Introduction to Piezoelectric Accelerometers

The measurement of acceleration, velocity and displacement can be used to measure vibration. Of these methods, piezoelectric accelerometers are the most widely used sensors in the fields of vibration and shock instrumentation.

Types of vibration sensors

- Vibration sensors
  - Contact sensors
    - Acceleration
      - Piezoelectric (several Hz to several tens of kHz)
      - Electrodynamic (DC to 300 Hz)
      - Strain gauge (DC to several kHz)
      - Semiconductor (DC to 1 kHz)
    - Velocity
      - Electrodynamic (several Hz to several kHz)
    - Displacement
      - Strain gauge (DC to several tens of Hz)
  - Non-contact sensors
    - Displacement
      - Eddy current (DC to several tens of Hz)
      - Capacitive (DC to several kHz)
      - Optical (laser interference method)
      - Linear Variable Differential Trans (DC to several kHz)

Features of piezoelectric accelerometers

Piezoelectric accelerometer offer the following features compared with strain gauge, electrodynamic, and other types of sensors.

- High sensitivity, small size
- Wide band: from low- to high-frequency measurement
- Wide measurement range: from very faint vibrations to high accelerations
- High physical strength
- High environmental resistance
- No power supply required (except for models with internal pre-amplifiers)

How piezoelectric accelerometers work

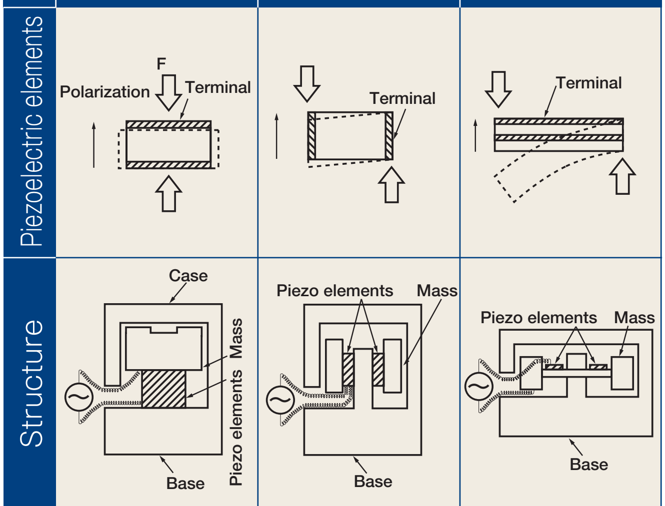
The piezoelectric element is a functional material that generates an electric charge when applied to an inertial force (F). The quantity of the electric charge (Q) is constant depending on the composition. ······①
The basic structure of a piezoelectric accelerometer is as follows. The piezoelectric element is sandwiched between a constant mass (m) and a base.
From Newton's Second Law, the relationship between the acceleration (α) applied to the accelerometers sensor, and the inertial force (F)
applied to the piezoelectric element can be expressed ······②
Therefore, it becomes formula ③, that at this point, since (d) and (m) are constant, the generated electric charge (Q) is linearly proportional to the acceleration (α).

① $Q = d \cdot F$ d : Piezoelectric constant

② $F = m \cdot \alpha$

③ $Q = d \cdot m \cdot \alpha$

■Structures and features



	Compression Designs	Shear Designs	Bending Designs
Features	■Mechanical strength, can measure high vibration, high acceleration ■High resonant frequency, can measure a wide frequency band	■Can measure down to low frequencies because the pyroelectric influence is suppressed ■High relative mechanical strength and high resonant frequency, can measure a wide frequency band	■Can be made very sensitive, so is suitable for the measurement of faint vibrations ■Low resonant frequency and low mechanical strength, therefore used for low frequency bands and low acceleration

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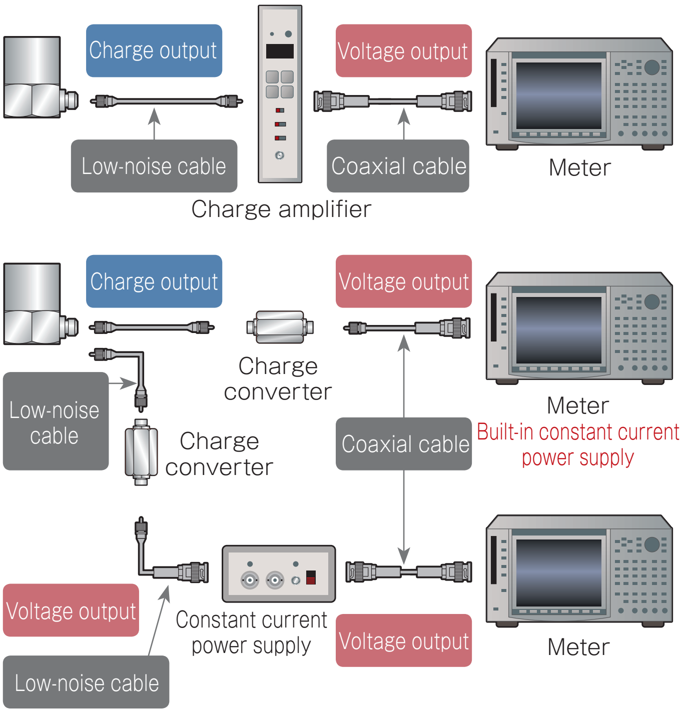
Examples of measuring system

