AE 242
Aerospace Measurements Laboratory

Inertial sensors

Sensed quantity is related to inertia (mass) of the sensor.

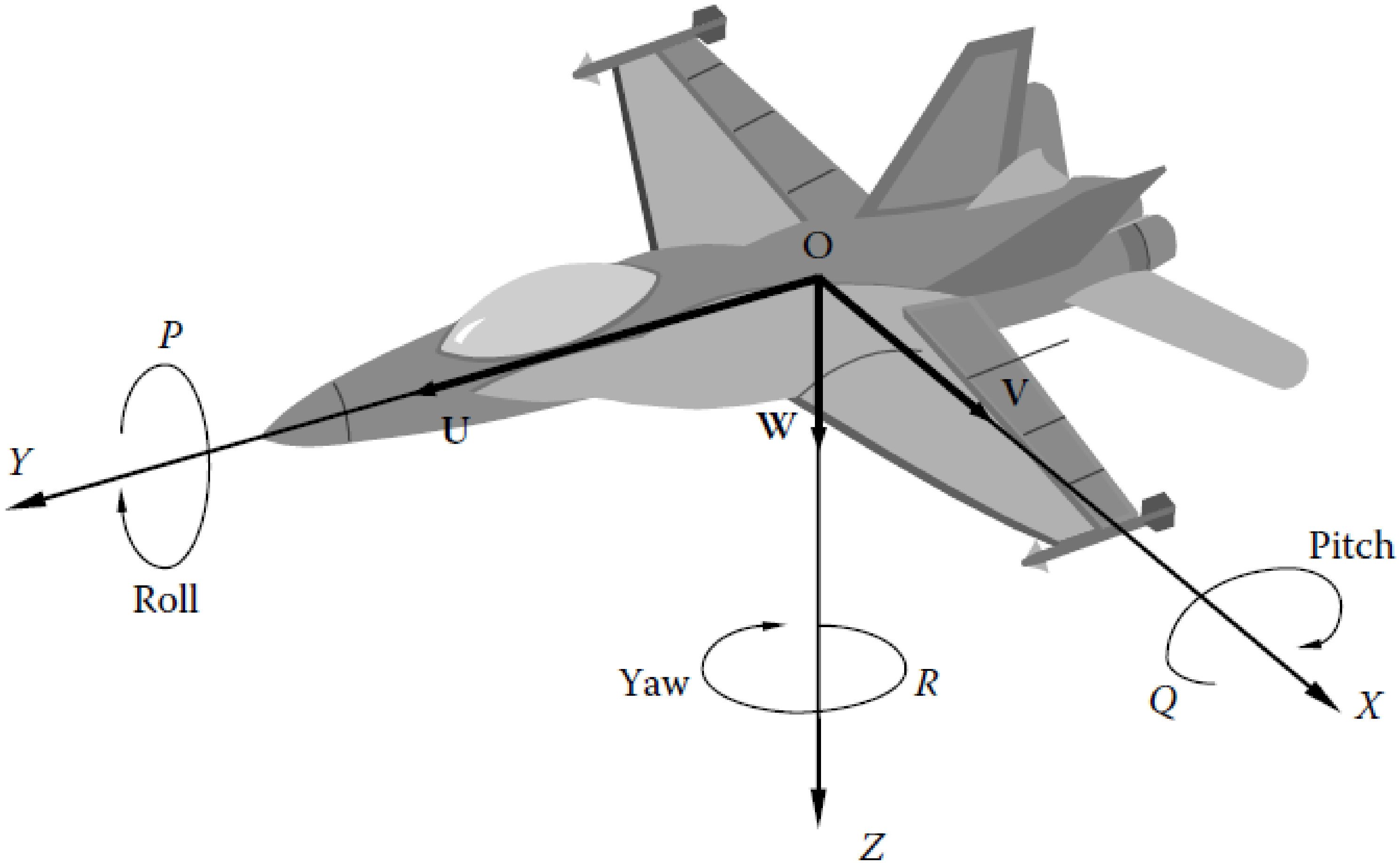
Accelerometers : Measures acceleration of an object. Change in velocity per unit time, commonly expressed in ‘g’. Can be used for estimating velocity and displacement, with respect to initial condition.

