Feeling a bit peaky

How can we calculate peak particle velocity to ensure that data from different consultants or instruments is comparable?

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Above: Vibration meter measuring construction vibration

The measurement of vibration is something that many consultants feel less confident with than carrying out noise measurements. There are many Standards that address the issue of how to measure and assess vibration and there is now a Standard that specifies the requirements for instrumentation to measure vibration (BS 8041-1:2017 Human response to vibration. Measuring instrumentation. General purpose vibration meters). Everyone doing this type of work should have the confidence that there is sufficient guidance to ensure measurements are accurate and repeatable. However, one aspect of vibration measurement that causes some discussion, particularly in the UK, is the use of the peak particle velocity (PPV) descriptor for the quantification and assessment of vibration.

The primary use of PPV originated from BS 7385-2:1993 Evaluation and measurement for vibration in buildings, a guide to damage levels from ground-borne vibration, which is concerned with the potential for damage to buildings and structures. The use of the metric has been expanded to cover the assessment of human response to construction works and is now the primary indicator used when examining the effects of mechanised construction works on both buildings and their occupants.

How do you calculate a PPV?

With such widespread adoption in the industry, it would be reasonable to expect the PPV to be well-defined. However, there is no formal definition of how instrumentation should calculate the PPV from the incoming transducer signals. If you require a peak sound level, the instrumentation Standard defines the acceptable limits on how the meter calculates this, but there is no equivalence for PPV in BS 8041-1.

So, the big question arises; how do you calculate a PPV? To answer this, you first need to understand what it is you are trying to quantify. If you look back at the literature that forms some of the earliest work looking at vibration effects on buildings; documents such as TRL report 429 (ground-borne vibration caused by mechanised construction works, 2000) collated much of the early work in this area.

Previous studies had used PPV defined in four different ways, namely:

- the peak value in the vertical direction;
- the largest of the three mutually perpendicular components;
- the true resultant, which is the maximum value of the vector summation of the three components; and
- the square root of the sum of the squares of the three components, which is the vector summation of the maximum of each component regardless of the times at which they occurred.

Which of these is the correct method? The reality is you could find people to argue in favour of all four, which is where the problem lies. If people are doing this differently, how can we be sure that data from different consultants or instruments are comparable?

Frequency bandwidth

One aspect that can be defined relatively easily is regarding the criteria used for building damage. Within BS 7385-2, Table 1 gives the guide values for cosmetic building damage and is clear that the guide values are for peak component particle velocity. This means that it refers to the largest of the three perpendicular axes and BS 7385-2 is clear that when assessing building damage, vibration should normally be measured using three orthogonally oriented transducers. But does the same hold for when measuring PPV for human exposure?

Human response to vibration is covered by BS 6472-1:2008 (Guide to evaluation of human exposure to vibration in buildings. Vibration sources other than blasting) and this requires the use of the vibration dose value (VDV) for assessing potential for annoyance from whole body vibration. The use of PPV for assessing human response is required by Standards such as BS 5228-2:2009+A1:2014 (Code of practice for noise and vibration control on construction and open sites. Vibration), which acknowledges BS 6472-1, but states that in construction environments using PPV is more appropriate due to often needing to carry out building damage measurements at the same time.

One aspect of the calculation of the VDV is that it is based on a frequency weighted acceleration level, with different weightings for vertical and horizontal axes. The two weightings have their most sensitive regions at different frequencies, which could mean that a vibration of a certain magnitude would be perceived differently if it was experienced in the vertical or horizontal direction, but would be assigned the same PPV under the assessment method required by BS 5228-2. However, in practice, most vibration sources are usually broadband to a certain extent, so the effect on real world perception would be minor. But this leads to something that should be given serious consideration, namely what frequency bandwidth should the PPV be assessed over?

Building damage assessments

If vibration measurements are to be used for the assessment of building damage, the appropriate British Standards of BS ISO 4866 and BS 7385-2 can be used for some guidance. BS ISO 4866:2010 (Mechanical vibration and shock. Vibration of fixed structures. Guidelines for the measurement of vibrations and evaluation of their effects on structures) states that most structural damage occurs in the range of 1to 150 Hz and BS 7385-2 covers a frequency range from 4 to 250Hz. Therefore, based on this, it is clear that when measuring the PPV, the instrumentation should cover the range of 1Hz to 250 Hz as a minimum. When measuring whole body vibration, BS 6472-1covers the range of 0.5 to 80 Hz and the applied weighting filters roll-off above 80 Hz and will attenuate any vibration that occurs above this frequency. This attenuation of the higher frequencies would not occur if measuring the PPV, so it may be beneficial to obtain frequency response data to ensure that measured PPV can be correlated with perceptions on site.

Transducers

This leads on to a further aspect of PPV that should be considered. It is common for many sound level meters to be sold with the ability to also measure vibration by attaching an accelerometer as the input transducer. A sound level meter, by requirement of their instrumentation Standard, can measure over the audio range of 20 Hz to 20 kHz, but many can also measure below 20 Hz.

However, of greater concern is what happens to the frequencies above the 250 Hz upper frequency required for building damage. The same is also true for general purpose data acquisition units which are designed to measure sound and vibration using the same acquisition hardware. Many general purpose accelerometers, particularly if attached to a lightweight mounting plate, can pick up airborne sound above the 250 Hz upper frequency limit, which may give a higher signal level than the vibration being measured in the structure. This can lead to an inaccurate PPV being reported by the instrument due to noise which is not part of the vibration signal. If this is the case, the input signal should be filtered to ensure that only vibration in the frequency range of concern is measured.

Another consideration that should be factored into the choice of instrumentation is the transducer to be used. When measuring PPV, it would make most sense to use a velocity transducer. However, the most common velocity transducer is the geophone, which has its resonance at the low frequency end of its frequency response. This means that the low frequency cut-off frequency is a physical characteristic of the transducer and if measurements are required to as low as 1Hz, care would need to be taken in the choice of an adequate transducer. It should also be noted that the resonance effects of the transducer at low frequencies will affect the phase of the signal, which may have implications for the calculation of the peak value.

More common is the use of accelerometers, which being mass controlled transducers, do not often have the same low frequency considerations as geophones. Because accelerometers output signals that are dependent on acceleration, the signal cannot be used directly for measuring the PPV. To enable this, some form of numerical integration is required. Many modern instruments can carry out this integration in real time, but it should be noted that many forms of numerical integration can introduce large low frequency components as a result of the integration process. The user should be aware of this and ensure that any spurious low frequency components are filtered out, if necessary, to ensure the true PPV has not been corrupted by the necessary signal processing of the acceleration data.

Calculations

The remaining aspect of PPV which remains undefined is the time base for which the peak should be calculated over. Using a modern data acquisition unit recording raw data (or a wave recording function of an SLM), it is possible to calculate the instantaneous peak based on the highest number that comes out of the analogue to digital convertor, which is how many modern SLMs calculate the peak response. However, it is worth remembering that the limits for building damage are based on empirical data from many years ago which were used to define the thresholds. It is possible that these data are not from high sample rate instantaneous peak data and without a definition of what time considerations should be used to define the peak, it is not possible to definitively say whether data are comparable.

Many readers will probably now be wondering if this article will give definitive answers to these questions and define the correct approach to take. But that is the heart of the issue. There is no definition of what a PPV is and how it should be calculated within an instrument and what the acceptable tolerances are. It could be that if you were to take meters from different manufacturers and measure the same vibration you could get different answers. And without a definition, it is impossible to say who is correct. ◎