t) equation is plotted algorithmically, the exponential diagram is changed into a straight line (Figure 3, right), and then:

$$10\,log\left[{X(t)}/{X_{ref}}\right]^2 = 10\,log\left(\frac{X_0}{X_{ref}} \times e^{-\zeta\omega_n t}\right)^2 = 20\,log\frac{X_0}{X_{ref}} - (20\zeta\omega_n \mathrm{t}\,log\,e) = C_0 - 8/69\,\zeta\omega_n t \quad (3)$$

If the gradient of the logarithmic diagram is named DR we will then have:

$$DR = 8/69\,\zeta\omega_n \quad (4)$$

And then ζ can be calculated.

$$\zeta = \frac{DR}{8/69\omega_n} \quad (5)$$

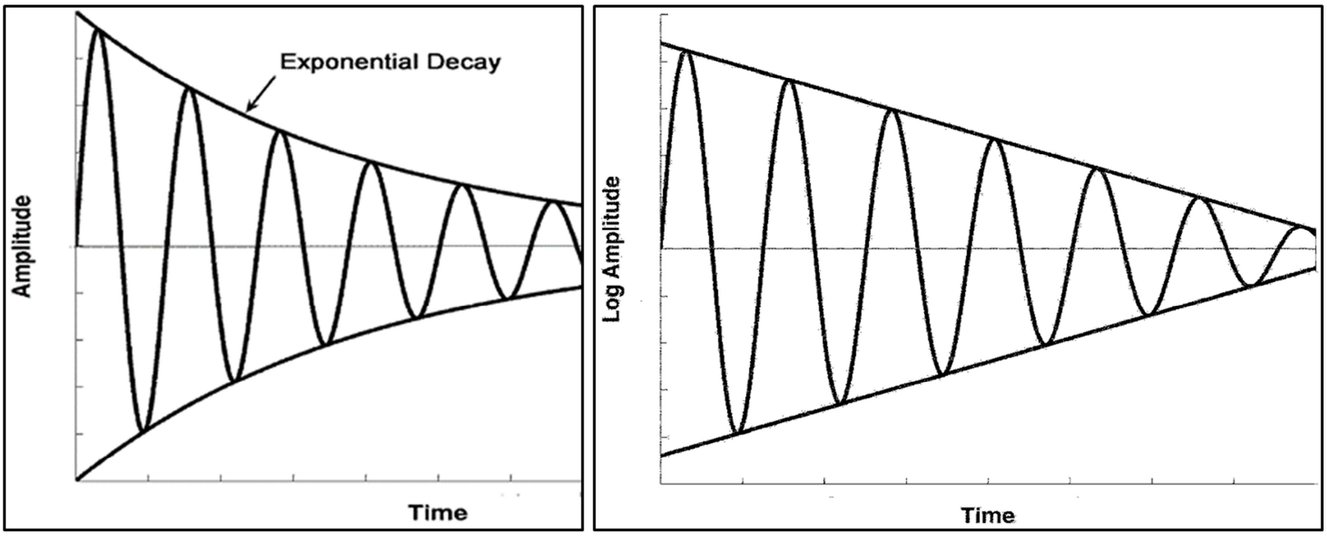

Figure 3. *Trend of reduction of free vibration amplitude in a damping system.*

3. Specimen and Test Preparation

The test specimens for determining vibration damping characteristics shall be the following:

Three flat steel bars, each 9.5mm by 76 mm by 1016 mm.

Three flat steel bars, each 9.5mm by 76mm by 1016mm, with strips of the tiles completely covering one 76 by 1016mm face on each bar (bars from (a) may be used after measurement of bare-bar damping characteristics

The tile strips shall be bonded to the sandblasted faces of the steel bars. The assembled test specimens shall be allowed to set at 27 ± 5°C for at least 96 hours prior to temperature conditioning for the vibration tests.

3.1. Testing Equipment

The manufactured specimen should be actuated in odd longitudinal modes by a shaker and the vibration damping time be measured. For this purpose, the 3560D modulus analysis device model made by B&K Company was used. This device is shown in Figure 4.