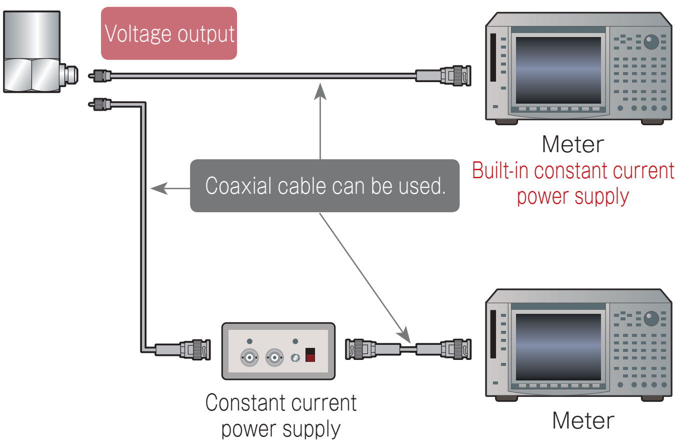
There are two kinds of piezoelectric accelerometers: charge output types and types that have built-in amplifiers (line drive types).
The vibration measuring systems that use these two kinds of accelerometers are shown below.

●Charge output accelerometers (amplifier not built-in)



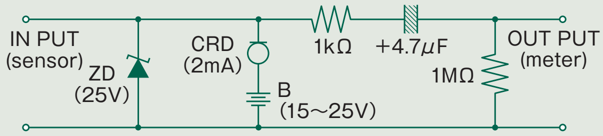
The charge output accelerometer sends out a high impedance charge signal. This requires a charge amplifier to be placed in the circuit before the meter to convert this signal into a low impedance voltage signal.
This kind of charge amplifier is a line drive type, where the power supply and the signal line use the same cable. Some charge amplifiers, like our CA-201 model, are powered by batteries—but most need external power supplies.
Low-noise cables must be used to connect the sensor to the charge amplifier.
It is now possible to use small-sized charge converters, if one uses a meter that has a built-in line-drive constant-current power supply, together with constant current power supply like our CCPS-3.

●Voltage output accelerometers (amplifier built-in)



In sensors that have built-in amplifiers, the pre-amplifier inside the sensor converts the sensor output signal into a low-impedance voltage signal, so a charge amplifier is not required. These sensors are powered by line-drive constant-current power supplies, generally 0.5 to 5 mA constant-current, 15 to 25 V DC power supplies.

Example of the circuit of a line-drive constant-current power supply



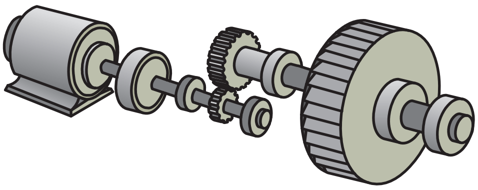
The power supply can be designed by the customer.
※Battery B can be changed into external power
※CRD : Current regulative diode

The application of Accelerometers

There are all kinds of vibrations in the world around us, and there are so many fields in which accelerometers are being used : vehicles such as cars and trains, electrical products like PCs, audio equipment (and the electronic components within them),
manufacturing machinery, factories, the ground and buildings, even in our own bodies!

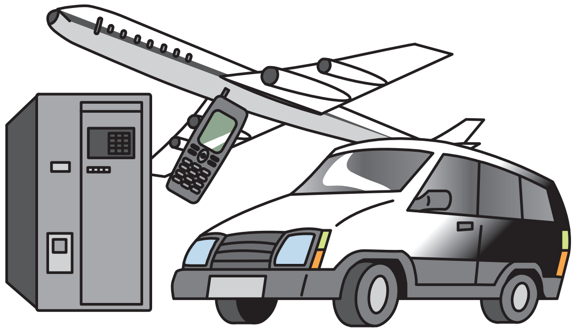
Monitoring of abnormal vibrations in factories, machine diagnosis

The monitoring of the vibration of rotating machinery in steel works, paper mills, petrochemical plants, power stations, cement plants, etc. and the diagnosis of bearing degradation



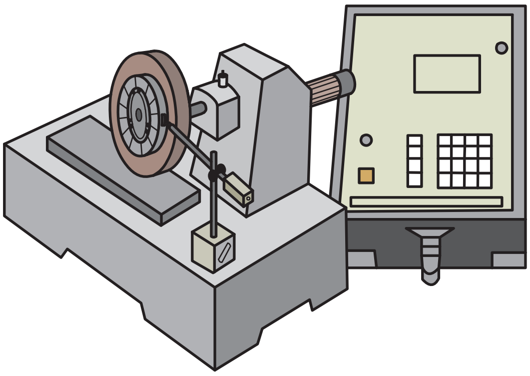
Research into the vibration characteristics of manufactured products, reliability testing, and pre-shipment inspections

