Measuring vibration using sound level meter Nor140

This technical note describes the use of the sound level meter Nor140 for measurement of acceleration levels. The normal microphone is then substituted by an accelerometer. The note also describes calibration and the relation between the level in decibel and the acceleration in linear units.

Introduction

Most sound level meters and sound analysers can be used for vibration measurements, even if they do not provide absolute (linear) units in the display. To simplify the description, this application note describes the use of the handheld sound level meter Norsonic Nor140. However, the described principles also apply to other types of sound level meters.

Although several transducer principles are commercially available, this application note will deal with the accelerometer only, simply because it is the transducer type most commonly encountered when measuring vibration levels. As the name suggests, the accelerometer measures the acceleration it is exposed to and provides an output signal proportional to the instant acceleration.

The accelerometer normally consists of a seismic mass mechanically connected to the accelerometer base through a piezoelectric material. Piezoelectric materials have the property of producing electrical charge when bent and twisted (even shear forces will work here). Basically, a charge is generated. Dependent of the type of transducer, this charge may be the output signal or the transducer includes an amplifier delivering an output signal with low impedance. A popular type of transducers is the ICP® or CCP type. These are powered by a constant current through the signal cable and deliver an output voltage which is the sum of a constant voltage and an AC-voltage proportional to the acceleration.
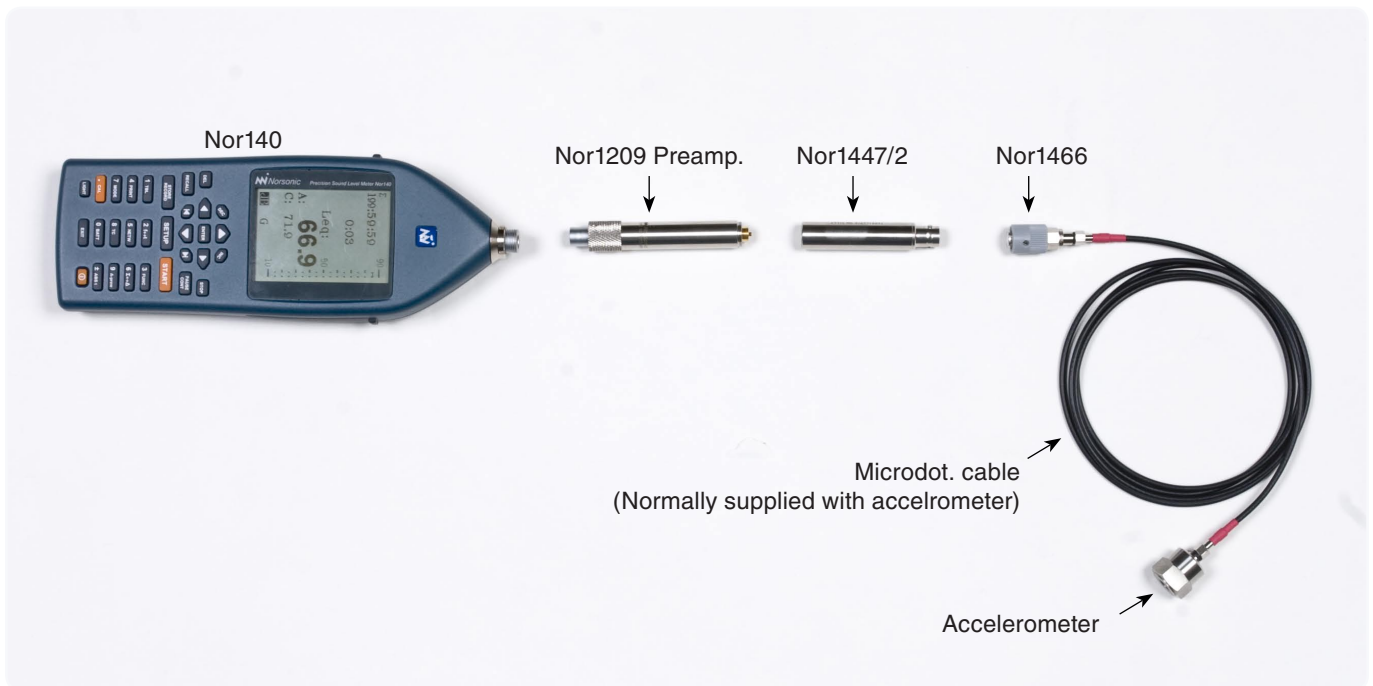
Accelerometer