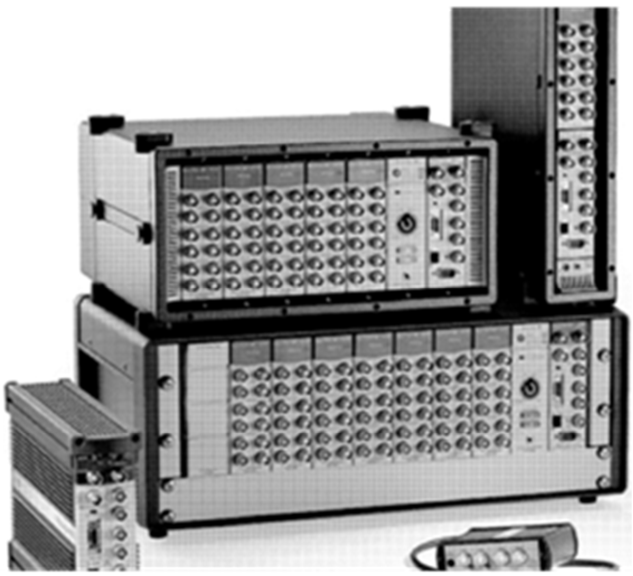

Figure 4. *Modulus analysis device, B&K Company.*

3.2. Materials

In this test three kind of rubber were used in different thickness. They are NBR with 2 and 20 mm thickness, neoprene with 2mm, and a type of Polyartan commercially named Sikafloor with 1 mm.

One of the important factors in using the damping layer is the type of the adhesive. Two types of adhesives commercially named the Soontex adhesive and the Hermabond adhesive were used.

3.3. Testing Process

The specimens were conditioned at about 24.0±1.1°C. for at least 2 hours and tested at this temperature. Vibration damping tests should be conducted by the method of the decay rate of free vibrations. A bar shall be suspended edgewise from two light nylon or cotton cords at least 61 centimeters long and attached to the bar at the approximate nodal points of the first flexural mode of vibration.

Excitation of the bar should be by an electrodynamics vibration exciter. The exciter should be securely attached to the flat. Face of the bar at the intersection of the longitudinal center line and the vertical center line.

The rate of vibratory actuation should be up to a limit that the signal of the received acceleration is 40 decibels higher than that of the noise signals observed in the vibratory diagram. The amplitude of the vibratory signal frequency should also be traced. An accelerometer weighing no more than 31 grams and having a resonance frequency of 20 KHz or higher shall be, used to sense the vibration decay. The accelerometer shall be attached opposite to the attachment of the vibration exciter. It is permissible to remove sufficient damping tile to permit necessary attachment. The measurement system for decay rate should be in a way that we assure that the decay rate is measured at least up to 15% of the critical damping ($\zeta = 15\%$)

The free bar shall be excited at each of the odd-numbered, lengthwise flexural modes of the bar; Care should be exercised to identify the modes excited and to avoid torsional longitudinal and combined modes. It is also important that the alignment of the vibration exciter be such that the direction of excitation is normal to the face of the test bar to which the vibration exciter is attached

4. Calculating the Percentage of Critical Damping

The percent's of critical damping at each mode found for the three bare bars should be averaged. Likewise, the percent's of critical damping at each mode found for the three coated bars should be averaged. The corrected percent's of critical damping should be calculated using the following equation:

Percent of critical damping (corrected) = Dc-D

Where: Dc is the averaged dampings of the coated bars at the specified mode and temperature.

D is the averaged dampings of the bare bars at the specified mode.

5. Performing Tests on the Specimens

The testing system was also installed according to Figure 5 and Figure 6.

