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Mechanical Inerter

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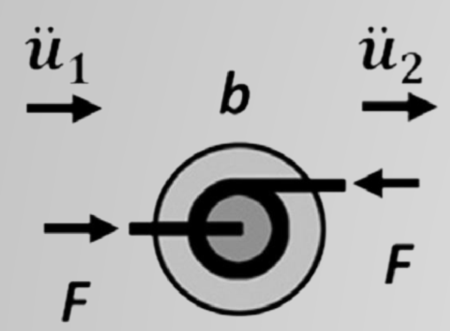
Project Description

An earthquake releases a large amount of energy into the structure of a building which can cause vibrations. Dr. Pai Wang is conducting research to determine if a large chain of mechanical inerters can be developed to damp low frequency vibrations. The damping force provided by inerters is proportional to the relative acceleration of both ends, as shown in Figure 1. This project represents a one dimensional chain in a metamaterial to validate the creation of frequency-damping metamaterials. Our team was tasked with the design, production, and assembly of mechanical inerters and creating a test setup to determine their effectiveness.



$$F = b\,(\ddot{u}_1 - \ddot{u}_2)$$

Figure 1: Equation for force in a rack and pinion inerter

Problem

Inerter Specifications:

- Operating frequency of 0.1 Hz to 3.8 Hz
- Negligible friction
- Inertance values are consistent within ±5% tolerance between inerters
- Inerter insertion and removal possible
- Possible inertance-to-mass ratio ≥ 1000
- Maximum cost is $70 per inerter
- Maximum size is 10 x 10 x 10 cm per inerter
- Maximize number of masses
- Damp vibrational amplitude by 33%

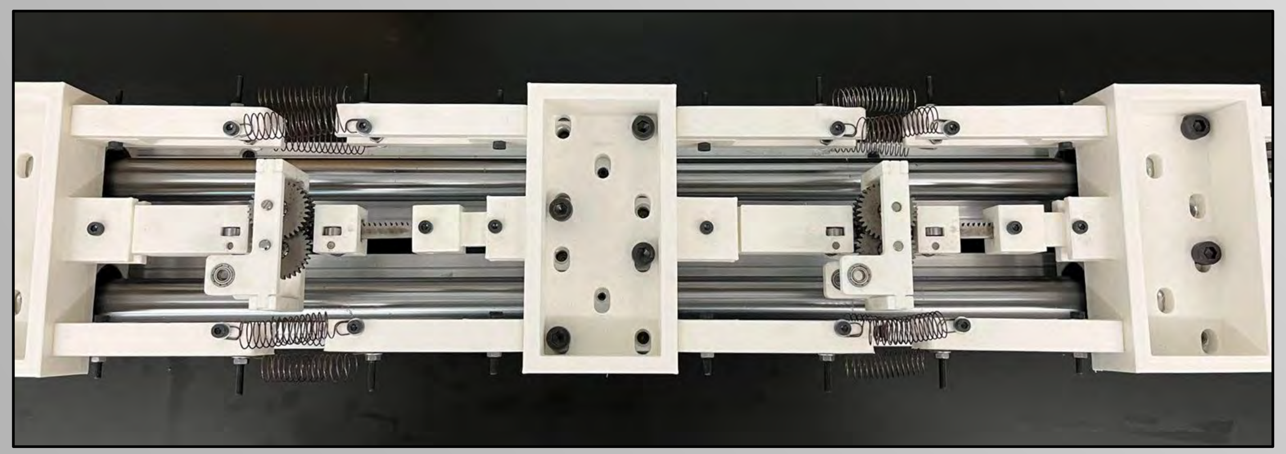


Figure 2: Mass spring chain test setup with inerters in place.

