CONNECTION TECHNOLOGY CENTER, INC.

LEVEL 2 – LESSON 2

FREQUENCY RESPONSE AND MOUNTED RESONANCE FOR ACCELEROMATERS: A BASIC UNDERSTANDING

INTRODUCTION

Welcome to **Level 2, Lesson 2** of CTC's free online vibration analysis training. We're glad you have taken the time to view this self-paced lesson on Frequency Response and Mounted Resonance for Accelerometers. We hope you enjoy the training and will continue to build your vibration analysis knowledge as you progress through Level 2.

OBJECTIVES

After completing this training module you will understand the concepts of:

- ☐ **Natural Frequency**
- ☐ **Frequency Response**
- ☐ **Resonance**
- ☐ **Mounted Resonance**

You will also learn how each of the above concepts 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."

FREQUENCY RESPONSE - 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 independent 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**.

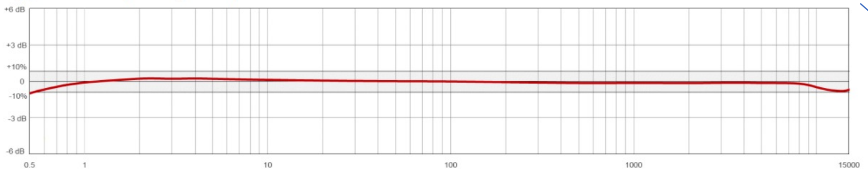
The natural frequency of an accelerometer or velocity sensor is typically listed as the **Resonant Frequency** on the sensor's datasheet.

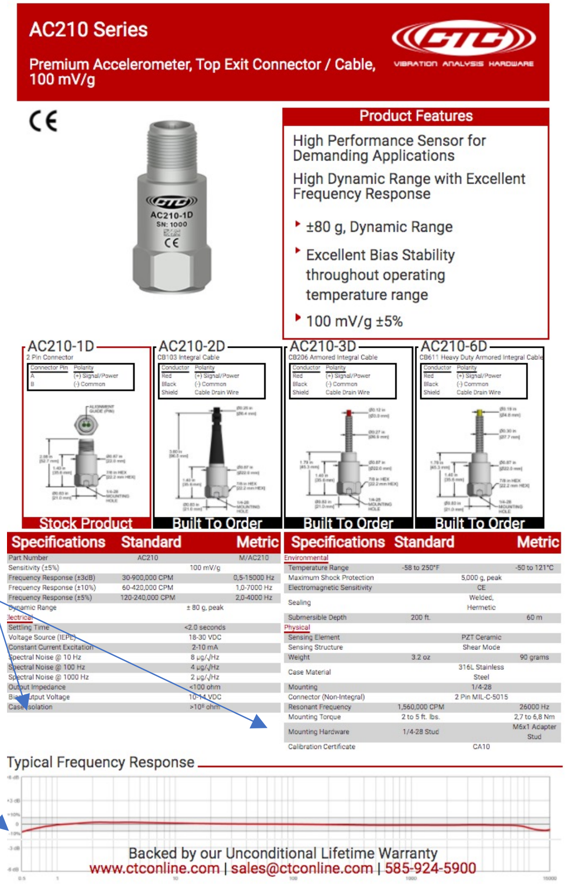
The natural or resonant frequency of a sensor will have a direct effect on that sensor's **Frequency Response** – a sensor's ability to measure the correct amplitude of a vibration at a given frequency. A sensor's data sheet will typically list a sensor's frequency response in relation to the minimum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

Specifications	Standard	Metric
Part Number	AC210	M/AC210
Sensitivity (±5%)	100 mV/g	
Frequency Response (±3dB)	30-900,000 CPM	0,5-15000 Hz
Frequency Response (±10%)	60-420,000 CPM	1,0-7000 Hz
Frequency Response (±5%)	120-240,000 CPM	2,0-4000 Hz

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

Typical Frequency Response





AC210 Series

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

Product Features

High Performance Sensor for Demanding Applications

High Dynamic Range with Excellent Frequency Response

- ±80 g, Dynamic Range
- Excellent Bias Stability throughout operating temperature range
- 100 mV/g ±5%

AC210-1D 2 Pin Connector — Stock Product

AC210-2D CB103 Integral Cable — Built To Order

AC210-3D CB206 Armored Integral Cable — Built To Order

AC210-6D CB611 Heavy Duty Armored Integral Cable — Built To Order

Specifications	Standard	Metric
Part Number	AC210	M/AC210
Sensitivity (±5%)	100 mV/g	
Frequency Response (±3dB)	30-900,000 CPM	0,5-15000 Hz
Frequency Response (±10%)	60-420,000 CPM	1,0-7000 Hz
Frequency Response (±5%)	120-240,000 CPM	2,0-4000 Hz
Dynamic Range	± 80 g, peak	
Electrical		
Settling Time	<2.0 seconds	
Voltage Source (IEPE)	18-30 VDC	
Constant Current Excitation	2-10 mA	
Spectral Noise @ 10 Hz	8 µg/√Hz	
Spectral Noise @ 100 Hz	4 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		
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
Physical		
Sensing Element	PZT Ceramic	
Sensing Structure	Shear Mode	
Weight	3.2 oz	90 grams
Case Material	316L Stainless Steel	
Mounting	1/4-28	
Connector (Non-Integral)	2 Pin MIL-C-5015	
Resonant Frequency	1,560,000 CPM	26000 Hz
Mounting Torque	2 to 5 ft. lbs.	2,7 to 6,8 Nm
Mounting Hardware	1/4-28 Stud	M6x1 Adapter Stud
Calibration Certificate	CA10	

Typical Frequency Response

Backed by our Unconditional Lifetime Warranty
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FREQUENCY RESPONSE – MASS AND 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 route 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**

FREQUENCY RESPONSE – EXAMPLE 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 pitch.

