Testing Brake Rotor Natural Frequencies: Contact vs Non-Contact Sensors

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Background

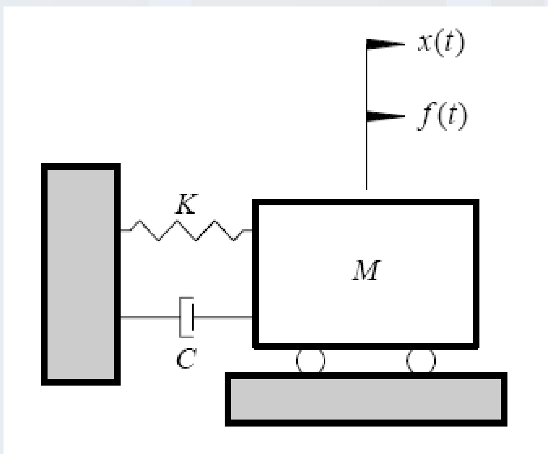
- Resonance Frequencies of Brake Rotors have always been a known contributor to brake noise and longevity of brake pads & shoes.
- Automotive OEMs are requiring suppliers to perform a more demanding Resonance Frequency Inspection.
- Requirements include 100% inspection, including pass-fail metrics based on resonance frequencies and frequency spacing between modes of vibration.

What are brake rotor modes?

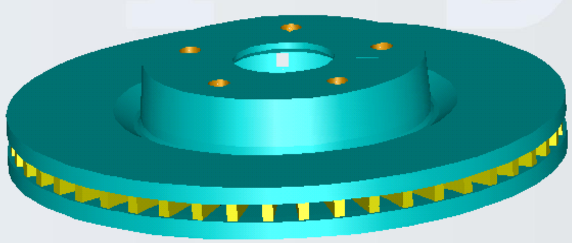
- A brake rotor (or most any mechanical structure) can be made to vibrate naturally at any one, or a combination, of a large number of resonance frequencies.
- Associated with each resonance frequency is a deformation pattern called a mode shape.
- When vibrating naturally in one mode of vibration, that mode is characterized by the resonance frequency, modal mass, modal stiffness, modal damping and mode shape.

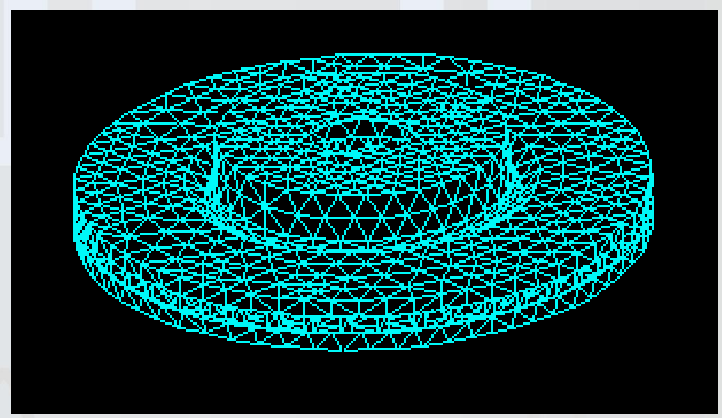
Modal Characteristics

A rotor mode of vibration is described mathematically as a modal mass, modal spring, modal damper having a resonance frequency and mode shape



