HONEYBEE ROBOTICS
Spacecraft Mechanisms Corporation

Flywheel Balancing System

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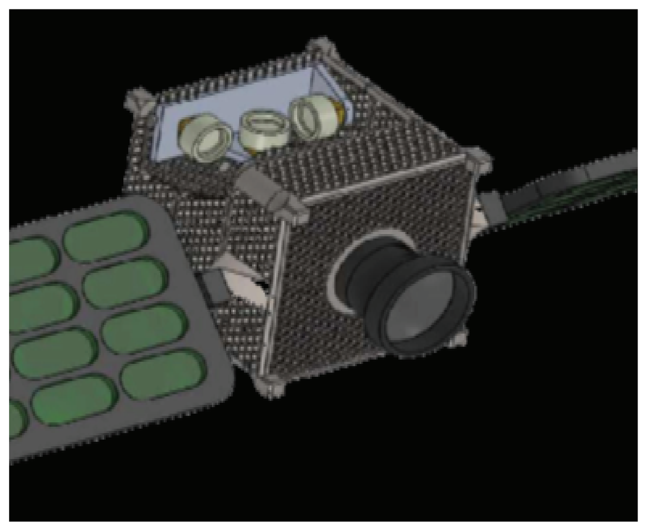
DESIGN CENTER COLORADO
DESIGN • BUILD • INVENT

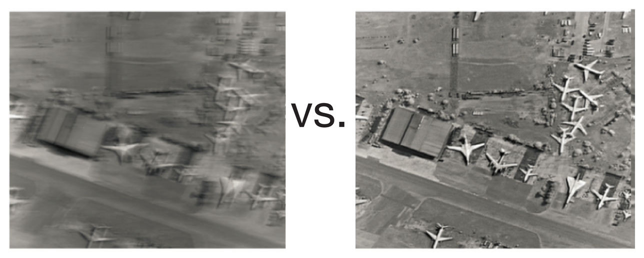
Motivation

Control Moment Gyroscopes (CMGs) conserve angular momentum and control the orientation of a satellite in space

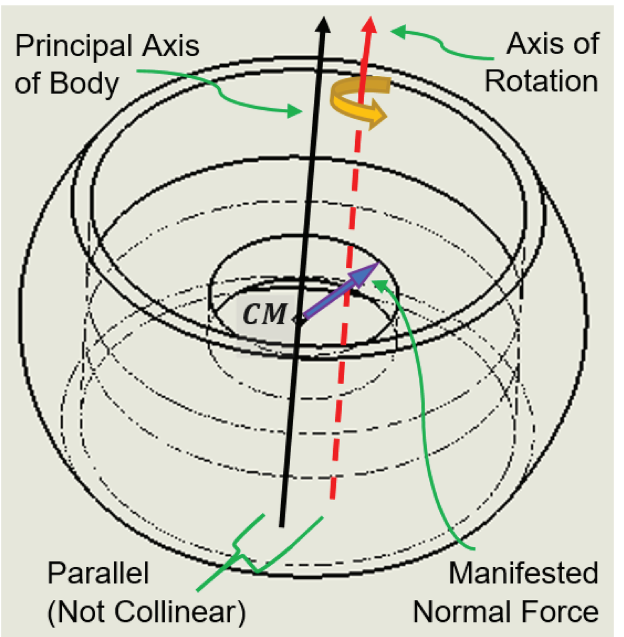
Sensitive equipment aboard the satellite are prone to disturbance if the vibration from the CMGs is too severe

With less vibration, the onboard camera can capture a cleaner photo





Why does unbalance cause vibration during rotation?



