

# APPLICATIONS OF VIBRATION TRANSDUCERS

## 1) Measurements on Structures or Machinery Casings: Accelerometers and Velocity Sensors

Used in gas turbines, axial compressors, small and mid-size pumps.

These sensors detect high frequency vibration signals related to bearing supports, casing and foundation resonances, vibration in turbine/compressor vanes, defective roller or ball bearings, noise in gears, etc.

## 2) Displacement measurements relative to rotating shafts: Proximity Probes (capacitance or eddy-current)

Used in turbomachinery supported on fluid film bearings, centrifugal compressors, gears and transmissions, electric motors, large pumps (>300HP), some turbines and fans.

These sensors detect shaft static displacements, unbalance response, misalignment, shaft bending, excessive loads in bearings, dynamic instabilities, etc.

### ACCELEROMETERS

#### Advantages

- Simple to install
- Good response at high frequencies
- Stand high Temperature
- Small size

#### Disadvantages

- Sensitive to high frequency noise
- Require external power
- Require electronic integration for velocity and displacement

### VELOCITY SENSORS

#### Advantages

- Simple to install
- Good response in middle range frequencies
- Stand high temperature
- Do not require external power
- Lowest cost

#### Disadvantages

- Low resonant frequency & phase shift
- Cross noise
- Big and heavy
- Require electronic integration for displacement

### PROXIMITY SENSORS

#### Advantages

- Measure static and dynamic displacements
- Exact response at low frequencies
- No wear
- Small and low cost

#### Disadvantages

- Electrical and mechanical noise
- Bounded by high frequencies
- Not calibrated for unknown metal materials
- Require external power
- Difficult to install

Novel types: **OPTICAL FIBERS and LASER BEAMS**. Their performance is not well known yet.

From *Reference*: Harry N. Norton, Handbook of transducers, Prentice Hall, Chap:5,6,7

### **VELOCITY SENSORS**

**Electromagnetic linear velocity transducers** : Typically used to measure oscillatory velocity. A permanent magnet moving back and forth within a coil winding induces an *emf* in the winding. This *emf* is proportional to the velocity of oscillation of the magnet. This permanent magnet may be attached to the vibrating object to measure its velocity.

**Electromagnetic tachometer generators** : Used to measure the angular velocity of vibrating objects. They provide an output voltage/frequency that is proportional to the angular velocity. *DC tachometers* use a permanent magnet or magneto, while the *AC tachometers* operate as a variable coupling transformer, with the coupling coefficient proportional to the rotary speed.

### **ACCELERATION SENSORS**

**Capacitive accelerometers** : Used generally in those that have diaphragm supported seismic mass as a moving electrode and one/two fixed electrodes. The signal generated due to change in capacitance is post-processed using LC circuits etc., to output a measurable entity.

**Piezoelectric accelerometers** : Acceleration acting on a seismic mass exerts a force on the piezoelectric crystals, which then produce a proportional electric charge. The piezoelectric crystals are usually preloaded so that either an increase or decrease in acceleration causes a change in the charge produced by them. But they are not reliable at very low frequencies.

**Potentiometric accelerometers** : Relatively cheap and used where slowly varying acceleration is to be measured with a fair amount of accuracy. In these, the displacement of a spring mass system is mechanically linked to a viper arm, which moves along a potentiometric resistive element. Various designs may have either viscous, magnetic or gas damping.

**Reluctive accelerometers** : They compose accelerometers of the differential transformer type or the inductance bridge type. The AC outputs of these vary in phase as well as amplitude. They are converted into DC by means of a phase-sensitive demodulator.

**Servo accelerometers** : These use the closed loop servo systems of force-balance, torque-balance or null-balance to provide close accuracy. Acceleration causes a seismic mass to move. The motion is detected by one of the motion-detection devices, which generate a signal that acts as an error signal in the servo-loop. The demodulated and amplified signal is then passed through a passive damping network and then applied to the torquing coil located at the axis of rotation of the mass. The torque is proportional to the coil current, which is in turn proportional to the acceleration.

**Strain Gage accelerators** : these can be made very small in size and mass. The displacement of the spring-mass system is converted into a change in resistance, due to strain, in four arms of a Wheatstone bridge. The signal is then post-processed to read the acceleration.

# A FEW SENSOR TYPES USED FOR COMMON VIBRATION MEASUREMENTS

Disclaimer: The material in this document was copied ad-verbatim from the sources noted. Its accuracy can not be warranted.

- 1) Accelerometers (piezoelectric)
- 2) Velocity Sensor
- 3) Proximity Probes (capacitance or eddy current)
- 4) Laser displacement sensors

## 1) **ACCELEROMETERS** **REFERENCE: [WWW.OMEGA.COM](http://WWW.OMEGA.COM)**

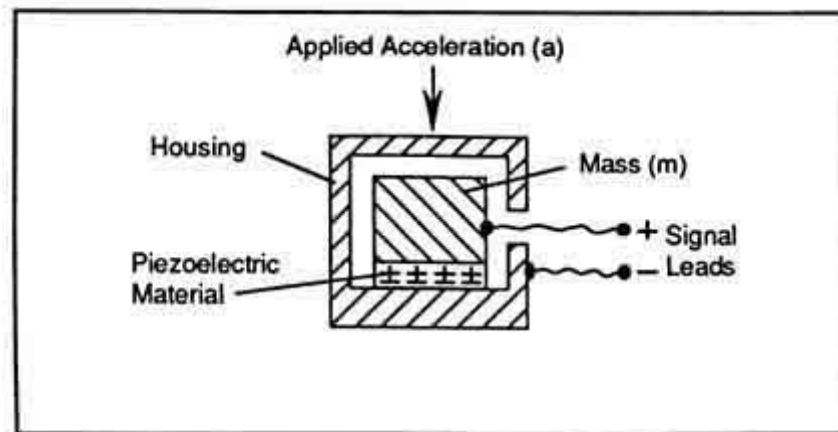
An accelerometer is a device that measures the vibration, or acceleration of motion of a structure. The force caused by vibration or a change in motion (acceleration) causes the mass to "squeeze" the piezoelectric material which produces an electrical charge that is proportional to the force exerted upon it. Since the charge is proportional to the force, and the mass is a constant, then the charge is also proportional to the acceleration.

