Frequency Response and Mounted Resonance for Accelerometers

- A Basic Understanding

VIBRATION ANALYSIS HARDWARE

Narration

About this Presentation

We are glad that you have taken the time to view this self-paced training module on *Frequency Response and Mounted Resonance for Accelerometers*.

This is a narrated slide show. The narration can be played through the speakers on your computer, or, if you do not have speakers or wish not to disturb others around you, the entire narration for each slide will be displayed on the screen in a blue box such as this one.

We hope you enjoy the training.

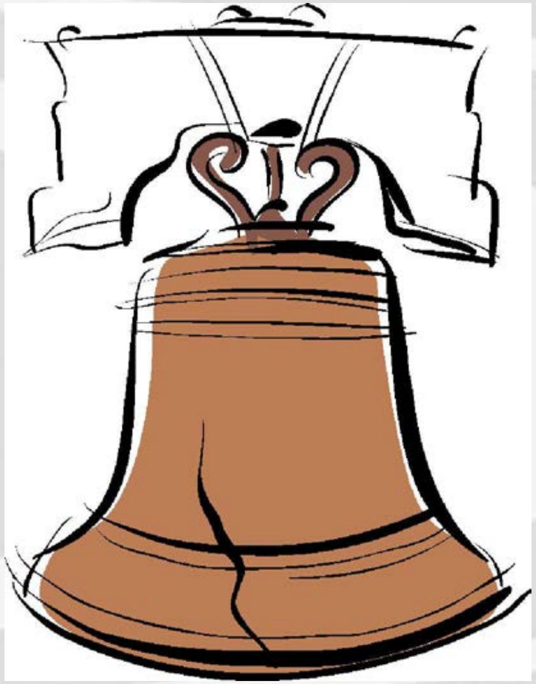
Frequency Response and Mounted Resonance for Accelerometers – A Basic Understanding, was created and presented by **CTC** (Connection Technology Center, Inc.)

CTC manufactures a full line of Industrial Vibration Analysis Hardware, and Process and Protection Instruments, all backed by the Industry's only **Unconditional Lifetime Warranty**.

MADE IN THE USA

Objectives

After taking this training module you will understand the concepts of natural frequency, frequency response, resonance, mounted resonance, and how they affect the data used for vibration analysis and condition monitoring. Better understanding these principles will enable you to make sure that you are not missing important data, and will ultimately assist you in “making better calls.”



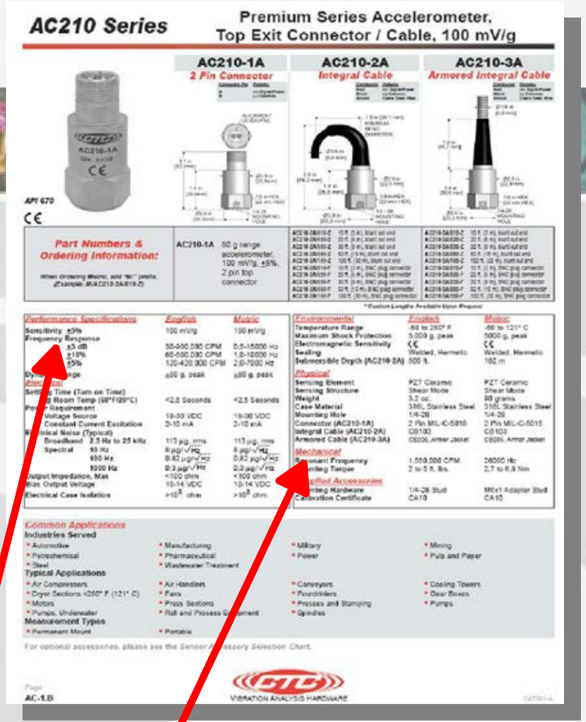
Terms

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.

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

The natural frequency of an Accelerometer or Velocity Sensor is typically listed as the “**Resonant Frequency”** on the sensor’s data sheet.

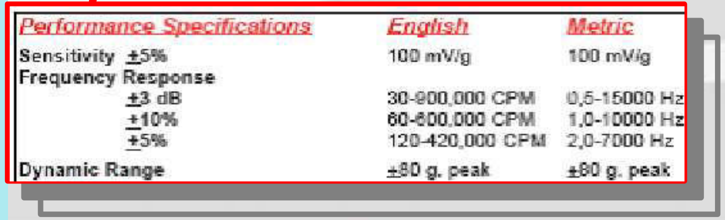
The natural or resonant frequency of a sensor will have a direct effect on that sensor’s “**Frequency Response”** (a sensor’s ability to measure the correct amplitude of a vibration at a given frequency). A sensor’s data sheet will typically list a sensor’s frequency response in relation to the minimum and maximum frequencies that the sensor can measure to a given degree of accuracy.



AC210 Series

Premium Series Accelerometer, Top Exit Connector / Cable, 100 mV/g

Mechanical		
Resonant Frequency	1,560,000 CPM	26000 Hz
Mounting Torque	2 to 5 ft. lbs.	2,7 to 6,8 Nm



Performance Specifications	*English*	*Metric*
Sensitivity ±5%	100 mV/g	100 mV/g
Frequency Response		
±3 dB	30-900,000 CPM	0,5-15000 Hz
±10%	60-600,000 CPM	1,0-10000 Hz
±5%	120-420,000 CPM	2,0-7000 Hz
Dynamic Range	±80 g, peak	±80 g, peak

Mass & Stiffness

Mass and Stiffness play a key role in defining the Natural Frequency.

The natural frequency F_n is equal to:

> **1/(2π) x the square root of the stiffness (K) divided by the mass (M).**

Mass (M) can be expressed as the weight (W) divided by gravity (g).

If the stiffness decreases, the natural frequency will also decrease *(direct relationship).*

If the mass (weight) increases, the natural frequency will decrease *(inverse relationship).*

- $F_n = 1/(2\pi)\sqrt{k/m}$ where:
  - F_n = Natural Frequency (Hz)
  - k = Stiffness
  - m = Mass
  - m = Weight/gravity
- As stiffness increases, the natural frequency increases.
- As mass increases, the natural frequency decreases.

Example of Stiffness & Natural Frequency

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

Now let's look at a fan which is mounted to a frame. When the fan is run at the frame's natural frequency, the fan will resonate. Unlike on 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.

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.

