EXPERIMENTAL IDENTIFICATION ON NON LINEAR PROPERTIES OF RUBBER MOUNT

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ABSTRACT

In actual installation, rubber mount are usually excited by different engine force amplitude and frequency. For better characterization of rubber mount, dynamic properties of metal to rubber mount are tested in this paper by using hysteresis loop method. Stiffness and loss factor of rubber mount are calculated from measured hysteresis loop. Experimental works are carried to identify the non-linearity in the amplitude dependent and frequency dependent properties of rubber mount. The s-shaped of hysteresis loop represent as non-linear behavior of rubber mount. The comparison is done for the dynamic properties of rubber mount under different excitation condition. The non-linear behavior of the rubber mount under excitation forced are reported. The result show stiffness change non-linearly according to different amplitude excitation force under different excitation frequency. The observation is significant especially when the excitations force is higher than 5N for the small metal to the rubber mounts. However this observation is different compared to the condition where excitation frequency getting higher. The non-linearity in the rubber mount is becoming not significant when the excitation frequency is getting higher.

Keywords: Rubber mount, Stiffness, Force amplitude and Non-linearity

INTRODUCTION

Rubber mounts are commonly used to resolve vibration and noise in any device or machine since 1930[1]. Although several mounting system had been developed from elastomeric mount to hydraulic mount, from passive to active, the rubber mount still been selected to studied due to its compact, cost-effective, maintenance free and provided consistent performance[2][3]. In general, the performance of rubber mounts is influenced by dynamic properties of rubber components[4]. The dynamic properties of rubber mounts include stiffness and loss factor. Stiffness contributed to the energy store in system and damping characteristic is representing energy loss from the system.

Viscoelastic behavior of rubber make rubber mount to deform linearly and non-linearly under different excitation frequency and amplitude[5]. In order to obtain good description of viscoelastic material, several methods have been carried out. Shimizu et al. (1999) and Fukunaga et al. (2004) modeled viscoelastic materials by the fractional derivative model[6][7]. However, experimental validation was not been carried out during their studies. Lin et al. (2005) and Ooi et al. (2014) were conducted experiment study to evaluate frequency dependent stiffness and frequency dependent lost factor of rubber mount by using impact technique[8][9]. However, the authors were not focused on non-linear region small force excitation was applied in the studied and linear region behavior is assumed in the study. The non-linear frequency dependent properties of rubber mount were studied by Sjoberg et al. and Zhu et al. in both experiment and simulation[10][11]. However, authors only focused their studied in low frequency range which is in between 0 Hz to 100 Hz.

Gade et al. used resonant and non-resonant methods to study complex modulus and loss factor of rubber mount which is shaker is used as excitation source. However, the experiment carried out by authors focused on linear behavior of frequency dependent only[12]. Lin et al. was used impact technique to evaluate the frequency dependent stiffness and damping characteristic of rubber mount. However, the measured force and acceleration responses of the rubber mounts are determined by using Fast Fourier Transform (FFT)[8]. Ooi et al. (2011) further developed the impact technique to determine dynamic transfer stiffness and dynamic driving point stiffness. The difference between dynamic driving point stiffness and dynamic transfer stiffness due to the force applied and measured was considered at different position of the rubber mount[13]. Recently, shaker had been used in the experimental measurement in the low frequency testing on the cable isolators by Guzman et al. to study non-linear behavior of rubber mount. The damping properties are determined by using the shaker test[14]. The shaker excitation method is also applied by Vangipuram et al. in the dynamic characterization of rubber mounts in terms of linear and non-linear behavior.[15].

Hysteresis loop method can be used in several application such as rubber, magnetic field, electrical and so on[10][16][17]. Due to damping rubber material, hysteresis loop are obtained when plotting amplitude of instantaneous force versus instantaneous displacement in a material of all value of time. The linear behavior for dynamic properties of rubber mount will visualize the hysteresis loop in elliptical shape. For non-linear behavior, the shape of elliptical of hysteresis loop will be change to s-shape[18]. Hysteresis loop method is proposed here to provide alternative method in characterization of non-linear behavior of rubber mount.

