Misurare le vibrazioni

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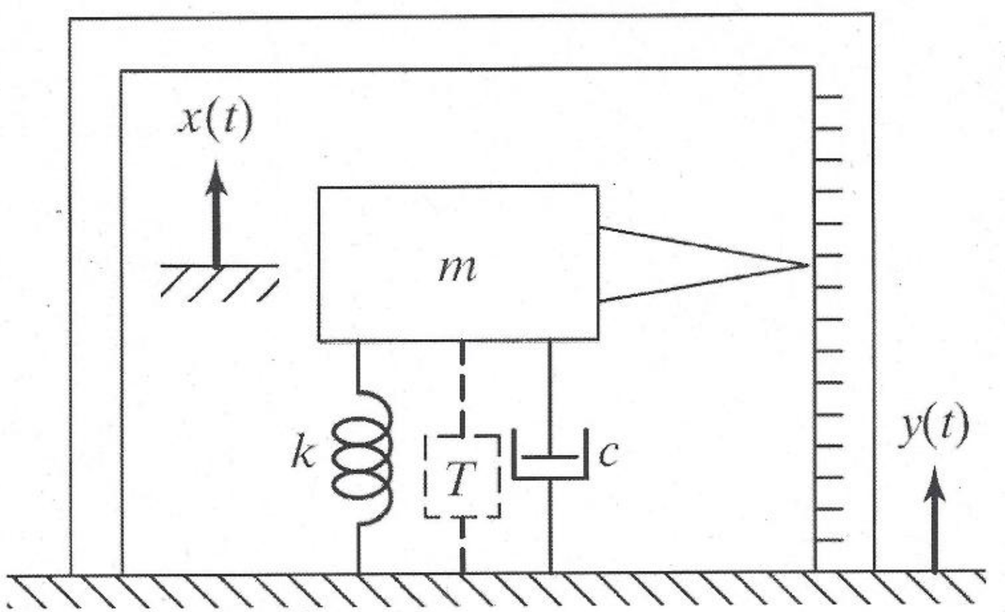
MechLav – Laboratorio per la meccanica avanzata

ACCELEROMETER – HOW IT WORKS



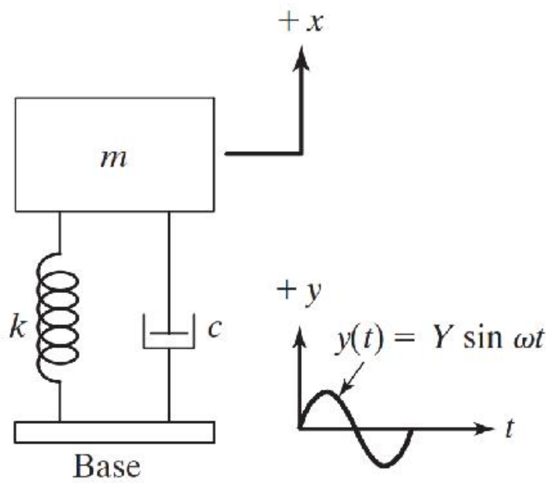
Relative displacement:

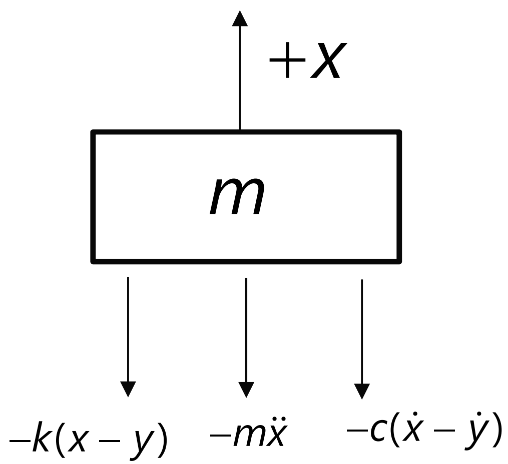
$$z(t) = x(t) - y(t)$$

If $x(t) \simeq 0 \quad \rightarrow \quad z(t) \simeq -y(t)$

Vibrometer: $z(t) \propto y(t-{}^{2})$

Acceleromter: $z(t) \propto \ddot{y}(t-{}^{2})$





Equation of motion of the mass

$$m\ddot{x} + c(\dot{x} - \dot{y}) + k(x - y) = 0$$

↓

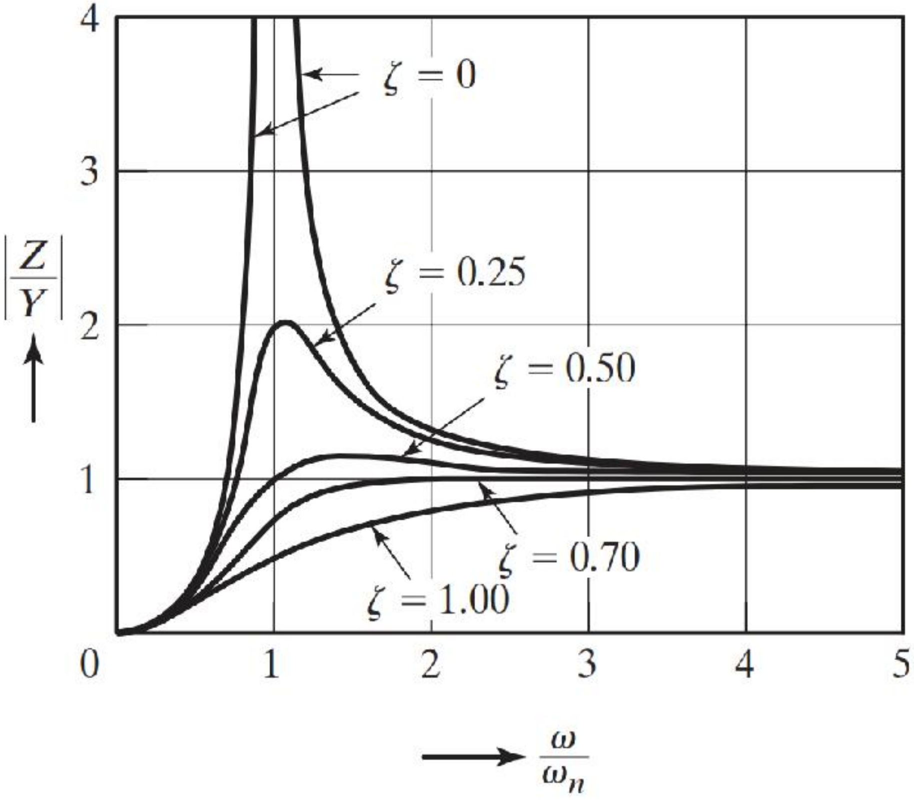
$$m\ddot{z} + c\dot{z} + kz = m\mu^2 Y \sin(\mu t)$$

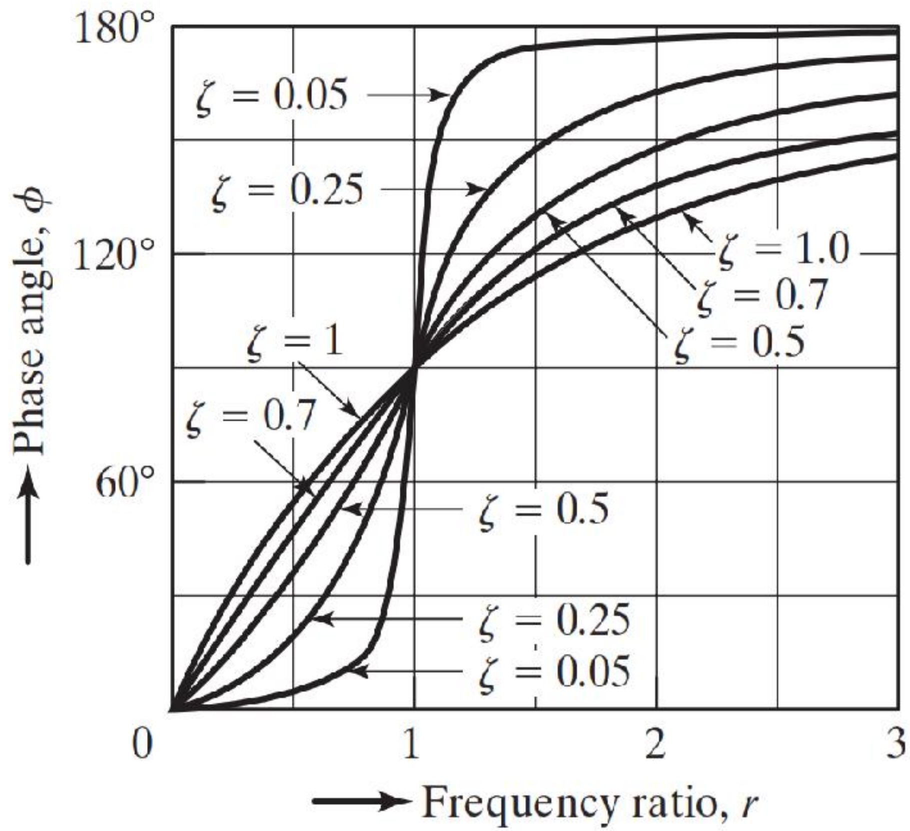
ACCELEROMETER – HOW IT WORKS

The solution is

$$z(t) = Z\sin(\mu t - ¤) \longrightarrow Z = \frac{\mu^2 Y / \mu_n^{\;2}}{\sqrt{\left(1-r^2\right)^2 + \left(2¸ r\right)^2}} \qquad ¤ = \tan^{-1}\left(\frac{2¸ r}{1-r^2}\right)$$

$$r = \frac{\mu}{\mu_n} \qquad ¸ = \frac{c}{2m\mu_n}$$





ACCELEROMETER – HOW IT WORKS

The acceleration of the base is $\ddot{y}(t) = -\mu^2 Y \sin(\mu t)$

Therefore $$-z(t)\mu_n^2 = \frac{1}{\sqrt{\left(1-r^2\right)^2 + \left(2¸r\right)^2}}\left(-\mu^2 Y \sin(\mu t - ¤)\right)$$

ACCELEROMETER – HOW IT WORKS

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$\dfrac{1}{\sqrt{\left(1-r^2\right)^2 + \left(2\text{¸} r\right)^2}} \simeq 1$

