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Low-Pass Mechanical Filter Evaluation Using Frequency-based Kolsky Bar Analyses

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Introduction

Isolation of components to shock or other impact mechanical loading is a key concept in protecting sensitive constituents in a system. An effective shock isolation material must be capable of absorbing external impact energy and attenuating acceleration when subjected to shock/impact loading. Though a variety of crushable materials such as glass microbeads have been used effectively for shock isolation [1], elastomers are also commonly used as shock isolation materials for their energy absorption and vibration damping capabilities.

A wide range of frequencies is associated with shock or impact loading. Typically the goal is to dampen or isolate particularly high frequencies which could be damaging to internal components. In some applications however, it is desired that a low-pass shock isolation material be selected that dampens high frequencies but always allows low frequencies to pass through with minimal attenuation. Here the dampening is represented by the ratio of transmitted acceleration through the shock isolation material over excited acceleration. While transmitted acceleration in the time domain is a measurable parameter to evaluate the shock isolation performance [2-4], time domain performance gives no insight with respect to shock isolation performance in the frequency domain. Additionally, shock isolation materials may become preloaded during installation, which represents a change in stress state and thus could affect shock isolation performance.

Recently, a Kolsky compression bar has been employed to characterize the frequency response and shock isolation performance of a polymethylene diisocyanate (PMDI) based rigid polyurethane foam [5]. The PDMI foam showed excellent shock isolation performance wherein all frequencies higher than 1.5 kHz were absorbed. The PDMI foam also attenuates accelerations at frequencies below 1.5 kHz, meaning that PDMI foam would not be a good candidate material for a low-pass mechanical filter. In this study, a modified Kolsky compression bar was used to apply dynamic loading to passively confined and preloaded elastomeric samples. A preload up to 15.5 kN was applied to different elastomeric samples to characterize the response in terms of acceleration attenuation at different frequencies for low-pass shock isolation performance. The effects of preload and specimen geometry on the low-pass mechanical response were also investigated.

Materials and Specimens

Polyurethane, neoprene, and ethylene propylene diene monomer (EPDM) were characterized and evaluated for low-pass shock isolation performance. The rubber specimens were made with different initial diameters of 25.4 mm, 19.05 mm, 15.88 mm, and 9.53 mm. Specimen thickness for polyurethane, neoprene, and EPDM were 3.08 mm, 2.97 mm, and 3.10 mm, respectively.

The acceleration transmission ratio δ_{AT} is calculated using the frequency spectra from the input and output and output accelerations using the magnitudes of the Fourier transforms of the incident, reflected, and transmitted pulses, or $B_i(f)$, $B_r(f)$, and $B_t(f)$, respectively:

$$\delta_{AT}(f) = \frac{B_t(f)}{B_i(f) - B_r(f)} \tag{1}$$

Results and Discussion

Figure 1 shows a comparison of the acceleration transmission behavior of polyurethane rubber with and without any preload. As Fig. 1 shows, the non-preloaded sample significantly attenuated the acceleration compared to the preloaded specimen where the acceleration of the incident bar was less attenuated. Hence, the acceleration transmission ratio for the non-preloaded specimen was lower than 1 at low frequencies.

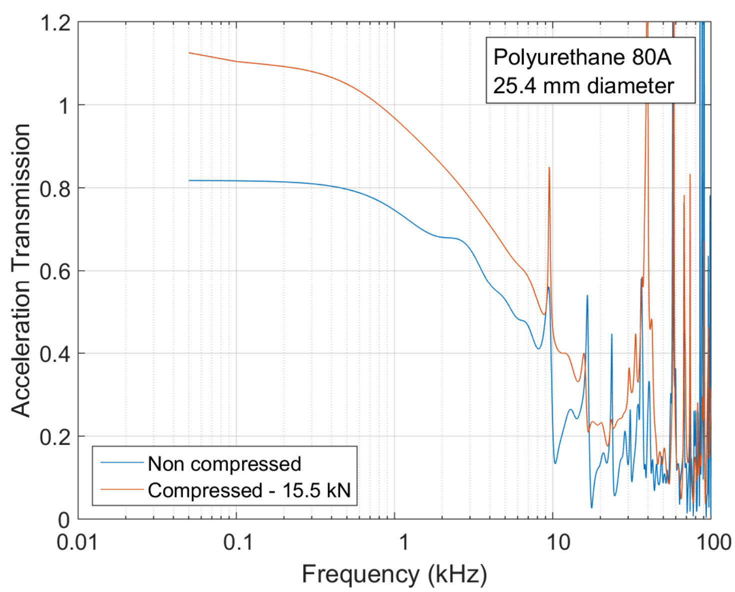

Fig. 1. Comparison of acceleration transmission of compressed and non-compressed polyurethane rubber

Acceleration transmission behavior of the polyurethane rubber with different initial diameters were pre-loaded to 15.5 kN before subjected to the same impact loading are shown in Fig. 2. Two experiments at each condition were conducted to check repeatability. Figure 2 shows that the acceleration transmission ratios for all specimens are close to 1 when the frequency is below 1 kHz, which indicates good transmission up to 1 kHz. The acceleration transmission behavior at frequencies above 1 kHz was found to vary, depending on the initial diameter of the specimen. In general, as the specimen diameter decreased, the highest cutoff frequency for polyurethane rubber increased. For this study, the low-pass cutoff frequency was chosen to be 90% transmission.