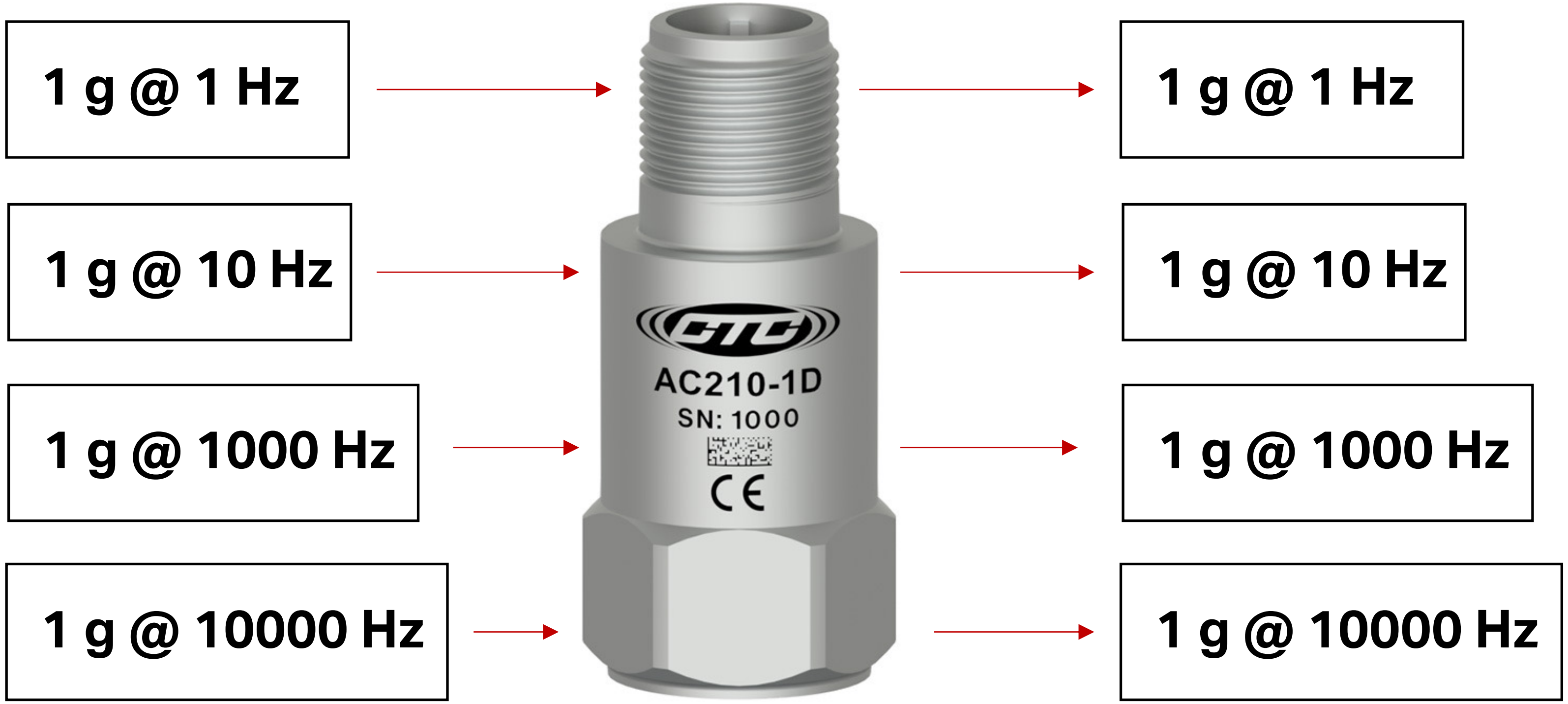
Now let's look at a fan which is mounted to a frame. **When the fan is run at the frame's natural frequency, the fan will resonate**. Unlike a guitar string, achieving resonance on a large fan is not desirable. An analyst may recommend that the frame of the fan receive additional structural support, 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.

FREQUENCY RESPONSE – WHAT IS IT?

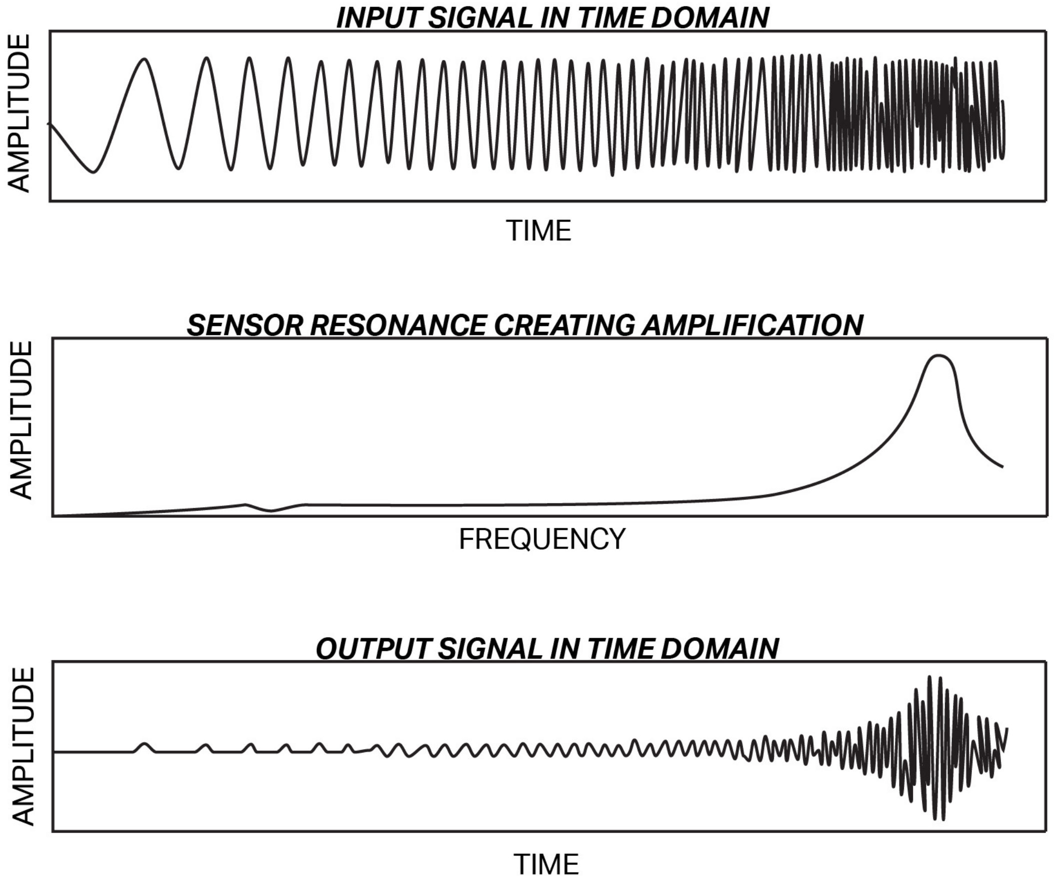
As discussed previously, **frequency response is a sensor's ability to measure the correct amplitude of a vibration at any frequency**.