1. Resonance Frequency
2. Damping - C
3. Modal Mass - M
4. Modal Stiffness - K
5. Mode Shape – $\{\Psi\}$

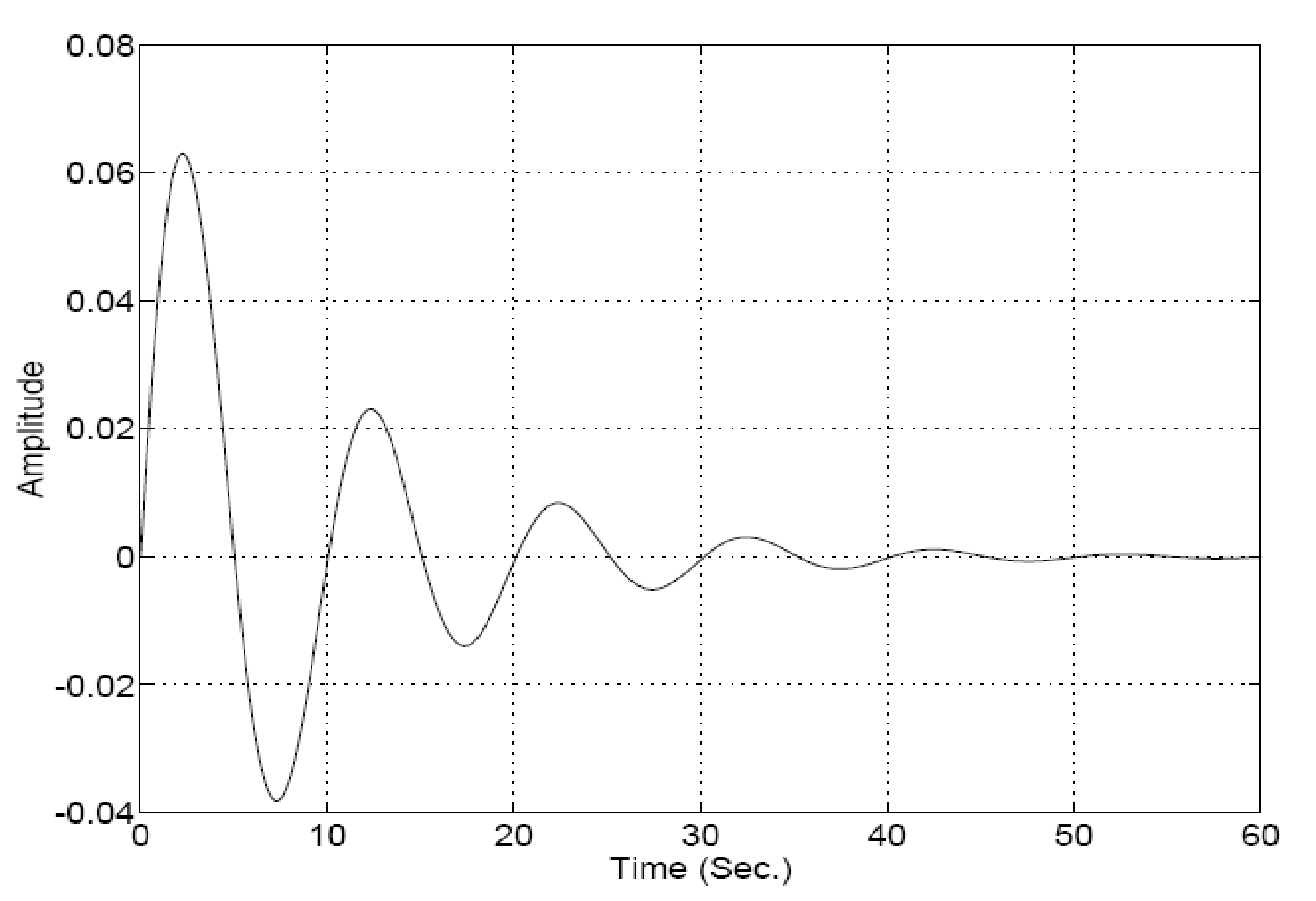




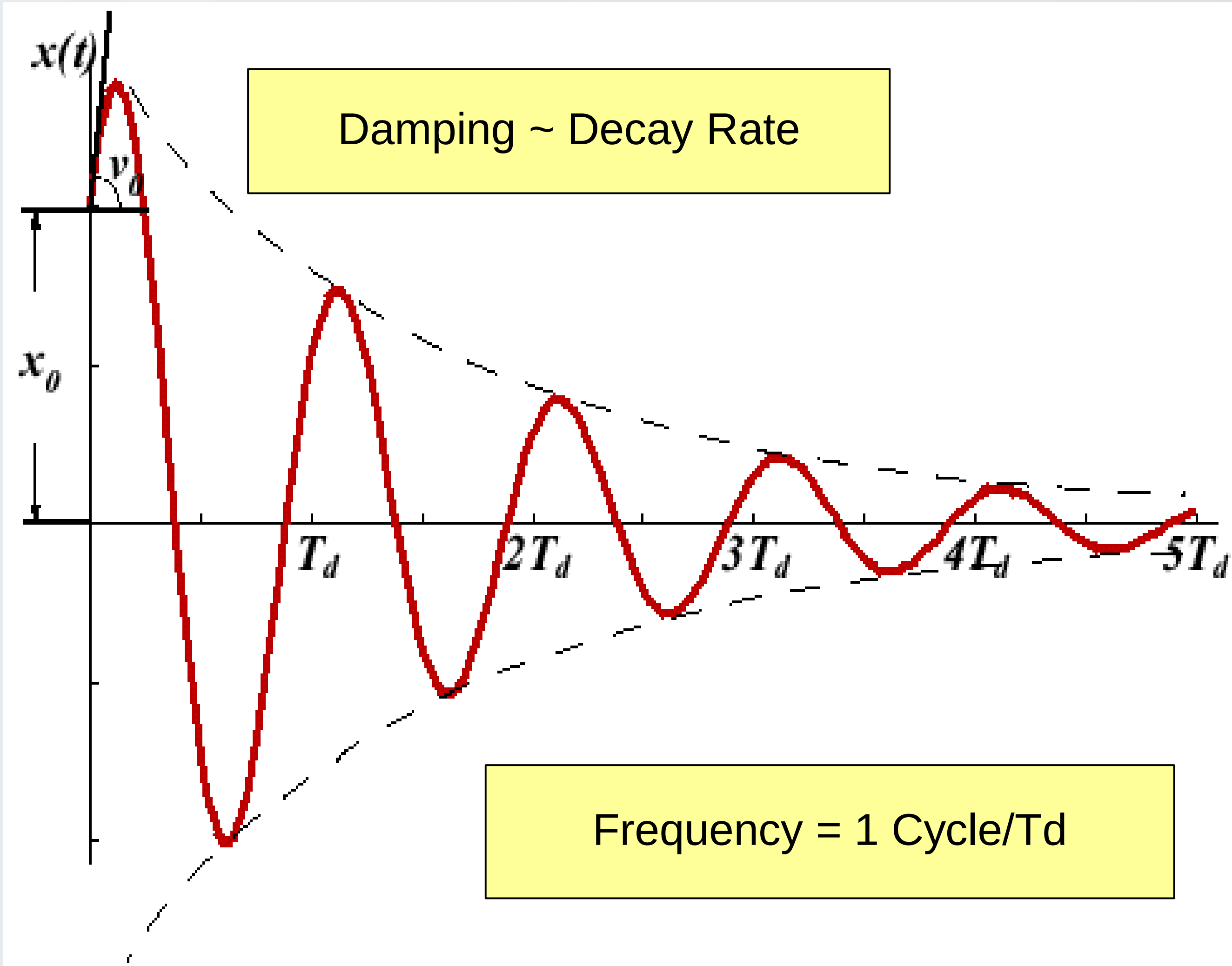
Vibration Excitation Methods

- There are several basic methods for exciting brake rotor resonant vibration
  - Using a shaker with any of the commonly used excitation functions, e.g., sine, random, transient
  - Using a dyno and braking system
  - Impact Hammer
- The Impact Hammer method is typically favored for the manufacturing environment requiring 100% inspection.