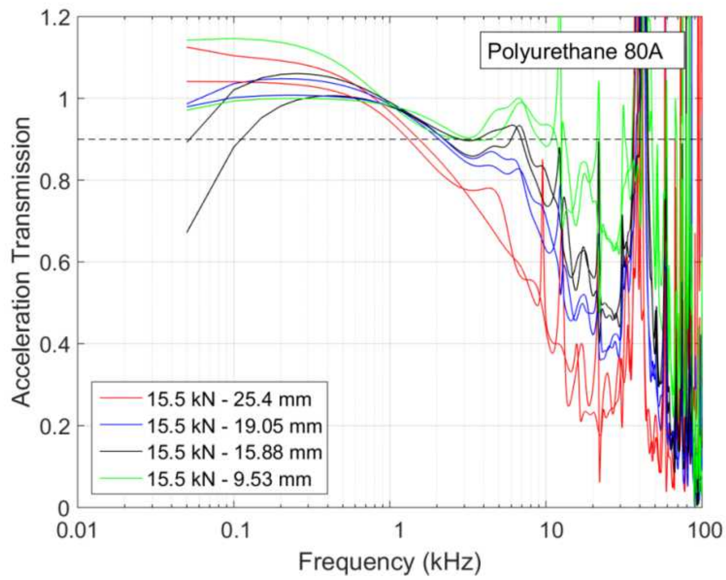

Fig. 2. Acceleration transmission behavior of polyurethane rubber at different initial diameters. The dashed line represents the low-pass cutoff acceleration transmission of 90% defined for this study

The effect of specimen diameter on the low-pass cutoff frequency is summarized for the three rubber materials in Fig. 3. Polyurethane exhibits the most significant effect of specimen diameter whereas neoprene and EPDM rubber show no effect of specimen diameter on the cutoff frequency. Since the initial geometry of the samples was similar, such a difference may be caused by different intrinsic material responses for each of the three materials.

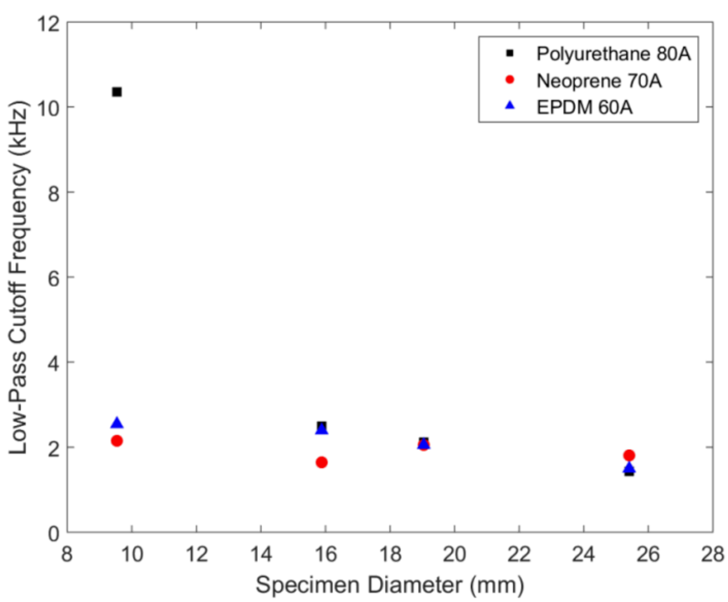

Fig. 3. Effect of specimen diameter on low-pass cutoff frequency

Conclusion

A Kolsky compression bar was modified to preloaded elastomeric specimens to evaluate the shock isolation capabilities under impact loading. A maximum load of 15.5 kN was applied axially to samples confined in a steel tube to provide passive confinement that mimicked the stress-state seen by elastomers after the assembly process. Polyurethane rubber was observed to have a higher acceleration transmission with a preload of 15.5 kN, particularly at low frequencies. Comparing the different elastomers, polyurethane was observed to exhibit an effect of specimen diameter on the low-pass cutoff frequency whereas neoprene and EPDM rubber did not.

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