USING TRANSMISSIBILITY AND VIBRATION POWER FLOW METHODS TO EVALUATE THE EFFECTIVENESS OF ELASTOMERIC MOUNTS FOR VIBRATION AND NOISE CONTROL

Md Rejab Mohd Noor Arib, Abd Rahman Roslan, Raja Hamzah Raja Ishak

Department of System Dynamic and Control, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia.

Inayat-Hussain Jawaid Iqbal

Department of Mechanical Engineering, College of Engineering, Universiti Tenaga Nasional.

Ahmad Nazirah, Ismail Asyraf

Malaysian Rubber Board (MRB), Engineering & Product Design Unit, Technology & Engineering Division.

Putra Azma

Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka.

e-mail: mnarib@unimap.edu.my

This paper presents the results of an experimental evaluation of elastomeric mounts used to isolate vibration from a block (representing a powertrain) to a structure test rig (representing a vehicle structure). Four types of elastomeric mounts were considered, where three of them are from green material natural rubber (SMR CV60, ENR50 and DPNR) and one from petroleum based synthetic rubber (EPDM). Measurement of the dynamic stiffness and loss factor of these elastomers were initially performed. Dynamic stiffness and loss factor were measured in the axial direction for a range of frequency between 5 Hz and 150 Hz at with a dynamic amplitude of 0.2 mm (p-p). Shaker excitation using random vibration signal in the frequency range of 10 Hz to 150 Hz at constant force magnitude was applied to the block in order to quantity the effectiveness of the elastomeric mounts. Measured vibration amplitudes in the axial direction on both sides of each mount were used to calculate the transmissibility and vibration power flow. Sound radiation from a plate attached to the structure test rig was also measured to evaluate the elastomeric mounts contribution to structure-borne noise. The results from transmissibility showed that vibration was high on EPDM, particularly in the ranges 25 to 35 Hz, 60 to 80 Hz and 100 to 120 Hz. ENR50 ability to reduce or damped the amplitude at resonance was found to be the best as compared to the other elastomers. The total vibration power flow was observed to be highest on ENR50 followed by EPDM. The high transmissibility on EPDM was due to its high dynamic stiffness and low loss factor. The larger total vibration power flow on ENR50 was attributed to its high dynamic stiffness and high loss factor.

1. Introduction

One of the automotive research and development effort in controlling noise and vibration problems to achieve improvements in ride comfort is through the improvement of the isolation system of its powertrain. Engine and mounting systems play critical roles in noise, vibration and harshness (NVH) of the vehicle. One of the factors contributing to the increase of vibration in passenger cars is due to the use of composite material in the vehicles' parts and components, which has made these cars much lighter, and due to the development of engines with much higher power output. These fatcors affect vibratory behaviour and increase the vibration and noise in the compartment of passenger cars. Vibration problem of passenger cars is considered more critical as compared to noise. The main causes of vibration is the engine excitation force generated by gas pressure of fuel explosion in the cylinder, and the inertia force of rotating piston and connecting rod. These vibrations are transferred through the mounting system to theseat track structure causing discomfort to passengers. Various types of isolators have been proposed to attenuate the unwanted vibration of powertrain that is transfer to the body structure. Elastomers have been used as engine mounts to reduce vibration from the powertrain to the structure since 1930s. Compactness, cost-effectiveness and low maintenance of the main advantages of these elastomeric mounts[1]. Most of the elastomeric mounts are made from synthetic rubber, which is a petroleum-based product. The used of petroleum-based raw material not only depletes the planet's non-renewable natural resources but also causes environmental hazards. Elastomeric mounts, which are disposed each day, usually end up as landfill. Elastomers buried in landfill sites release highly toxic chemicals into the groundwater in addition to releasing carcinogens to the enviroment[2]. Increasing awareness of environmental sustainability has motivated researchers to explore the use of environment-friendly non-petroleum-based raw material in the development of eco-elastomeric mounts. Natural rubber (NR) has been considered as an alternative to synthetic rubber due to its advantage as a way to conserve land that also acts as a sink for CO_2 generated by automobiles. From the perspective of energy consumption in the preparation of these elastomers, NR also has an advantage over synthetic rubber as shown in Table 1.