In other words, 1 g input at 1 Hz should yield 1 g output from the sensor at 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 @ 1 Hz	**1 g @ 1 Hz**
1 g @ 10 Hz	**1 g @ 10 Hz**
1 g @ 1000 Hz	**1 g @ 1000 Hz**
1 g @ 10000 Hz	**1 g @ 10000 Hz**

FREQUENCY RESPONSE – IN THE REAL WORLD


INPUT SIGNAL IN TIME DOMAIN

SENSOR RESONANCE CREATING AMPLIFICATION

OUTPUT SIGNAL IN TIME DOMAIN

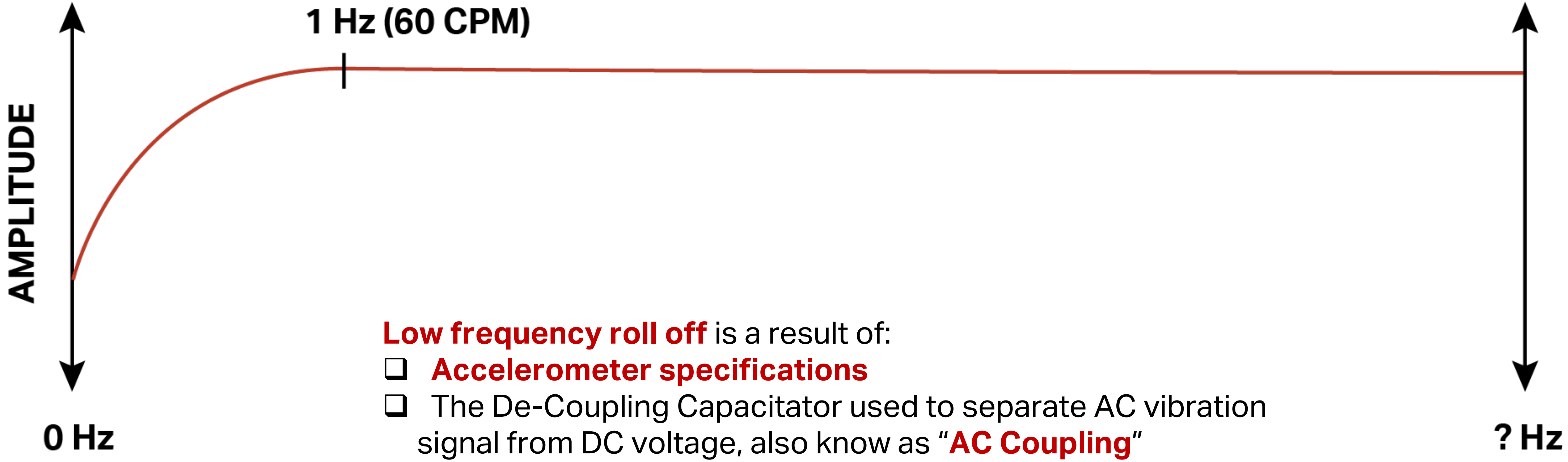
Unfortunately, in the real world, the frequency response is not always flat!

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 plot**.

FREQUENCY RESPONSE – LOW FREQUENCY



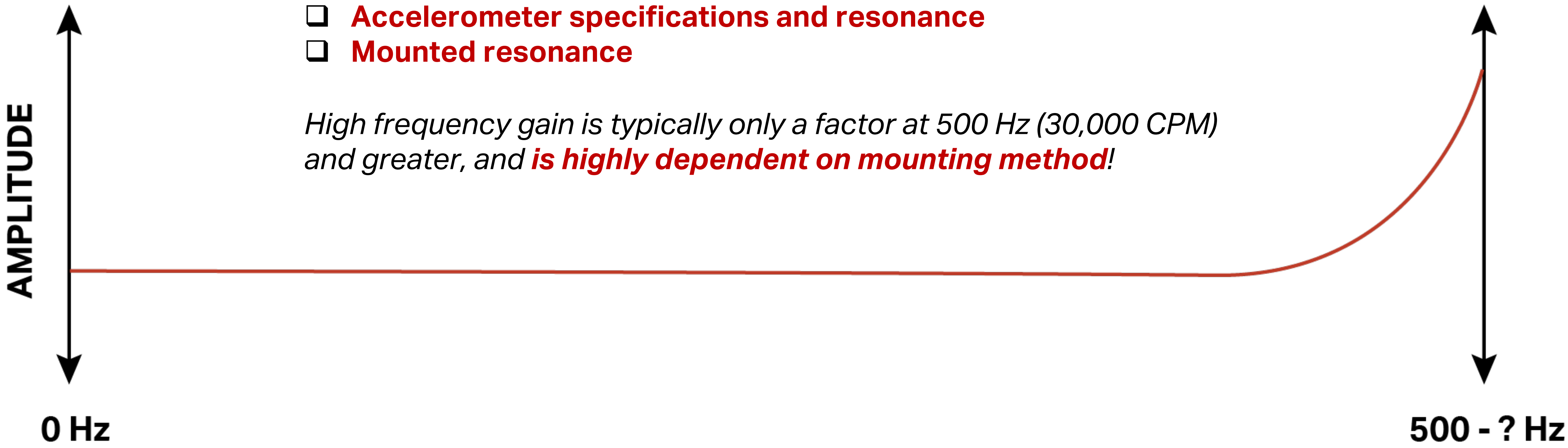
Low frequency roll off is a result of:

☐ **Accelerometer specifications**

☐ The De-Coupling Capacitator used to separate AC vibration signal from DC voltage, also know 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.

Several things can happen at resonance:

☐ Large gains in amplitude
☐ Errors in signal amplitude
☐ Phase change ≈ 180°
☐ Destructive forces can occur

MOUNTED RESONANCE – TRANSMISSION, AMPLIFICATION, ISOLATION

- ☐ **TRANSMISSION**
- ☐ **AMPLIFICATION**
- ☐ **ISOLATION**

There are three regions of a typical accelerometer response curve!

