CTC UNIVERSITY

LEVEL 2, LESSON 2

FREQUENCY RESPONSE AND MOUNTED RESONANCE FOR ACCELEROMETERS

Introduction

Welcome to **Level 2, Lesson 2 – Frequency Response and Mounted Resonance for Accelerometers**, part of CTC's free online vibration analysis training series.

We hope you enjoyed and benefitted from the previous course and will continue to build your vibration analysis knowledge as you progress through Level 2.

Training Objectives

This training will focus on the following concepts:

- Natural Frequency
- Frequency Response
- Resonance
- Mounted Resonance

Upon completion of this lesson, you will:

1. *Understand how each of the above concepts affects the data used for vibration analysis and condition monitoring*
2. *Understand these principles which will enable you to ensure you are not missing important data and will ultimately assist you with making better calls*

Frequency Response Terms

Natural Frequency
Every object or system has a natural frequency – the frequency or set of frequencies at which an object or system will vibrate when struck, set in motion, or disturbed. The natural frequency of an object or system is dependent upon the stiffness and mass of that object or system.

Frequency Response
The natural or resonant frequency of a sensor will have a direct effect on the sensor's frequency response – a sensor's ability to measure the correct amplitude of a vibration at a given frequency. A sensor's datasheet will typically list a sensor's frequency response in relation to the minimum or maximum frequencies that the sensor can measure to a given degree of accuracy.

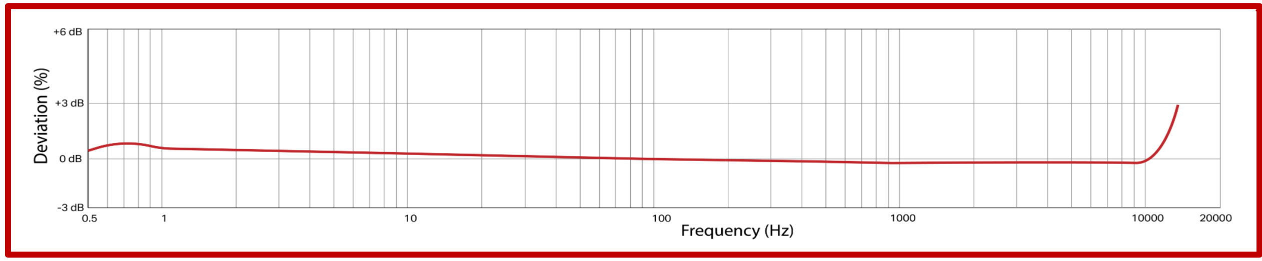
Resonance
When an object or system is excited at its natural frequency, the result is a greatly amplified vibration known as resonance.

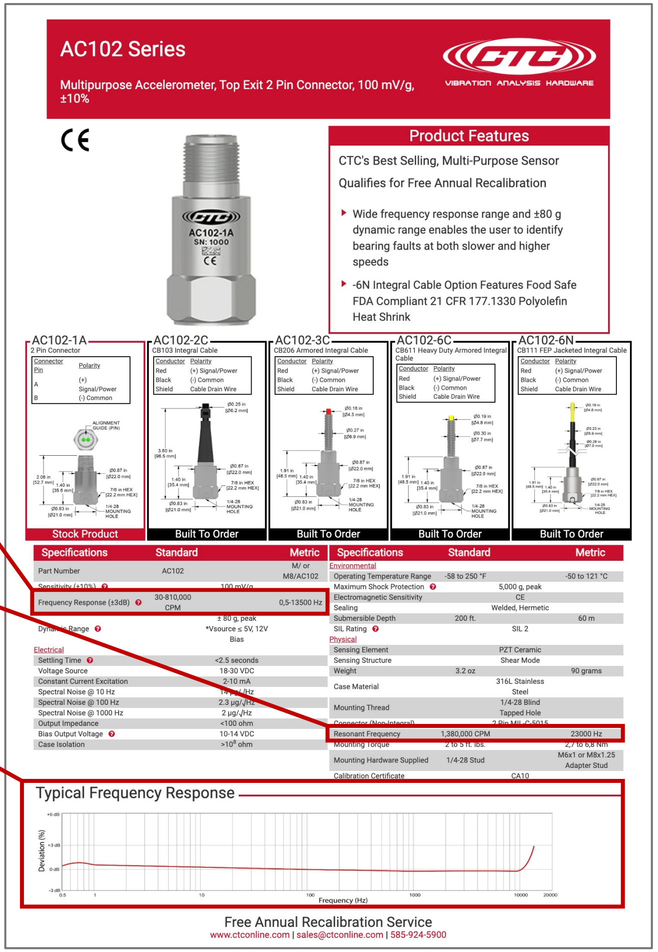
Resonant Frequency
The natural frequency of an accelerometer or velocity sensor is typically listed as the resonant frequency on the sensor's datasheet.