ACCELEROMETER – HOW IT WORKS

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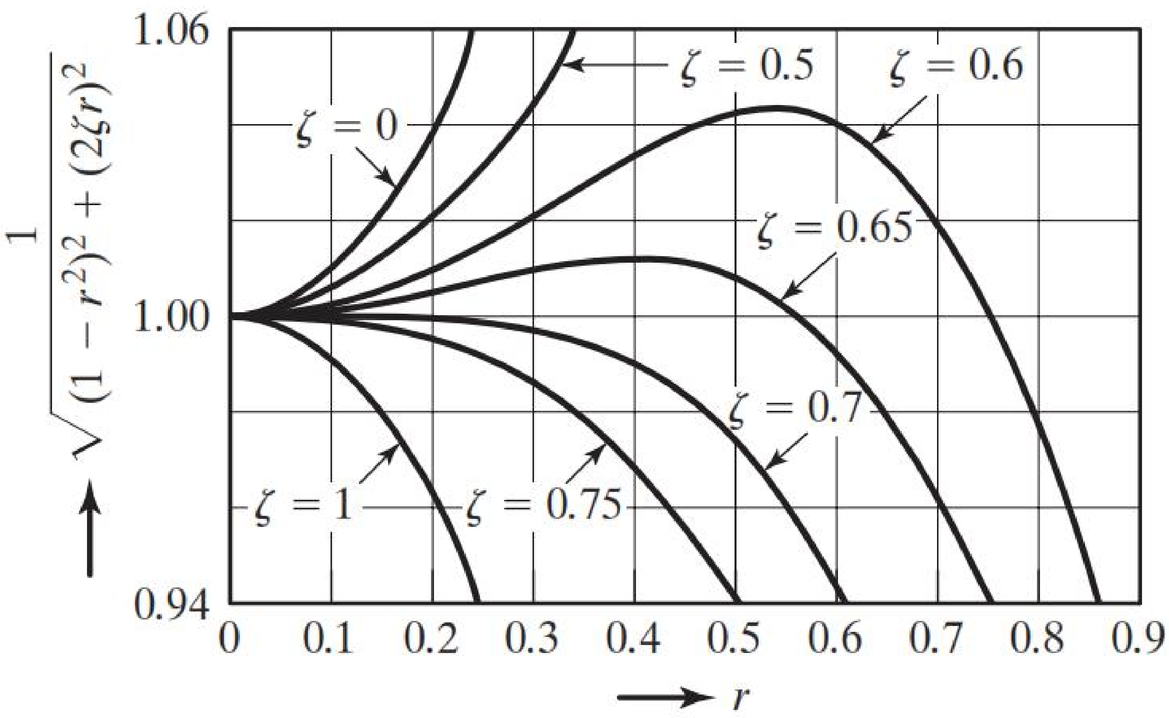
Therefore $-z(t)\mu_n^2 = \dfrac{1}{\sqrt{\left(1-r^2\right)^2 + \left(2\text{¸} r\right)^2}}\left(-\mu^2 Y \sin(\mu t - \text{¤})\right) \longrightarrow -z(t)\mu_n^2 = -\mu^2 Y \sin(\mu t - \text{¤})$

$\simeq 1$



If:

$0 \le r \le 0.6$

$0.65 \le \text{¸} \le 0.7$

$0 \le r \le 0.3$

$\text{¸} \simeq 0$

$$\frac{1}{\sqrt{\left(1-r^2\right)^2 + \left(2\text{¸} r\right)^2}} \simeq 1$$

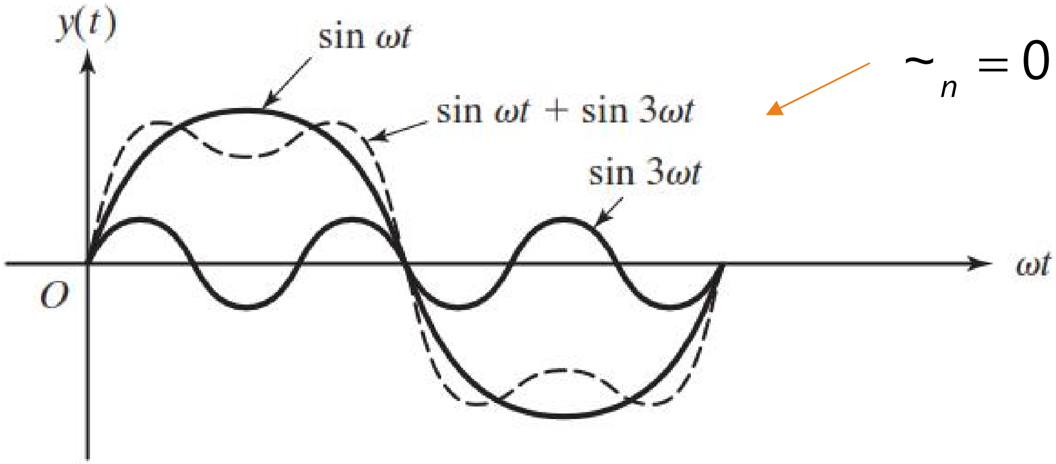
ACCELEROMETER – HOW IT WORKS

Phase distorsion error

As a general case, *y*(*t*) could be expressed as a sum of several harmonics as

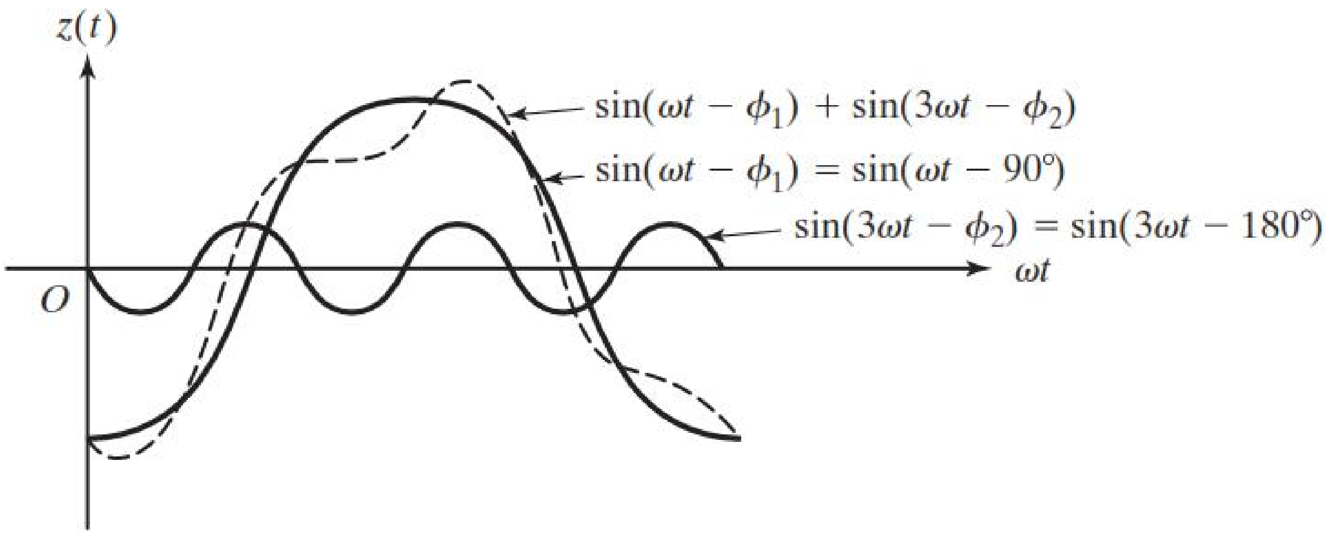
$$y(t) = \sum_{n=1}^{N} Y_n \sin\left(n\mu t + \sim_n\right)$$

$$z(t) = \sum_{n=1}^{N} Z_n \sin\left(n\mu t + \sim_n - \text{¤}_n\right)$$



$$\sim_n = 0$$

(a) Input signal



ACCELEROMETER – HOW IT WORKS

Single component:

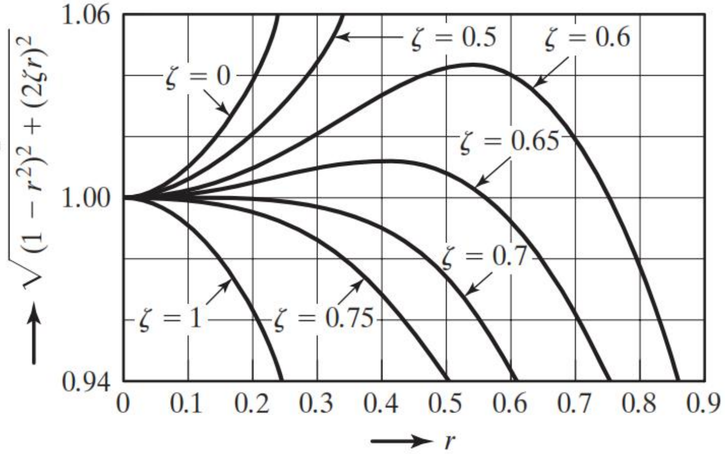
$$\ddot{y}(t) = -\mu^2 Y \sin(\mu t) \longrightarrow z(t) = \frac{1/\mu_n^2}{\sqrt{\left(1-r^2\right)^2 + \left(2\text{¸}\, r\right)^2}}\left(\mu^2 Y \sin(\mu t - \text{¤})\right)$$

Multiple component:

$$\ddot{y}(t) = \sum_{n=1}^{N} -n^2\mu^2 Y_n \sin\left(n\mu t + \sim_n\right) \longrightarrow z(t) = \sum_{n=1}^{N} \frac{1/\mu_n^2}{\sqrt{\left(1-n^2r^2\right)^2 + \left(2\text{¸}\, nr\right)^2}} n^2\mu_n^2 Y \sin\left(n\mu t + \sim_n - \text{¤}_n\right)$$