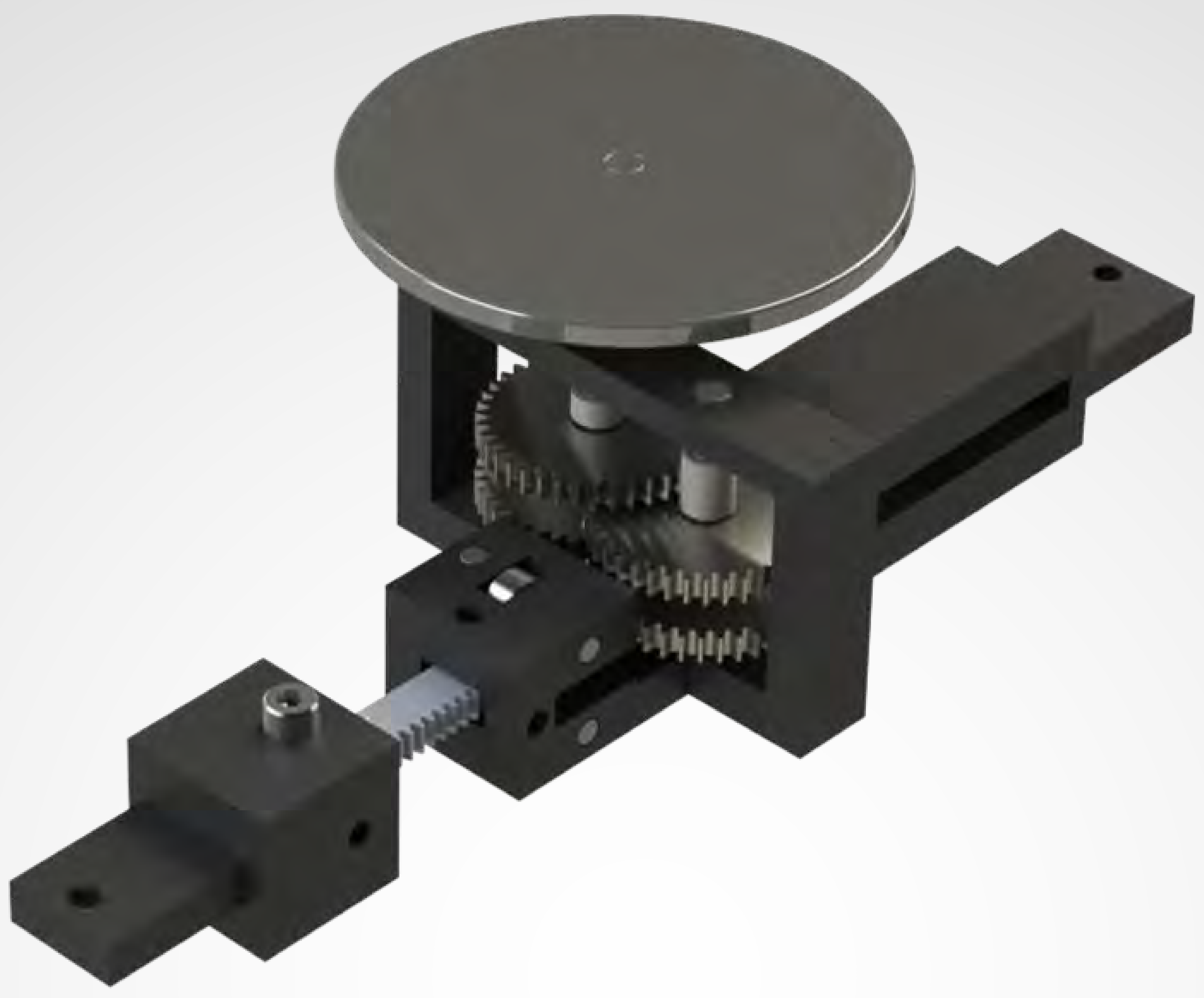


Figure 3: Rack and pinion mechanical inerter assembly

Methods

Our solution for damping low frequency vibrations in a compact and low-cost way is to use mechanical rack and pinion inerters, as shown in Figure 3. Rack and pinion inerters are damping devices that provide inertia in the form of gears and a flywheel while only taking up a small amount of space compared to other damping devices. When the inerters are combined together to form a chain, as shown in Figure 2, they can be effective at eliminating vibration propagation within a given frequency range.

In addition to the assembly of rack and pinion inerters, a mass spring chain of seven mass blocks on linear rails was constructed to facilitate the testing of the performance of the inerters. A shake table was used to oscillate the first mass block in the system and six inerters were placed in between the masses. Position and time data of the mass blocks were collected at a range of low frequencies to assess the performance of the inerters. The data was analyzed using MATLAB to create figures similar to Figure 4 and to compute the percentage of vibration amplitude that was reduced.