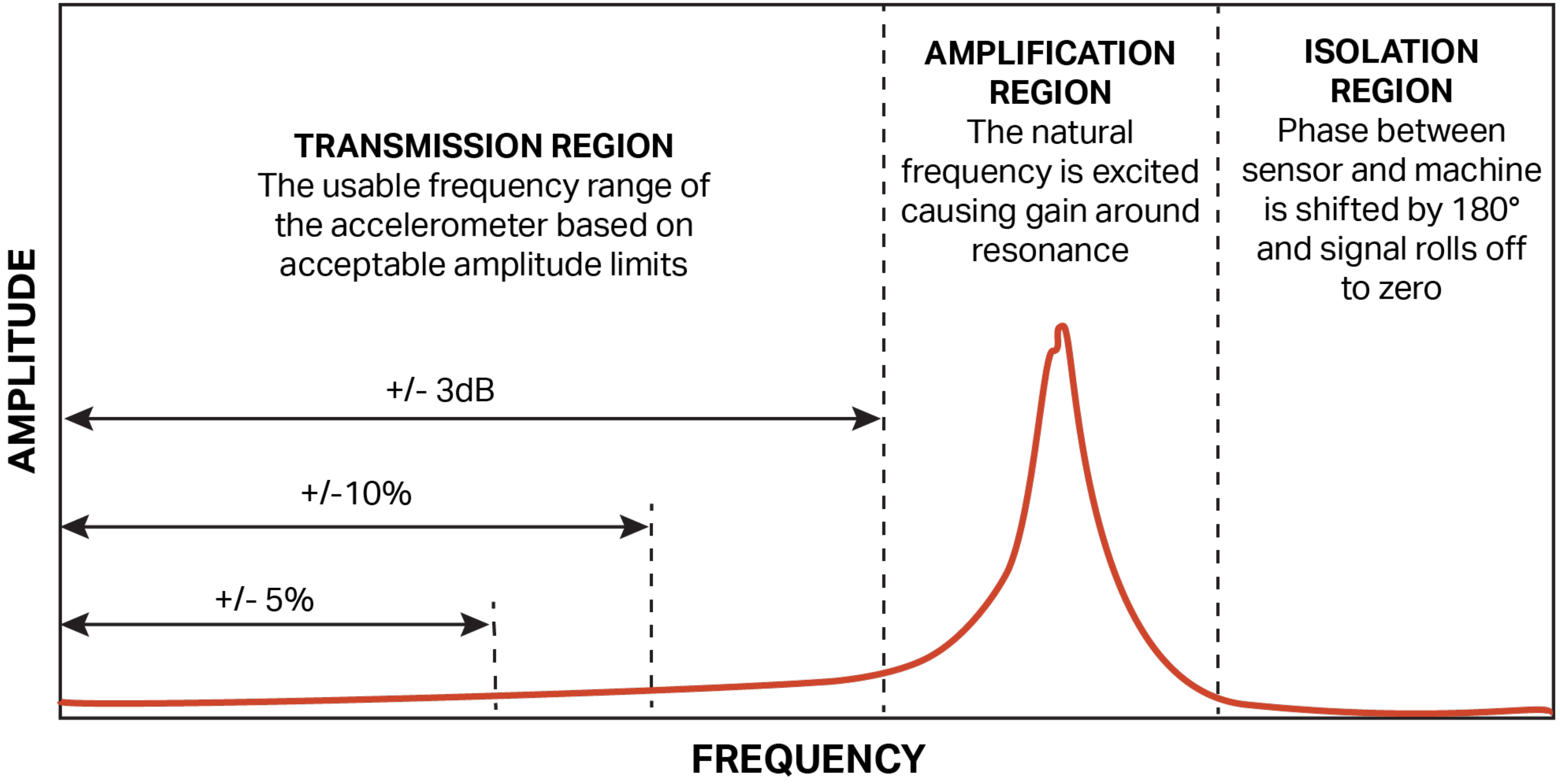
The **transmission** region is defined as the usable region of the accelerometer, and will be specified at + / - 5%, + / - 10%, or + / - 3dB.

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**.

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**.



TRANSMISSION REGION
The usable frequency range of the accelerometer based on acceptable amplitude limits

AMPLIFICATION REGION
The natural frequency is excited causing gain around resonance

ISOLATION REGION
Phase between sensor and machine is shifted by 180° and signal rolls off to zero

MOUNTED RESONANCE – RESONANCE CHANGES AND MOUNTING

The mounting method used for an accelerometer can affect mounted resonance. **Mounted resonance can in turn effect**:

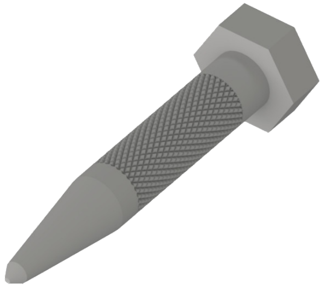
- ☐ **Transmission**, **amplification** and **isolation range** of the sensor
- ☐ **Frequency response** of the sensor

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.

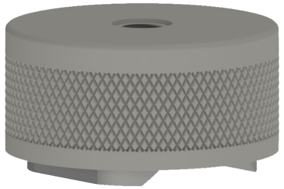
MOUNTED RESONANCE – TYPICAL MOUNTING METHODS

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

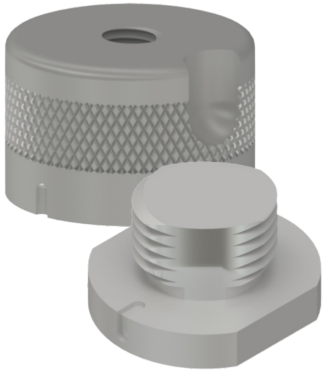
Remember, each of these methods is very useful, but they can all have an effect on the frequency response of the accelerometer.