Table 1. Energy consumption for preparation of various elastomer[2].

Material	Approximately Energy Consumption (GJ/t)
NR	15-16
BR	108
PP	110
SBR	130-156
EPDM	142-179
IIR	174-209
CR	120-144

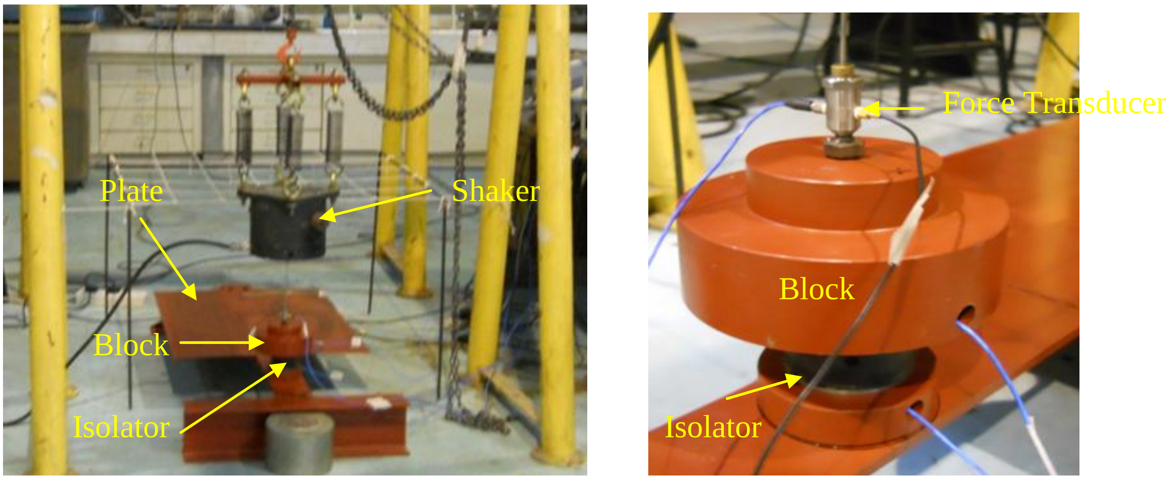
Noise in the compartment is due to the transmission path from either structure-borne noise or airborne noise. Airborne noise transmission path dominates above 500 Hz while structure-borne noise transmission path dominates at low frequency (<200 Hz). Most of airborne noise is due to aerodynamic or wind especially at high speed while structure-borne noise is due to the engine and road excitation. An example of the occurence of structure-borne noise is when the engine of a vehicle is running. The vibration will be transferred to the vehicle structure through the engine mounts, which will then propagate over the whole vehicle structure into the panels facing the passenger compartment. The vibration of this panel will transfer the energy to the air cavity inside the compartment, generating noise that is perceived by the passengers. The high or low vibration transmission from powertrain to structure depends on the mounting system[3]. Therefore, it is important that the influence of the mounts on the transmission of vibration from the powertrain to structure be investigated.

The effectiveness of an isolation system is expressed in terms of transmissibility which is the ratio of transmitted force or motion to the receiver to force or motion generated by the source. However, by determining transmissibility alone, information about the structure-borne noise phenomena cannot be directly obtained. Therefore, additional method should be used to determine the effectiveness of elastomeric mount in reducing structure-borne noise. Vibration power flow is commonly used to evaluate the effectiveness of mount from the structure-borne noise point of view[4]. This method can provide information on the magnitude of vibration energy flow from the powertrain to the structure or chassis. This paper presents the comparison between natural rubber and synthetic rubber mounts' effectiveness in controlling vibration and noise. The natural rubber considered in this work are SMR CV60, ENR50, DPNR, and the syntetic rubber is EPDM. Vibration power flow method was used to assess vibration transmissibility of these mounts and to identify which mounts contribute to the highest vibration power flow to the structure.