Many types of acceleration sensitive sensors exist. For connection to Nor140 sound level meter the easiest is to apply an ICP® or CCP type. This type of transducers has low output impedance and may be supplied through a coaxial able. Nor1270 (Sens. 10 mV/ms^{-2}; 23 g) and Nor1271 (Sens. 1,0 mV/ms^{-2}; 3,5 g) are recommended. Connect the accelerometer through the BNC/Lemo cable Nor1438 and the BNC to microdot adaptor Nor1466. You also need a BNC-BNC female connector. See the figure below.

Alternatively, a charge sensitive accelerometer may be used and coupled to the normal microphone preamplifier Nor1209 through the adapter with BNC input Nor1447/2 and the BNC to microdot adaptor Nor1466. The voltage sensitivity will depend on the total capacitance of the cables and adaptors and the calibration procedure is thereby more complicated than for the ICP-type of accelerometers if a vibration calibrator is not at hand. Due to the high impedance of the signal from the transducer, the cables will also often be sensitive to vibration. However, charge sensitive accelerometers often have lower weight and may tolerate higher temperatures.

Set-up for using an ICP® or CCP type of accelerometer connected to Nor140. Power to the accelerometer is supplied from the instrument by selecting ICP in the instrument menu as preamplifier.

Set-up for using a charge-sensitive type of accelerometer connected to Nor140. The charge produced by the accelerometer generates a voltage proportional to the inverse of the capacitance loading the charge generator. The capacitance is the sum of the capacitance for the accelerometer and all cables connected to the transducer. The microphone preamplifier, normally Nor1209, has very high input impedance – typically 10 gigaohm and an input capacitance below 1 pF – and will not modify the loading impedance. The voltage representing the acceleration is transferred to the sound level meter through the preamplifier. Typical attenuation through the adapter Nor1447/2 and the preamplifier Nor1209 is 0,1 dB. Select the "Standard" preamplifier in the instrument set-up menu, but switch off the polarisation voltage.

Levels and linear units

Sound pressure is normally indicated as sound pressure level in decibel (dB). The level in dB is 10 times the logarithm of the square of the sound pressure, x, to the square of a reference value, x_0, or as a mathematical equation:

$$L = 10 \lg \left\{ \frac{x^2}{x_0^{\,2}} \right\}$$

The standardized reference value for sound levels is 20 µPa. When the sound level meter is used for the measurement of acceleration, the unit is normally m/s^2. The reference value for acceleration will therefore be 20 $µm/s^2$. Conversion from a level reading, L, in dB to acceleration, a, in linear units my therefore be done by the following equation:

$$a = 20 \mu m\,s^{-2} \cdot 10^{\frac{L}{20}}$$

The conversion may easily be done in an Excel worksheet after transferring the values from the instrument to a PC by use of the PC program NorXfer (Nor1020).

The instrument Nor140 has the ability to present the result in linear units directly: Select engineering units, **EU**, in the set-up menu. When measuring acceleration, the recommended engineering unit is 1 ms^{-2}. If data is transferred to a PC, all values are transferred as dB levels and the conversion has to be redone in the computer.

It is ofcourse possible to use other reference values than 20 $µm/s^2$ for the dB indication; however, the calculation between logarithmic values in dB and linear units in the instrument is linked to this reference value.

When acceleration levels in dB are specified, it is common to use 1 $µm/s^2$ as the reference value. The difference between 20 $µm/s^2$ and 1 $µm/s^2$ corresponds to 26,02 dB. Add this value to the dB value shown in the instrument to obtain the level referred to the reference value 1 $µm/s^2$. Alternatively, offsetting the calibration sensitivity with the same amount will produce the corrected level, but if you switch to engineering units the value will be wrong by the factor 20.

Calibration

Calibration is easily done if you have access to a vibration calibrator producing a known acceleration level. If the calibrator delivers 1 ms^{-2}, the acceleration level is 94 dB above the reference value 20 $µm/s^2$. By adjusting the sound level meter to display this level, the instrument is calibrated in the same way as when using a microphone and a sound calibrator. However, be aware of the frequency for the vibration calibrator since the instrument automatically selects C-weighted response when the calibration key is pressed. Correct for the attenuation at the particular frequency or make a Z-weighted or a fractional octave-band reading when you adjust the sensitivity.

