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Good Practice Guide on the USE OF INSTRUMENTATION TO MEASURE VIBRATION AFFECTING PEOPLE

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Preface

This guide aims to assist in identifying good measurement practice in relation to vibration measuring equipment likely to be employed when assessing the effects that vibration has on people. It is not a textbook, and can be used section by section without the need to read all that has preceded it. This does mean that certain key facts are repeated between sections where relevant, but it is hoped that this approach enables a fast-find route to information without the need to continually cross refer to other sections of the Guide. Key points and facts are to be found in green-tinted sections of the text. The contents pages also give a brief overview of what each section contains. Use of the Guide alone will not fully equip anyone with all the knowledge required to measure vibration, as this is probably a never-ending saga, but is intended to provide a basic platform of knowledge on the instrumentation requirements to enable measurement to take place that approaches best-practice status.

The Guide has been developed under the auspices of the National Measurement System Directorate (NMSD) of the DTI, Project ref. no. GBBK/1/13c item 2.3 This project was in two parts, 2.3.1 undertook to evaluate the uncertainties of measurement associated with a range of commercially available instrumentation applicable to human response to vibration, whilst 2.3.2 produced this Guide. A.V.I. Acoustic and Vibration Instruments was awarded the competitively tendered project, and the programme of work was completed in June 2004. For more information on section 2.3.1 reference should be made to the DTI as this is the subject of a separate report by AVI.

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Use this section to decide what equipment is required and what data should be gathered.

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SECTION 1 - INTRODUCTION

1.1 PURPOSE OF THE GUIDE

The aim of this guide is to provide a quick reference source of information on equipment and methods to measure hand-arm and whole body vibration.

It is arranged in sections that should enable the reader to move directly to the relevant topic without the need to read all that precedes it, whilst finding enough information to establish vibration measurement that is both relevant to the task being undertaken and executed in a reliable manner.

The reader is assumed to have a degree of knowledge about vibration in general, but requires more guidance with respect to its measurement.

Vibration that affects people is measured for many reasons, but principally to establish a person's exposure level, so that vibration exposures likely to damage people's health can be avoided. This guide is relevant to both those who need to define the exposure a given person experiences and to those who declare vibration emission levels from vibrating sources such as power tools.

The Physical Agents (Vibration) Directive (PA(V)D), Directive 2002/44/EC has now been published by the European Union. The action values and limits it defines will affect a wide variety of people in a working environment. To implement this in the U.K., the Health and Safety Executive will be issuing the "Control of Vibration at Work Regulations" in 2005. The need for more knowledge of exposure levels will require more measurement to be undertaken than has previously been the case. This guide should provide the basic information to allow this data to be gathered in a robust fashion.

This guide is concerned with instrumentation and measurement to define what a person may experience.

1.2 DEFINITIONS OF TERMS AND QUANTITIES MEASURED

Acceleration – a rate of change of velocity used to describe vibration magnitude. It is also the effect the earth's gravity produces, a rate of change of 9.81 meters per second per second (m/s^2), usually referred to as 1 g.

Vibration – is produced whenever a solid body moves with some form of oscillating motion. This motion may be quite random or repeat rapidly or slowly. When the solid body interacts with a person, it causes reactions that can have far reaching consequences on the health and well being of that person.

Hand-Arm vibration – vibration transmitted to the hand, arms and upper torso of a person by hand contact with a vibrating source, e.g. using hand-held power tools such as grinders.

Whole body vibration — vibration transmitted to the human body by contact at the supporting surface (buttocks, feet etc.), e.g. from sitting or standing in a moving vehicle on rough terrain.

m/s² — the SI unit of acceleration.

r.m.s. — the root-mean-square of a signal. The integral of the second power of the frequency weighted instantaneous acceleration in m/s^2. This produces the value over a defined time interval and is the most common unit displayed on measuring instrumentation for the instantaneous value being measured.

Frequency weighting — the adaptation of the measured frequency response to the normal perception of human beings.

Peak — the maximum instantaneous positive or negative acceleration value over the frequency range of interest.

VDV — Vibration Dose Value of a signal. The integral of the fourth power of the frequency weighted instantaneous acceleration in $m/s^{1.75}$ as defined in ISO 2631-1.

EAV — Exposure Action Values. The vibration daily exposures set in the EU Physical Agents (Vibration) Directive as requiring control for Health and Safety purposes.

ELV — Exposure Limit Values. The daily vibration exposures set in the EU Physical Agents (Vibration) Directive as the maximum permitted, which is not allowed to be exceeded.

1.3 RELEVANT STANDARDS

There are many National and International Standards covering vibration measuring instrumentation and measurement.

The International Standards Organisation (ISO) publishes a very comprehensive set of documents covering many aspects of vibration measurement. Principally, these include:

ISO 8041:1990. Human response to vibration – Measurement Instrumentation
This defines the requirements for all instrumentation used to measure human response to vibration.

NOTE: THIS STANDARD IS BEING REVISED AND WILL BE REPLACED BY ISO8041:200X, publication expected in 2005.

ISO 2631-1:1997. Mechanical vibration and shock – Evaluation of human exposure to whole body vibration.

Part 1: General Requirements.

This defines the measurements to be made for whole-body vibration experienced by a seated person.

ISO 5349-1:2001 and ISO 5349-2:2002. Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration.

Part 1: General requirements

Part 2: Practical guidance for measurement at the workplace.

These define the methods for making hand-arm vibration measurements relating to people

BS EN14253:2003. Mechanical vibration – Measurement and calculation of occupational exposure to whole-body vibration with reference to health – Practical guidance.

Reference to these Standards is strongly recommended, and these documents can be purchased from the British Standards Institute (BSI). Contact details for BSI and many other Standard Authorities will be found in Annex A of this Guide. BSI also publishes some British Standards to support both general and particular vibration measurement tasks.

1.4 WHY MEASURE VIBRATION AT ALL?

Vibration affects people in many different ways. The most common health effects include Hand-Arm vibration syndrome (HAVS) and Vibration White Finger, where problems of blood circulation cause loss of sensory perception in fingers and hands, and back pain problems associated with prolonged exposure to whole body vibration. These and other health effects can produce a significant reduction in the quality of life for the people affected by vibration exposure. It is to avoid these effects that the limits set in the Physical Agents (Vibration) Directive and elsewhere are seeking to address. A secure knowledge of the actual exposures and recommended limits, together with appropriate action to reduce exposures below the recommended limits, should spare many people from the health problems that have been suffered in the past.

Representative vibration measurement requires both care and time. High quality equipment is available but is not low-cost, while time to measure always incurs a variety of costs. An alternative approach to measuring a person's exposure where people are using tools or work practices that are standardised is to take declared vibration emission values from the manufacturers or suppliers. Declaration of these emission values is mandated by the European Union, and a knowledge of this value together with information on their daily usage does allow an assessment of the vibration exposure of the tool operator to be made. These standardised measurements can be made with the type of equipment covered in this Guide.

Data from many different sources shows that this approach, whilst likely to give an indication of the daily exposure, is unlikely to give the true levels the operator experiences. The test conditions under which the emission values are measured often underestimate the levels found in real life situations, and many of the test codes (ISO 8662 series especially) are currently being reconsidered.

Measurement is the only method that will give confidence in the actual levels being experienced by a person, but note that it does not guarantee an accurate answer, even if measured very carefully.

There will always be some degree of uncertainty in any measurement, as will be covered later in this Guide.

If the daily exposure produced from available data is well below any action values, then relying on this data may be sufficient. However, when the levels are anywhere near the action values, the only means of being certain of the exposure is to measure them. Even then, variations can be expected due to different tasks and conditions under which the operator is working, so a very precise value is not to be expected – even with top quality equipment and best measurement practices. Note that an employer does not have to be absolutely certain of all exposures experienced by the workforce. However, control measures should be in place where there is an assumption that the Exposure Action Value is likely to be exceeded.

Data from many vibration source measurements made in different circumstances is gradually being acquired by a variety of interested parties including vibration consultants, tool manufacturers and universities. In the future, it may be possible to rely more on data from these sources to predict exposure without the need to actually measure it each time, especially if the data has "in-use" characteristics similar to those requiring exposure assessment. It will probably be many years before this type of data is freely available to all interested parties, However, investigation of currently available data may save significant time and effort in establishing calculated exposures.

At present, therefore:

Actual measurement will always give the best information available on the person's exposure and has to be the recommended course of action where uncertainty of exposure levels exists (e.g. lack of suitable data) or where measures taken to reduce exposure are unquantified.

Note: Although this guide is applicable to measurements of motion sickness and comfort, these may require more specialised information than is presented here.

SECTION 2 – WHAT'S NEEDED TO MEASURE VIBRATION?

This section outlines the equipment and accessories required to make most hand-arm or whole body vibration measurements.

The range of vibration sources is huge, and there may be the need for more specialist items for the more unusual sources, but with thought before measurement commences, some of the equipment covered in the following sections will give adequate measurement accuracy in most circumstances. The basic measuring system will include a transducer such as an accelerometer to attach to the source of the vibration, some suitable processing of the electrical signal from this device, and a means of displaying the results in units applicable to the task in hand.

2.1 HAND – ARM VIBRATION

An everyday source of hand-arm vibration exposure for many people

2.1.1 INSTRUMENTATION

a) ISO 8041 Requirements

The principal Standard that applies to the measurement equipment on sale in the UK today is ISO 8041:1990 (currently with Type 1 and Type 2 accuracy grades, but these will merge in the current revision). The use of equipment that does not claim to meet this Standard is not recommended, neither is the practice of converting sound level meters to measure vibration with a "vibration adaptor" that replaces the microphone — unless this fully meets the requirements of ISO 8041.

Many of the requirements given in this Standard are not supported by tests to prove that the instruments meet the Standard, and there is no Standard at all for vibration exciters or calibrators, which should be used to check the measuring instrumentation before and after use. These omissions currently make it difficult to check fully whether instrumentation is working correctly and to get it tested at calibration laboratories in a consistent manner.

These omissions are being corrected in a completely revised version of ISO 8041 that is due for publication in 2005. This will supersede the 1990 edition, and should lead to a more uniform approach to instrumentation and its calibration, but may take some time to improve the consistency of instrumentation on sale. In general, the new version will require improved performance in all areas of the instrument's specification.

b) Hand-held or Mains Operated

Unless there are significant reasons for using mains operated equipment, battery operated equipment is available for almost all measurement tasks and has the advantages of avoiding errors due to induced effects caused by the mains voltage supply. The particular problem that often occurs is called an earth loop, where the signal common terminal and the mains Earth connection form two similar but different connections to the measuring equipment. This can cause errors in the signals measured that may not be apparent at the time of measurement. With battery operated equipment, this problem is usually avoided. Battery operated instruments will also simplify field measurement work. Computer based systems, which may be operable from either power source, can provide more extensive analysis capabilities, but may not be sufficiently rugged for all applications.

c) Basic Parameters to be Measured

The most common parameter required is the *acceleration* level, normally expressed in either m/s^2 or g (the acceleration due to gravity = 9.81 m/s^2). Measurement in terms of acceleration is the main requirement in the EU's Physical Agents (Vibration) Directive [PA(V)D].

Some other standards call for the *velocity* to be measured (in m/s), and information about the *displacement* (in m) may also be required. All three parameters can be obtained by measuring with an accelerometer as the transducer, and processing the measured signal electronically to obtain the desired data, as for many other computed parameters.

In addition to the instantaneous value of these parameters, an instrument should record the true r.m.s. exposure over time (A_{eq}), together with any overloads of the instrumentation that have occurred. These parameters form the basis of all commonly required measured data. It is often useful to have available the maximum r.m.s. level over time, the true peak and the maximum peak over time, but these are not essential unless investigative work into product design and improvement is the object of the measurement.

d) Weighting Curve

The human response to vibration is not equally sensitive to all applied frequencies. For most hand-arm vibration sources, frequencies in the range from 4 Hz to 2000 Hz are of principal interest, but these need to be adjusted or weighted to take account of their likely effect on people.

For vibration measurement, a large number of different weighting curves have been defined. These are defined as W_v where v is the weighting for the task in hand.

Of these W_h is the only one relating to Hand-arm vibration and is always required for any hand-arm measurement. It has small, well-defined tolerance values between 6.3 Hz and 1250 Hz, with less precision above and below these frequencies. It applies to any axis of measurement.

2.1.2 TRANSDUCERS

The choice of transducer can have a significant effect on the accuracy of the measurements obtained, so care is needed in this area. The weight or mass of the transducer will have an effect on the vibration source, which suggests that a device that is small and lightweight would always be preferred. This may need to be offset by transducer sensitivity, as it is still largely true that if you want a large output signal from your transducer, it will require a bigger physical size (and therefore mass) to produce this output.

Various masses have been suggested as maxima, but as a guide, keeping the total mass, including any mounting device, to less than 50 grams is a starting point. Use less if the source of vibration is itself lightweight, where the transducer mass is recommended to be less than one twentieth of that of the source. This is particularly important when measuring on lightweight tool handles, often made of hollow plastic, where the transducer mass may modify the vibration emitted.

a) Charge or Voltage Outputs

There are many different types of accelerometer on the market. Principally these offer two types of electrical output, a voltage or a charge proportional to the measured signal. This only affects the instrumentation connected to the transducer in that charge output devices require a charge amplifier to convert the input to (usually) a voltage before measurement of the signal commences. Either the measuring instrument must have a charge amplifier fitted internally to allow these transducers to be used, or a separate charge amplifier must start the measurement chain, which usually make the measurement system more expensive to purchase.

Charge transducers have outputs expressed in $pC/m/s^2$ or pC/g (where pC is pico Coulombs and g is the acceleration due to gravity = 9.81 m/s^2), whereas voltage types will usually be in $mV/m/s^2$. Charge output devices are almost unaffected by the length of cable that can be attached to them, so have benefits where long cable lengths are need to access the measurement point.

Voltage output devices can usually support fair lengths of cable (e.g. 5 m), but some types will suffer from changes in their frequency response if longer cables are used. The manufacturer should be able to supply information on cables if requested.

b) Transducer Construction

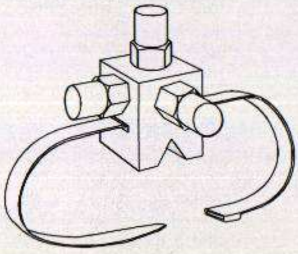
Transducers are often referred to as Piezo devices. This is due to their construction from a crystalline material that generates a signal when stressed correctly. There are two different types which have different properties.

