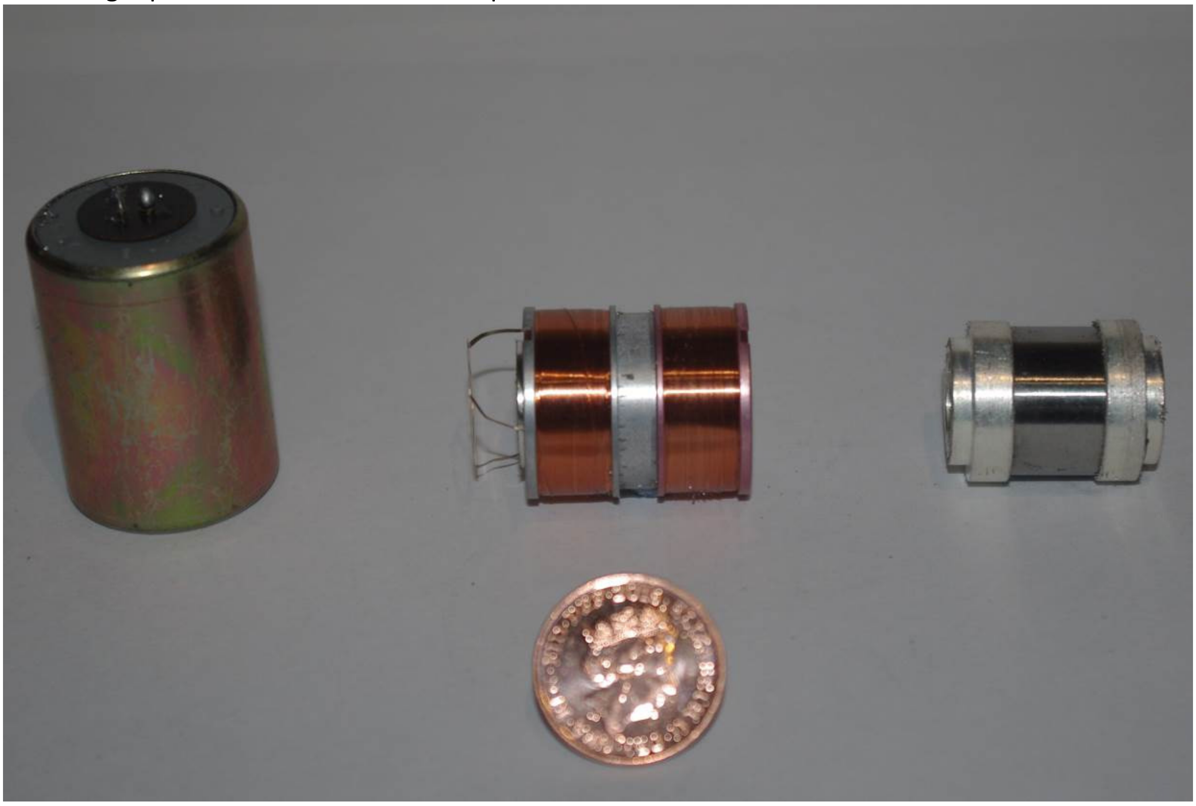
A guide for users of seismographs equipped with tri-axial geophones

When undertaking civil engineering works that create vibration, for example: piling, compaction, breaking and demolition, it is good practice and may be necessary to show compliance with conditions by monitoring ground-borne vibration. This is achieved using a seismograph in order to prevent damage to structures or nuisance to people.

The metric used when measuring ground vibration is Peak Particle Velocity (PPV) in mm/s^2, the velocity of molecular particles within the ground. Not the ground surface movement; that is the Amplitude and it is measured in mm.

Whilst seismographs measure in three axes, the British Standard's limits refer to the maximum plane reading, i.e. the reading from whichever axis is largest.

Because it is necessary to monitor velocity, Seismographs are equipped with velocity transducers, known as geophones, to enable accurate measurements of Peak Particle Velocity. It is useful to look at the construction of a geophone in order to fully understand how it works. The photograph below shows a geophone that has been taken apart.



From left to right: geophone housing, coil with one spring visible, magnet.

The permanent magnet is held in the centre of the coil by a fine spring at each end. When vibration arrives at the securely mounted geophone, the magnet remains still and the coil moves about the magnet creating an alternating voltage within the coil. The voltage, in the order of millivolts, is proportional to the movement. Geophones are highly sensitive. The magnet has typically just 4mms of movement back and forth within the coil. If the magnet were to hit the end stops during a measurement, full scale would be exceeded and the seismograph would over-range.

