DEWESoft®

Human body and Whole-body Vibration, Hand-arm vibration

Human vibration and why we need to measure it

Human vibration is defined as the effect of mechanical vibration of the environment on the human body. During our normal daily life, we are exposed to various sources of vibration, for example, in buses, trains, cars. Many people are also exposed to other vibrations during their working day, for example, vibrations produced by hand tools, machinery or heavy vehicles.

Human vibration can be pleasant, unpleasant or harmful. Gentle vibrations, such as that experienced when sitting in a rocking chair, dancing or running are pleasant. More violent vibrations, for example, those experienced when traveling in a car down a bumpy road or when operating a power tool, are unpleasant or harmful. The harmfulness of vibration depends on its intensity and frequency content and the time of exposure.

Especially at workplaces exposed to vibrations, there is a big likelihood of permanent damage to some parts of the human body. One effect is known as Raynaud's disease or the effect of white fingers where the fingers change color to white and become painful. Another typical effect of working with heavy machinery or vehicles (a typical example is a helicopter) is the problems with the lumbar region.

Harmful effects of vibration on human health is a serious problem. Mechanical vibrations transmitted from power tools and other vibrating devices to the human body may have a negative impact directly on individual tissues and blood vessels, can cause excitation of vibration of the internal organs or body parts, and even cellular structures.

In practice, the most dangerous is hand-arm vibration transmitted to the upper parts of the body, which can cause pathological changes in the nervous system, vascular (cardiovascular) and osteoarticular. Changes in the human body resulting from the contact with the mechanical vibrations are recognized as an occupational disease, called the vibration syndrome. The three forms of vibration disease are identified: neurovascular, osteoarticular, and mixed. According to data, in 2008 the percentage of vibration syndrome in all occupational diseases was: 2.9% in forestry, 5.6% in mining, 4.3% in the production of metals and as much as 8.7% in construction.

Image 1: Example of white finger disease

The human vibration module provides measurements to be able to judge the risk of such damage. It is based on an ISO 2631-1 (dated in 1997) standard that defines basic procedures, ISO 8041 (dated 2017), which defines exact procedures for measurements and ISO 2631-5 (dated 2018) which defines evaluation of human exposure to whole-body vibration.

There are two main types of measurements:

- **whole body measurements** (are measured with the help of the so-called seat sensor, where we need to install the triaxial sensor in the rubber adapter on which we sit on)
- **hand-arm measurements** (is a measurement of hand-arm where the sensors are installed on special adapters for holding them on the handle or between fingers)

Both measurements are performed with triaxial accelerometers (it is very common to use 50 g sensors) and using special adapters. For workplaces with high vibrations (for example impact hammers), it is necessary to use high g sensors (500 g or more). This sensor should also survive the high shock.

For the measurement, we need several ICP channels with a 24 bit sigma-delta AD card (Sirius or Dewe-43, for example).

In theory, we would need to measure a full working day with all the significant loads. Often the measurement interval is shorter, but we need to ensure that all the significant vibration patterns are covered correctly in the obtained measurements.

There are several parameters, that needs to be calculated:

- **RMS** - the "root means square" value is a statistical measure of the magnitude of a weighted signal,
- **Peak** is the maximum deviation of the signal from the zero line,
- **Crest factor** is the ratio between the peak and RMS,
- **VDV** is the fourth power vibration dose value,
- **MSDV** is the motion sickness dose value,
- **MTVV** is the maximum transient vibration value, calculated at a one-second interval.

Measuring human vibration

Vibrations can be desired and perceived as pleasant or give useful feedback over ongoing processes. However, just as often they are undesired, irritating, cause stress, induce panic and can lead to physical reactions such as sweating, nausea and vomiting. While these can be extremely unpleasant experiences and strongly influence a person's life and mental state, for most people the effect of vibrations will only be temporary or, once the exposure to the vibrations is stopped, the physical effects will disappear over time.

The physical effect of vibrations on the human body may also be permanent. The risk for irreparable injuries is especially high for human vibration occurring in context with work, where the vibration magnitudes can be substantial, the exposure times long and the vibration exposure may occur regularly or even daily. Typical risk groups are drivers of lorries, trucks, agricultural/farming, construction site and forest machinery, pilots of certain helicopters, and workers operating hand-fed machines, hand-guided machines or hand-held power tools and who need to hold workpieces. During their work, a worker's entire body or parts of it, especially the hand-arm region may be exposed to excessive vibrations.

Unfortunately, the relation between vibration exposure and health damage is often not that obvious. Injuries may develop over a long period of time and other activities, such as lifting heavy loads, could be the reason for the injury (e.g., lower back pain). A worker may feel numbness or fatigue after a working day while exposed to intensive vibrations, but initially these effects will only be temporary and the next day everything will seem fine. However, once these effects are permanent (such as cold fingers, lower back pain, etc.) it is often too late. Many of these injuries are irreversible.

It is therefore of the utmost importance to prevent excessive vibration exposure. In Europe, the Vibration Directive (Directive 2002/44/EC) has been introduced in order to set minimum standards for controlling the risks, both from hand-arm and whole-body vibration. The directive sets action values, above which it requires employers to control the vibration risks, and limit values, above which workers must not be exposed.

For hand-arm vibrations these values are:

- A daily exposure action value of 2.5 m/s^2
- A daily exposure limit value of 5 m/s^2

For whole-body vibrations these values are:

- A daily exposure action value of 0.5 m/s^2 (or, at the choice of the individual EU Member State, a vibration dose value of 9.1 m/s)
- A daily exposure limit value of 1.15 m/s^2 (or, at the choice of the individual EU Member State, a vibration dose value of 21 m/s)

Employers are obliged to determine and assess the risk resulting from both hand-arm and whole-body vibrations and ensure that the exposure values are not exceeded. If analysis suggests that workers are at risk, employers should set a management program into action to keep the exposure to vibration at a minimum and prevent the development and progression of injury.

At the first stage, the analysis can be based on emission values, i.e., data of vibration magnitudes that occur when operating or working with a particular tool, vehicle or machinery. Today such data is often provided by manufacturers of machines and vehicles but can also be found in databases maintained by independent organisations and institutes. However, employers must be aware that these data have been determined following harmonised codes. Emission data determined according to such standards are primarily meant to allow the customer direct comparison of similar products. In practice, however, the emission values occurring under real conditions may be significantly greater.

The reason for this can be wear, overly rough road surfaces, operating vehicles or mobile machinery on sloped surfaces, and other factors of real, everyday usage. Therefore, measurements at the site are highly recommended to validate and verify that using the tool or machine in that particular context does not lead to larger vibration magnitudes than specified by the producer.

Whether data are taken from databases or collected by carrying out vibration measurements at the site, it is very important to perform a detailed analysis of the precise exposure times at the specific working place. This is not only important for finding the actual daily vibration exposure for the current situation, but also to have sufficiently precise data with which to work when making suggestions to reduce exposure and risk.

Whole-body vibration measurement

Human exposure to whole-body vibration should be evaluated using the method defined in ISO 2631-1. Whole-body vibration is applicable to motions transmitted from workplace machines and vehicles to the human body through a supporting surface. For health and safety evaluations, this is through the buttocks and feet of a seated person or the feet of a standing person.

When carrying out whole-body measurements, it is preferable to measure over the entire exposure time. If that is not possible or necessary, measurements should be made over periods of at least 20 minutes. Where short measurements are necessary, they should be at least three minutes long and should be repeated to achieve a total measurement time of more than 20 minutes. Longer measurements of 2 hours or more are preferable (half or full working day measurements are sometimes possible).

When assessing whole-body vibrations, acceleration should be picked up at the seat surface for a seated person or underneath the feet of a standing person. The accelerometer should be placed in a Seat Pad, which is preferably fixed to the floor or seat using tape or a strap to ensure that the accelerometer remains at the desired position and is able to withstand any position changes of the driver or operator of a machine. However, for correct results, the Seat Pad must be loaded during the measurement by the worker, who should stand or sit on the pad.

RMS vibration magnitude, Peak value, MTVV and VDV of the frequency-weighted acceleration should be measured simultaneously in all three directions, where Z-direction is always along the main body axis (i.e., for measurements at the feet and seat it is vertical to the seat and floor plane), the X-direction is aligned with the fore-and-aft motion and the Y-direction with a side-to-side motion.

In contrast to hand-arm vibration assessment, frequency weightings are different for X, Y, and Z-direction. In the context of health risk assessment, when measuring whole-body vibration at the feet and seat, ISO 2631-1 requires the use of Wk in the Z-direction, whereas Wd is used for the acceleration in the X and Y directions

Whole-body vibrations are measured with the help of the so-called seat sensor, where we need to install the triaxial sensor in the rubber adapter on which we sit. It is important that the z-axis is in a vertical direction since it is weighted differently than x and y.

Image 4: Seat pad sensor

Vibration should always be evaluated by measuring the weighted vibration acceleration. Crest factor determines the method for evaluation of the vibration. In the case of a high crest factor (greater than 9) to evaluate the vibration, running RMS or VDV should be used. Using the vector sum (total vibration value) is recommended for the evaluation of comfort and health risk assessment if the vibration in two or three axes are comparable.

For an assessment of occasional shocks and short-term vibration, the running RMS is used. In this case, the maximum value in the observation time is called as MTVV and is defined as the maximum instantaneous vibration magnitude. Vibration transmitted to the human body should be measured at a point between the body and the vibrating surface. In the case of a sitting person, this will be a seat, the seat back or the floor under feet.

Vibration should be measured according to the axis direction that begins at the point of human contact with the vibrating surface. The vertical axis (Z) should follow the orientation of the body, so the Z axis does not necessarily have to be vertical. The direction of the axis must be specified in the report.