2. Experimental set-up and procedures

The procedure to determine dynamic stiffness of elastomeric mount was based on JIS K6385: 1977[5]. Following this standard, a preload of ¼ of the weight of the powertrain was applied to the elastomeric mounts considered in this work. Dynamic testing was undertaken for a range of frequency between 5 Hz and 150 Hz, and the dynamic amplitude which was applied in the axial direction of these mounts was set to ± 0.2 mm (p-p). Dynamic stiffness and loss factor of these elastomeric mounts were derived from the measured force, dynamic amplitude and the phase angle between the force and the dynamic amplitude. A test rig was designed and fabricated for the purpose of evaluating the effectiveness of these elastomeric mount in controlling vibration and noise. The test rig consists of a block placed on top of the elastomeric mount used in this work, and a beam and a plate composite structure. The block and the elastomeric mount represented the powertrain and engine mounting, whilst the beam represented the flexible structure of the vehicle where the block and elastomeric mount were attached to. The plate represented the floor of the vehicle; its sole purpose is for the evaluation of the contribution of structure-borne noise of the various elastomeric mounts considered in this work, Fig. 1(a) and (b). Measurements of the natural frequency of the block-elastomeric mounting system, noise radiation from the plate, transmissibility and vibration power flow through the elastomeric mounts were performed.

Natural frequency of the test rig was determined using the Operational Modal Analysis (OMA) method. An accelerometer was attached to the block of 10-kg mass, and a hammer was used to generate an impulse excitation in the axial direction of the mount. The axial natural frequencies were then determined from these measurements. The procedures to determine the noise radiation from the plate were based on BS 7703:1993[6]. A cord mesh was built around the plate. This mesh covered the entire surface of the plate. The intensity probe (face to face probe) used in this measurement was calibrated with the spacing of 100 mm. Measurements were done by placing the intensity probe at the center of each mesh, Fig. 2(b). The sound intensity was measured during shaker excitation of the test rig using random signal that consist of frequencies from 10 Hz to 150 Hz. Sound intensity was recorded in a narrow-band frequency range and the total sound power level (W) was then determined. Lee's method was used to determine the vibration amplitudes on both sides of the elastomeric mount[4]. This method required two accelerometers to be fixed on both sides of the elastomeric mount, Fig. 2(a). One side represented the source of vibration, and the other side represented the receiver of vibration. Vibration amplitudes were measured during random-signal shaker excitation of the test rig in the range of frequency between 10 Hz and 150 Hz, which was similar to the frequency range used in the measurement of noise radiation from the plate.



(a) (b)

Figure 1. Measurement set-up: (a) test rig and shaker, (b) force transducer and block of 10 g mass.

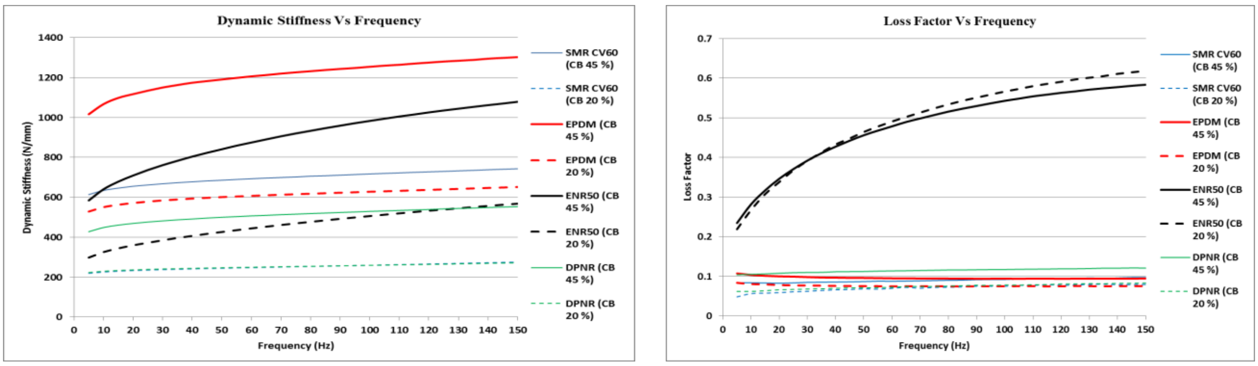
(a) (b)

