

Experimental Comparison of Nonlinear Stiffness and Damping Between Taylor Devices' Pumpkin Isolators and Industry-Standard Wire Rope Isolators in 45° Angled Installations

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Taylor Devices' pumpkin isolators and industry-standard wire rope isolators were both tested in a 45° shear/roll angled installation. Nonlinear stiffness and hysteretic damping results are shown, including effects of input frequency and amplitude. The nonlinear damping behavior is linearized at different operating points to show how the damping and spring rate vary with input amplitude and frequency. The wire ropes isolators showed greater damping, but it was highly non-linear, and varied significantly with input amplitude and frequency. The pumpkin isolators showed smaller damping, but it was more linear, and more consistent across different inputs. Applications that each type of isolator are particularly suited for are also discussed.

Introduction

Isolators are used to mount sensitive equipment in high shock and vibration environments. They can be modeled as a spring and damper in parallel, where the spring provides the travel to absorb large shocks, and the damper dissipates the kinetic energy into heat. Both the spring rate and damping relationship need not be linear. The right combination of spring and damping depends on the application, and can be tuned to give an optimal response for a given environment.¹

The industry standard shock and vibration isolators are wire rope mounts and elastomeric supports. Wire rope mounts are constructed from coiled wire rope. The rope is stiff enough to act like a spring, and for large displacements, the strands of the wire rope slide against each other providing frictional damping. Elastomeric mounts are constructed from molded elastomer, which provides mechanical support with its stiffness, and the hysteresis of its stress/stain curve provides damping.

Pumpkin mounts from Taylor Devices are composed of metal leaves with elastomer molded between them, giving some characteristics of both types of mounts. The elastomer provides damping, and the metal leaves provide stiffness. The metal leaves control most of the spring rate of the isolators, provide

¹ *Unique 6 Degree of Freedom Isolation System Composed of Isolators and Overtravel Snubbers, with Power Input Considerations and Limited Sway Space* – SAVE Conference Vendor Session 2024

overload protection, and provide support even if a fire melts the elastomer. Two isolators were mounted symmetrically at a 45° angle in each testing setup. One of each kind of isolators are shown in Figure 1.

