Departures of linearity in driven torsional oscillations

Thresa Kelly, Jacob West, and Michael Murray
University of Kansas, PHSX 616 Physical Measurements
(Dated: October 27, 2023)

[Note:: Add couple sentences of science context.]
In this research, we will be inspecting the non-linear properties of damping from magnetic, sliding, and fluid damping in a driven torsional oscillator. When driving the apparatus at its resonant 862±2 mHz frequency, we observe that magnetic damping fails to behave linearly at large driving amplitudes of ∼0.2 V.

I. INTRODUCTION

[Note:: discuss the following: development of oscillatory motion theory (damping, resonance, driving), then talk about electromagnetism with Faraday's law of induction equations]

In this research, we will be inspecting sources of non-linearity in torsional oscillations. We will vary the amplitude of the driving signal and record the amplitude of the response for three different sources of damping: sliding (v^0), magnetic (v^1), and fluid (v^2).

II. METHOD

Figure 1 shows a diagram of the torsional oscillator used in this research. The oscillations of the apparatus can be damped or driven using magnets and inductors. A pair of magnets generate a magnetic field from the North to South magnet. Moving metal between the magnets causes a changing magnetic field in the metal, which creates a counterclockwise electric field. The electric field induces circular currents, called Eddy currents, that an opposing magnetic field; this causes the moving metal to decelerate. In the apparatus, there are two pairs of magnets surrounding the oscillating disk that dampen the torsional oscillating motion. These magnets can be adjusted to cover more or less area on the oscillator to increase or decrease the damping. Magnetic fields can also be used to increase oscillations. An inductor, or coil of current carrying wire, generates a strong magnetic field through the core. The field applies forces on external charges. In the apparatus, there is a magnet connected to the oscillating disk placed between two inductors. Powering the inductors attracts or repulses the central magnet, depending on the direction of the current. Oscillating the inductor currents drives torsional oscillations in the apparatus.

In this research, we will be inspecting the non-linear properties of the torsional oscillator apparatus. Under normal conditions, the driving inductors cause linear changes in the torsional oscillations: increasing the amplitude of the source waveform increases the amplitude of rotational motion. However, is the linear range of source amplitudes limited? We will test this by increasing the peak-to-peak amplitude of the source waveform at its resonant frequency to the oscillator.

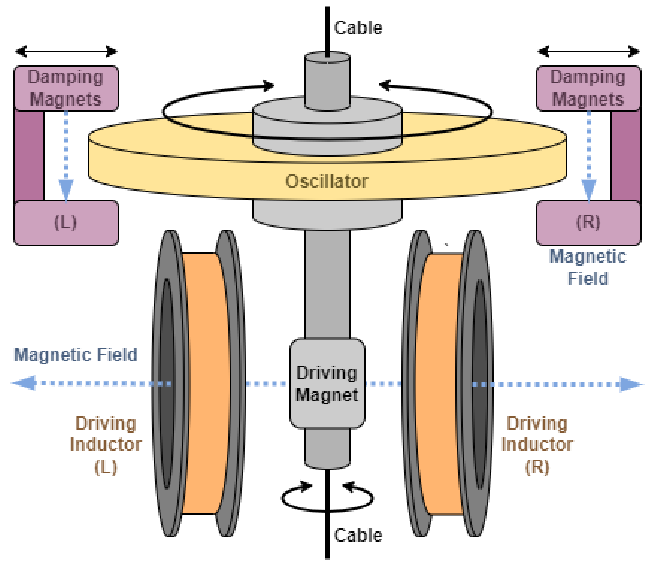

FIG. 1. Torsional oscillator apparatus. A large central copper disk (yellow) is suspended by a taut cable and can twist freely. There are two sets of magnets (purple) on the left and right sides of the disc which can be moved closer and farther from the oscillating disk. These magnets create Eddy currents in the disk which oppose the changing magnetic field, which dampen the oscillations. Below the disc are a two inductors (orange) whose current is controlled by an external wave generator. The inductors create a magnetic field that generates a force on a central magnet, which drives the oscillations. The torsional motions of the disc is measured with an oscilloscope.

Under ideal conditions, the only source of damping in the apparatus are the drag from the damping magnets (v^1; linearly correlated with velocity). However, there are two other sources of drag: sliding friction from twisting (v^0; independent of velocity) and fluid friction from the air surrounding the apparatus (v^2; square of the velocity). To test the v^0 damping, we attached a taught cord through the oscillator and then observe how the driving amplitude changes with respect to the response amplitude. Next, we will test v^2 by attaching paddles to the oscillator disk before observing the driving and response amplitudes.