There are two types of piezoelectric accelerometers (vibration sensors). The first type is a "high impedance" charge output accelerometer. In this type of accelerometer the piezoelectric crystal produces an electrical charge which is connected directly to the measurement instruments. This type of accelerometer is also used in high temperature applications (>120C) where low impedance models cannot be used.

The second type of accelerometer is a low impedance output accelerometer. A low impedance accelerometer has a charge accelerometer as its front end but has a tiny built-in micro-circuit and FET transistor that converts that charge into a low impedance voltage that can easily interface with standard instrumentation.

**Piezoelectric Accelerometers** Reference : [www.pcb.com](http://www.pcb.com)

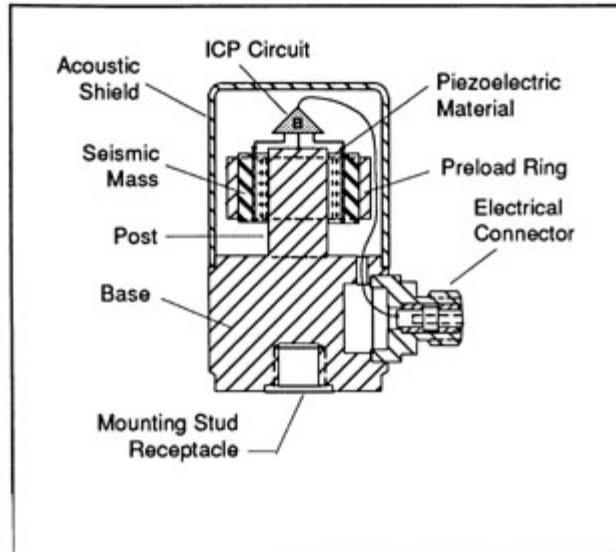
Piezoelectric accelerometers rely on the piezoelectric effect of quartz or ceramic crystals to generate an electrical output that is proportional to applied acceleration. The piezoelectric effect produces an opposed accumulation of charged particles on the crystal. This charge is proportional to applied force or stress. A force applied to a quartz crystal lattice structure alters alignment of positive and negative ions, which results in an accumulation of these charged ions on opposed surfaces. These charged ions accumulate on an electrode that is ultimately conditioned by transistor microelectronics.



In an accelerometer, the stress on the crystals occurs as a result of the seismic mass imposing a force on the crystal. Over its specified frequency range, this structure approximately obeys Newton's law of motion,  $F=ma$ . Therefore, the total amount of accumulated charge is proportional to the applied force, and the applied force is proportional to acceleration. Electrodes collect and wires transmit the charge to a signal conditioner that may be remote or built into the accelerometer.

## Shear Mode Accelerometer

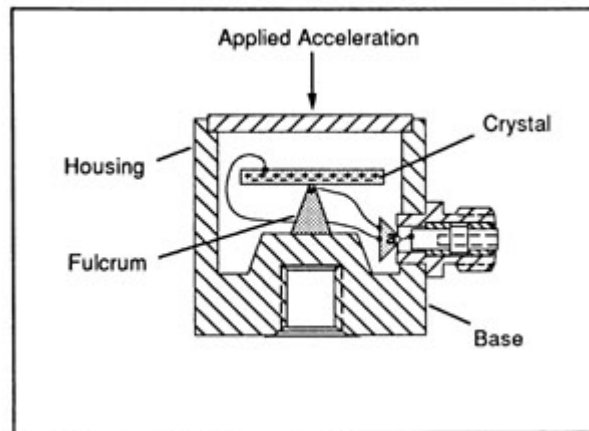
Shear mode designs bond, or "sandwich," the sensing crystals between a center post and seismic mass. A compression ring or stud applies a preload force required to create a rigid linear structure. Under acceleration, the mass causes a shear stress to be applied to the sensing crystals. By isolating the sensing crystals from the base and housing, shear accelerometers excel in rejecting thermal transient and base bending effects. Also, the shear geometry lends itself to small size, which minimizes mass loading effects on the test structure.



**Shear Mode Accelerometer**

## Flexural Mode Accelerometer

Flexural mode designs utilize beam-shaped sensing crystals, which are supported to create strain on the crystal when accelerated. The crystal may be bonded to a carrier beam that increases the amount of strain when accelerated. This design offers a low profile, light weight, excellent thermal stability, and an economical price. Insensitivity to transverse motion is also an inherent feature of this design. Generally, flexural beam designs are well suited for low-frequency, low-g-level applications like those which may be encountered during structural testing.