The duration of the measurement shall be sufficient to ensure statistical accuracy and should take into account the typical vibration exposure. Measuring time should also be included in the report. The health of sitting persons is affected by vibrations in the frequency range of 0.5 Hz to 80 Hz. Measurements should be made using the appropriate frequency weightings: the Wk (Z-axis) and the Wd (axes X, Y). Because horizontal vibration is more harmful, the weighting coefficients should be 1.4 for the X, Y and 1 for the Z axis. Weighted RMS should be assessed in each of the 3 directions on the seat surface. In special cases, other weightings, such as Wc, Wf, We, Wj should be used.

Whole-body vibration should be evaluated on the basis of the result of the daily dose of A (8) expressed as equivalent frequency-weighted acceleration within eight hours, and calculated as the highest value of RMS or VDV determined in three axes X, Y, Z.

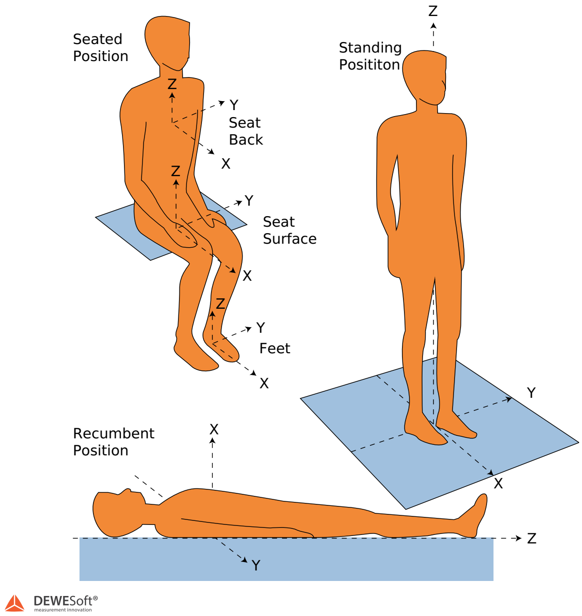


Image 5: Different measurement positions at whole-body vibration measurement

Based on the frequency-weighted acceleration signals, the daily vibration exposure is determined by calculating the exposure for each of the three axes separately and then selecting the highest of the three values. This necessitates an additional factor, **ki**, that must be applied to the measured vibration values. For the X and Y-direction, the factor is 1.4. For the Z-direction, the factor is 1.0:

$$A_x(8) = a_{wx} \cdot 1.4 \sqrt{\frac{T_{exp}}{T_0}}$$

$$A_y(8) = a_{wy} \cdot 1.4 \sqrt{\frac{T_{exp}}{T_0}}$$

$$A_z(8) = a_{wz} \cdot 1.0 \sqrt{\frac{T_{exp}}{T_0}}$$

The maximum of these three values will then be the daily vibration exposure:

$$A(8) = \max\{A_x(8), A_y(8), A_z(8)\}$$

This is significantly different than the procedure used to determine hand-arm vibration exposure, where the three axes were combined to a single, total vibration value. However, according to ISO 2631-1, Section 6.5, a vibration total value may be used if no dominant axis of vibration can be found. The vibration total value for whole body vibration is calculated according to the following equation:

$$a_v = \sqrt{k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2}$$

In some countries, different exposure limit values are given for different axes. Therefore, a paradox may occur such that, while the axis with the largest exposure value will not be found critical, another axis with a smaller exposure value will be above the limit for this axis. The report, based on the axis with the highest value, would not indicate a risk, even though the limit is violated for another axis.

If a worker is exposed to more than one source of vibration, the partial vibration exposure Aj, i(8), for each axis and operation **i**, is to be calculated first:

$$A_{x,i}(8) = a_{wx,i} \cdot 1.4 \sqrt{\frac{T_{exp}}{T_0}}$$

$$A_{y,i}(8) = a_{wy,i} \cdot 1.4 \sqrt{\frac{T_{exp}}{T_0}}$$

$$A_{z,i}(8) = a_{wz,i} \cdot 1.0 \sqrt{\frac{T_{exp}}{T_0}}$$

The partial vibration exposures are then added for each of the three axes separately, and the total daily vibration exposure is found as the maximum of these three sums:

$$\left.\begin{array}{l} A_x(8) = \sqrt{A_{x,1}^2(8) + A_{x,2}^2(8) + \ldots + A_{x,n}^2(8)} \\ A_y(8) = \sqrt{A_{y,1}^2(8) + A_{y,2}^2(8) + \ldots + A_{y,n}^2(8)} \\ A_z(8) = \sqrt{A_{z,1}^2(8) + A_{z,2}^2(8) + \ldots + A_{z,n}^2(8)} \end{array}\right\} A(8) = \max\{A_x(8), A_y(8), A_z(8)\}$$

The total daily vibration dose, A(8), applies well if the vibration history is rather smooth, free of shocks or other sudden changes or peaks in the acceleration. However, when, for example, driving a vehicle over rough surfaces, such as found on construction sites and sandpits, shock like events may occur and an assessment based on RMS values may no longer be appropriate. The fourth power vibration dose value (VDV) has been developed to take such transients into account. Unlike RMS vibration magnitude, the measured VDV is a cumulative value and increases with the measurement time. It is, therefore, important for any measurement of VDV, to know the period over which the value was measured. Further, due to the fourth power, transients and peaks are given more weight in the integration. If the measurement time is shorter than the estimated exposure time, the measured VDV must be expanded to the actual exposure time:

$$VDV_{\mathrm{exp},x} = VDV_x \cdot 1.4\left(\frac{T_{\mathrm{exp}}}{T_{\mathrm{meas}}}\right)^{1/4}$$

$$VDV_{\mathrm{exp},y} = VDV_y \cdot 1.4\left(\frac{T_{\mathrm{exp}}}{T_{\mathrm{meas}}}\right)^{1/4}$$

$$VDV_{\mathrm{exp},z} = VDV_z \cdot 1.0\left(\frac{T_{\mathrm{exp}}}{T_{\mathrm{meas}}}\right)^{1/4}$$

Where T_{meas} is the measurement period and T_{exp} is the full expected exposure time, and note again the k-factors (1.4, 1.4 and 1.0). Further, if a person is exposed to more than one vibration source, the total VDV is to be calculated from the partial vibration dose values for each axis:

$$\left.\begin{array}{l} VDV_x = \left(VDV_{x,1}^4 + VDV_{x,2}^4 + \ldots + VDV_{x,n}^4\right)^{1/4} \\ VDV_y = \left(VDV_{y,1}^4 + VDV_{y,2}^4 + \ldots + VDV_{y,n}^4\right)^{1/4} \\ VDV_z = \left(VDV_{z,1}^4 + VDV_{z,2}^4 + \ldots + VDV_{z,n}^4\right)^{1/4} \end{array}\right\} (\text{daily}\, VDV)$$

$$= \max\{VDV_x, VDV_y, VDV_z\}$$

The highest of the three individual VDVs gives the daily VDV.

Another useful quantity when investigating human vibration with transients is the running RMS. It has a short integration time of 1 s and thus, is well suited to indicate the magnitude of short events. The so-called maximum transient vibration value (MTVV) represents the maximum running RMS value found over one measurement period.

ISO 2631-1 provides some guidelines concerning when it is recommended to consider VDV, running RMS and MTVV instead of the vibration magnitude, aw:

- If,
  $$CF = \frac{Peak}{RMS} > 9$$
  VDV should be considered in addition to RMS
- If,
  $$\frac{MTVV}{RMS} > 1.5$$
  MTVV should be considered in addition to RMS
- If,
  $$\frac{MTVV}{RMS \cdot T^{1/4}} > 1.75.$$
  VDV should be considered in addition to RMS

If one of these conditions is given, it indicates that the vibration history had peaks significantly above the general average vibration level.

The ratio between the Peak value and RMS vibration magnitude, the crest factor (CF), is considered to be a rather uncertain criterion because the peak may have occurred at a different time ranging from minutes to hours before or after the vibration event that determined the RMS.

Hand-arm vibration measurement

The second application is the measurement of hand-arm where the sensors are installed on special adapters for holding them on a handle or between fingers. The orientation of the sensor is not important in this case since all three axes have the same weighting.

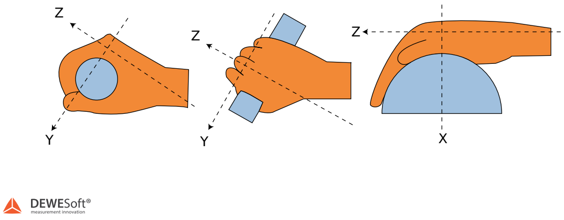


Image 6: Hand-arm vibration measurement sensor

Hand-arm vibration is experienced through the hand and arm. Daily exposure to hand-arm vibration over a number of years can cause permanent physical damage, usually resulting in what is commonly known as white finger syndrome, or it can damage the joints and muscles of the wrist and/or elbow.

Measurement of hand-arm vibration refers to three main cases:
- when the operator's hands have direct contact with the surface of the vibrating machine (steering wheel or handle),
- when the operator feeds the machine with the material through which the vibration is transmitted to a hand (woodcutting),
- when the operator holds the vibrating device in their hands (drills, pneumatic hammers).

Typical vibration exposure consists of short periods in which the operator has a contact with the tool. Therefore, it is recommended to perform a few short measurements rather than one long measurement. For each task, the measurements should be done at least 3 times and results averaged. The total measuring time should be at least 1 minute. Measurement blocks shorter than 8 seconds should be avoided because they would not correctly capture low-frequency content.

The fundamental quantity used in the evaluation of hand-arm vibration is the vector sum called AEQ which is the basis for the calculation of daily exposure.