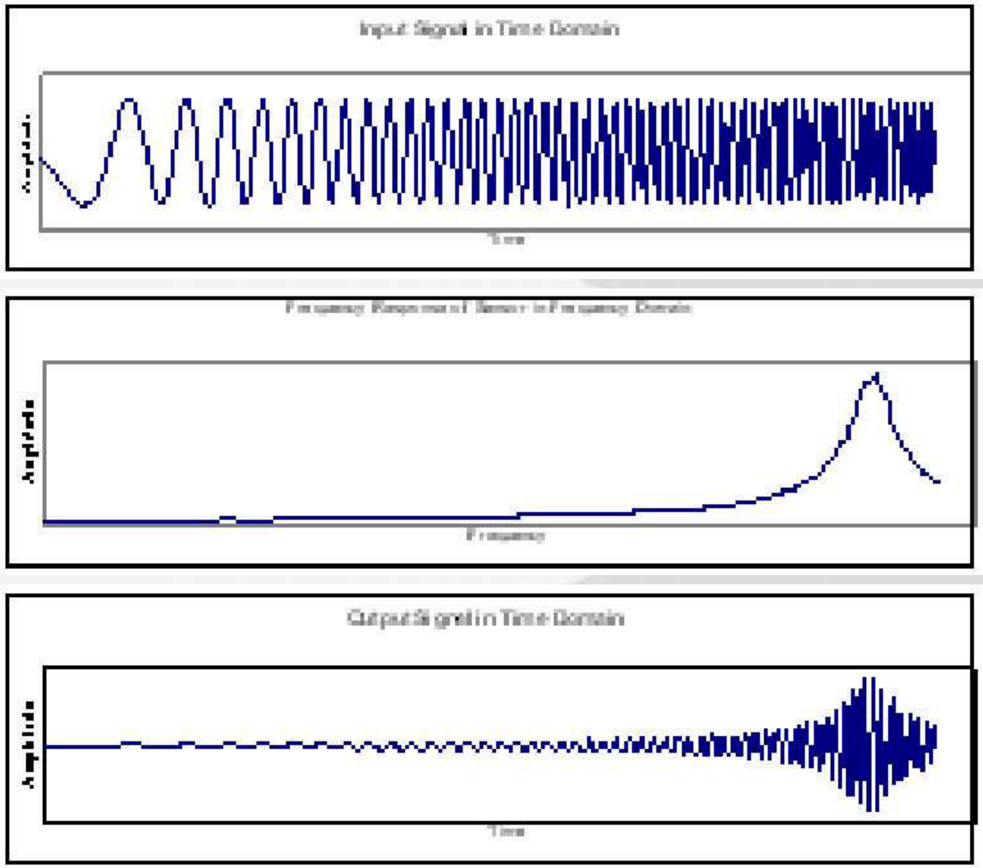
What is Frequency Response ?

As discussed 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 1Hz; just as 1 g input at 1000 Hz should produce a 1 g output from the sensor at 1000 Hz, and so on.

1g @ 1Hz → 1g @ 1Hz
1g @ 10 Hz → 1g @ 10 Hz
1g @ 1000 Hz → 1g @ 1000 Hz
1g @ 10000 Hz → 1g @ 10000 Hz

Real World Frequency Response



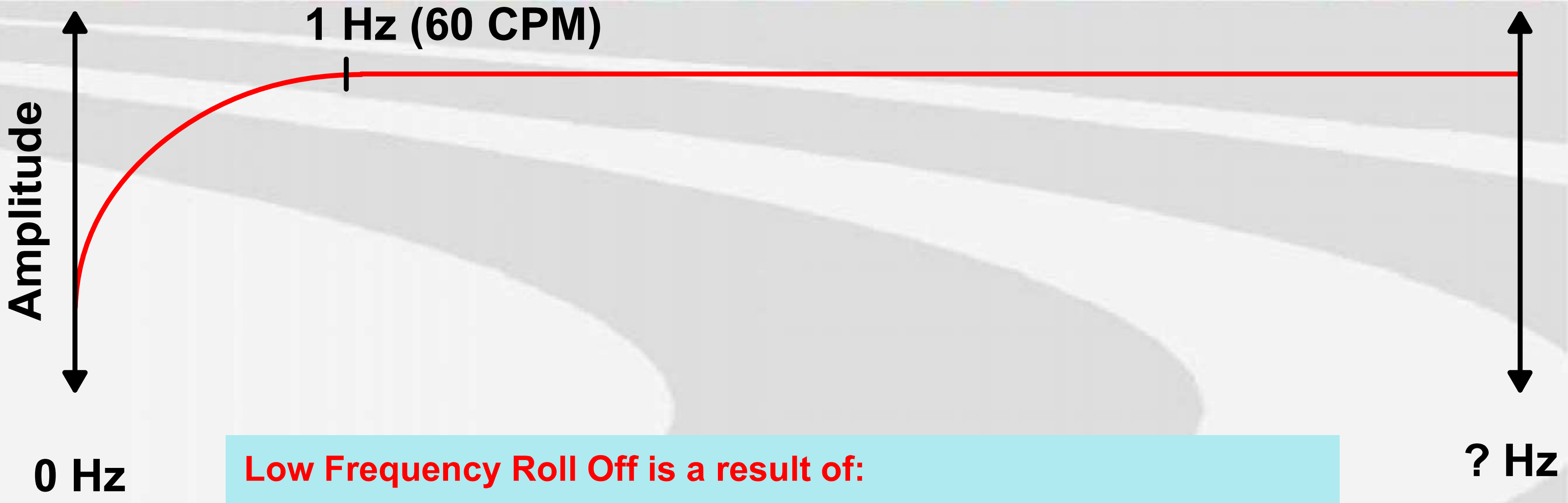
Unfortunately, in the real world, the frequency response is not always FLAT!

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

The frequency response of the sensor always has limitations. The center plot shows sensor resonance creating amplification.

If the sensor illustrated in the center plot is used to measure the signal illustrated in the upper plot, the output signal in the time domain is modified as a result of resonance, and amplification occurs as shown in the bottom p

Low Frequency



Low Frequency Roll Off is a result of:

- Accelerometer specifications
- The De-Coupling capacitor used to separate AC vibration signal from DC bias voltage. Also known as “AC coupling.”

Low frequency roll off is typically a factor at <u>less than</u> 1 Hz (60 CPM).

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 dependant on mounting method!

What is Mounted Resonance ?