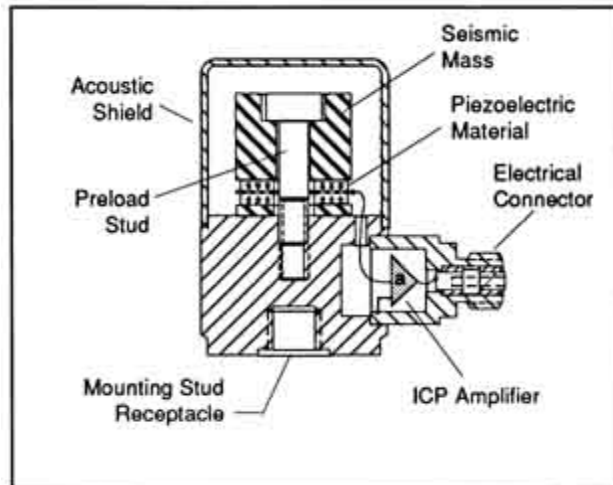


**Flexural Mode Accelerometer**

## Compression Mode Accelerometer

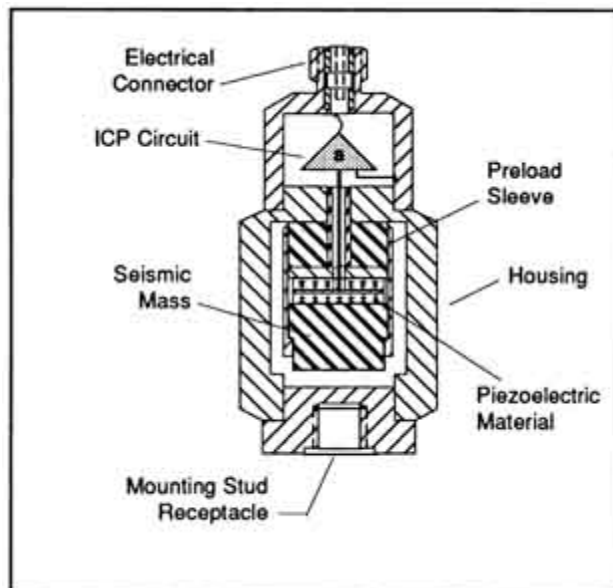
Compression mode accelerometers offer simple structure, high rigidity, and historical availability. There are basically three types of compression designs: upright, inverted, and isolated.

Upright compression designs sandwich the piezoelectric crystal between a seismic mass and rigid mounting base. An elastic stud or screw secures the sensing element to the mounting base. When the sensor is accelerated, the seismic mass increases or decreases the amount of force acting upon the crystal, and a proportional electrical output results. The larger the seismic mass is, the greater the stress and, hence, the output are.



**Upright Compression Accelerometer**

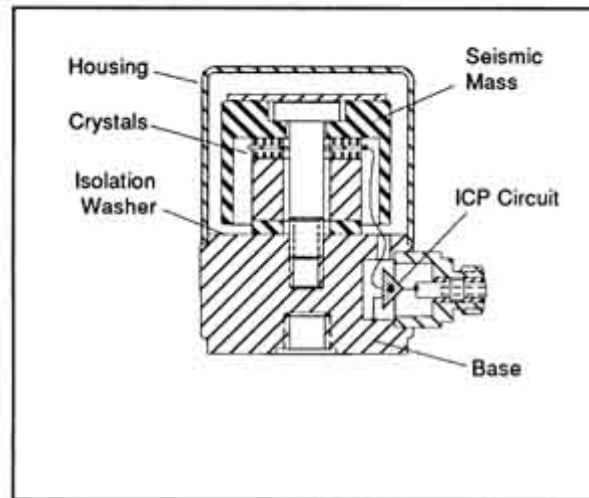
**Inverted compression** designs isolate the sensing crystals from the mounting base, reducing base bending effects and minimizing the effects of a thermally unstable test structure. Many reference standard calibration accelerometers use this design.



**Inverted Compression Accelerometer**

**Isolated compression** designs reduce erroneous outputs due to base strain and thermal transients. These benefits are achieved by mechanically isolating the

sensing crystals from the mounting base and utilizing a hollowed-out seismic mass that acts as a thermal insulation barrier. These mechanical enhancements allow stable performance at low frequencies, where thermal transient effects can create signal "drift" with other compression designs.



**Isolated Compression**

## Piezoelectric Material

There are two types of piezoelectric material that are used in PCB accelerometers: quartz and polycrystalline ceramics. Quartz is a natural crystal, while ceramics are man-made. Each material offers certain benefits, and material choice depends on the particular performance features desired of the accelerometer.

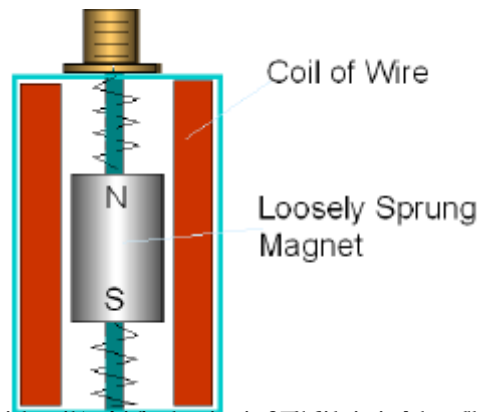
Quartz is widely known for its ability to perform accurate measurement tasks and contributes heavily in everyday applications for time and frequency measurements.

## 2) VELOCITY SENSORS

**Theory of Operation** REFERENCE : [www.reliabilitydirect.com](http://www.reliabilitydirect.com)

When a coil of wire is moved through a magnetic field, a voltage is induced across the end wires of the coil. The induced voltage is caused by the transferring of energy from the flux field of the magnet to the wire coil. As the coil is forced through the magnetic field by vibratory motion, a voltage signal representing the vibration is produced.

## The Velocity Probe [Reference:www.dliengineering.com](http://www.dliengineering.com)



Scientific and technical illustration of a velocity probe. The unit is a cylindrical metal housing with a brass cap at the top. Inside, a coil of wire is wound around a central shaft. A magnet is mounted on the shaft, held in place by two springs. The magnet is labeled with 'N' and 'S' poles. The coil is labeled 'Coil of Wire' and the magnet is labeled 'Loosely Sprung Magnet'.