Figure 5. *Manner of installing the specimen and equipment for testing.*

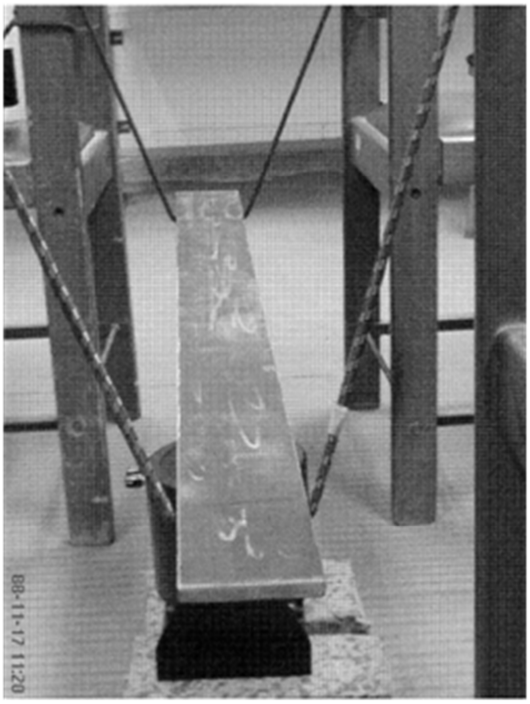

Figure 6. *Manner of installing the specimen and equipment for testing.*

First, on each of the specimens a modal analysis test was performed to extract the natural frequency of each of the specimens. After the extraction of the natural frequencies, each specimen was separately actuated in its longitudinal natural frequency for a specific time. The actuation was then stopped and the acceleration diagram was plotted in terms of its time, of which a specimen of the acceleration diagram in terms of time is shown in Figure 7

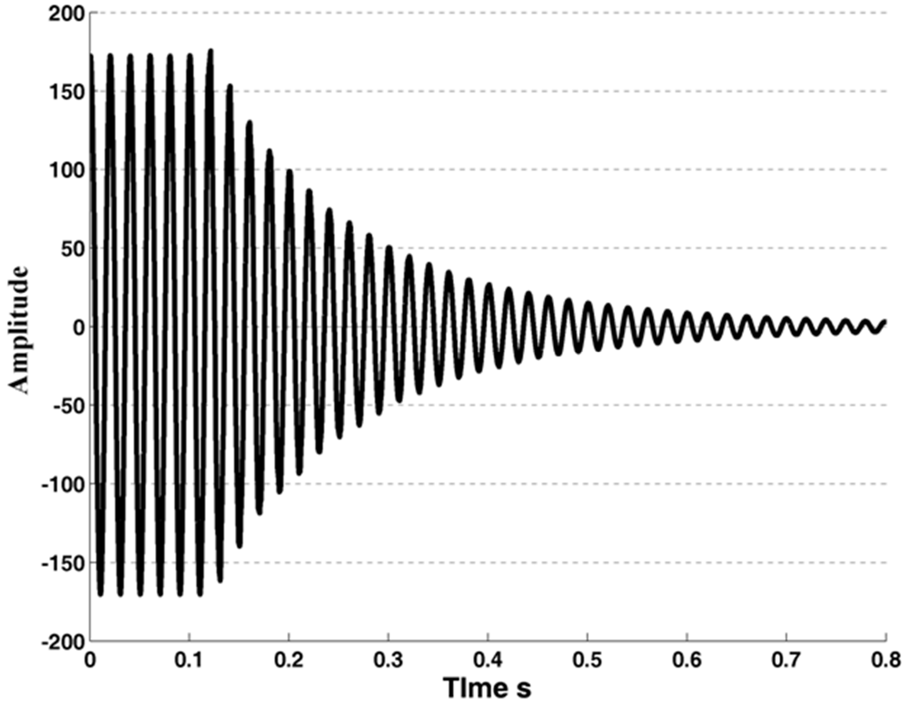

Figure 7. *Amplitude diagram in terms of time for one of the specimens.*

The damping superpose exponential diagram was obtained and was algorithmically plotted. The result is depicted in Figure 8. By the use of the obtained diagram slop, the values of ζ were calculated.