PROBE TIP

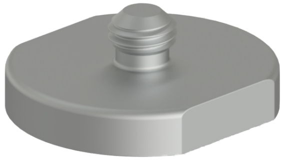


CURVED SURFACE MAGNET

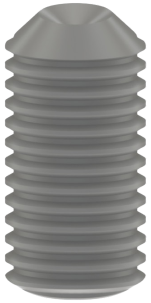


QUICK DISCONNECT

FLAT MAGNET WITH TARGET



ADHESIVE MOUNT



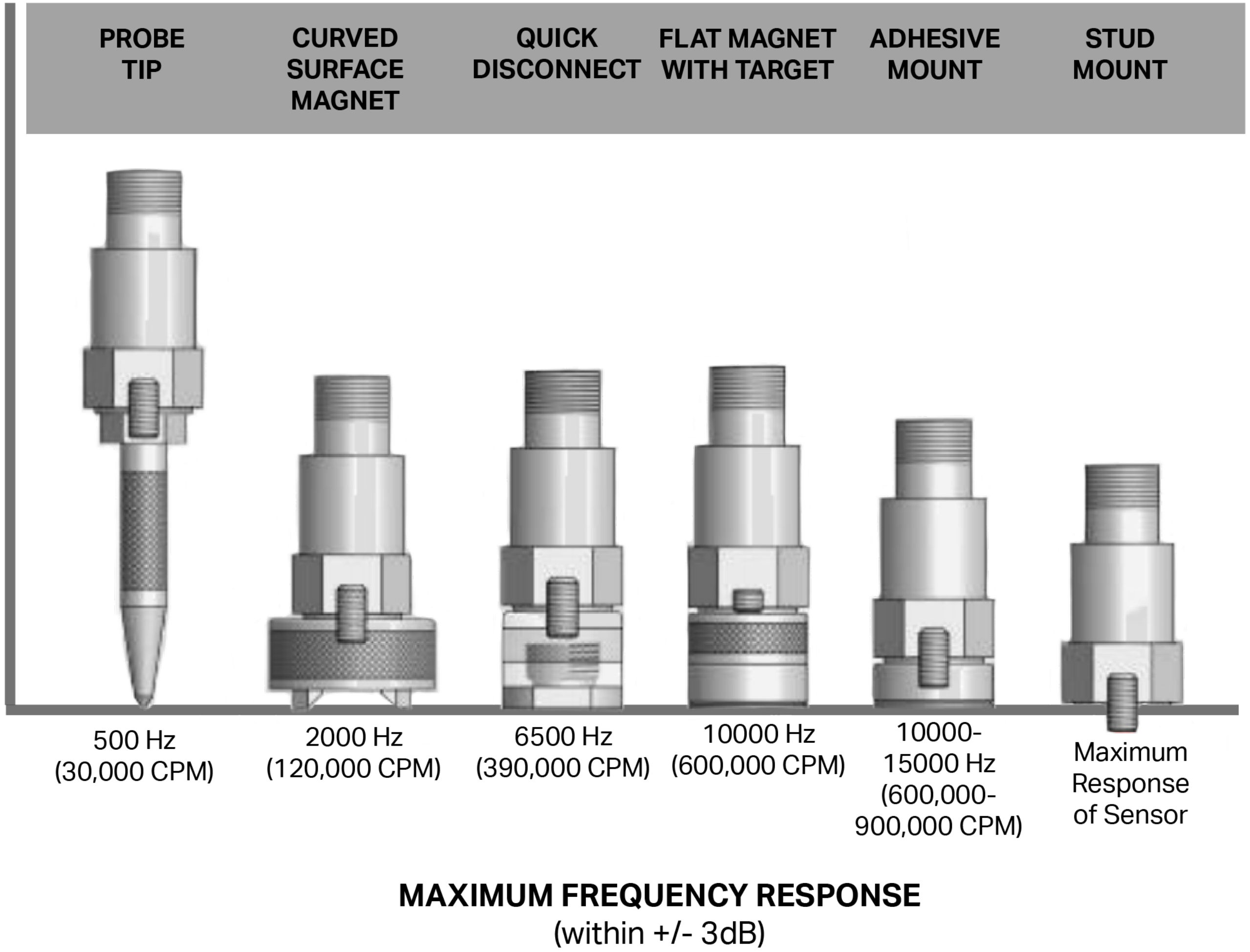
STUD MOUNT

MOUNTED RESONANCE – TYPICAL CHANGES IN RESPONSE

The following are the changes in 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.

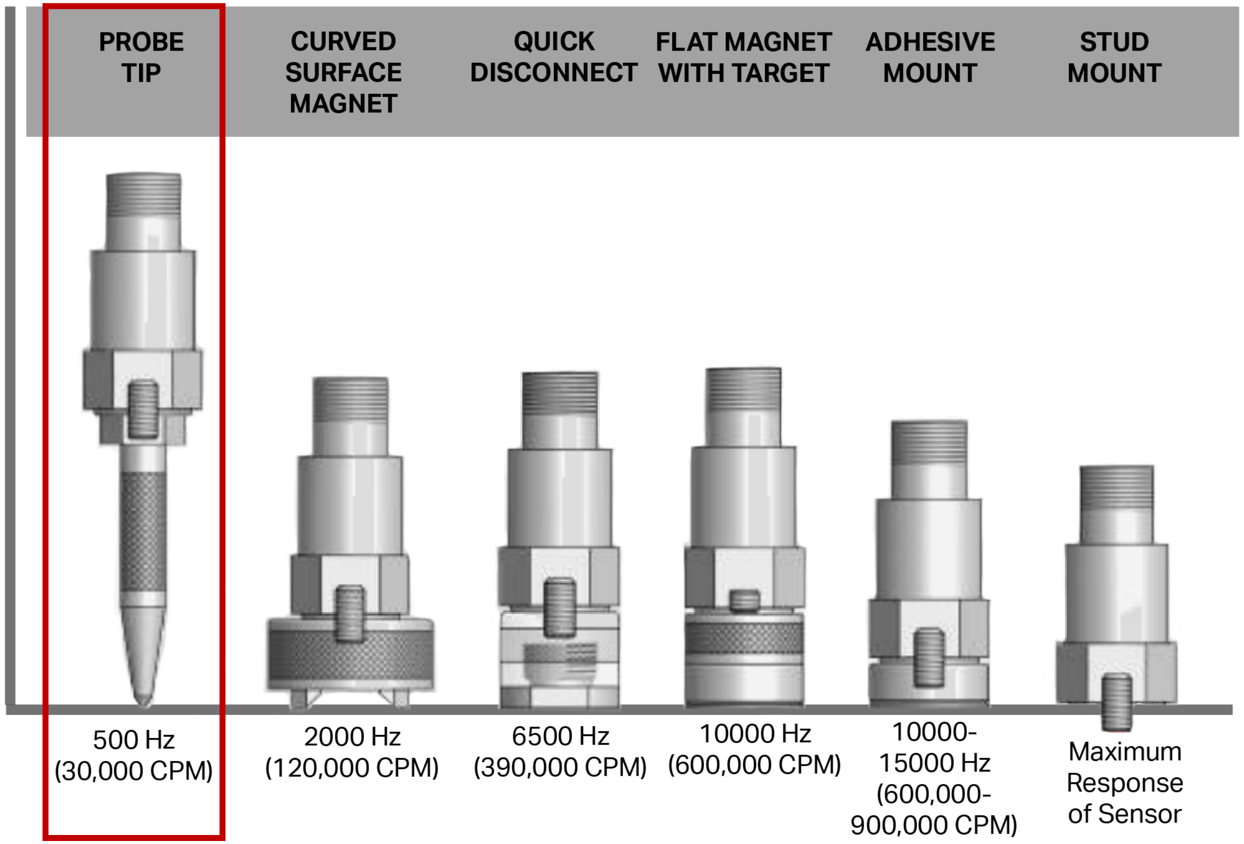
Be careful when choosing the mounting method for your sensor. Don't miss valuable data!



MOUNTED RESONANCE – 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 dramatically lower mounted resonance which reduces the effective high frequency response (at 3dB) 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.