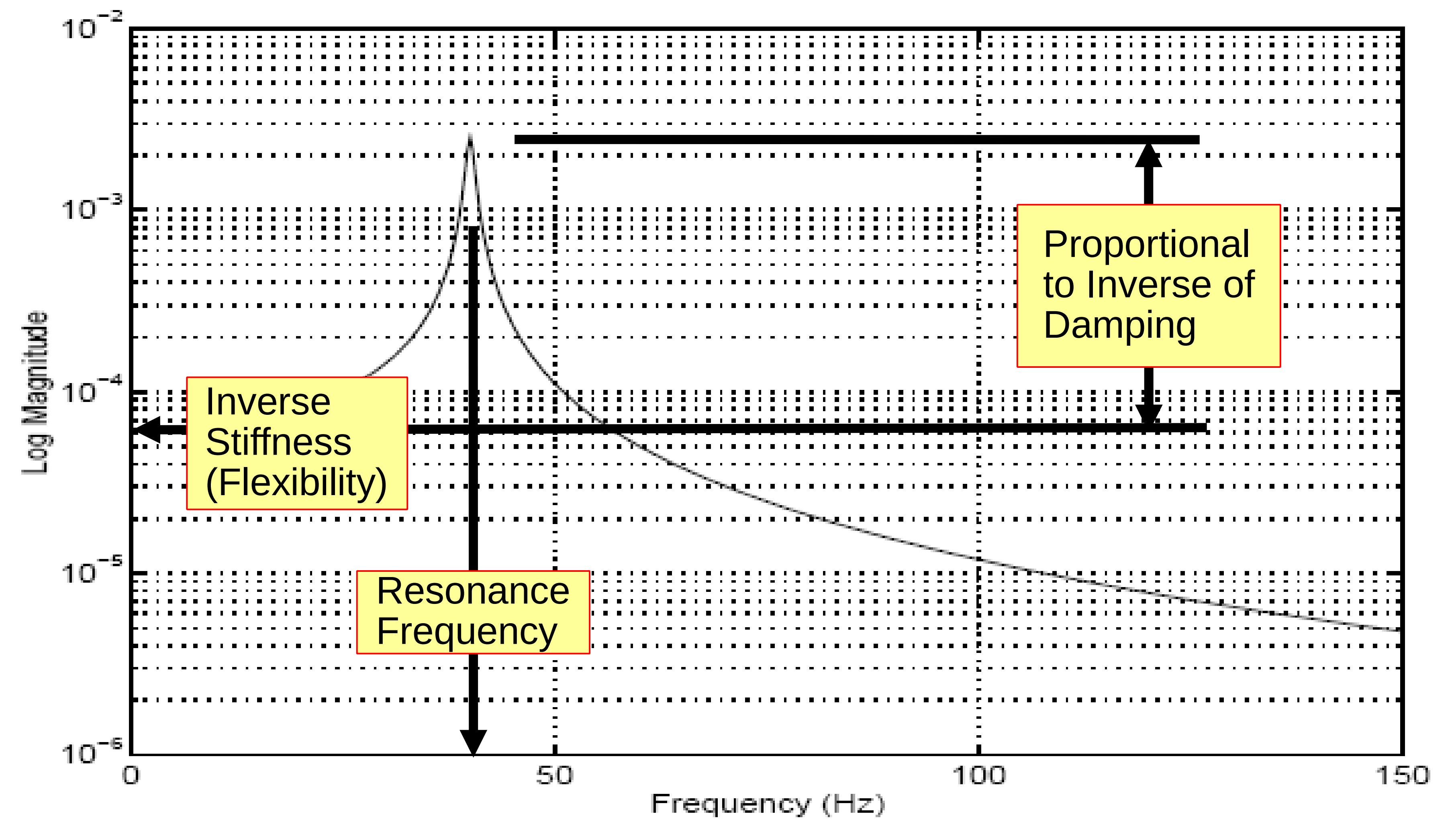
Free Response to an Impulse
(damped sine wave)



Damping and Period of Oscillation



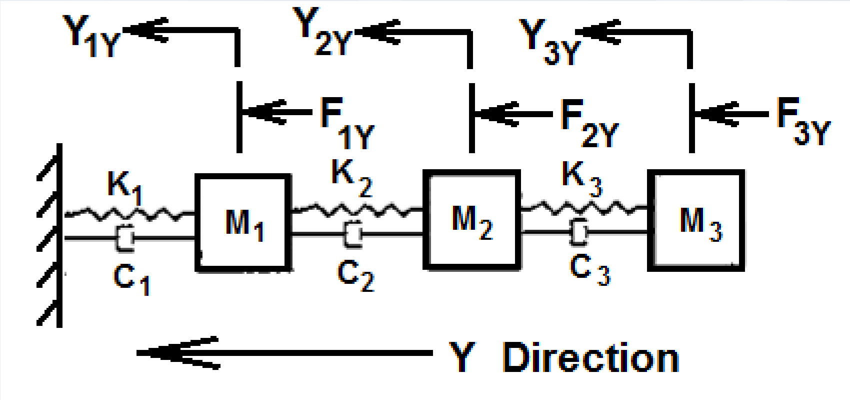
Frequency Domain Representation
(Spectrum of Damped Sine)