From cars, aircraft, ships, rockets and satellites, to motors, HDDs, fans, AV equipment and mobile telephones



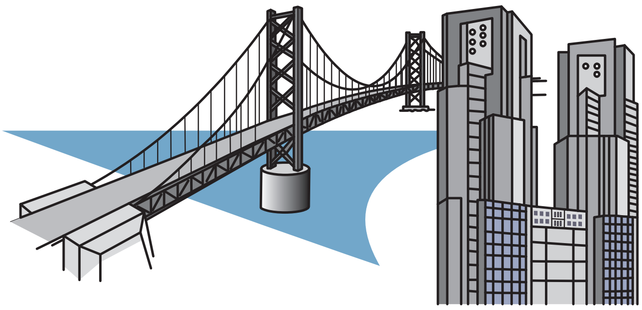
Measurement of unbalanced vibration

Adjustment of the balance of lathes, grinders, silicon wafer cleaners



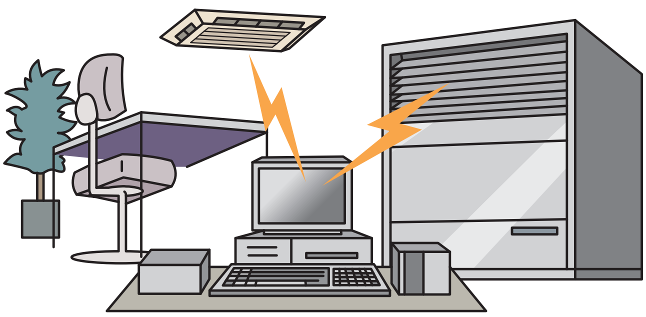
Studies of the earthquake resistance of large structures

Buildings, dams, bridge girders, steel towers



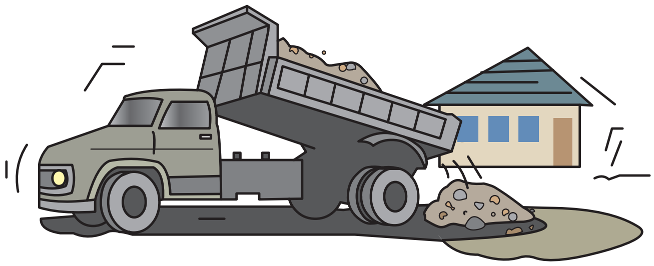
Monitoring of the operation of air conditioners

Clean rooms, intelligent buildings



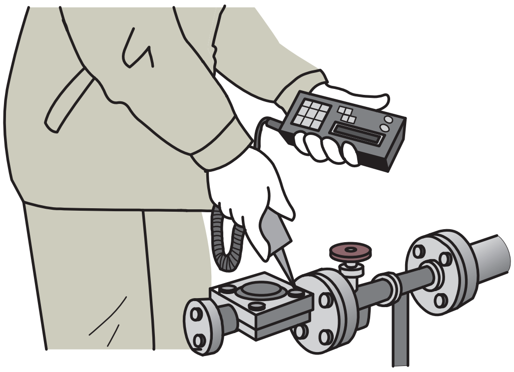
Surveys of vibration pollution

Construction sites, road traffic, factories, the ground



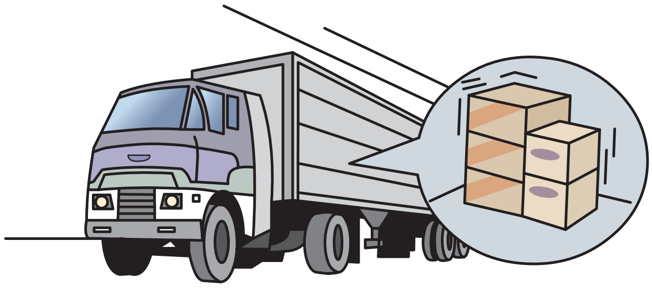
Leak detection of pipe and trap

Factory maintenance, measures to reduce energy consumption



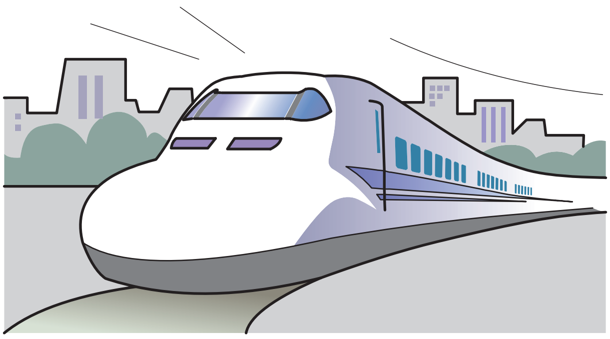
Measurement of vibration and shocks during product transportation