The velocity probe was one of the first vibration transducers to be built. It consists of a coil of wire and a magnet so arranged that if the housing is moved, the magnet tends to remain stationary due to its inertia. The relative motion between the magnetic field and the coil induces a current that is proportional to the velocity of motion. The unit thus produces a signal directly proportional to vibration velocity. It is self-generating and needs no conditioning electronics in order to operate, and it has a relatively low electrical output impedance making it fairly insensitive to noise induction.

### 3) CAPACITIVE and EDDY CURRENT SENSORS

**REFERENCE:** [www.lionprecision.com](http://www.lionprecision.com)

Capacitive sensors use the electrical property of "capacitance" to make measurements. Capacitance is a property that exists between any two conductive surfaces within some reasonable proximity. Changes in the distance between the surfaces change the capacitance. It is this change of capacitance that capacitive sensors use to indicate changes in position of a target. High-performance displacement sensors use small sensing surfaces and as result are positioned close to the targets .





**CAPACITIVE SENSOR** Reference: [www.news.thomasnet.com](http://www.news.thomasnet.com)

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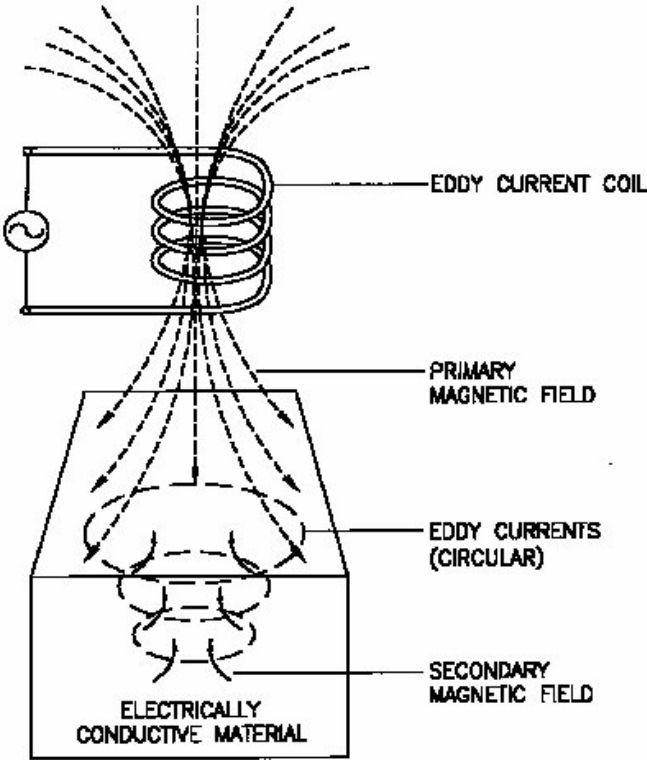


### EDDY CURRENT SENSOR PROBE

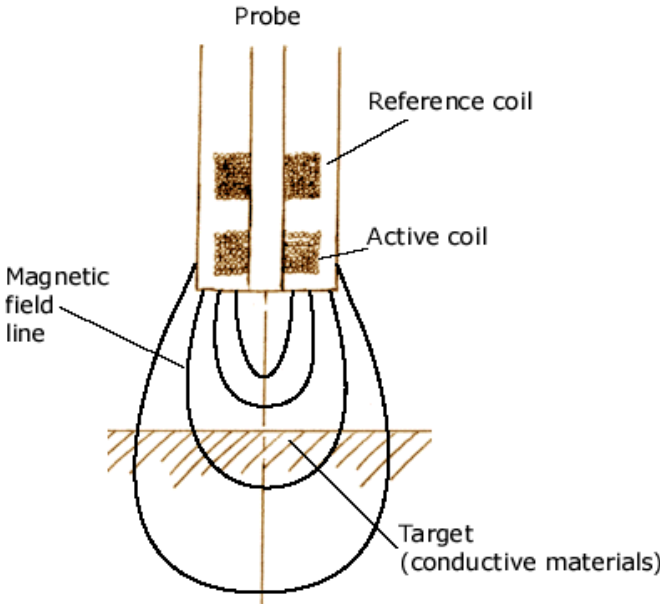
**The working principle of the eddy current sensor is described below.**

Eddy currents are formed when a moving (or changing) magnetic field intersects a conductor, or vice-versa. The relative motion causes a circulating flow of electrons, or currents, within the conductor. These circulating eddies of current create electromagnets with magnetic fields that oppose the effect of the applied magnetic field. The stronger the applied magnetic field, or greater the electrical conductivity of the conductor, or greater the relative velocity of motion, the greater the currents developed and the greater the opposing field (Reference : [www.wikipedia.org](http://www.wikipedia.org)).

Eddy current probes sense this formation of secondary fields to find out the distance between the probe and the target material.

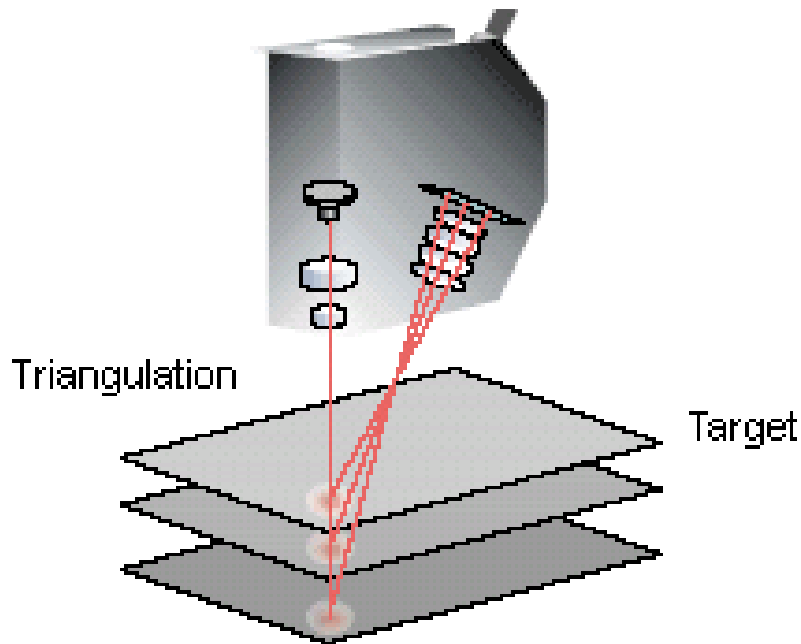


REFERENCE: [www.geocities.com/raobpc/](http://www.geocities.com/raobpc/)