A body is unbalanced when its principal axis is not collinear with its axis of rotation

Unbalances cause normal forces in the body during rotation

Forces impact periodic vibration on the fixture

$$F = mr\omega^2$$

m = wheel mass [g]

r = axial distance [mm]

ω = wheel spin speed [rad/s]

Project Objectives

√ Measure unbalance

√ Output mass and angle of unbalance for correction

√ Decrease the unbalance in the CMG’s below the ISO G0.4 standard

√ Accommodate CMG’s between 200 and 1000 grams

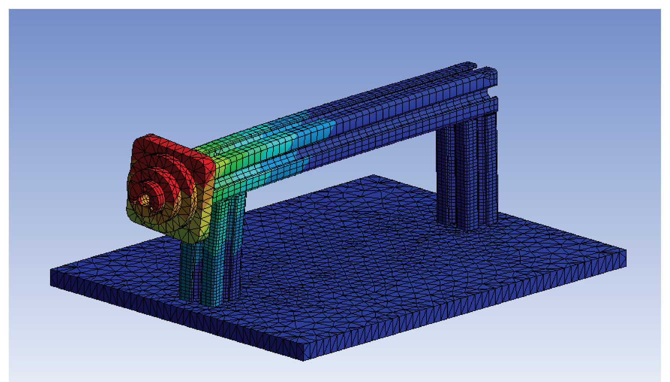
√ Accommodate spin rates between 6000 and 15000 rpm’s

Model Based Engineering

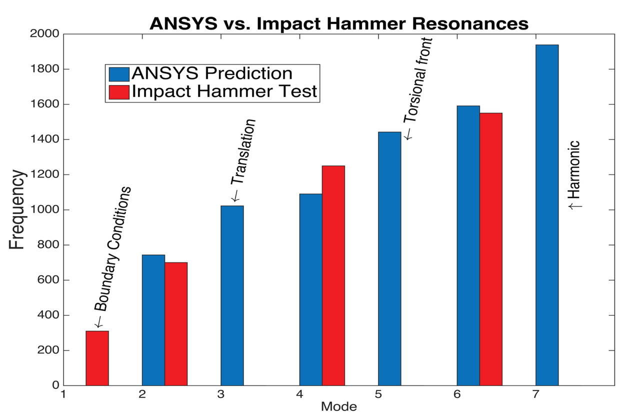
To ensure a pure translation of unbalance to vibration, the fixture should have linear response, with resonant modes outside the spin rate of the CMG

ANSYS Finite Element Analysis (FEA) was used to inform critical design decisions, and then compared to empirical testing data to validate design

FEA of mounting designs ensured the desired resonance range was achieved while enough mechanical vibration was translated to sensors