Investigating transportation conditions, rationalization of packaging



Studies of the ride quality of vehicles

Trains, cars, aircraft, farm machinery, construction machinery

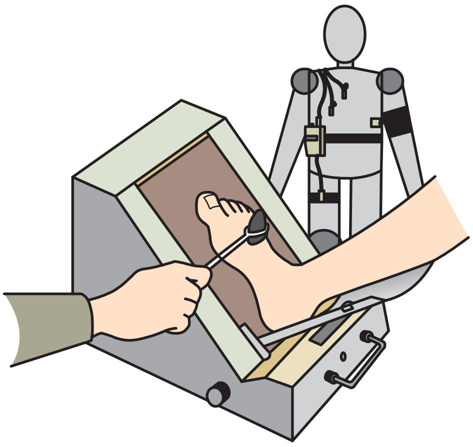


Development of sporting equipment

Vibration mode analysis of skis, racquets, helmets

Medical fields

Diagnosis of osteoporosis, monitoring body motion

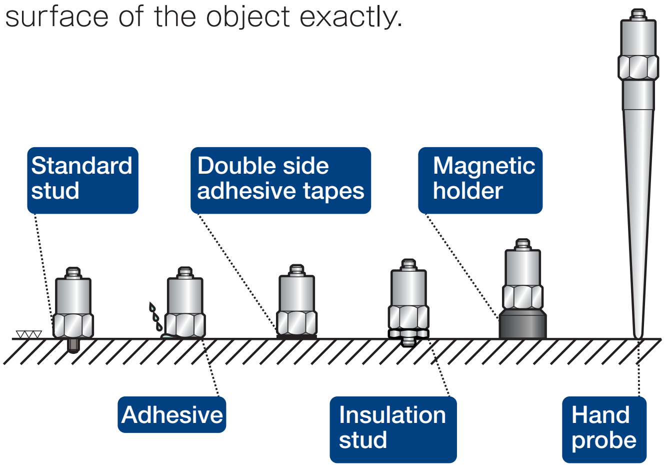


Use in listening devices

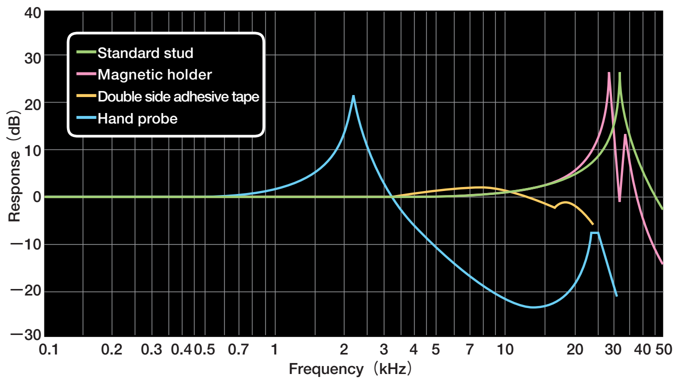
Detection for leaks in water mains, rescues in civil disasters

Installation method / Glossary

Mounting an accelerometer to a vibrating object creates a vibrating system with its own resonant frequency known as the mounted resonant frequency.
The mounted resonant frequency will vary, depending on the method used to mount the accelerometer to the object and the state of contact.
In mounting the accelerometer to the object, the most important thing is to stik the sensor base to the surface of the object exactly.



Typical frequency characteristics



Standard stud mount

The ideal mounting method is to apply silicone grease to the finished surface, and tighten the screw to the specified torque to maximize the performance of the accelerometer. If silicone grease is not used, or if the finish of the surface where the measurement is taken is rough, then the mounted resonant frequency will decrease.

Adhesive mount

If adhesion conditions are good when the sensor is mounted, then a performance similar to that of standard stud mount can be achieved.

Double side adhesive tape mount

This is a suitable method to temporarily mount the sensor when the vibration frequency and amplitude are low. If the adhesion conditions are good, measurements of vibrations around 10 kHz are possible.

Insulation stud mount

Non-insulated accelerometers may be affected by the ground loop noise. Since the insulation stud electrically insulates the accelerometer from the surface being measured, the affects of the noise can be reduced. If the attachment condition is good, characteristics close to those achieved in standard stud mount may be obtained.

Magnetic holder mount

A magnetic holder may be used if the object being measured is made of a metal that magnets will stick onto. This form of mount should only be used as a temporary means for preliminary measurements; nevertheless, if the surface conditions of the object are good, a performance can be achieved that is very close to that obtained by coating the surface with silicone grease and mounting a sensor by a standard stud.

Hand probe mount

This approach is used when there is no space to mount a stud or if the accelerometer cannot be mounted. If a 100 mm stainless steel probe is used, the measurable range of frequencies is 1 kHz or less. This method is quite practical for vibration measurement in the lower frequencies.

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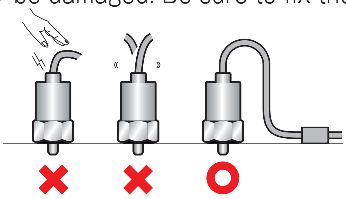
Standard tightening torque

If excessive torque is applied when mounting the sensor, gluing shearing may occur inside the sensor. Be sure to apply the correct torque.