ACCELEROMETER – HOW IT WORKS

Amplitude



$Nr \leq 0.6$

$¸ \simeq 0.7$

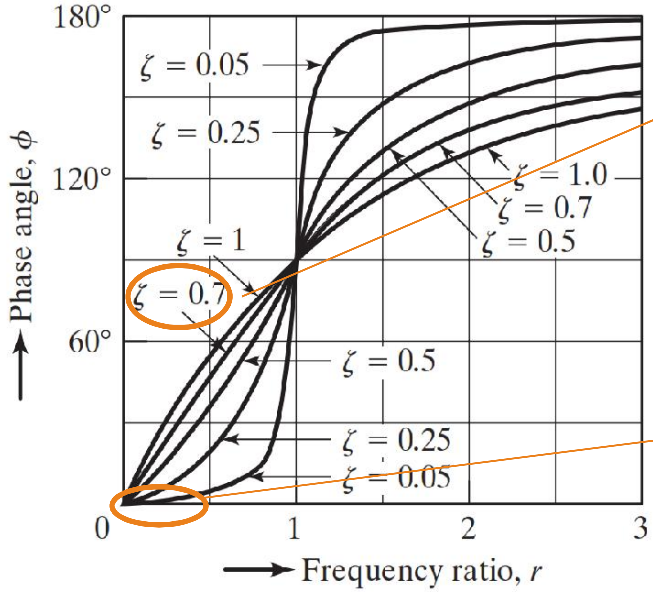
$Nr \leq 0.3$

$¸ \simeq 0$

$$\frac{1}{\sqrt{\left(1-n^2r^2\right)^2+\left(2¸\ nr\right)^2}} \simeq 1$$

Time lag

$$^2 = \frac{¤_n}{nµ}$$



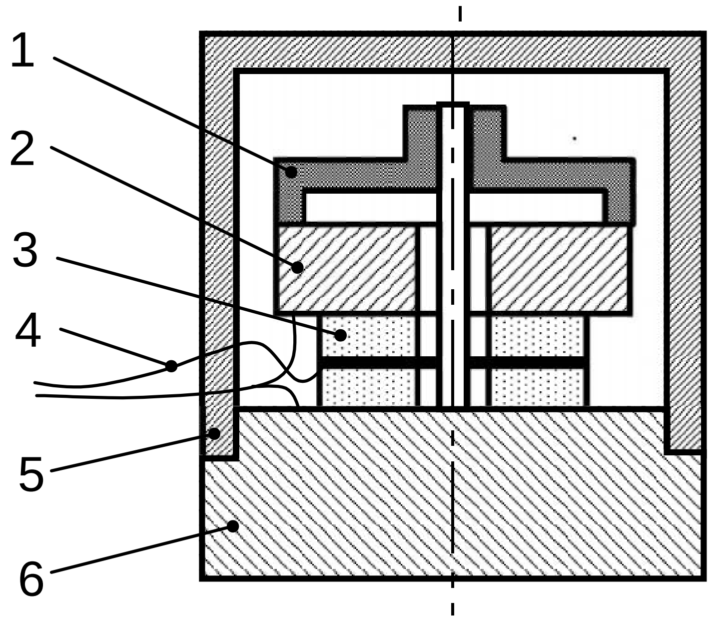
$$¤_n \simeq \frac{nµ}{µ_n} \rightarrow \ ^2 = \frac{¤_n}{nµ} \propto \frac{1}{µ_n}$$

$$¤_n = 0 \rightarrow \ ^2 = \frac{¤_n}{nµ} = 0$$

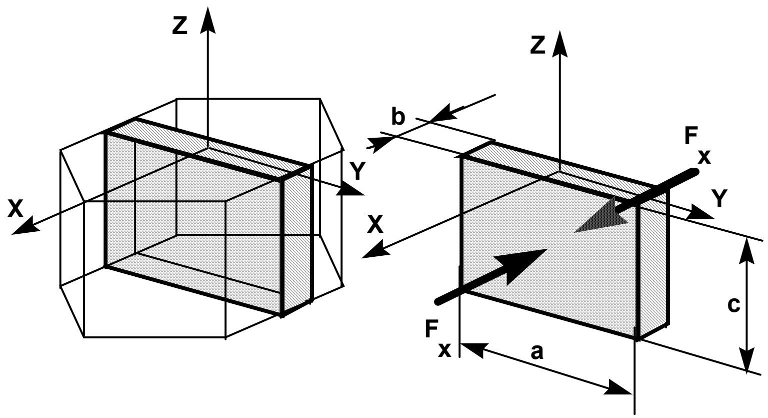
PIEZOELECTRIC ACCELEROMETER

The piezoelectric accelerometer is widely accepted as the best available transducer for the absolute measurement of vibration. This is a direct result of these properties

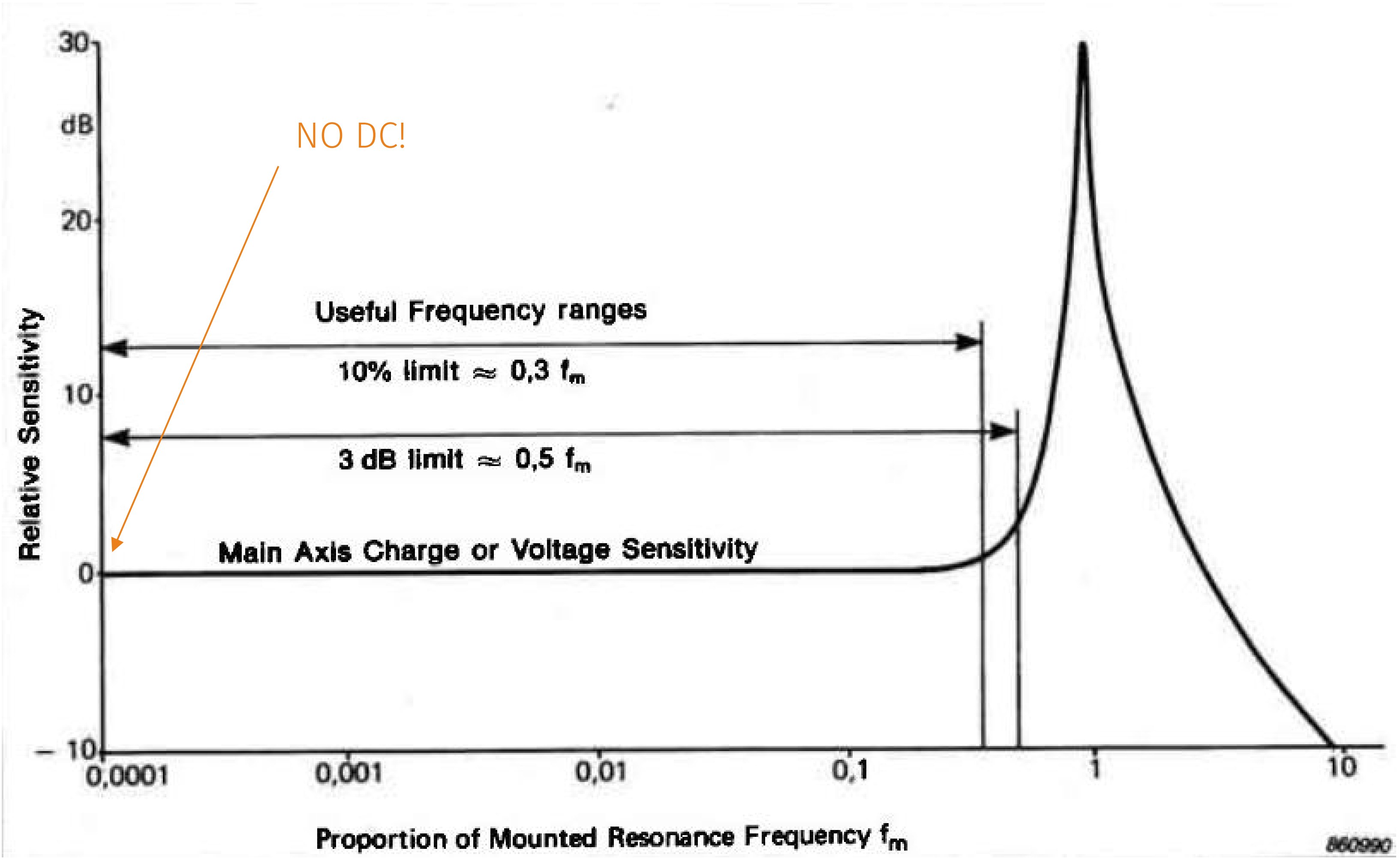
1. Usable over very wide grequency ranges.
2. Excellent linearity over a very wide dyamic range.
3. Acceleration signal can be electronically integragted to provide velocity and displacement data
4. Vibration measuments are possible in a wide range of environmental condition while still maintaining excellent accuracy
5. Self-gerating so no external power supply is required
6. No moving parts hence extremely durable.
7. Extremely compact plus a high sensitivity to mass ratio.



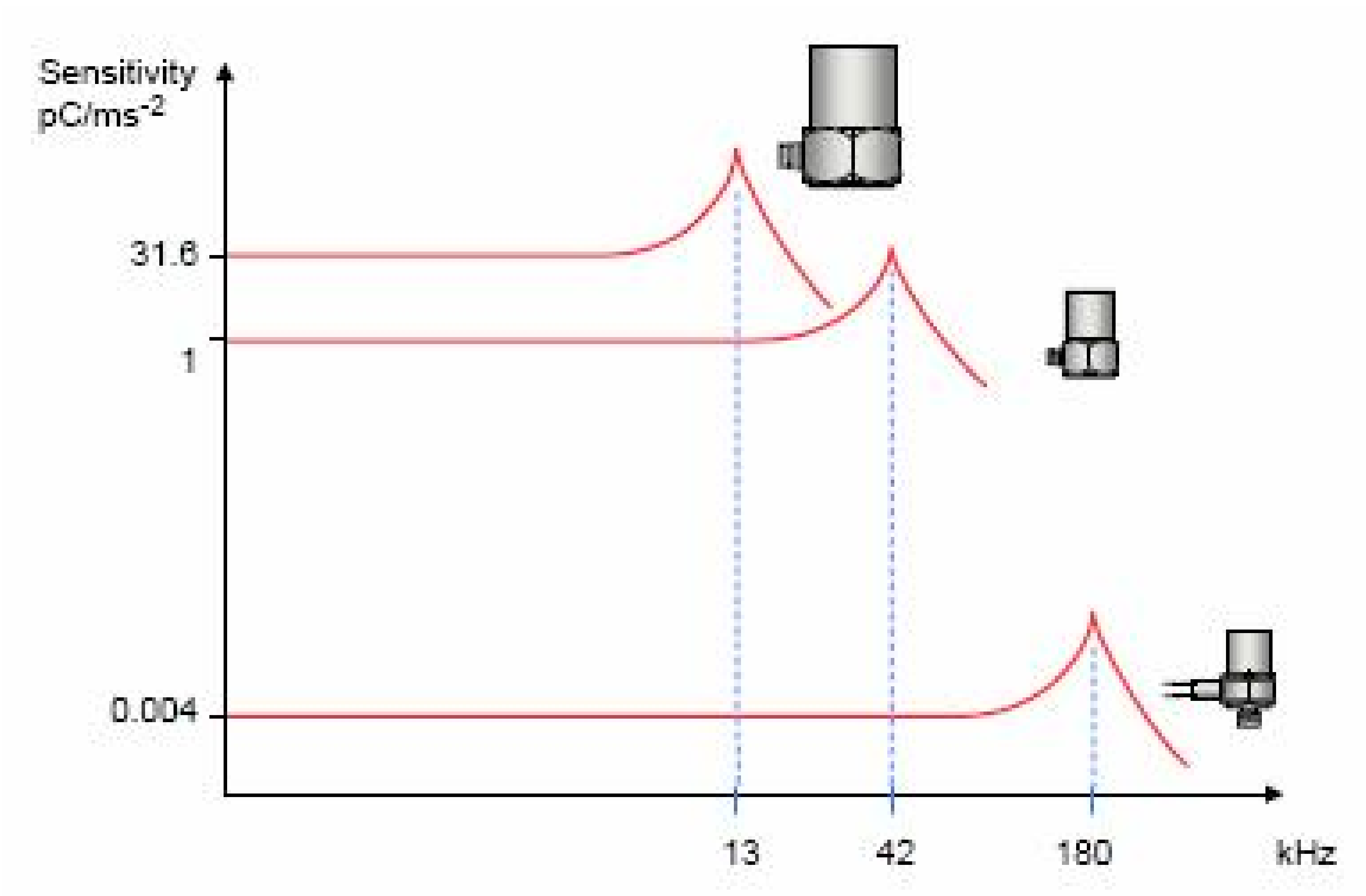
1. Spring
2. Seismic mass
3. Piezoelectric material
4. Cables
5. Case
6. Base