Figure 2. Measurement set-up: (a) vibration transducers at the source and receiver of the elastomeric mount for the measurements in the axial direction, (b) cord mesh and sound intensity probe used in the measurements of noise radiation from the plate.

3. Results and discussion

Measurements of dynamic stiffness and loss factor was undertaken on eight different elastomeric mounts. These elastomeric mounts were SMR CV60 with carbon black (CB) content of 45% and 20%, EPDM with CB content of 45% and 20%, ENR50 with CB content of 45% and 20% and DPNR with CB content of 45% and 20%. Figures 3(a) and 3(b) show the dynamic stiffness and loss factor of these elastomeric mounts for a range of frequency between 10 Hz and 150 Hz. The total sound power level determined from the noise radiation of the plate for different elastomeric mounts are shown in Figures 4(a) and 4(b), respectively for the elastomers that contain 45% CB and 20% CB. These figures showed that the noise radiation for the case of no elastomeric mount being used was considerably much higher than the noise radiation for the case where different types of elastomeric mounts were used. This is obviously due to the excitation energy from the block that was almost entirely transmitted to the structure when there was no mount used to provide impedance mismatch between the block (source) and the beam (receiver). The vibration energy propagated to the entire test rig structure (beam and plate) and was eventually radiated as noise from the vibration of the plate, which is considered as an efficient noise radiator as compared to the beam. No significant differences were observed in the magnitude of noise radiation from the plate among the different elastomeric mounts considered in this work. The vibration transmissibility was however observed to be considerably influenced by the different types of elastomeric mounts as shown in Figures 5(a) and 5(b). The transmissibility was derived from the vibration response (source and receiver accelerations) measured on both sides of the mount in the axial direction. The transmissibility was calculated using Eq. 1, where, X_r, V_r and a_r are respectively the displacement, velocity and acceleration of receivers, while X_s, V_s and a_s are respectively the displacement, velocity and acceleration of sources. It is observed in Figures 5(a) and 5(b) that the mounts based on EPDM produced higher transmissibility at resonance frequency around 25 to 35 Hz, 60 to 80 Hz and 100 to 120 Hz, while SMR CV60, ENR50 and DPNR produced lower transmissibility at the same resonance frequencies. ENR50 appeared to have a higher ability to reduce or damped resonance compared to the elatomers. This is atributed to the high loss factor of ENR50.

$$T_r = \frac{F_T}{F_0} = \frac{X_r}{X_s} = \frac{V_r}{V_s} = \frac{a_r}{a_s} \quad (1)$$



(a) (b)

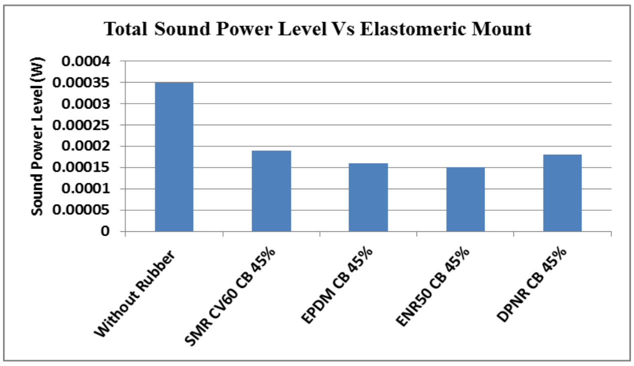
Figure 3. (a) Dynamic stiffness of elastomeric mounts, (b) loss factor of elastomeric mounts.