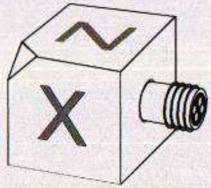
Piezoelectric types only produce an output proportional to the applied strain, so produce no output unless attached to a source of vibration. They normally produce charge outputs, but many newer models fit miniature charge amplifiers inside the transducer to give a voltage output. These are usually referred to as ICP types.

Piezo resistive types are constructed in a "bridge" arrangement that produces an output due to the earth's gravitational field, and therefore have a frequency response which extends down to d.c. This output, which must be accounted for when measuring, will change polarity if the transducer is inverted. To avoid this effect, it is simpler to use piezoelectric types for measuring hand-arm vibration, but the extended low-frequency response may be of great value for some whole-body measurements.

c) Single Axis or Triaxial Transducer

In the past, to avoid the necessity of full triaxial measurement capability, many hand-arm measurements were made using single axis devices, and additional axis information gleaned from moving the transducer. This was because the "dominant" axis was always to be the one reported. This changed in 2001 when full triaxial data became the requirement to conform with ISO 5349-1 and subsequently to the Physical Agents (Vibration) Directive.





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Three single transducers on mounting block

Single block device

Triaxial Transducers

Using a single transducer for each axis is permitted, but the method then requires separate leads to each of the three transducers being used. The downside of this may be the total weight of the transducers and the mounting device keeping them orthogonal. The mass criterion for the transducer/mount combination does not change just because there are now three transducers!

The measurement chain must read three signals accurately all the time, not just one. There are instruments that attempt to read all three signals with just one measuring channel, using high speed switching techniques, but there are often inaccuracies with this method so this is not usually a recommended approach.

Another parameter that may need checking is the transverse sensitivity of the three accelerometers in the transducer. The effects of vibration on one axis must produce (ideally) no output from either of the other two axes. In practice output levels of <5% of the axis under vibration is normally acceptable. Cost, time and accuracy need to be considered before a final choice is made.

d) Other Transducers

There are transducers available that give outputs which are proportional to either the velocity of the source or the magnitude of its displacement. For the measurement of hand-arm vibration, these are of limited use, as it is difficult to produce the acceleration information normally required directly from these transducers.

For specialist applications, they may have advantages as displacement tends to be largest at low frequencies, and velocity often gives a larger output signal than acceleration across the range of frequencies of interest. However, the signals of interest to the majority of people measuring hand-arm vibration are sufficiently large that the advantages these other transducer types may offer is not normally a relevant factor.

2.1.3 BASIC CHARACTERISTICS REQUIRED

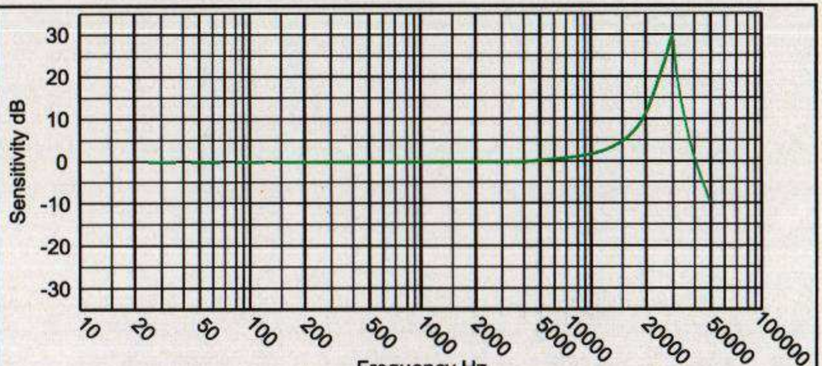
a) Size

The size of the transducer should (ideally) be as small as possible, to allow it to fit as close as possible to the hand position on the vibration source but still allow full operational capability of the source. Modern accelerometers are often of the cylindrical style, approx. 15 mm diameter and 10 – 20 mm tall. The cable connection can be side or top mounting. Both size and mass are gradually being reduced with no loss of sensitivity with newer designs.

Triaxial versions are similar in size, but are often rectangular. The surface designed to mate with the vibrating source must be ground to a high degree of surface flatness to ensure the best coupling to the source and should always be kept clean. Larger devices than suggested here may be too heavy for the task in hand.

b) Frequency Response

The ideal transducer has equal response to all frequencies in the range of interest, and the 4 – 2000 Hz range already quoted is a useful guide, however, the measurement requirements are specified in the Standards from 0.8 Hz to 4000 Hz.



Frequency characteristic of a typical piezoelectric accelerometer

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Most transducers have excellent response to low frequencies, and are usually limited in their accuracy here only by the processing electronics measuring the signal. At high frequencies, the mounted resonance of the transducer must be considered.

All transducers will have this resonance, and it is affected by the method of mounting the transducer, but it is a good guide to ensure that the resonance quoted by the manufacturer of the transducer is at least four times the upper frequency of measurement interest, as this will allow the mounting to degrade this somewhat without influencing the measurement accuracy to any extent.

c) Dynamic Response

The transducer must respond accurately to sudden changes in applied vibration. There are very few defined tests to quantify the accuracy of these changes for the transducer, although there are tests performed on the instruments themselves where an electrical signal is substituted for the transducer. Most transducers appear to have adequate capability, but the phenomenon of d.c. shift (in piezoelectric transducer types only) must be borne in mind.

d.c. shift may occur when a very large "shock" is applied to a piezoelectric transducer measuring percussive vibration sources such as road breakers, rivet guns or chipping hammers. The transducer is principally being used to measure quite small signals, so a sudden large one can cause a temporary shift in the transducer's background signal output level. Whilst the effects of this shock are decaying, the transducer gives an output, usually as a slowly changing d.c. voltage, that should not be present, where this voltage can be of the same order as the hand-arm signal being measured. It is usually low-frequency, but can cause spuriously high readings on sources that have percussive actions sufficiently often that the transducer does not "recover" between "shocks".

In triaxial measurements any of the three axes may be affected, regardless of which axis or axes are dominant. However, the measuring range of piezoelectric transducers is often best suited to Hand-arm measurements, so for many applications they are the best choice.

Voltage output transducers will be limited by the power supply arrangements used to activate them. The dynamic range of these devices is often adjusted by the manufacturer to suit the intended measurement levels, so care should be taken to select the appropriate sensitivity, and ensure that overload indicators in the measurement instrumentation show if transients have exceeded the maximum specified output levels.

d) *Cabling*

The problem of the cable connecting the transducer to the measuring system is often the "Achilles heel" of the measurement process. It is unfortunate that a cable is needed at all, but as almost any other system is either heavy or extremely expensive, it is likely to be something that will be present for some time to come.

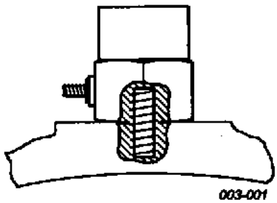
The cable should always be fixed to the same structure as the transducer wherever this is possible. Tape or clips can be used, and there should be a small amount of slack in the cable between the transducer and the cable fixing. This will also reduce the flexing of the transducer/cable joint.
To use no cable fixing at all is a recipe for trouble.

Moving cables can generate their own signal, known as the triboelectric effect, especially with piezoelectric transducers. Therefore restricting the vibration to which the cable is subjected prevents spurious signals from being measured by the instrumentation.Cable assemblies that fully detach from the transducer may be preferred as damage to a cable fixed to a transducer may require replacement of the whole item. Possessing a spare cable is highly recommended as whole measurement sessions can be halted *if* just one cable connection fails.

2.1.4 MOUNTING

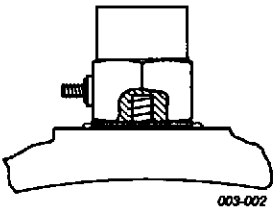
Mounting the transducer correctly is the most worthwhile investment in measurement accuracy that you can make. The transducer must be mounted as rigidly and with its mounting surface as flush to the source of vibration as possible.

Where this is not possible, the best available compromise may have to be used, but in the approximate order of preference suggested here:-



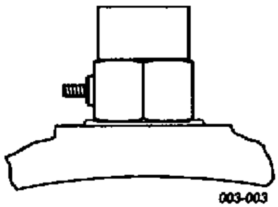
Tapped stud mounting

a) Drill and tap a stud into the source and screw the transducer to it, making sure the whole of the transducer base is flush with the source.



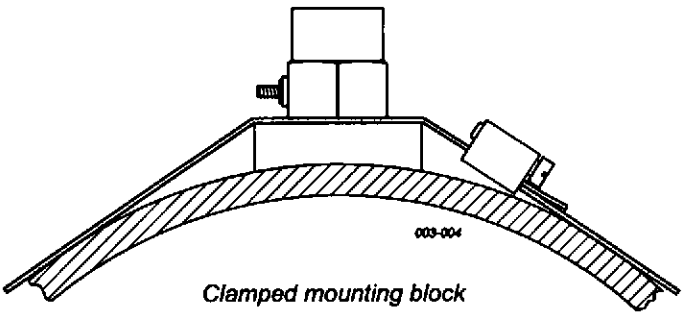
Glued stud mounting

b) Glue a stud fixture to the source using an epoxy or cyanoacrylate cement, or any other adhesive that dries rigid, then screw the transducer to the stud.



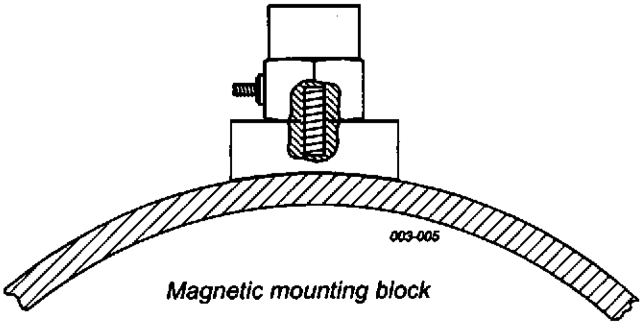
Beeswax mounting

c) Fix the transducer to the source using a layer of beeswax between the two, kept as thin as possible whilst retaining adhesion.



Clamped mounting block

d) Fix the transducer to a mounting block that can be strapped to the source using Jubilee clips, cable ties or other proprietary fixings. If plastic cable ties are used, they should be tightened with an appropriate tool as hand tightening is usually insufficient. Keep mass to a minimum.

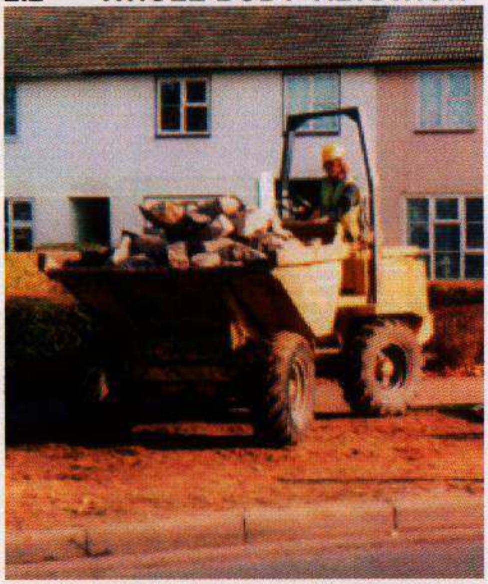


Magnetic mounting block

e) **For ferrous surfaces, use a permanent magnet that carries a stud fixing for the transducer (but keep total mass to a minimum).**

Hand-held mounts exist, including ones where the person experiencing the vibration also holds the transducers on to the vibration source. The results from these are usually extremely variable and the mounted resonance often falls within the bandwidth of interest. However, where there is no other alternative, it may be the only solution. **They are NOT recommended.**

2.2 WHOLE BODY VIBRATION



A common source of whole body vibration

The range of sources of vibration affecting the whole body is vast, and comes in many different forms. Unlike hand-arm vibration, which at least is measured with respect to one section of the body, it can affect any part of the anatomy and different techniques may be required to effect correct measurement. This section concentrates on the aspects of measurement required for the Physical Agents (Vibration) Directive, and therefore does not cover in any detail the very low frequency effects on people such that cause motion sickness, where often even more specialised instrumentation is required due to the low frequencies being measured.

2.2.1 INSTRUMENTATION

a) ISO 8041 Requirements

The principal Standard that applies to the measurement equipment on sale in the UK today is ISO 8041:1990 (currently with Type 1 and Type 2 accuracy grades, but these will merge in the current revision). The use of equipment that does not claim to meet this Standard is not recommended, neither is the practice of converting sound level meters to measure vibration with a "vibration adaptor" that replaces the microphone – unless this fully meets the requirements of ISO 8041.

Many of the requirements given in this Standard are not supported by tests to prove instruments meet the Standard, and there is no Standard at all for vibration exciters or calibrators, which should be used to check the measuring instrumentation before and after use. These omissions currently make it difficult to fully check whether instrumentation is working correctly and to get it tested in a consistent manner at calibration laboratories.

These omissions are being corrected in a completely revised version of ISO 8041 that is due for publication in 2005. This will supersede the 1990 edition, and should lead to a more uniform approach to instrumentation and its calibration, but may take some time to improve the consistency of instrumentation on sale. In general, the new version will require improved performance in all areas of the instrument's specification.

b) Hand-Held or Mains Operated

In most cases, mains operated equipment will not be an option for measuring the most frequently-experienced sources of whole-body vibration. Unless there are significant reasons for using mains operated equipment, battery operated equipment is available for almost all measurement requirements and will simplify field measurement work. Computer based systems, which may be operable from either power source, can provide more extensive analysis capabilities, but may not be sufficiently rugged for all applications.

c) Basic Parameters to be Measured

The most common parameter required is the *acceleration*, normally expressed in either m/s^2 or g (the acceleration due to gravity = $9.81 m/s^2$). Measurement in terms of acceleration is the main requirement in the EU's Physical Agents (Vibration) Directive [PA(V)D].

Information about *velocity* (measured in m/s), and *displacement* (measured in m) may also be useful. All three parameters can be obtained by measuring with an accelerometer as the transducer, and processing the measured signal electronically to obtain the desired data, as for many other computed parameters

One parameter that can be used as an alternate metric to measure whole body vibration as specified in the PA(V)D, is the Vibration Dose Value (VDV). This is complex mathematically, but has the effect of making the result more sensitive to peaks in the measured signal. It is measured in $m/s^{1.75}$ and can be computed on measuring instruments designed for the purpose.