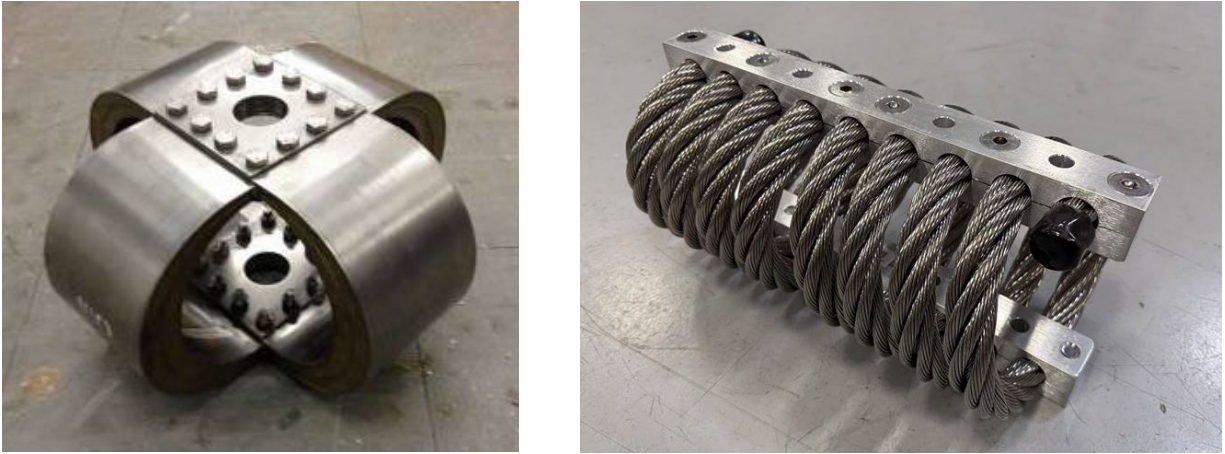


Figure 1 – Pumpkin and wire rope isolator

Testing Setup

Both the pumpkins and wire ropes were tested in the setup shown in Figure 2 and Figure 3. Two isolators were tested at a time, so that their lateral forces would cancel out. A hydraulic ram was connected to the moving side of both isolators, and the other side was held stationary. The non-moving side of the isolator was connected to the frame of the testing machine with rigid instrumented struts. There were six struts supporting each isolator base, making it fully statically determinate, and allowing all three reaction forces and three reaction moments to be calculated. The instrumented struts had S-beam load cells in line with their applied force. The force on the hydraulic ram was measured with a load cell, and the displacement of the ram with a potentiometer.

By using different mid plates, and varying the length of the links supporting the base plates, to vary their installed angle (shown in Figure 2 and Figure 3), different angled installations of isolators can be tested. The tests in this paper used a 45° installation. Straight tension and compression, 22.5°, 30°, and shear and roll installations are also possible, and are planned to be evaluated in the next round of testing.

Many different sine wave test profiles were run, with varying the frequencies, amplitudes, and offsets. Both the pumpkins and wire ropes were tested with ± 0.01 , 0.03, 0.1, 0.3, and 0.5-inch amplitude sine waves at 1, 3, and 5 Hz. They were also tested with an offset of 0.1 inches and an amplitude of 0.1 inches, and a offset of 0.3 inches a amplitude of 0.2 inches. The frequency was limited by the control algorithm of the hydraulic ram of the testing machine.

The pumpkin tested was a TDI 20742 (-8 size), and the wire ropes tested were M32-700-08, purchased from IDC. This testing setup is capable of testing pumpkins between TDI's -5 to -10 sizes, and wire ropes between IDC's M16 to M40 sizes.