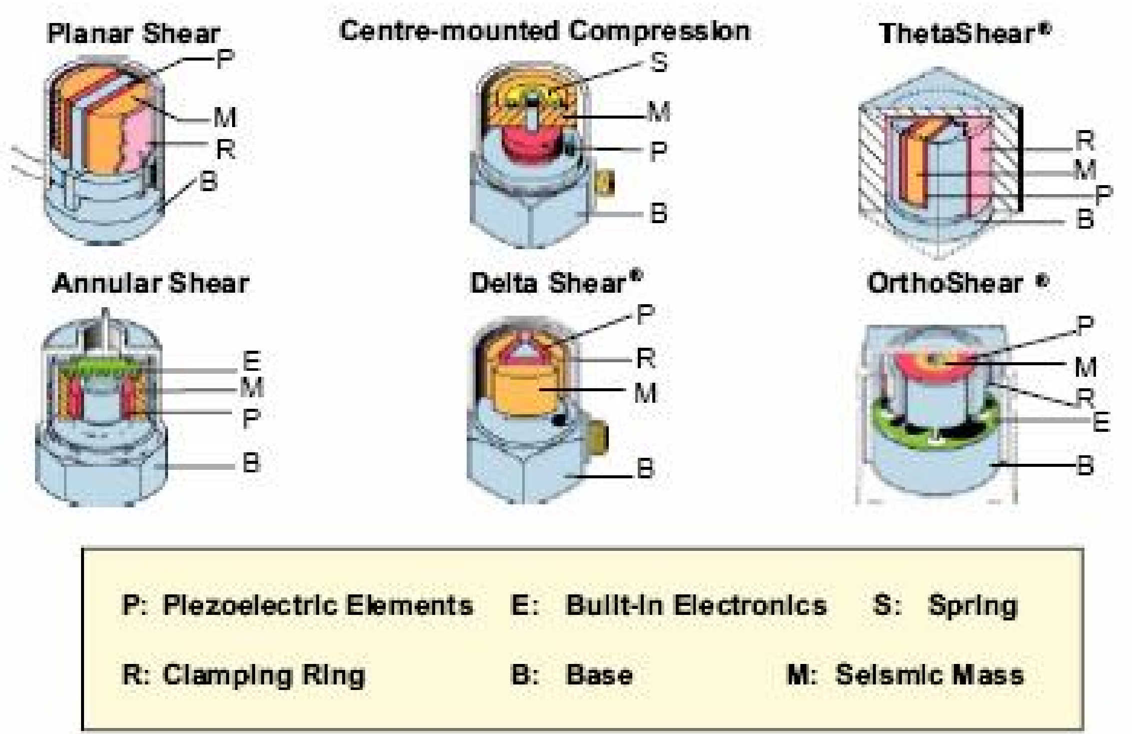
ACCELEROMETER PERFORMANCE IN PRACTICE



ACCELEROMETER PERFORMANCE IN PRACTICE



ACCELEROMETER PERFORMANCE IN PRACTICE



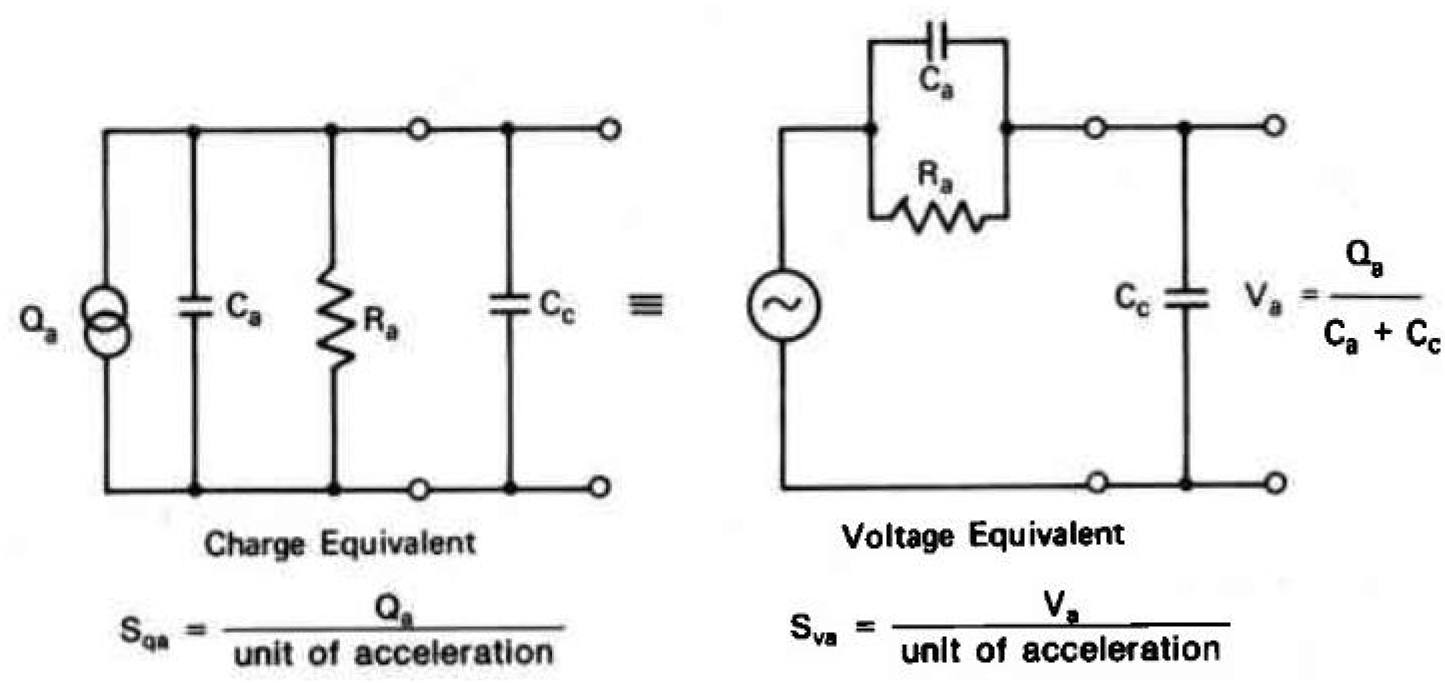
Delta Shear Design. This design gives a high sensitivity-to-mass ratio compared to other designs and has a relatively high resonance frequncy and high isolation from base strains and temperature transients. The excellent overall characteristics of this design make it ideal for both general purpose accelerometers and more specialized types

Centre-mounted Compression design. This design gives a moderately high sensitivity-to-mass ratio. However, any dynamic changes in the base such as bending or thermal expansions can cause stresses in the piezoelectric elements and hence erroneous outputs. For these reasonos this type of accelerometer is used for high level measurements (i.e. shock measurements) where the erroneous output is small compared with the vibration signal. This accelerometer is also used in the controlled environment of accelerometer calibration.

ACCELEROMETER PERFORMANCE IN PRACTICE

The accelerometer can be regarded as either a charge source or a voltage source.

The voltage produced by the accelerometer is divided between the accelerometer capacitance and the cable capacitance. Hence a change in the cable capacitance, caused either by a different type of cable and/or a change in the cable length, will cause a change in the voltage sensitivity. A sensitivity recalibration will therefore be required.



Charge sensitivity:

$$S_{qa} = \frac{pC}{ms^{-2}}$$

Voltage sensitivity:

$$S_{va} = \frac{mV}{ms^{-2}}$$

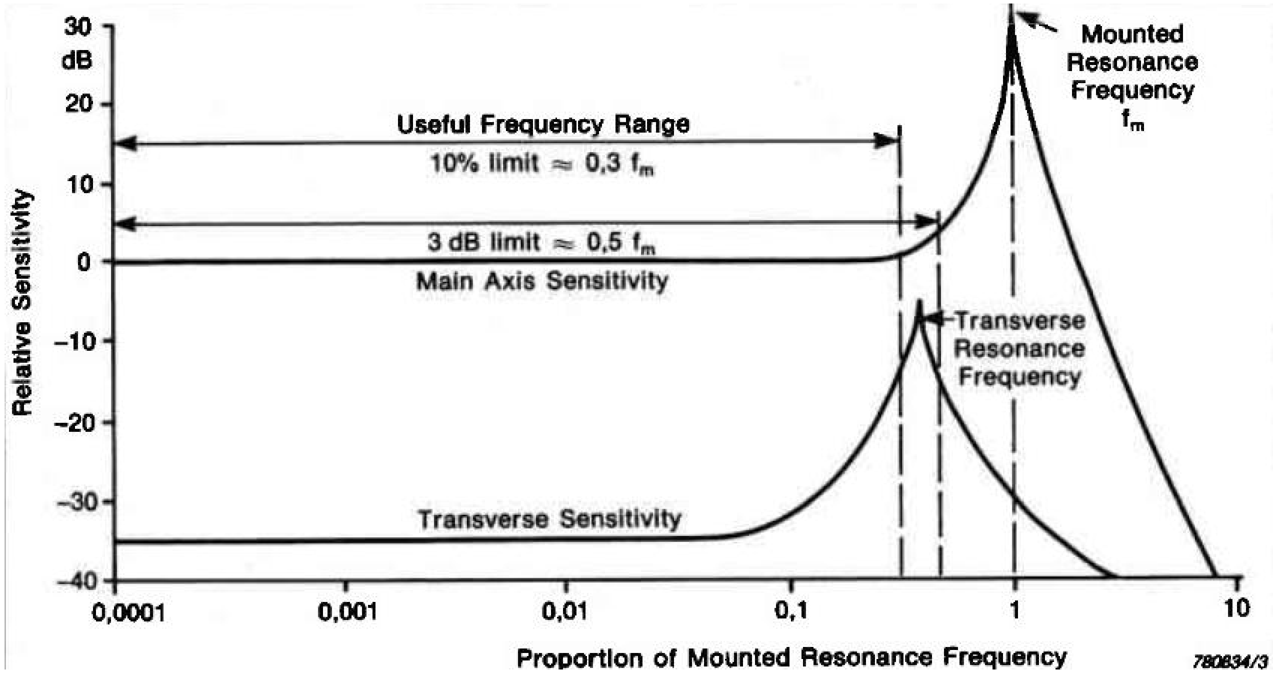
ACCELEROMETER PERFORMANCE IN PRACTICE

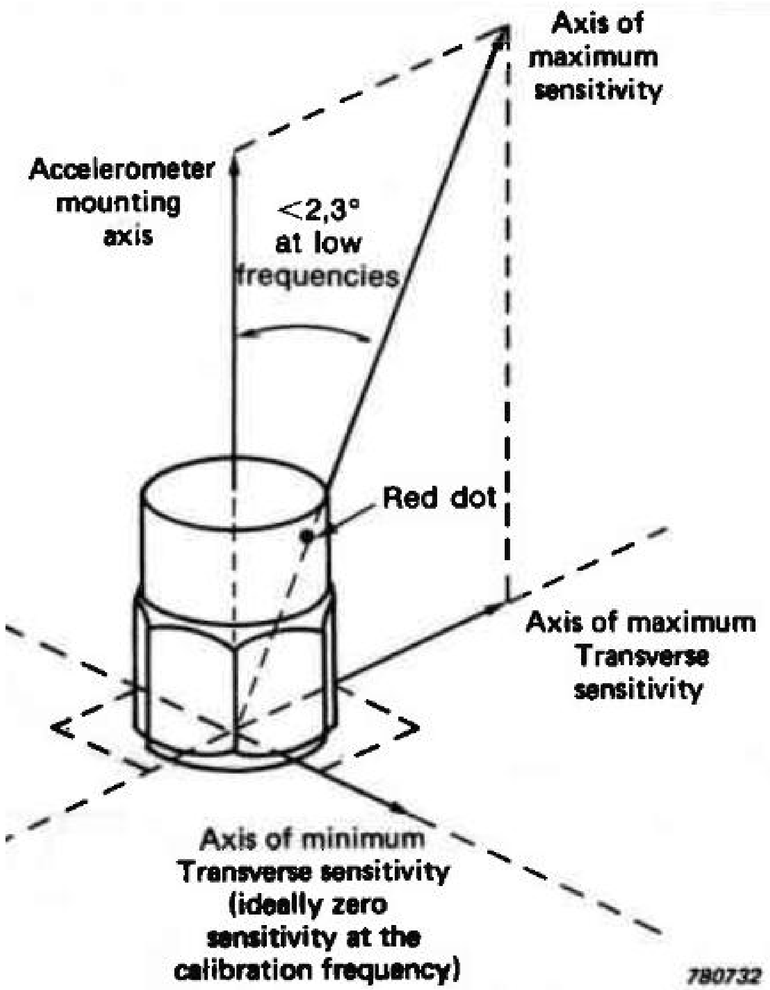
Accelerometer manufacturers use different names for the pre-amplified version:

Manufacturer	Brand name
Brüel & Kjær	Deltatron
Dytran Instruments	LIVM
Endevco	Isotron
Kistler Instrument Corp.	Piezotron
PCB Piezotronics Inc.	ICP

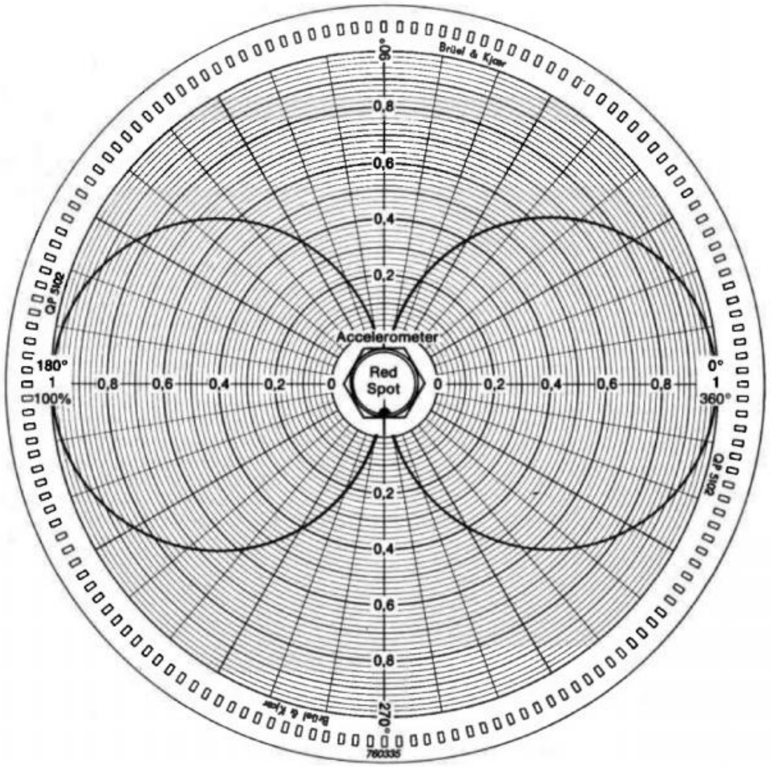
ACCELEROMETER PERFORMANCE IN PRACTICE

When an accelerometer has acceleration applied at right angles to ints mounting axis, there will still be some output from the accelerometer. Ideally the transverse sentitivity of an accelerometer should be zero, but in practice minute irregularities in the piezoelectric element and in metla parts prevent this.