As noted earlier, **Resonance** is the result of operating a machine, sensor, or accelerometer at it’s 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.

Several things can happen at resonance:

- *Large gains in amplitude*
- *Errors in signal amplitude*
- *Phase change* $\approx 180^0$
- *Destructive forces can occur*

Transmission, Amplification, Isolation

- Transmission
- Amplification
- Isolation

There are three regions of a typical accelerometer response curve!

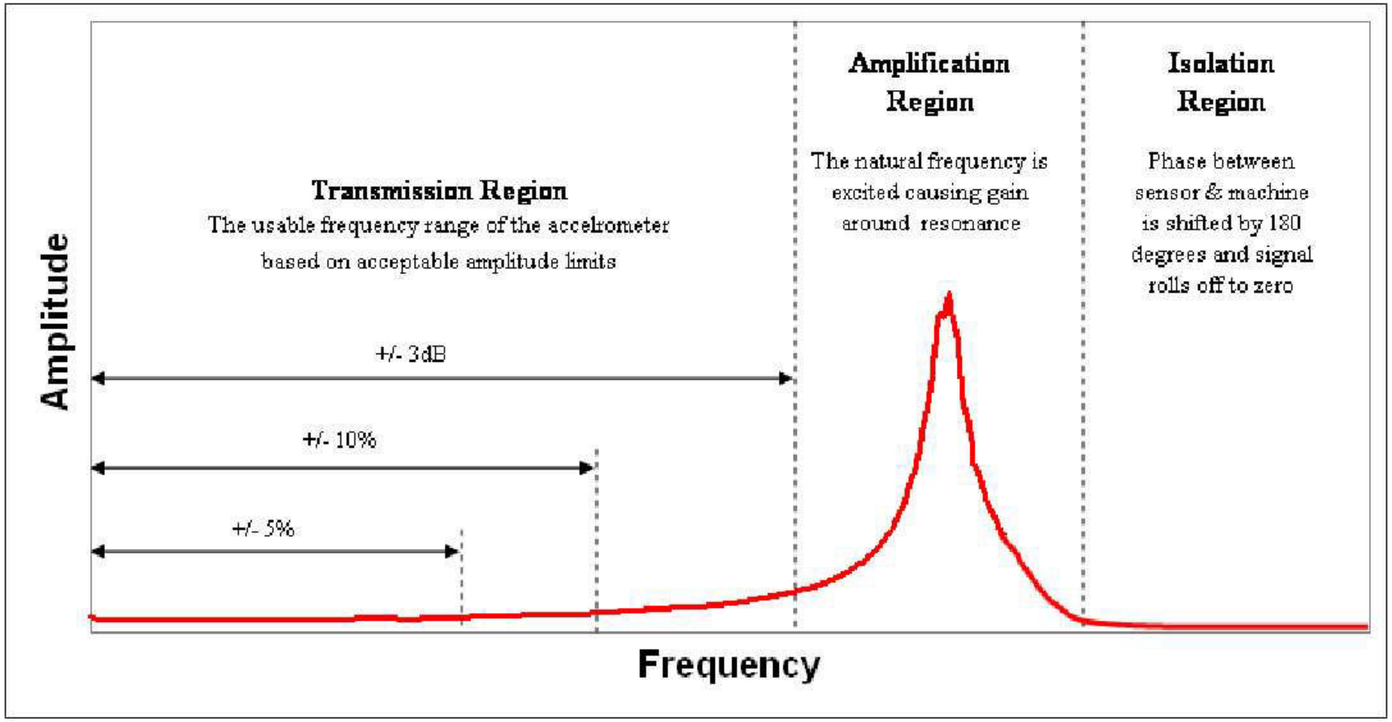
The Transmission region is defined as the usable region of the accelerometer, and will be specified at +/- 5%, +/- 10%, or +/- 3dB.

The Amplification region is defined as the area in which resonance is occurring and creating significant signal gain. Measurements in the amplification region should be taken with care using special programs provided by the data collector manufacturers.

The Isolation region is defined as the area above resonance that has unpredictable gain, phase, and amplitude. The isolation region should *never* be used for measurements.

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.



Resonance Changes & 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
- Frequency Response of the sensor

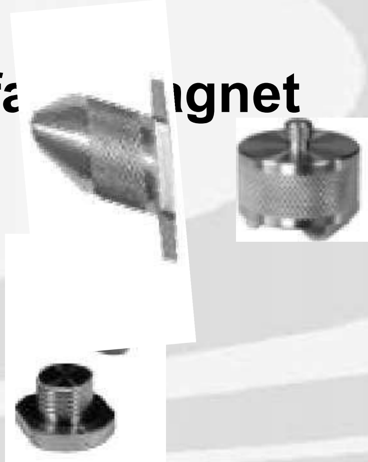
Therefore, analysts using mounting methods other than the standard stud mount, must consider what effect the new mounted resonance and new frequency range will have on the data being collected.

Typical Mounting Methods

Let’s take a look at six typical mounting methods for an accelerometer.

Remember, each of these methods is very useful, but they can all have an effect on the frequency response of the accelerometer.