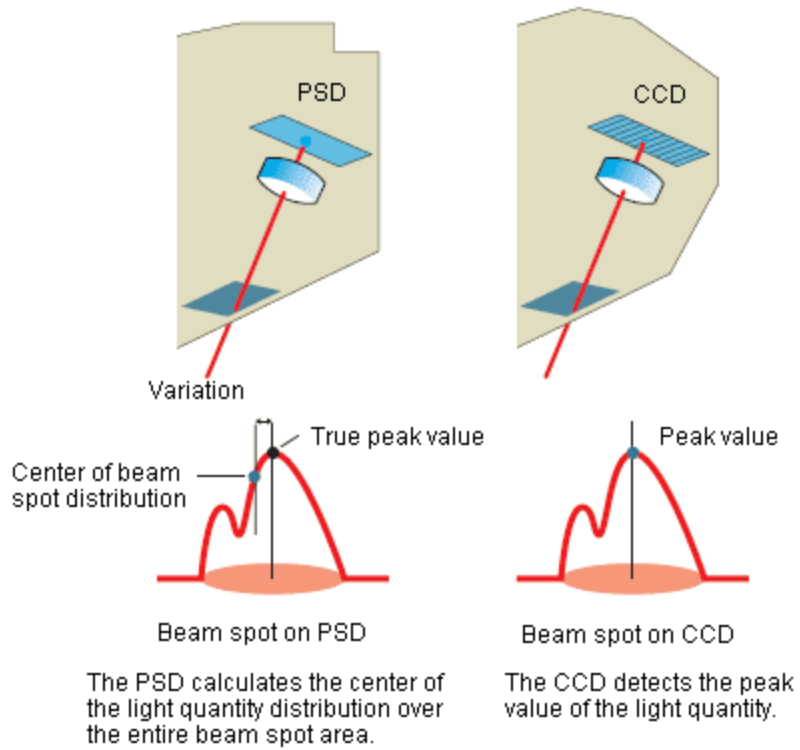
REFERENCE : [www.efunda.com](http://www.efunda.com)

#### 4) LASER DISPLACEMENT SENSOR Reference : [www.keyence.com](http://www.keyence.com)



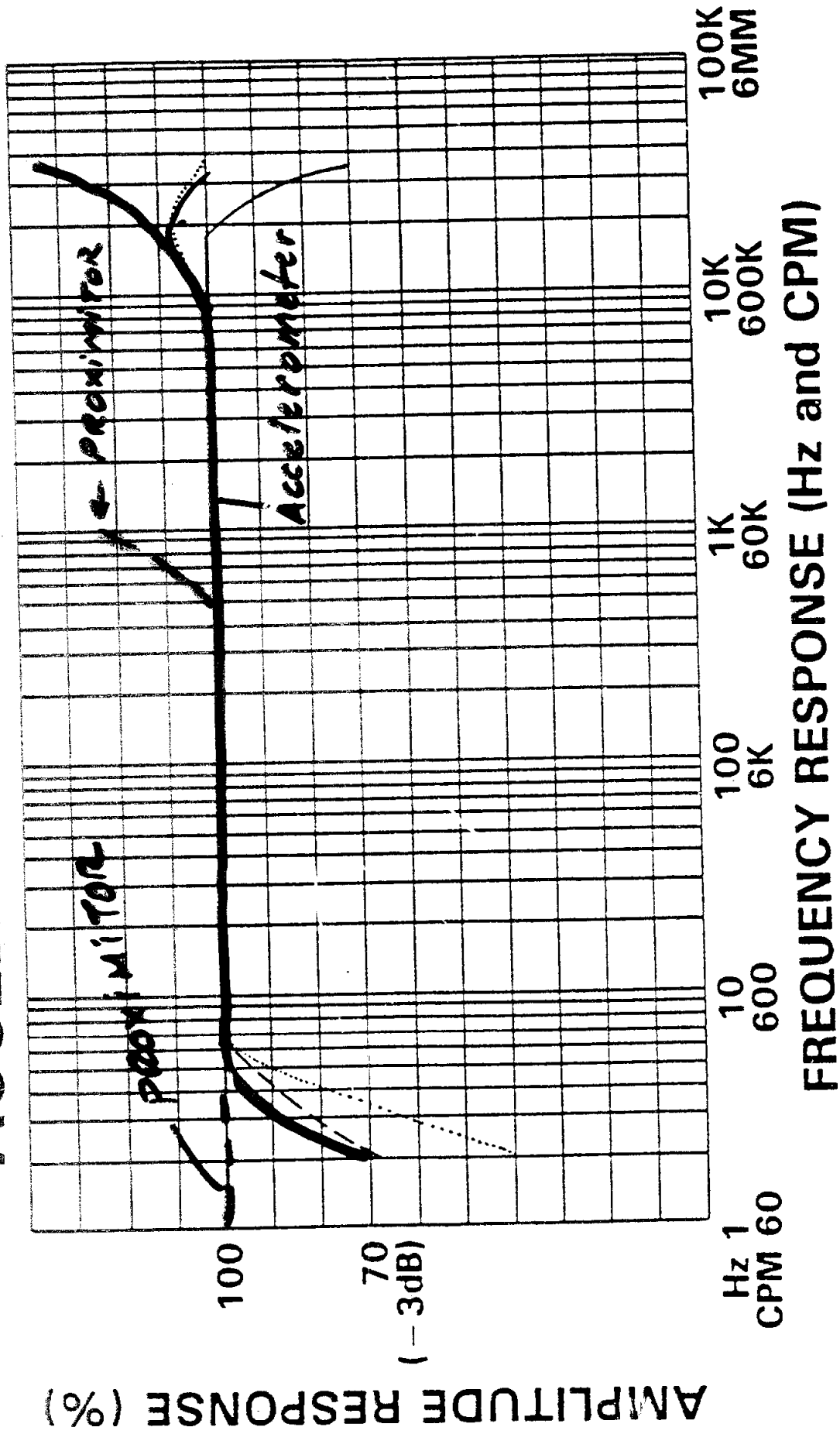
The Charge coupled device (CCD) laser displacement sensor uses a triangulation measurement system. Conventional laser displacement sensors employ a Position sensitive detector (PSD) as the light-receiving element.. The light reflected by a target passes through the receiver lens and is focused on the PSD or CCD. The PSD uses the light quantity distribution of the entire beam spot entering the light receiving element to determine the beam spot center and identifies this as the target position. However, the distribution of light quantity is affected by the surface condition of the target, causing variations in measured values. The CCD detects the peak value of the light quantity distribution of the beam spot for each pixel and identifies this as the target position. Therefore, the CCD enables stable highly accurate displacement measurement, regardless of the light quantity distribution of the beam spot.