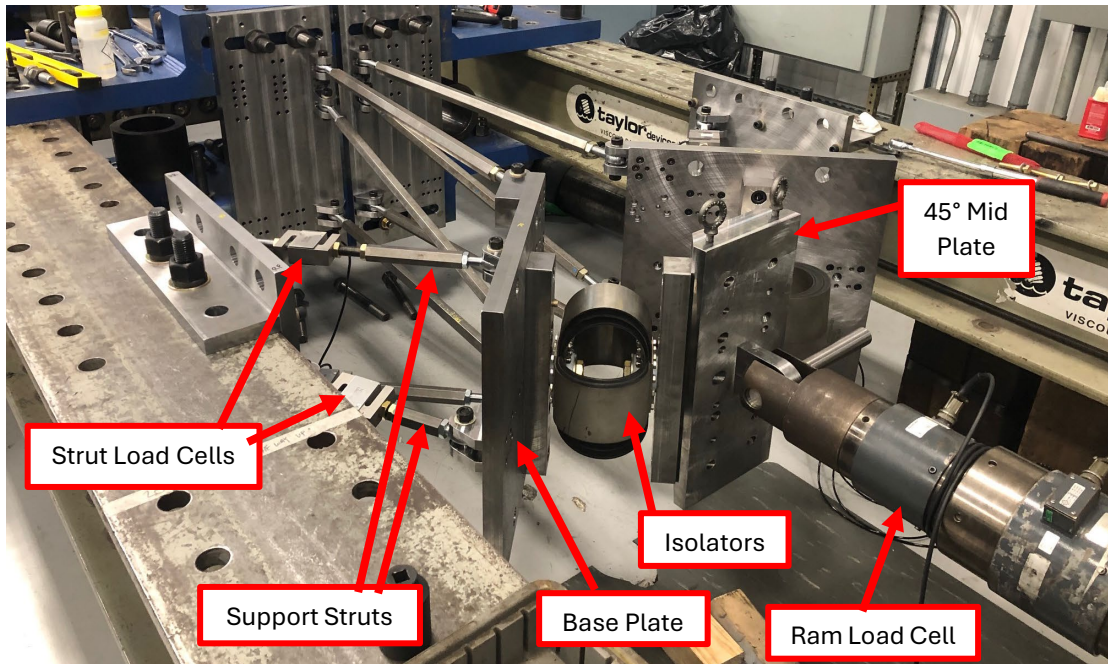


Figure 2 – Testing setup

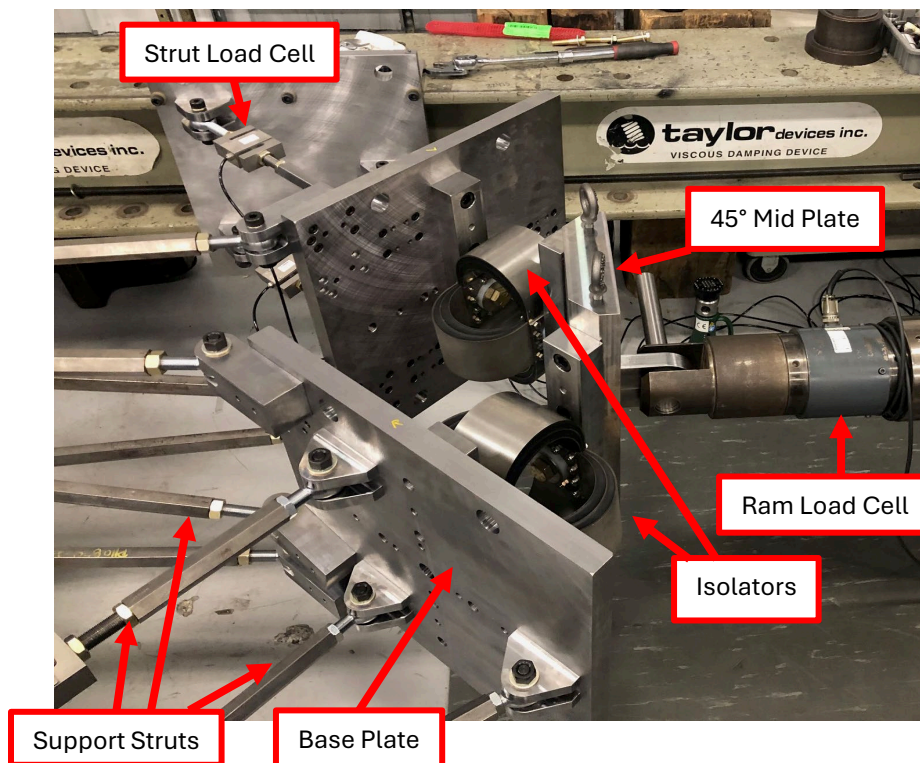


Figure 3 – Testing setup detail

Analysis Process

The average linear spring rate, k_{eq} , was calculated so that one full stroke with the real, nonlinear spring rate absorbed the same amount of spring energy as the same stroke with an equivalent linear spring. The force used, F_{mean} , was the average of the loading and unloading parts of the force vs displacement curves, so that hysteresis and damping did not affect the average linear spring rate. This relationship was

$$\frac{1}{2} * k_{eq} * X_{max}^2 = \int F_{mean} * dx \quad (1)$$

where X_{max} is the maximum displacement of the force vs displacement cycle being considered.

The energy absorbed in a damping cycle, ΔU , is the integral of the hysteresis loop:

$$\Delta U = \int_0^{X_{max}} F * dx \quad (2)$$

The equivalent linear damping coefficient, ζ_{eq} , was then calculated with

$$\zeta_{eq} = \frac{\Delta U}{2 * \pi * k_{eq} * X_{max}^2} \quad (3)$$

which is calculated independently for both the tension and compression parts of the test.

Comparison

Over the frequencies and amplitudes tested, the pumpkin's spring rate varied between 9.4 and 22.2 kip/in. The wire ropes varied between 4.9 and 42.3 kip/in.

The pumpkin's damping ratio varied between 7.2% and 12.9%. The wire ropes varied between 13.9% and 28.2%

One each of the hysteresis curves for the pumpkins and wire ropes is compared in Figure 4. The pumpkins had 9% of critical damping in tension, and a stiffness of 12.1 kip/in, and 11% damping in compression and 9.4 kip/in. In tension, the wire ropes exhibited 16% critical damping, and had a spring rate of 11.9 kip/in. In compression, damping increased significantly to 26%, and the stiffness decreased to 4.9 kip/in.