- **Probe Tip**
- **Curved Surfa gnet**
- **Quick Disconnect**



- **Flat Magnet with Target**

- **Adhesive Mount**

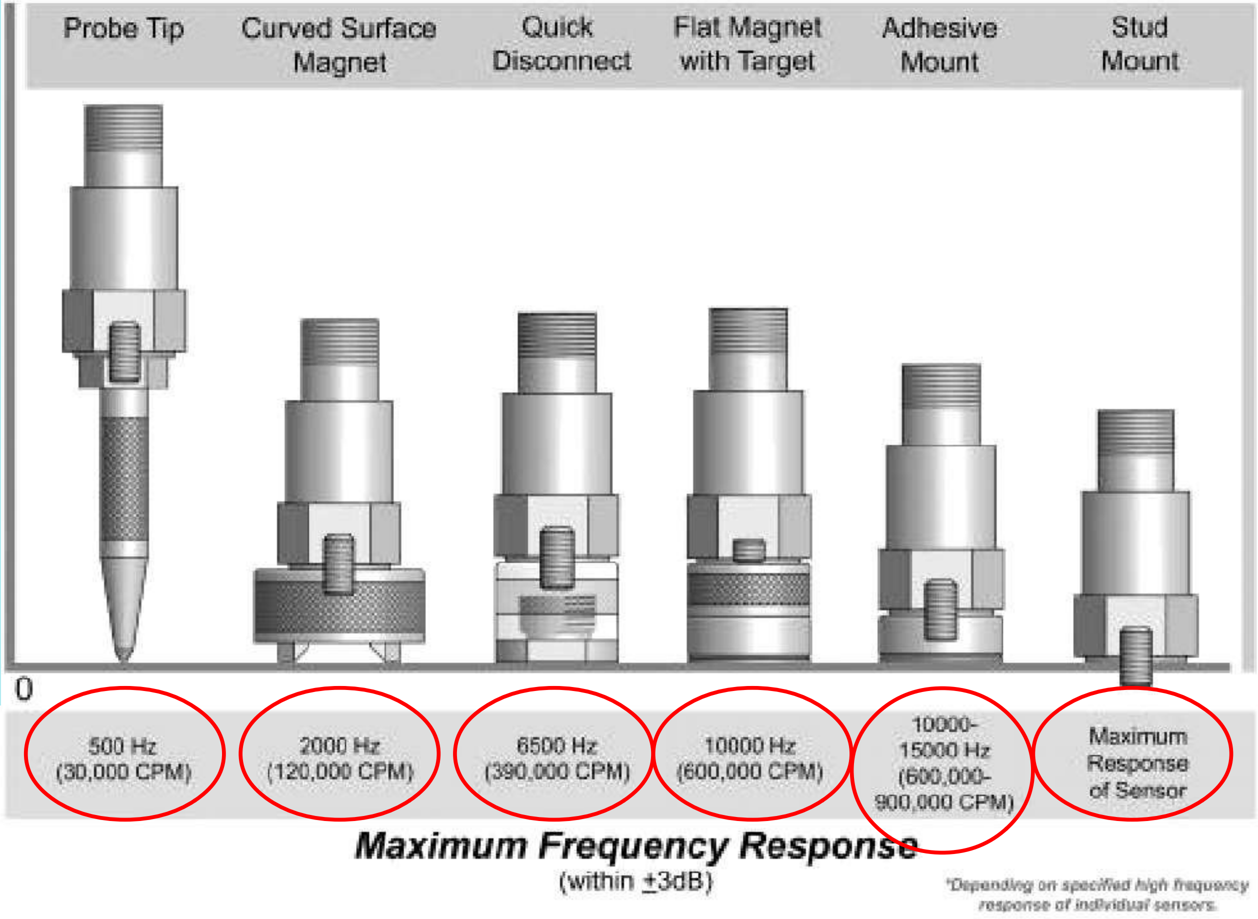
- **Stud Mount**

Typical Changes in Response

The following are the changes in the frequency response of the accelerometer based on +/- 3dB limits using the six typical mounting methods.

Notice that the mounting method can limit the frequency response.

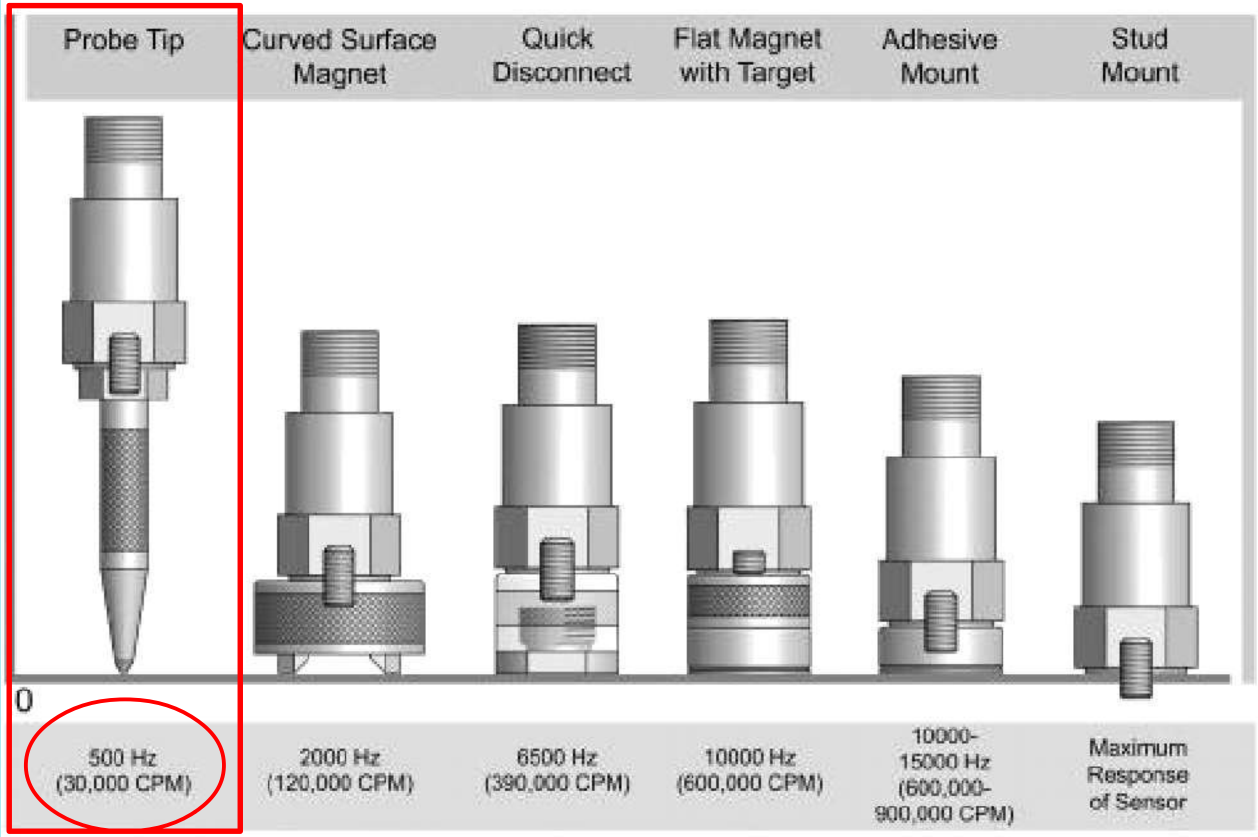
Be careful when choosing the mounting method for your sensor. Don't miss valuable data!



Typical Changes in Response

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 a dramatically lower mounted resonance which reduces the effective high frequency response (at 3 dB) to just 500 Hz (30,000 CPM).

The conclusion is that analysts looking for critical data above 500 Hz should opt for a different method of mounting their accelerometer.