These sensors can be used in high temperature environments.



**Light quantity distribution of beam spot on light-receiving element**

# ACCELEROMETER RESPONSE

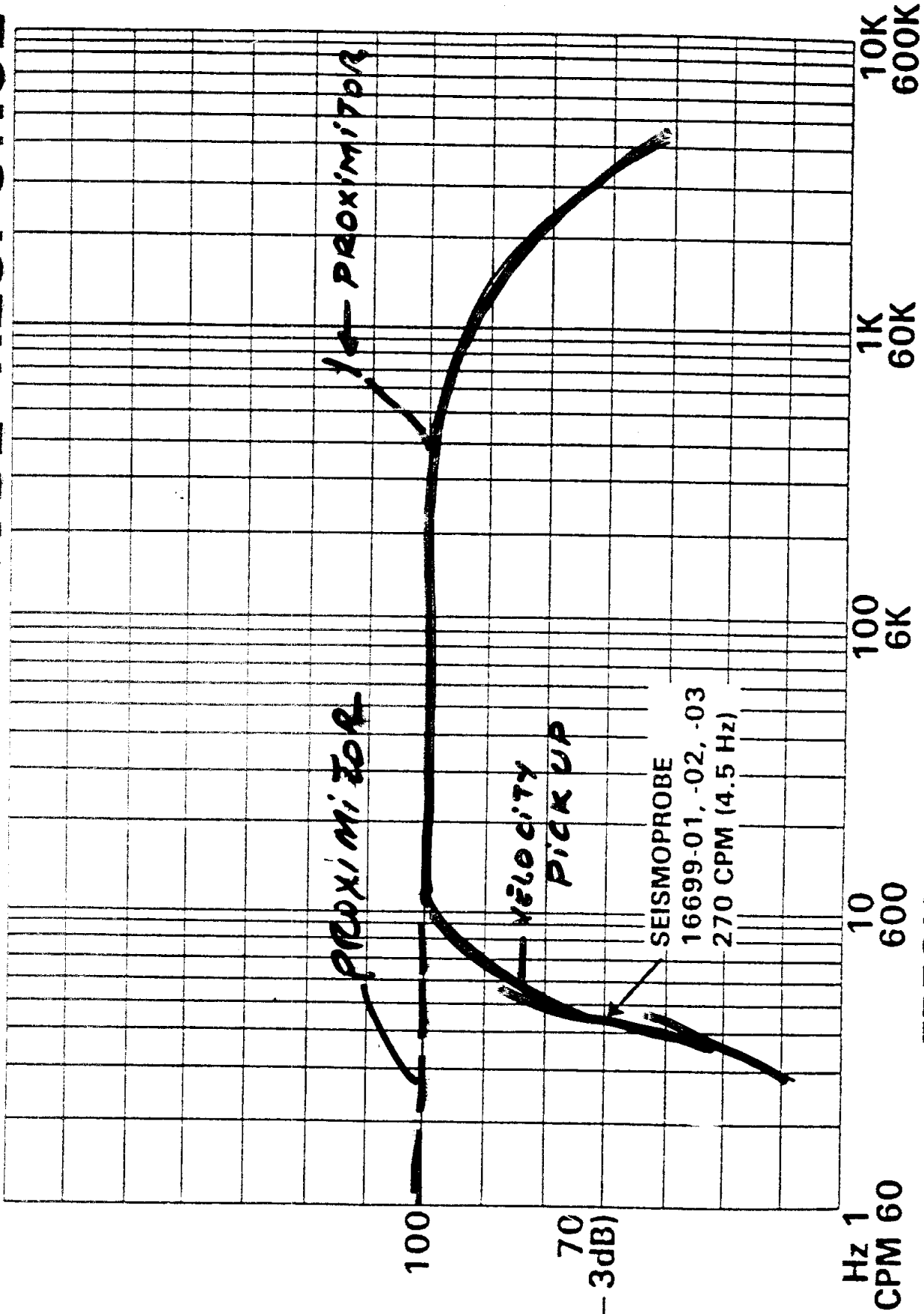


KEY

|       |                       |
|-------|-----------------------|
| ..... | INTERFACE MODULE ONLY |
| ----- | ACCELEROMETER ONLY    |
| _____ | SYSTEM                |