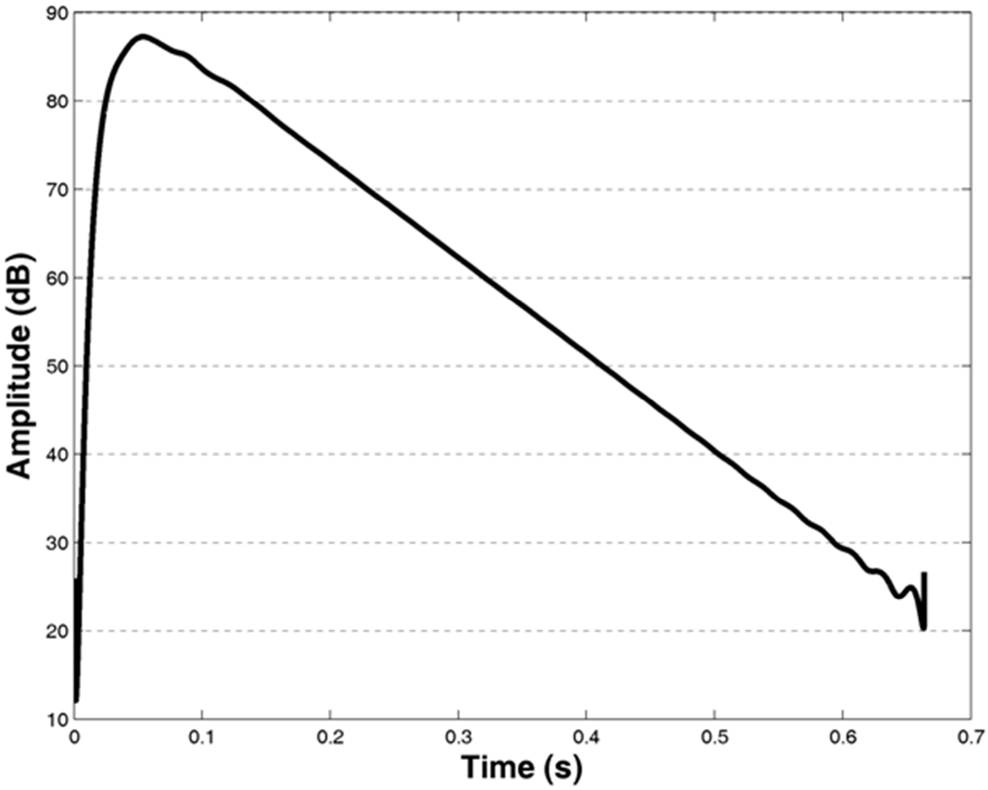

Figure 8. *Amplitude diagram plotted logarithmically.*

6. Results

Damping of the flat steel bar, each 9.5mm by 76 mm by 1016 mm in different modes is measured Figure 9 shows the results.

Now, the Sikafloor layer with a thickness of 1mm is glued on the surface of the plate. The damping of this specimen is studied in two states of constrained and free layers. Figure 10 shows different damping of several modes.

One of the important factors in using the damping layer is the type of the adhesive. To investigate this issue, the NBR 2mm layer is glued on the surface of the metal with two types of adhesives commercially named the Soontex adhesive and the Hermabond adhesive. Figure 11 shows the effect of the type of adhesive on damping with two types of glue.

The material of the viscoelastic layer is another important factors involved in the rate of the damping of the structure. To study this issue, the damping of a NBR 2mm layer is compared with a Neoperan 2mm layer. Figure 12 shows the effect of the type of viscoelastic

By adding a layer of viscoelastic, the natural frequency of the system is changed. NBR 2mm, NBR 20mm and the constrained Sikafloor state are added to specimens Figure 13 shows the percentage of the natural frequency reduction in each of the specimens.

Figure 14 shows the effect of the thickness of rubber on the system damping. The damping of the system is shown for a rubber of NBR 2mm and NBR 20mm in different modes in the figure.

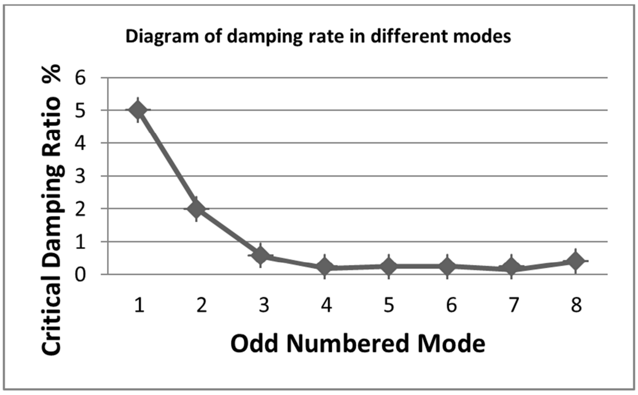

Figure 9. Diagram of damping rate in different modes.