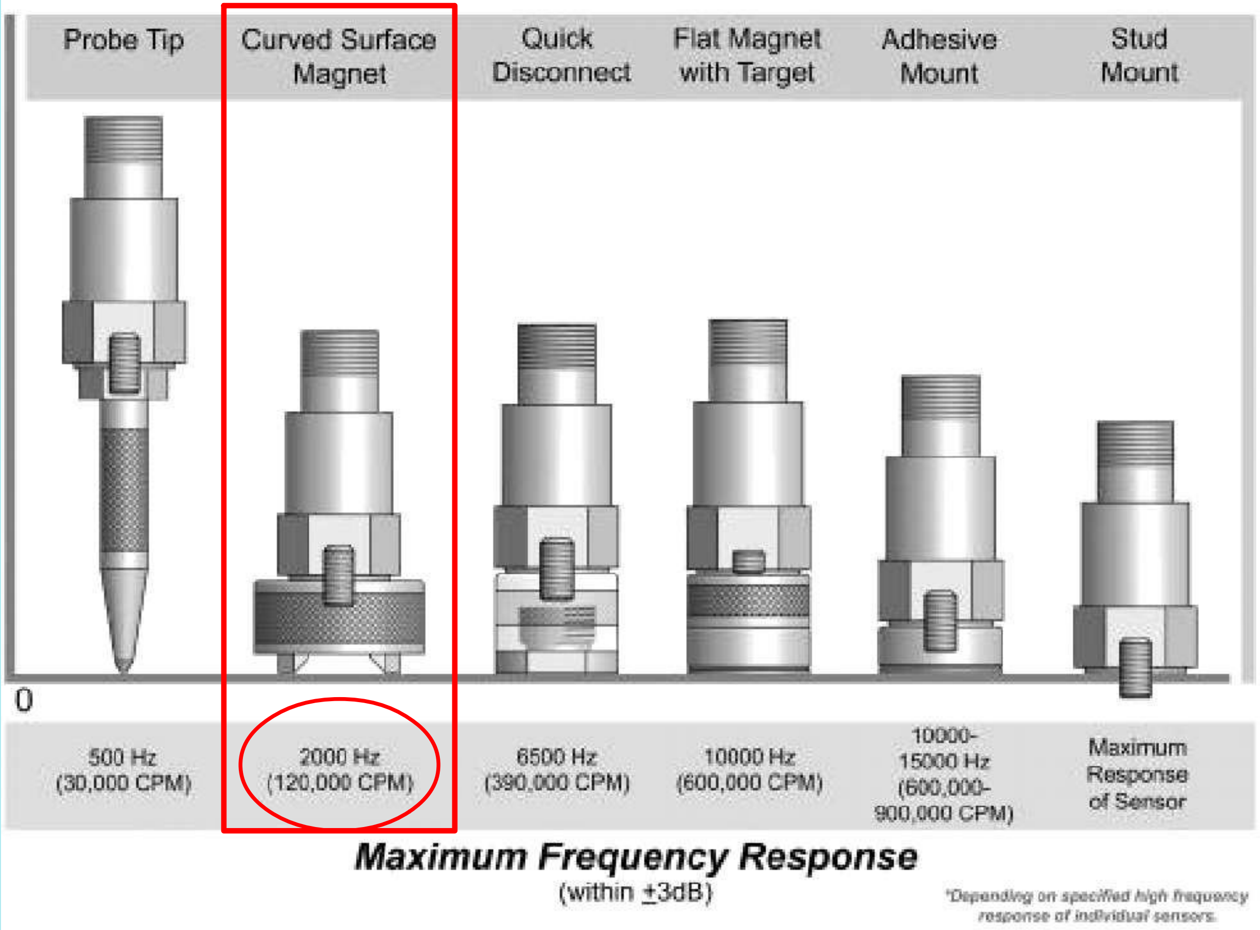
Maximum Frequency Response
(within ±3dB)

**Depending on specified high frequency response of individual sensors.*

Typical Changes in Response

The curved surface magnet increases stiffness with more surface area contact and a 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 method. Curved surface magnets have an effective transmission range under 2,000 Hz (120,000 CPM).

It is interesting to note that a stronger magnet, which would increase stiffness, does not yield significantly better data on most applications since the added mass of the larger magnet counteracts the benefits of the increased stiffness.