To identify the daily exposure it is necessary to identify all the sources of vibration, which means to identify all working modes of tools (drilling with a hammer and without), and changes in the conditions of use of the device. This information is necessary for the proper organization of measurement so as to include as many common tasks of the operator, during which he is exposed to hand-arm vibration. Daily exposure should be calculated for each source of vibration.

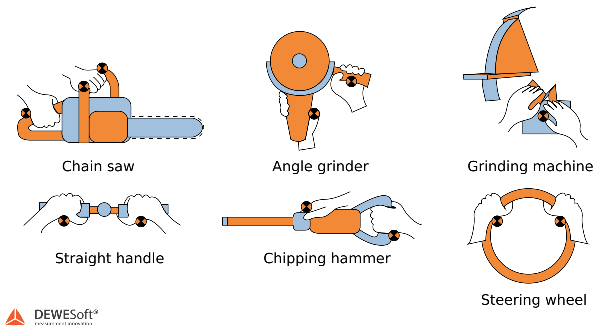


Image 7: Vibration sources for hand-arm vibrations

The next step is to choose how to mount the accelerometer. Hand-arm vibration should be measured in place, or at the point of contact with the hand tool. The best location is in the center of the handle, it is the most representative of the location if the position does not interfere with the performance of tasks. The accelerometer should be rigidly attached to a vibrating surface. Measurements directly at hand are performed using special adapters. In the case of some power tools, measurement on both sides of the hand is also recommended. The mounting location should be included in the measurement report. Measuring time should include a representative tool for operation time. The measurement should start from the moment you touch a vibrating device and should end when the contact is broken or the vibration stops. In case the real-time of the contact is short, the measurement time can be artificially extended in order to better estimate the exposure to vibrations during contact with the device.

Image 8: Measuring hand-arm vibrations with an accelerometer attached to the device

In the event that the device generates a sudden shock, the measurement should include shocks and the appropriate length of time before and after the occurrence of shocks. It is also important to determine the number of shocks per shift. The minimum period of time depends on the vibration signal, tools, and activities. The total measurement time, however, should not be less than 1 minute. Measurements of less than 8 seconds are considered to be uncertain, particularly with regard to the assessment of low frequency and should be avoided.

If it is impossible to measure for more than 1 minute, multiple measurements should be carried out to create a combined measurement of at least 1 minute. Typical exposure time is calculated on the basis of the relevant exposure during the complete task or over the duration of 30 minutes in typical work and the information about the work cycle (number of cycles per shift). Assessment of exposure time can be made by using a timer, the analyzer or analysis of video recordings.

The three-axis measurement is recommended. If this is not possible, measurement in one dominant axis is allowed.

ISO 5349-1:2001 recommends determining the frequency-weighted RMS acceleration in three directions: On axis with the arm and in two other directions in the plane between hand and grip. The best solution is using a miniature triaxial accelerometer, which picks up the vibration in all three directions at the same point and only adds a few grams of transducer mass.

When addressing root mean square values of acceleration in human vibration, ISO standards use lowercase a. The frequency range included in the analysis is 8 - 1000 Hz. Frequency weighting Wh is used for all three axes, even though the anatomy and thus sensitivity of the hand-arm system differ along the arm and in a transverse direction.

The three frequency weighted acceleration components are denoted ahwx, ahwy and ahwz. These are then combined with the so-called vibration total value, ahv, the root-sum-of-squares of the three components:

$$a_{hv} = \sqrt{(k_x a_{hwx})^2 + (k_y a_{hwy})^2 + (k_z a_{hwz})^2}$$

In contrast to whole-body vibrations, when calculating the root sum of squares for hand-arm vibrations, all axes are, theoretically, multiplied with the same weighting factor, k=1.0. Usually, to simplify the equations, the factors will be dropped.

The daily vibration exposure A(8) is calculated from this vibration total value:

$$A(8) = a_{hv}\sqrt{\frac{T_{\exp}}{T_0}}$$

Where T_0 is the reference duration of 8 hours and T_{exp} is an estimate of the time that the tool operators are exposed to the vibration or the duration of the entire operation including breaks. If a person is exposed to more than one source of vibration, a partial vibration exposure Ai(8) for each operation i is to be calculated:

$$A_i(8) = a_{hv,i}\sqrt{\frac{T_{\exp,i}}{T_0}}$$

The partial vibration exposure values are then combined to give the overall daily exposure value A(8), for that person:

$$A(8) = \sqrt{A_1^2(8) + A_2^2(8) + \ldots + A_n^2(8)}$$

Exposure point system

The measurement engineer, or any other professional, dealing regularly with vibration measurements will easily develop a good feeling for quantities such as the Daily vibration exposure value (A(8)) and VDV. However, to the layman, exposures expressed in units such as m/s2 will usually be difficult to grasp. If this person then must make decisions based on such quantities, those decisions may become needlessly difficult.

In order to facilitate those decisions, a more simple and intuitive means to express daily vibration exposure A(8) has been introduced, exposure points. For the user or decision-maker, expressing exposure with the point system has two advantages:

- 1) The point system avoids units: The critical vibration magnitudes for hand-arm and whole-body vibrations differ (the hand-arm system can cope with larger magnitudes). In contrast, the exposure point system is defined in such a way that, in both cases (hand-arm and whole-body vibrations), the exposure action value is reached at 100 points.
- 2) Once the exposure is expressed in points, there is no need for complicated power laws: Exposure points are simply added together. If a worker is exposed to several vibration sources, the total number of exposure points is simply the sum of the exposure points for the sources. This also means that exposure points change simply with time Ã‚â€“ twice the exposure time, twice the number of points.

For hand-arm vibrations, exposure points are calculated for the combined three axes, as follows:

$$P_E = \left(\frac{a_{hv}}{2.5\ \mathrm{m/s}^2}\right)^2 \frac{T_{\exp}}{T_0} 100$$

Where ahv is the vibration total value (RMS VTV), Texp the exposure time in hours and T0 the reference duration of 8 hours. Note that the vibration magnitude of 2.5m/s2 corresponds to the action value for hand-arm vibrations. As a consequence, the conversion between A(8) and PE will be such, that the exposures equal to the action value (2.5 m/s2 A(8)) will give 100 points, and exposures equal to the limit value (5 m/s2 A(8)) will give 400 points. It is also possible to directly convert between A(8) and PE:

$$P_E = A(8)^2 \frac{100}{(2.5\ \mathrm{m/s}^2)^2}$$

For whole-body vibrations, exposure points are calculated for each of the three axes separately, as follows:

$$P_{E,j} = \left(\frac{k_j a_{wj}}{0.5\ \mathrm{m/s}^2}\right)^2 \frac{T_{\exp}}{T_0} 100$$

Where kj is the weighting factor for the X, Y or Z-axis respectively; awj is the vibration magnitude (RMS value) of either the X, Y or Z-axis; Texp is the exposure time in hours, and T0 is the reference duration of 8 hours. Note that the vibration magnitude of 0.5m/s2 corresponds to the action value for whole-body vibrations. Also in the case of whole-body vibrations, the conversion between A(8) and PE is such that an exposure action value of 0.5 m/s2 would be equal to 100 points. However, the exposure limit value of 1.15 m/s2 will be equal to 529 points.

To directly convert between A(8) and PE:

$$P_E = A(8)^2 \frac{100}{(0.5\ \mathrm{m/s}^2)^2}$$

Measurement of seat effective amplitude transmissibility - SEAT

Determination of Seat Effective Amplitude Transmissibility (SEAT) does not directly give information about human exposure to vibration. The goal of the measurement is to determine the capability of a seat design to attenuate the vibrations present in a vehicle - to protect the driver from excessive vibrations.

The measurement, therefore, involves the determination of the vibration magnitude at two positions:

- On the seat pan
- Directly on the floor of the vehicle right underneath the seat.

Measurement at these two points is done simultaneously and the SEAT is computed as the ratio between these two magnitudes. To express SEAT, one may use the frequency-weighted RMS vibration magnitudes (aw) or the VDVs. Further, rather than just using the ratio (a SEAT factor), one may multiply the result with 100 to express the seat effective vibration amplitude in percent.

Whether to use RMS or VDV depends on the vibrations encountered during the measurement. If the vibration history was rather smooth, then the RMS vibration magnitude is preferable. If, however, the vibrations included transients and shocks, it is recommended to compute SEAT based on VDVs.

$$SEAT_{RMS} = \frac{a_{w,\,\mathrm{seat}}}{a_{w,\,\mathrm{floor}}}$$

$$SEAT_{VDV} = \frac{VDV_{\mathrm{seat}}}{VDV_{\mathrm{floor}}}$$

$$SEAT\% = SEAT \times 100$$

A seat would improve ride comfort when the SEAT is smaller than 1 or, expressed in percentage when SEAT% is less than 100%. If the value exceeds these limits, the seat actually amplifies vibrations and, thus, worsens ride comfort.

In context with health risk assessment, frequency weighting used for SEAT measurements is the same as for whole-body measurements

When assessing a seat's ability to attenuate vibrations, it is important to keep in mind that the seat and driver must be seen as one system. The driver will add mass to the seat, which preloads the seat springs, and changes the resonance behavior. Further, depending on posture, the seat driver combination will lead to a more or less stiff system (e.g., vibrations will be different if the driver sits relaxed or if feet are pressed against the floor).

Thus, depending on the driver's body and posture, the performance of seats can be very different. As a consequence, several measurements with different drivers and postures should be carried out to get the full picture.

Standards for laboratory SEAT measurements define exact masses to be used, specific seat adjustments, and detailed procedures, including processes such as warming up the seat, etc. Instead, the focus is on the assessment of SEAT factors under real working conditions, with real workers and no warm-up times. SEAT assessment standards may and should be consulted because they provide useful guidance.

