

# MECHANICAL INERTER TEST RIG

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## Intro

Inerters function by transforming translational energy into rotational energy. This allows for the inertia created in the mechanism to provide a damping effect known as inertance.

Inerters were originally designed by F1 teams. Due to the secrecy surrounding the initial design of inerters, no work has been done to standardize the characterization and testing of the b-value. The b-value is a property that relates the force applied and the difference in acceleration between the two terminals of an inverter.

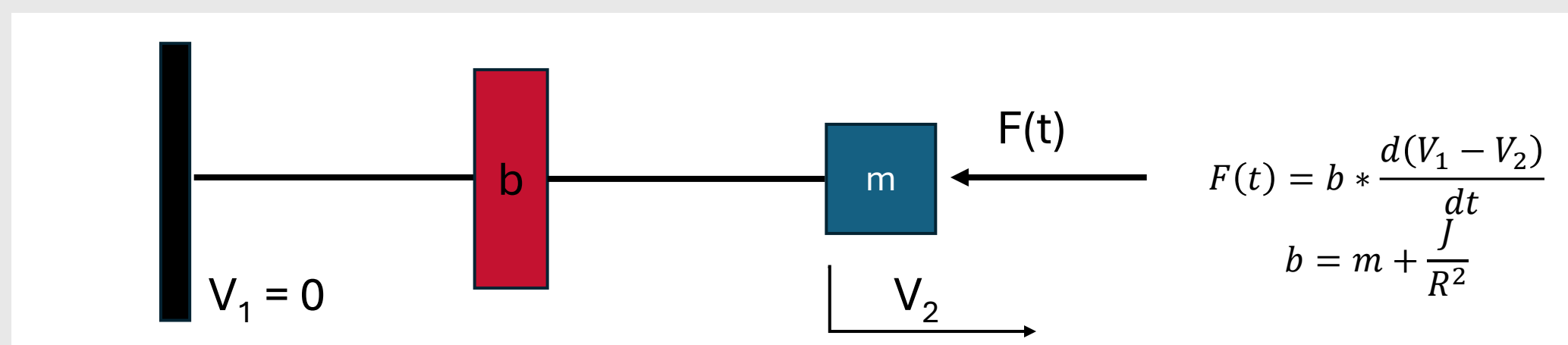


Figure 1: Free body diagram of the inverter test setup with the characteristic equation. It is assumed the left terminal is static, and there is no friction between components.

## Objective

- Create a standardized testing framework that will allow manufacturers and researchers to consistently and accurately characterize an inverter's b-value
- Provide a handbook of best practices for inverter testing
- Compare theoretical and experimental b-values

## Methods

The developed test stand fulfills four critical functions:

- Provide linear actuation to the inverter
- Ground one terminal of the inverter
- Gather force and acceleration data
- Minimize external vibrations

Table 1 quantifies these critical functions as well as other limitations on the project.

Table 1: Project metrics and the achieved values. Values that don't meet current project metrics are highlighted in red.

Metric	Target Value	Achieved Value
Repeatability	10% Average Normalized Error	3.9% Average Normalized Error
Force Range	0.1 N to 50 N	0.1 N to 50 N
Acceleration Range	0.1 $m/s^2$ to 40 $m/s^2$	1 $m/s^2$ to 44 $m/s^2$
Frequency Range	0.5 Hz to 5 Hz	1 Hz to 16 Hz
Control Locations	< 3 Locations	2 Locations
Inverter Size	5x5x200cm	10x10x350cm