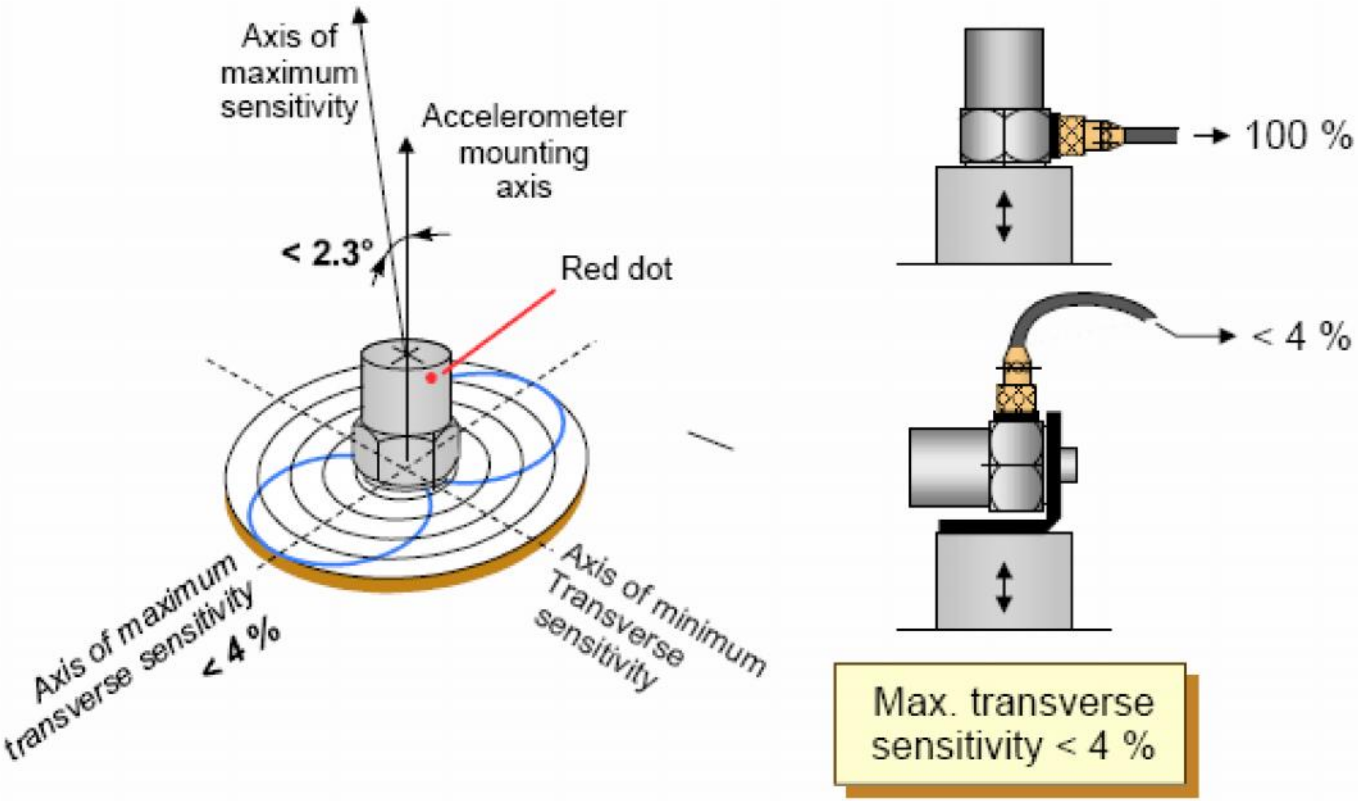


ACCELEROMETER PERFORMANCE IN PRACTICE

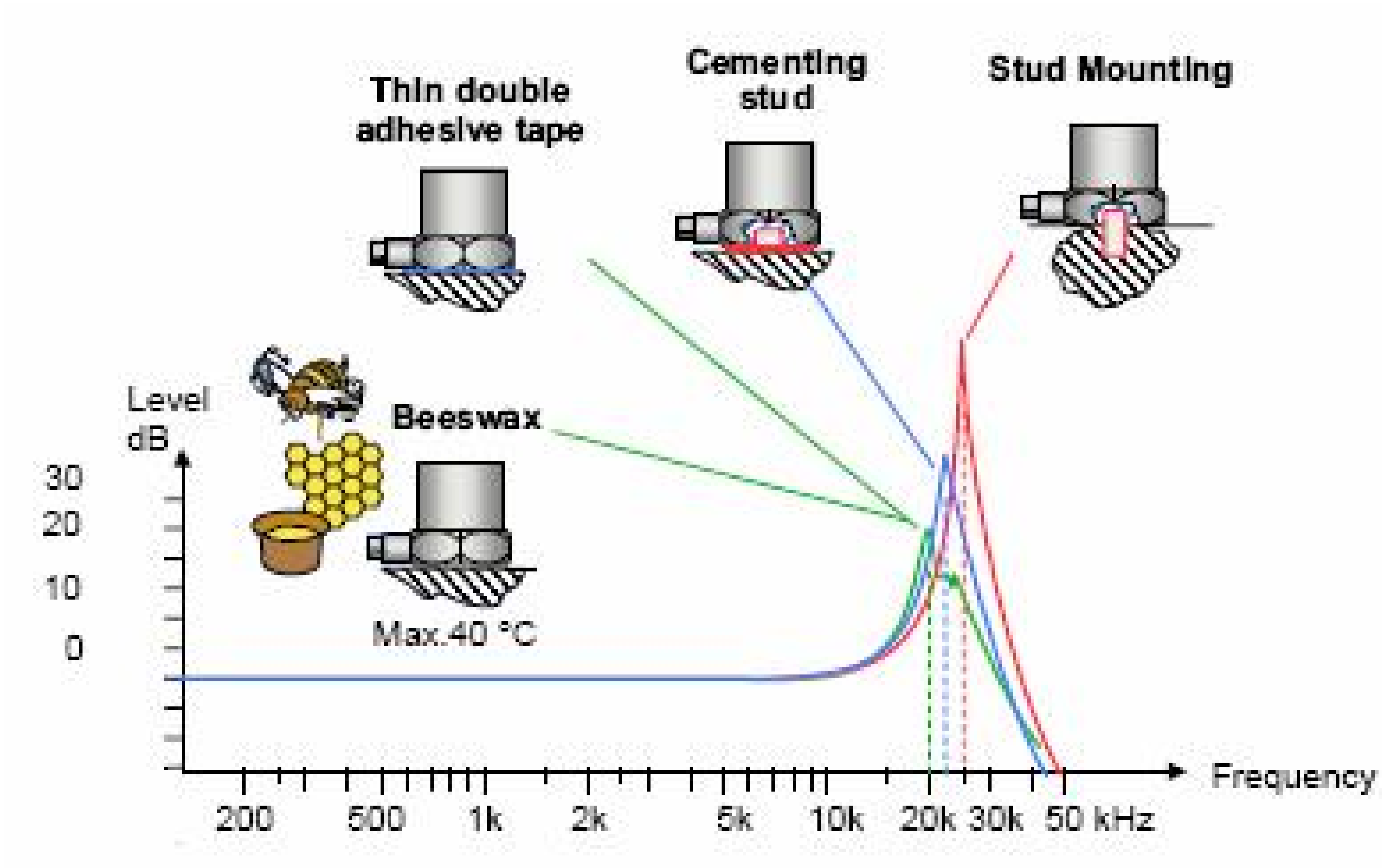


The maximum transverse sensitivity is usually below 4% of the main axis sensitivity

Delta Shear design has only one transverse resonance. Other shear designs may have two or more transverse resonances



ACCELEROMETER PERFORMANCE IN PRACTICE



ACCELEROMETER PERFORMANCE IN PRACTICE

Suggested mounting:

1. Stud
2. Cyanoacrylate (epoxy adhesives)
3. Beeswax
4. Magnet

Not Suggested mounting:

1. Self-Adhesive
2. Probes

ACCELEROMETER PERFORMANCE IN PRACTICE

		 Enlarge	 Enlarge	 Enlarge	 Enlarge
		Product Data	Product Data	Product Data	Product Data
Product Type		2273A	2273AM1	2273AM20	2276
Order No		EE 0019	EE 0019-002	EE 0019-003	EE 0020
Description		Side Connector	Side Connector	Top Connector	Side Connector
Sensitivity		3 pC/g	10 pC/g	10 pC/g	10 pC/g
Frequency Range	Hz	0.5 to 8000	0.5 to 6000	10 to 6000	0.5 to 7000
Resonance Frequency	kHz	30	27	27	27
Residual Noise Level in Spec Freq Range (rms)	mg	0.21	0.11	0.12	0.12
Temperature Range (C)	C	-184 to 399	-55 to 399	-55 to 399	-55 to 482
Temperature Range (F)	F	-300 to 750	-67 to 750	-67 to 750	-67 to 900
Maximum Operational Level (peak)	'g'	1000	500	500	500
Maximum Shock Level (± peak)	'g'	10000	3000	3000	3000
Weight	gram	25	32	32	30
Connector, Electrical		10-32 UNF	10-32 UNF	10-32 UNF	10-32 UNF
Mounting		Stud	Stud	Stud	Stud
Accessory Included (Selected)		3075M6-120	3075M6-120	3075M6-120	3075M6-120
Clip/Stud/Screw included		2981-12	2981-12	2981-12	2981-12
Output		Charge/PE	Charge/PE	Charge/PE	Charge/PE

ACCELEROMETER PERFORMANCE IN PRACTICE

When an accelerometer is mounted onto a vibrating specimen the increase in overall mass, combined with a change in the local stiffness, will inevitably alter the dynamc propertis of the structure. These changes are only significant if the accelerometer introduces an additional impedance of similar magnitude to that possesed by the structure before the addition of the accelerometer.

$$a_m \simeq a_s \frac{m_s}{m_s + m_a}$$

$$f_m = f_s \sqrt{\frac{m_s}{m_s + m_a}}$$

$a_m =$ Acceleration measured by the accelerometer

$a_s =$ Acceleration of the structure witiout the accelerometer

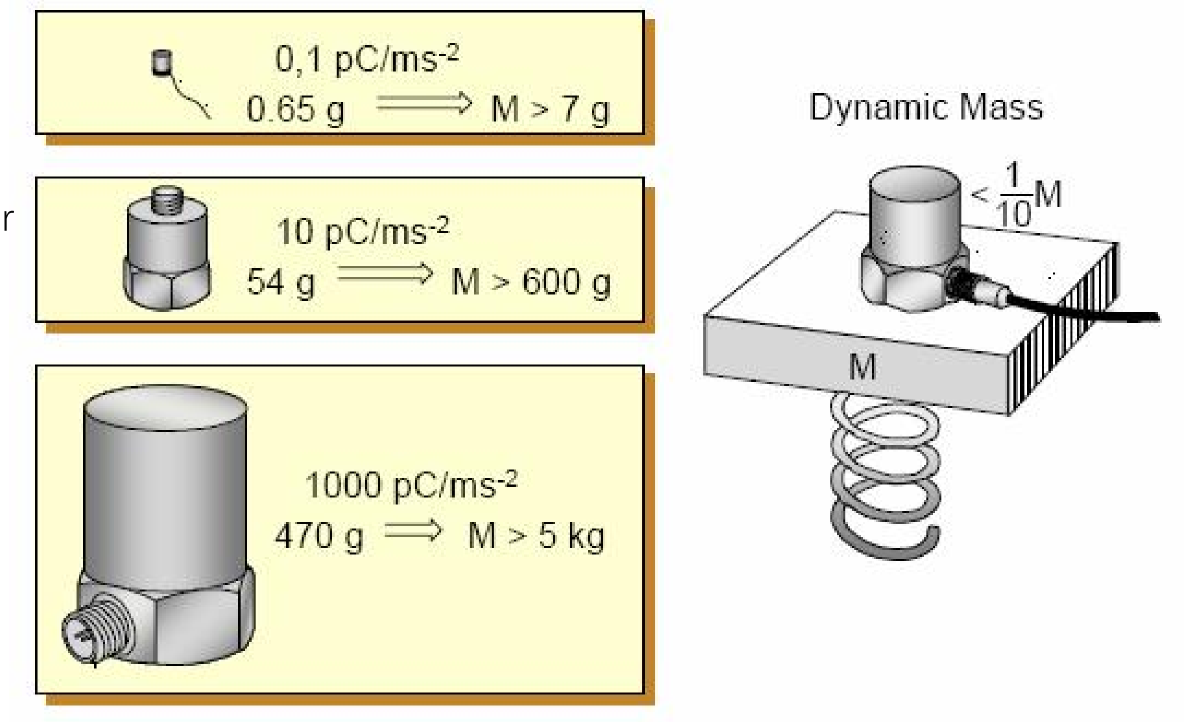
$f_m =$ Any resonance frequency of the structure

$f_s =$ Any resonance frequency of the structure without the influence of the accelerometer mass

$m_a =$ Accelerometer mass

$m_s =$ Structure mass

As a general rule:



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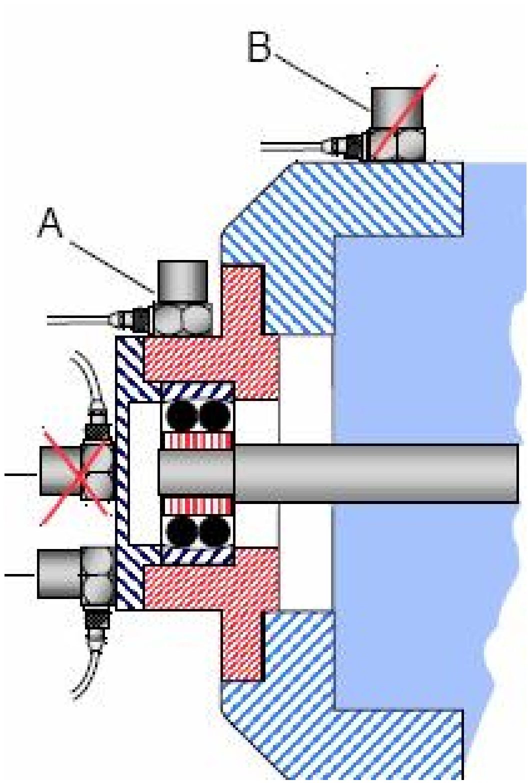


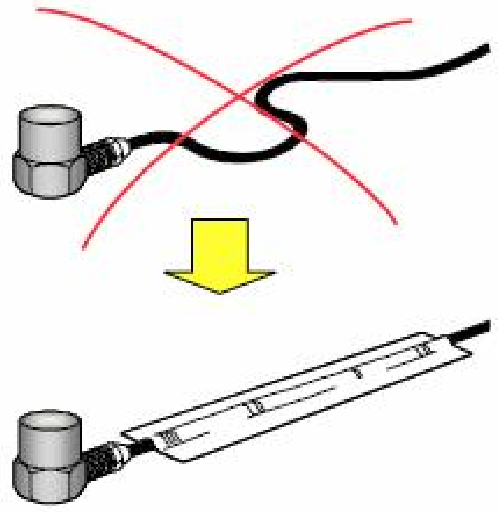
The accelerometer should be mounted so that the desired measuring direction coincides with the main sensitivity axis. Accelerometers are slightly sensitive to vibrations in the transverse direction, but this can normally be ignored as the maximum transverse sensitivity is typically only a few percent of the main axis sensitivity.