Lumbar spine measurement

The adverse health effects of prolonged exposure to the vibration that includes multiple shocks are related to dose measures.

The method described in ISO 2631 is generally applicable in cases where adverse health effects in the lumbar spine are concerned.

The calculation of the lumbar spine response described in ISO 2631 assumes that the person subjected to the vibration is seated in an upright position and does not voluntarily rise from the seat during the exposure. Different postures can result in different responses in the spine.

Predictive models are used to estimating the lumbar spine accelerations (a_{Ix} , a_{Iy} , a_{Iz}) in the x , y and z-directions in response to accelerations measured at the seat pad (a_{Sx}, a_{Sy} , a_{Sz}) along the same bicentric axes.

The determination of the spinal response acceleration dose involves the following steps:

- calculation of the human response
- counting of number and magnitudes of peaks
- calculation of an acceleration dose by application of a dose model related to the Palmgren-miner fatigue theory

In the x - and y-axes, the spinal response is approximately linear and is represented by a single-degree-of-freedom (SDOF) lumped-parameter model, having the following characteristics:

- natural frequency, f_n = 2,125 Hz (ω_n = 13,35 Hz)
- a critical damping ratio, ζ = 0,22

The lumbar spine response, a_{Ik} in [m/s2], is calculated from the equation of motion of an SDOF system:

$$a_{Ik}(t) = 2\zeta\omega_n(v_{Sk} - v_{Ik}) + \omega_n^2(s_{Sk} - s_{Ik})$$

- k is x or y
- s_{Sk} and s_{Ik} are the displacement time histories in the seat and in the spine
- v_{Sk} and v_{Ik} are the velocity time histories in the seat and in the spine

The values for the SDOF resonance frequency and damping ratio given above, result in the following values for the multipliers: $2\zeta w_n = 5,87s^{-1}$ and $w_n^2 = 178s^{-2}$.

Spinal response in a vertical direction

In the z-direction, the spinal response is non-linear and is represented by a recurrent neural network model.

Lumbar spine z-axis acceleration, $a_I z$ in [m/s2], is predicted using the following equations:

$$a_{Iz}(t) = \sum_{j=1}^{7} W_j u_j(t) + W_8$$

$u_j(t) = \tanh[$

The model coefficients are specific to a sampling rate of 160 per second. Therefore, data collected at a different sampling rate shall be resampled to 160 samples per second.

Z-axis model coefficients for the equation for aIz:

W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8
57,96539	52,32773	49,78227	53,16885	56,02619	−27,79550	72,34446	21,51959

Z-axis model coefficients for the equation for uj:

j	1	2	3	4	5	6	7
w_{j1}	0,00130	0,01841	−0,00336	0,01471	0,00174	0,00137	0,00145
w_{j2}	−0,00646	−0,00565	−0,00539	0,01544	−0,00542	0,00381	0,00497
w_{j3}	−0,00091	−0,02073	0,00708	−0,00091	0,00255	−0,00216	0,01001
w_{j4}	0,00898	−0,02626	0,00438	−0,00595	−0,00774	−0,00034	0,01283
w_{j5}	0,00201	0,00579	0,00330	−0,00065	−0,00459	−0,00417	−0,00468
w_{j6}	0,00158	0,00859	0,00166	0,00490	−0,00546	0,00057	−0,00797
w_{j7}	0,00361	0,00490	0,00452	0,00079	−0,00604	−0,00638	−0,00529
w_{j8}	0,00167	−0,00098	0,00743	0,00795	−0,01095	0,00627	−0,00341
w_{j9}	−0,00078	−0,00261	0,00771	0,00600	−0,00908	0,00504	0,00135
w_{j10}	−0,00405	−0,00210	0,00520	0,00176	−0,00465	−0,00198	0,00451
w_{j11}	−0,00563	0,00218	−0,00105	0,00195	0,00296	−0,00190	0,00306
w_{j12}	−0,00372	0,00037	−0,00045	−0,00197	0,00289	−0,00448	0,00216
w_{j13}	−0,31088	−0,95883	−0,67105	0,14423	0,04063	0,07029	1,03300

Calculation of acceleration dose

The acceleration dose, Dk [m/s2], in the k-direction, is defined as

$$D_k = \left[\sum_i A_{ik}^6 \right]^{1/6}$$

- Aik is the ith peak of the response acceleration aik(t)
- k = x,y or z

A peak is defined here as the maximum absolute value of the response acceleration between two consecutive zero crossings. For the x and y directions, peaks in positive and negative directions shall be counted. For the z direction, only positive peaks shall be counted (compression of the spine is of primary interest for exposure severity).

In calculating the dose, peaks of a considerably lower (by a factor of three or more) magnitude than the highest peak will not significantly contribute to the value associated with the 6th power term may be neglected.

For assessment of health effects, it is useful to determine the average daily dose, Dkd, in metres per second squared, to which a person will be exposed, using the following equation:

$$D_{k\mathrm{d}} = D_k \left[\frac{t_\mathrm{d}}{t_\mathrm{m}} \right]^{1/6}$$

- td is the duration of the daily exposure
- tm is the period over which Dk has been measured

Equation for Dkd may be used when the total daily exposure can be represented by a single measurement period. When the daily vibration exposure consists of two or more periods of different magnitudes, the acceleration dose, in metres per second squared, for the total daily exposure shall be calculated as follows:

$$D_{k\mathrm{d}} = \left[\sum_{j=1}^{n} D_{kj}^6 \frac{t_{\mathrm{d}j}}{t_{\mathrm{m}j}} \right]^{1/6}$$

- t_{dj} is the duration of the daily exposure to condition j
- t_{mj} is the period over which D_{kj} has been measured

Flowchart for calculation of the acceleration dose

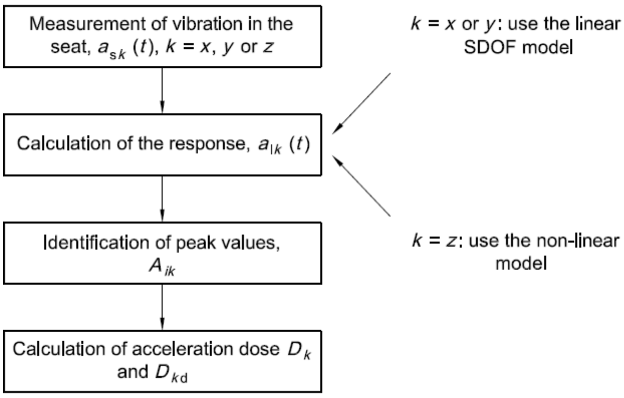


Image 9: Flowchart for calculation of acceleration dose

Relationship between acceleration dose and health effects

This guidance applies to people in normal health who are regularly exposed to vibration containing multiple shocks. Individuals with previous disorders affecting the spine, including those suffering from latent osteoporosis or other spinal disorders, may be more susceptible to injury. The guidance in this part of ISO 2631 applies to rectilinear x, y and z basicentric axes of the human body. It does not apply to high magnitude single-event shocks such as may result from a traffic accident that causes trauma.

It is assumed that multiple shocks cause transient pressure changes at the lumbar vertebral endplates that over time may result in adverse health effects, arising from material fatigue processes. Essential exposure-related factors are the number and magnitudes of peak compression in the spine. The peak compression in the spine is affected by anthropometric data (body mass, the size of endplates) and posture.

Adverse health effects of long-term whole-body multiple-shock exposure include an increased risk to the lower lumbar spine and the connected nervous system of the segments affected. Excessive mechanical stress and/or disturbances of the nutrition of and diffusion to the disc tissue may contribute to the degenerative processes in the lumbar segments. Multiple shocks and vibration exposure may also worsen certain endogenous pathological disturbances of the spine.

For the evaluation of the effects of internal pressure changes, the Palmgren-Miner approach is applied. Experimental data show that the value of the Palmgren-Miner exponent varies with biological tissue and test methodology from 5 to 14 for the cortical and trabecular bone to 20 for cartilage. For the purpose of estimating adverse health effects, a conservative exponent of 6 has been selected here.

The relationship between the predicted pressure changes and the predicted total tolerance of the exposed person can be used to assess the potential of an adverse health effect. The predicted response is of the bony vertebral endplate (hard tissue). The assessment is based on upright posture. A bending forward or twisting posture is likely to increase the adverse health effect.

Assessment of health effects

By the use of a biomechanical model, based on experimental data, it has been shown that there is a linear relationship between the part of compressive stress that is due to the input shocks and the peak acceleration response in the spine. An equivalent static compressive stress, Se, in megapascals, is calculated as follows:

$$S_e = \left[\sum_{k=x,y,z} \left(m_k D_k \right)^6 \right]^{1/6}$$

Recommended values of mk are:

- m_x = 0,015 MPa/(m/s^2)
- m_y = 0,035 MPa/(m/s^2)
- m_z = 0,032 MPa/(m/s^2)

The daily equivalent static compression dose, Sed, is obtained by normalizing Dk to the acceleration dose Dkd for the average daily exposure time

$$S_{ed} = \left[\sum_{k=x,y,z} \left(m_k D_{kd} \right)^6 \right]^{1/6}$$

In general a factor R can be defined for use in the assessment of the adverse health effects related to the human response acceleration dose. R should be calculated sequentially taking into account increased age (and reduced strength) as the exposure time increases. It is defined as follows:

$$R = \left[\sum_{i=1}^{n} \left(\frac{S_{ed} \cdot N^{1/6}}{S_{ui} - c} \right)^6 \right]^{1/6}$$

- N is the number of exposure days per year
- i is the year counter
- n is the number of years of exposure
- c is a constant representing the static stress due to gravitational force
- Sui is the strength of the lumbar spine for a person of age (b+i) years
- b is the age at which the exposure starts

A value of c = 0,25 MPa can be normally used for driving posture.