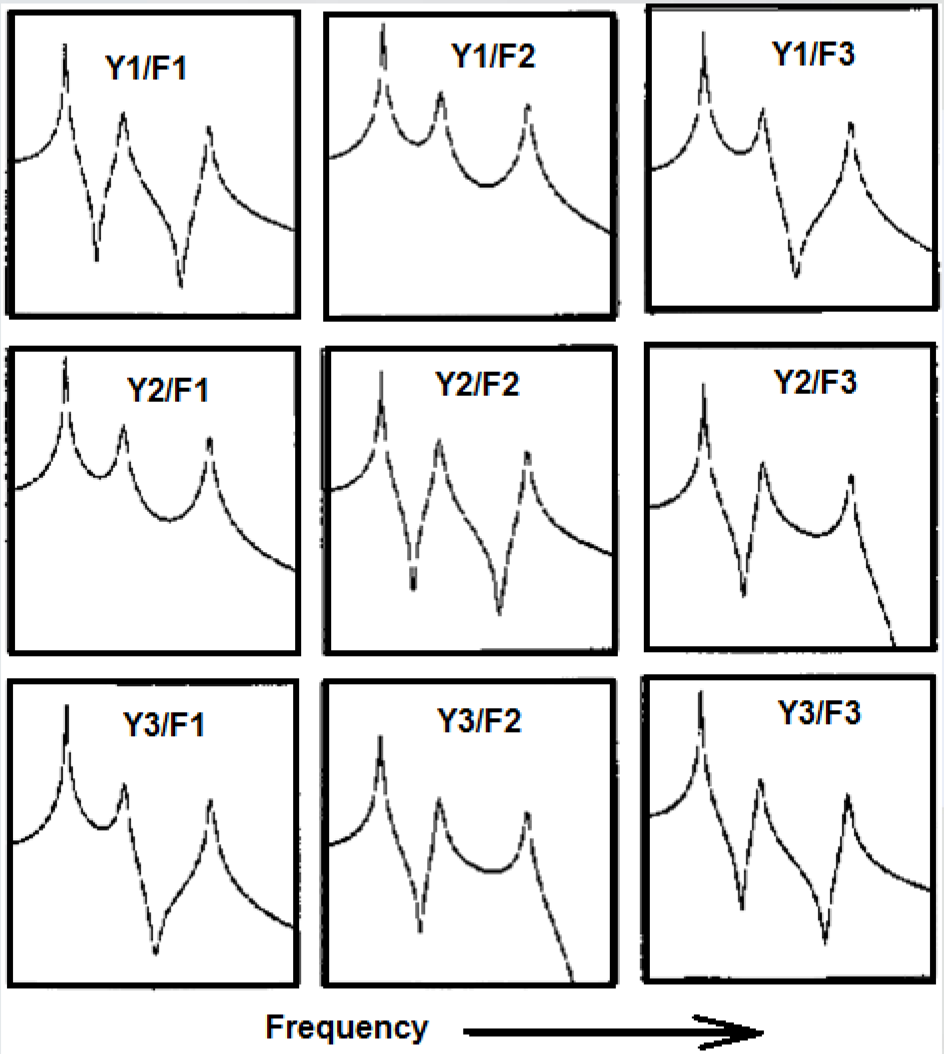


FRFs for Three Modes of Vibration

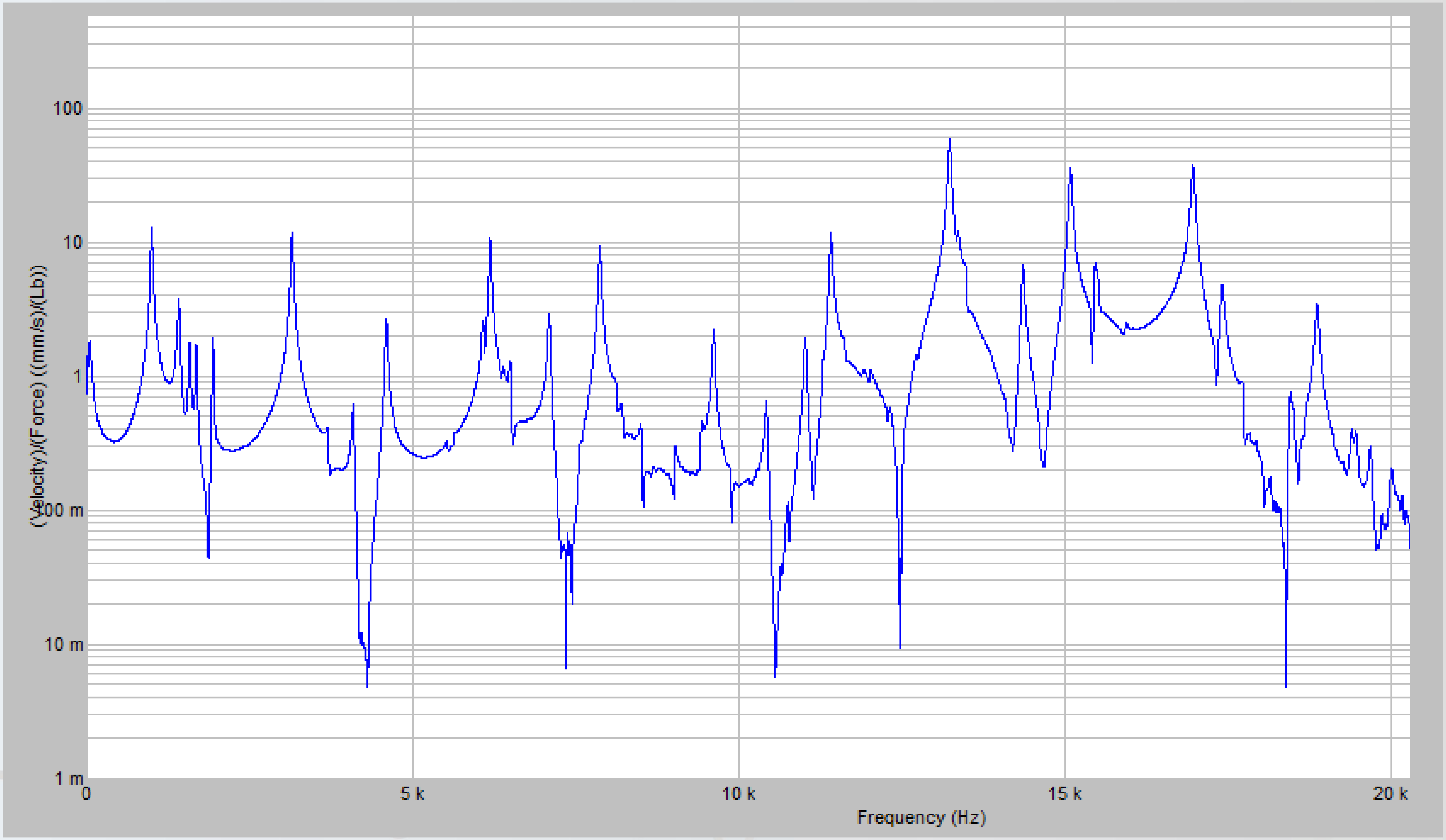
An FRF is the ratio of the motion of some mass point divided by the force applied at some mass point as a function of frequency. The motion may be expressed as displacement, velocity or acceleration.

$$\text{FRF:}\quad h(f)_{jk} = \frac{Y_j(f)}{F_k(f)}$$





FRF Measured on Rotor



Vibration Response Measurements

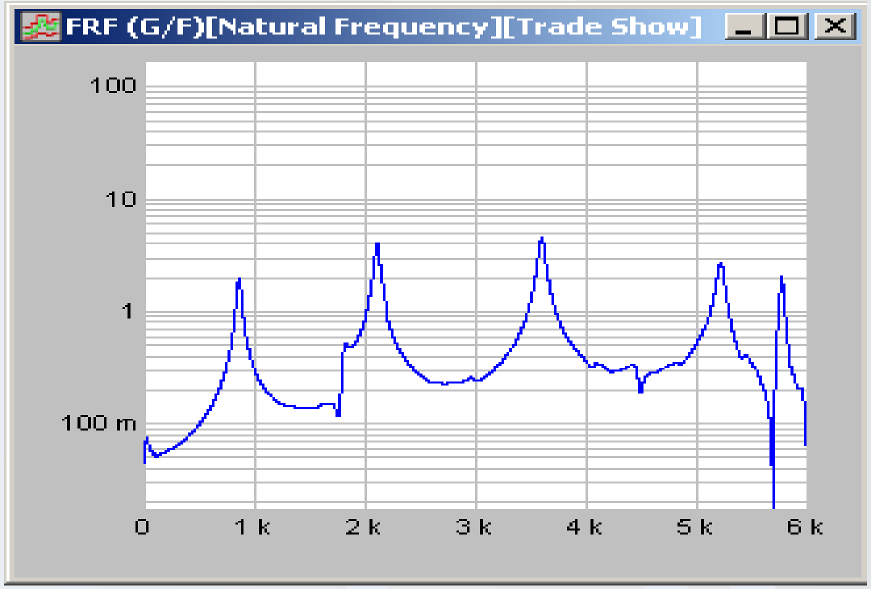
- There are several methods for measuring the response due to excitation of a brake rotor
  - Microphone
  - Accelerometer
  - Laser Vibrometer
- In a manufacturing environment accelerometers and laser vibrometers are the most common measurement devices.