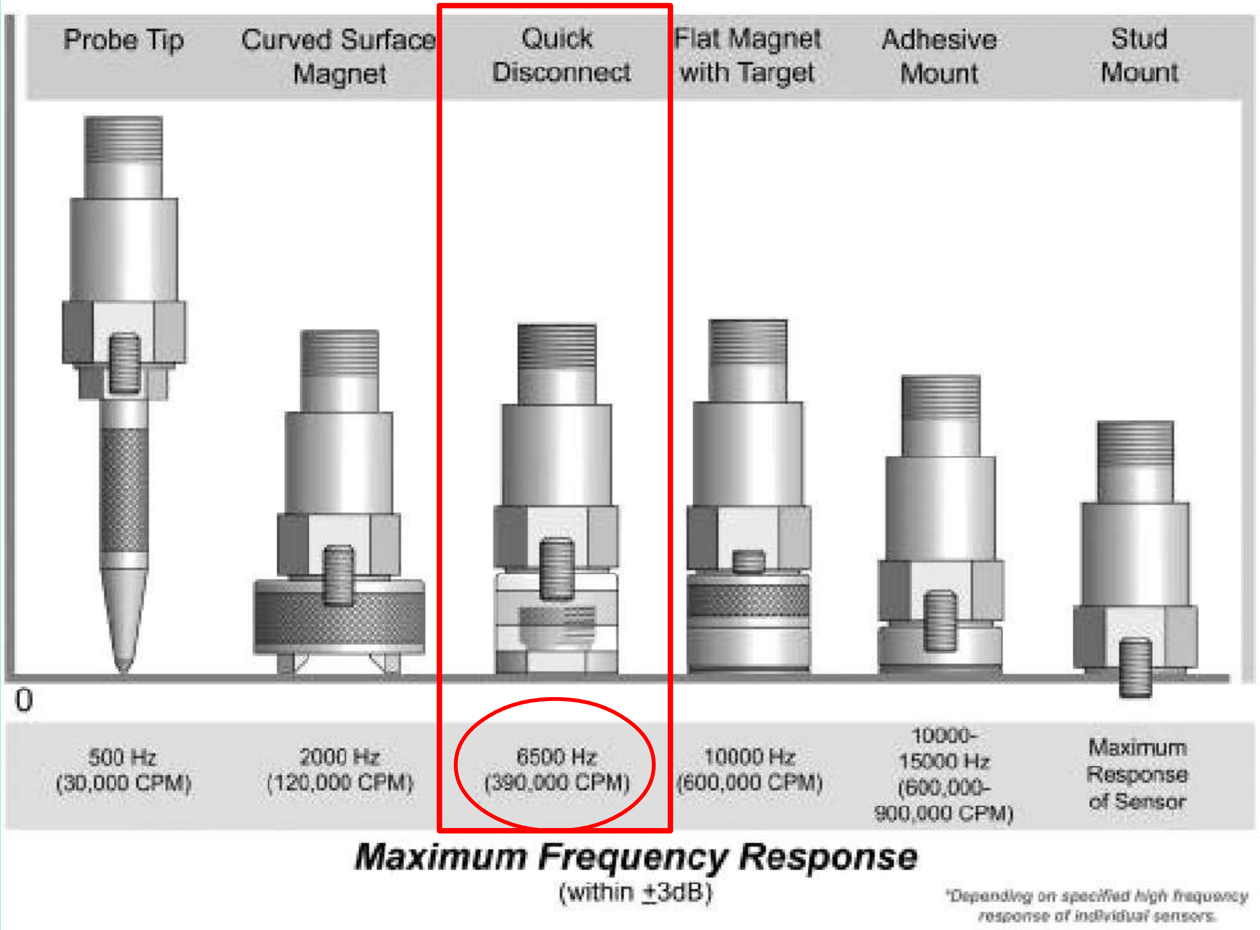


Typical Changes in Response

There are a variety of Quick Disconnect systems on the market. 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, 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.

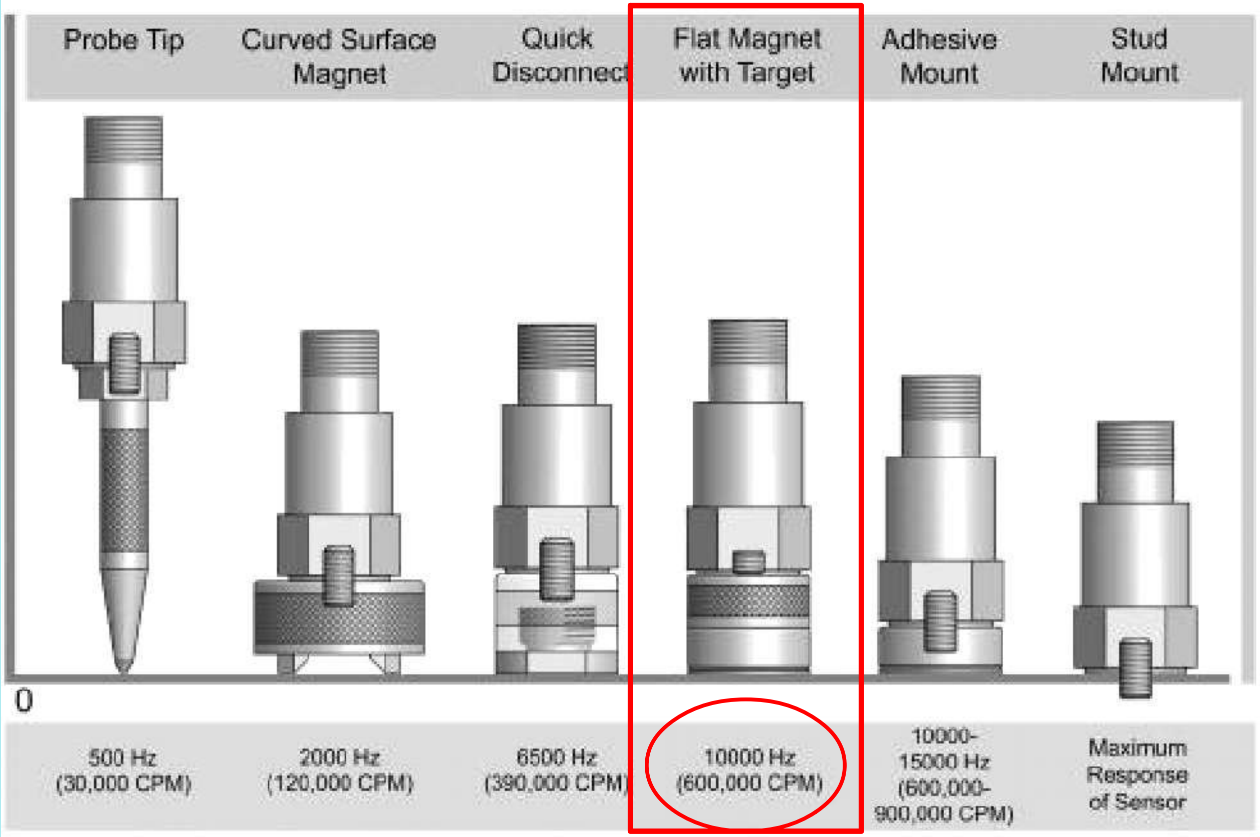
CTC's Quick Disconnect engages 5 threads with a quarter turn, and provides the best high frequency response in the industry at 6,500 Hz (390,000 CPM).



Typical Changes in Response

When a flat magnet is used on a machined 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 to 8,000 Hz (420,000 to 480,000 CPM) before hitting 3 dB and entering the amplification range. However, with perfect installation and execution, some analysts report frequency responses as high as 10,000 Hz (600,000 CPM).



