THE UNIVERSITY OF UTAH
MECHANICAL ENGINEERING

Mechanical Inerter for Seismic Protection

Joe Cochran, Will Gilliland, Cooper Hansen, Nathan LeCheminant, Eric Schneggenburger, Scott Stack
Advisor: Dr. Pai Wang

Background

Current aseismic technology is expensive and failure prone because damping is generally reliant on large singular parts. Mechanical inerters provide a novel solution to damping vibrations. Borrowed from Formula 1 suspension technology, the mechanical inerter is easily tunable and can be implemented in mass

Goal

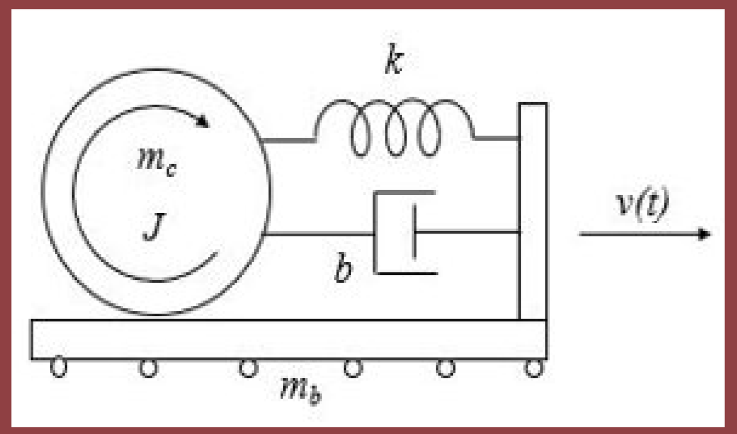
Design a mechanical inerter and experimental set-up, and then determine the damping capabilities of the mechanical inerter

Objectives

Objective	Metric	Target Value	Achieved Value
Dampen vibrations	Decrease in magnitude	> 50%	56%
Scalable design	Prototype volume	< 1000 cm^3	783.75 cm^3
Affordable design	Prototype price	< \$100	\$64.47
Design a shake table testing apparatus	Motion frequency	0 Hz – 2 Hz	0.88 Hz
Create an accurate analytical model	R^2 value	> 0.90	0.87

Analysis

A mathematical model of the mechanical inerter and shake table system was created to verify experimental results and to more easily analyze the mechanical inerter's response across varying parameters and inputs.



Simplified lumped model of the system

List of the system's parameters

Parameter	Symbol	Value
Pinion Gear Radius	r	$2.8\ cm$
Shake Table Mass	m_b	$800\ g$
Mechanical Inerter Cart Mass	m_c	$483\ g$
Flywheel Inertia	J	$3.5x10^{-5}\ kg \cdot m^2$
Spring Constant	k	$186\ N/m$
Viscous Damping	b	$10\ N \cdot m/s$
Velocity Input	$v(t)$	$6\pi f sin(\omega t)$
Frequency	f	$0.88\ Hz$