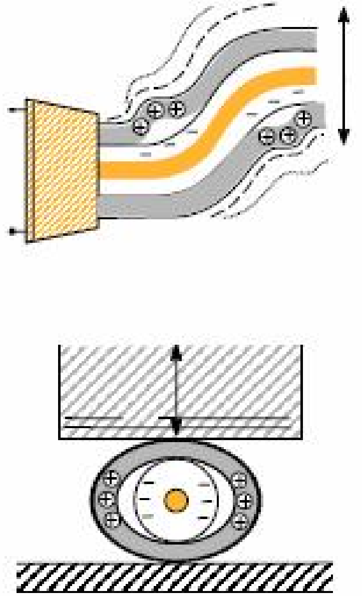
The reason for measuring vibration will normally dictate the position of the accelerometer. In the figure the reason is to monitor the condition of the shaft and bearing. The accelerometer should be positioned to maintain a direct path for the vibration from the bearing.

Accelerometer "A" thus detects the vibration signal from the bearing predominant over vibrations from other parts of the machine, but accelerometer "B" receives the bearing vibration modified by transmission through a joint, mixed with signals from other parts of the machine. Likewise, accelerometer "C" is positioned in a more direct path than accelerometer "D".

It is very difficult to give general rules about placement of accelerometers, as the response of mechanical objects to forced vibrations is a complex phenomenon, so that one can expect, especially at high frequencies, to measure significantly different vibration levels and frequency spectra, even on adjacent measuring points on the same machine element.

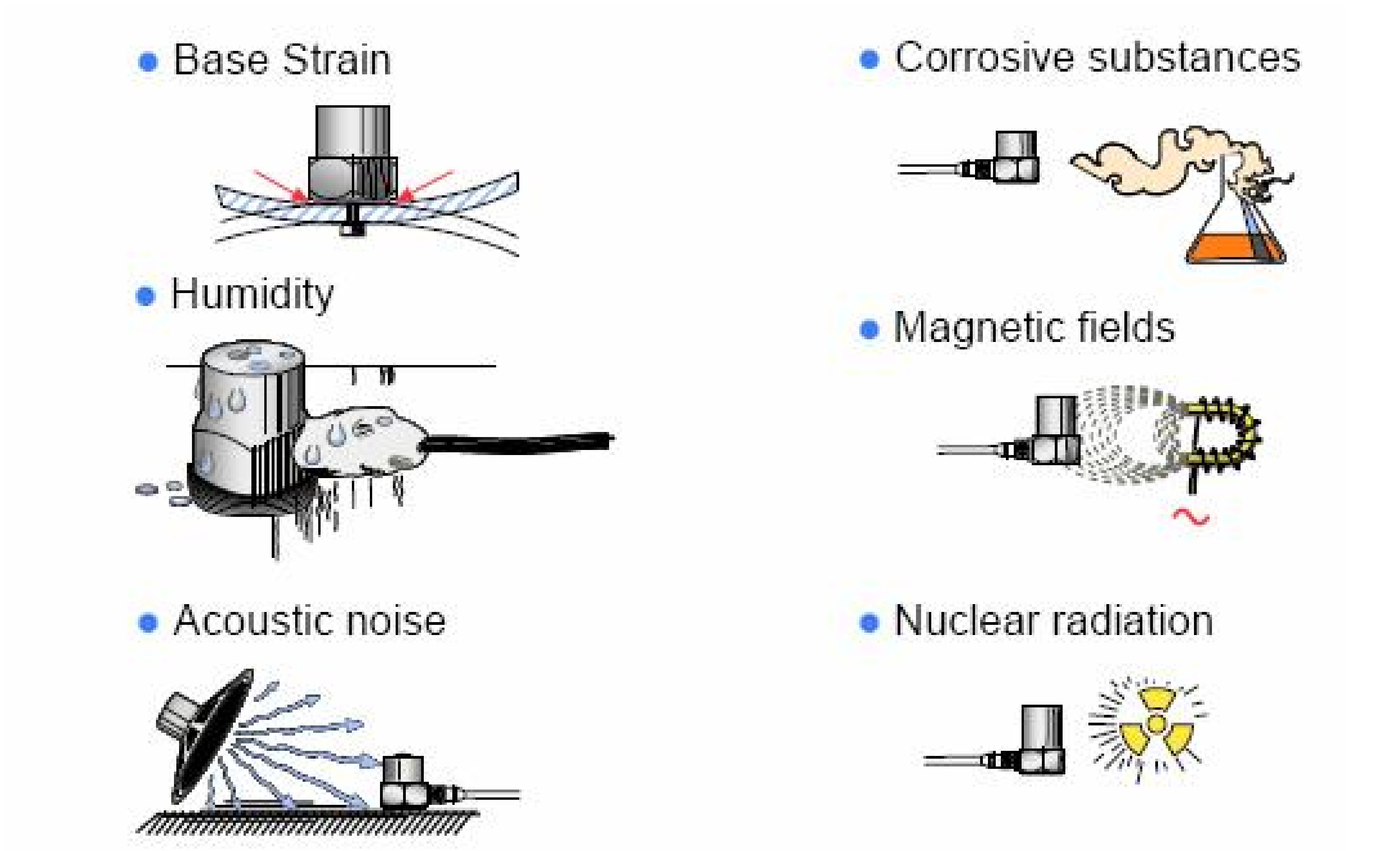
ACCELEROMETER PERFORMANCE IN PRACTICE





Movement (vibration) of the accelerometer cable during use can cause the screen of the cable to be separated from the insulation around the inner core of the cable. A varying electrical field is thereby created between the conducting screen and the non-conducting insulation, causing a minute current to flow in the screen which will be superimposed on the accelerometer signal as a noise signal. This phenomenon can be prevented by using low noise (or super low noise, which has similar precautions around the center conductor) accelerometer cables and fixing them to the test object e.g. with the aid of adhesive tape near the accelerometer, and let them leave the structure at a point with minimum motion.

ACCELEROMETER PERFORMANCE IN PRACTICE



ACCELEROMETER PERFORMANCE IN PRACTICE

Base Strain: Base strain sensitivity has been reduced by the use of a very thick base in the accelerometers. Delta Shear accelerometers are best in this respect as the elements are not in direct connection with the base.

Humidity: The accelerometer itself is sealed, so moisture can only enter the connector. In wet conditions this effect can be prevented by the use of a silicon rubber sealant.

Acoustic Noise: Has normally negligible influence on the vibration signal from the accelerometer.

Corrosive Substances: Special materials which are resistant to most corrosive substances are used in the construction of the accelerometer.

Magnetic Fields: The magnetic sensitivity is typically in the range

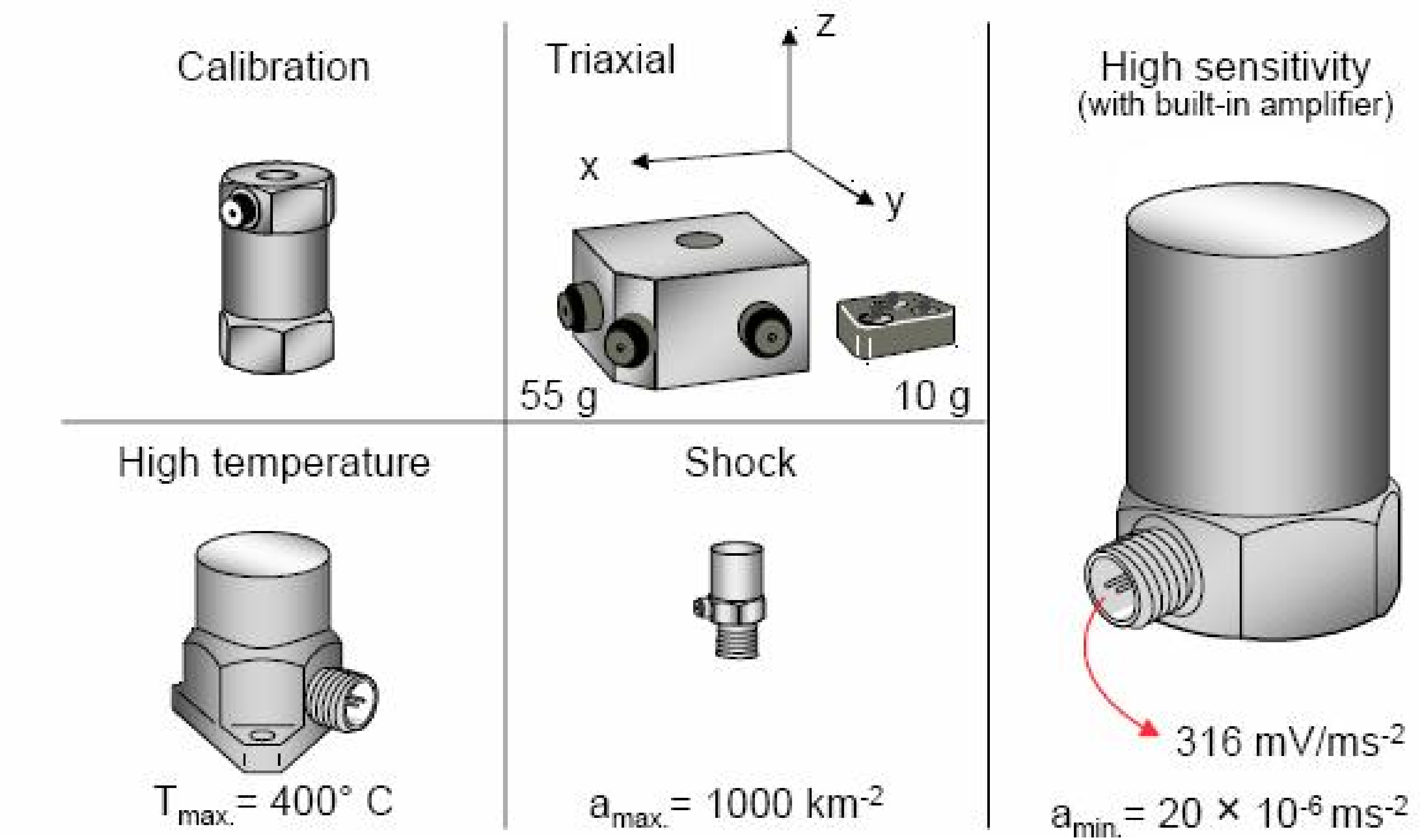
0.5 to 30 ms^{-2}/Tesla and thus normally not causing any problems.