The value S_{ui} varies with the bone density of the vertebrae, which normally is reduced with age. From in-vitro studies, the following relationship between S_{ui} (in megapascals) and b+i (in years) has been derived:

$$S_{ui} = 6{,}75 - 0{,}066\,(b + i)$$

There is a significant human variability and R < 0,8 indicates a low probability of an adverse health effect; R > 1,2 indicates a high probability of an adverse health effect.

A sequential calculation for a person who starts being exposed at the age of 20 years (b = 20) will reach R = 0,8 at the age of 65 (n = 45) if the daily dose Sed is equal to 0,5 MPa. The same person will reach R = 1,2 at the age of 65 if the daily dose Sed is equal to 0,8 MPa. This calculation is based on 240 days of equal exposure (N) per year. For application to another number of days of exposure per year, the appropriate Sed limits are achieved by multiplying the values 0,5 MPa and 0,8 MPa by (240/N)1/6.

The procedure for assessment of adverse health effects from the acceleration dose

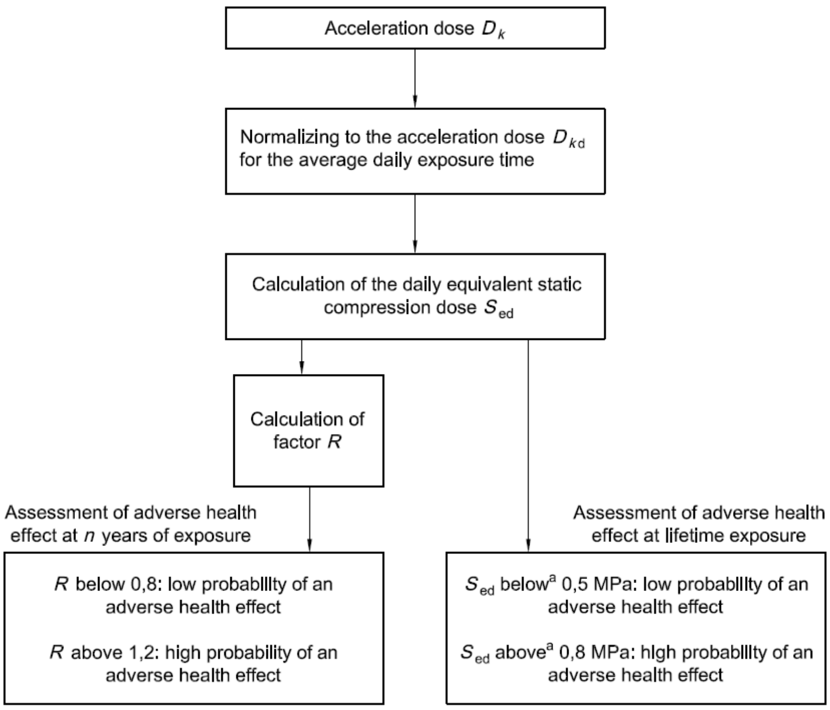


Image 10: Procedure for assessment of adverse health effects from the acceleration dose

Example of assessment of adverse health effects

Measurements have been made for a period of 2,5 minutes on the seat pad at the operator's seat of an off-road machine during traveling.

Image 11 shows the x-axis acceleration input and lumbar response for the time period between 75 seconds and 80 seconds.

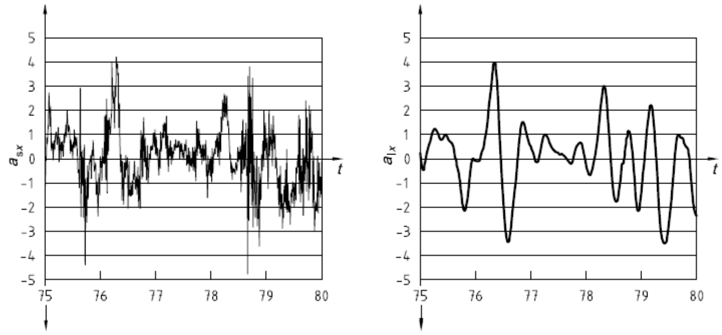


Image 11: X-axis acceleration input and lumbar spine response

In order to calculate the dose, the absolute acceleration values of the positive and negative peaks in the x- and y-axes response and the acceleration values of the positive peaks in the z-axis response are determined.

The dose values over the 2,5 min record are calculated by taking the 6th root of the sum of the 6th power of the peaks. The results are:

- $D_{x,2,5min}$ = 8,6 m/s^2
- $D_{y,2,5min}$ = 13,6 m/s^2
- $D_{z,2,5min}$ = 7,2 m/s^2

Assume that the record of the acceleration time history is representative of the conditions to which the driver is subjected and that the exposure lasts, on average, a period of 30 min per workday. The average daily dose is:

- D_{xd} = 8,6 (30/2,5)$^{1/6}$ = 13,0 m/s^2
- D_{yd} = 13,6 (30/2,5)$^{1/6}$ = 20,6 m/s^2
- D_{zd} = 7,2 (30/2,5)$^{1/6}$ = 10,9 m/s^2

The daily equivalent daily static compressive stress is calculated:

$S_{ed} = [(0{,}015 \times 13{,}0)^6 + (0{,}035 \times 20{,}6)^6 + (0{,}032 \times 10{,}9)^6]^{1/6} = 0{,}72$ MPa

The results indicate a moderate adverse health effect (0,5 MPa < Sed < 0,8 MPa) for a person who is exposed to these conditions during the whole working life.

Human vibration module in Dewesoft

A new Human vibration module can be added by clicking on Human vibration icon:

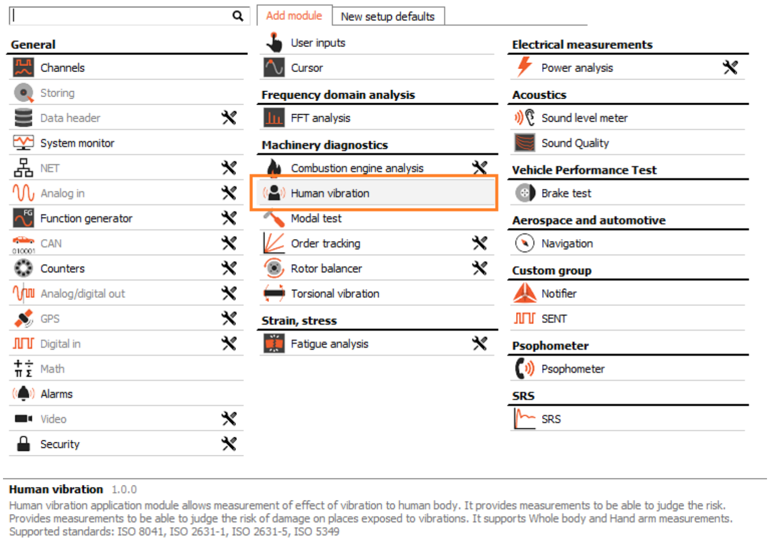
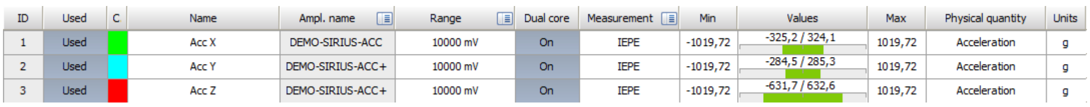


Image 12: Adding a new Human vibration module

Required hardware	SIRIUS ACC, MULTI, DEWE-43+DSI adapter
Required software	DewesoftX, SE or higher + HBV option, DSA or EE
Setup sample rate	At least 5 kHz

To use the human vibration module, please first select at least three vibration analog channels in the **Analog in** tab.



ID	Used	C	Name	Ampl. name	Range	Dual core	Measurement	Min	Values	Max	Physical quantity	Units
1	Used		Acc X	DEMO-SIRIUS-ACC	10000 mV	On	IEPE	-1019,72	-325,2 / 324,1	1019,72	Acceleration	g
2	Used		Acc Y	DEMO-SIRIUS-ACC+	10000 mV	On	IEPE	-1019,72	-284,5 / 285,3	1019,72	Acceleration	g
3	Used		Acc Z	DEMO-SIRIUS-ACC+	10000 mV	On	IEPE	-1019,72	-631,7 / 632,6	1019,72	Acceleration	g

Image 13: An example of a triaxial accelerometer, each axis has its own channel

Then add a new Human vibration module. Several modules can be used within a setup, and we will need three channels for each module.

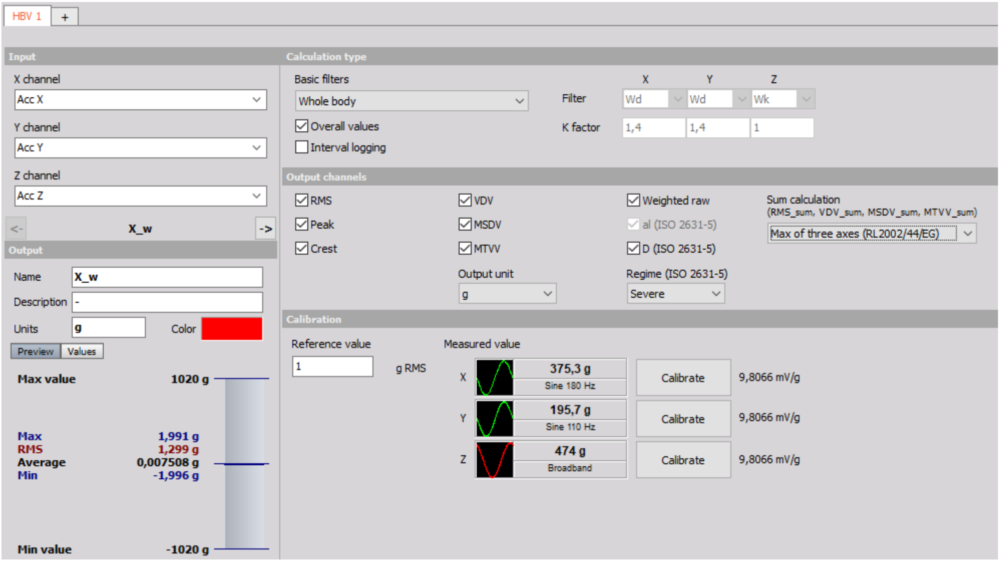


Image 14: Setup screen of Human vibration module in Dewesoft

The next step is to assign them in the Input section of the Human vibration module. We should then already see our live values in the calibration part of the screen.