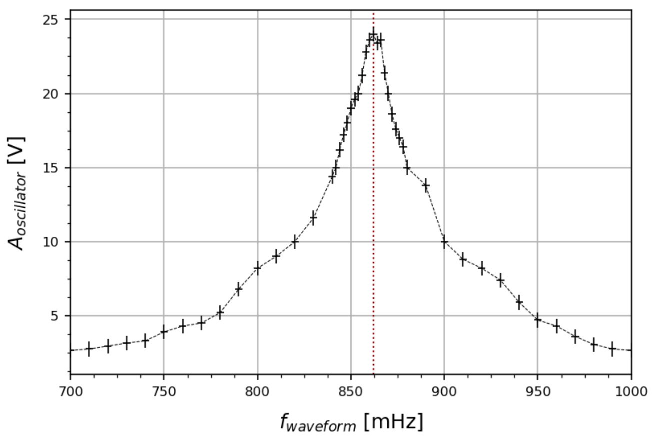

FIG. 2. Amplitude of torsional oscillations (A) as a function of the driving waveform frequency (f). The source amplitude was set to 2.500±0.005 V Resonance occurs at the peak amplitude at 862±2 mHz (red dotted line). Data is taken at finer frequency resolution near the resonant peak.

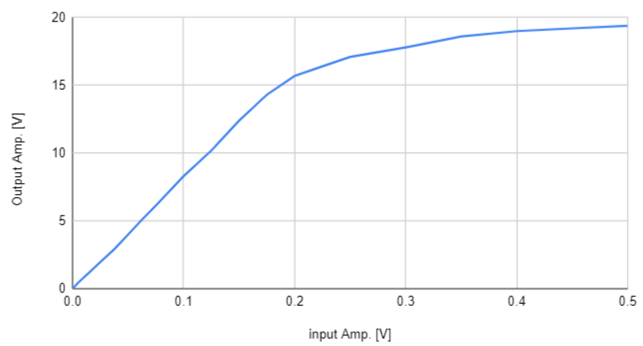

FIG. 3. Response amplitude for varying driving amplitude voltages. The response is linear up until a driving amplitude of ∼0.2, where the slope begins to decrease. The response amplitude levels off to ∼20 V for large values of the driving amplitude. Error bars are not drawn on this plot. *[Note:: Build better plot in Python. Draw best fit line in linear region and to chi-squared. Do chi-squared for all data to show that it is a very bad fit.]*

III. RESULTS AND DISCUSSION

In this work, we test the non-linearity of v^0, v^1, and v^2 damping in driven oscillations. We claim the following instrumental uncertainties: the driving amplitude is ±0.005 V, the driving frequency is ±2 mHz, the response amplitude is ±0.5 V

We determine the resonant frequency of the apparatus by varying the frequency of the 2.50±0.01 V driving waveform and measuring the amplitude of the response. The results are shown in Figure 2. Resonance occurs when the amplitude is maximized. We find that the apparatus is resonant at a 862±2 mHz driving frequency. The amplitude drops off rapidly at lower and higher frequencies.

Next, we inspect the v^1 damping from the magnets located above and below the copper oscillator disk. These magnets are adjusted to the furthest distance from the disk to provide weak damping. We vary the driving amplitude from 0.005±0.005 V to 0.500±0.005 V at the resonant frequency and measure the resulting torsional amplitude; the results are shown in Figure 3. The apparatus behaves linearly up to around a source amplitude of 0.2 V. Beyond this, the response begins to drop off towards an asymptote of about 20 V. The disk is oscillating quickly at these high frequencies, which leaves less time for the Eddy currents to form in the disk and oppose the velocity.

IV. CONCLUSION

The goal of this research was to define the non-linear properties of driven torsional oscillations for three different sources of damping, each having a different relationship with the rotational velocity (v). Sliding damping (v^0) results from friction in the cable. Magnetic damping (v^1) occurs by placing the oscillating copper disk between magnets and generating Eddy currents. Lastly, fluid (v^2) damping originates from drag from the device moving in air. To perform this research, we use a torsional oscillator apparatus, which consists of a copper disk suspended between tight cables, two driving inductor coils, and two sets of damping magnets.

First, we find that the resonant frequency of the apparatus occurs at a driving signal of 862±2 mHz. We operate the driving current at this frequency for the duration of the experiment. Next, for v^1, we found that the resultant amplitude for varying driver amplitude becomes non-linear at driving amplitudes greater than ∼20 V. At higher amplitudes, the disc is moving too quickly to be effectively slowed by the damping Eddy currents from the magnets.