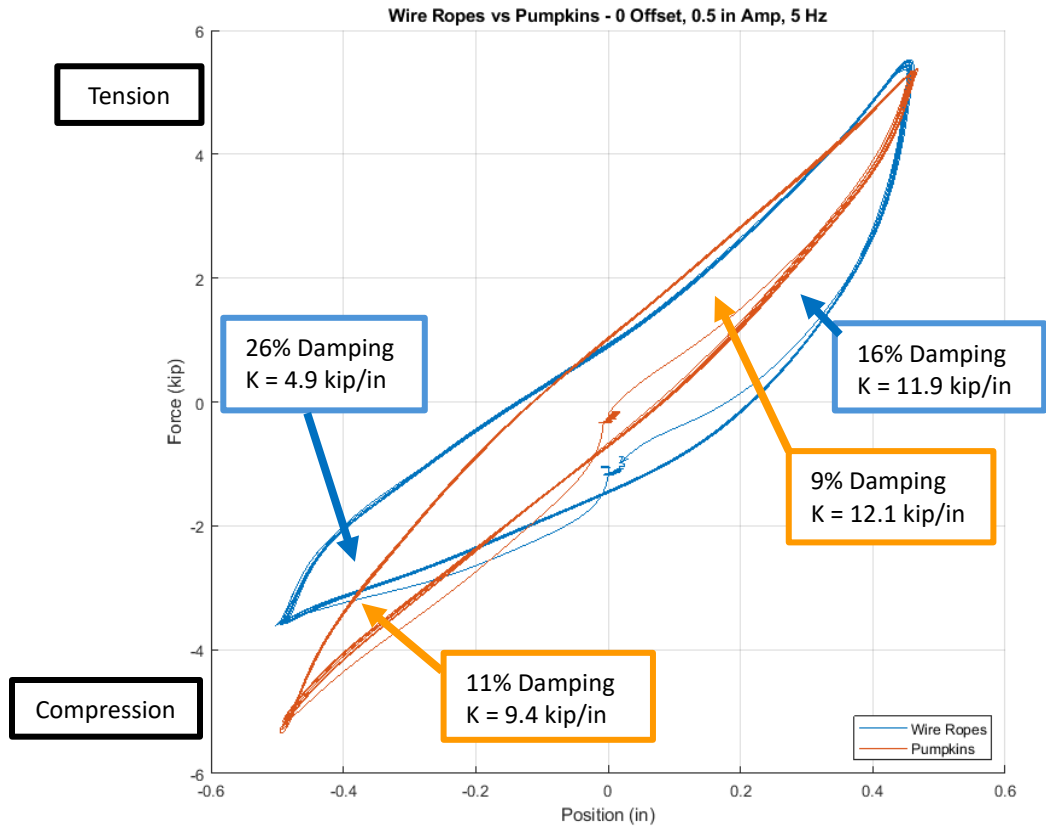


Figure 4 – Wire Rope vs Pumpkin Hysteresis Curve Comparison

The spring rate and damping varied significantly with amplitude, which is shown in Figure 5 and Figure 6.