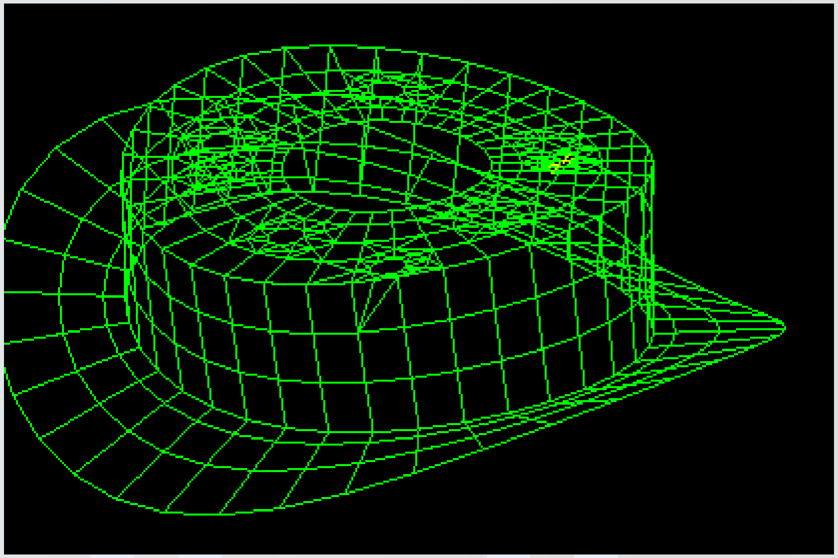
Brake Rotor Resonance Frequency Testing

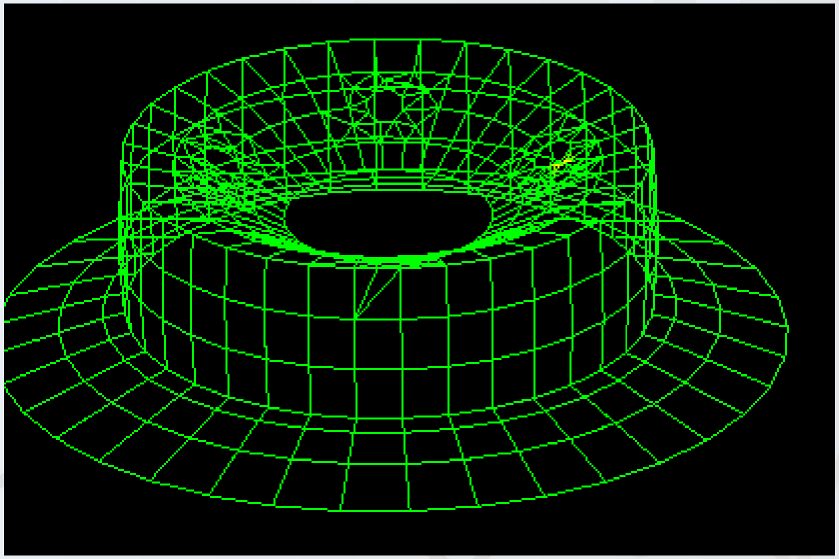
Key Considerations

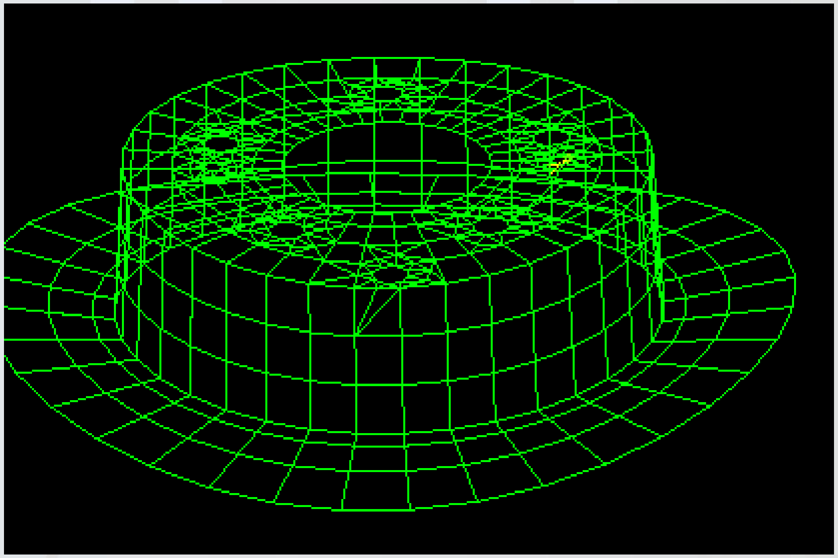
- Appropriate Factory or Lab Test Environment
- Impactor for Vibration Excitation
- Rotor Vibration Isolation From Test Stand
- Appropriate Measurement Transducers
- Appropriate Data Acquisition System/Computer Interface
- Appropriate Computer System
- Appropriate Application Software