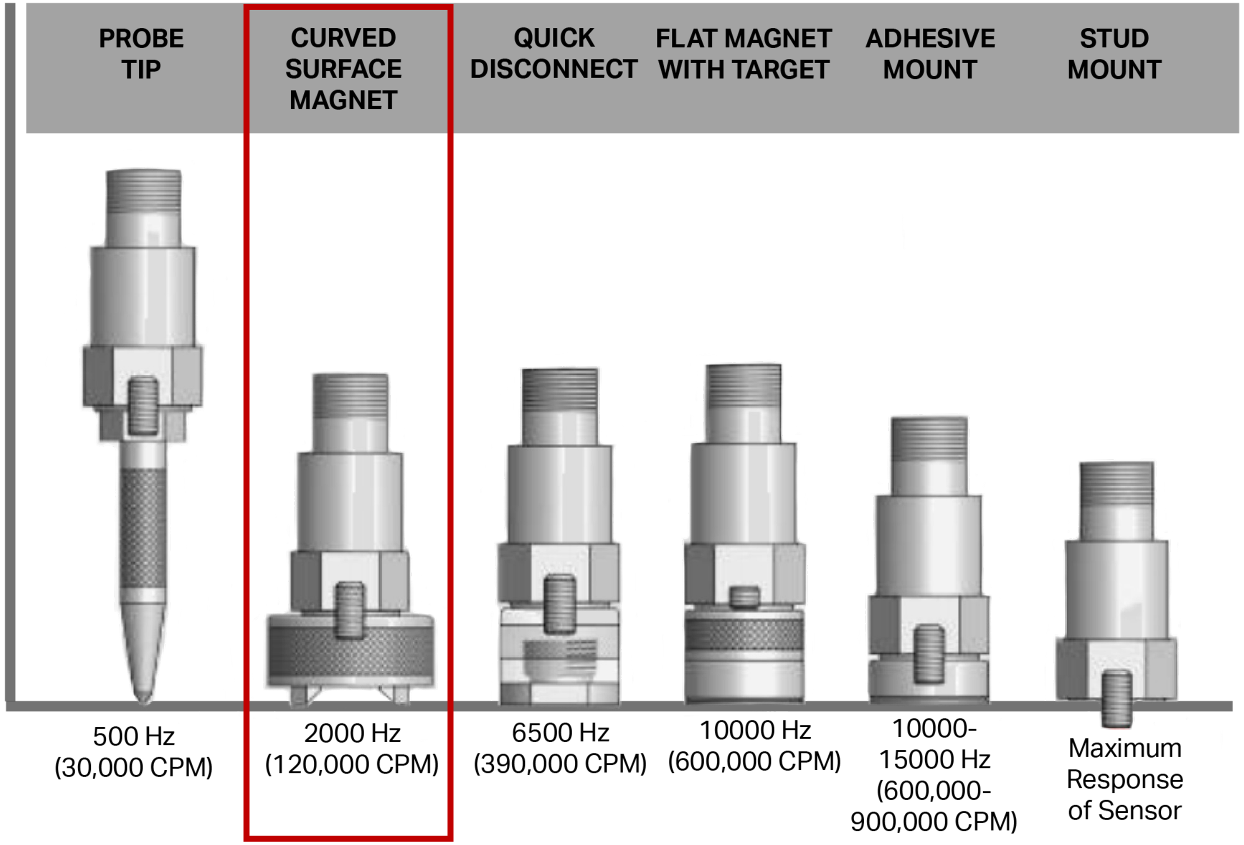


MAXIMUM FREQUENCY RESPONSE
(within +/- 3dB)

MOUNTED RESONANCE – TYPICAL CHANGES IN RESPONSE

The **curved surface magnet** increases stiffness with more surface area contact a magnetic pull. However, it also adds significant mass. These factors result in a higher mounted resonance and better high frequency response (at 3dB) than the probe tip method. Curved surface magnets have an effective transmission range under 2000 Hz (120,000 CPM).

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



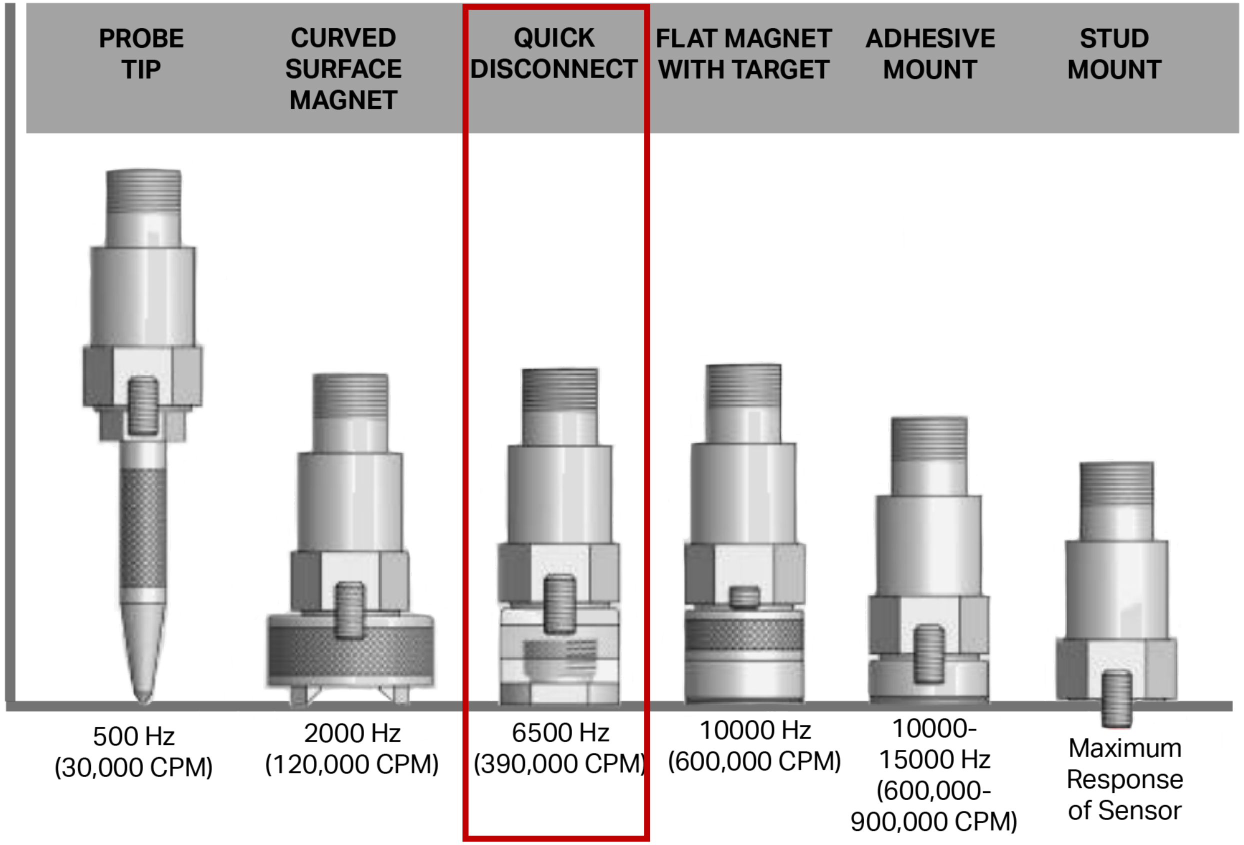
MAXIMUM FREQUENCY RESPONSE
(within +/- 3dB)

MOUNTED RESONANCE – 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 five threads with a quarter turn, and provides the best high frequency response in the industry at 6500 Hz (390,000 CPM).