Frequency Response Terms

Frequency Response (±3dB)	30-810,000 CPM		0,5-13500 Hz

Resonant Frequency	1,380,000 CPM	23000 Hz





AC102 Series

Multipurpose Accelerometer, Top Exit 2 Pin Connector, 100 mV/g, ±10%

CTC VIBRATION ANALYSIS HARDWARE

Product Features

CTC's Best Selling, Multi-Purpose Sensor

Qualifies for Free Annual Recalibration

- Wide frequency response range and ±80 g dynamic range enables the user to identify bearing faults at both slower and higher speeds
- -6N Integral Cable Option Features Food Safe FDA Compliant 21 CFR 177.1330 Polyolefin Heat Shrink

AC102-1A – 2 Pin Connector – Stock Product

AC102-2C – CB103 Integral Cable – Built To Order

AC102-3C – CB206 Armored Integral Cable – Built To Order

AC102-6C – CB611 Heavy Duty Armored Integral Cable – Built To Order

AC102-6N – CB111 FEP Jacketed Integral Cable – Built To Order

Specifications	Standard	Metric
Part Number	AC102	M/ or M8/AC102
Sensitivity (±10%)	100 mV/g	
Frequency Response (±3dB)	30-810,000 CPM	0,5-13500 Hz
Dynamic Range	± 80 g, peak *Vsource ≤ 5V, 12V Bias	
Electrical		
Settling Time	<2.5 seconds	
Voltage Source	18-30 VDC	
Constant Current Excitation	2-10 mA	
Spectral Noise @ 10 Hz	14 μg/√Hz	
Spectral Noise @ 100 Hz	2.3 μg/√Hz	
Spectral Noise @ 1000 Hz	2 μg/√Hz	
Output Impedance	<100 ohm	
Bias Output Voltage	10-14 VDC	
Case Isolation	$>10^8$ ohm	

Specifications	Standard	Metric
Environmental		
Operating Temperature Range	-58 to 250 °F	-50 to 121 °C
Maximum Shock Protection	5,000 g, peak	
Electromagnetic Sensitivity	CE	
Sealing	Welded, Hermetic	
Submersible Depth	200 ft.	60 m
SIL Rating	SIL 2	
Physical		
Sensing Element	PZT Ceramic	
Sensing Structure	Shear Mode	
Weight	3.2 oz	90 grams
Case Material	316L Stainless Steel	
Mounting Thread	1/4-28 Blind Tapped Hole	
Connector (Non-Integral)	2 Pin MIL-C-5015	
Resonant Frequency	1,380,000 CPM	23000 Hz
Mounting Torque	2 to 5 ft. lbs.	2,7 to 6,8 Nm
Mounting Hardware Supplied	1/4-28 Stud	M6x1 or M8x1.25 Adapter Stud
Calibration Certificate	CA10	

Typical Frequency Response

Free Annual Recalibration Service

www.ctconline.com | sales@ctconline.com | 585-924-5900

Frequency Response – Mass And Stiffness

Mass and stiffness play a key role in defining the natural frequency

$$f_n = 1/(2\pi)\sqrt{k/m}$$

The natural frequency (F_n) is equal to 1/(2π) x the square root of stiffness (k) ÷ the mass (m)

- F_n = natural frequency (Hz)
- **k** = stiffness (lb/in)
- **m** = mass
- **mass** = weight (lb)/gravity (386.1 in/sec^2)

Frequency Response – Mass And Stiffness

If the **stiffness (k)** decreases, then the **natural frequency (f)** will also decrease (direct relationship)

If the **stiffness (k)** increases, then the **natural frequency (f)** will also increase (direct relationship)

If the **mass (m)** increases, then the **natural frequency (f)** will decrease (inverse relationship)

If the **mass (m)** decreases, then the **natural frequency (f)** will increase (inverse relationship)

Frequency Response – Examples Of Stiffness And Natural Frequency

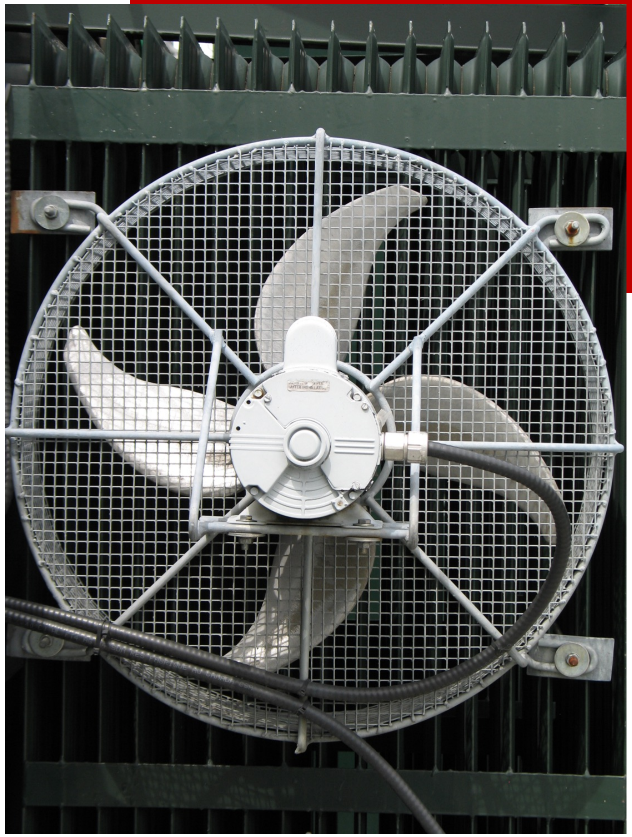
A simple example of the effects of stiffness on natural frequency is a guitar string, which when plucked will resonate at its natural frequency.