Brake Rotor Modes of Vibration









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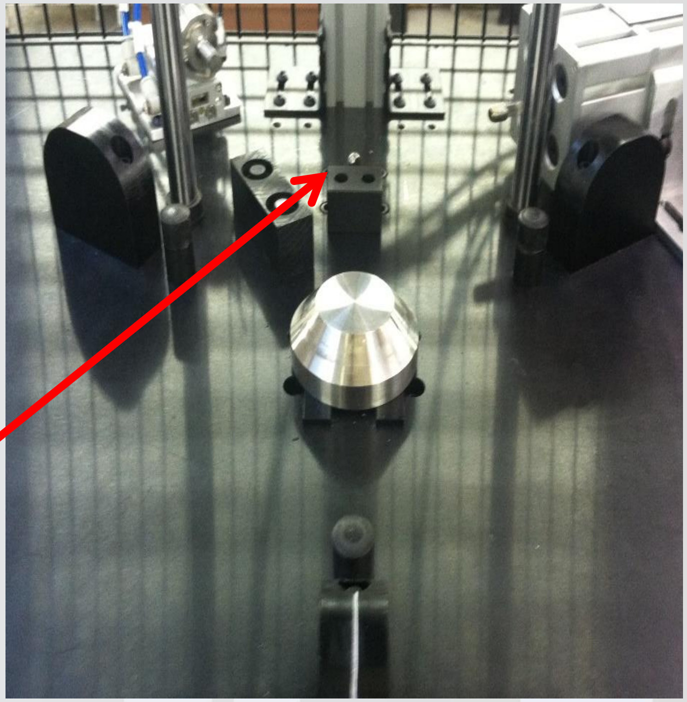
Automated Impactor

Test System Requirements

- Excite Modes Over Customer Frequency Range
- Measurement Repeatability
- High Durability
- Mfg Environment Reliability
- Adaptable For All Types measurements