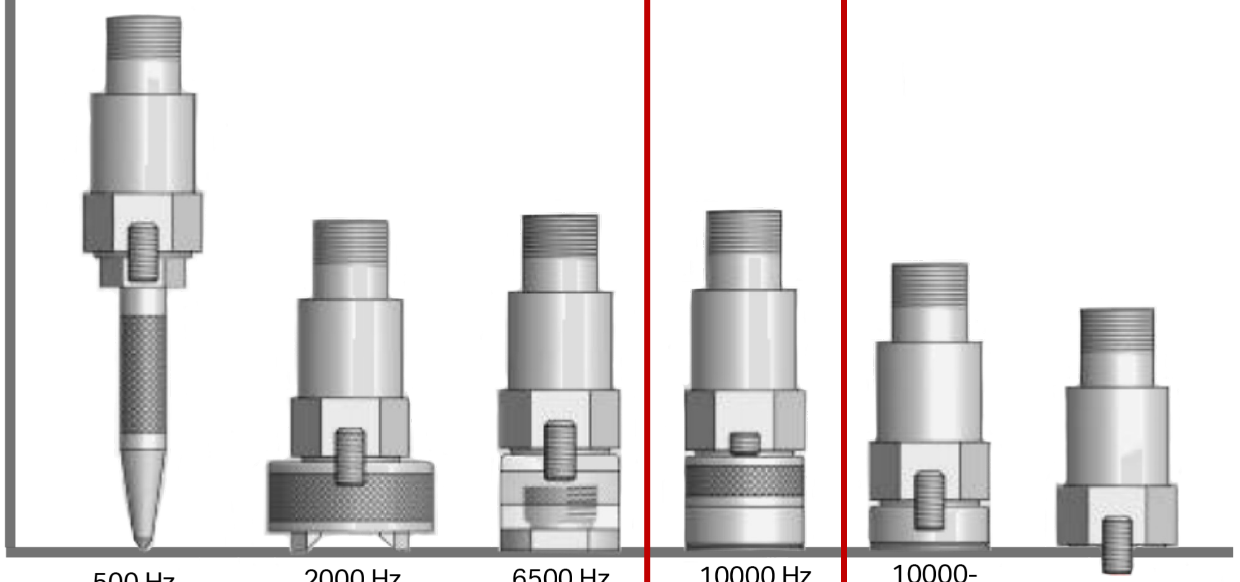
PROBE TIP	CURVED SURFACE MAGNET	QUICK DISCONNECT	FLAT MAGNET WITH TARGET	ADHESIVE MOUNT	STUD MOUNT
500 Hz (30,000 CPM)	2000 Hz (120,000 CPM)	6500 Hz (390,000 CPM)	10000 Hz (600,000 CPM)	10000-15000 Hz (600,000-900,000 CPM)	Maximum Response of Sensor

MAXIMUM FREQUENCY RESPONSE
(within +/- 3dB)

MOUNTED RESONANCE – 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 7000 – 8000 Hz (420,000 – 480,000 CPM) before hitting 3dB and entering amplification range. However, with perfect installation and execution, some analysts report frequency responses as high as 10000 Hz (600,000 CPM).



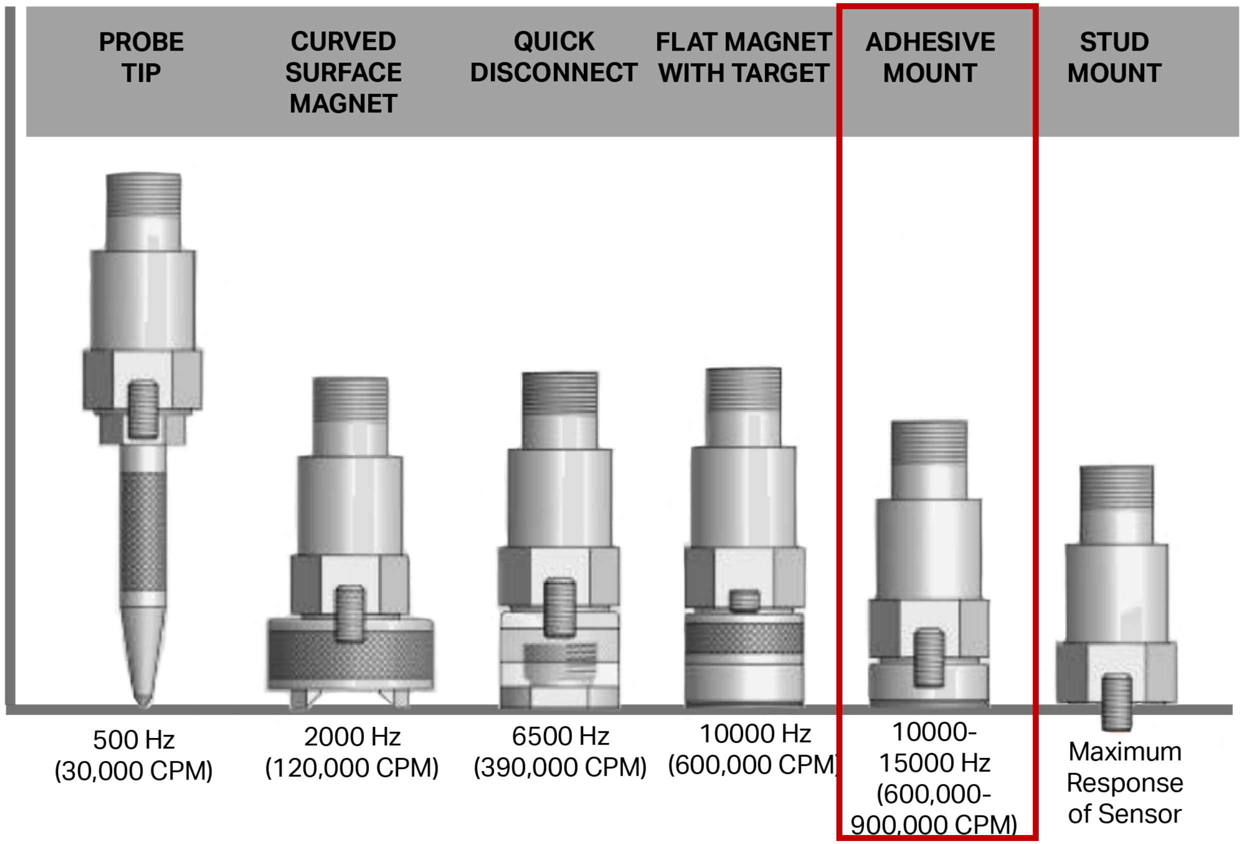
PROBE TIP	CURVED SURFACE MAGNET	QUICK DISCONNECT	FLAT MAGNET WITH TARGET	ADHESIVE MOUNT	STUD MOUNT
500 Hz (30,000 CPM)	2000 Hz (120,000 CPM)	6500 Hz (390,000 CPM)	10000 Hz (600,000 CPM)	10000-15000 Hz (600,000-900,000 CPM)	Maximum Response of Sensor

MAXIMUM FREQUENCY RESPONSE
(within +/- 3dB)

MOUNTED RESONANCE – TYPICAL CHANGES IN RESPONSE

Adhesive mounting is generally for permanent installation and should yield data as high as 10000 to 15000 Hz (600,000 - 900,000 CPM).