The study presented in this paper will measure the frequency dependent and amplitude dependent stiffness of rubber mount based on hysteresis loop method. The non-linear behavior is determined within this frequency and amplitude dependent range. The reason to measure frequency dependent and amplitude dependent stiffness at several force and frequency is to study the effect of force and frequency of non-linear properties of rubber.

METHODOLOGY

Experimental measurement

The experiment setup used in this study consist of three rubber mounts, an accelerometer, force transducer, 0.9kg preload mass, power amplifier, LMS Scadas, stringer and shaker as the controlled excitation force. Rubber mount with diameter of 15mm and length of 20mm are used. Figure 1(a) shows the experiment setup and the apparatus used in this experiment. The different forces at different frequencies are set on Spectral Testing software and LMS Scadas. LMS Scadas is used as interface with controller to provide signal and collect data. The controller is used to generate voltage sinusoidal wave signal in order to drive the shaker as excitation source. The excitation force and frequency from shaker then will transmitted to the force transducer via stringer. The force transducer is used to measure the input force from the shaker. As Figure 1(b), the accelerometer located below the preload is used to measure the acceleration response of engine mounts. The experiment is repeated at differences force excitation of 6N and 10N. The experiment also will repeated with different excitation of frequency. First, the natural frequency of rubber mount is measured by determined the Frequency Response Function (FRF) of the system. Lin et. Al. stated in their studied, the range of natural frequency is determined by defined the half of FRF peak value as stated [8]. Then, the curved of FRF then subdivided into three section: (1) below natural frequency range; (2) within natural frequency range; (3) above natural frequency range.

Below natural frequency range ($0 \leqslant f \leqslant 90$ Hz).

In this experiment, the frequency used for below natural frequency range is 80 Hz.

Within natural frequency range ($90 \leqslant f \leqslant 140$ Hz)

Frequency of 100Hz is chose for study the stiffness of rubber mount within the natural frequency range

Above natural frequency range ($140 \leqslant f \leqslant 400$ Hz)

The frequency used for above natural frequency is 200 Hz. The above natural frequency range is ended at 300 Hz where the noise contamination in data becomes severe.

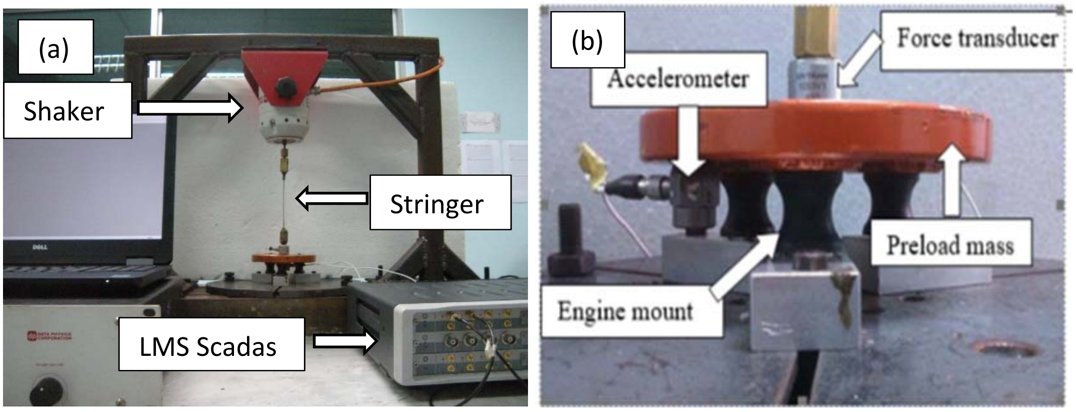

Figure 1. (a) Experiment setup for engine mount and (b) Experiment setup for sine swept method

Hysteresis loops are plotted from the data collected in above setup. Stiffness can be obtained by determine the slope of the loop[10][18]. From the Figure 2, the area of the loop represent as energy lost to the system. The stiffness can be calculated by determine the gradients of each force and displacement from the s-shaped loop. The graph is plotted to determine the stiffness at different gradient for each force and displacement of non-linear s-shaped loops.