When that string is tightened, stiffness is added to the system of the string, bridge, and key, the natural frequency increases, and the note you hear is higher pitched.

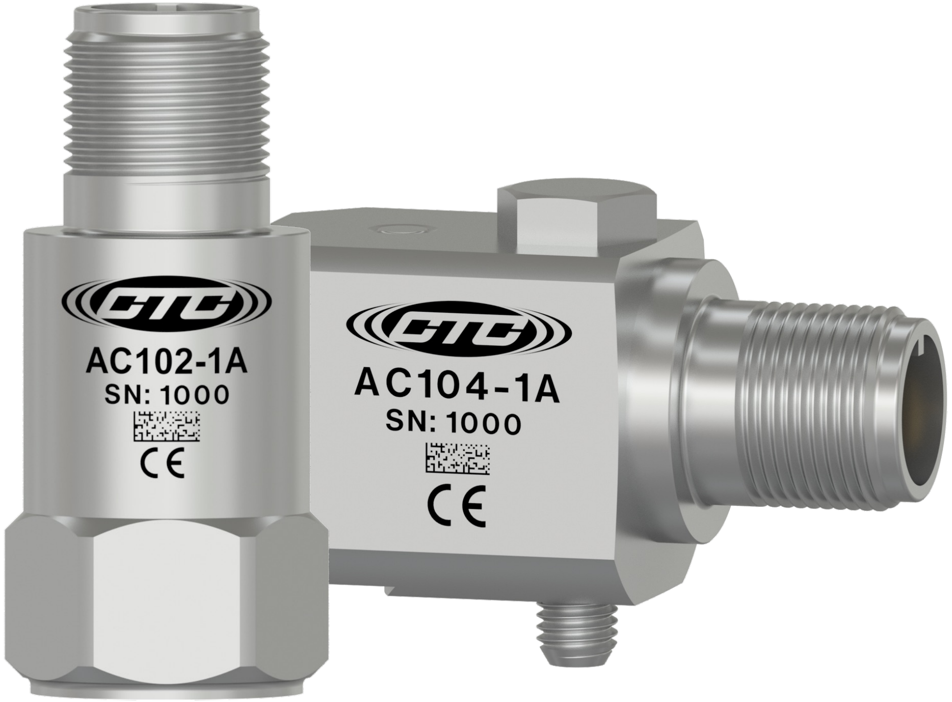
Frequency Response – Examples Of Stiffness And Natural Frequency

Another example is when a fan is mounted to a frame. When the fan is run at the frame's natural frequency, the fan will resonate.

Unlike a guitar string, achieving resonance on a large fan is not desirable. An analyst may recommend that the frame of the fan receive additional structural support, thus stiffening the system and raising the natural frequency beyond the running speed of the fan, so that the fan does not go into resonance under normal operating conditions.



Frequency Response – Examples Of Stiffness And Natural Frequency



These same principles are at work in an accelerometer.

Your sensor is designed to maximize stiffness and minimize mass to achieve a desired resonant frequency and frequency range.

Frequency Response – What Is It?

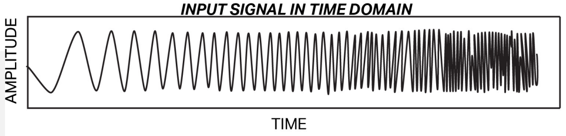
As mentioned previously, frequency response is a sensor's ability to measure the correct amplitude of a vibration at any frequency.

In other words, 1 g input at 1 Hz should yield 1 g output from the sensor at 1 Hz, just as 1 g input at 1000 Hz should produce a 1 g output from the sensor at 1000 Hz, and so on.

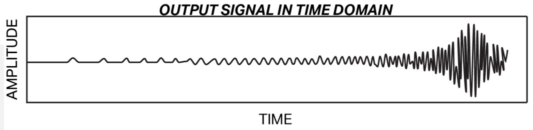
Input	Output
1 g at 1 Hz	1 g at 1 Hz
1 g at 10 Hz	1 g at 10 Hz
1 g at 1000 Hz	1 g at 1000 Hz
1 g at 10000 Hz	1 g at 10000 Hz

Frequency Response – In The Real World

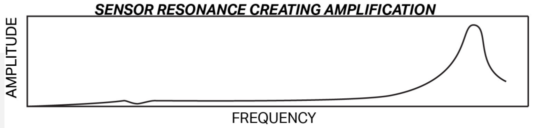
Unfortunately, in the real world, the frequency response is not always flat



In this plot, the input signal in the time domain has equal amplitudes although the frequency increases