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

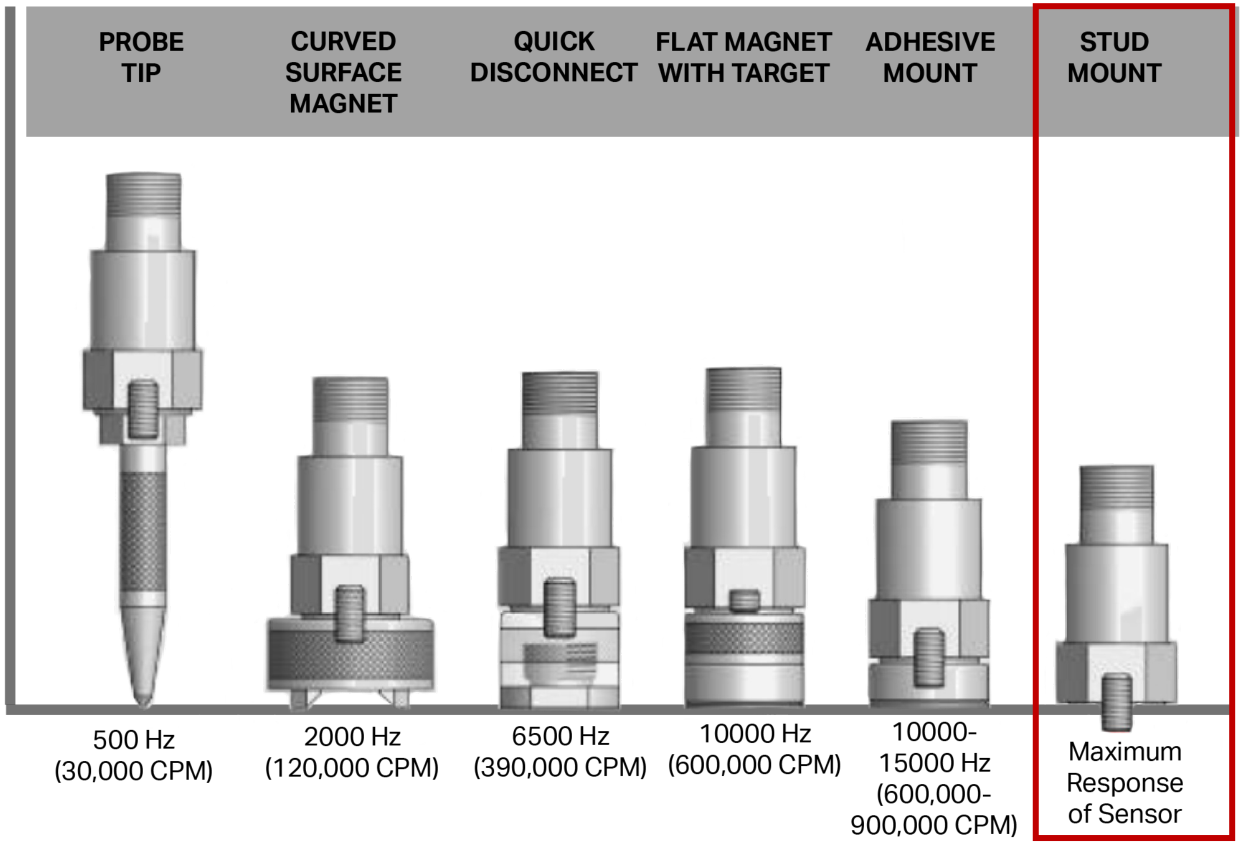


MAXIMUM FREQUENCY RESPONSE
(within +/- 3dB)

MOUNTED RESONANCE – TYPICAL CHANGES IN RESPONSE

And, of course, the maximum stiffness with the least additional mass is the **stud mount** option. The stud mount option 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…



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)

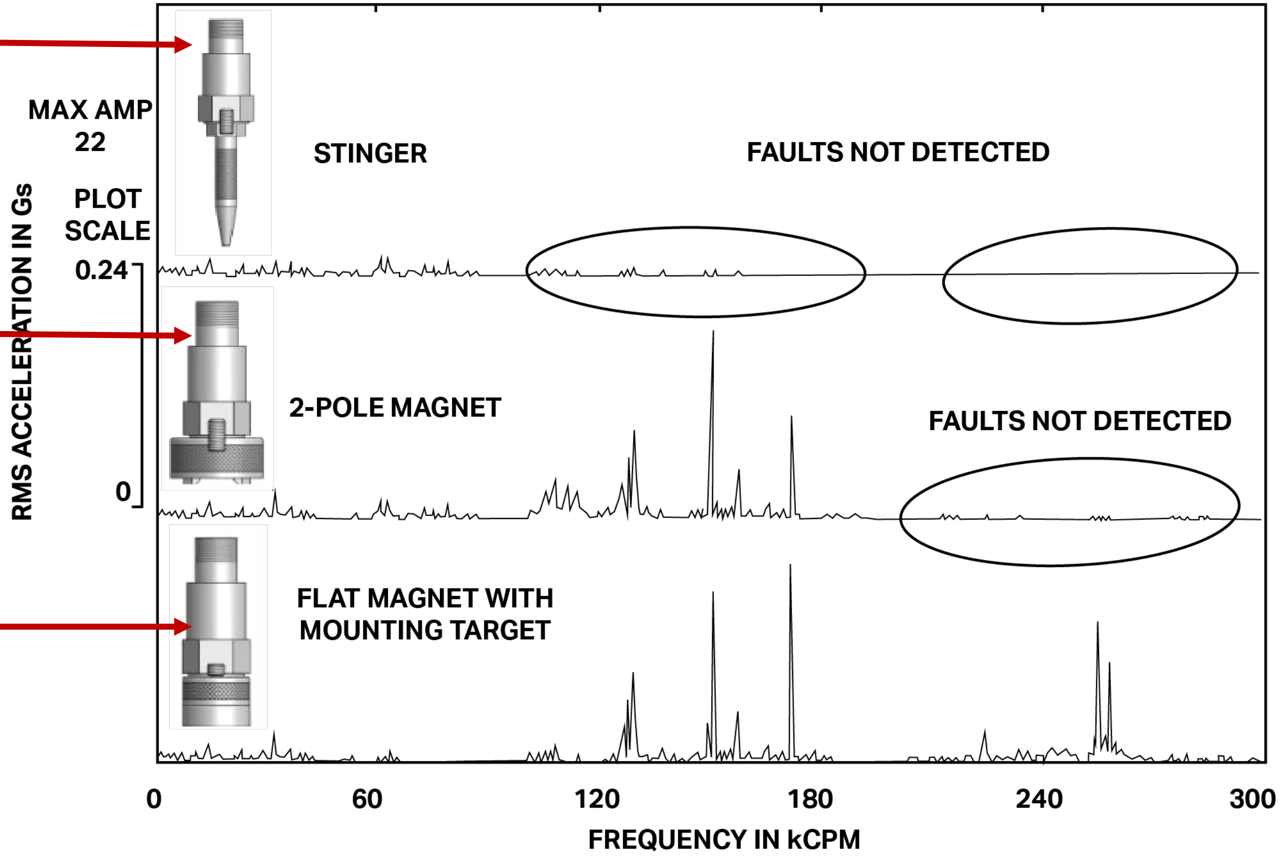
MOUNTED RESONANCE – REDUCED FREQUENCY RESPONSE

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 Y**OUR** machine frequencies and **avoid resonance**

- ❑ Work within the "transmission" range of the **frequency response**

SUMMARY

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

CTC prides itself on the industry's best customer service 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 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**.

SUMMARY

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

- ☐ **Superior durability**
- ☐ **Accuracy and performance**
- ☐ **Quick service (shipping most orders in 3 days)**
- ☐ **Knowledgeable support staff**

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