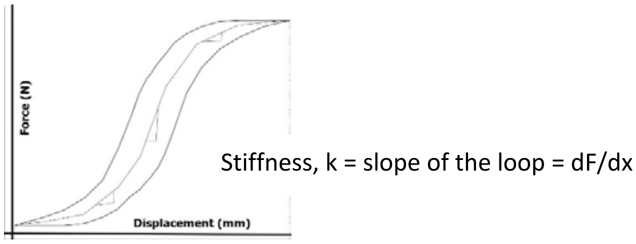

Figure 2: Scematic of Hysteresis loop of rubber mount

RESULTS AND DISCUSSION

The frequency response function (FRF) of the system is measured. Natural frequency is determined from the peak value of the FRF that is 113.5Hz. In this study, three frequencies have been chosen to represent three different natural frequency range. For below natural frequency, 80 Hz is selected. Within the natural frequency, 100 Hz is selected and for above natural frequency, 200 Hz is selcted.

Figure 3(a) shows the hysteresis loops that measured with different excitation force. The excitation force applied are 3N, 5N and 10N. From Figure 3(a), the shape of hysteresis loop is s-shape when the force is applied. The s-shape indicated the rubber mount behave non-linearly. Similar finding was reported by Aiken et. al that shows similar shape of hysteresis loops for non-linear behavior in their analytical studied of hysteresis model[19]. Stiffness was calculated as explained in methodology section. Figure 3(b) shows the stiffness calculated based on result from different excitation force but constant excitation frequency. From Figure 3(b), at excitation of 5N, the higher the force the higher the stiffness of rubber mount. The results of 7N and 10N excitation force shows similar trend with 5N. At 1N of 5N excitation force is 133.33kN/mm, while 1N for 7N and 10N of excitation forces are 109.8kN/mm and 90.9kN/mm respectively. The percentage different between 1N of 5N, 7N and 10N excitation force is less than 20%. Similar trend of stiffness shows from 2N to 5N at different of 5N, 7N and 10N excitation force.

Figure 3(c) shows the hysteresis loops that measured at 100Hz but different excitation force. The force applied were 3N, 6N and 7N. The results represented properties of rubber mount within natural frequency range. From Figure 3(c), the loops exhibit linear and the area of the loops are bigger compared to result obtained at 80Hz and 200Hz as shown from Figure 3(a) and Figure 3(e) respectively. Zainudin et al. (2017) also found the area of the loop become bigger when the excitation force near natural frequency of rubber since more energy loss to the system[20]. Figure 3(c) shows that the linear behavior occur to the system when excitation frequency within the natural frequency since the loops is elliptical shape. Figure 3(d) shows the stiffness of the rubber mount under different excitation force. The change of stiffness is very small when the excitation force change from 1N to 7N. The different is below t 15% for each force at different excitation force.

Figure 3(e) shows the hysteresis loops that measured at 200Hz but different excitation force. Same force level were applied for this frequency range. From the Figure 3(e) the shape of the hysteresis loops is elliptical shape which is linear behavior of the rubber mount system. Similar finding was reported by Ramorino et al. found the linear behavior of rubber mount when excited at higher than natural frequency. Figure 3(f) shows that the increase of the excitation force, the stiffness also increase. The different of stiffness between 3N, 6N and 7N of excitation force for 1N is smaller. The different forces of at 1N excitation force is below than 10%. The similar trend were found at different excitation force.