Gyroscope : To measure angular motion about an axis. Can be used to estimate the attitude of an object.

Accelerometers and gyroscopes are key sensors for Inertial Navigation System (INS). INS is used in missiles, aircraft, ships, submarines, satellite launch vehicles, satellites etc.

It is an independent system and no external signal is required for its operation, or it is self contained system. Low cost INS is aided to remove errors accumulated due to integration process e.g. unmanned vehicles. Aiding signal will be from independent source e.g. GNSS or some know land marks, celestial bodies etc.

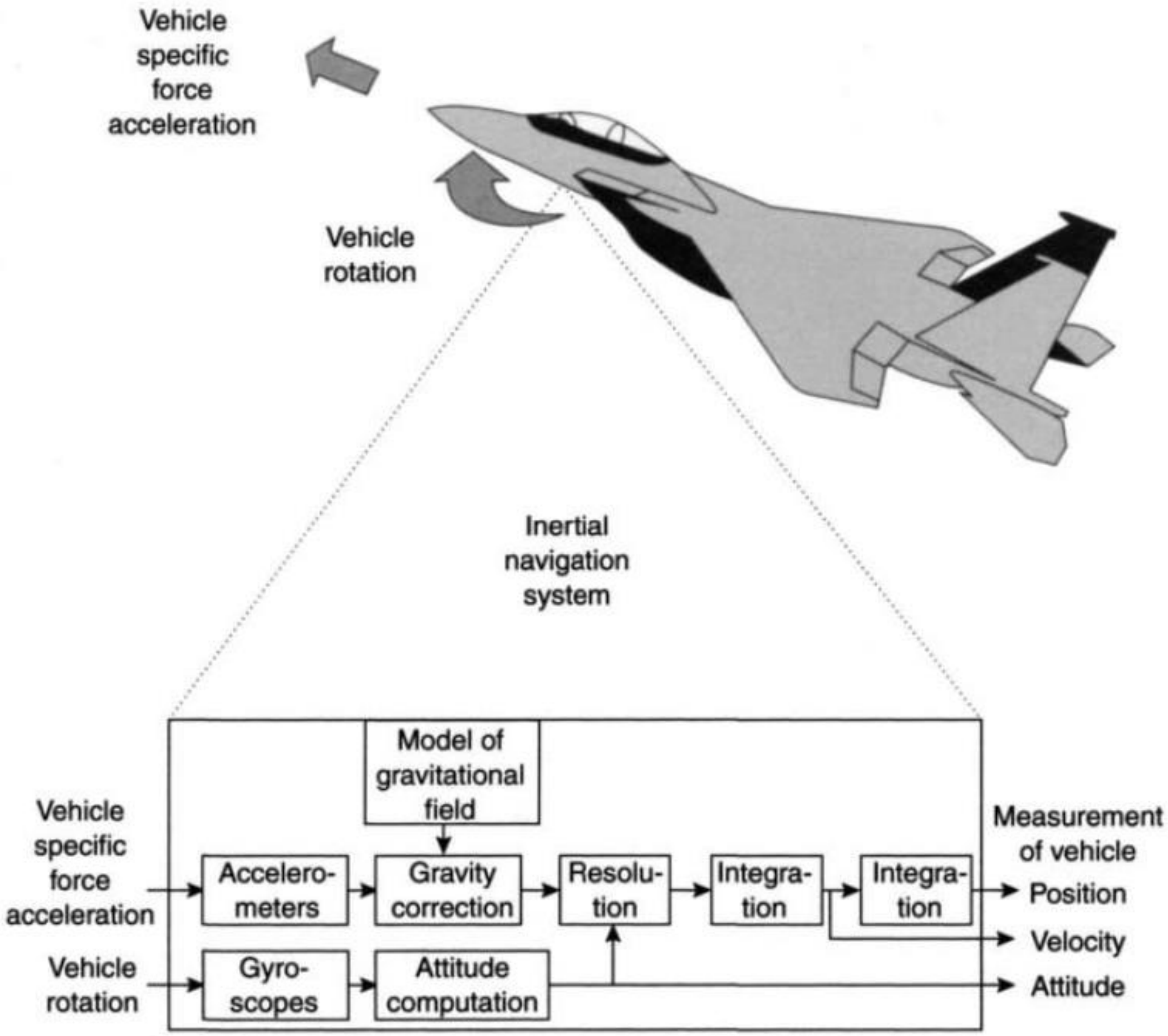
Inertial sensors



Inertial sensors are used to measure acceleration, angular rates of aircraft body. Process these quantities to obtain velocity, position and attitude.