In addition to the instantaneous value of these parameters, an instrument should record the true r.m.s. exposure over time (Aeq), together with any overloads of the instrumentation that have occurred. Measurement of VDV may also be required. These parameters form the basis of all commonly required measured data. It is often useful to have available the maximum r.m.s. level over time, the true peak and the maximum peak over time, but these are not essential unless investigative work into product design and improvement is the object of the measurement.

d) Weighting Curves

The human body is not equally sensitive to vibration at all applied frequencies. For most whole body vibration sources, frequencies in the range 0.25 Hz to 160 Hz are of principal interest, but these need to be weighted to take account of their likely effect on people.

For vibration measurement, a large number of different weighting curves have been defined. These are defined as W_v where v is the weighting for the task in hand. Whole body weighting curves are dependent on the position and axis of measurement, and are therefore numerous. For full definitions of axes with respect to people see Section 4 of this Guide, but in general, the x-axis is front-to-back, y-axis is side-to-side and z-axis is up-and-down.

The main weightings required for the assessment of health effects are W_d which applies to the x and y axis of seated, standing or recumbent people, and W_k which applies to the same people in the z axis. These have small, well-defined tolerance values between 0.5 Hz and 125 Hz, with less precision above and below these frequencies.

There are weighting curves for measuring at the seat back (W_c), rotational vibration (W_e), motion sickness (W_f), head vibration (W_j) and vibration in buildings (W_m).

Fuller definitions of these weightings and their applications can be found in ISO 2631 (parts 1, 2, and 4) and ISO 8041 (see Annex A). There is also curve W_b which has similar attributes to W_k and is used in place of W_k in some older standards. W_b is now used only in ISO standards when measuring comfort in railway carriages.

It is important that the correct weighting curve is applied to the measurements undertaken, and care is needed to be certain the correct curve has been selected. Not all instruments have all the weighting curves fitted, so check the meter is fitted with the one needed for the task in hand.

2.2.2 NUMBER OF AXES

a) Seat, Back and Floor Mounting

It is becoming increasingly common to measure all three axes simultaneously on seat pads, but measurement on the seat back and floor of vehicles may be adequate using a single axis. However, the measurements required in the PA(V)D require the level of the dominant axis, where the measurements of the x- and y-axes are multiplied by 1.4 but the z-axis is direct. The 1.4 factor must be included when determining the largest amplitude measured.

A typical source of whole body vibration applied to the feet and the seat – a dump truck cab

The need to position transducers close to different parts of the body often leaves limited space for the transducers, and the need to switch a single axis transducer through all three orientations often causes problems with cabling and operator comfort. Instrumentation is often linked to triaxial transducers to enable the correct selection of weighting curves for the requisite axis automatically to avoid errors.

The most popular triaxial device especially for whole body measurements is the seat-pad transducer. Here three small accelerometers are mounted within a flexible pad that can be positioned at the contact or excitation point without unduly disturbing the comfort of the operator. It can be placed on the seat under the buttocks of any seated person, can be strapped to the seat back or the back of the seated person, or placed on the floor with (usually) some additional mass placed above it to keep it in position.

Other triaxial transducers can be used for surface vibrations e.g. the floor pan of vehicles that do not need the flexible pad. Mass is not usually a concern here, but it is important to ensure that they are rigidly fixed to the vibrating surface, as rough terrain vehicles can cause large jolts that must be measured correctly, and not include the transducer jumping about as well, which is where the seat-pad style transducer's use may be limited. Measurements on lighter or moveable structures such as steering wheels (for the hand-arm vibration effects) require careful instrumentation and cable connection and the transducer manufacturer should be consulted for the most suitable type available.

2.2.3 TRANSDUCERS

a) Charge or Voltage Outputs

There are many different types of transducer on the market. Principally these offer two types of electrical output, a voltage or a charge proportional to the measured signal. This only affects the instrumentation connected to the transducer in that charge output devices require a charge amplifier to convert the input to (usually) a voltage before measurement of the signal commences. Either the measuring instrument must have a charge amplifier fitted internally to allow these transducers to be used, or a separate charge amplifier must start the measurement chain, which will usually make the measurement system more expensive to purchase.

Charge transducers have outputs expressed in pC/m/s² or pC/g (where pC is pico Coulomb and g is the acceleration due to gravity = 9.81 m/s²) whereas voltage types will usually be in mV/m/s². Charge output devices are almost unaffected by the length of cable that can be attached to them, so have benefits where long cable lengths are need to access the measurement point. Voltage output devices can usually support fair lengths of cable (e.g. 5 m), but some types will suffer from changes in their frequency response if longer cables are used. The manufacturer should be able to supply information on cables if requested.

b) Transducer Construction

The accelerometers used in the transducer are often referred to as Piezo devices. This is due to their construction from a crystalline material that generates a signal when stressed correctly. There are two different types which have different properties.

Piezoelectric types only produce an output proportional to the applied strain, so produce no output unless attached to a source of vibration. They normally produce charge outputs, but many newer models fit miniature charge amplifiers inside the transducer to give a voltage output. These are usually referred to as ICP types.

Piezo resistive types are constructed in a "bridge" arrangement that produces an output due to the earth's gravitational field, and therefore have a frequency response which extends down to d.c. This output, which must be accounted for when measuring, will change polarity if the transducer is inverted and this feature can sometimes be used as a means of calibrating the measuring system as the two readings should be of equal magnitude. The extended low-frequency response may be of great value for some whole-body measurements.

A variety of triaxial transducers are available to suit most measurement requirements, and the use of single axis transducers for whole body measurements is becoming less common, except for seat back or vehicle floor measurements. Most whole body meters measure three axes simultaneously, although care needs to be taken over this, as some meters have only one measuring channel and switch this to each of the input signals in turn. This can produce some measurement errors in unexpected places and the need to verify the instrument's full performance against ISO 8041 is necessary to ensure these errors do not occur.

One item worth noting is the difficulty in making an effective calibration of some types of seat-pad transducer. As normally there is no means supplied for mounting this device in any axis on a standard vibration exciter, calibration checks on this device are often difficult for the user to make themselves. This is covered further in Section 4 of this Guide.

c) *Other Transducers*

There are transducers available that give outputs that are proportional to either the velocity of the source or the magnitude of its displacement. For the measurement of whole body vibration, these are of limited use, as it is difficult to produce the acceleration information normally required directly from these transducers. The phase response of velocity transducers can also give rise to errors when measuring VDV.

For specialist applications, they may have advantages as displacement tends to be largest at low frequencies, and velocity often gives a larger output signal than acceleration across the range of frequencies of interest. However, the signals of interest to the majority of people measuring whole body vibration are sufficiently large that the advantages these other transducer types may offer is not normally a relevant factor.

2.2.4 BASIC CHARACTERISTICS REQUIRED

a) *Size*

The size of the transducer is largely dictated by the position into which it is to be placed. Seat-pad type devices are not required to be particularly small or lightweight, but should ensure adequate grip between person and the source of vibration. Their dimensions should conform to those defined in EN1032. (see 4.2.a of this Guide)

Other positions measured may require lightweight devices when measuring low-mass sources, but for many applications mass is not particularly relevant. Getting a good contact with the source and maintaining it under all measurement conditions is more important.

b) Frequency Response

The ideal transducer has equal response to all frequencies in the range of interest, and the 0.25 – 160 Hz range already quoted is a useful guide, but the measurement requirements are specified in the Standards from 0.1 Hz to 400 Hz.

Most transducers have excellent response to low frequencies, and are usually limited in their accuracy here only by the processing electronics measuring the signal. The low frequency response is difficult to measure overall, and there is a lack of standard methods for verifying its accuracy. At high frequencies, the mounted resonance of the transducer must be considered. (See typical frequency response curve in Section 2.1.3 b)

However, as the mounted resonance frequencies of transducers are usually well above the measured frequency range, and the variety of mounting positions change these continuously, a transducer specification that shows it to be above 1 kHz will normally be adequate for the task in hand.

c) Dynamic Response

The transducer must respond accurately to sudden changes in applied vibration. There are very few defined tests to quantify the accuracy of these changes for the transducer, although there are tests performed on the instruments themselves where an electrical signal is substituted for the transducer. Most transducers appear to have adequate capability.

d) Cabling

The problem of the cable connecting the transducer to the measuring system is often the "Achilles heel" of the measurement process. It is unfortunate that a cable is needed at all, but as almost any other system is either heavy or extremely expensive, it is likely to be something that will be present for some time to come.

The cable should always be routed clear of anything that may impede the subject being measured, and keep clear as far as possible of any sources of electrical interference which may disturb the measuring equipment. Tape or clips can be used, and there should be a small amount of slack in the cable between the transducer and the cable fixing.

e) *Mounting*

As the variety of places to which the transducer is required to be mounted is almost infinite, no precise methods can be suggested for transducer mounting. It is important to ensure that the transducer, whatever type and wherever positioned, is in permanent contact with the vibrating surface at all times, and that the influence of the person on the fixing is as small as possible. The mounting methods shown in Section 2.1.4 may be suitable for some whole body measurements. Seat pad devices may be taped in position to ensure that the operator does not move it during the measurement interval.

SECTION 3 – HOW TO MEASURE HAND-ARM VIBRATION

Cutting tools can present significant hand arm vibration in situations where the arms and shoulders are not in ideal positions to cushion their effect

Before starting to make hand-arm vibration measurements, it is as well to consider the state of the equipment to be used, when the overall system was last calibrated (if at all), and to what application the measured data is to be put. Ensuring the equipment is in good working order, fit for purpose and having evidence of this to hand if required can save much time after the measurements have been made. Equipment calibrations should be traceable to National Standards.

When using this section to decide what equipment is required and possibly purchased, the sections will show the parameters of interest that need to be available from the instrumentation. This could form the basis of a purchase specification when tailored to the task in hand.

For the vast majority of hand-arm measurements taken, their use is to determine whether the person being assessed is receiving vibration exposures around or above the action value or limit value in the Physical Agents (Vibration) Directive. This section includes the measurement requirements to gather the necessary information, but for those wanting to measure the emissions from hand-held sources for product certification purposes, most of the information required is identical. However, data supplied by manufacturers should either state the test code used (if one exists) or describe the operating conditions used for the test. These conditions should attempt to resemble realistic usage of the device under test.

3.1 EQUIPMENT SETUP

a) Instrumentation

The equipment to be used should claim design accuracy to ISO 8041 currently specifying Type 1 or 2 instruments, (but shortly to be updated with these merged into one grade). For most general purposes, the lower accuracy of current Type 2 should be sufficient, but it is advisable to employ Type 1 where product certification tests are undertaken (although this is not mandatory) and where the vibration source is percussive.

A small, lightweight transducer that is recommended for use with the measuring meter and a suitable means of securely mounting this transducer on the vibration source and connecting to the meter via a suitable cable should be available.

The system should be capable of being checked against a known vibration source (not an "internal reference") from time to time, as well as before and after each measurement session if at all possible. (See calibration below.) Check the condition of batteries in portable equipment before commencing measurement, and replace if they are likely to run-out in the near future.

The more specific requirements are detailed in the following sections. In choosing an instrument to make these measurements, the parameters required must be fully known. The Data Gathered part of this section will show the most likely measurements required and the meter needs to be specified to measure all of these as a minimum.

b) Calibration

The measuring equipment should be calibrated prior to individual measurement usage by fixing the transducer to a known source such as a vibration exciter or calibrator and confirming or adjusting the displayed reading for correct data.

A number of manufacturers can supply vibration calibrators, and most of these are single level, single frequency devices that give confidence that the accuracy of the measuring system is acceptable. Instruments that claim some form of "internal calibration" but that do not include the transducer are of limited value as the most likely source of error today lies in the transducer and associated cabling, and not inside the meter itself. Single level, single frequency devices will not show that anything other than this one reading is correct.

From time to time, say every 1 – 2 years, it is recommended to have as much as possible of the whole measuring system checked at a calibration laboratory.

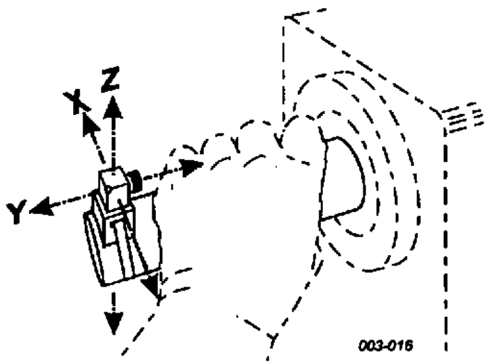
At present in the UK there are only a few laboratories offering this service, as at present there is no standard test procedure for them to work to and therefore to certify to a defined Standard. This will change when the new edition of ISO 8041 is published, as it corrects this omission and will allow certification to this Standard that could be made directly Traceable to National Standards, and could be certified by bodies such as UKAS. It also specifies recommended frequencies and levels for vibration calibrators.

For anyone undertaking hand-arm vibration measurements that may be used in a court of law, it is strongly recommended that calibrated equipment is used. At present vibration exciters/calibrators and measuring instruments checked at reputable laboratories that can claim Traceability to National Standards is quite acceptable, but in the future, thought should be given to using UKAS Accredited laboratories for this.

It may be of interest to note that the UK National reference for acceleration is held at the PTB (Physikalisch-Technische Bundesanastalt) in Germany.

c) Direction of Vibration

Unlike whole body vibration, the three axes that can be measured are not subject to different measurement analysis, so although there are various conventions for axis designation, in practice any reasonable choice may be made. Notes should be kept of how these are orientated relative to the source in question, but will not have any influence on the data collected from the source. Where vibration control is considered, a means of specifying the relevant axis or axes is required, and the illustration below defines the directions.



Suggested axes for Hand-Arm vibration measurement

d) Frequency Analysis

The measuring system should be equipped with the Hand-Arm weighting curve (W_h), as defined in ISO 5349-1. This covers the entire frequency spectrum to be measured and will only produce a single answer value, which may be adequate for the task in hand. The PA(V)D only requires this level of detail.

For more detailed investigative measurements, particularly for machine designers, a knowledge of the frequency spectrum being emitted by the vibration source can often be of immense value. This requires instrumentation that can produce either octave band or fractional octave band filters, with third octave being the most common, or Fast Fourier Transform (FFT) analysis. Either of these methods will be able to show fairly accurately at what frequency or frequencies there lies significant energy in the source, and from this knowledge it is often possible to apply remedial treatment to reduce these levels or make adjustments to reduce or eliminate their dominance. FFT frequency resolution should probably be less than 10 Hz to give meaningful answers.