Results

- Without inerters at 1.5 Hz the last mass vibrated with a minimum amplitude of 8.54 mm.
- With inerters in the chain, at 1.5 Hz, the last mass vibrated with a maximum amplitude of 4.62 mm.
- The inerters were effective at damping the oscillation of the last mass for frequencies from 1.0 Hz to 1.5 Hz.
- Because of variability in manufacturing, each inerter needed to be tuned to get the desired damping effect
- Experimental inertance was 25% lower than theoretical inertance.
- Percent of vibrational amplitude reduced with inclusion of inerters:
  - 1.0 Hz: 42.32%
  - 1.5 Hz: 45.93%

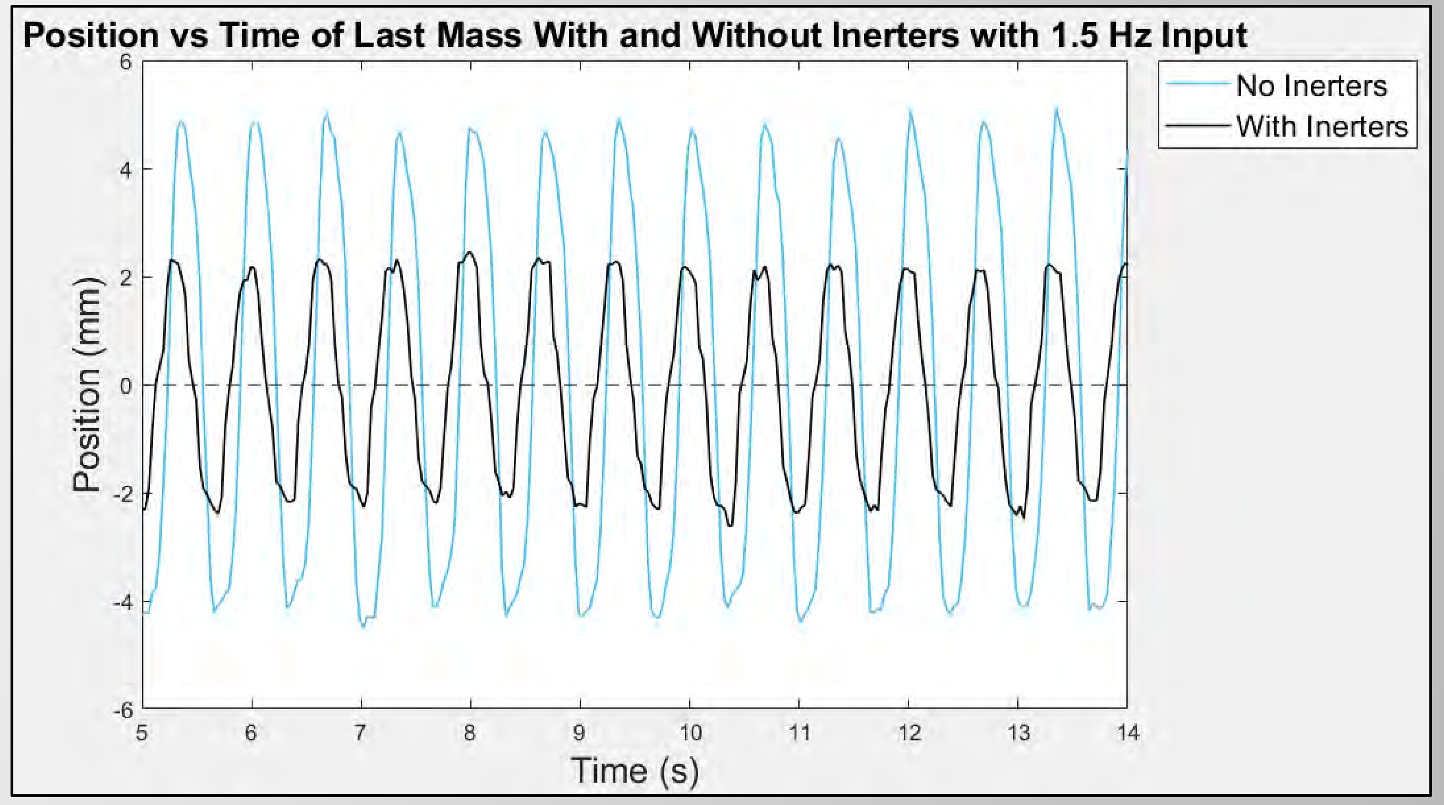


Figure 4: Position vs time of the last mass in the chain without inerters (light blue) and with inerters (black). A shake table was used to oscillate the first mass at 1.5 Hz for both cases.

Conclusion

The mechanical inerter chain causes damping in the frequency and amplitude of vibrations from 1.0 Hz to 1.5 Hz. As shown in the results, between 1.0 Hz and 1.5 Hz the inerters reduced vibrational amplitude by 44.13% on average. Some of this damping is caused by friction in the system, which may be amplified by including the inerters in the chain. Additional research could be conducted to characterize the effect of friction on the system with and without the inerters. More tests could be performed to analyze the consistency of the inerters in practice and characterize them against repeated trials.