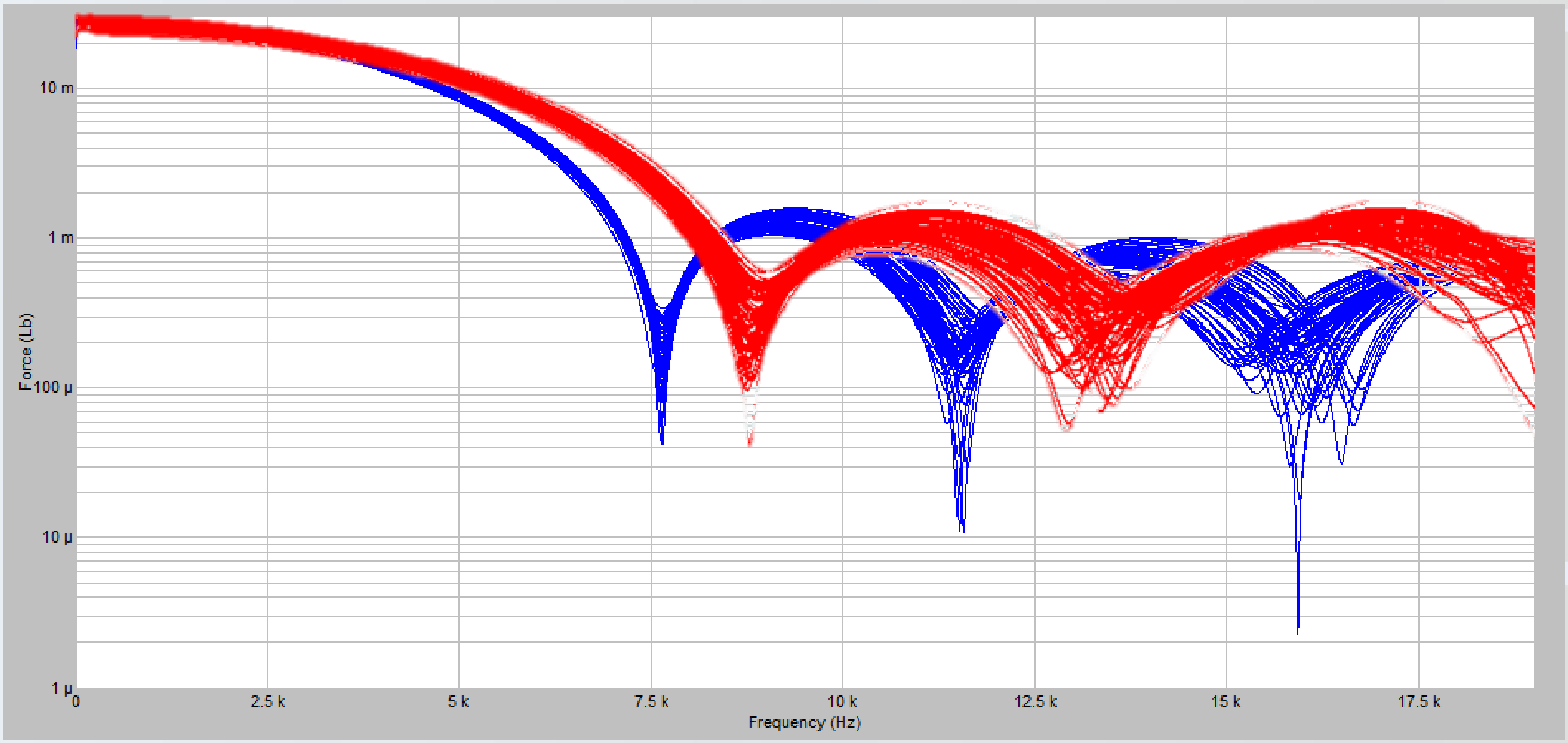


Automatic Hammer

Axial Excitation

Radial Excitation

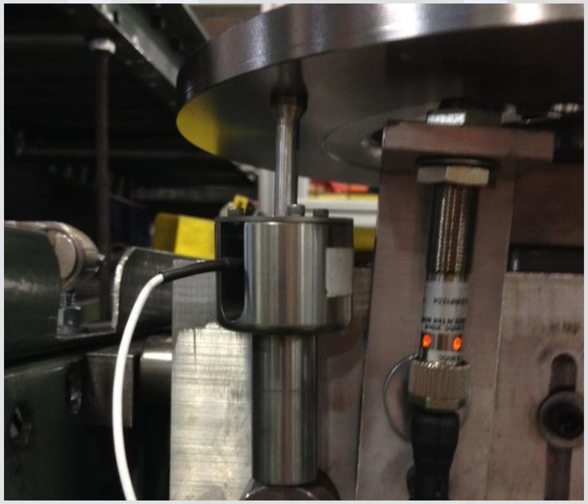
Force Spectrum



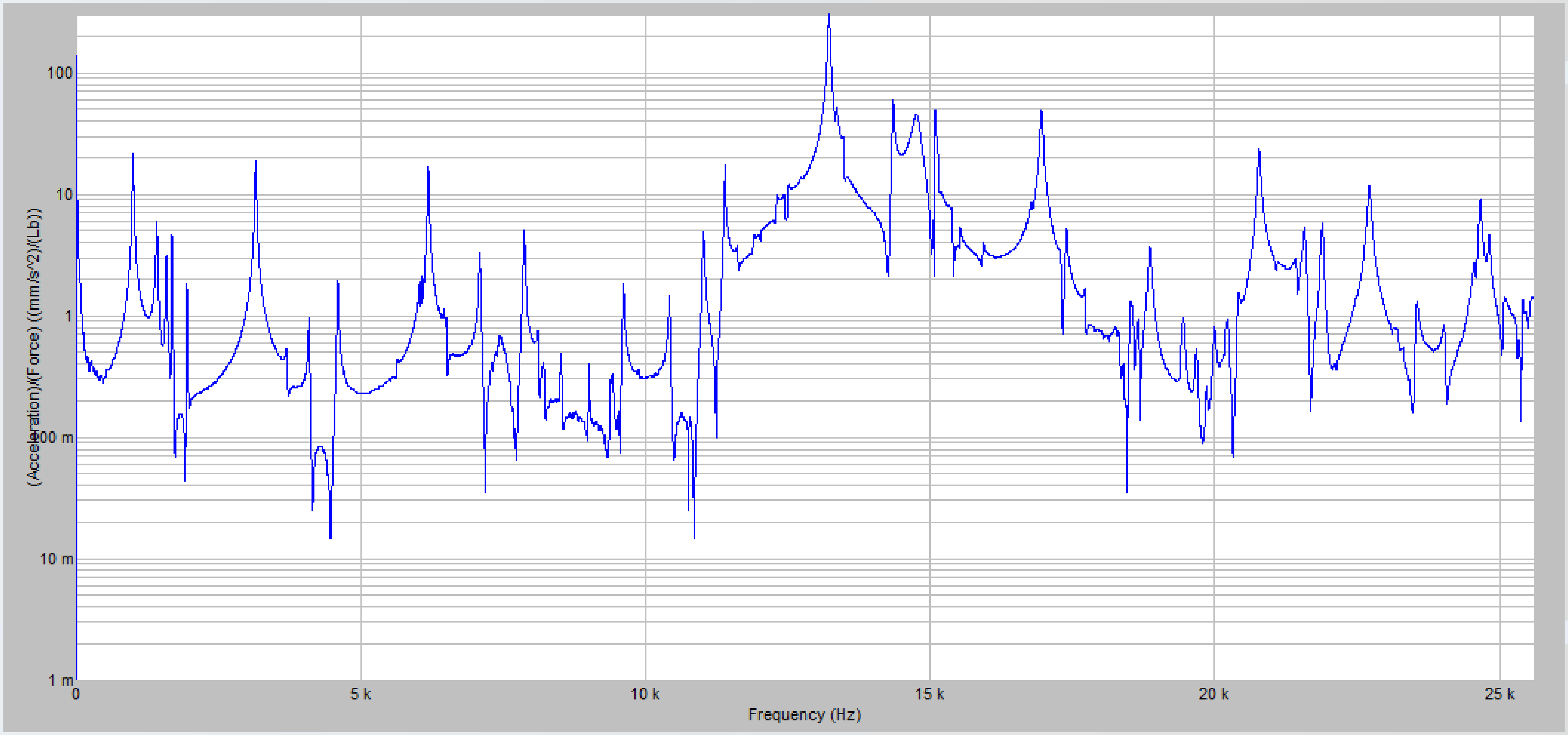
Blue: SigHammer, long shaft, long tip. 100 tests shown.
Red: SigHammer, short shaft, short tip. 100 tests shown.

Contact vs Non-Contact sensors

- Accelerometer Properties:
  - Accurate response up to 15 KHz (Bolted to part); 5 KHz using Magnetic Tip
  - Needs to touch the part on each measurement
  - Needs to be fixed over a mechanism to interact with rotor
  - Needs a cable susceptible to breakage
  - Needs a housing to withstand industrial use
  - Price $$