$$\frac{dx}{dt} = \frac{A(m_b + m_c)v(t) + Bp}{1 - m_c}$$

$$\frac{dp}{dt} = -b\frac{A(m_b + m_c)v(t) + Bp}{1 - m_c} - kx$$

$$A = \frac{-r^2 m_c}{m_b m_c r^2 + J(m_b + m_c)}$$

$$B = \frac{r^2(m_b + m_c)}{m_b m_c r^2 + J(m_b + m_c)}$$

$$x_{c/g} = v(t) + x$$

System of Equations

List of the system's outputs

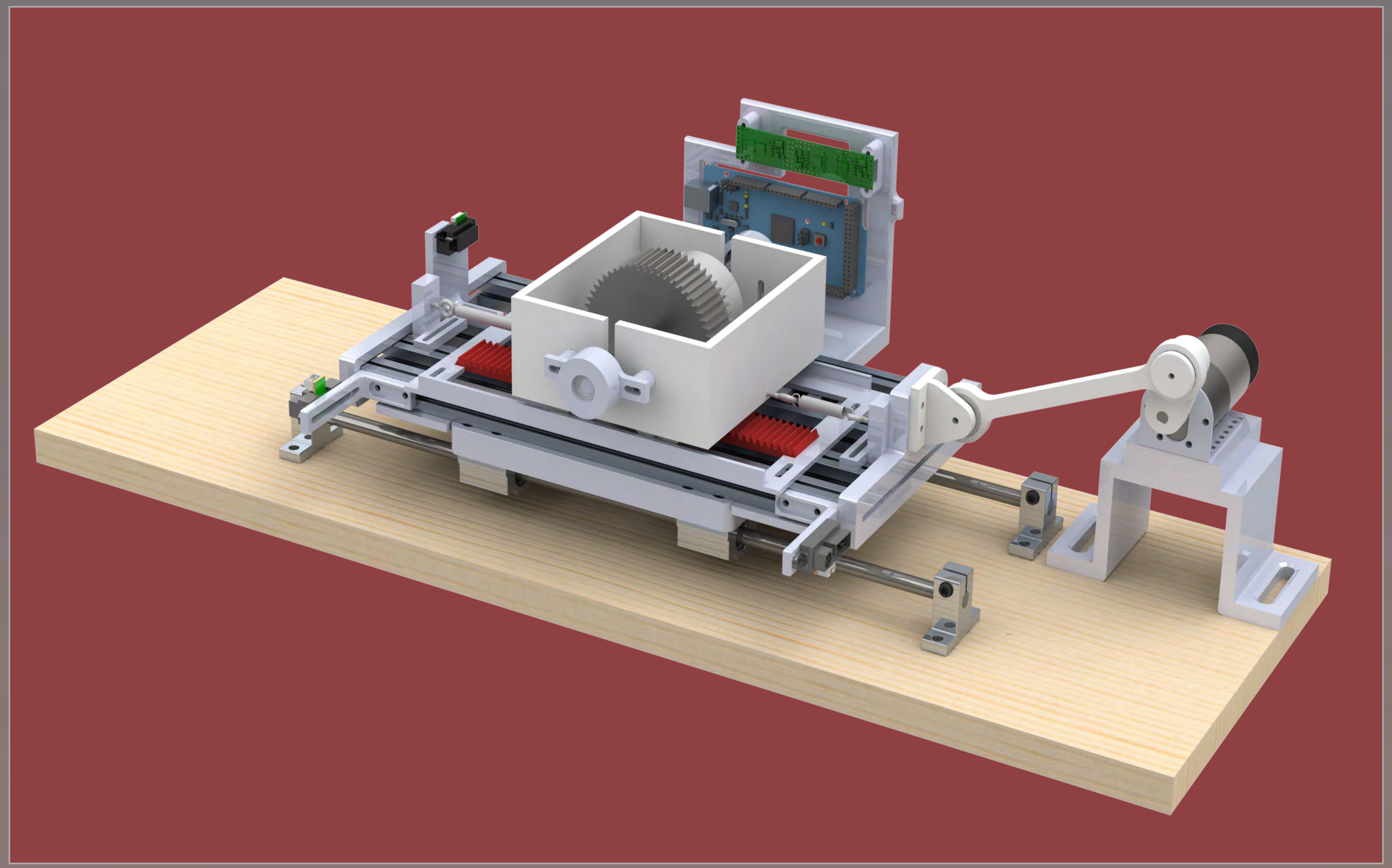
Output Term	Symbol
Relative Mechanical Inerter Displacement	x
Relative Momenta	p
Mechanical Inerter Displacement	$v_{c/g}$