Several battery-operated hand-held instruments offer these analysis features, so they are not confined to expensive mains-powered analysers and are an affordable means of analysing vibration. They also have one additional asset in that they can more easily identify poor and inappropriate transducer mountings, as these invariably show up as an excessive vibration level at a particular frequency that may otherwise not be apparent. However, care should be taken not to confuse this with a strong fundamental vibration frequency being measured.

e) Documentation

Before, during and after measurement it is very advisable that some form of record be kept of the equipment used, its calibration details both overall and at the time of measurement, and details of how and where the transducer was mounted, plus details of the operator, type of equipment being measured, its operating conditions, and the manner of working.

In fact, it is worthwhile to try to record as much information about the measurement operation as possible. Details such as the task being performed, material being worked on (if relevant) and any accessories being used can all affect the measured values.

The time and duration of the measurements made should also be recorded. There should be enough information logged to enable a different person with no knowledge of this measuring session to be able to repeat exactly the measurement taken without having to ask any questions. Documentation guides are available in ISO 5349

3.2 FIXING TRANSDUCERS

a) Methods of Mounting

The most popular methods of mounting transducers were listed and illustrated in Section 2. Mounting requirements and recommendations can also be found in ISO 5349-1 and -2. Measurement should be made as close to the hand, and as near to the centre of the gripping zone, as is possible. Not all methods are usually available or appropriate, and the option of drilling and tapping mounting studs into the vibration source is usually very limited. Unless the measuring system is to be permanent, fixing the transducer to the source with epoxy or cyanoacrylate adhesives is also unlikely.

The fixing method is often the one recommended by the equipment supplier, and recently these have tended to favour attaching the transducer to a mounting block of some description, then attaching the block to the vibration source. The mounted resonance of the transducer and block is usually lower than that of the transducer alone, and the method of attachment to the vibration source can lower this still further.

However, if the fixing of the block to the source is really rigid, and the block and the machined surface of the transducer are well aligned and tight, then the reduction is quite small, and good quality measurement can be made. Where, however, the fixing strap is not that tight, this can allow secondary vibration between the source and the block and can give very erroneous answers. As mentioned in the discussion on filters, this is often easily spotted with frequency analysis, but is difficult to identify otherwise. As the effects of poor mounting often result in higher readings of low frequencies, some instruments fit simple means of identifying this fact. To avoid this problem, some mechanical means of tightening the fixing strap is always recommended. If using plastic cable ties, ratchet type tighteners are available fairly cheaply, and should be used in preference to hand tightening. Metal clips with screwdriver operated adjusters are also widely available.

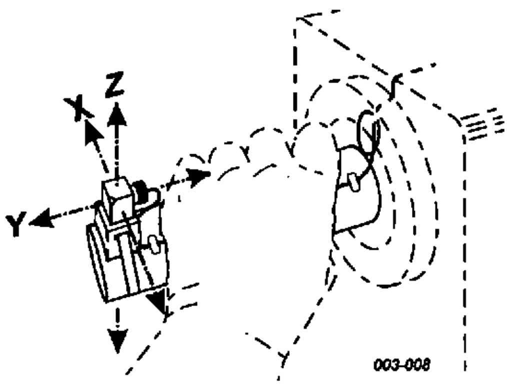
Beeswax or similar proprietary substances can produce excellent mounts for lightweight devices, but may not be able to withstand the rigour of the work cycle to which the source is subjected, especially if the surface gets warm or hot.

Magnetic mounts may be useable, but many sources are tools with handles that are not directly made of a ferrous material, so these are often of limited use and add mass to the system.

Hand held grips are available for mounting, but are notoriously unreliable in terms of being able to reproduce any measurements made. However, for some types of power tool, where the handles used by the operator are covered in a flexible material aimed at reducing the vibration transmitted to the hand, these may be the only way of getting a measure of the vibration transmitted.

b) Effects of Different Mounting Techniques

The principal effect of the different mounting techniques is the lowering of the mounted resonance of the transducer. Whilst small mass transducers will have resonances above 20 kHz, which will be substantially maintained by tapping, gluing and beeswax attachment, block mounts will reduce the resonance to around 10 – 15 kHz, and hand held mounts could well reduce this into the frequency range of interest. Apart from the hand-held case, these resonances should not cause any measurement error on normal sources of hand-arm vibration, as the response should remain essentially flat up to about 2 kHz, the highest frequency of interest. The response of adaptors, if supplied by the manufacturer of the instrumentation, will require testing for compliance with the revision of ISO 8041.



Mounting for three axes transducer showing suggested cable run and ties

However, where the source is percussive, e.g. a road breaker, higher levels of higher frequency inputs may be experienced. Where the transducer has a wide frequency response, e.g. greater than 20 kHz, these levels may enter the measurement chain, although they are often removed by the mounting system and should be filtered out by the weighting filter during measurement.
Such higher levels can cause instrument or transducer overload, but do not lie in the frequency range of interest.

There is, therefore, an argument for removing them before they enter the measurement chain. This may be possible by using mechanical filters fitted to the transducer. The availability and use of mechanical filters requires care, but the transducer manufacturer should be able to advise whether a suitable device exists for the task in hand. If available, they are normally screwed to the mounting surface of the transducer, while the other face of the mechanical filter becomes the new mounting surface, complete with stud. Some specialist transducers are fitted with mechanical filters inside the transducer housing as standard for this application. Mechanical filters may not be an option with all-in-one-block triaxial transducers, as the filters cannot be applied to each axis.

Where triaxial measurements are taken simultaneously, and the values measured take account of all three axes, the position of the mount may alter the answers reported for each axis, but should not affect the overall answer. This is obviously not true of a single axis measuring device, and care is needed to ensure that either the three axes are measured sequentially and truly orthogonally, preferably by using a mounting system that enables the transducer to be fixed to each of the axes in turn without disturbing the mounting of the system to the source under investigation. If only single axis measurements are being taken, great care is needed to correlate the measured value either with a defined axis or to the maximum vibration level being emitted by the source.

c) Transducer Positioning

Ideally the transducer should be mounted in exactly the same place as the person would hold and grip the vibration source, and as near to the centre of this position as possible. In most instances this is not possible, and compromises must be made between best measurement practice and interfering with the correct and safe usage of the device emitting the vibration. It is very important that the positioning of the transducer does not give rise to any safety risks to the operator or change the way in which the vibration source is operated. Locating the transducer as close to the centre of the grip area may mean it is sited close to the thumb or the little finger unless it is small enough to allow the hand to envelope it in some way. On power tools with lightweight plastic handles, this may lead to very different measured values at each side of the hand as the handle will flex far more at the unsupported end.

d) Cabling

There are only two things to say about cables – keep them in good condition and always secure them close to the transducer, if at all possible fixing them to the same source of vibration as the transducer. The less the cable can move around, the longer it will usually last and the fewer problems it will give.

Avoid using cables that are much longer than needed, as there is always the risk of spurious pickup from sources like mobile phones when long cables are used. Most transducers today are not dependent on the cable length for accurate measurement, so using both short and long cables as appropriate will minimise the risk of any undue cable effects with no other side effects introduced. However, minimising the stress on the cable/transducer interconnection is always recommended.

3.3 MEASUREMENT DURATION

There are no mandated durations for measurement, although a period of 15 seconds is usually taken as the shortest viable. The longer the measurement interval of uninterrupted vibration can be, the better the measurement accuracy is likely to be.

Where the measurement is of an operator using a power tool, it must be recognised that the work being undertaken and the skill of the tool operator all affect the measured result. Measurements lasting as long as possible or 3 – 15 minutes are preferred if at all possible.

If the measurement is of a pattern of vibrations that repeat regularly, several patterns should be measured, preferably consecutively, if at all possible. Instruments that time the duration of measurements automatically are recommended, as the accuracy required for short duration measurements that are to be used as the basis of a daily exposure calculation requires accuracy better than usually available manually. Beware of analysing periods of tool operation where the operator is not actually holding the handle to which the transducers are mounted.

a) Work Analysis

Ask someone using a power tool how long they use it for each day and the answer will almost always be considerably longer than is actually experienced. This is because the actual time spent holding the tool whilst it is working is usually a fraction of the time it is in the operator's hands. Therefore care must be taken in understanding how much vibration the person receiving the vibration (i.e. the subject of the hand-arm vibration exposure measurement) actually receives.

It is recommended that the operator is observed as part of the measurement process for sufficient time to establish the true duration of the vibration exposure from the measured source.

Operators often use many different sources of vibration during the course of one working day, and the means of finding their overall daily exposure is detailed in section 5 of this Guide. Measurement should be taken for long enough on the source under investigation to typify normal usage by the operator during a typical working day. Once a sample measurement has been made from each source, it is possible to use the data from all the sources to calculate the daily effect of the total usage of all the sources, which is also to be found in Section 5.

b) Vibration Emission Values

If the measurements being made are to produce a declaration of vibration emission values, then the measurements shall be repeated five times, (unless a different number is defined in the test code - usually a Standard) for the machine under test, and using three operators. The arithmetical average result for the 15 readings is the value to be declared. This should be achieved when operating the machine in a manner representative of the highest vibration levels anticipated, and measured at the hand position giving the highest values. When published, ISO 20643:200X will contain more details; until then refer to BS EN 1033:1995.

c) Number of Measurements

Again there is no requirement mandated, but vibration measurements are notoriously variable and basing a whole day's exposure on data gathered in a few seconds is likely to be inaccurate.

If the work cycle being measured is fairly short and time and the operator's good-will prevail, repeating the measurements between 5 and 10 times is usually well worth the effort in obtaining a representative sample of the vibration emissions.

d) Have I Got Enough Data ?

If you are able to take 10 measurements each lasting long enough to accommodate the length of the work task (or at least 3 minutes) for each vibration source operating on a representative sample of work tasks, and you have an accurate record of the total number of minutes or hours the source is used during the working day, then you probably have enough data to make a reasonably accurate assessment of the daily exposure.

Most of the time, this situation is not achievable, for many different reasons, and the measurements must be tailored to producing the best data available at the time. Notes on working practice and the decisions reached may usefully be added to the measurement documentation mentioned earlier in the Section.

3.4 DATA GATHERED

a) Parameters Required

In order to make a sensible judgement on the data gathering process, a display of the instantaneous vibration level is required, updated at least once per second on the instrument's display.

This is normally referred to as: a_{hv} – the time-average weighted acceleration value, and is the r.m.s. value of the hand-arm weighted signal at any given instant in time.

For meters connected to simultaneously reading triaxial transducers, this may be presented either as a single answer combining the measurement of the three axes or (more commonly) three readings, one for each axis. This is normally displayed in units of m/s², but may also be displayed in decibels (dB). To convert from one to the other requires referencing the decibels to the reference acceleration of 1×10^{-6} m/s², such that:

$$L_h = 20 \, Log_{10}\left(\frac{A_{hv}}{1 \times 10^{-6}}\right) dB$$

(L_h in m/s². As a guide, 10 m/s² equates to 140 dB here. Different reference accelerations may be used, check the value carefully).

It may be useful to store the running maximum of this parameter during the measurement if analysis of the source is under consideration.

Where the vibration is at all percussive, the peak levels are sometimes measured. This should not be confused with A_{hmax} as peak does not have the r.m.s. averaging applied to it, and therefore truly represents the highest reading of the source at any instant. $A_{hpeakmax}$ can therefore also used to show how impulsive the source is, if available from the instrumentation.

For calculation of the daily exposure, a meter must compute the measured energy over the time measured and display this information. This is most usefully presented as the equivalent acceleration level, A_{eq}, and the measured duration.

Some instruments will show this as the 8 hour exposure level, the standard working day length, which assumes that the vibration source was in constant use for 8 hours uninterrupted! Care should be taken to ensure the derivation of any daily figure produced in the instrumentation is fully understood.

It may be helpful if the meter is able to compute the daily exposure based on entered durations for the work cycle (or cycles) and the levels measured, which will then give the more representative data for the working day. Many people prefer to use the basic measured data and apply post-measurement computations to arrive at the daily exposure.

b) *Accuracy Checks*

It is strongly recommended that a vibration exciter or calibrator is used both before and after the measurement process to verify that the complete measuring instrumentation chain is operating correctly.

This is the only practical accuracy check in the field, but is often overlooked. If time permits, mounting, measuring, dismounting and remounting the transducer and re-measuring the same source (primarily for single axis measurements), will give confidence in the transducer mount, but can be time-consuming. Checking the spectrum of the transducer output may also help identify poor mounting.

c) *Likely Problems*

1. Poor transducer mounting. Ensure tight and well-aligned fit of transducer to source
2. Cables – intermittent or high resistance – vibration calibrator check with cable movement will often reveal
3. Loose or poor connections between equipment items
4. Insufficient measurement duration for representative result
5. Pick-up from RF sources such as ultrasonic heaters or mobile telephones corrupting data
6. Earth loops on mains operated measuring equipment
7. Inappropriate settings on the measuring equipment.

SECTION 4 – HOW TO MEASURE WHOLE-BODY VIBRATION

Before starting to make whole-body vibration measurements, it is as well to consider the state of the equipment to be used, when the overall system was last calibrated (if at all), and to what application the measured data is to be put. Ensuring the equipment is in good working order, fit for purpose and having evidence of this to hand if required can save much time after the measurements have been made.

When using this section to decide what equipment is required and possibly purchased, the sections will show the parameters of interest that need to be available from the instrumentation. This could form the basis of a purchase specification when tailored to the task in hand.

For the vast majority of whole-body measurements taken, their use is to determine whether the person measured is receiving vibration exposures around or above the designated action values in the Physical Agents (Vibration) Directive. This section includes the measurement requirements to gather the necessary information, but for those wanting to measure the emissions from product sources for certification purposes, most of the information required is identical, and only the information relating to the source's use is not required.

4.1 EQUIPMENT SETUP

a) Instrumentation

The equipment to be used should claim design accuracy to ISO 8041 Type 1 or 2 (but shortly to be updated with these merged into one grade). For most purposes, the lower accuracy of Type 2 should be sufficient, but it may be advisable to ensure Type 1 where product certification tests are undertaken (although this is not mandatory). A transducer, preferably triaxial, that is recommended for use with the measuring meter and a means of mounting this transducer on the vibration source and connecting to the meter via a suitable cable should be available.