## Experimental Setup

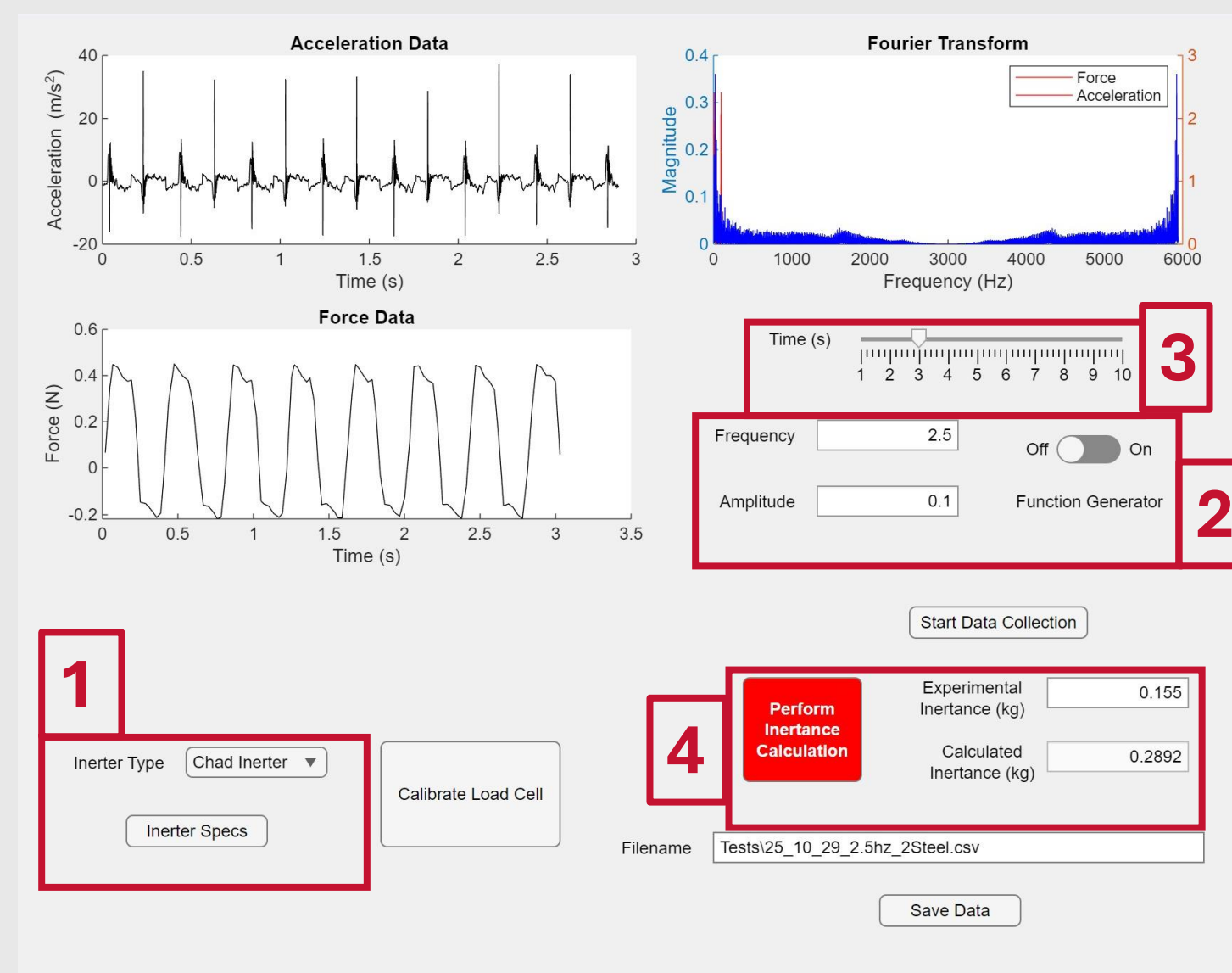


Figure 2: MATLAB GUI

The GUI allows the operator to (1) configure the parameters of their inverter, (2) control the output of the function generator, (3) select a data collection interval, and (4) collect/analyze the data. The GUI plots the acceleration data, force data, and the Fast Fourier Transform. All information gathered by the GUI can then be saved to a user specified location.