The design was verified by comparing FEA simulations to prototype tests



CMG

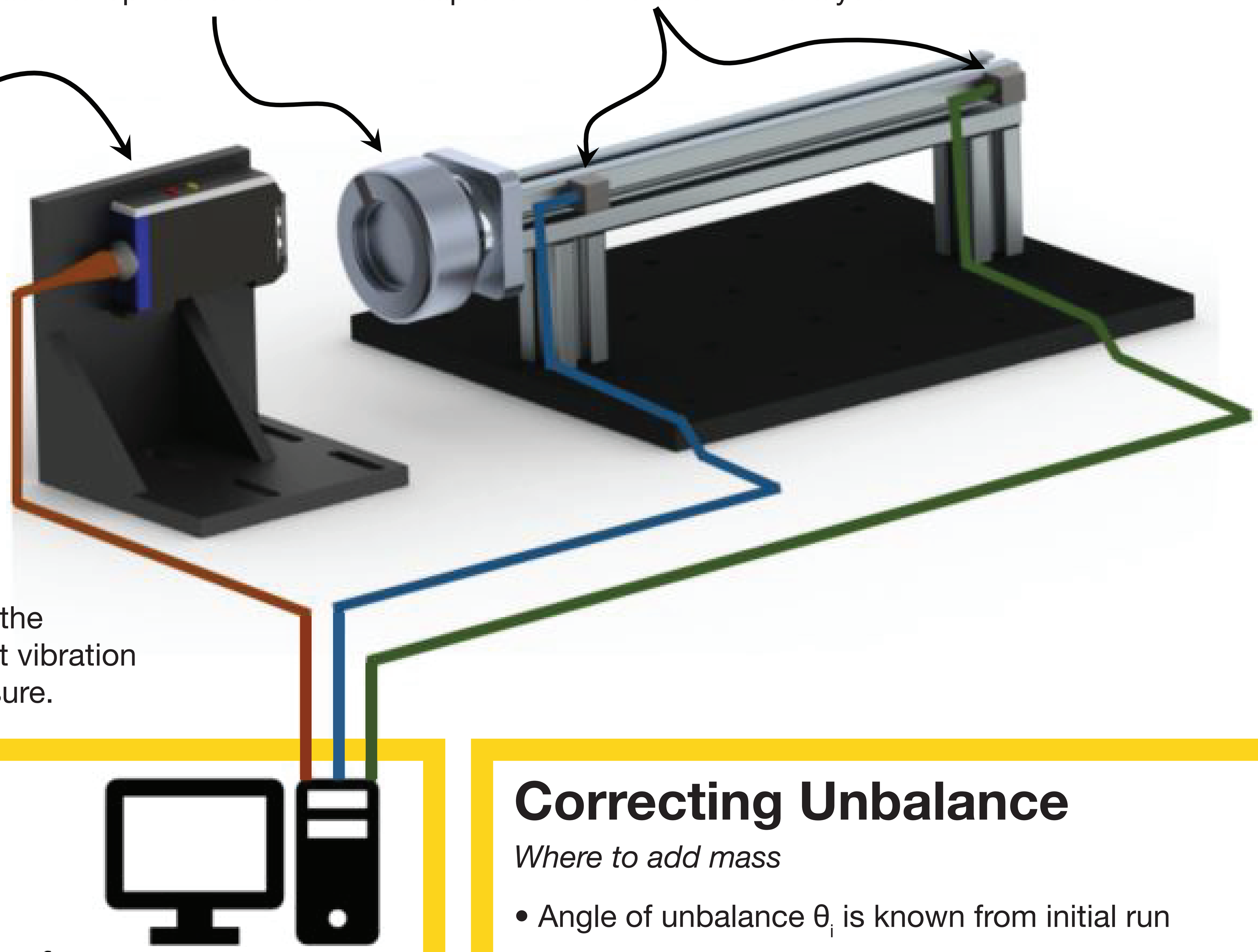
- Spinning between 6000 and 15000 rpm
- Edge mark on face for optical detection

Accelerometers

- Force of unbalance causes structure to vibrate
- Captures this vibration for analysis