The system should be capable of being checked against a known vibration source from time to time, (not an "internal reference") preferably before each measurement session if at all possible (see calibration below), but in many instances this is not possible in the field. Check the condition of batteries in portable equipment before commencing measurement, and replace if they are likely to run-out in the near future.

The more specific requirements are detailed in the following sections. In choosing an instrument to make these measurements, the parameters required must be fully known. The Data Gathered part of this section will show the most likely measurements required and the meter needs to be specified to measure all these as a minimum.

b) Calibration

The measuring equipment should be calibrated prior to individual measurement usage by fixing the transducer to a known source such as a vibration exciter or calibrator and confirming or adjusting the displayed reading for correct data.

A number of manufacturers can supply vibration calibrators, and most of these are single level, single axis and single frequency devices that give confidence that the accuracy of the measuring system is acceptable. Instruments that claim some form of "internal calibration" but which do not include the transducer are of limited value as the most likely source of error today lies in the transducer and associated cabling, and not inside the meter itself. None of these devices show that anything other than the one measured point is correct.

However, with triaxial transducers such as the seat-pad type, this type of "on the job" calibration is impossible as no reliable calibrators are available at present, and many other types will only easily allow one of the three axes to be checked. Trust has to be placed in the quality of the transducer's stability with time, and the manufacturer's data used for its calibration. It is also worth noting that it is rare for all three transducers in a triaxial device to have exactly the same sensitivity. Better quality instrumentation will normally allow each axis to be calibrated independently, and the correct level for each axis to be stored in the instrument for re-use without the need to recalibrate the system each time it is turned on.

If the transducer is of the piezo resistive type and the instrumentation allows the measurement of d.c. signals, the calibration can be checked if the value of gravity at the location is known. Inverting the transducer should give an equal and opposite polarity signal.

From time to time, say every 1 – 2 years, it is recommended to have as much as possible of the whole measuring system checked at a calibration laboratory.

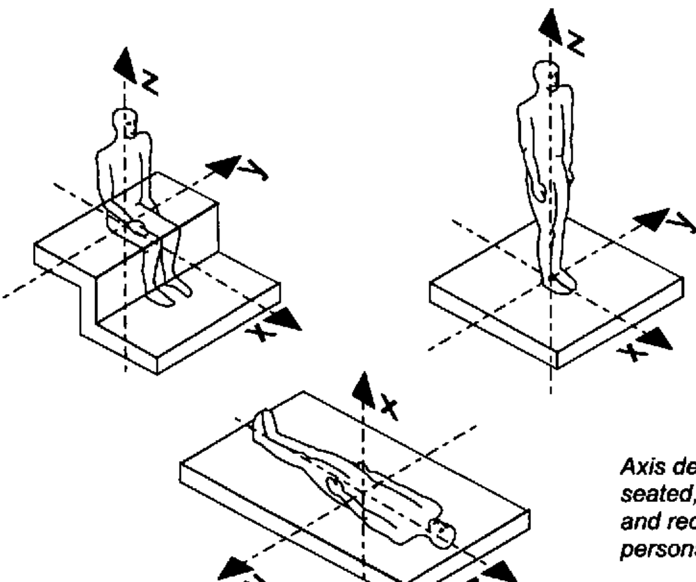
At present in the UK there are only a few laboratories offering this service, as at present there is no standard test procedure for them to work to and therefore to certify to a defined Standard. This will change when the new edition of ISO 8041 is published, as this corrects this omission and will allow certification to this Standard that could be made directly Traceable to National Standards, and could be certified by bodies such as UKAS.

For anyone undertaking whole-body vibration measurements that may be used in a court of law, it is strongly recommended that calibrated equipment is used. At present vibration exciters/calibrators and measuring instruments checked at reputable laboratories that can claim Traceability to National Standards is quite acceptable, but in the future, thought should be given to using UKAS Accredited laboratories for this.

It may be of interest to note that the UK National reference for acceleration is held at the PTB (Physikalisch-Technische Bundesanastalt) in Germany.

c) Direction of Vibration

The terminology commonly used to relate measurement axes to the human skeleton is illustrated below.



Axis definitions for seated, standing and reclining persons

x-direction – from back to chest
y direction – from right side to left side
z direction – from foot or buttocks to head.

d) Frequency Weighting

The measuring system should be equipped with weighting curves as defined in ISO 8041. There are a considerable number of these for whole-body measurements, and the correct application of these is essential for the measurements to be valid. The most common applications of each weighting are listed below. Note that each of these weightings covers the entire frequency spectrum to be measured and will only produce a single answer value, which may be adequate for the task in hand. The PA(V)D only requires this level of detail, and only employs W_d (with multiplication factor 1.4) and W_k.

W_b Used only for measurement of vertical z-axis vibration on a seated, standing or recumbent person in a railway carriage, according to ISO 2631-4, for comfort assessments, so only the z-axis is considered. It has been used instead of W_k in older standards and instrumentation as it is very similar.

W_c Used when measuring on the seat back with a seated person present, for horizontal x-axis vibration.

W_d The most widely used weighting (in conjunction with W_k). Measures horizontal vibration in both X and Y axis for seated, standing or recumbent people.

W_e Used when rotational vibration is being measured. Applies to all directions for seated people and is normally reported in the units of rad/s².

W_f Used for assessing motion sickness at very low frequencies, principally below 1 Hz. Applies to vertical z-axis vibration.

W_j Applies only to the measurement of vertical head vibration on a recumbent person, (which is the x-axis).

W_k Applies to vertical z-axis measurements for seated, standing or recumbent people, and is the third axis measurement when W_d is being used for the x and y axis.

W_m Used for measuring in all directions for whole body vibration in buildings (known as W_B Combined in older standards and instruments)

e) *Which do I Need ?*

For many measurement tasks, the ability of the instrumentation to measure according to W_d and W_k is the primary requirement. Instruments that measure more than these two weightings are only required if the more specialist tasks to which the other weightings apply are ever required to be measured.

Note that the definitions of these weightings were revised in 1997 and measuring instruments manufactured before or around that time may not contain the current versions of these weighting curves.

For more investigative measurements, a knowledge of the frequency spectrum being emitted by the vibration source can often be of immense value. This requires instrumentation that can produce either octave band or fractional octave band filters, with third octave being the most common, or Fast Fourier Transform (FFT) analysis. FFT analysers are the most likely to be able to show fairly accurately at what frequency or frequencies there lies significant energy in the source, and from this knowledge it is often possible to apply remedial treatment to reduce these levels or make adjustments to reduce or eliminate their dominance. FFT analysers will require a frequency resolution between 0.1 and 0.5 Hz to give meaningful analysis.

Several battery-operated hand-held instruments offer these analysis features, so they are not confined to expensive mains-powered analysers and are an affordable means of analysing vibration. They also have one additional asset in that they can more easily identify poor and inappropriate transducer mountings, as these invariably show up as an excessive vibration level at a particular frequency that may otherwise not be apparent. However, care should be taken not to confuse this with a strong fundamental vibration frequency being measured.

f) *Documentation*

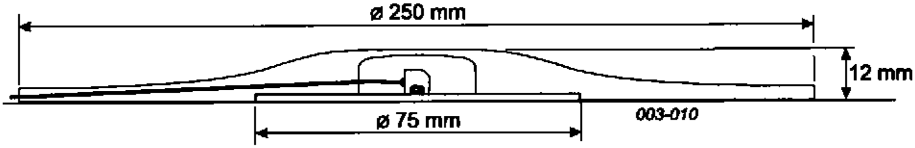
Before, during and after measurement it is very advisable that some form of record be kept of the equipment used, its calibration details both overall and at the time of measurement, and details of how and where the transducer was mounted, as well as details of the operator, the source of the vibration being measured, the operating conditions, and the manner of working. In fact, it is worthwhile to try to record as much information about the measurement operation as possible.

The time and duration of the measurements made should also be recorded. There should be enough information logged to enable a different person with no knowledge of this measuring session to be able to repeat exactly the measurement taken without having to ask any questions.

4.2 FIXING TRANSDUCERS

a) Methods of Mounting

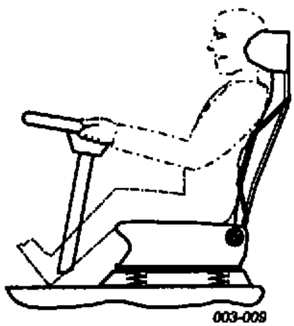
There are so many different applications and types of transducer being used, that any specific guidance on mounting is likely to have only limited application.



Typical dimension of a seat pad transducer

Seat-pad type transducers can usually be strapped or otherwise fastened in place on seats and seat backs, but may also be strapped to the person, especially on their back. However, always ensure that if fixing to a person this does not present a hazard to them executing the tasks causing the vibration in any way. When placed on the seat cushion, it should be positioned so that the "bulge" in the seat pad is located between the person's ischial tuberosities.

The primary factor in placing the transducer is to ensure that it stays directly in contact with the source (seat cushion or backrest) AND the person at all times, and cannot vibrate in any other mode than that of the source it is trying to measure. Ensuring this can be difficult, but is essential if the measurements are to mean anything.



Correct positioning of a seat back transducer, between the person's back and the front of the upright part of the seat back.

It should be firmly retained in position and always be in contact with the person's back.

The mounting methods for hand-arm transducers may be applicable. (See Section 2). This means that drilling and tapping a mounting stud or gluing is worth considering if possible. Magnetic mounts may be suitable, but often the sources are of sufficient magnitude that the transducer becomes dislodged during measurement. Using a mounting block and fixing strap approach may also be possible, but care is needed to ensure the block is rigid in all three axes. Mounting the transducers in the middle of a rigid metal plate (say 300 x 400mm) with the operator standing on the plate can also be used when the operator is standing on a platform covered in a resilient material.

In most instances, provided the mounting is correctly transmitting the vibration to the transducer, the transducer and its mount have very little impact on the vibration source, and its effects can be ignored.

b) Cabling

Keep all cables in good condition and ensure they cannot create a hazard to the person under surveillance. Some means of retaining them in a fixed position may be desirable. In general, the less the cable can move around, the longer it will usually last and the fewer problems it will give.

Avoid using cables that are much longer than needed, as there is always the risk of spurious pickup from sources like mobile phones when long cables are used. Most transducers today are not dependant on the cable length for accurate measurement, so using both short and long cables as appropriate will minimise the risk of any undue cable effects with no other side effects introduced.

4.3 MEASUREMENT DURATION

There are no mandated durations for measurement, although a period of 5 minutes is usually taken as the shortest viable. The longer the measurement interval of uninterrupted vibration can be, the better the measurement accuracy is likely to be. When the measurement is of a pattern of vibrations that repeat regularly, several repetitions should be measured, preferably consecutively, if at all possible, and lasting for at least 15 minutes. Instruments that time the duration of measurements automatically are recommended, as the accuracy obtained is better than usually available manually.

a) Work Analysis

It is recommended that the operator is observed as part of the measurement process for sufficient time to establish the true vibration exposure from the measured source.

For whole-body vibration, this is often best effected by using video cameras and recorders to monitor the actual working day.
Measurement of the source under investigation should be taken for long enough to typify normal usage by the operator during a typical working day.

Once a measurement has been made, it is possible to use the data to calculate the daily effect of the total usage of the source, which is also to be found in Section 5.

Of special note are measurements relating to driving activity, especially the off-road type, where short-duration samples may be inappropriate. To obtain meaningful exposures it may be necessary to monitor for several hours or even the entire working shift to fully embrace the whole range of vibration sources.

b) Vibration Emission Values

If the measurements being made are to produce a declaration of vibration emission values, then the measurements shall be repeated N times, where N is defined in the test code (usually a Standard) for the machine under test and using two operators. The average result for the N readings for each operator is then averaged across the two operators, and the value to be declared is the 75th percentile of the vibration values achieved when operating the machine in a manner representative of the highest vibration levels anticipated. BS EN 1032:2003 has more details.

It is important that the operating conditions are specified fully. Test type, speed, location and many other details should be recorded. Full information required is usually listed in the test code if it has been standardised.

c) Number of Measurements

Again there is no requirement mandated, but vibration measurements are notoriously variable and basing a whole day's exposure on data gather in a few minutes is likely to contain wide variations.

Even if the work cycle being measured is fairly short, and time and the operator's good-will prevail, continuous monitoring for a lengthy period is desirable, but care needs to be taken to ensure that only the vibration being transmitted to the person is measured.

One difficulty often encountered is measuring the vibration transmitted to the seated vehicle driver. The driver must be sitting properly on the seat. However, they will quite often lift themselves off and back onto the seat as part of the work cycle (e.g. delivery drivers). The (often) large "shock" when the person sits down again on the seat should not be counted as part of the daily exposure! Some instruments allow the measurements to be paused manually, which can assist in overcoming this effect.

d) Have I Got Enough Data ?

Measure for as long as time permits, and take an accurate record of the total number of minutes or hours the source is used during the working day, then you probably have enough data to make a reasonably accurate assessment of the daily exposure. For irregular vibration exposures, such as off-road driving, long measurement durations may be required.

Most of the time, this situation is not achievable for many different reasons, and the measurements must be tailored to producing the best data available at the time. Notes on working practice and the decisions reached may usefully be added to the measurement documentation mentioned earlier in this Section.

4.4 DATA GATHERED

a) Parameters Required

In order to make a sensible judgement on the data gathering process, a display of the instantaneous vibration level is required, updated at least once per second on the instrument's display.

This is normally referred to as: a_w – the time-average weighted acceleration value, which is the r.m.s. value of the w-weighted signal at any given instant in time, where w is any of the weighting curves for each of the three axes. For meters connected to simultaneously reading triaxial transducers, this may be presented either as a single answer combining the measurement of the three axes or (more commonly) three readings, one for each axis. This is normally displayed in units of m/s² or mm/s² but may also be displayed in decibels (dB). To convert from one to the other requires referencing the decibels to the reference acceleration of 1×10^{-6} m/s², such that:

$$L_w = 20\ Log_{10}\left(\frac{A_w}{1 \times 10^{-6}}\right) dB$$

(L_w in m/s². As a guide, 10 m/s^2 equates to 140 dB here. Different reference accelerations may be used, check the value carefully).

It may be useful to store the running maximum of this parameter during the measurement if analysis of the source is under consideration.