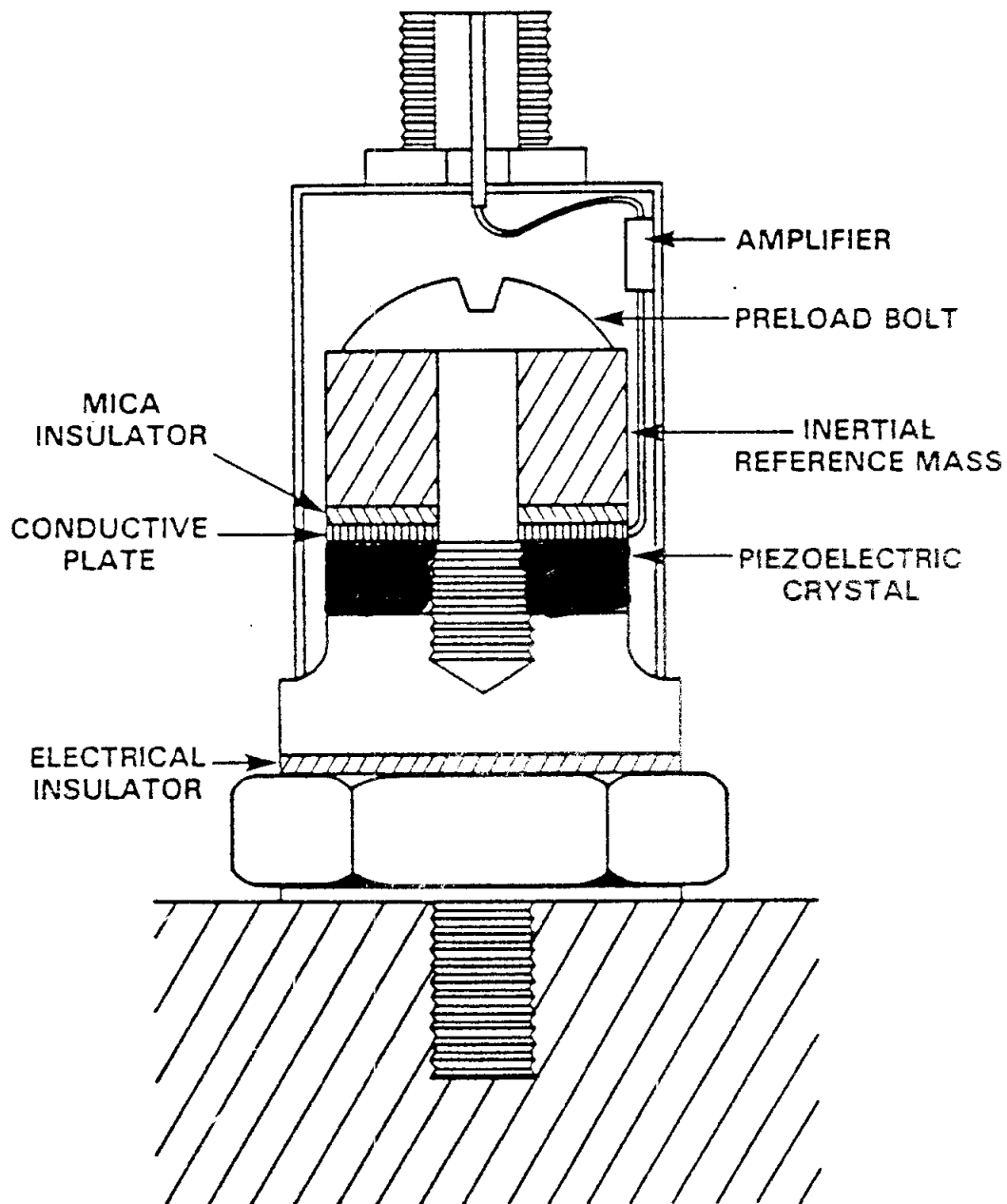
# VELOCITY SEISMOPROBE RESPONSE

AMPLITUDE RESPONSE (%)