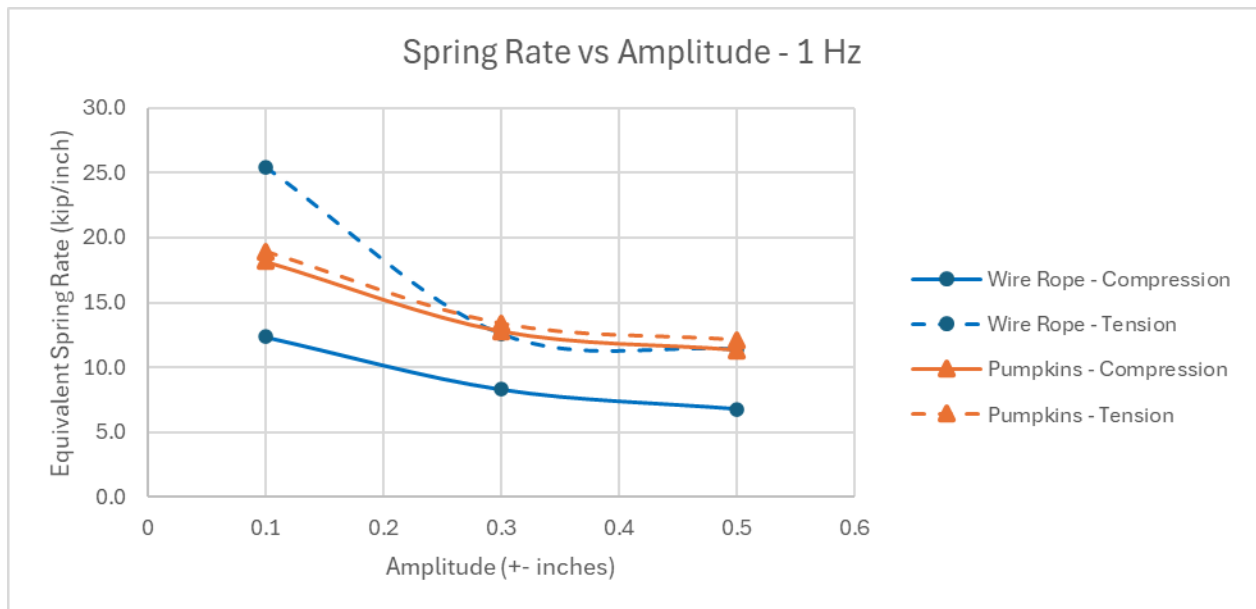


Figure 5 – Spring rate vs amplitude

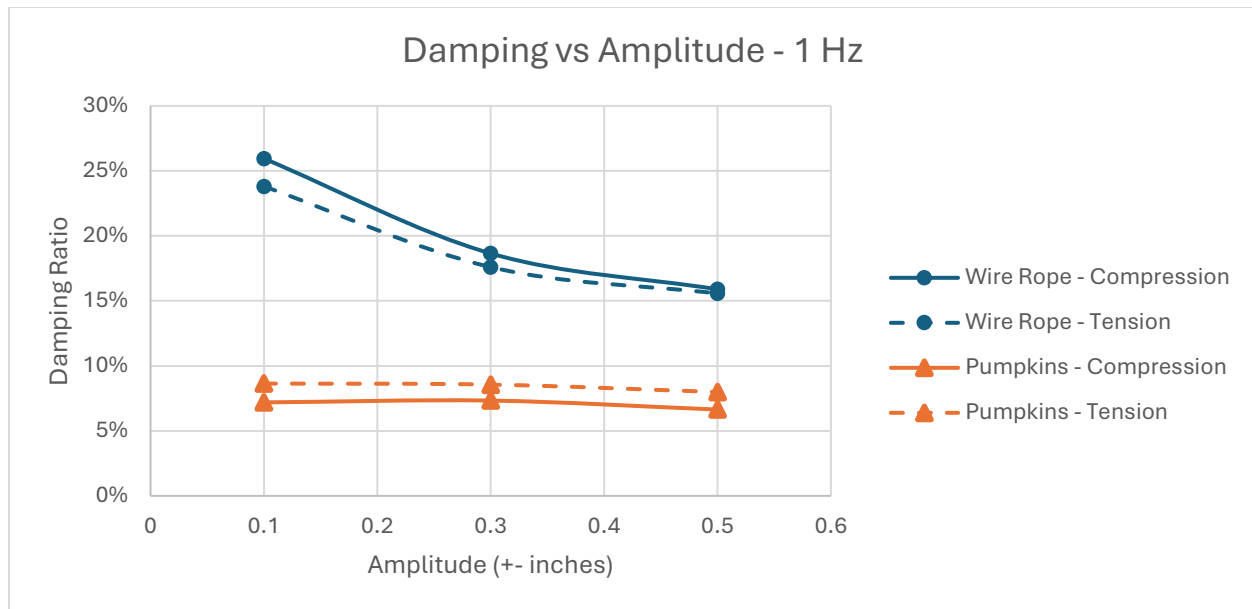


Figure 6 – Damping vs amplitude

The spring rate and damping ratio did not vary as significantly with frequency, which is shown in Figure 7 and Figure 8.