Vibrations sensors

To learn more about the vibration sensor please take a look at the Vibration measurement course.

You will also learn how to use and calibrate accelerometers.

	I1A-50G-1	I3A-50G-1	I1TI-50G-1	C1T-5000G-1
				
Number of axis	single	triaxial	single	single
Sensitivity	100 mV/g	100 mV/g	100 mV/g	50 pC/g
Range	50g	50g	50g	5000g
Type	IEPE	IEPE	IEPE	charge
Frequency range	+/- 5 %: 0.3 to 5000 Hz	+/- 10 %: 2 to 5000 Hz	+/- 10 %: 0.3 to 10 000 Hz	+/- 8 %: up to 5000 Hz
TEDS	yes	yes	no	no
Features	miniature size	case isolated, triaxial	case isolated, industrial	high temperature
Dimensions	10,2 x 10,2 x 10,4 mm	15,5 x 15 x 15 mm	17,5 x 42,2 mm	12,7 x 24,4 mm
Weight	4,3 g	10 g	44 g	25 g
Temperature range	-51…+82 °C	-51…+82 °C	-51…+121 °C	-51…191 °C (up to 260 °C on request)

	I3T-500G-1	I3T-50G-1
		
Number of axis	triaxial	triaxial
Sensitivity	10 mV/g	100 mV/g
Range	500g	50g
Type	IEPE	IEPE
Frequency range	Axis 1 & 2: 1.5 to 5,000 Hz (+15/-5%) Axis 3: 1.5 to 10,000 Hz (+15/-5%)	+15/-10%: 0.3 to 10,000 Hz
TEDS	no	no
Features	lightweight; triaxial	low noise; triaxial
Dimensions	12,4 x 9,1 x 9,1 mm	21 x 12 x 11 mm
Weight	4 g	5,6 g
Temperature range	-51…+121 °C (up to 160°C on request)	-51…+82 °C

Image 15: Vibration measurement sensors

Measurement modes

The next step is to define the measurement parameters. There are two basic modes of operation. First is the Whole body mode and the second one is Hand-arm mode.

Different modes define different Basic filters used to simulate the human response to the vibrations. These filters are defined from numerous measurements of the natural frequencies of certain parts of the human body.

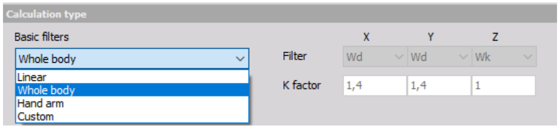
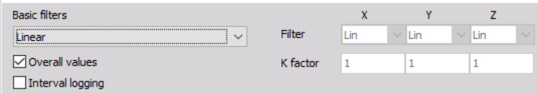
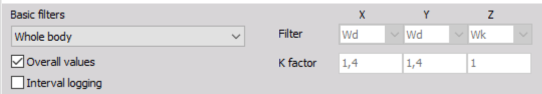
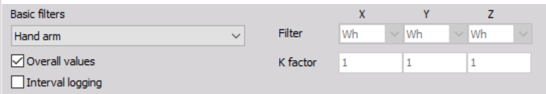
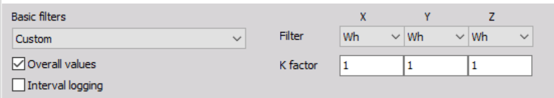
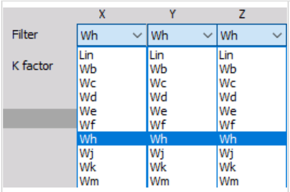


Image 16: Different calculation types in Dewesoft HBV module

Linear - individual Filter and K factor settings can't be chosen, these are predefined. We can also use the Linear filter to check the measurement chain.	 Image 17: HBV linear filter
Whole-body - individual Filter and K factor settings can't be chosen, these are predefined. Whole-body is used for motion sickness (for example on ships).	 Image 18: HBV Whole-body filter
Hand-arm - individual Filter and K factor settings can't be chosen, these are predefined.	 Image 19: HBV hand-arm filter
Custom - Filter and K factor needs to be defined.	 Image 20: HBV Custom filter

Custom filter

For Custom filter we need to define Filter X, Y and Z value: this individual value can be selected from drop-down lists on the right side to do special measurements (for example building vibrations or sea sickness). Filters are defined as following:

 Image 21: Filter selection for each axis individually	• **Lin** - unweighted linear • **Wb** - vertical whole body, z axis (older ISO 2631-4) • **Wc** - horizontal whole body, x-axis • **Wd** - horizontal whole body, x or y axis • **We** - rotational whole body, all directions • **Wf** - motion sickness, z axis • **Wh** - hand arm, all directions • **Wj** - vertical head vibration, an x axis • **Wk** - vertical whole body, z axis • **Wm** - building vibration; all directions

With a custom filter, we also need to define the weighting K factor. This is a multiplication factor for each axis when calculating the vibration sum.

I would like to point out that we need to keep in mind the high pass frequency limit of the sensor and the amplifier used. For hand-arm mode, the high pass frequency is 6.4 Hz, which is easy for any sensor. For the whole body, the frequency limit is 0,4 Hz, where we need to choose the sensor and an amplifier carefully (we have an option to integrate high-pass filter in the accelerometer different from standard one, that is 1 kHz - which is too high). We can also use higher filters (like 3 Hz), if we know there is no frequency content below this limit. This will help to perform a measurement faster and with less error (lower frequency filters means longer settling times).

The recommended sampling rate of the measurement also depends on the application. For hand-arm, the minimum sampling rate is 5 kHz while for all the others 1 kHz is enough.

Special attention must be paid to the whole body filter for motion sickness (for example on ships) where the frequency limit is only 0,08 Hz. We need a very special sensor to measure this. One, that can be used, can be found here. It is a DC accelerometer, with micro-g resolution and it has a range from 2g to 200g.

Image 22: DC accelerometer for motion sickness measurement

Calculated parameters IN HBV module

Next, we need to select the calculated parameters on the Calculate type section. These parameters can be either Overall values, which means that we have only one value at the end of the measurement, and/or Interval logged values. If we have an interval logged values, the time interval for logging in a contiguous field is defined in sec. For example, if we select to have Interval logging for RMS with 5-second intervals, we will get a new value of RMS after each 5-second interval. After that, the value is reset and the calculation is started again over.

Image 23: Overall or Interval logging

We have several parameters to calculate.

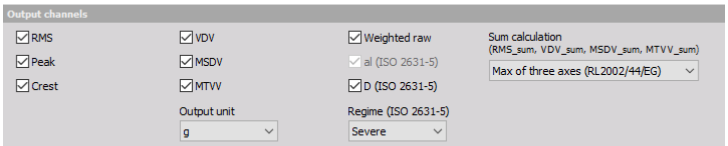


Image 24: Output channels from HBV module

- The "root means square" (abbreviated RMS) value is a statistical measure of the magnitude of a weighted signal
- Peak is the maximum deviation of the signal from the zero line
- Crest is the ratio between the peak and RMS
- VDV is the fourth power vibration dose value
- MSDV is the motion sickness dose value
- MTVV is the maximum transient vibration value, calculated at one second interval.
- Weighted raw channel. This is the full speed time signal weighted with a chosen filter. We can use those channels for the calculation of the FFT or CPB spectrum
- al and D are the values based on ISO 2631-5 which describe the calculations and the limits for lumbar spine response to vibrations. The base for this standard is that the professional drivers of buses or trucks are exposed to vibrations when driving on rough roads or over bumps. Multiple shocks cause transient pressure changes at the lumbar vertebral end plates which can cause damage after years of driving. The al is the lumbar spine response from excitation measured in all three directions. The D value is the acceleration dose, measured from the lumbar spine response. These values are enough to evaluate the human vibration exposure according to ISO 2631-5.

Name	Description	Unit	Output type	Output rate
RMS_X	RMS value of the signal	g m/s^2 mm/s^2	Single value	One value per measurement
Peak_X	Maximum deviation of the signal from the zero line	g m/s^2 mm/s^2	Single value	One value per measurement
Crest_X	Ration betweem peak and RMS	/	Single value	One value per measurement
VDV_X	Fourth power vibration dose value	$\left\{ \begin{matrix} g \\ m/s2 \\ mm/s2 \end{matrix} \right\} * s^{0.25}$	Single value	One value per measurement
MSDV	Motion sickness dose value	$\left\{ \begin{matrix} g \\ m/s2 \\ mm/s2 \end{matrix} \right\} * s^{0.5}$	Single value	One value per measurement
X_w,	Full speed raw weighted time signal	g m/s^2 mm/s^2	Synchronous	Full rate
alX	Lumbar spine response to vibrations	g m/s^2 mm/s^2	Synchronous	AI – full rate; Alz - 160 Hz
DX	Acceleration dose	g m/s^2 mm/s^2	Single value	One value per measurement

Image 25: Output channels with description, unit, type and rate

Output unit can be selected from:

- g
- m/s2
- mm/s2

Each value is calculated for each axis individually while the RMS, MSDV, VDV, and MTVV are also calculated for the sum of all three axes. These values are enough to evaluate human vibration exposure according to ISO 2631 and ISO 8041.