Strapdown Inertial Navigation System – system strapped to body

Inertial sensors



Functional components of INS

Strapdown Inertial Technology, D.H. Titterton and I.L. Weston

Accelerometer

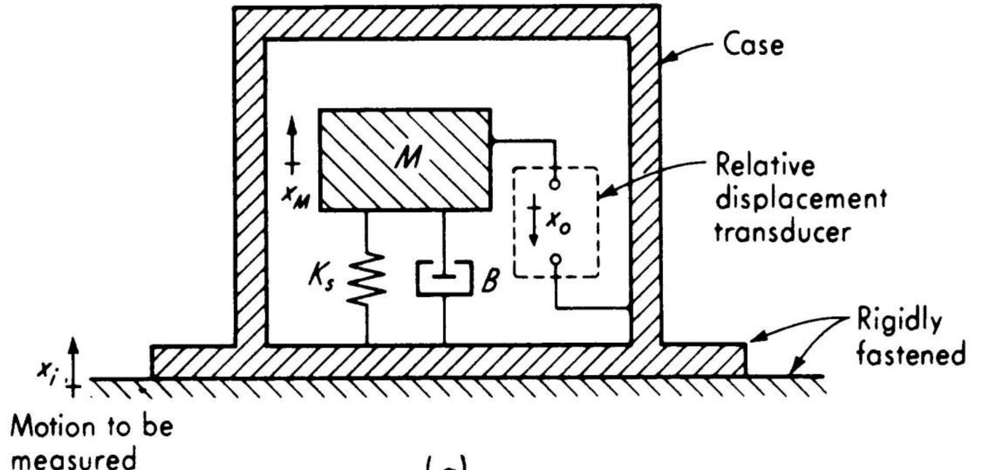
Popularity of accelerometers:

1) Frequency response is from zero to high limiting value. Piezo electric type are generally for dynamic measurement.

2) Displacement and velocity can be obtained by integration. A preferred way compared to differentiation.

3) Destructive forces are more close to acceleration as compared to velocity or displacement.

4) Measurement of transients (shock) motion is more readily achieved than with displacement or velocity pickup.



(a)

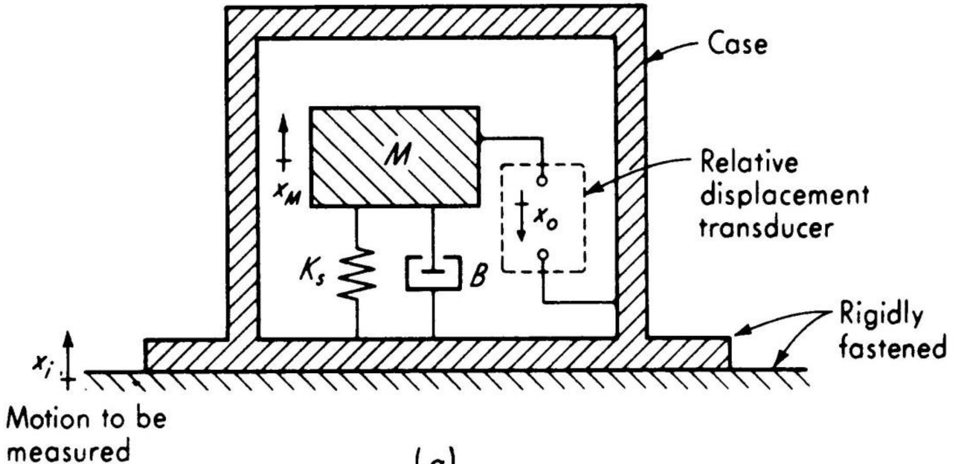
Accelerometer

Governing equation for such a system:

$$\mathbf{K_s x_o} + \mathbf{B\dot{x}_o} = \mathbf{M\ddot{x}_M} = \mathbf{M(\ddot{x}_i - \ddot{x}_o)} \qquad \omega_\mathbf{n} = \sqrt{\frac{\mathbf{K_s}}{\mathbf{M}}} \qquad \zeta = \frac{\mathbf{B}}{2\sqrt{\mathbf{K_s M}}}$$