ICP-type

If you use an ICP-type of accelerometer with a known sensitivity, it is easy to calculate the required sensitivity setting for the instrument. Just enter the sensitivity for the accelerometer in volt per unit as a level-sensitivity in dB.

Example: Assume the sensitivity for the accelerometer is 2,5 mV/ms^{-2}. The level-sensitivity is therefore:

$$L_S = 10\lg\left\{\frac{\left(0,0025\,\frac{V}{ms^{-2}}\right)^2}{\left(1\frac{V}{ms^{-2}}\right)^2}\right\} = -52,0\ dB$$

By entering this value as sensitivity in the calibration menu, the instrument is calibrated and the reading in engineering units will be given in ms^{-2}. *Remember to select ICP as preamplifier and set the preamplifier correction to "Off".*

Charge type

If you use a charge sensitive accelerometer, you need to know the capacitance of all cables and accessories in addition to the charge sensitivity and the capacitance of the accelerometer. The following example will show how to calculate the sensitivity.

The accelerometer is assumed to have the charge sensitivity 3 pC/ms^{-2} (pC = pico-coulomb) and a capacitance of 950 pF. The capacitance of all cables and adaptors between the accelerometer and the preamplifier is measured to be 230 pF. The voltage sensitivity will be the charge sensitivity divided by the sum of the capacitances of the accelerometer and the cable with accessories:

$$\frac{3\,\frac{pC}{ms^{-2}}}{950pF + 230pF} = 2,542\cdot10^{-3}\,\frac{V}{ms^{-2}}$$

The corresponding level sensitivity will be:

$$L_S = 10\lg\left\{\frac{\left(0,002542\,\frac{V}{ms^{-2}}\right)^2}{\left(1\frac{V}{ms^{-2}}\right)^2}\right\} = -51,9\ dB$$

Typical attenuation through the adapter Nor1447/2 and the preamplifier Nor1209 is 0,1 dB. Subtract this attenuation from the level sensitivity (E.g: -52,0 dB).

Remember to select "Standard" as preamplifier and set the preamplifier correction and polarization voltage to "Off" in the set-up menu for the instrument.

Velocity and displacement

Vibration is often measured as velocity or displacement. The velocity can be obtained from the acceleration by time integration of the signal. In a similar way displacement may be obtained by integrating the acceleration twice. No integration is performed in the sound level meter Nor140. However, if the vibration signal is sinusoidal with frequency *f,* an integration correspond to dividing the acceleration by the angular frequency $\omega = 2\pi f$. This may also be used for more complex signals analysed in 1/3-octave bands or analysed by the FFT-option. An example may illustrate how this is done.

Assume that the vibration level in the 80 Hz band (1/3-octave is assumed) is 74 dB or 0,1 ms^{-2}. The exact midband frequency for the 80 Hz filter is $10^{1,9} = 79,43...$ Hz (See ISO 8041). The vibration velocity is therefore:

$$\frac{0,1\,ms^{-2}}{2\pi\cdot79,43\ s^{-1}} = 0,0002\ m\,s^{-1}$$

The corresponding vibration displacement is:

$$\frac{0,1\,ms^{-2}}{\left(2\pi\cdot79,43\ s^{-1}\right)^2} = 0,000\,000\,4\ m = 0,4\ \mu m$$

Calculation of frequency weighted acceleration

Different types of frequency weightings are in use for obtaining a single value for the vibration severity. The international standard ISO 8041 specify nine different frequency weightings related to human response to vibration. The different time-averaged weighted acceleration values may be calculated from the levels in the 1/3-octave bands.

If the acceleration in ith frequency band is a_i, and w_i is the weighting factor for that band, the weighted acceleration, a_w, will be given by:

$$a_w = \left[\sum_i\left(w_i\,a_i\right)^2\right]^{1/2}$$

The values for w_i are found in ISO 8041 and depends on the selected weighting. An Excel-workbook for such calculation *VibCalc_01*, may be obtained from Norsonic.

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