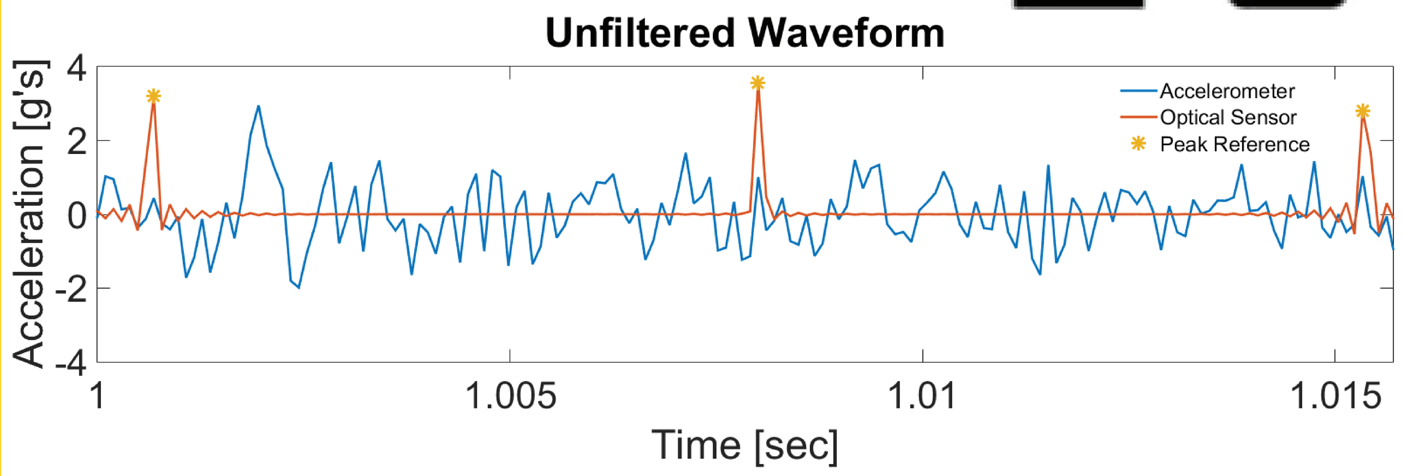
Optical Contrast Sensor

- Voltage peak when edge mark on wheel passes
- Allows us to find the angle of unbalance

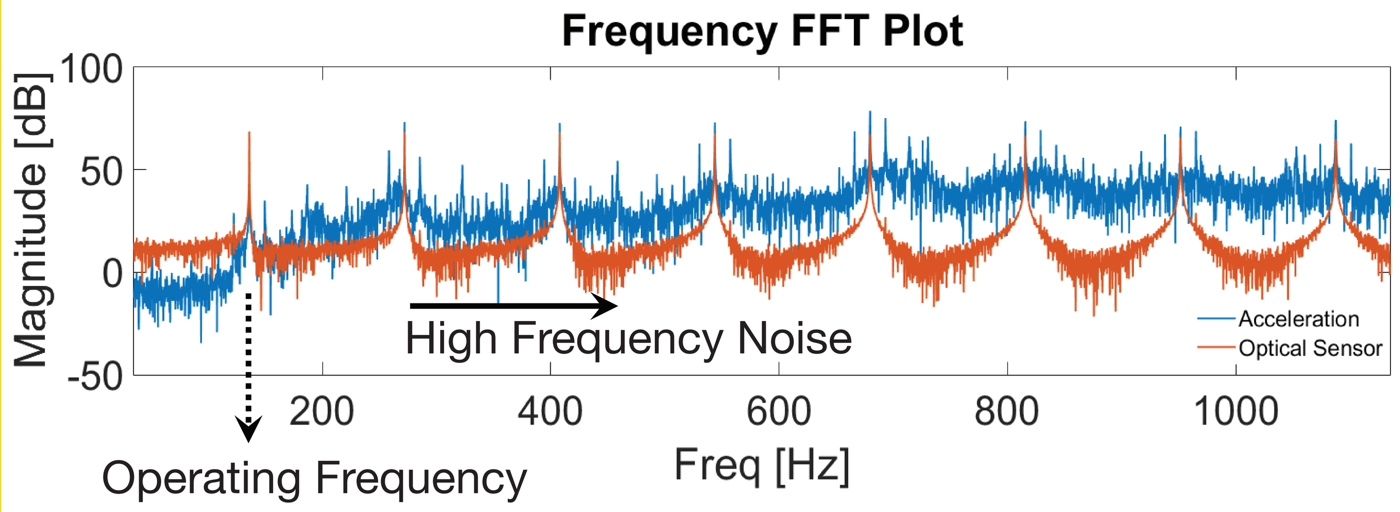


The fixture translates the signature of the imbalance and compares two different vibration signals to extract the imbalance measure.