Where the vibration is at all percussive, the peak levels are sometimes measured. This should not be confused with A_{wmax} as peak does not have the r.m.s. averaging applied to it, and therefore truly represents the highest reading of the source at any instant. $A_{wpeakmax}$ can therefore also used to show how impulsive the source is, if available from the instrumentation.

For calculation of the daily exposure, a meter must compute the measured energy over the time measured and display this information. This is most usefully presented as the equivalent acceleration level, A_{eq}, and the measured duration. Some instruments will show this as the 8 hour exposure level, the standard working day length, which assumes that the vibration source was in constant use for 8 hours uninterrupted! Care should be taken to ensure the derivation of any daily figure produced in the instrumentation is fully understood.

For the PA(V)D, (taken from ISO 2631-1) the measurements from the three axes require an additional factor applied to them. The readings obtained from the x and y axes must be multiplied by 1.4, and by 1.0 for the z axis to produce the daily exposure in either parameter. The highest of the three axes readings is the value used, NOT the combined root sum of squares value, which is different from the Hand-Arm requirements. Care is needed to determine whether instrumentation includes the 1.4 factor or not when producing daily exposure answers. Note that other measurement applications may not require these multiplication factors.

It may be helpful if the meter can compute the daily exposure based on entered durations for the work cycle (or cycles) and the levels measured, which will then give the more representative data for the working day. Many people prefer to use the basic measured data and apply post-measurement computations to arrive at the daily exposure.

If a meter also displays other parameters, then the VDV value may be useful, In the UK, the Health and Safety Executive may feature the measurement of this parameter in the future guidance, so instrumentation that can measure both A_w and VDV type measurements may be preferred. However many meters do not currently include VDV, and outside the UK VDV is only rarely used. The PA(V)D defines action and limit values in terms of VDV as well as r.m.s

A means of computing this particular exposure is given in Section 5.

b) Accuracy Checks

It is strongly recommended that any check that includes the transducer and cabling and that is practical in the field is performed before and after the measurement session. However, these are rarely performed due to lack of suitable sources to enable this.

If time permits, mounting, measuring, dismounting and remounting the transducer and re-measuring the same source (primarily for single axis measurements) will give confidence in the transducer mount, but can be time-consuming. Checking the spectrum of the transducer output may also help identify poor mounting.

c) Likely Problems

1. Poor transducer mounting. Ensure tight and well-aligned fit of transducer to source
2. Cables – intermittent or high resistance – vibration calibrator check with cable movement will often reveal
3. Insufficient measurement duration for representative result
4. Loose or poor connections between equipment items
5. Pick-up from RF sources such as ignition systems, ultrasonic heaters or mobile telephones corrupting data
6. Earth loops on mains operated measuring equipment
7. Unobserved operator-induced signals such as "getting comfy" on a seat fitted with a seat-pad transducer
8. Inappropriate settings of the measuring equipment.

SECTION 5 – HOW TO ESTIMATE DAILY VIBRATION EXPOSURE

If the measurements taken are aimed at evaluating a person's daily exposure to vibration, then usually some calculations have to be applied to these (or to data derived from vibration emission declarations by manufacturers) in order to arrive at the actual daily exposure. The following sections provide the means of calculation where the instrumentation does not already produce the answers, and suggests what to check is being calculated if the answers are automatically produced.

On many portable items that vibrate, manufacturers are required to make vibration emission declarations. This is the level of vibration that someone using the item is supposed to expect. The emissions are measured using the principals set out in Sections 3 & 4 of this Guide, but currently with the item operating in a controlled manner that often does not represent real use.

Test fixtures are often required to hold and load the item in a repeatable manner, and many of these are defined in the ISO 8662 series of standards. (See Annex A.) The values declared by these methods do enable some form of comparison between items of a similar type, but experience shows that the reported emission values are usually lower, *often far lower*, than those experienced by people using the items in real life situations. These declared levels can be used as the basis of computing daily exposures without making any measurements at all, but it would probably be as well at least to double the computed exposure calculated this way in order to approach the likely exposure of the person involved.

Data from measured sources is becoming more available (see Section 1). Manufacturers, consultants and regulatory authorities are gradually acquiring more relevant data, and this information should form a more accurate basis for assessment.

5.1 HAND-ARM MEASUREMENTS - SINGLE AXIS AND TRIAXIAL

With the introduction of ISO 5349-1:2001 (and subsequently the PA(V)D), the trend has shifted away from single-axis measurements towards making triaxial measurements. Until recently, single axis equipment was more readily available, was lighter to attach to the vibration source, and lower in cost to purchase. The dominant axis could be determined and its value quantified, as was then required. Now the Action Values for hand-arm vibration set by the PA(V)D are in terms of readings for the vector sum from all three axes, (and a knowledge of magnitudes in all three axes is often required for whole body measurements as well), simultaneous triaxial measurement capability has become important. It is therefore essential that the measured data either gives the true multi-axis reading or is able to give data on each axis in some form.

Where only a single axis measuring instrument is available, one possibility is to make measurements on each of the three axes in turn and compute the resultant triaxial level from the formula:

$$A_{hv} = \sqrt{(a^2_{hx} + a^2_{hy} + a^2_{hz})}$$

This value is the one required by the PA(V)D for hand-arm vibration and to which the following sections apply. If it is not possible to measure all three axes and compute the above, then multiplication factors must be applied to the axis with the largest vibration magnitude. This axis is known as the dominant axis, which will need some prior knowledge of the source. The factor lies between 1.0 and 1.7 depending on how much energy lies in the measured axis and how much lies elsewhere. Where the levels of vibration in the dominant axis are significantly larger than the levels in the other two axes, then the factor of 1.0 applies. This is the one all single axis equipment should attempt to measure. Where the energy is equally distributed across all three axes, the measured axis should be multiplied by 1.7 to obtain the required reading.

To use this or any other factor requires some knowledge of the energy in each axis, which implies you can measure it somehow. A fuller discussion of the computation of this factor is found in ISO 5349-2 section 6.1.6. Unless there is reliable knowledge of the levels produced on the two axes not measured, and it is believed that the measurements are being taken from the axis with the largest vibration levels, it may be best always to multiply the readings from the measured axis by 1.7 to ensure that the worst case values are known.

The factor of 1.7 does not necessarily represent the worst case possible. An overloaded tool or application of the factor to the wrong axis due to change of loading can produce vibration magnitudes in excess of that computed with this factor.

a) Daily Exposure

The vibration daily exposure is expressed as the measured level and duration experienced per day compared to the standard working day of 8 hours (regardless of how long the actual working day is), using the formula:

$$A(8) = Aw\sqrt{\left(\frac{T}{T_0}\right)}$$

where T_0 is the reference duration in seconds (28 800 = 8 hours)
T in seconds is the total time the item was used for. (Note this can be greater than 8 hours if appropriate).
Aw is the average value of the weighted vibration measured (across all three axes) for the item.

The term A(8) is more correctly annotated as $a_{w(eq,8h)}$, but is rarely shown in this fashion.

b) How to Add Exposures Together

Many daily exposures for people receiving hand-arm vibration are made up of a number of sources, each being present for only some, often, small part of the working day. If the exposure from each vibration source is measured individually, and each source is only used once per day, then the formula for finding the daily exposure is:

$$A(8) = \sqrt{\left(\frac{1}{T_0}\sum_{i=1}^{n} a^2_{hvi} T_i\right)}$$

How this is worked out in practice is best illustrated by the following example:

A vehicle body repairer uses a grinder for 1 hour a day, which gives a measured average level from all three axes of 3.5 m/s², and a sander for 0.5 hours per day, measuring 6.5 m/s². He also uses a polisher for 4 hours a day, measuring 1.5 m/s².

His daily exposure is calculated as follows:

$$A(8) = \sqrt{\frac{1}{8}\left\{(3.5^2 \times 1\ h) + (6.5^2 \times 0.5\ h) + (1.5^2 \times 4\ h)\right\}} = 2.3\ m/s^2$$

Note that the times here are all expressed in hours. There is no need to convert exposures to seconds provided ALL exposures and the reference duration are in the same units of time.

c) How to compute daily exposure from single or multiple short measurements

There is no difference in effecting daily exposure calculations from single or multiple measurements. What must be known is the total duration each source is used for during the day. Taking the example above, if the vehicle body repairer worked longer hours, and the sander was used for 6 sessions, each lasting 0.5 hours, the total exposure time is 3 hours. Substitute 3 hours for the 0.5 hour in the original work pattern above and compute the new exposure.

$$A(8) = \sqrt{\frac{1}{8}\{(3.5^2 \times 1\ h) + (6.5^2 \times 3\ h) + (1.5^2 \times 4\ h)\}} = 4.3\ m/s^2$$

Only one set of measurements of each tool is required, which should be representative of the task under consideration. Where several different tools are used during the day, and with a knowledge of the total daily usage of each tool, the daily exposure can be computed for as many sources as are used during the day for whatever total time they are used for.

Some measuring instruments on sale can effect this calculation automatically by allowing the user to enter total daily exposure time after each measurement is completed and then adding them all together when all data is gathered. For some people, this may be more reliable than trying the calculations manually. The daily exposure is sometimes referred to as the DOSE received by the person, so make sure you fully understand the parameters reported on the instrument.

d) Action Values and Limits

Levels of Hand-arm vibration below 1.0 m/s^2 A(8) are generally considered to be of low risk to people.

The **EXPOSURE ACTION VALUE** (above which employers must implement control actions and health surveillance) is set at 2.5 m/s^2 A(8) triaxial (this was formerly defined as 2.8 m/s^2 A(8) - highest axis - in the UK, but was superceded by the PA(V)D).

The EXPOSURE **LIMIT VALUE** above which no-one may be exposed is set at 5.0 m/s^2 A(8).

These values are all A(8) exposures measured triaxially, or computed to give the equivalent triaxial level.

If the measured values, or values derived from declared emission values, approach or exceed these limits, then action must be taken to reduce the vibration exposure. In many cases it proves possible to alter processes or working practices to avoid the need for vibrating equipment. Investigations of the condition of the vibration source can often prove valuable, and checks to ensure any power tool is properly serviced can often pay good rewards. Choosing newer, low-vibration tools may improve the situation, as can training of the operator for best grip and posture. Advice on lowering vibration exposures can be found in the HSE books referred to in Annex A.

If no means can be found of lowering the vibration levels, then the only way of meeting these targets is to reduce the exposure time per day until the daily exposure is complied with.

The requirements of the PA(V)D will be implemented in the UK from July 2005 when the control of Vibration at Work Regulations are introduced. Most people in employment will be covered from that date, but a few industries are permitted more time to reduce exposures. (see the PA(V)D for specific information).

In the worked example above, the original exposure lay below the action value, whilst the additional time sanding has raised the exposure close to the limit value. It would therefore be wise to reduce the sanding operations to little more than 0.5 hours per day every day.

5.2 WHOLE BODY MEASUREMENTS - SINGLE AXIS AND TRIAXIAL

With the introduction of the PA(V)D, triaxial measurements have predominantly become the norm, although the use of triaxial equipment was already more often used for seated whole-body than hand-arm. Single axis equipment is lower in cost to purchase, but will usually need to be deployed on all three axes sequentially to gather the required data.

All the Action Values now set by the PA(V)D are in terms of readings obtained from all three axes. It is therefore essential that the measured data either gives the true multi-axis reading or is modified to take account of the omissions. For whole body measurements, the readings for each of the axes must be known. (Whereas for hand-arm measurements, the triaxial reading alone is sufficient, although a knowledge of the individual readings may be beneficial). One addition for whole-body measurements is the inclusion of the parameter VDV (Vibration Dose Value) as an alternative to the r.m.s. based measurements. The computations arising from the use of VDV are different from the r.m.s. based ones, and will be found towards the end of this section.

Where only a single axis measuring instrument is available, make measurements on each of the three axes in turn. The action values defined in this document are determined by the highest of the 8 hour exposures of 1.4X, 1.4Y or 1.0Z where X, Y and Z are the readings from the three axes individually as defined in Section 4.1.c of this guide. The Factor of 1.4 for the X and Y axes must be included in the calculations, although the exact validity of this number has been questioned.
There is no requirement in the PA(V)D to calculate the vector sum for WB vibration, but this may be required for other applications, and the multiplying

factors may need to be included in the calculation. (see ISO 2631-1 for more information).

a) Daily Exposure

The vibration daily exposure is expressed as the measured level and duration experienced per day compared to the standard working day of 8 hours (regardless of how long the actual working day is), using the formula:

$$A(8) = Aw\sqrt{\left(\frac{T}{T_0}\right)}$$

where T_0 is the reference duration in seconds (28 800 = 8 hours),
T is the total time the item was used for. (Note this can be greater than 8 hours if appropriate).
Aw is the average value of the weighted vibration measured (across all three axes) for the item.

The term A(8) is more correctly annotated as $a_{w(eq,8h)}$, but is rarely shown in this fashion.

b) How to Add Exposures Together

Many daily exposures for people receiving vibration are made up of a number of sources, each being present for only some, often, small part of the working day. If the exposure from each vibration source is measured individually, and each source is only used once per day, then the formula for finding the daily exposure is:

$$A(8) = \sqrt{\left(\frac{1}{T_0}\sum_{i=1}^{n} a^2_{hvi}Ti\right)}$$

This is worked out in practice as best illustrated by the following example:

A delivery driver drives a lorry for 4 hours a day, which gives a measured average level from the Z axis (found to be clearly the dominant axis) of 0.4 m/s², and he also drives a fork-lift truck in the factory for 2 hours per day, measuring 0.7 m/s².

His daily exposure is calculated as follows:

$$A(8) = \sqrt{\frac{1}{8}h\ \{(0.4^2 \times 4\ h) + (0.7^2 \times 2\ h)\}} = 0.45\ m/s^2$$

Note that the times here are all expressed in hours. There is no need to convert exposures to seconds provided ALL exposures and the reference duration are in the same units of time. Note also that if the highest levels were from the X or Y axes, then the measured levels would need to be multiplied by 1.4 before entering the values into the above calculation.

c) How to compute daily exposure from single or multiple short measurements

There is no difference in effecting daily exposure calculations from single or multiple measurements. What must be known is the total duration each source is used for during the day. Taking the example above, if the fork lift truck was used for 2 sessions, one lasting 2 hours and the other 1 hour but on rough ground outdoors (measuring 1.5 m/s²) instead of the smoother factory floor, three different exposure levels are now in the overall calculation. Substitute these revised exposures in the original work pattern above and compute the new exposure:

$$A(8) = \sqrt{\frac{1}{8}\{(0.4^2 \times 4\ h) + (0.7^2 \times 2\ h) + (1.5^2 \times 1\ h)\}} = 0.7\ m/s^2$$

Only one measurement of each vehicle is required, possibly lasting an hour, but which should be representative of the tasks under consideration, hence two different levels for the fork lift truck. From a knowledge of the total daily time spent in each vehicle, the daily exposure can be computed for as many sources as are used during the day for whatever total time they are used for.