Figures 6(a) and 6(b) show the total vibration power flow through the elastomeric mounts that respectively contained 45% and 20% carbon black. The vibration power flow was calculated using Eq. 2 and Eq. 3, where M_{rs} is the apparent mass determined from the complex form of the dynamic stiffness (K') and loss factor (η) of the elastomeric mount. The other variables, a_s and a_r, respectively represents the accelerations of the source and the receiver. Both accelerations are in complex form.

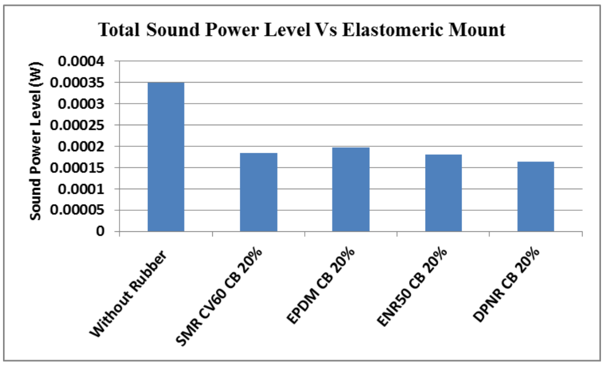
$$P \cong \frac{1}{2\omega} Im(\tilde{M}_{rs}\tilde{a}_s\tilde{a}_r^*) \tag{2}$$

$$\tilde{M}_{rs} = \frac{K\prime}{\omega^2} + j\eta\frac{K\prime}{\omega^2} \tag{3}$$

The solid line in Figure 6 represents the positive vibration power flow while the dotted line represents the negative vibration power flow. It is noticed that the frequency region of the dominant vibration power flow is at low frequency, in the range 15 Hz to 35 Hz. The positive and negative total vibration power flow of each elastomeric mount are plotted in the bar graphs shown in Figures 7(a), 7(b), 8(a) and 8(b). It is observed that the total vibration power flow was higher on ENR50 and EPDM for CB content of 45% and 20%. This is due to the higher dynamic stiffness and loss factor of these elastomers. Although the influence of different elastomeric mounts on the structure-borne noise was not so apparent from Figures 4(a) and 4(b), the results presented in Figures 5(a), 5(b), 7(a), 7(b), 8(a) and 8(b) indicate that ENR50 and EPDM with 45% and 20% CB produced much higher structure-borne noise as compared to SMR CV60 and DPNR.

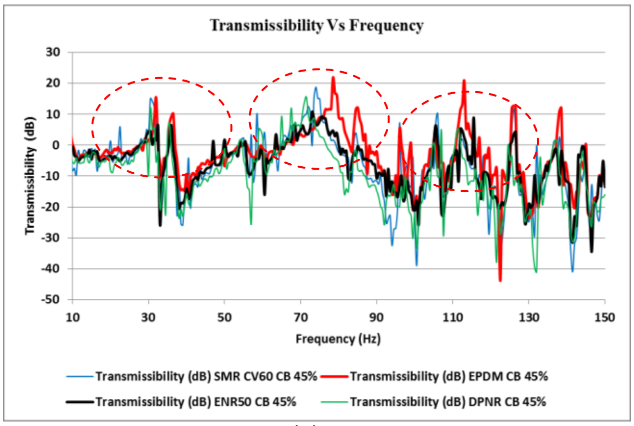


(a)

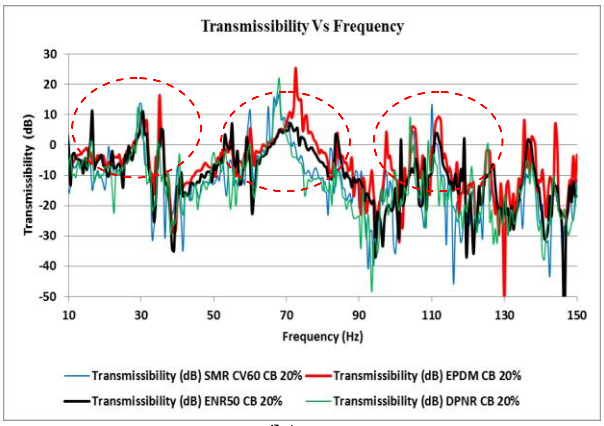


(b)

Figure 4. (a) Total sound power level of the plate for elastomeric mounts with 45% CB, (b) total sound power level of the plate for elastomeric mounts with 20% CB.