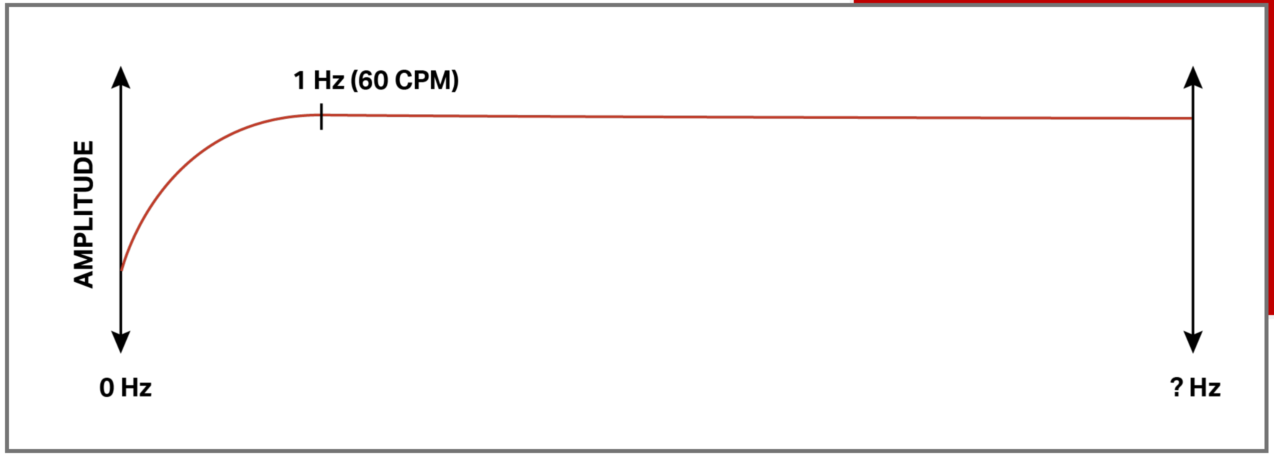


The frequency response of the sensor always has limitations. In this plot, the sensor resonance creates amplification



If the sensor illustrated in the center plot is sued to measure the signal illustrated in the first plot, the output signal in the time domain is modified as a result of the resonance and amplification occurs as shown in this plot

Frequency Response – Low Frequency



Low frequency roll-off is a result of:

- Accelerometer specifications
- The decoupling capacitator used to separate AC vibration signal from DC voltage, also known as AC Coupling

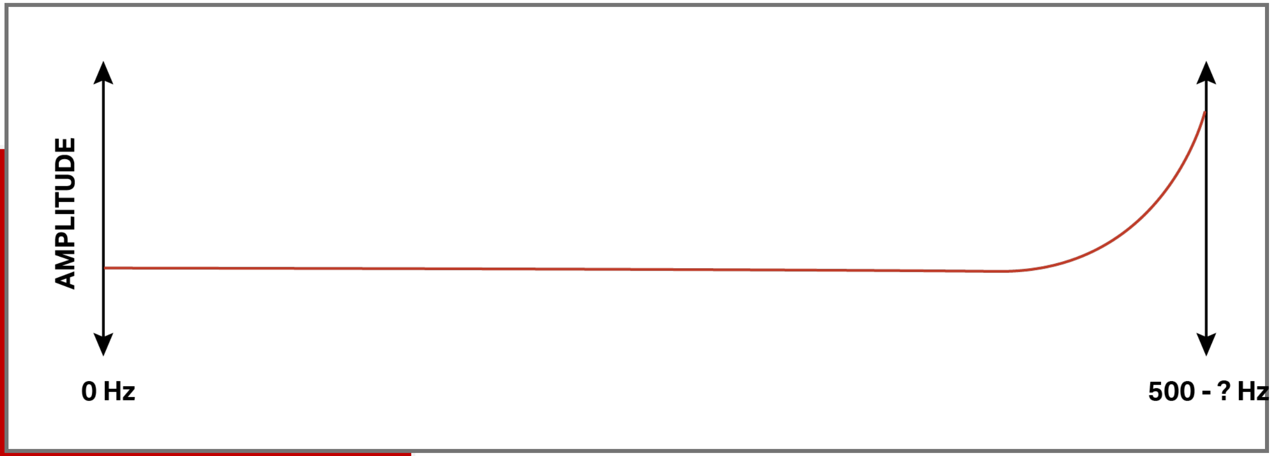
Low frequency roll-off is typically a factor at less than 1 Hz (60 CPM)

Frequency Response – High Frequency

High frequency gain is a result of:

- Accelerometer specifications and resonance
- Mounted resonance

High frequency gain is typically only a factor at 500 Hz (30,000 CPM) and greater, and is highly dependent on mounting method



Mounted Resonance – What Is It?

As noted earlier, resonance is the result of operating a machine, sensor, or accelerometer at its natural frequency.

Mounted resonance is the resulting change in natural frequency, caused by the structural change of the accelerometer, based on the mounting method used. This change in natural frequency is a direct result of the change in mass and stiffness.

What can happen at resonance?