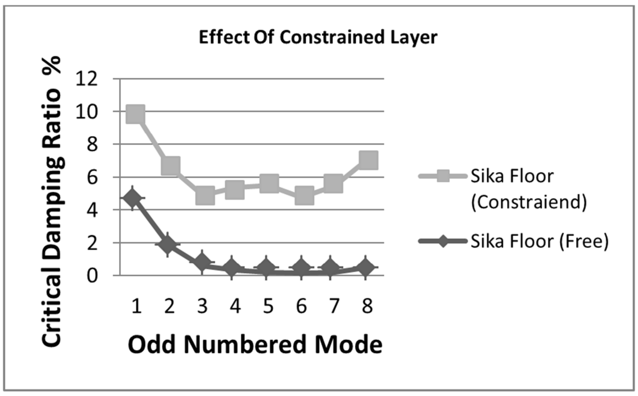

Figure 10. Effect of Constrained Layer.

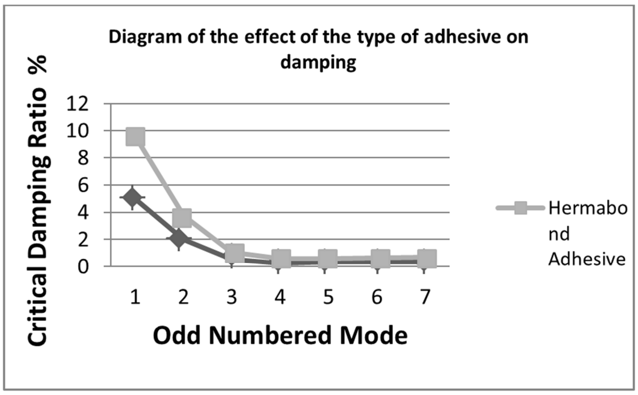

Figure 11. Diagram of the effect of the type of adhesive on damping.

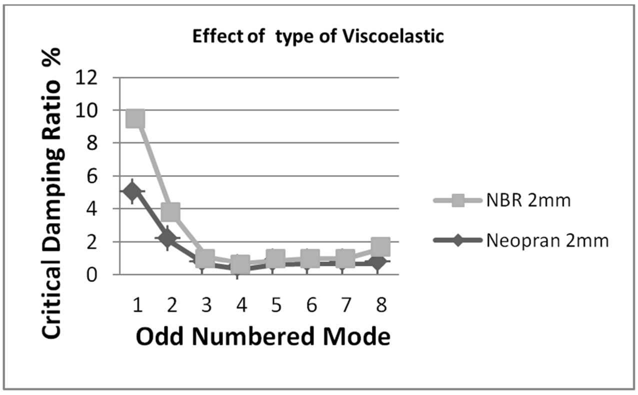

Figure 12. Effect of type of Viscoelastic.

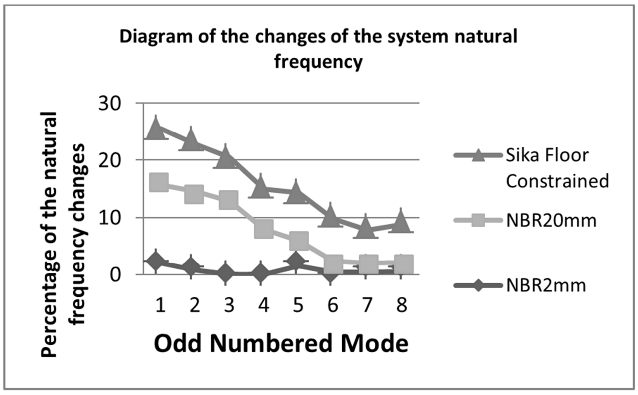

Figure 13. Diagram of the changes of the system natural frequency.

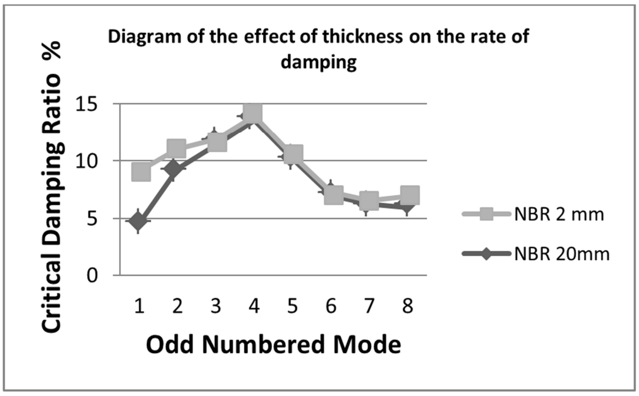

Figure 14. Diagram of the effect of thickness on the rate of damping.