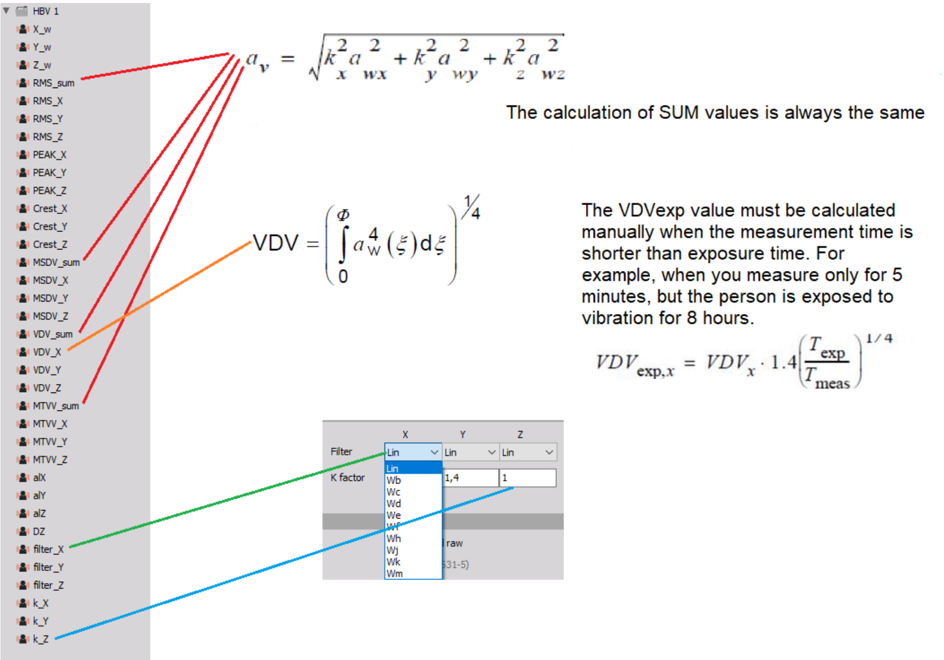


Image 26: Calculation of output parameters from the HBV module

How to calculate Daily vibration exposure with Dewesoft

For a simulation of an acceleration input, we have created a math channel, with a sine wave with known frequency and amplitude.

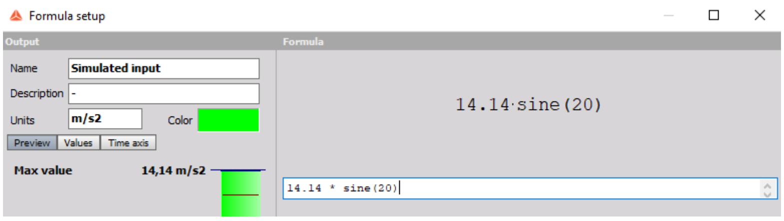


Image 27: Simulated vibration input with formula setup in Dewesoft

Lower case a is used when addressing root mean square values of acceleration in human vibration. The three frequency-weighted acceleration components are denoted a_{hwx}, a_{hwy} and a_{hwz}. These are then combined with the so-called vibration total value, a_{hv}, the root-sum-of-squares of the three components:

$$a_{hv} = \sqrt{(k_x a_{hwx})^2 + (k_y a_{hwy})^2 + (k_z a_{hwz})^2}$$

To get the RMS value of acceleration in human vibration select the input channels and select the RMS output channel.

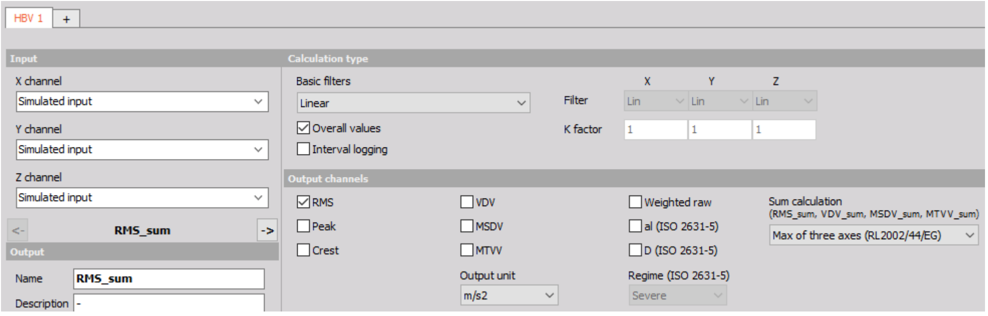


Image 28: RMS value calculation in Human vibration module

The daily vibration exposure A(8) is calculated from this vibration total value:

$$A(8) = a_{hv}\sqrt{\frac{T_{exp}}{T_0}}$$

For calculation of A(8) we create another math channel.

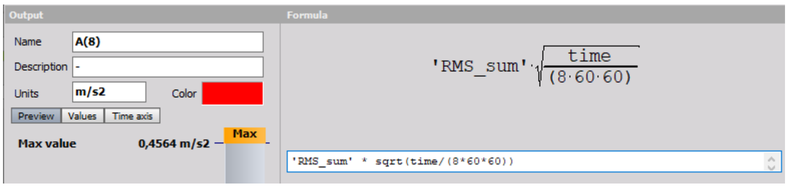


Image 29: A(8) calculation with Formula setup in Dewesoft

Where T_0 is the reference duration of 8 hours and T_{exp} is an estimate of the time that the tool operators are exposed to the vibration or the duration of the entire operation including breaks. If a person is exposed to more than one source of vibration, a partial vibration exposure Ai(8) for each operation i is to be calculated:

To get a maximum value of the daily vibration exposure we use Basic statistic math inside Dewesoft X.

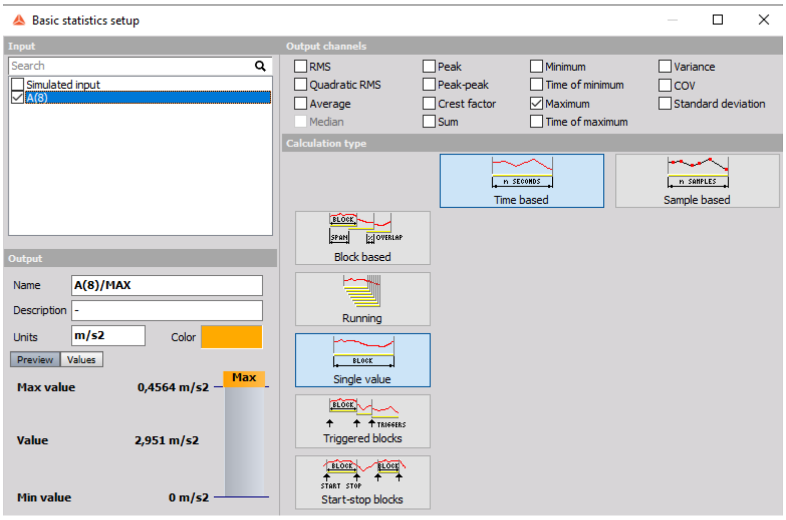


Image 30: Maximum value of daily vibration exposure using Basic statistics module in Dewesoft

Example of SEAT measurement in Dewesoft X

Determination of Seat Effective Amplitude Transmissibility (SEAT) does not directly give information about human exposure to vibration. The goal of the measurement is to determine the capability of a seat design to attenuate the vibrations present in a vehicle - to protect the driver from excessive vibrations.

The measurement involves a determination, of the vibration magnitude at two positions. For this example, we created two simulated channels (acceleration).

1.) Acceleration directly on the floor of the vehicle right underneath the seat

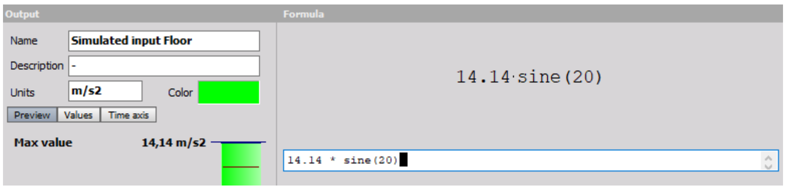


Image 31: Simulation of floor vibration

2.) Acceleration on the seat pan

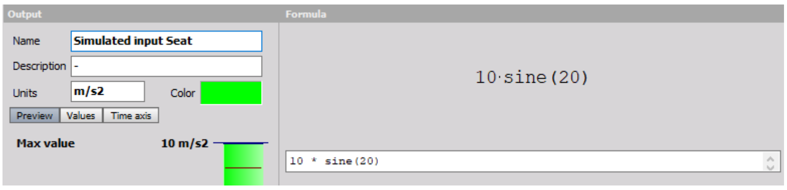


Image 32: Simulation of seat vibration

In order to calculate SEAT values, two instances of the Human vibration module need to be added.

The first one calculates the RMS of the floor vibration.

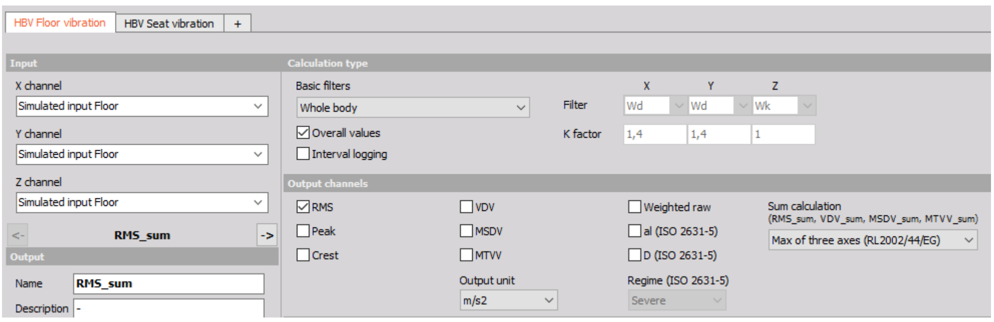


Image 33:RMS of the floor vibration

The second one calculates the RMS of seat vibrations.