Nuclear Radiation: Most accelerometers can be used under gamma radiation of 100 kRad/h up to accumulated doses of 100 MRad without significant change in characteristics. High temperature (400°C) accelerometers can be used up to 1000 MRad.

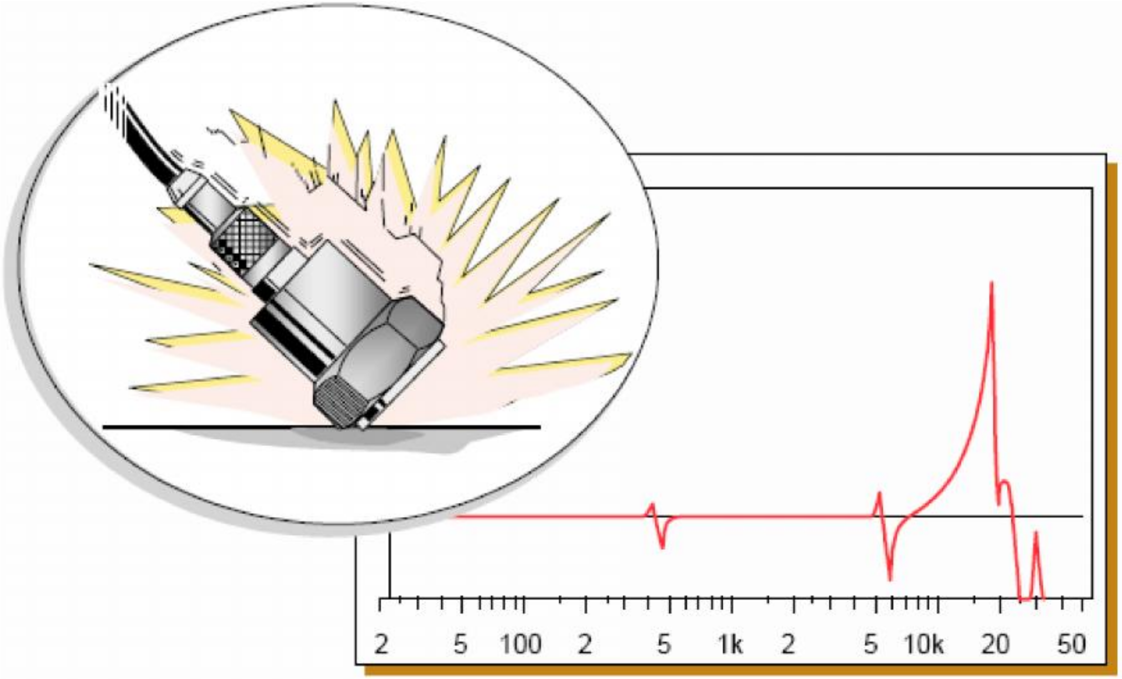
Influence of Temperature Transients: Temperature transients (rapid fluctuations) can cause an electrical output from the accelerometer, but this effect has been considerably reduced in the Delta Shear accelerometer. The charges developed on the piezoelectric material due to temperature transients are mainly developed on surfaces normal to the polarisation of the piezoelectric material and are thus not measured.

A shift in temperature will cause a small reversible change in the sensitivity of the accelerometer. For use at high temperatures it is recommended to use one of the accelerometers designed specifically for use in such conditions. The accelerometer base temperature may be kept down if a heat sink and mica washer are included in the mounting. If forced air cooling is employed check that the cooling system (fan) does not induce significant vibration.

ACCELEROMETER PERFORMANCE IN PRACTICE



ACCELEROMETER PERFORMANCE IN PRACTICE

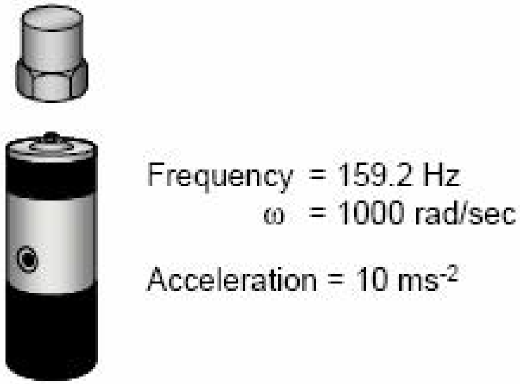


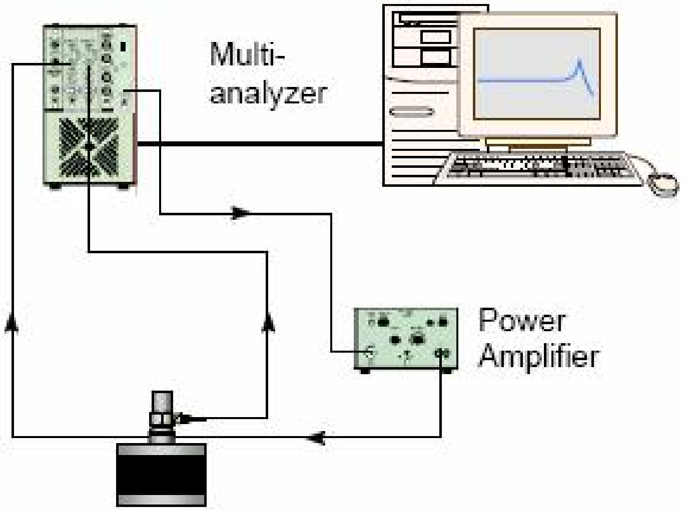
Although most accelerometers are specified to withstand several thousand g's it is quite possible to attain such levels if the accelerometer is handled carelessly. A drop on a hard floor or a hit against a machine part might create shocks of several thousands of g. This could mean change in sensitivity or even severe damage to the accelerometer.

If it is known that the accelerometer has been subjected to such treatment it is advisable to recalibrate the accelerometer, preferably with a check of the frequency response curve.

ACCELEROMETER PERFORMANCE IN PRACTICE

- In the field
  - Sensitivity check
  - Total system check
- In the lab
  - Frequency Response
  - Sensitivity Calibration

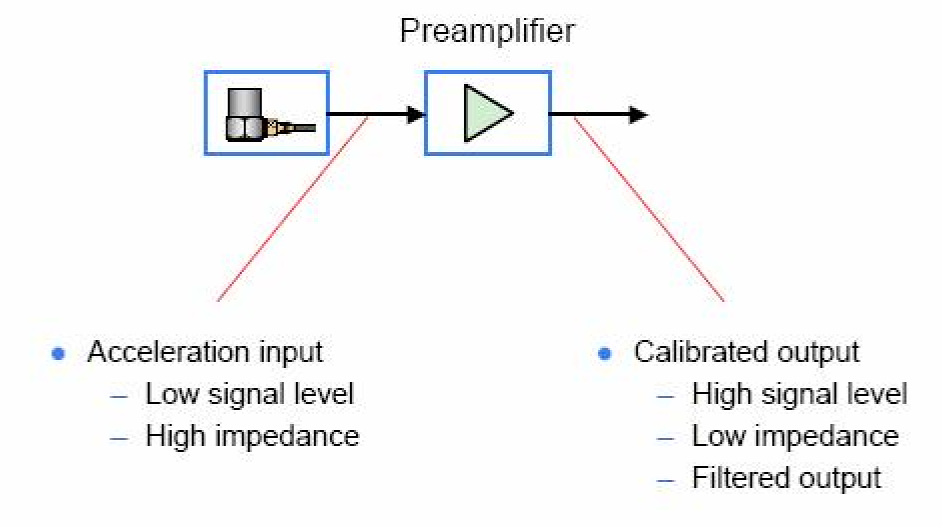




Check of accelerometer sensitivity and system setup

A small portable calibrator providing e.g. 10 ms^{-2} at ω = 1000 rad/sec is ideal for checking accelerometer sensitivity and the whole setup of a measuring chain.

ACCELEROMETER PERFORMANCE IN PRACTICE



Preamplifiers for piezoelectric accelerometers

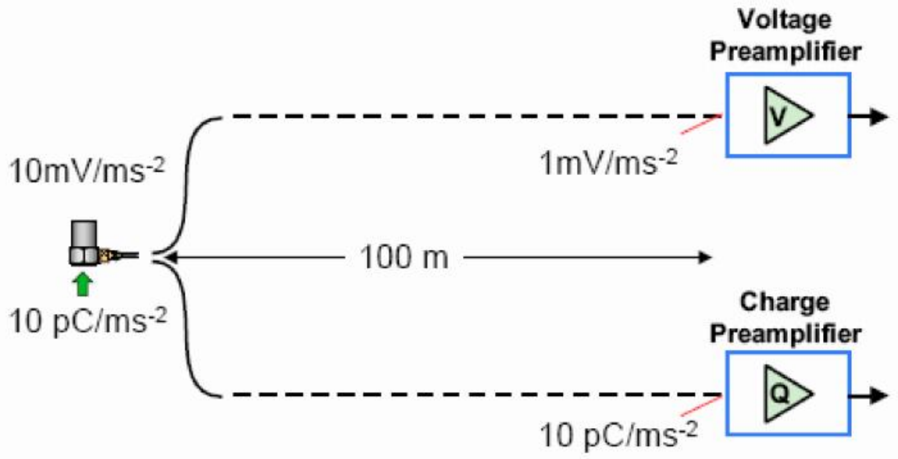
Due to the high impedance and low signal levels at the output of a piezoelectric accelerometer it is nearly always necessary to use preamplifiers before entering into common instrumentation.

The functions performed by the preamplifier are:

- Impedance Conversion
- Amplification
- Matching output signal to measuring instrumentation input sensitivity (Conditioning)
- Filtering
- Integration to obtain velocity or displacement output signals
- Warning of overloads anywhere before the following instrumentation

Normally at least the first two points are found in a preamplifier.

ACCELEROMETER PERFORMANCE IN PRACTICE



In principle both voltage and charge preamplifiers can be used to make the necessary impedance conversion etc.

However, as indicated on the figure, the sensitivity seen by the amplifier varies dramatically with cable length when voltage amplifiers are used. This means that a new calibration (or calculation) has to be made if the cable used is changed. Furthermore the lower limiting frequency can be affected by cable length and resistance.

Therefore the majority of preamplifiers used today are charge amplifiers as they are not affected by cable length or resistance changes within reasonable limits.

For input stages in built-in preamplifiers this is not quite as clear a choice, but for the best performance charge amplifiers are still to prefer.