Mounting thread	M3	M4	M5	10-32	M6	M8
Standard tightening torque (Nm)	0.6	1.6	3.0	3.0	5.0	12.0

Signal cable

If excessive force is applied to the connector and the point where the signal cable exits the sensor, or if the signal cable is allowed to wiggle or vibrate excessively then performance will be impaired. In extreme cases, the cable may break or the connector may be damaged. Be sure to fix the cable to the object being measured and make sure that excessive force is not applied to the cable when in use.



■Charge sensitivity (pC/m/s²)

When a force is applied to the piezoelectric element, a electric charge accumulates. The value that expresses the quantity of the charge is called the charge sensitivity. Since the charge sensitivity is unaffected by the capacitance load, sensitivity does not vary with changes in the length of the cable. When charge sensitivity is used to measure vibration, a charge amplifier is used. The charge amplifier converts charge into voltage.

■Voltage sensitivity (mV/m/s²)

The voltage sensitivity generally indicates the sensitivity of accelerometers that have built-in amplifiers. In these types of sensor, there in an amplifier inside the sensor, so the sensor outputs a voltage signal instead of a charge signal. On the other hand, when an accelerometer that does not have a built-in amplifier is used together with a voltage amplifier, the vibration is measured by the voltage output, then this output is also called the "voltage sensitivity." However, this later method is affected by the cable capacitance shown in the following formula. As the cable length increases, the sensitivity decreases, making this approach impractical.

$V = Q/(Cd + Cc)$

V: voltage sensitivity, Q: charge sensitivity,
Cd: sensor capacitance, Cc: cable capacitance

■Mounted resonant frequency

Resonant phenomena occur at the boundaries of components. In the case of piezoelectric accelerometers, resonance occurs chiefly at ① the detector element and ② the sensor mountings (Mounted resonant frequency). In other words, to measure vibration properly, you need to consider the frequency being measured and the "frequency range" of the sensor. The mounted resonant frequency in ② above differs according to the state of contact between the sensor and the surface being measured, and the method of attachment. The relationship between the mounted resonant frequency (fo) and the voltage sensitivity (Sv), the larger the voltage sensitivity, the lower the mounted resonant frequency; however, since this is influenced by both the structual designs of the sensor and the shape.

■Frequency response

The frequency response expresses the range of frequencies of vibrations that the accelerometer is capable of measuring. Our accelerometers are delivered together with a chart showing the frequency characteristics in the range of 100 Hz to 60 kHz. Please note that the guaranteed range is 100 Hz to 15 kHz, due to the characteristics of the calibrating equipment.
Frequencies of 15 kHz or higher are used as reference data in checks for mounted resonant frequencies or the diagnosis of other anomalies.
Lower cut-off frequency (fc) is determind by capacitance and amp's input impedance.

Glossary / Selection Guide

■Maximum acceleration (measurement range)

The dynamic range of piezoelectric accelerometers is extremely wide, and posses linearity up until the maximum acceleration that they can be used to measure. The lower limit will down to theoretical noise level.
However, before the sensor output falls down, the limit is reached due to the noise level of the measuring system and external noise. When measuring low-level vibrations, it is important to maintain a high S/N ratio across the entire measuring system.
For accelerometers that have built-in amplifiers, the maximum acceleration that they can be used to measure depends on the maximum output voltage of their internal amplifier, but be wary of saturation. For example, even if the vibration is within the maximum measurable range, the vibration which contains the resonance frequency component may lead to saturation.

■Shock limit

Limit value against physical shocks.

■Transverse sensitivity (Cross-talk)

Piezoelectric accelerometers generally have one axis that is the most sensitive to acceleration; this is known as the main axis of sensitivity; however, sensor has sensitivity on the other axis with a slight error during manufacture. It called cross-talk. Generally, cross-talk is expressed as a percentage of the maximum horizontal axial sensitivity with respect to the main axis of sensitivity.

■Insulation resistance

Generally, ① in accelerometers (those without internal amplifiers) there is insulation resistance between the output terminals. ② In insulated accelerometers, there is insulation resistance between the case and signal ground. Insulation resistance between the output terminals is lowered by humidity, and can influence the behavior and characteristics of the charge amplifier. When the insulation resistance that occurs between the case and signal ground of insulated accelerometers is low, the sensor is more easily affected by ground loop noise.

■Sensitivity change with temperature

Generally, as the temperature increases, the charge sensitivity and the capacitance of piezoelectric accelerometers increase, and the voltage sensitivity decreases. The percentage change differs, depending on the material used in the piezoelectric ceramics, and the composition of the other components.

■Pyroelectric sensitivity (Transient temperature effects)

Since piezoelectric ceramics have the same composition as the elements used in pyroelectric sensors (perovskite crystal), they produce an electric charge in response to changes in temperature; therefore care should be taken when using piezoelectric accelerometers to measure several Hz or less.

■Base strain sensitivity

If an accelerometer's base is subjected to external stress, or if there are bending mode strains in the surface that the sensor is attached to, then the piezoelectric element mounting may be deformed, creating noise in the form of an electric charge.