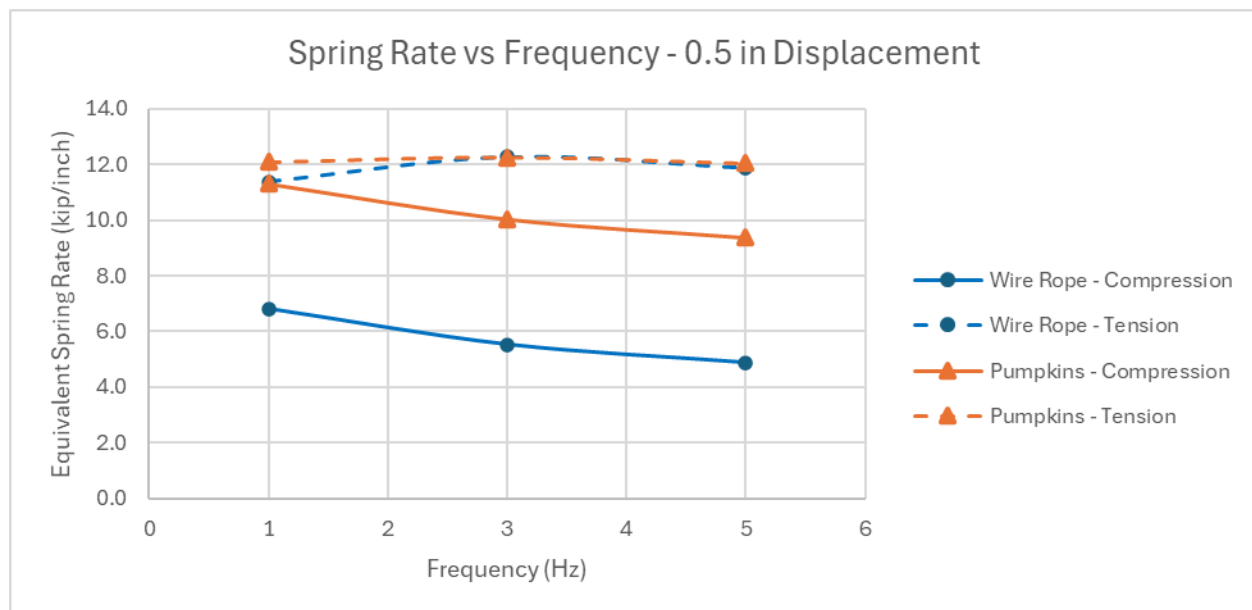


Figure 7 – Spring rate vs frequency

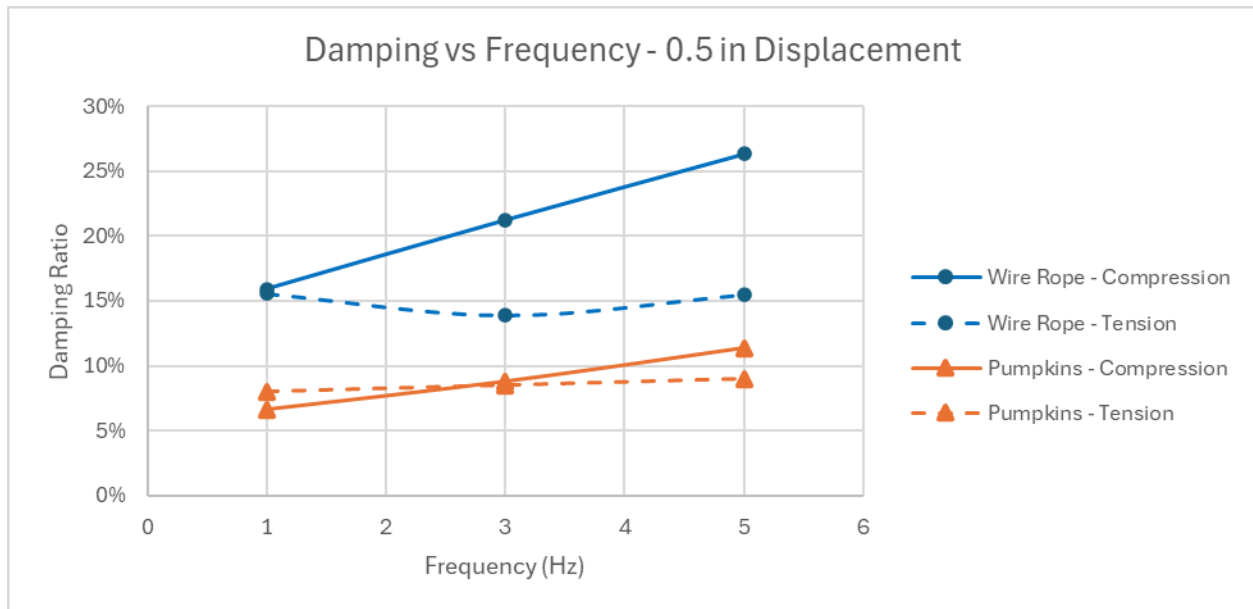


Figure 8 – Damping vs frequency

Conclusions

The pumpkins tested showed lower, but more consistent damping than the wire rope isolators tested, as shown in Figure 6 and Figure 8. This makes wire rope isolators more suitable for applications that require high damping, but pumpkins more suitable for applications that require more predictable and consistent damping.

Both pumpkins and wire rope isolators spring rate varied similarly with input amplitude and frequency, as shown in Figure 5 and Figure 7. Wire rope isolators spring rate, however, varies significantly between tension and compression, which can be seen in Figure 5. Pumpkins had a much more consistent spring rate across their tested deflection range. Like the effect of damping, this makes pumpkins more suitable for applications requiring consistent stiffness between tension and compression.

Based on these two effects, pumpkins behave more like ideal, linear, spring and damper isolators. This can be used by isolation system designers to accurately analyze and design isolation systems using pumpkins. With the linear assumption, design and analysis may be performed in the frequency domain, as opposed to the time domain, which greatly speeds up the process, and makes the results more applicable across a wider range of inputs. The more consistent properties also make the system more robust to inputs that vary from the ones considered during design. If the input vibrations and shocks are well defined, this is not necessary. But, if there is a wide range of inputs that must be protected against, this property will better protect the item being isolated.