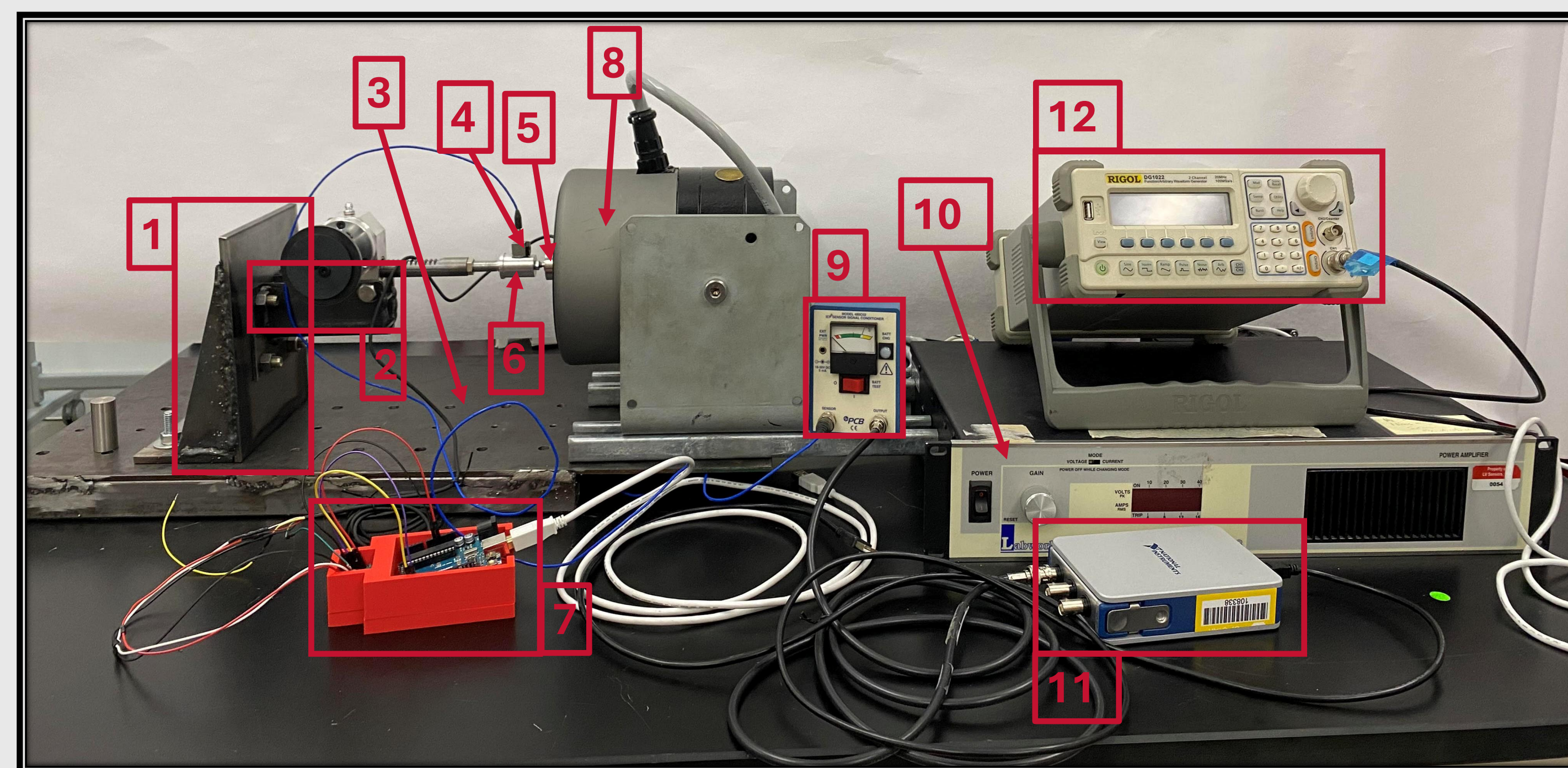


Figure 3: Full Experimental Setup

1. Ground Plate
2. Gear Inverter Mounting Assembly
3. Baseplate Assembly
4. Accelerometer
5. Load Cell
6. Inverter-Load Cell Connector
7. Load Cell Amplifier and Arduino
8. MT-160 Modal Thruster
9. Accelerometer Signal Conditioner
10. PA-138 Linear Power Amplifier
11. cDAQ-9171 Data Acquisition Box
12. Waveform generator

## Test Procedures

1. Calibrate Load Cell with GUI
2. Assign inverter specifications
3. Align MT-160 and ground with inverter
4. Connect inverter and accelerometer to MT-160
5. Clamp test stand to stable surface to reduce external vibration
6. Use GUI to run tests between 1.5 Hz and 16 Hz
7. Save and plot data to see trends

These test procedures were used to gather experimental data on an inverter with different flywheels: no flywheel, a 2.5" aluminum flywheel, and a 2.5" steel flywheel. The experimental b-values were then compared to the theoretical b-values of the inverter.