B – damping co-efficient

Damping force is proportional to velocity for viscous damping



(a)

Accelerometer

Governing equation for such a system:

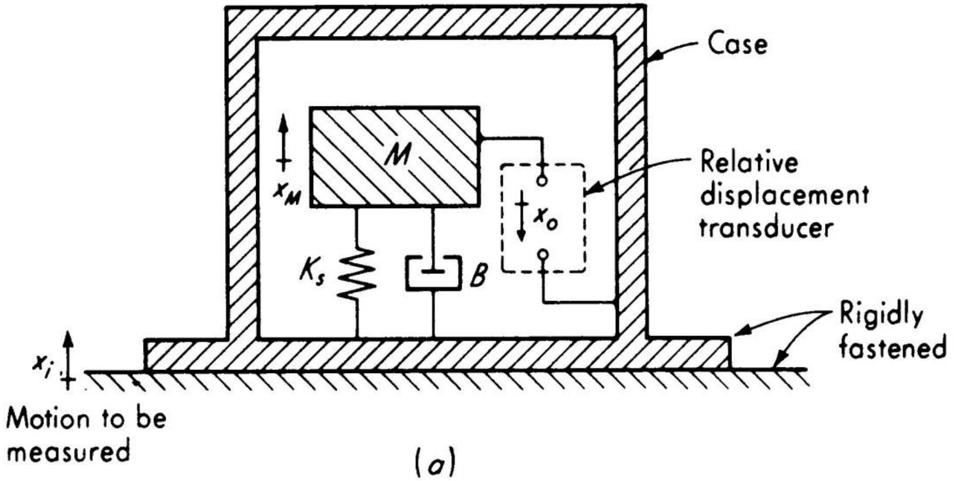
$$\mathbf{K_s x_o + B\dot{x}_o = M\ddot{x}_M = M(\ddot{x}_i - \ddot{x}_o)}$$

$$\omega_{\mathbf{n}} = \sqrt{\frac{\mathbf{K_s}}{\mathbf{M}}} \qquad \zeta = \frac{\mathbf{B}}{2\sqrt{\mathbf{K_s M}}}$$

$$\boxed{M\ddot{x}_o + B\dot{x}_o + K_s x_o = M\ddot{x}_i}$$

$$\frac{\mathbf{x_0}}{\mathbf{x_i}}(\mathbf{D}) = \frac{\mathbf{D}^2/\omega_{\mathbf{n}}^2}{\mathbf{D}^2/\omega_{\mathbf{n}}^2 + 2\zeta\mathbf{D}/\omega_{\mathbf{n}} + 1}$$

Input is casing displacement and output is sensor relative displacement



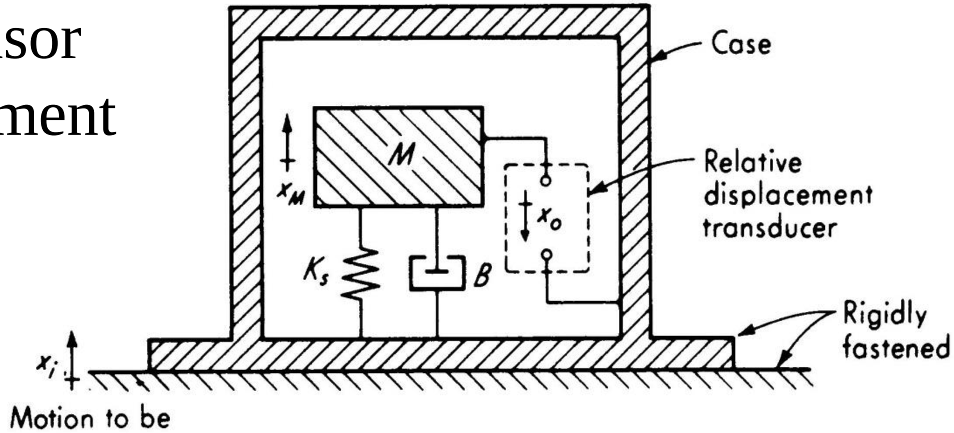
Accelerometer

Output is proportional to acceleration and it is a second order system. All the properties of the second order system are applicable. High natural frequency for a flat response. Frequency response of output will be from zero to some fraction of natural frequency.