Some measuring instruments on sale can effect this calculation automatically by allowing the user to enter total daily exposure time after each measurement is completed and then adding them all together when all data is gathered, but make sure you fully understand the parameters calculated and reported on the instrument as they may not be exactly what is required. For some people this may be more reliable than trying the calculations manually. The daily exposure is sometimes referred to as the DOSE received by the person.

d) Action Values and Limits

The **EXPOSURE ACTION VALUE** is set at 0.5 m/s² A(8).

The EXPOSURE **LIMIT VALUE** above which no-one may be exposed is set at 1.15 m/s² A(8).

These values are all A(8) r.m.s. exposures calculated as 1.4X, 1.4Y or 1.0 Z axis measured readings.

If the measured values, or values derived from declared emission values, approach or exceed this Exposure Limit Value, then action must be taken to reduce the vibration exposure. Investigations of the condition of the vibration source can often prove valuable, and checks to ensure any vehicle is properly serviced and tyres are at correct pressures can often pay good rewards. Choosing the correct seat and mounting in vehicles and minimising the distance travelled can all yield dividends. Only travelling over smooth surfaces and at slower speeds will make significant inroads to exposure values (a doubling of travel speed often equates to a doubling of vibration levels). Training of the operator in best techniques for posture and seat adjustment may also provide assistance in reducing the health risks.

If no means can be found of lowering the vibration levels, then the only way of meeting these targets is to reduce the exposure time per day until the levels are complied with.

The requirements of the PA(V)D will be implemented in the UK from July 2005 when the control of Vibration at Work Regulations are introduced. Most people in employment will be covered from that date, but a few industries are permitted more time to reduce exposures. (see the PA(V)D for specific information).

In the worked example above, the original exposure lay below the action value, whilst the additional time on the fork-lift truck has raised the exposure above the action value and nearer to the limit value. It would therefore be necessary to reduce the fork lift truck operations to little more than 2 hours per day every day; unless exposure can be reduced by other means (e.g. smoother surfaces to drive over or a more suitable vehicle for the rough terrain work).

5.3 USING THE VDV MEASUREMENT METHOD

Vibration Dose Values are more sensitive to peaks in the vibration source than the r.m.s. measurements. Equipment is required that will measure the VDV directly, as there is no accurate means of converting r.m.s. readings to VDV. If only one axis is measured at a time, a similar approach to that using r.m.s. values, including the multiplication of 1.4 on the x and y axes, can be used to find the VDV levels for each vibration source.

However, the computation of the daily exposure from multiple sources is different. Whereas it was necessary to square the r.m.s. data and then find the square root of the sum, the VDV (Z-axis) data has to be raised to the fourth power, and then the fourth root of the sum taken.

As an example, if the driver we have met already drives the lorry for 4 hours with a VDV value of 2.5 $m/s^{1.75}$, and the fork lift in the factory gives a VDV of 4.7 $m/s^{1.75}$ for 2 hours.

The exposure for the day becomes:

$$VDV = \{(2.5^4 X\ 4\ h) + (4.7^4 X\ 2\ h)\}^{0.25} = 5.8\ m/s^{1.75}$$

The effects of exposure time on the daily exposure are significant and may require more complex considerations than are shown here. There is an on-line calculator for daily VDV exposures on the HSE website which can be accessed at www.hse.gov.uk/vibration

a) VDV Action Values and Limits

The **EXPOSURE ACTION VALUE**, is set at 9.1 $m/s^{1.75}$

The EXPOSURE **LIMIT VALUE** above which no-one may be exposed is set at 21 $m/s^{1.75}$

These values are all daily VDV exposures calculated as 1.4X, 1.4Y or 1.0 Z axis measured readings.

If no means can be found of lowering the vibration levels, then the only way of meeting these targets is to reduce the exposure time per day until the levels are complied with.

The requirements of the PA(V)D will be implemented in the UK from July 2005 when the control of Vibration at Work Regulations are introduced.

The Regulations may require the use of VDV or A(8) rms values, but not both.

ERRATA

The text ' The exposure for the day becomes:' and the formula at the top of Section 5 Page 9 should be deleted and replaced with:-

The VDV values are measured for the durations given, so no additional time element is required in combining exposures, therefore the exposure for the day becomes:-

$$VDV = \{2.5^4 + 4.7^4\}^{0.25} = 4.8\ m/s^{1.75}$$

The remaining text on the page is correct.

SECTION 6 – INSTRUMENTATION AND MEASUREMENT ACCURACY

6.1 TRANSDUCER MOUNTING

Probably the commonest source of measurement error is the inability of the transducer to accurately measure the vibration source of interest. Whilst the inappropriate choice of transducer may account for some of these problems, the vast majority can be attributed to poor mounting. Ensuring that the vibration source does not also vibrate the transducer in a different mode is essential for true measurement.

a) Hand-Arm Sources and Measurement

For hand-arm vibration measurements, the mass of the accelerometer or other transducer used can play a role in the measurement accuracy. A suggestion of 1/20th or less of the mass of the item to which is attached is a useful guide, with a maximum of around 50 grams total, including any mounting device used.

The mass of the item to which it is attached needs careful consideration. It will not normally be the mass of the whole tool or whatever the vibration source is, but just a small section of it, e.g. a handle or guide. A heavy or large transducer will load the vibration emanating from this part, but may equally interfere with the correct operation of the tool by its operator, which will also result in abnormal measurements. Tools with very lightweight handles or other gripping points may require low-mass transducers glued to them to avoid undue mass loading.

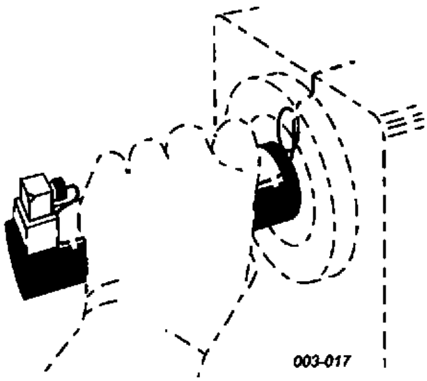
The dynamic range of the transducer must also be considered when impulsive sources such as riveting guns and impact wrenches are to be measured. The instantaneous vibration levels from these devices can easily cause transducer and instrumentation overloads, resulting in false measurements. Mechanical filters may help reduce the amplitude of signals that do not lie in the frequency range of interest, and care should be taken to check that the maximum input levels of the devices in use are not exceeded.

For illustrations of a variety of mounting methods, see Section 2.

b) Resilient Coatings

Where a tool has handles with resilient coatings, the vibration transmitted is usually related to the force with which the transducer is attached to it. As these coatings are mainly applied to give improved grip rather than reduce transmitted vibration, it is recommended that either the coating is removed from the areas where the transducer is mounted (if possible), or that the transducer is fixed with the coating fully depressed to give maximum transmissibility.

If the coating is supposed to offer reduction in transmitted vibration, the grip of the operator's hand becomes a factor in the measurements, and then a hand-held mount, possibly of the type shown below may be the only practical means of assessing the typical level of transmission.



A simple-hand held mount for the handle of a power tool

The mount must be held by the operator during all normal operations, but could be loosely retained on the tool by adhesive tape to maintain an approximate position. Results from hand-held mounts tend to be difficult to repeat, and this combined with the often minimal reductions in transmitted vibration resulting from the resilient coating make measurement of their effect of limited value. Hand-held mounts in general are not recommended unless there is no other means of attaching the measuring transducer.

c) Whole-Body Sources and Measurement

The mass of the transducer for most whole body measurements is usually less critical than for hand-arm measurement. Nevertheless, it is recommended that the mass be kept as low as is practical, and the transducer size small, as far as is possible.

Different transducers serve different tasks, so generalisation is more difficult, but seat pad transducers around 500 gm total mass and perhaps 250 mm (10") diameter would be typically acceptable. These can be strapped either to the seat or surface being measured, or to the person occupying the seat, although care for their safety is required using this approach.

If the person is free to move around during the measurement period, a means must be used to check and if necessary remove, the effects of the person getting on and off of the seat as part of the work pattern, as large excursions are usually transmitted during these activities. This is particularly important when measuring VDV, as the effect of any high reading is a significant contribution to the final answer. Some instruments contain a Pause facility for removing this type of occurrence.

Transducers mounted on parts of the structure transmitting vibration to the person can be attached by a variety of means. Straps and clamps are usually effective but may not be easy to use, but just resting the transducer on the vibrating surface is usually unsuitable. As an indication, total mass of transducer and mount of 100 gms in vehicles and 1000 gms in buildings is recommended.

6.2 EFFECTS OF POOR TRANSDUCER MOUNTING

a) Resonance

If the transducer is mounted incorrectly, the combination of its mass and the vibrating surface to which it is nominally attached can create additional vibration in the transducer. This can result in the amplitude of the vibration having a resonance that is related to the vibration source, but is not actually present in the source at all. There have been many instances where this induced vibration exceeds the magnitude of the source being measured, and has misled many in the past. Some instruments are equipped with means to attempt to check the quality of the mounting, but probably no absolute method will ever exist.

The most likely effects of mounting resonance may show as large levels of very low frequency energy, so any instrument fitted with a frequency analysis facility can help identify this effect. Of course a knowledge of the expected frequency outputs of the source being measured is required before an informed opinion can be made on the quality of the mounting.

The other likely effect is that the mounting method used alters the natural resonance frequency of the transducer employed. Where this resonance is well above the frequencies measured using the selected weighting curve, the change is of no consequence. Where the natural resonance is lowered sufficiently to bring it within the measured bandwidth of the weighting curve (typical below 2000 Hz for hand-arm or 200 Hz for whole-body), frequencies at the higher end of the measurement spectrum may be artificially amplified, causing spuriously high readings.

Most reasonable mounting methods will not lower the resonance this much if the natural resonance starts at least 10 times higher than the highest frequency of interest, but some hand-held mounts have been shown to achieve large reductions, which makes their use require great caution.

b) Frequency Response

Ideally, the transducer should have a frequency response that is uniformly sensitive to all frequencies of interest. Most transducers can achieve this with only small variations (say ±1 dB or ±10%) over the bandwidth of interest.

For hand-arm vibration this should be at least 4 to 2000 Hz and for whole body at least 0.25 to 160 Hz. Most transducers are limited at the low frequency end by the measuring system to which they are connected, and the accuracy is dependent on the joint effects. At high frequencies, the effects may be either reduction or an increase in sensitivity caused by the design of the transducer and its mounting. Many of these effects will be attenuated by the weighting curves applied by the measuring instrument.

If the mounted resonance of the transducer is well above (say at least 2 octaves or 4 times) the highest frequency of interest, then the measurements should not be affected by the transducer's response. Instruments may fit additional high frequency roll-off to reduce these effects, but a knowledge of their likely frequency and amplitude is worthwhile if at all possible. Transducers where the mounted resonance lies within the measured bandwidth should be avoided at all costs.

c) Cable Effects

A good quality cable, secured close to the transducer and to the same vibration source as is being measured, will not normally introduce any measurement errors as far as human vibration measurements are concerned. For whole-body measurements, securing the cable may be less important than ensuring it will not create a safety hazard for the person under surveillance.

Cables where the screening connections are not low-resistance, possibly caused by wear and tear on the cable or its termination to a connector of some description, can introduce noise to the measured signal, the effects of which can only be guessed at. This will also allow interference from outside electrical sources, such as mobile telephones and powerful electric fields from industrial equipment to induce spurious signals into the cable.

Allowing the cable to "flap in the breeze" under the influence of the vibration source and any other factors in the vicinity, may induce unwanted signal into the cable. This is referred to as the triboelectric effect. It is small and is not usually a major source of error even when present, but the lower the signal from the transducer, the greater its effect on measurement accuracy. Proper support for, and securing of, the cable normally reduces this to negligible effect.

6.3 ACCURACY OF INSTRUMENTATION

a) Tolerances from ISO 8041

The current publication of ISO 8041:1990 specifies a number of tolerances on the accuracy of the measurement instrumentation and defines two grades of accuracy: Type 1 and Type 2, with Type 1 being the most accurate. It is not practical to list every item here, but a few salient numbers are included as a guide to the expected accuracy.

Instruments are required to define a reference calibration acceleration and frequency, often 1 or 10 m/s^2 at 8 or 80 Hz. The accuracy of this single reference point when compared to the "true" level must be within 8% (0.7dB) for Type 1 and within +12/-11% (1dB) for Type 2 instruments at 20 deg. C and 65% RH. Additionally, this point may change by up to 6% either as the temperature changes between 20 and –10 or +50 deg C or as the humidity changes from 65% to 30 or 90%.

The frequency weightings applied to the measured signal have tolerances which vary with applied frequency. For the most important region of their response, these are +12/-11% or ±1 dB, and they include the frequency response of the transducer. The tolerances are identical for both Types of instrument.

The accuracy of the data over the whole measuring range of the instrument is specified with respect to the reference acceleration to which the instrument was calibrated. At its best, this is required to be accurate within 8% (0.7 dB) for a Type 1 meter and within +12/-11% (1 dB) for Type 2. These accuracies are measured electronically, and there are a number of other tests with pulses and bursts of signal that check the dynamic performance of the instrument. In most cases, the tolerances allowed are wider for Type 2 than for Type 1.

Although these requirements are defined, there is no set of standard tests to prove an instrument fully complies with them. This has led to difficulties in obtaining certified calibration of instruments, as a test laboratory has first to define its own tests which are, by definition, then unique to that laboratory. Nevertheless, a set of basic checks are available from reputable calibration professionals, and it is well worthwhile having the full measuring system checked periodically.

b) *ISO 8041 Revision*

The above information relates to the 1990 edition of ISO 8041. A new version is currently in preparation that will alter this information quite significantly.