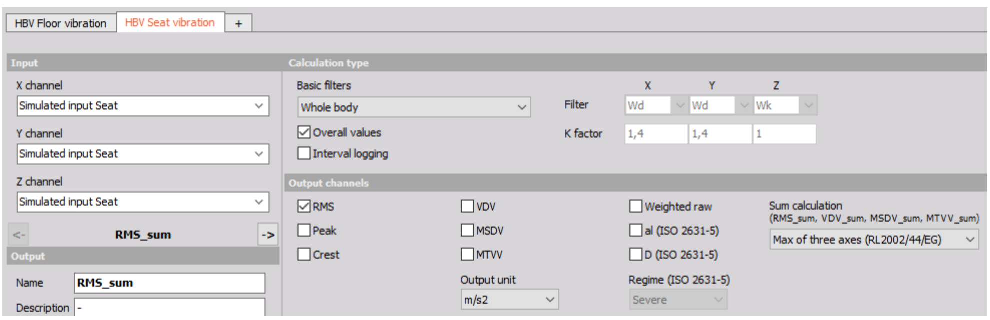


Image 34: RMS of the seat vibration

The daily vibration exposure is calculated according to the equation for A(8).

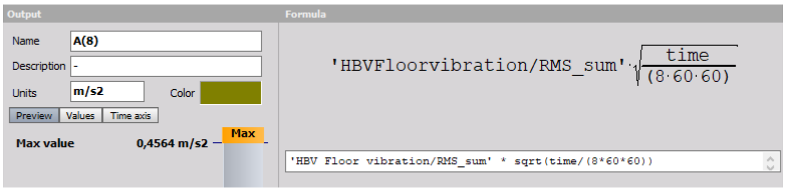


Image 35: Daily vibration exposure for floor vibration

The maximum value of daily vibration exposure is calculated with Basic statistics in Dewesoft.

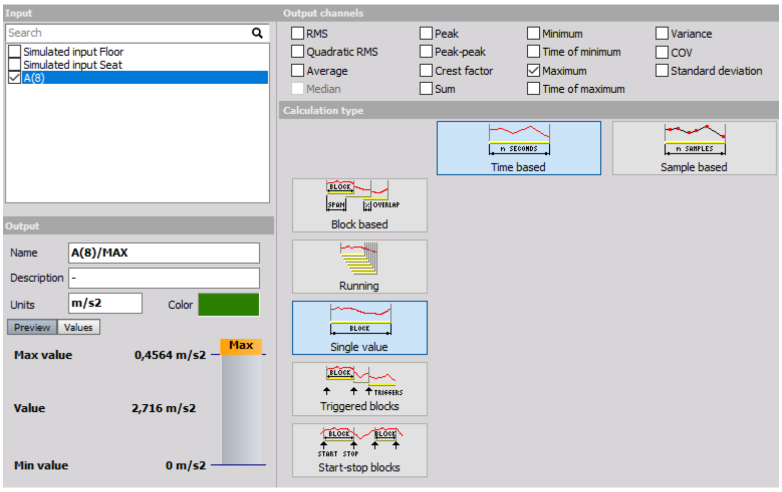


Image 36: Maximum value of daily vibration exposure

SEAT is computed as the ratio between the magnitude of seat vibrations and the magnitude of floor vibrations. To express SEAT, we may use the frequency-weighted RMS vibration magnitudes (a_w) or the VDVs. Rather than just using the ratio (a SEAT factor), we may multiply the result with 100 to express the seat effective vibration amplitude in percent.

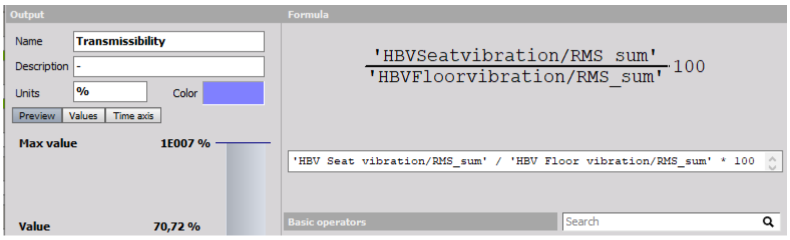


Image 37: Formula for transmissibility in Dewesoft

In the measurement screen, the visual controls can be added freely. On the left side, we have floor vibration values and on the right side we can see seat vibration values. The transmissibility is expressed in percentage (%) and is the ratio between those two values.

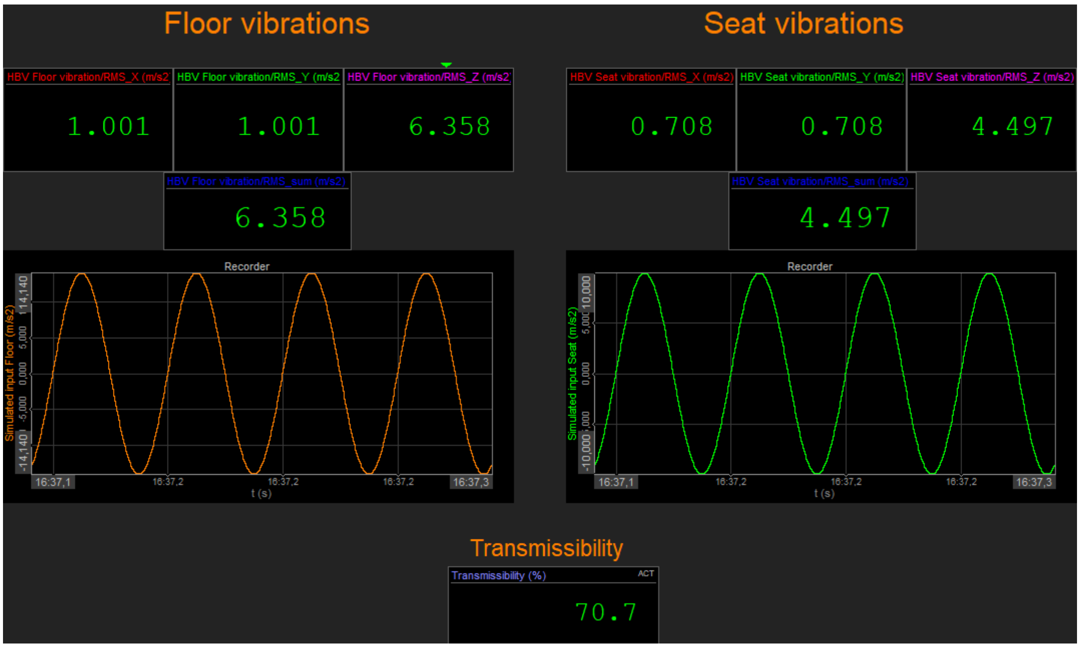


Image 38: Measurement screen for SEAT and Transmissibility measurement

Measurement example of human vibration on a motorcycle

The human vibration module does create a display automatically.

On the image below there is an example of Human vibration done on a motorcycle.

The tri-axial accelerometer was attached to a steering wheel to measure hand-arm vibrations.

The driver was sitting on a seat pad sensor to measure whole-body vibration.

Some applications require the user to measure the CPB or narrowband FFT. For this, we need to enable the weighted raw channels and select them in the FFT or CPB display. This will give us the weighted frequency spectrum of the signal. The CPB spectrum will be slow since the bands with low frequencies need a longer time to recalculate.

With DS-IMU2 we measured position and speed.

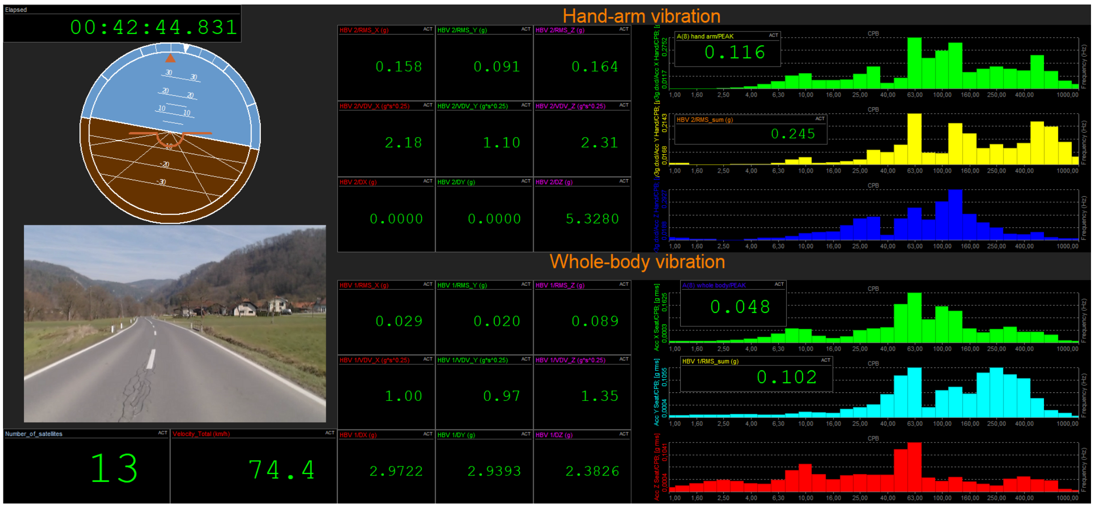


Image 39: Measurement of hand-arm and whole-body vibration on a motorcycle

Dewesoft X does not offer just raw numbers - we offer also time domain and frequency domain analysis in real-time. This is the key point in research!