$$\boxed{M\ddot{x}_o + B\dot{x}_o + K_s x_o = M\ddot{x}_i}$$

$$\frac{\mathbf{x}_0}{\mathbf{D}^2\mathbf{x}_\mathbf{i}}(\mathbf{D}) = \frac{\mathbf{x}_0}{\ddot{\mathbf{x}}_\mathbf{i}}(\mathbf{D}) = \frac{\mathbf{K}}{\mathbf{D}^2/\omega_\mathbf{n}^2 + 2\zeta\mathbf{D}/\omega_\mathbf{n} + 1} \qquad \mathbf{K} = \frac{1}{\omega_\mathbf{n}^2}$$

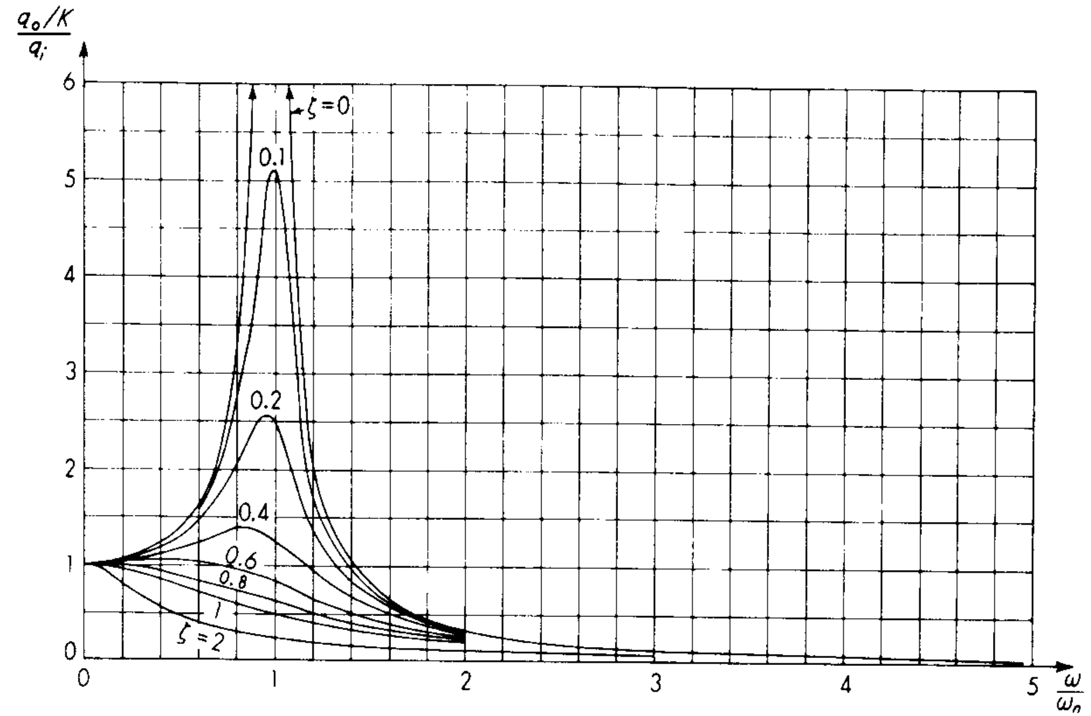
Input is casing acceleration and output is sensor relative displacement