■Ground loop noise

Noise from the ground loop may occur if ther are two or more earths in the measuring system. This is caused by the slight potential differences between the earths, which means that there is an earth current circulating inside the measuring system. To eliminate this noise source, the system must have only one earth. This can be achieved either by using insulated accelerometers or using insulated studs.

■About weight of accelerometer

To prerent the vibration mode change of the measurement object, need to select accelerometer weight less than 1/10 of the measurement object.

Selection Guide

Recommendation products, unless BA24CM, SAF11, SAF51A and STAF223.

●Charge output accelerometers

S04SG2
0.035pC/m/s²

S2SG
0.16pC/m/s²

S3SC
0.3pC/m/s²

S2SCB2
0.2pC/m/s²

S41SCB2
3.67pC/m/s²

BW21SG2
1.84pC/m/s²

S31SC
3pC/m/s²

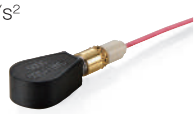
P51C
5pC/m/s²

S42SC
35pC/m/s²

P51SCH2
5pC/m/s²

●Voltage output accelerometers (built-in pre-amplifier)

SAR11SCG
1mV/m/s²



SA11C
1mV/m/s²

SA11SC
1mV/m/s²

SA51SC
5mV/m/s²

SA12SC
10mV/m/s²

BA24CM
1500mV/m/s²

SAR12SCLM
10mV/m/s²

Selection Guide

Recommendation products, unless BA24CM, SAF11, SAF51A and STAF223.

●Industrial accelerometers for machine monitoring (Water proof and insulated)

SAF11
1mV/m/s²

SAF51A
5mV/m/s²

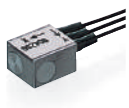
PAF51SU
5mV/m/s²

SAF12C
10mV/m/s²

STAF223
20mV/m/s²

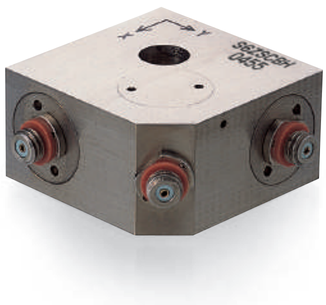
●Triaxial accelerometers

S04ZSG
0.04pC/m/s²



S2ZSCG
0.16pC/m/s²

S6ZSCBH
0.6pC/m/s²



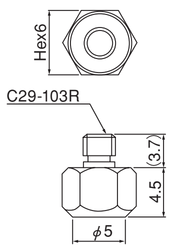
SA11ZSCA
1mV/m/s²
SA12ZSCA
10mV/m/s²
3511A2・3512A2
TEDS

SA11ZSC-TI
1mV/m/s²
SA12ZSC-TI
10mV/m/s²
3511A1・3512A1
TEDS

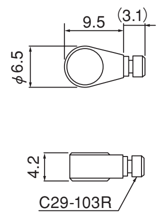
Digest

■Charge output accelerometers

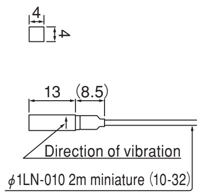
S06CG



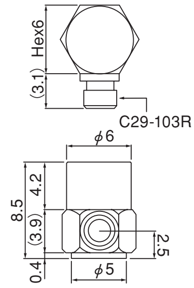
S2SCG



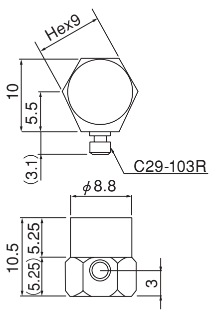
B21SG



S1SCG

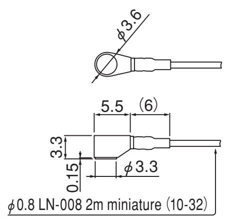


P3SCM

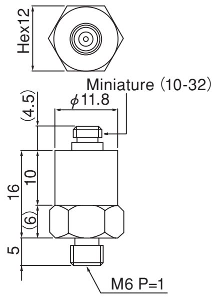


Mtg thread
Female (M3・P0.5・D1.6)

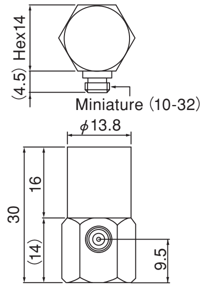
SW05SG



S21C

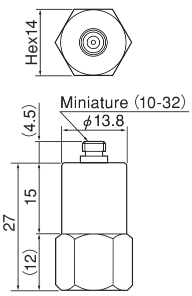


P51SC



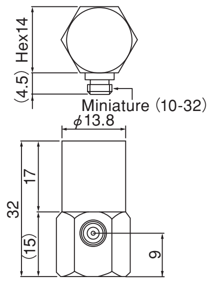
Mtg thread
Female (M6・P1・D5)

S12C



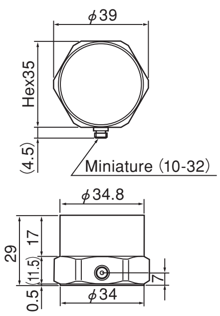
Mtg thread
Female (M6・P1・D5)