Large gains in amplitude

Errors in signal amplitude

Phase change ≈ 180°

Destructive forces can occur

Mounted Resonance – Transmission, Amplification, Isolation

The three regions of a typical accelerometer response curve are:

Transmission

This is the useable region of the accelerometer, and will be specified at ±5%, ±10%, or ±3 dB.

Amplification

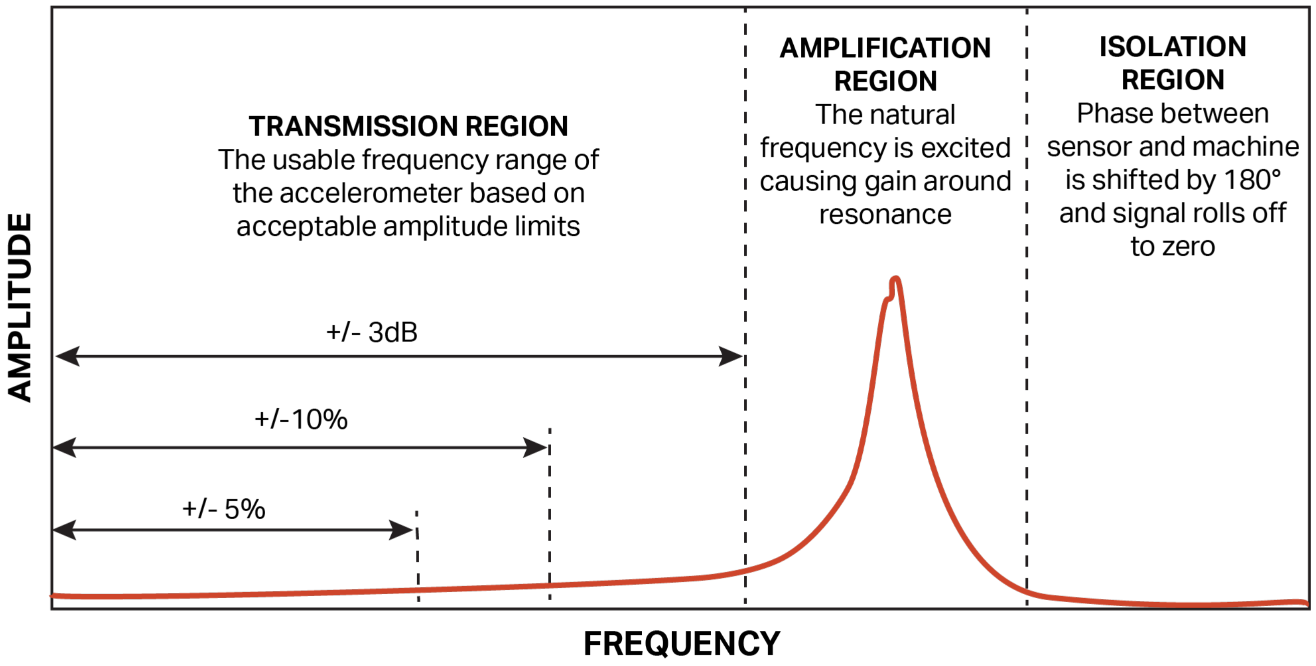
This is the area in which resonance is occurring and creating significant signal gain. Measurements in this region should be taken with care using special programs provided by the data collector manufacturer.

Isolation

This is the area above resonance that has unpredictable gain, phase, and amplitude. This region should never be used for measurements.

Mounted Resonance – Transmission, Amplification, Isolation

This is a graphical representation of the three regions of an accelerometer response curve as explained in the previous slide – transmission, amplification, and isolation

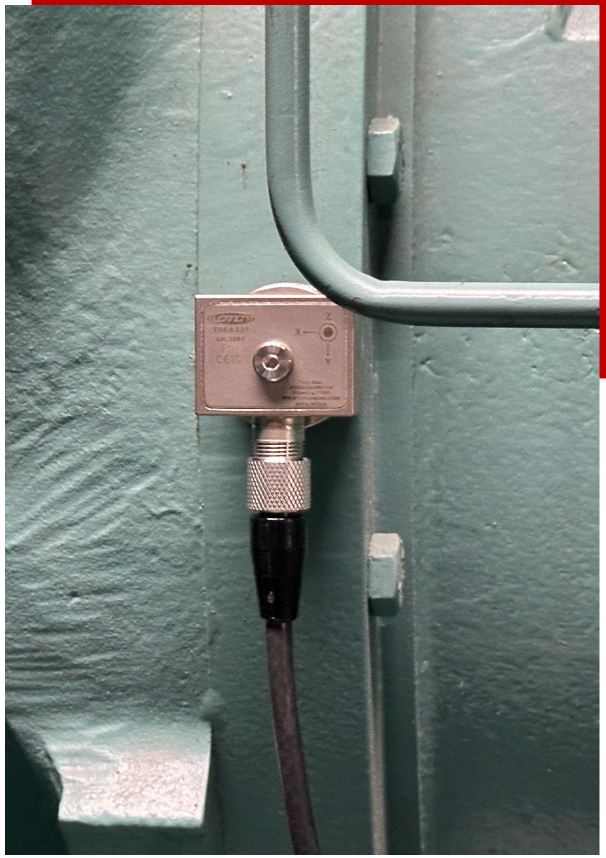


Mounted Resonance – Resonance Changes And Mounting

The mounting method used for an accelerometer can affect the mounted resonance

Mounted resonance can in turn effect the transmission, amplification, and isolation range of the sensor, as well as the frequency response of the sensor