Another property of wire rope isolators that has been observed in vibration testing is that the wire rope strands do not slide past each other until a certain minimum force is reached. The stiction between the strands must be overcome before they start to slide and provide frictional damping. This makes the isolator much stiffer at low amplitudes, even smaller than what is shown in Figure 5. This raises the natural frequency of the isolation system, sometimes by as much as a factor of 2. This is a particular problem for

time-compressed vibration profiles, such as composite wheeled vibration in MIL-STD-810. In those, a higher amplitude vibration is applied for a shorter time to test a system as much as the predicted in-service, lower-amplitude vibration applied for a longer time. If the system is linear, both of these vibration profiles will be equally severe for the system. But, if the in-service amplitudes of the system are significantly smaller than the time-compressed amplitudes, the test is not representative because the natural frequency of the isolation system is significantly different in test than in service. This is much less of a problem for pumpkins, which do not have stiction which must be overcome. So, a time-compressed test with pumpkin isolators is more accurate than with wire rope isolators. Even if the end-use is intended to be single-event shock events, such as MIL-DTS-901, there are still usually transportation requirements, such as MIL-STD-810, which the payload must survive.

In summary, pumpkins provide stiffness with metal leaves, like metal wire rope isolators do with their metal strands. This has the advantage over elastomeric supports in that it varies less with temperature, and provides overload and fire protection. Pumpkins provide damping via hysteresis of their elastomer's stress/strain curve, like elastomeric supports. This has the advantage over wire rope isolators of varying less with input amplitude and frequency. Hysteresis damping also does not suffer from stiction, which changes the isolation system's natural frequency at very low input amplitudes.