P12SC



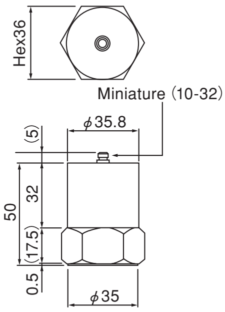
Mtg thread
Female (M6・P1・D5)

S13SC



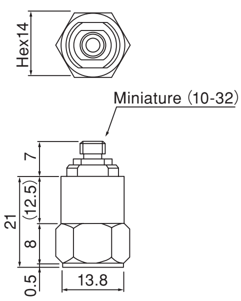
Mtg thread
Female (M6・P1・D5)

B24CM



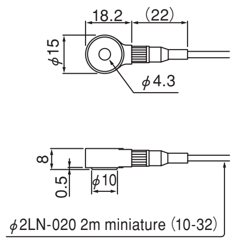
Mtg thread
Female (M6・P1・D5)

P11CH

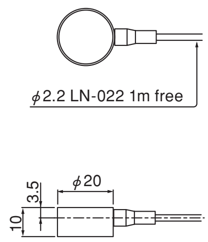


Mtg thread
Female (M6・P1・D5)

SW11SB



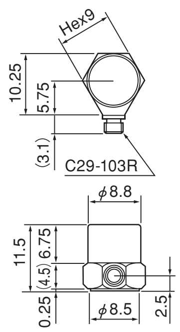
B51SGM



Digest

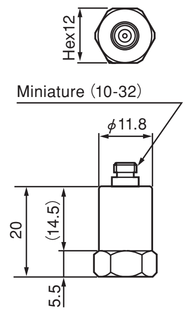
■Voltage output accelerometers (built-in pre-amplifier)

SA11SC



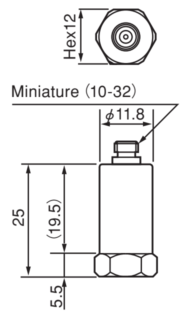
Mtg thread
Female (M3・P0.5・D2)

PA11C



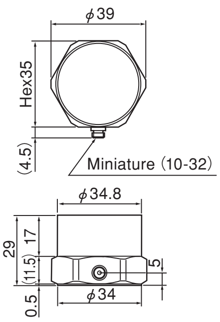
Mtg thread
Female (M6・P1・D5)

PA51C



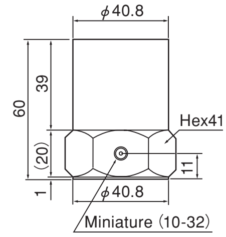
Mtg thread
Female (M6・P1・D5)

SA13SC



Mtg thread
Female (M6・P1・D5)

SA53SCM

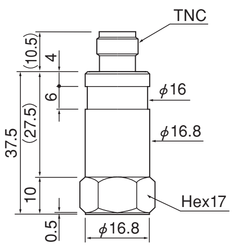


Mtg thread
Female (M8・P1.25・D8)

■Industrial accelerometers for machine monitoring (Water proof and insulated)

PAF51C

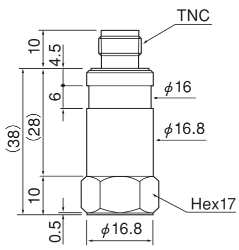
Voltage output type



Mtg thread
Female (M6・P1・D5)

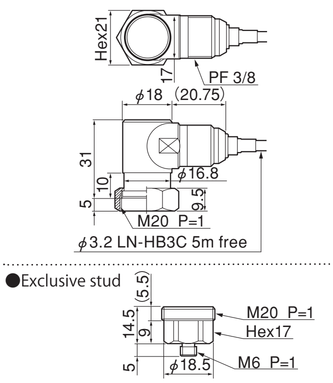
PF51C

Charge output type

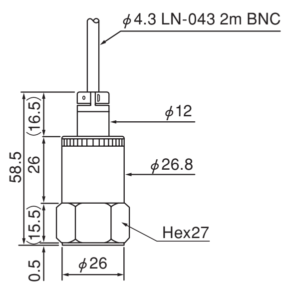


Mtg thread
Female (M6・P1・D5)

SF51SU



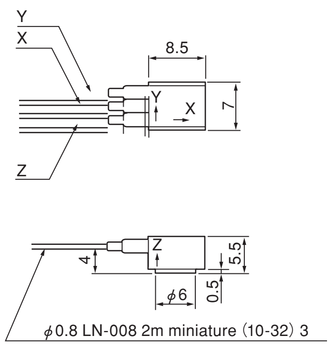
SF42M



Mtg thread
Female (M6・P1・D5)