7. Discussion

The increase of the thickness of the damping layer or installation of the layer in a constrained form causes significant increase in the rate of damping and reduction of vibration damping time. From Figure 9, one sees that the damping rate is significantly reduced with an increase in natural frequency. Therefore, the use of damping layers is more required for higher frequencies. From Figure 10, one observes that in the constrained layer the value of damping especially at higher frequencies is increased significantly. Also, the rate of damping at different frequencies is roughly increased evenly in this state. By adding a layer of viscoelastic, the natural frequency of the system is reduced. The more the thickness of the viscoelastic layer is increased, the more the natural frequency of the system is reduced when compared to no-layer state. From Figure 13, one sees that the percentage of natural frequency reduction in different modes for NBR 2mm has been approximately less than 2%, but it is dramatically increased in the first four frequencies for the NBR 20mm, while in other frequencies, no great increase is observed compared to the first frequencies. But the natural frequency reduction in all the frequencies has been approximately of similar rate for the constrained Sikafloor state.

By increasing the mass, the natural frequency of the system is reduced. With regard to equation 6, the addition of one layer of rubber does not bring about an increase in the stiffness of (K) system, because the elastic module of the rubber compared to steel is ignorable, but the mass of the system is increased.

$$f \propto \sqrt{\frac{K}{m}} \tag{6}$$

Therefore, the more the thickness of the rubber is increased, the more the mass of the system is increased and the natural frequency of the structure is reduced.

The more the thickness of the rubber is increased, the more the rate of damping is increased, provided its material and stiffness is not changed. Figure 14 shows the effect of the thickness of rubber on the system damping. The damping of the system is shown for a rubber of NBR 2mm and NBR 20mm in different modes in the figure. By an increase in the thickness in the third to fifth odd modes, damping is dramatically increased and after the fifth mode it is reduced again.

If the thickness of the rubber is increased, the location of mode with maxim damping will be changed. From Figure 14, one sees that for NBR 2mm first mode has maxim damping however for NBR 20mm fourth mode has maxim damping.

The material of the viscoelastic layer is one of the important factors involved in the rate of the damping of the structure. To study this issue, the damping of a NBR 2mm layer is compared with a Neoperan 2mm layer. With regard to Figure 12, the rate of the Neoperan damping is better than that of NBR, but the price and accessibility of the NBR rubber makes it more practical than the Neoperan rubber.

One of the important factors in using the damping layer is the type of the adhesive. The good quality of the adhesive with its thickness plays a significant role in the rate of damping. Also, care should be taken to spread the adhesive more evenly as much as possible to increase its efficiency. The layer of adhesive should be very thin so as to ignore its damping and hardness. With regard to Figure 11, the Soontex adhesive is more efficient than the Hermabond adhesive. The Hermabond adhesive is especially made for rubber, while the Soontex adhesive is made for general uses and its longevity is less than that of the first type. Therefore, to prevent unwanted chemical reactions between the rubber and adhesive, the Soontex adhesive is not recommended. With regard to the above reasoning, the Hermabond adhesive is therefore used for gluing the damping layers.

8. Conclusion

As mentioned earlier increase the thickness of the damping layer or installation of the layer in a constrained form causes significant increase in the rate of damping. Since the damping of the metal plane was significantly decreased by an increase in frequency, the use of HDR as a dissipating device in structural systems was very promising for increasing the damping. HDR could be installed as free layer state and constrained layer state. In free layer state increase of the thickness of damping layer causes significant increase in the rate of damping and reduction of vibration damping time but this increase was not even in all modes. While installation of the layer in a constrained form causes the rate of damping at different frequencies was roughly increased evenly. Also the use of the damping layer causes the reduction of the natural frequency of the system. Therefore in constrained layer state the thickness of damping layer must be chosen so that decreasing of the natural frequency system was not more than permissive range. Furthermore when thickness of viscoelastic was changed, the mode that has maximum damping will change. With regard to this fact the thickness of damping layer should be chosen so that the maximum damping occurred in the excitation frequency of system.

Several factors can influence property of damping layer. Some of them ware explained in above paragraph and another factor was explained below. The material of the viscoelastic layer is one of the important factors involved in the rate of the damping of the structure. The manner of gluing this layer on the surface of the metal, type of the adhesive and its quality and thickness have a great effect on the rate of damping.

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