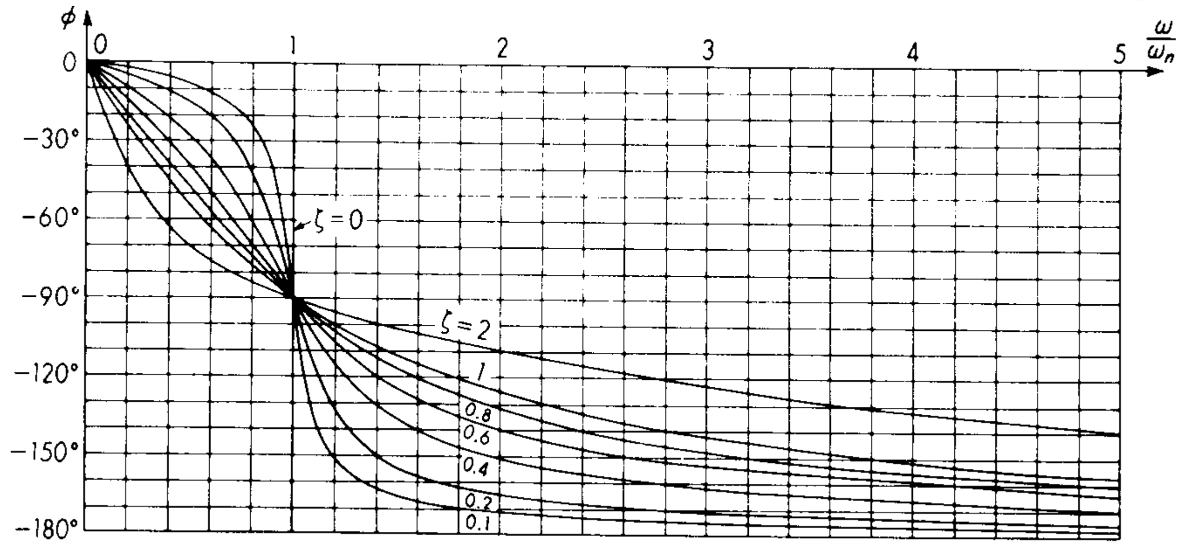


(a)

Accelerometer

Damping ratio of 0.6 – 0.8 gives a flat response upto some fraction of natural frequency. Sensitivity is inversely proportional to square of natural frequency. For large flat response, low sensitivity. Phase angle is linearly dependent of frequency.