Therefore, analysts using mounting methods other than the standard stud mount must consider what effect the new mounted resonance and new frequency range will have on the data being collected

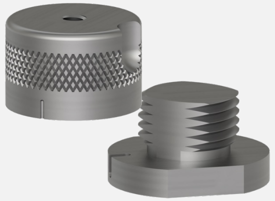


Mounted Resonance – Typical Mounting Methods

There are six typical mounting methods for an accelerometer:

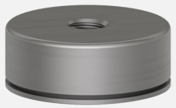
Probe Tip

Curved Surface Magnet

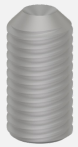


Quick Disconnect

Flat Magnet with Target



Adhesive Mount

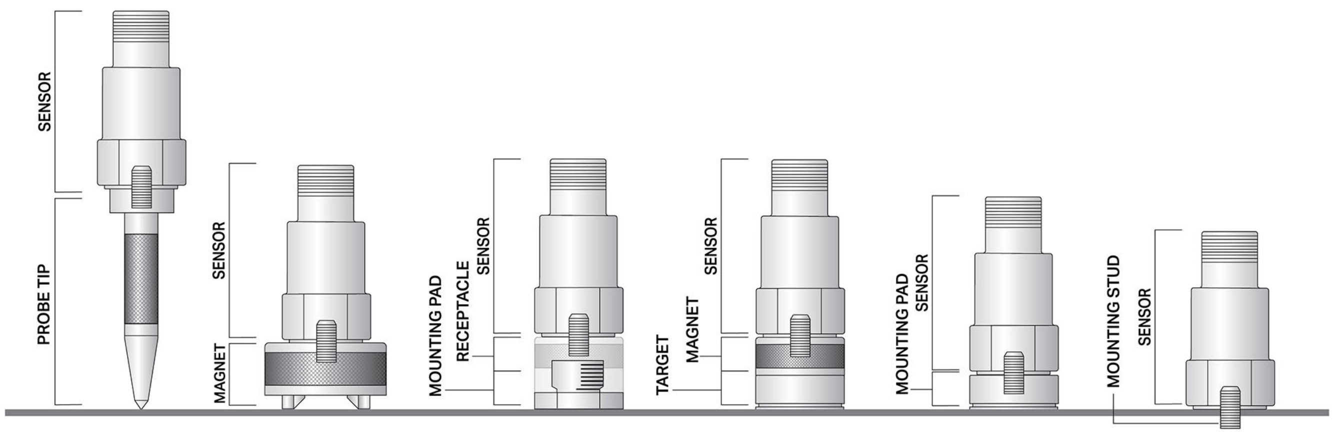


Stud Mount

Each method is very useful, but they each effect the frequency response of the accelerometer

Mounted Resonance – Typical Changes In Response

PROBE TIP	CURVED SURFACE MAGNET	QUICK DISCONNECT	FLAT MAGNET WITH TARGET	ADHESIVE MOUNT	STUD MOUNT
500 Hz (30,000 CPM)	2,000 Hz (120,000 CPM)	6,500 Hz (390,000 CPM)	10,000 Hz (600,000 CPM)	10,000 - 15,000 Hz (600,000 - 900,000 CPM)	Maximum Response of Sensor



Maximum Frequency Response*
(within ±3dB)

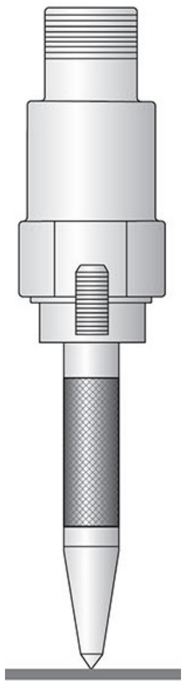
* depending on specified high frequency response of individual sensors

The following slides will show the changes in frequency response of an accelerometer based on ±3 dB limits using the six typical mounting methods.

Notice that the mounting method can limit the frequency response.

Be careful when choosing the mounting method for your sensor. Don't miss valuable data!