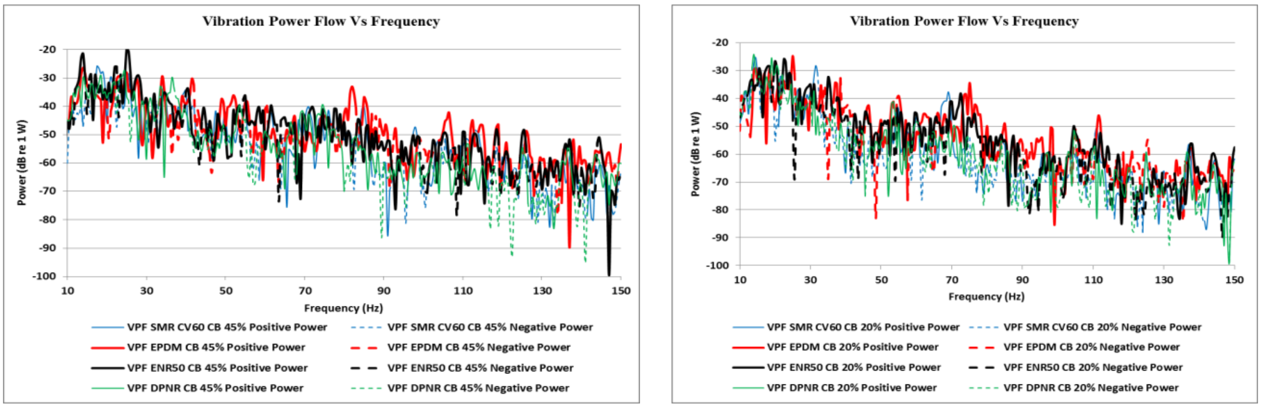


(a)



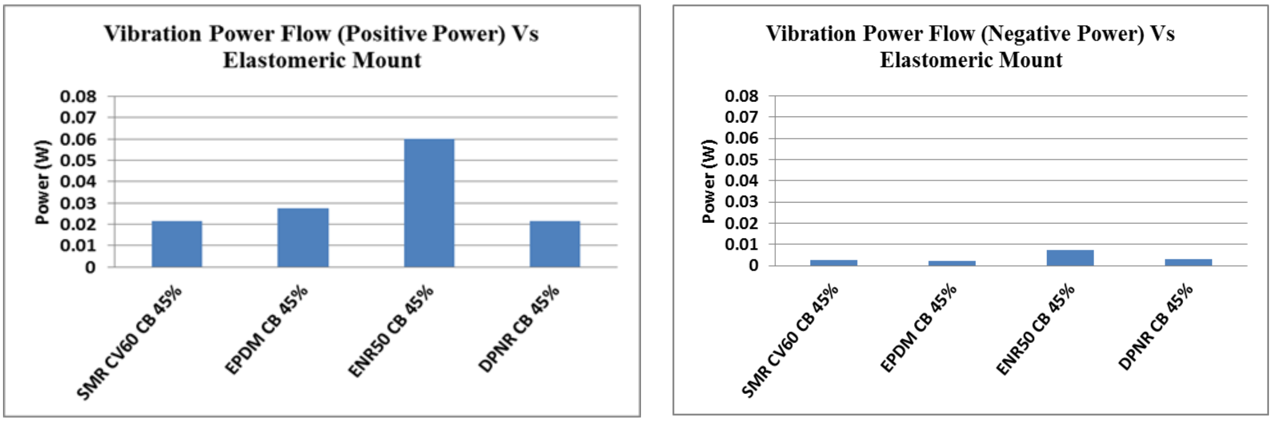
(b)

Figure 5. (a) Transmissibility of elastomeric mounts with 45% CB, (b) transmissibility of elastomeric mounts with 20% CB.