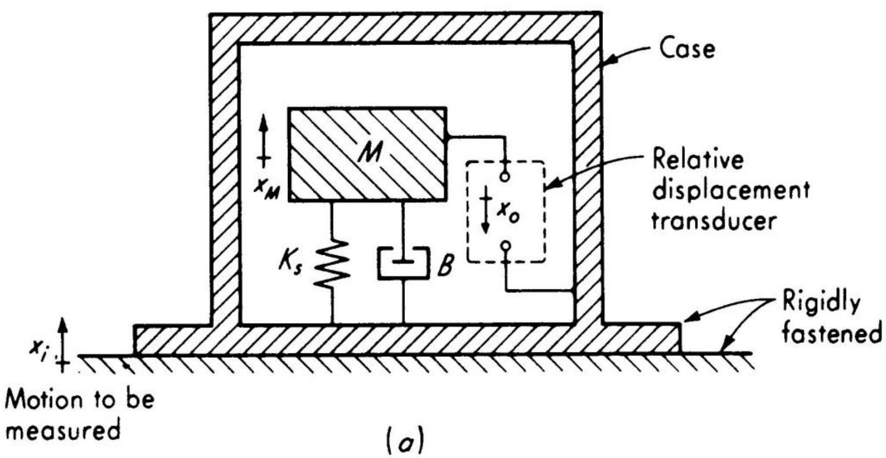


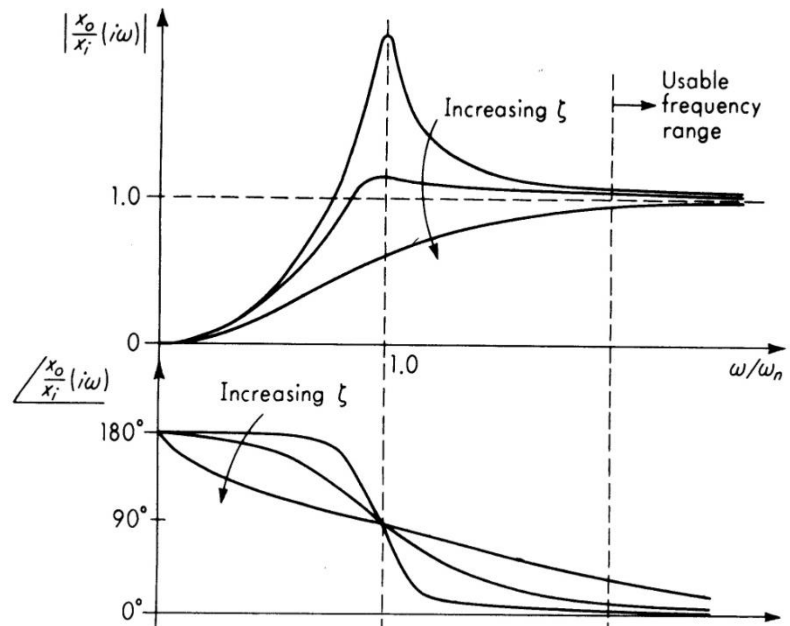


Accelerometer as Displacement Pickup

Desired output is displacement. For frequencies much above natural frequency the output is perfect measurement. For accurate displacement natural frequency of the sensor must be much small compared to lowest vibration frequency.

$$\frac{\mathbf{x}_0}{\mathbf{x}_\mathbf{i}}(\mathbf{D}) = \frac{\mathbf{D}^2/\omega_\mathbf{n}^2}{\mathbf{D}^2/\omega_\mathbf{n}^2 + 2\zeta\mathbf{D}/\omega_\mathbf{n} + 1} \qquad \omega_\mathbf{n} = \sqrt{\frac{\mathbf{K}_\mathbf{s}}{\mathbf{M}}} \qquad \zeta = \mathbf{B}/2\sqrt{\mathbf{K}_\mathbf{s}\mathbf{M}}$$





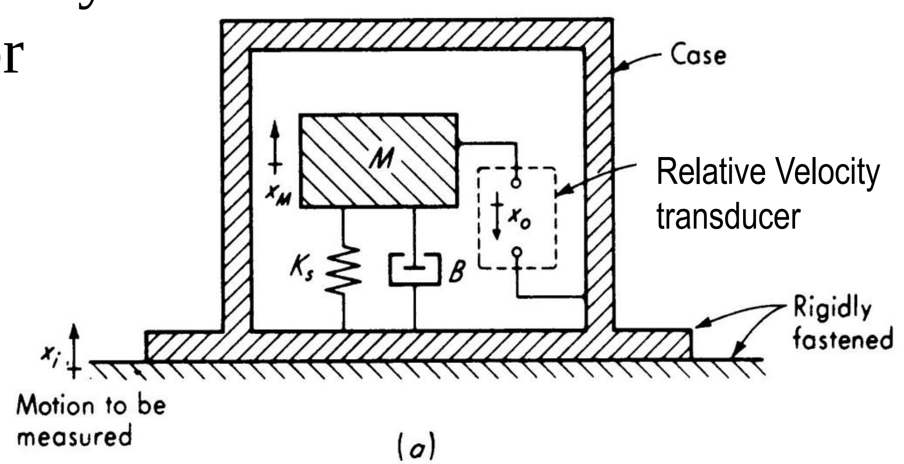
Accelerometer as Velocity Pickup

If the sensing element is dependent on velocity, then the relative displacement sensor described earlier can be used. Response will be same as the displacement sensor i.e. output will be flat for $\omega >> \omega_n$ Required displacement can be obtained by integrating.

$$\boxed{M\ddot{x}_o + B\dot{x}_o + K_s x_o = M\ddot{x}_i}$$

$$\frac{\dot{\mathbf{x}}_0}{\dot{\mathbf{x}}_\mathbf{i}}(\mathbf{D}) = \frac{\mathbf{D}^2/\boldsymbol{\omega}_\mathbf{n}^2}{\mathbf{D}^2/\boldsymbol{\omega}_\mathbf{n}^2 + 2\zeta\mathbf{D}/\boldsymbol{\omega}_\mathbf{n} + 1}$$