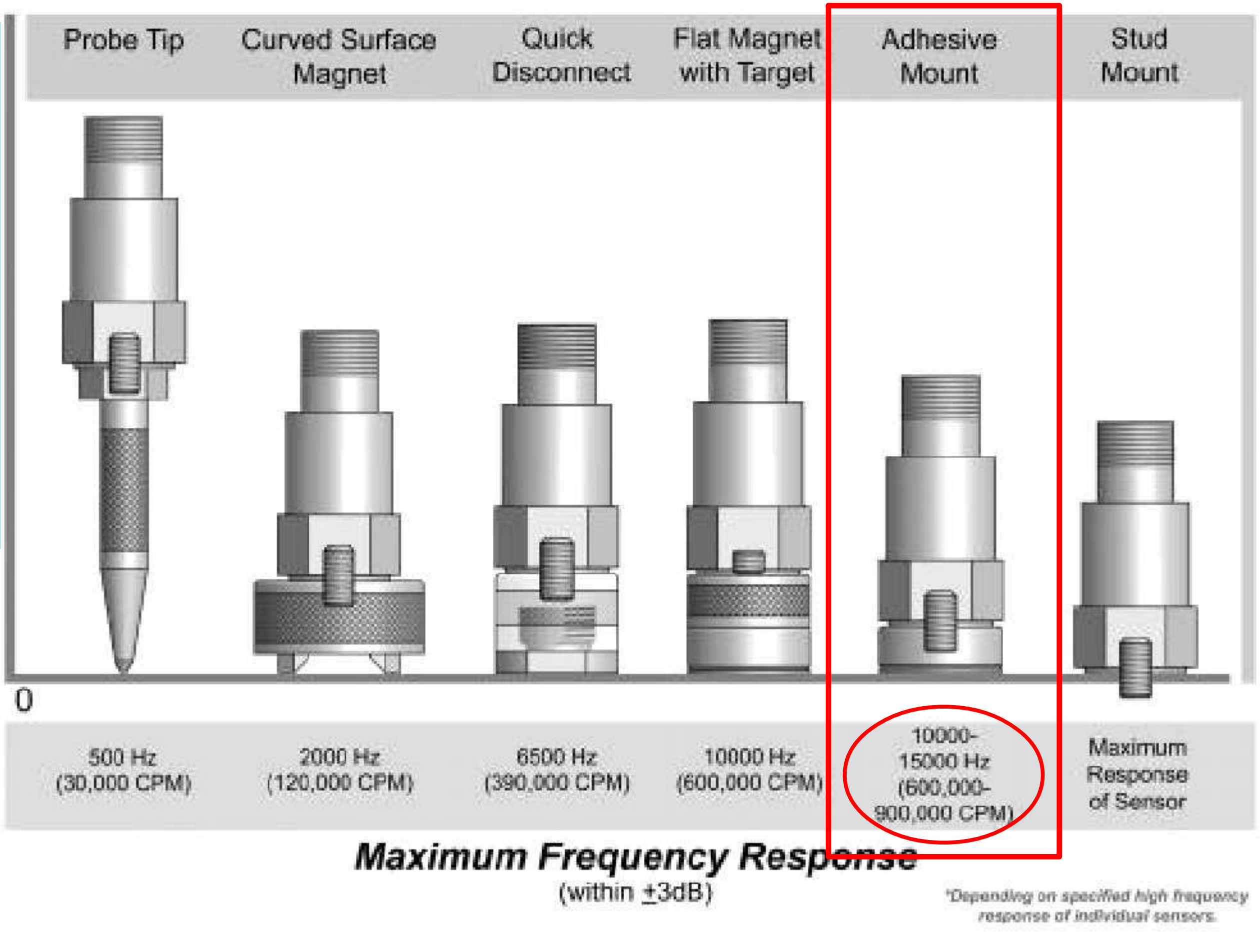
Maximum Frequency Response
(within ±3dB)

*Depending on specified high frequency response of individual sensors.

Typical Changes in Response

Adhesive mounting is generally for permanent installation 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.



Probe Tip	Curved Surface Magnet	Quick Disconnect	Flat Magnet with Target	Adhesive Mount	Stud Mount
500 Hz (30,000 CPM)	2000 Hz (120,000 CPM)	6500 Hz (390,000 CPM)	10000 Hz (600,000 CPM)	10000-15000 Hz (600,000-900,000 CPM)	Maximum Response of Sensor

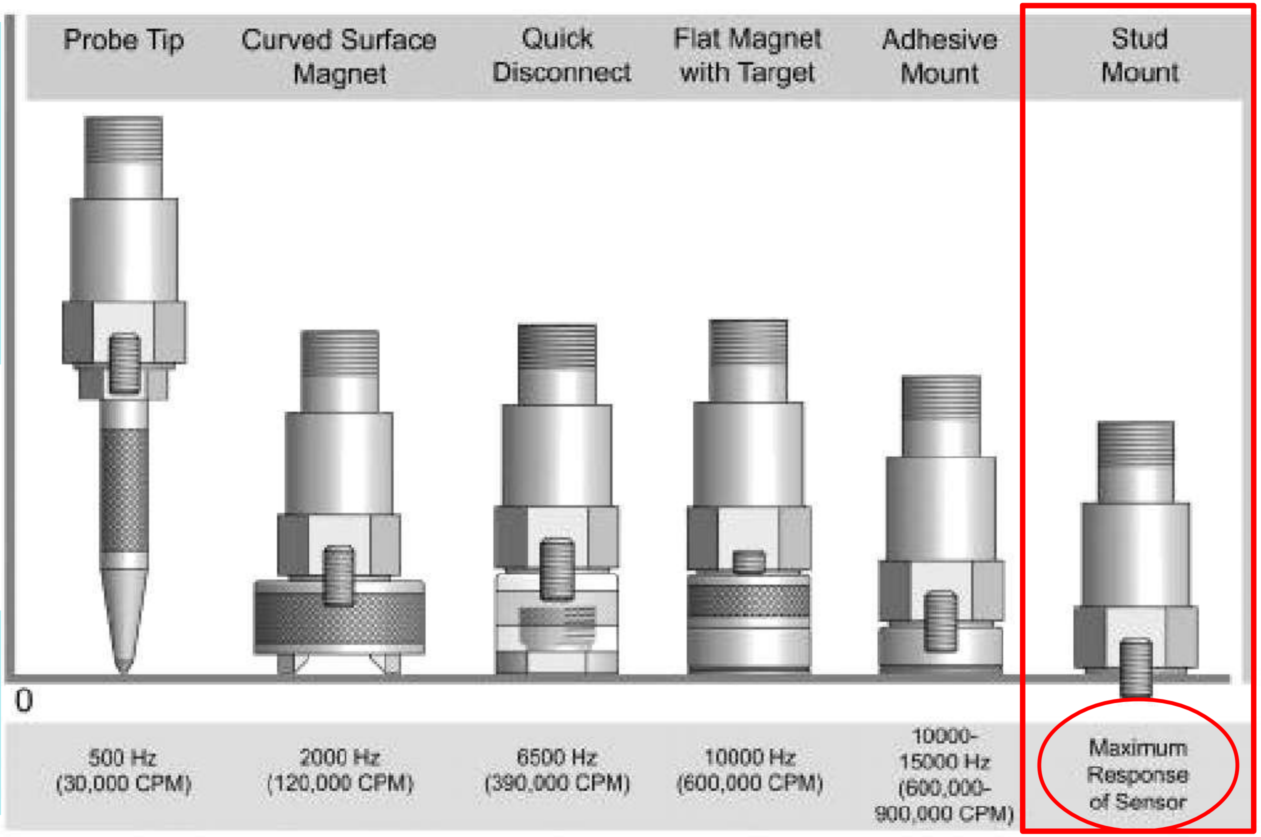
Maximum Frequency Response
(within ±3dB)

*Depending on specified high frequency response of individual sensors.