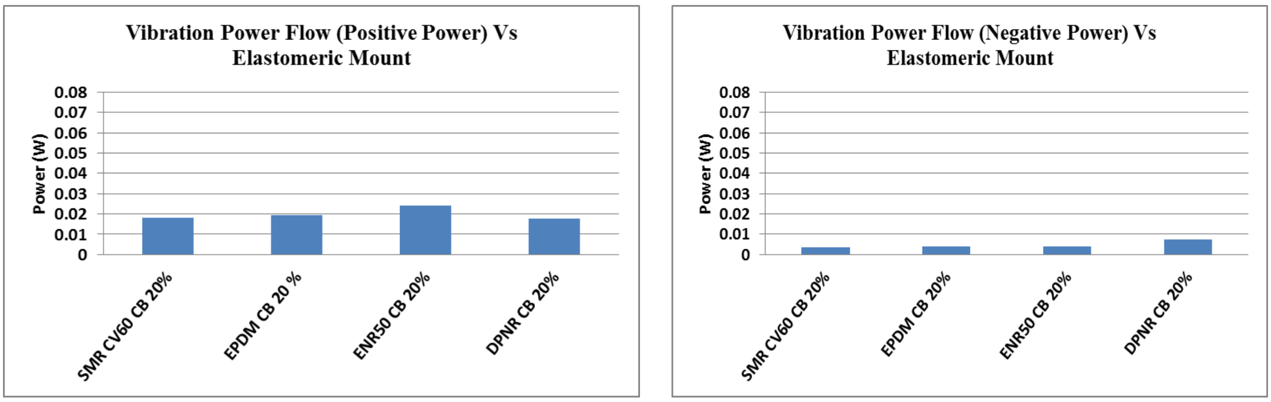
(a) (b)

Figure 6. (a) Vibration power flow through elastomeric mounts with 45% CB, (b) vibration power flow through elastomeric mounts with 20% CB.



(a) (b)

Figure 7. Total vibration power flow through elastomeric mounts with 45% CB. (a) Positive vibration power flow and (b) negative vibration power flow.



(a) (b)

Figure 8. Total vibration power flow through elastomeric mounts with 20% CB. (a) Positive vibration power flow and (b) negative vibration power flow.

4. Conclusion

This paper presents the results of an experimental work undertaken to determine the dynamic stiffness and loss factor of some elastomeric mounts, i.e., SMR CV60, EPDM, ENR50 and DPNR with 20% and 45% carbon black content. The transmissibility and vibration power flow through these elastomeric mounts and the resulting noise radiation were also measured on a test rig that represented a vehicle's powertrain and structure. The results showed that the EPDM mounts had the highest transmissibility at resonance frequencies, whilst the ENR50 had the lowest transmissibility. This indicated that the ENR50 was a more effective elastomer for damping vibration amplitude at resonance. The total vibration power flow was however found to be higher for the ENR50 mounts as compared to the EPDM mounts. The high transmissibility of the EPDM mounts was attributed to their larger dynamic stiffness and smaller loss factor. The high total vibration power flow of the ENR50 mounts, on the other hand, was due to their larger dynamic stiffness and larger loss factor. It is concluded from the results of the experimental work that the ENR50, which is a natural rubber compound, is potentially suitable to be used as an alternative to the more widely used synthetic rubber, EPDM, in noise and vibration control applications.

Acknowledgements. The authors would like to thank the Ministry of Higher Education of Malaysia (KPT) and Universiti Malaysia Perlis (UniMAP) for their financial support. Gratitude is also extended to the Malaysian Rubber Board (MRB) for the support and advice provided during the testing of the elastomers.

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