## Results

The theoretical b-value of the inverter is calculated by

$$b = m + \frac{J_{eff}}{R_{eff}^2}$$

where b is the expected inertance, m is the translational mass,  $J_{eff}$  is the rotational inertia of the flywheel, and  $R_{eff}$  is the effective radius. For all tests the translational mass (220.0 g) and the effective radius (15.52 mm) remain the same. Flywheel inertia is varied by material density/size.

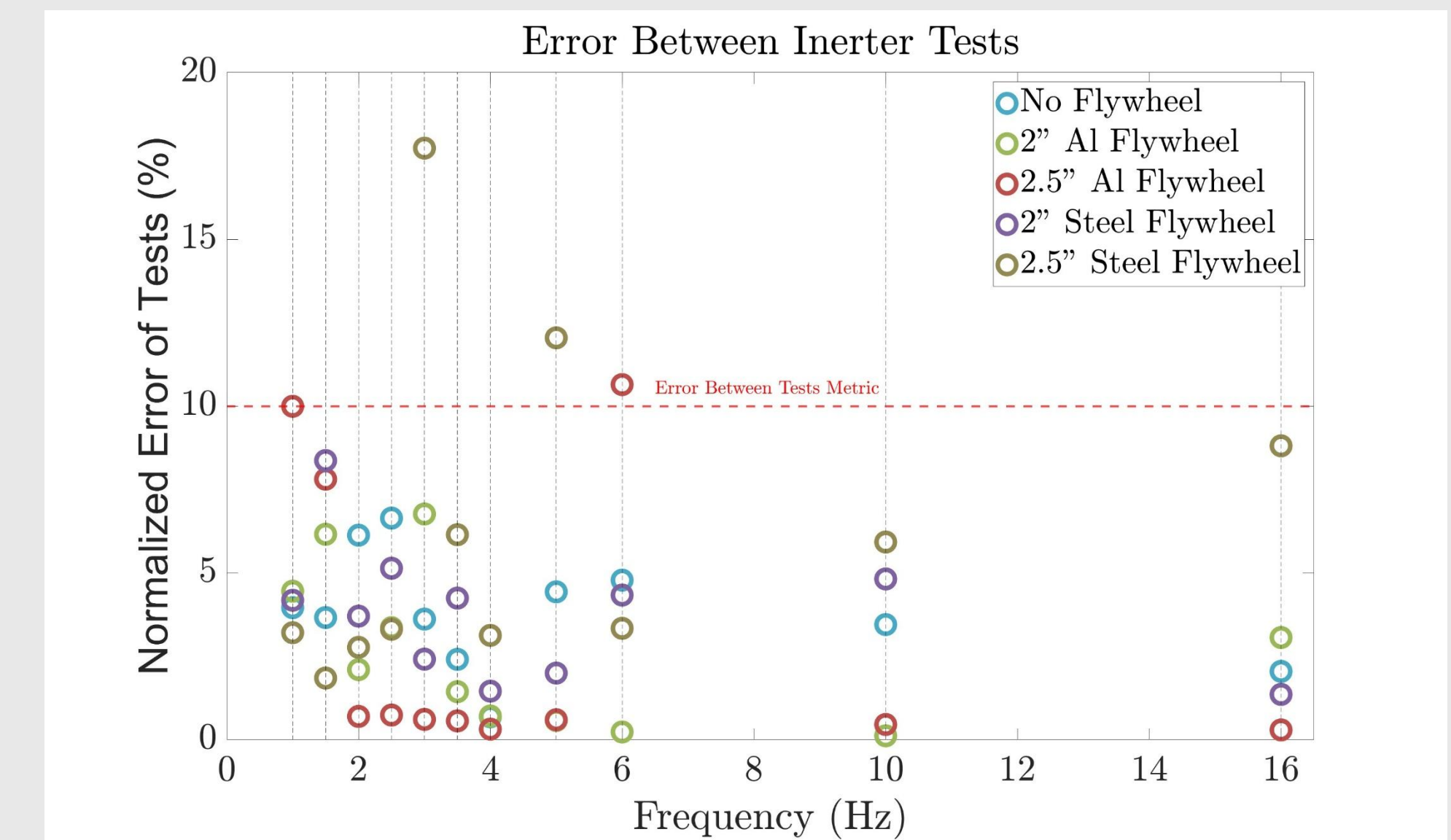


Figure 4: Error between tests vs frequency over three tests.