Typical Changes in Response

And of course the maximum stiffness with the least additional mass is the stud mount option which will yield the maximum frequency range of the sensor when properly installed.

Next, let's look at how these various mounting options effect the data collected on an application…



Maximum Frequency Response
(within ±3dB)

*Depending on specified high frequency response of individual sensors.

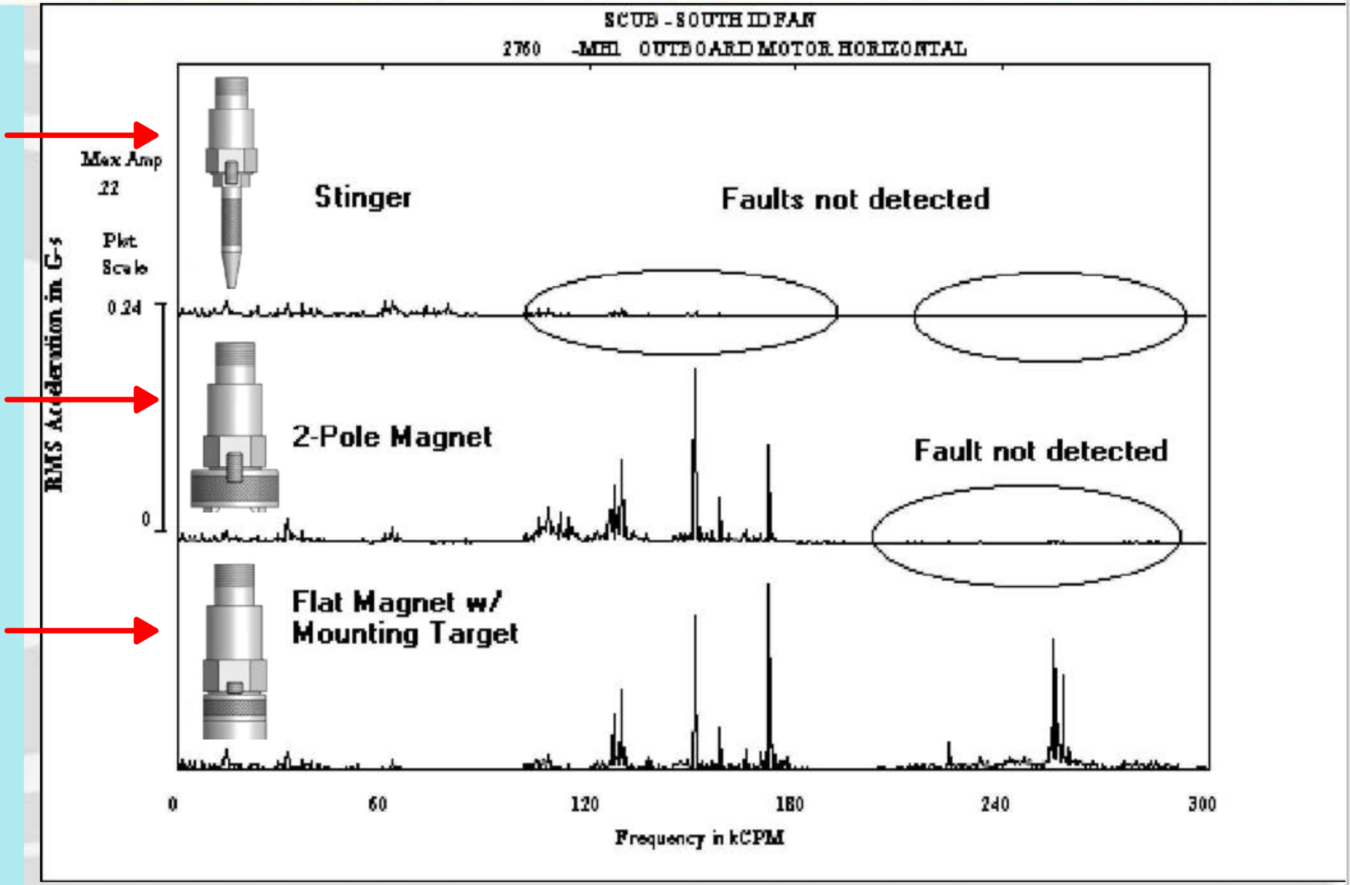
Reduced Frequency Response

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

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

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

Notice how the Flat Magnet with Target method is able to detect faults not seen with the other two methods.



Summary

- **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 to measure YOUR machine frequencies and avoid Resonance.

- Work within the “transmission” range of the Frequency Response.

Summary

Thank You!

Thank you for taking the time to review this training module. We hope that you learned something that will help you to collect more accurate data, and to allow you to make better "calls."

CTC prides itself on it's customer and technical support. Did you know that CTC employs several Vibration Institute Certified **Category 2** and **Category 3** Analysts, and one **Category 4** Analyst who also trains for the Vibration Institute? It is all part of our commitment to providing the industry's best service and support.

For more technical information, additional white papers, and training materials, we invite you to visit our website at **www.ctconline.com**, or contact one of our Analysts at (800) 999-5290 (in the US and Canada); or at +1-585-924-5900 (international).

Summary

Thank You !

Next time you need Sensors, Cables, Junction Boxes or Mounting Hardware and accessories, we would appreciate it if you would keep us in mind.

CTC offers a full range of vibration analysis hardware and process and protection instruments for industrial use. Our customers choose us based on:

- Superior Durability
- Accuracy and Performance
- Quick Service (shipping most orders in 3 days)
- Knowledgeable support staff
- Industry's only ***UNCONDITIONAL LIFETIME WARRANTY***

Thanks again for your time.

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