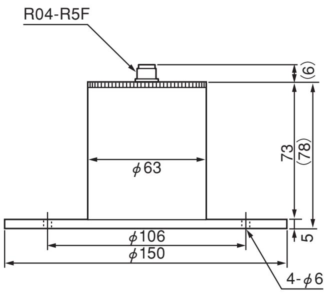
■Triaxial accelerometers

SW04ZSG



BA24ZCFM

Voltage output type



ES France - Département Composants & Modules - 127 rue de Buzenval BP 26 - 92380 Garches
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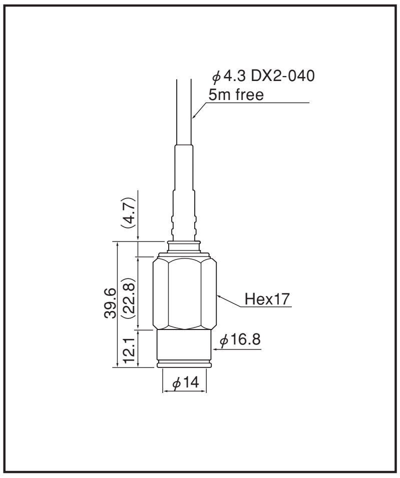
Special sensors

While developing new models of products with special characteristics, we are ready to receive any orders for models that meet your specific requirements.

●Dual output sensors

●Vibration & Temperature sensor

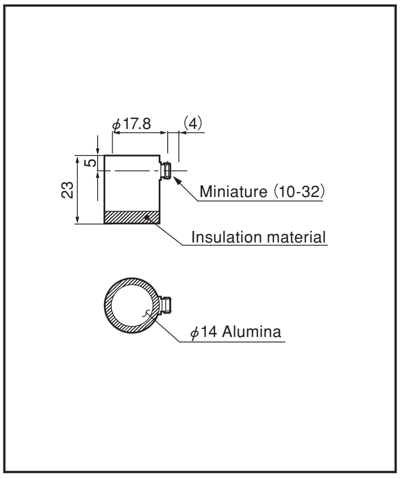
TSAF51A



5mV/m/s², ~8kHz
Built-in temperature sensor
Built-in amplifier, case insulated, water-proof

●Complex sensor for Vibration and Acoustic emission

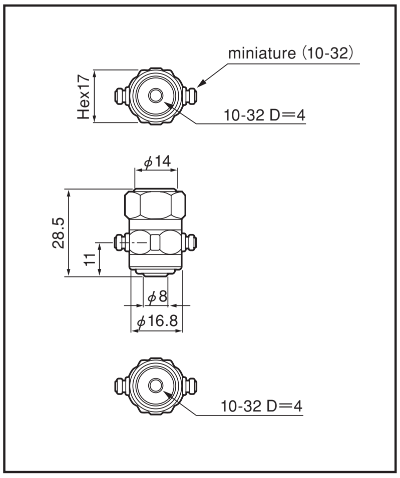
HS-10A-10M2



(Vib) 2mV/m/s², ~20kHz
(AE) 63dB, 200~600kHz
Built-in amplifier

●Impedance head (Vibration & Force sensor)

PFT215S

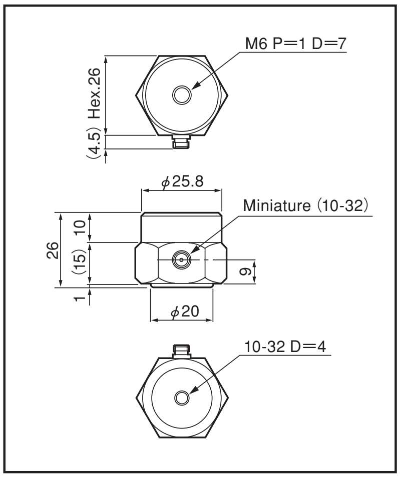


(Vib) 2pC/m/s²
(Force) 270pC/N

●Specific use sensors

●Reference accelerometer for calibration

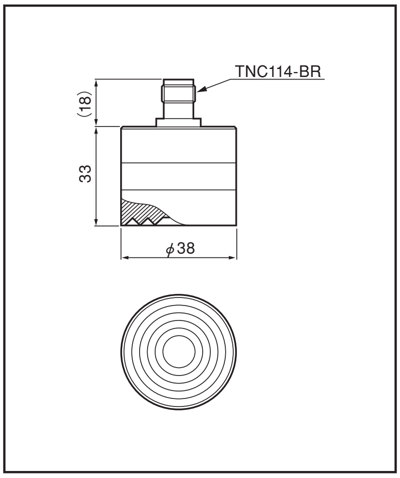
REF-A3S-M6



Back to back type
0.4mV/m/s², ~20kHz

●Water leak detector

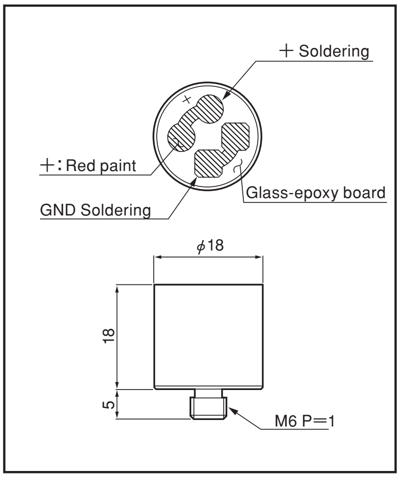
ABS-7000



Listening to leaks from water supply pipe
750mV/m/s², 1kHz

●Sensor device

B52XM



Detective component
50pC/m/s², ~800Hz