$$\text{Normalized Error of Tests} = \frac{\sigma_{\text{sample}}}{b_{\text{avg}}}$$

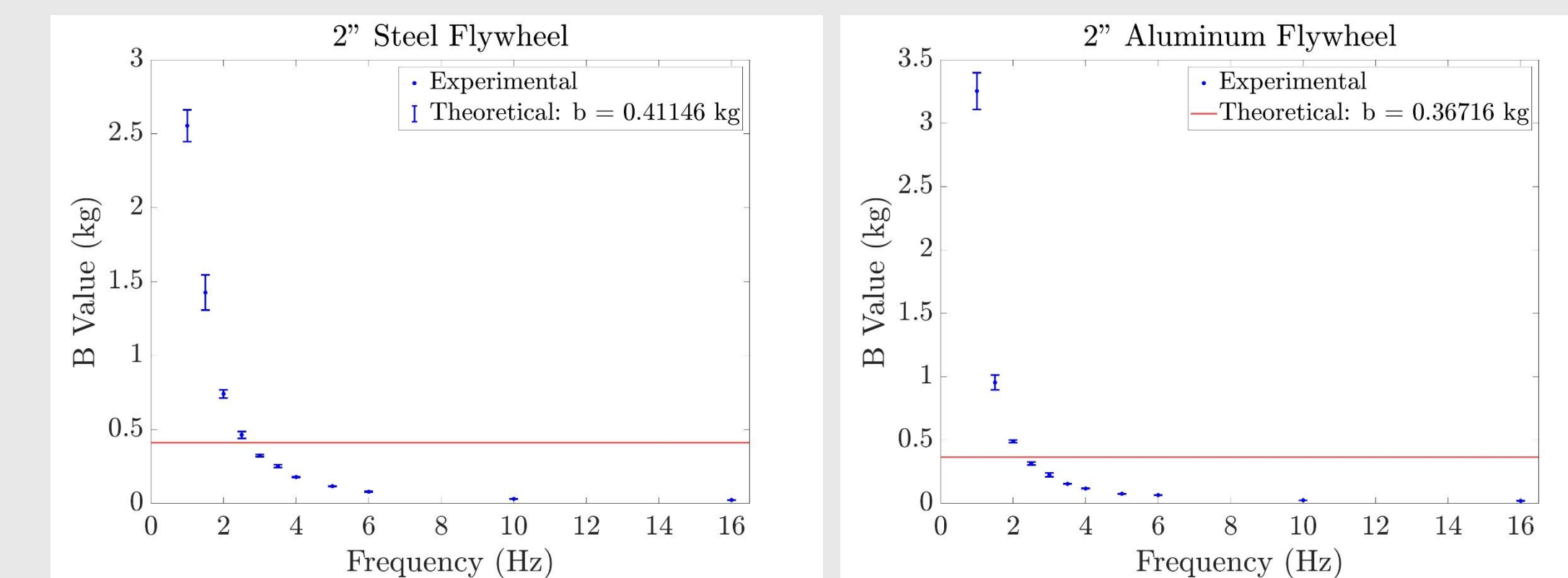


Figure 5: B-value vs frequency over three tests for different flywheel materials

Figure 4 demonstrates that only three tests exceeded our desired repeatability error of 10%, averaging 3.9%. Figure 5 compares the theoretical and experimental B-values; the experimental data highlights the dependence of the gathered B-values on frequency unaccounted for in our original theory.

## Conclusions

A standardized testing procedure has been created for testing mechanical inerters. The test stand can actuate various inerters and gather data required for calculating the b-value.

The current limitations are the sensors. Improved amplifiers for the load cell will allow for better testing at frequencies greater than 16 Hz. A more sensitive accelerometer will allow for more accurate testing at frequencies below 1.5 Hz