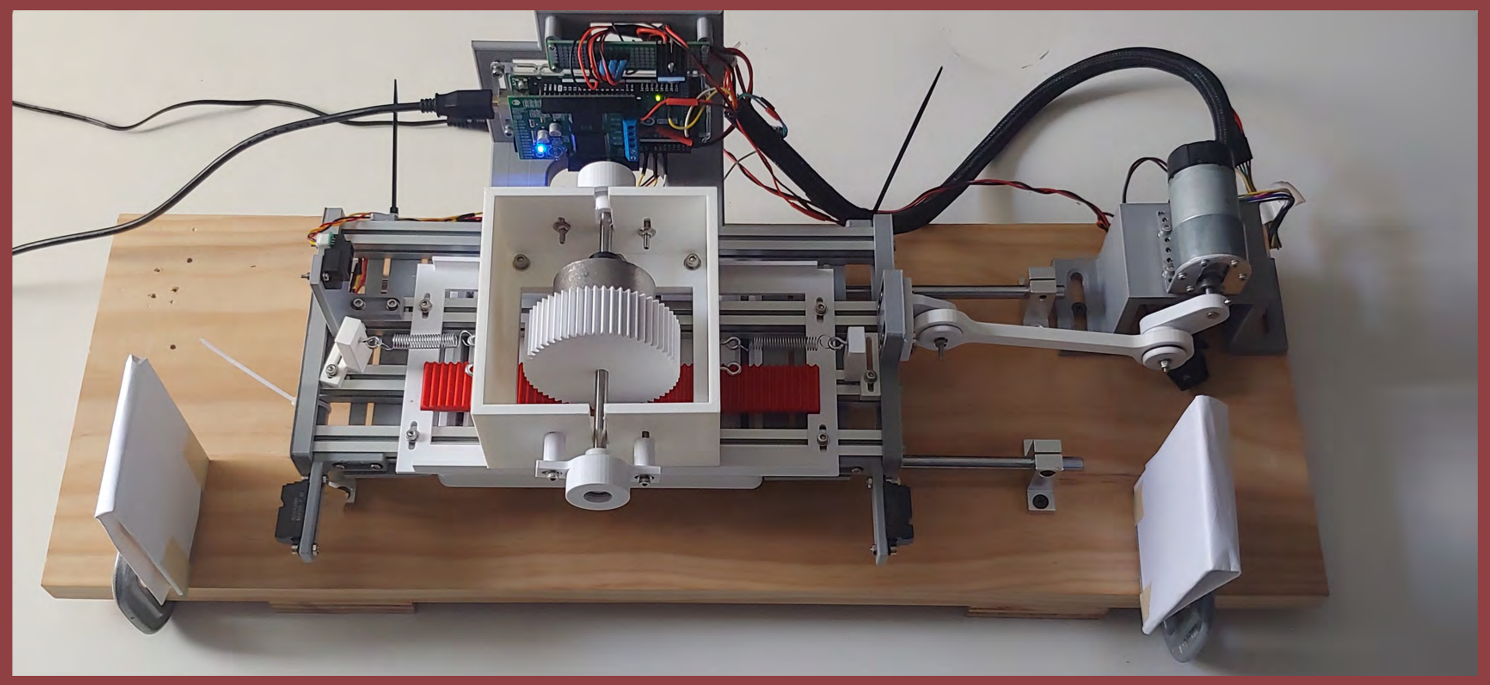
Mechanical Inerter

The mechanical inerter is a rack-and-pinion mounted in a cart. The pinion gear attaches to the same shaft as a flywheel. Two springs attach the cart to the shake table walls. The cart runs along a rack that is mounted to the shake table.

Shake Table

The shake table is a platform mounted on CNC rails which is driven by a crank-slider. The shake table's displacement is sinusoidal across a 6 cm range.





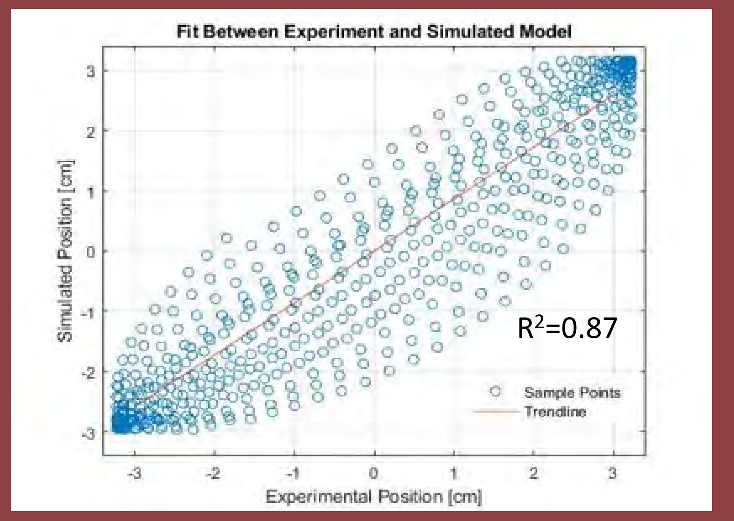
Shake Test

The shake table is run at steady sinusoidal motion for 10 seconds. IR sensors mounted on the shake table capture the displacement of the mechanical inerter and the displacement of the shake table itself. Shake table tests were run for a variety of different springs.

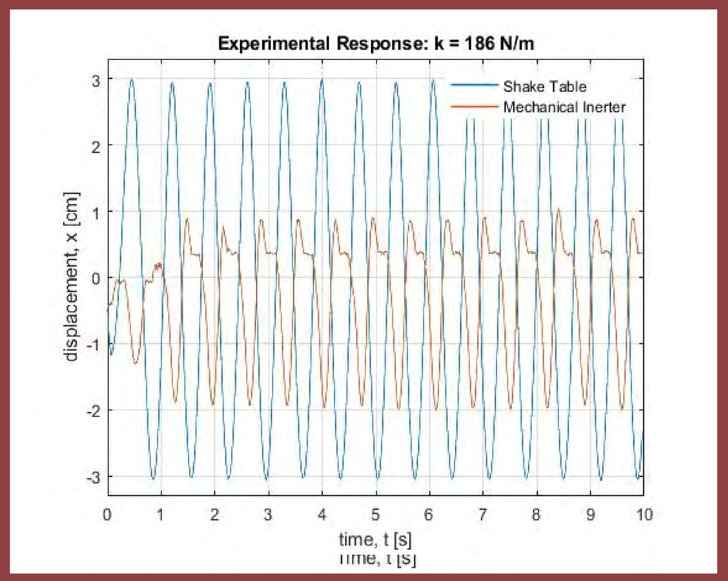
Watch video of test

Results

The top graph illustrates the fit between the experimental and analytical models with a spring constant of 0. The R^2 value is 0.87. As the spring constant increases, the fit worsens. The bottom graph contains the experimental displacement of the mechanical inerter compared to the shake table at a spring constant of 186 N/m. The mechanical inerter's steady state amplitude is 56% smaller than the shake table's amplitude.



Analytical and Experimental Comparison



Shake table and inerter displacement

Inerter Damping Effectiveness

Spring Constant [N/m]	Vibration Damping [%]
130	13
154	33
186	56

Conclusion

The mechanical inerter is an effective vibration dampener, reducing input vibrations by 56% when a spring of 186 N/m was used. There is some discrepancy between the analytical model and experimental tests. This is largely because nonlinear effects were ommited in the analytical model, and a more complicated model is necessary to accurately represent the system.

Future Work

As this project progresses forward with incoming teams, lots of work will center around the scalability of the device. The inerter itself will need to be embedded in the foundation of buildings and will require many units to accomplish the goal of seismic mitigation. Future teams will need to test arrays of inerters and develop methods for integration into the structures themselves.