Accelerometer FRF

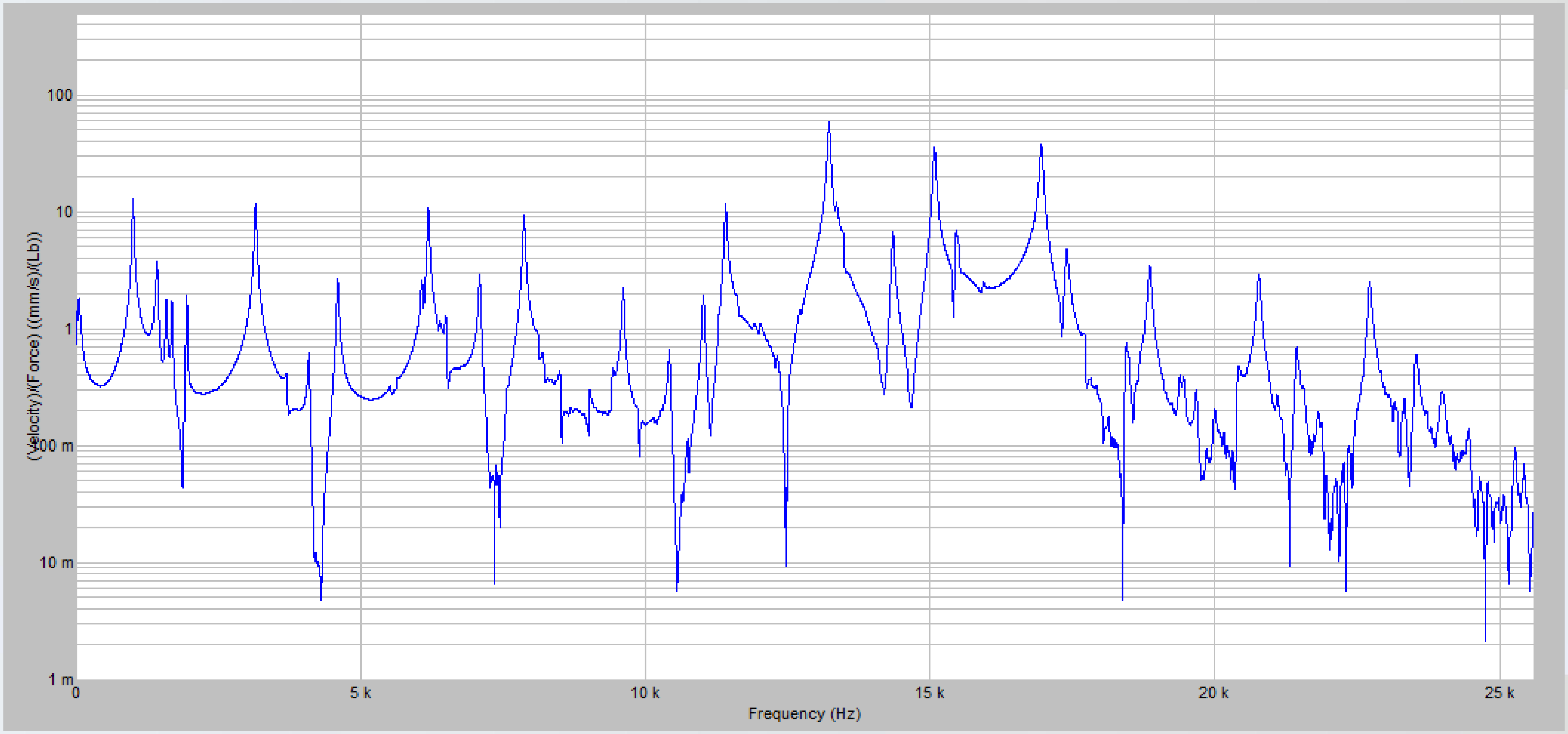


- Block Size 16384
- 10 mV/g Accelerometer
- 50mV/Lb Load Cell
- Single Impact - No Averaging

Contact vs Non Contact Sensors

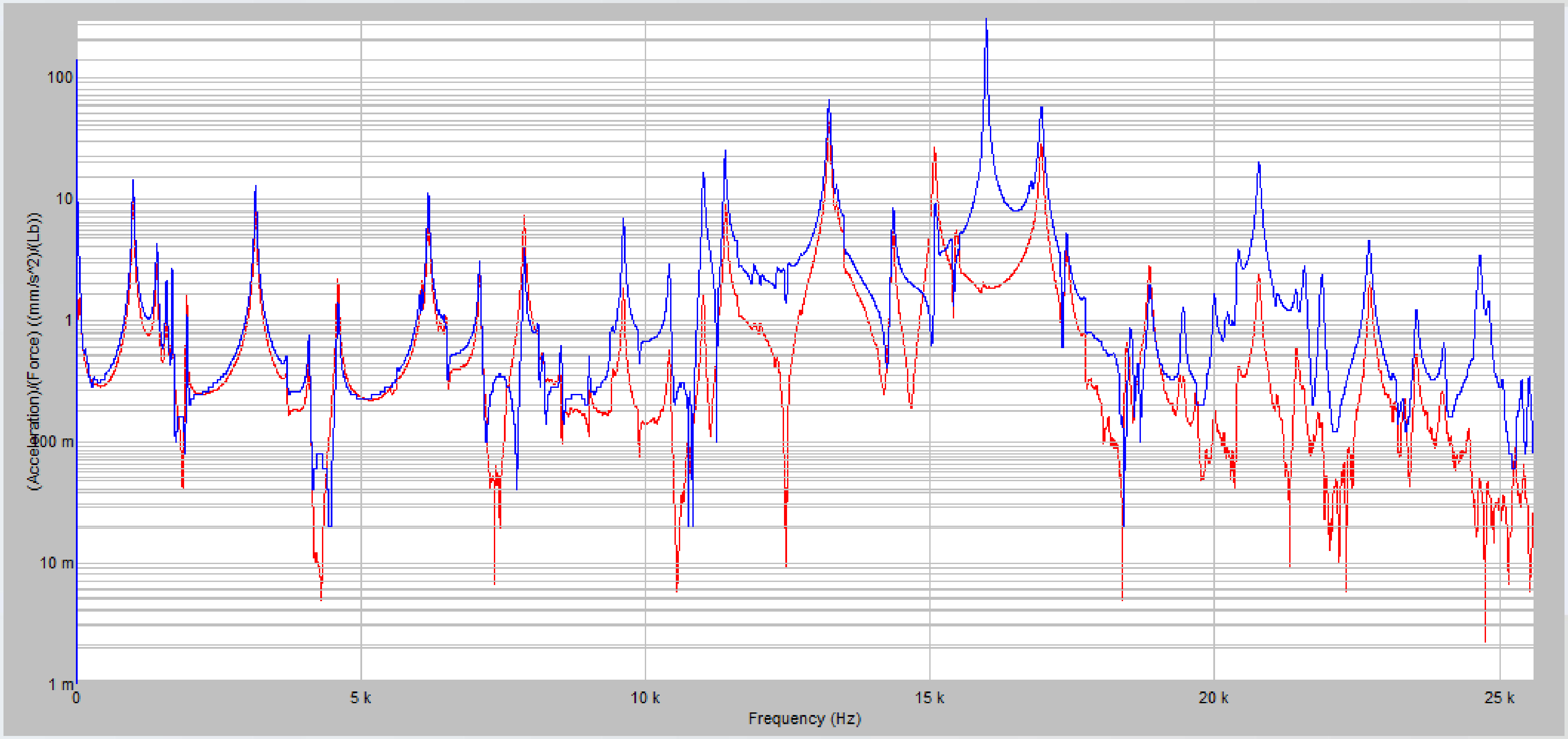
- Laser Vibrometer properties:
  - Accurate response up to 22Khz
  - Can measure accurately without touching the part
  - Must be rigidly mounted at a designed distance from rotor
  - Doesn’t need to move to take measurement
  - Doesn’t require fragile cabling susceptible to breakage
  - Built to withstand heavy duty industrial use
  - Price $$$$$

Vibrometer FRF



- Block Size 16384
- 5 mV/mm/s Laser Vibrometer
- 50mV/Lb Load Cell
- Single Impact - No Averaging

FRF Comparison – Laser vs. Accelerometer



Final Conclusions

- Having a capable excitation method for the Frequencies to be tested is crucial for the outcome of the test.

- The Laser Vibrometer's non contact ability ensures our measurements contains only the Frequency response function of a single mass under properly isolated fixturing, thus making it the go-to option for testing modes located on frequencies over 5 kHz.