Input is casing velocity and output is sensor relative velocity

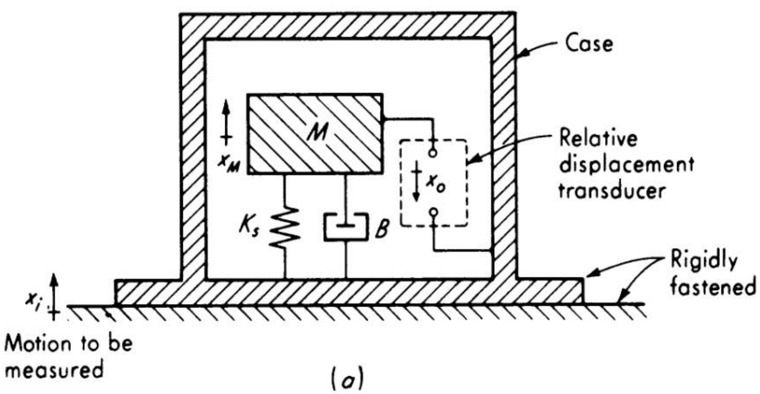


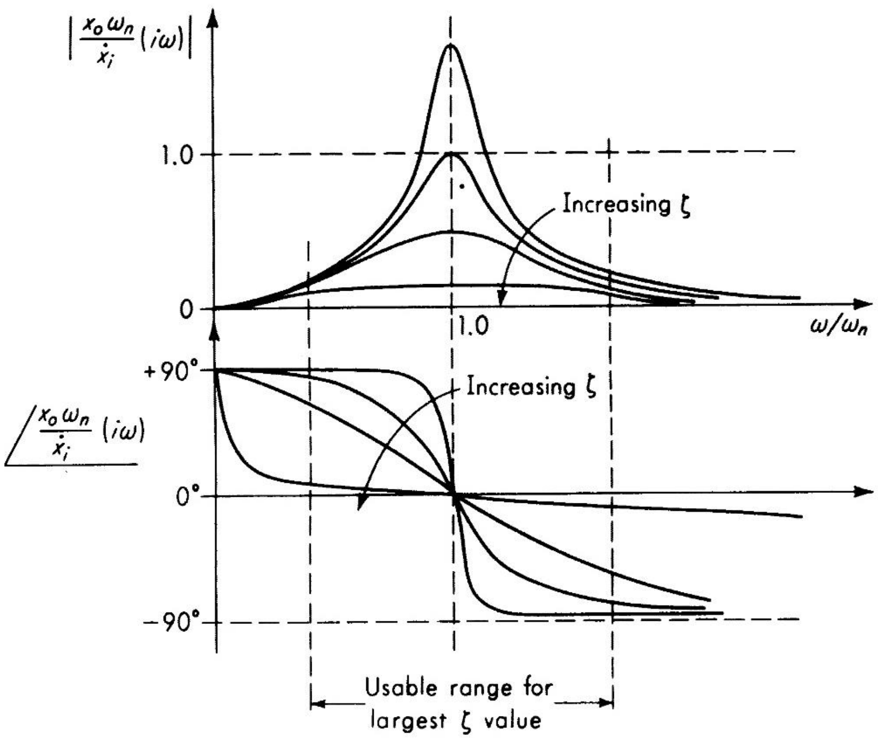
Accelerometer as Velocity Pickup

Velocity can be obtained by differentiation of displacement or integration of acceleration, both have problems in some form. If the damping is made large, output remains constant for large frequency variation. This also reduces sensitivity. It is meant for vibratory velocities.

$$\boxed{M\ddot{x}_o + B\dot{x}_o + K_s x_o = M\ddot{x}_i}$$

$$\frac{\mathbf{x_0}}{\mathbf{Dx_i}}(\mathbf{D}) = \frac{\mathbf{x_0}}{\mathbf{\dot{x}_i}}(\mathbf{D}) = \frac{\mathbf{D}}{\mathbf{D}^2 + 2\zeta\omega_\mathbf{n}\mathbf{D} + \omega_\mathbf{n}^2}$$





Pendulous Angular Displacement Sensor

Angular displacement relative to local vertical can be found. Good for non rotating and accelerating motion. Springs create a notch filter characteristics for dynamic motion.