Seismographs use a three component (tri-axial) set up (three geophones), orthogonally arranged as shown in the picture below.

The geophones are referred to as follows: Vertical, Transverse and Radial (sometimes also known as Longitudinal). There is often an arrow on the tri-axial geophone sensor's casing to show the alignment of the Radial geophone. The convention, when placing the sensor, is to align the Rradial geophone towards the vibration source.

Whilst the geophones look the same, the vertical geophone is manufactured so that the spring holding the magnet upright, is strong enough to centre the magnet within the coil. A vertical geophone is incompatible with a horizontal geophone (and vice-versa) and must be used in an upright (vertical) position. It cannot be used upside down, nor can horizontal geophones be used vertically. Geophones may be damaged if they are dropped. They may also be damaged if submerged in water depending upon the IP rating of the case.

The mass density of tri-axial geophones and their casing, is manufactured to be as close as possible to the mass density of typical soils, at about 1925 kg/m^3.

The working temperature range of typical geophones is -40° to +100°C, but the electromechanical validity for meeting specifications is 20°C.

A tri-axial geophone sensor is pictured below.

Note that there are no levelling legs because modern geophones will work accurately with between 0° & 10° degrees of tilt.

Using a seismograph to measure ground-borne vibration.

In order to achieve accurate measurements, it is helpful to understand how geophones work and how and where to place them.

Correct installation of the tri-axial geophone sensor is absolutely crucial to ensure accurate measurements. There are some do's and don'ts and the following points will highlight the means to achieve the most accurate results.

The British Standards suggest that when monitoring ground-borne vibration at a building, the sensors should be placed outside at foundation level or ground level and if possible on the building itself. A bracket may be used to attach the sensor unit if it is practical to do so. Otherwise, placing the geophone sensor unit on a solid and firm base is good practice. It may be held in place by putting a loosely filled sandbag over it so that the sandbag is in contact with the ground all the way around the sensor unit. Most tri-axial geophone packs are able to be fitted with a ground spike(s) for use in compacted earth. Burial of the sensor unit is a recommended way of 'coupling' the sensor to the ground. Burial is considered by many to be the best possible means of 'coupling' geophone sensors to the ground.

If readings are below a Peak Particle Velocity of 10 mm/s^2, merely levelling and placing the tri-axial geophone transducer on a firm and flat surface will be a sufficient way of 'coupling' the sensor unit.

Never place a brick or other heavy object on the top pf the sensor unit as that will raise the centre of gravity of the unit and is likely to magnify vibration.

Never place the seismograph on a paving stone as it is likely to vibrate more than the ground thereby amplifying the vibration.

In the UK there are several British Standards that provide guidance on making such measurements and these include:

BS:7385-2:1993 Evaluation & Measurement for Vibration in Buildings
Part 1 – Guide for Measurement of Vibrations & Their Effects on Buildings
Part 2 – Guide to Damage Levels from Ground-borne Vibration.

BS:5228-2:2009+A1:2014 Code of Practice for Noise & Vibration Control on Construction and Open Sites – Part 2: Vibration.

BS:6472-1:2008 Evaluation of Human Exposure to Vibration in Buildings.

Note: BS:7385 and BS:5228 are concerned with levels of vibration that may cause damage, whereas BS:6472 is a guide for nuisance levels. The latest revision of BS:5228, BS:5228-2:2009+A1:2014 now contains an addendum, Table 9.4: Guidance on Effects of Vibration Levels.

When measuring vibration at or near services or structures, for example: railway embankments, rail tracks, gas pipes, water mains and underground electricity cables, levels of vibration which must not be exceeded may be given by the owners or operators of the service or structure, such as the utility company or rail operator. Their levels may be higher or lower than levels in the British Standards.

High values of PPV are far more likely to give rise to damage when their peak frequencies are low.
Continuous vibration such as that from a vibratory piling rig may also cause ground settlement.
It is practically impossible to limit the low frequencies during vibration causing activities, so when setting limits using the guidance in British Standards it is advisable to assume the worst case lowest frequency that may occur. Seismographs of the type used in civil engineering and blasting generally have a range of Peak Particle Velocity from $0.03mm/s^2$ to around $150mm/s^2$ and a frequency range of 1Hz or 2HZ up to around 100Hz. The British Standards cover the frequency range of 4Hz to 100Hz with frequencies below 50Hz being contentious.

By Andy Maslin of Accudata Limited
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