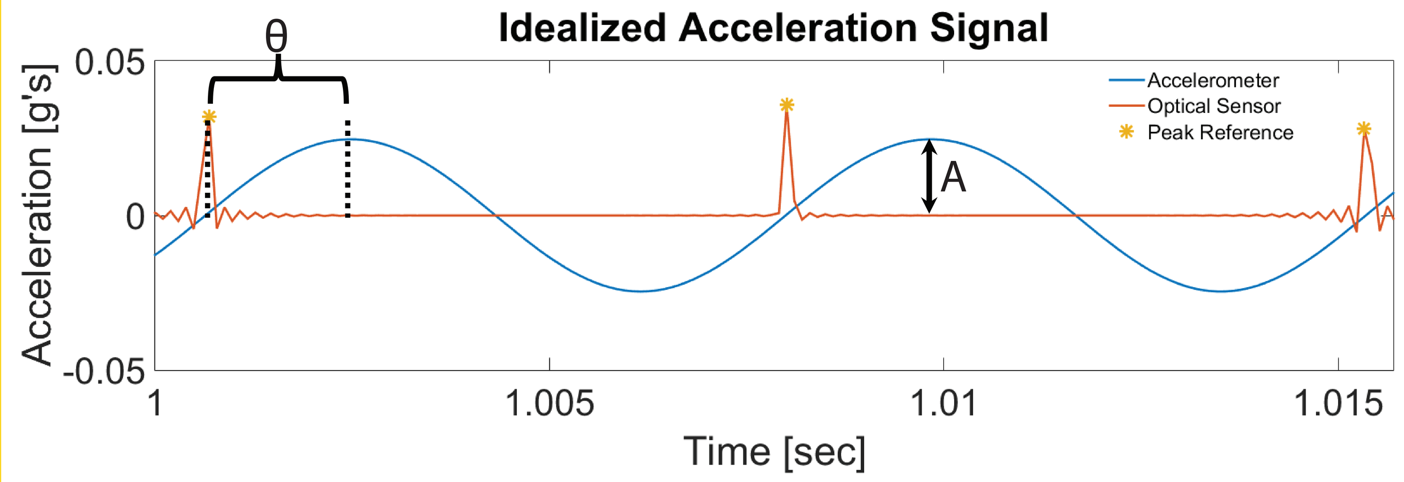
Data Acquisition and Analysis



A Fast Fourier Transform (FFT) is used to isolate unbalance signal



Unbalance response signal exists only at operating frequency



- Amplitude (A) proportional to mass of unbalance
- Frequency matches wheel spin rate
- Angle offset (θ) from optical sensor, which is the direction of imbalance in the CMG with respect to the edge mark

Correcting Unbalance

Where to add mass

- Angle of unbalance θ_i is known from initial run
- The correction angle θ_c is opposite θ_i

$$\theta_c = \theta_i + 180°$$

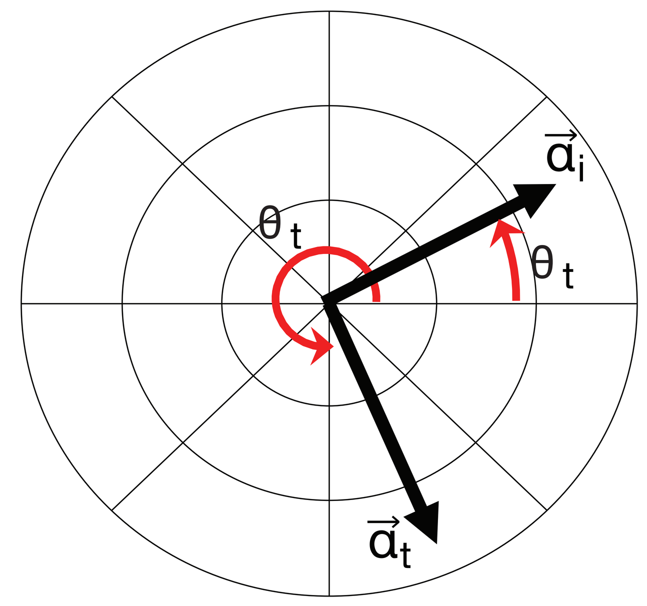
How much mass to add, m_c

1. Draw Initial Unbalance Vector: $\vec{a}_i$

   Magnitude A | Angle θ

2. Place trial weight - known mass at a known angle

   Draw Trial Unbalance Vector: $\vec{a}_t$



$$m_c = \frac{|\vec{a}_i|}{|\vec{a}_t - \vec{a}_i|} m_t$$

Results

√ Unbalance could not be directly correlated to acceleration » statistical analysis used to verify results

√ Achieved unbalance grade G0.06

√ Reduced unbalance of predicate CMGs by 98%,

√ Surpassed requirement by 150%

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