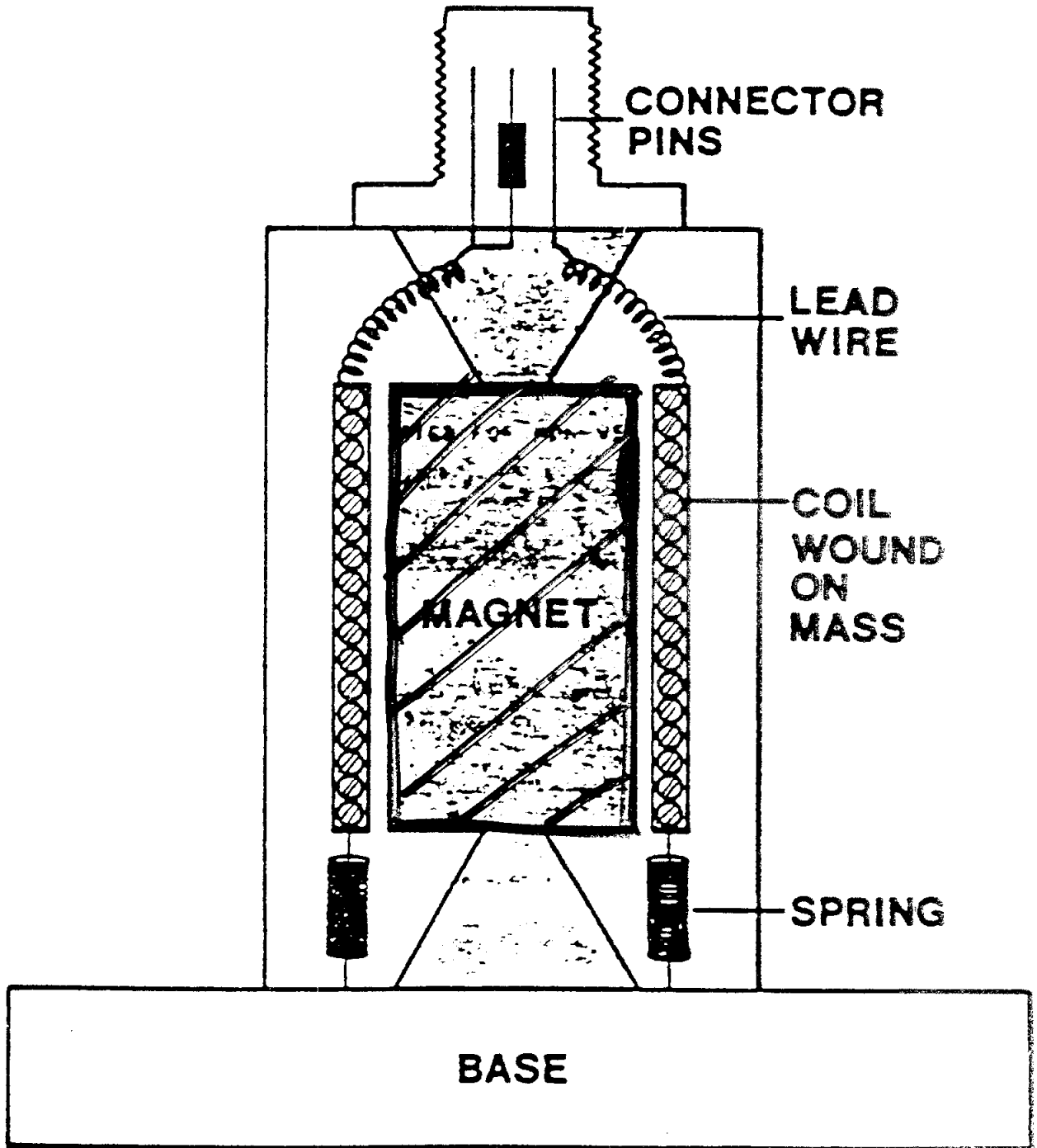
FREQUENCY RESPONSE (Hz and CPM)

# Accelerometer



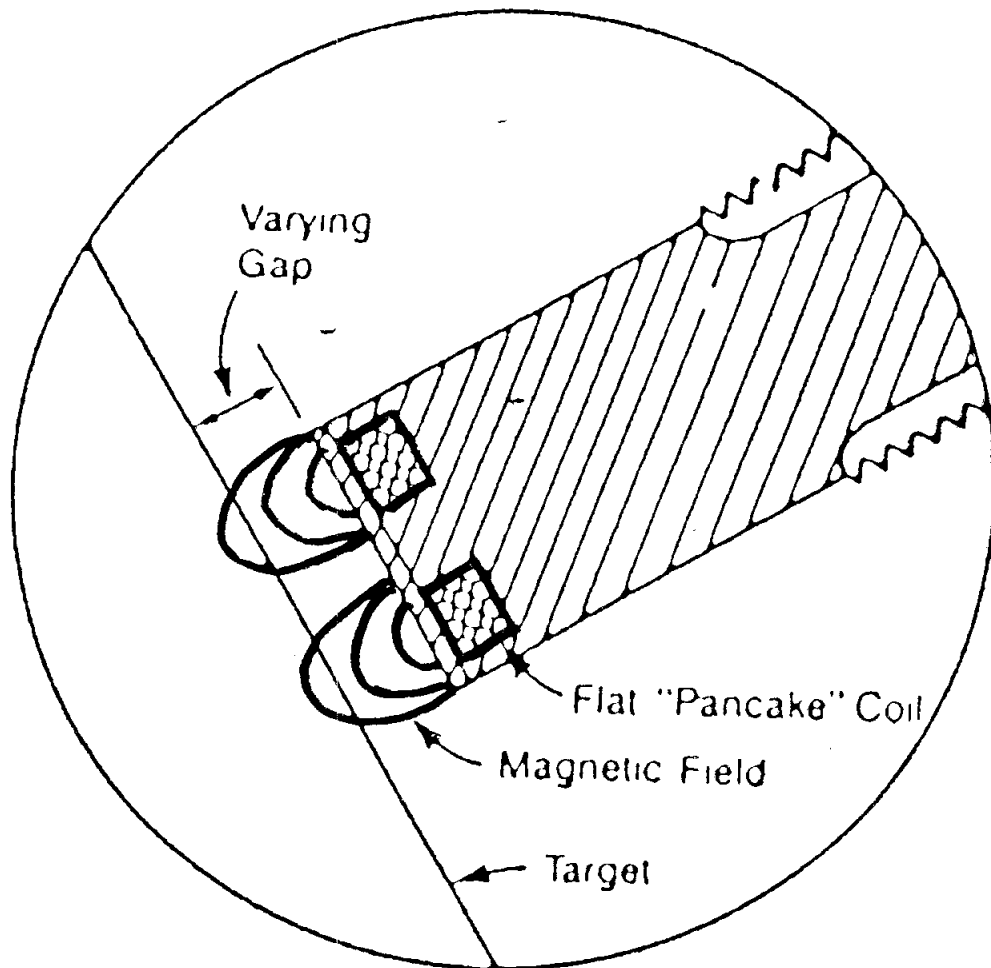
170.0.0.0

Velocity Pick Up.



DI 11-1-64





Eddy Probe Tip

# RADIAL VIBRATION MEASUREMENT