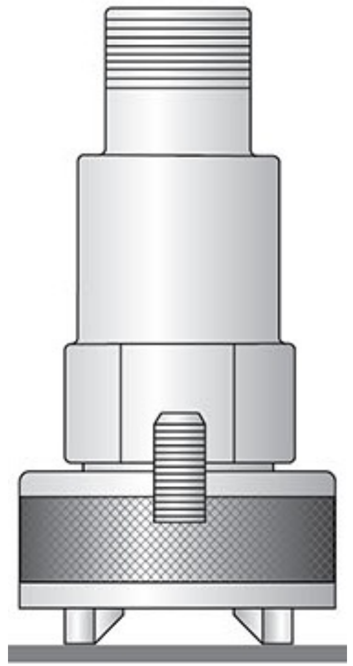
Mounted Resonance – Probe Tip



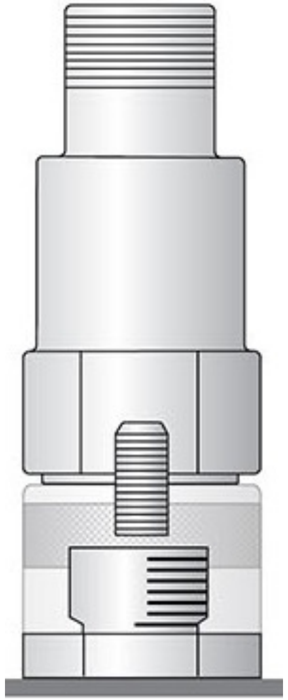
- The probe tip, or stinger, has the least amount of surface area contact and the least consistent and reliable pressure to fix the probe to the machinery.
- These factors all effect the stiffness of the mounting.
- The probe itself also adds mass to the sensor.
- The result is dramatically lower mounted resonance which reduces the effective high frequency response (at 3 dB) to just 500 Hz (30,000 CPM).
- The analyst looking for critical data above 500 Hz (30,000 CPM) should opt for a different mounting method.

Mounted Resonance – Curved Surface Magnet

- The curved surface magnet increases stiffness with more surface area contact and magnetic pull, however it also adds significant mass.
- These factors result in a higher mounted resonance and better high frequency response (at 3 dB) than the probe tip.
- Curved surface magnets have an effective transmission range under 2000 Hz (120,000 CPM).
- Interestingly, the stronger the magnet, which decreases stiffness, does not yield significantly better data on most applications - this is because the added mass on the larger magnet counteracts the benefits of the increased stiffness.



Mounted Resonance – Quick Disconnects



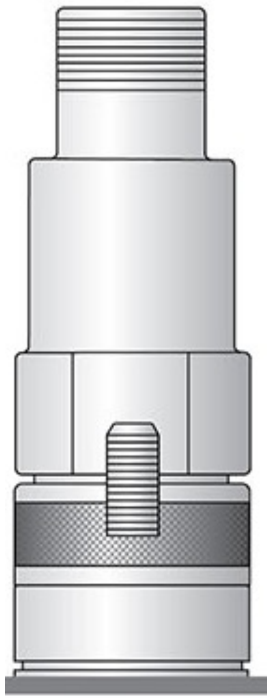
The intention of this mounting method is to increase the speed of route collection and ensure that data is taken from a consistent point.

Depending on the design of the system, of which there are a variety, some will also increase stiffness when compared to a curved surface magnet, thus raising the mounted resonance and the effective transmission range of the sensor.

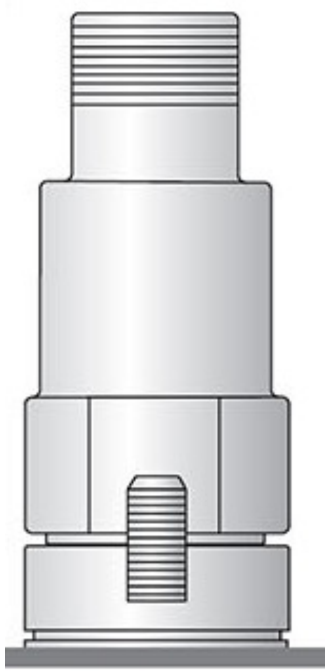
CTC's quick disconnect engages five threads with a quarter turn and provides the best high frequency response in the industry at 6500 Hz (380,000 CPM)

Mounted Resonance – Flat Magnet With Target

- When a flat surface magnet is used on a machine target, surface area contact is maximized and stiffness in general is increased over the other portable measurement methods.
- However, there is still additional mass when compared to the stud mount standard.
- Analysts should expect to yield good data up to roughly 7,000 – 8,000 Hz (420,000 – 480,000 CPM) before hitting 3 dB and entering amplification range.
- However, with perfect installation and execution, some analysts report frequency responses as high as 10,000 Hz (600,000 CPM).



Mounted Resonance – Adhesive Mounting

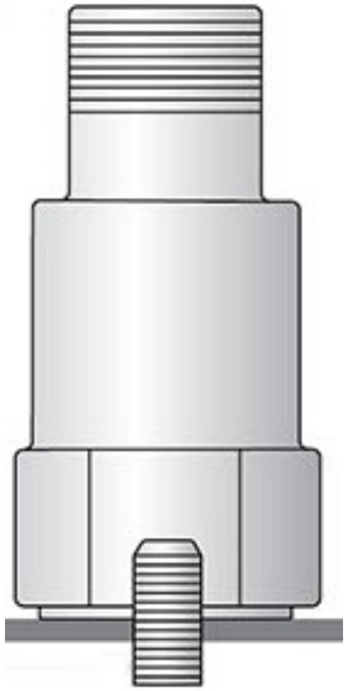


Adhesive mounting is generally for permanent installations and should yield data as high as 10,000 to 15,000 Hz (600,000 to 900,000 CPM).