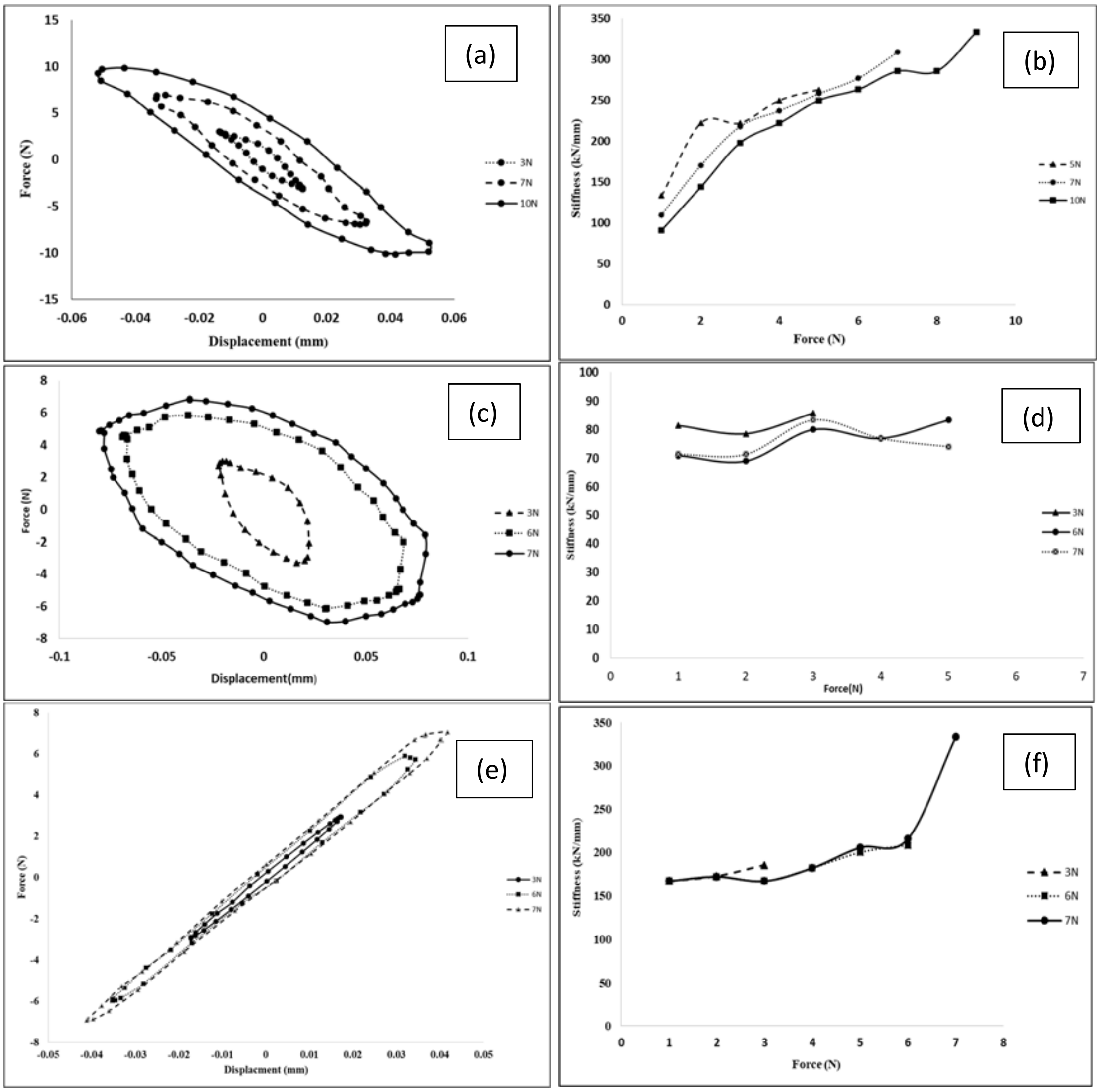

Figure 3(a), (c), (e) Hysteresis loop measures under different force amplitude at 80Hz, 100Hz, 200Hz. 3(b), (d), (f) Stiffness under different excitation force amplitude at 200H

The shape of loops at different frequencies are different. For the excitation frequency below and above natural frequency range, the shape of the loops are elliptical. It indicated the loops is linear. For the excitation frequency within natural frequency range, the shape of the loop is s-shape. It indicated that the loops is non-linear. Similar finding were reported by Aiken et. Al. where the shape of non-linear hysteresis loops is s-shaped. From figure 3(a), (c), (e) it is clearly seen that the shape of the hysteresis loop is not perfect. This might be cause by the external energy loss from rig and the connection of screw and nut between preload and rubber mount. The vibration through the rig and the screw and nut will cause energy loss and the losing in the thread of the screw significantly affect the input signal of the system [20].

CONCLUSION

The measurement using hysteresis loops method is carried out for different frequency and excitation force. The results shows stiffness change non-linearly when excited within natural frequency range. The observation is significant when the excitation force is higher than 5N. However this observation is different compared to the condition where excitation frequency is excited below and above natural frequency range.

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