In this method, stiffness is maximized and there is only a slight increase in mass compared to stud mounting.

Mounted Resonance – Stud Mount

- The maximum stiffness with the least additional mass is the stud mounting option.
- The stud mount option will yield the maximum frequency range of the sensor when properly installed.



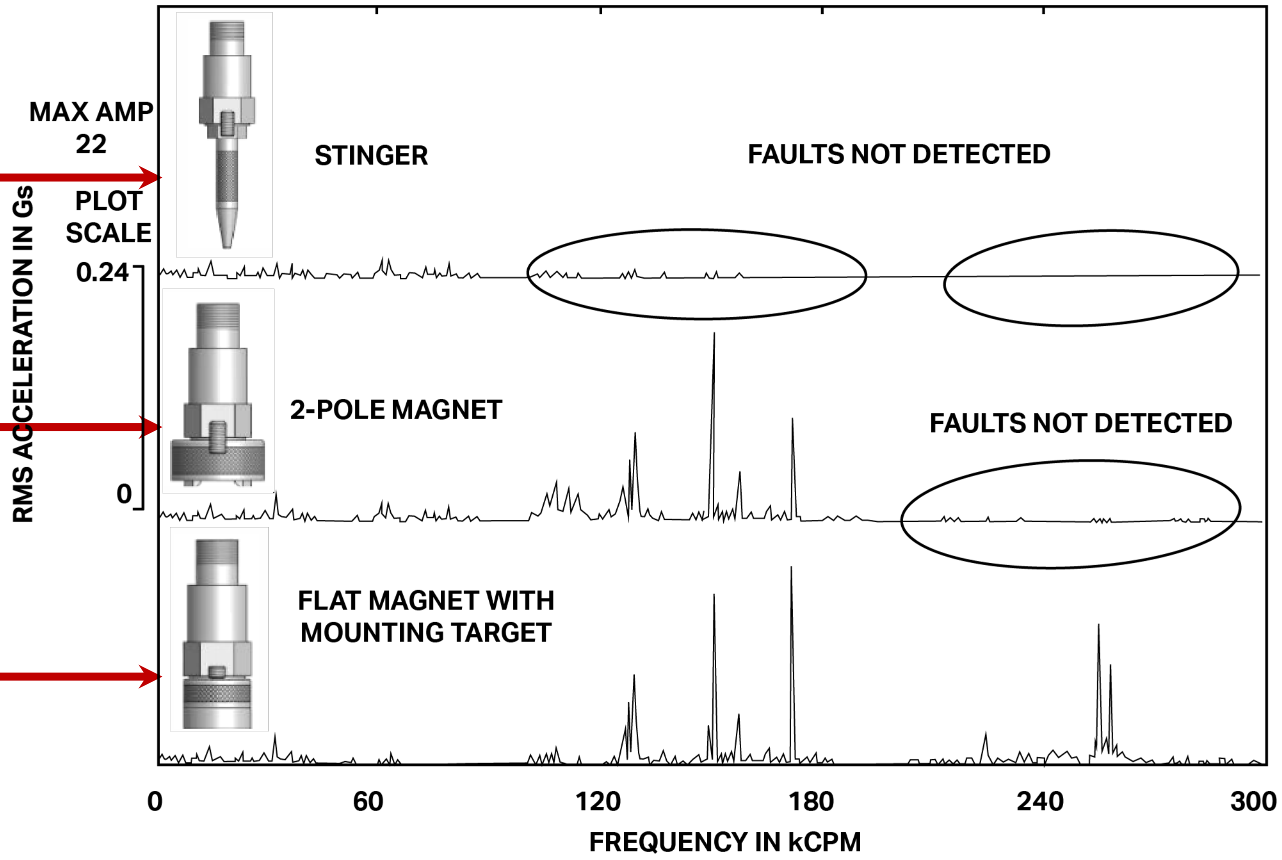
Mounted Resonance –
Reduced Frequency Response

Reduced frequency response of a probe tip affects amplitude above 30,000 CPM

Reduced frequency response of a curved surface magnet affects amplitudes above 120,000 CPM

Flat surface magnet with target measures all amplitudes less than 600,000 CPM

Notice how the flat surface magnet with target method can detect faults not seen with the other two methods.



Summary
Of Important Topics

- **Consider accelerometer specifications for frequency response** when selecting your accelerometer:
  - Frequencies above the operating specifications will have increased amplitudes
  - Frequencies below the operating specifications will have decreased amplitudes
- **Natural frequency** will depend on the mass and stiffness of the accelerometer and mounting
- **Resonance** occurs when the frequency of vibration is the same as the natural frequency of the accelerometer
- **Mounted resonance** is a result of the mounting method used and can have a direct effect on the natural frequency
- **Choose the accelerometer and mounting method YOU need for YOUR machine** frequencies and avoid resonance
- **Work within the transmission range** of the frequency response

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