There will be only one Grade of instrument, so there will not be a need to refer to Type 1 or 2 any more. The tolerances are in the most part tightened (even over the old Type 1), and standard tests to determine compliance are included. A specification for vibration exciters or calibrators is also included for the first time.

Until the new version is published, any figures quoted could be subject to change, and therefore at this point in time, it is not possible to quote these. However, any meter that claims the new version of the Standard will probably have better performance than any existing Type 1 instrument.

c) *Measurement Uncertainty*

It is now mandated that all International Standards include measurement uncertainty in the tolerances allowed. The existing ISO 8041 does not include or mention measurement uncertainty, so up to now, no allowance has been made for this by calibration laboratories. The new version of ISO 8041 does include these, and it will be interesting to see whether this results in more realistic assessments of actual measured uncertainties on vibration sources.

Uncertainty arises from all measured sources. An absolute unit of acceleration that can be checked for perfection does not exist. The measurements that define any quantity have a small degree of *possible* error that can usually be expressed in terms of a small fraction of the unit under consideration. For most of the parameters associated with vibration measuring instrumentation, the errors are finite and the estimate of their magnitude can be made under fairly closely controlled conditions.

Note that when assessing measurements against the values in the PA(V)D, the actual measured levels plus their associated uncertainty of measurement must be less than the Exposure Limit Values (ELV)

The following list shows typical values for some of the more common uncertainty terms that affect vibration measuring instruments:

Ref accelerometers – typically 0.7%, 2% at higher frequencies
Accelerometers in daily use – 3% - 5%
Voltmeter 0.25% for a.c. volts
Frequency counter – negligible

As the current standard for vibration measuring instrumentation does not require uncertainties to be considered, the accuracy required by ISO 8041 is misleading if quoted as above, but typically produces results that are within 8 - 10% of the "true" value. The current revision of this Standard will probably change this figure.

The number which is impossible to quote reliably in the above list is that associated with the mounting of the transducer. An allowance of 10% to cover the location and fit is probably a reasonable starting point.

Any uncertainty calculation must consider the following elements:

The mounting of the transducers
Location and orientation of the transducers
Changes from the normal operation caused by the introduction of the transducers
Changes in the machine condition during measurement
Changes in the operator's working conditions during measurement i.e. a vehicle on rough or smooth ground)
Errors in the duration of work cycles
Errors in the number of work cycles per day
Variability in the work patterns over different days
Errors in the measuring instrumentation.

As no-one usually knows the limit of uncertainty, it is usually calculated from formulae which define uncertainty with respect to a degree of confidence. The most common value used is 95%, and as an approximate rule, the uncertainty calculation is multiplied by 2 to give "the expanded uncertainty with a confidence level of 95%".

The uncertainties associated with the accuracy of the measuring equipment are usually dwarfed by those associated with trying to measure the vibration source. The effects of people on the vibration source can cause very large variations in the vibration transmitted to the person.

Positioning of transducers can cause significant differences between the measured level and the actual levels received by the person, and the quality of transducer attachment can impact on the measured values. Attempting to put figures to the uncertainty of these items is fraught with difficulty. A suggested range of values is given in the table below.

Indicative Uncertainty Values

Parameter	Uncertainty	Estimate of Typical Uncertainty (%)
		Best Practice
Instrumentation		
Accelerometer calibration (at reference)	**±3%**	**±3%**
Accelerometer frequency response	**±2.5%**	**+2.5/ -0**
Instrumentation	**±4%**	**±4%**
Measurement Process		
Measurement duration	**+10/ -0%**	**+10/ -0**
Triboelectric effect	**Negligible**	**±2%**
Electrical pickup	**Negligible**	**±2**
Mounting – rigid	**Negligible**	**±2**
Mounting – handheld	**+100/ -50%**	**-**
Mass of transducer(s)	**Negligible**	**±2%**
Transverse response (with or without mechanical filters)	**+4/ -0%**	**+4/ -0**
Location of transducer	**+100/ -50%**	**±15**
Exposure Time Measurement		
Video monitoring	**Negligible**	**±2**
Number of components from production records	**~±10%**	**±10**
Number of components by video	**~±2%**	**±4**
Active sampling	**Variable**	**±10**
Noise dosimeter	**±20%**	**±10**
Self estimates	**+60/ +490%**	It is assumed that this method is NOT used.

d) Examples of Instrument Accuracy

The National Measurement System of the DTI has funded experimental work to investigate uncertainty of measurement in the instrumentation of human exposure to vibration under the same basic project that is responsible for the production of this good practice guide. This work used a range of commercial instrumentation systems to measure hand-arm and whole body exposure in controlled yet realistic environments.

Individual measuring systems returned consistent and repeatable measures of vibration amplitude, well within the uncertainties suggested in the table above. Weighted acceleration results were distributed with a worst-case ratio of standard deviation to mean of $\sigma/\mu = 6.6\%$. This distribution was caused by the consequences of removing and replacing the accelerometer, rather than the intrinsic accuracy of the instrumentation system itself. In repeat measurements involving no such re-positioning of the transducer, the repeatability was such that $\sigma/\mu < 1.5\%$.

When the results of the different measuring systems were compared, more significant variations were revealed. For a full appreciation of this part of the project, the presentation written by Darlington in Annex A should be consulted or the DTI contacted as given in section 7.

6.4 PRINCIPALS OF UNCERTAINTY CALCULATIONS

6.4.1 EXAMPLE 1 - MEASUREMENT OF THE VIBRATION EMISSION OF A HAND HELD GRINDER

The standard test in ISO 8662-4 (Note this is under revision in 2004) describes measurement of the vibration emission of a hand held grinder. The dominant axis of vibration is measured at a specified location on the handle by glueing or strapping the transducer to the point of measurement. The test method involves four measurements on each of three subjects. BS EN 12096:1997 defines a method for estimating the uncertainty of such an emission measurement when a single tool is used.

a) *Calculation of uncertainty of an emission test on a single tool, according to BS EN 12096:1997*

A value for the uncertainty, K, is calculated from the results of all three operators. According to the provisions of EN 12096: 1997, which apply where a single tool is used to declare the vibration emission, K is calculated using the equation.

$$K = 1.65\sigma_R$$

Where an estimation of the standard deviation of reproducibility σ_R is calculated according to EN 12096: 1997 using the equation:

$$\sigma_R = \sqrt{(\sigma^2_{op} + \sigma^2_{rec})}$$

This involves calculation of the value σ_{rec} (the standard deviation of the recorded values from the same operator) and σ_{op} (the standard deviation of the recorded values from the different operators). However, the combination of the standard deviations from the three operators in the calculation of σ_{rec} is not defined. Here, the assumption is made that repeating the measurements on three operators would give a rectangular distribution. Therefore, the data from the three operators was combined using the following equation, (from A Beginner's Guide to Uncertainty Measurement, Bell 1999, see Annex A, a useful starting document for anyone needing help with uncertainty budgets):

$$\sigma_{rec} = \sqrt{\frac{(\sigma^2_1 + \sigma^2_2 + \sigma^2_3)}{3}}$$

Where σ_1, σ_2 and σ_3 are the standard deviations of the data provided by the measurements from operator 1, operator 2 and operator 3 respectively.

Worked Example:

The grinder emission test involves three test subjects. For each subject, four measurements are made. The table below contains results from an emission test.

	S1	S2	S3	
T1	4.67	4.99	3.32	
T2	4.78	5.89	2.70	
T3	3.59	3.63	4.48	
T4	3.50	3.29	3.59	
				Overall mean
Mean	4.14	4.45	3.52	a = 4.04
	⑨$_1$ = 0.68	⑨$_2$ =1.21	⑨$_3$ =0.74	⑨$_{op}$ = 0.91

$$\sigma_{rec} = \sqrt{\frac{(\sigma^2_1 + \sigma^2_2 + \sigma^2_3)}{3}}$$

$$\sigma_{rec} = \sqrt{\frac{(0.68^2 + 1.21^2 + 0.74^2)}{3}}$$

$$\sigma_{rec} = 0.91$$

$$\sigma_{op} = 0.91 \text{ (from the table)}$$

$$\sigma_R = \sqrt{(\sigma^2_{op} + \sigma^2_{rec})}$$

$\sigma_R = 1.29$

$K = 1.65 \times \sigma_R = 2.1\ m/s^2$

From the table above a = 4 m/s^2

Therefore the emission would be declared as the a + K value of

$4.0 + 2.1\ m/s^2 = 6.1\ m/s^2$

6.4.2 EXAMPLE 2 - MEASUREMENT OF THE DAILY VIBRATION EXPOSURE FROM A HAND HELD GRINDER

The following table (courtesy of The Health and Safety Laboratory (HSL)) is the result of extensive research into the uncertainties associated with each part of the measurement process for hand-transmitted vibration. The table can be used to estimate the uncertainty of a daily vibration exposure assessment as shown in the example below.

a) *Indicative uncertainty values for hand-arm vibration (results of HSL research)*

Uncertainties are based on best practice measurements.

INSTRUMENTATION	
Accelerometer Calibration (at reference)	±3%
Accelerometer frequency response	+2.5%, - 0%
Instrumentation	±4%
MEASUREMENT PROCESS	
Measurement Duration	+10%,-0%
Tribo-electric effect	±2%
Electrical pick up	±2%
Mounting - rigid mount	±2%
Mass of transducer(s)	±2%
Transverse response (with or without mechanical filters)	+4%, -0%
Location of transducer	±15%
EXPOSURE TIME MEASUREMENT	
Video monitoring	±2%
Number of components from production records	±10%
Number of components by video	±4%
Activity sampling	±10%
Noise dosemeter	±10%
Estimated overall typical percentage uncertainties based on the "typical uncertainties" above.	
Acceleration magnitude, a_w:	+20%, -17%
Exposure time, t:	±2% to ±10% (dependent on technique)
Daily vibration exposure A(8):	+21%, -18% (based on 10% error in t)

Worked example:

A fettler uses a 9 inch angle grinder with a highest axis vibration magnitude which has been measured as 7 m/s². The estimate of daily exposure time has been made by activity sampling of the operator carrying out normal work and is estimated at 4 hours a day. The resulting daily exposure figure or A(8) is given by:

$$A(8) = a_t\sqrt{\left(\frac{t}{8}\right)}$$

where $a_t = 7\ m/s^2$

and $t = 4\ hours$

so $A(8) = 4.95\ m/s^2$ *which would normally be quoted as 5.0 m/s² to be compatible with general measurement accuracy.*

Uncertainty of the daily exposure calculation

The expression for the uncertainty of a daily vibration exposure measurement is given below:

$$P_{A(8)} = \sqrt{(P^2_{ahv}) + \left(\frac{P^2_T}{4}\right)}$$

where P^2_{ahv} = uncertainty of the vibration measurement

and P^2_T = uncertainty of the exposure time measurement

Using this equation and based on the uncertainties in the forgoing table, the uncertainty of the daily exposure figure would be estimated as follows:

For the vibration measurement, P^2_{ahv}

Overall positive uncertainty (%) for single axis vibration measurement. From the table, take the root sum-of-squares of all the terms which apply to the measurement:

$$= \sqrt{(3^2 + 2.5^2 + 4^2 + 10^2 + 2^2 + 2^2 + 2^2 + 2^2 + 4^2 + 15^2)} = 20\%$$

Overall negative uncertainty (%) single axis. From the table, take the root sum-of-squares of all the terms which apply to the measurement:

$$= \sqrt{(3^2 + 2.5^2 + 4^2 + 2^2 + 2^2 + 2^2 + 2^2 + 15^2)} = 17\%$$

So the percentage error in P^2_{ahv} is +20% -17% (As shown in the previous table).

For the exposure time assessment, P^2_T

The overall uncertainty (%) of the exposure asessement is straight out of the table of uncertainties for video monitoring which is ±10%.

b) Combination of Uncertainties

Using the formula for combination of uncertainties:

For positive uncertainty

$$P_{A(8)} = \sqrt{(P^2_{ahv}) + (\frac{P^2_T}{4})}$$

This becomes

$$P_{A(8)} = \sqrt{(20^2) + (\frac{10^2}{4})} = \sqrt{425} = +21\%$$

Negative uncertainty

$$P_{A(8)} = \sqrt{(P^2_{ahv}) + (\frac{P^2_T}{4})}$$

Which becomes

$$P_{A(8)} = \sqrt{(17^2) + (\frac{10^2}{4})} = \sqrt{314} = -18\%$$

The final measurement of daily vibration exposure then becomes:

$A(8) = 4.95\ m/s^2\ (+1.04\ m/s^2 - 0.89\ m/s^2)$

Which, given general measurement accuracy, would probably be best shown as:

$A(8) = 5.0\ m/s^2\ (+1, -0.9\ m/s^2)$.

As no comparable study on Uncertainties for Whole Body (Triaxial) vibration is known, data is not available to provide meaningful examples of similar calculations to be prepared. The principals will be similar to those for hand-arm vibration, but obviously different components will contribute to the uncertainty budget.

SECTION 7 – WHERE TO SEEK ADVICE

Under the new Regulations, employers will have a duty to protect their employees from the risks associated with vibration exposure and to apply the Exposure Action Values and Exposure Limit Values to their operations. In the UK, the Health and Safety Executive (HSE) and/or Local Authorities will take action to enforce the PA(V)D from July 2005 onwards. Further information on employers and employees duties, and all aspects of assessing and measuring vibration affecting people can be obtained from the following sources.

7.1 GOVERNMENT BODIES

The Health and Safety Executive publish guidance on hand-arm and whole-body vibration, (see Annex A for details.)

The HSE also has a vibration website at www.hse.gov.uk/vibration

Specific enquiries can be addressed to the HSE Infoline

Phone: 08701 545500 (8 a.m. to 6 p.m. Mon – Fri).
Fax: 02920 859260
e-mail: hseinformationservices@natbrit.com
Post: HSE Infoline, Caerphilly Business Park, Caerphilly. CF83 3GG

The Department of Trade and Industry have a role in ensuring correct measurement practices and their impact on the commercial life of the UK. They can be contacted at:

Phone: 0207215 5000
Website: www.dti.gov.uk/nms
Post: 151 Buckingham Palace Road, London. SW1W 9SS

7.2 LOCAL AUTHORITIES

a) EH Departments

Most Local Authorities have Environmental Health departments or something that carries out this role that will be responsible for ensuring compliance with legislation in this area.

Environmental Health Officers may be able to offer advice on prevention of potentially damaging vibration conditions and may have information on other people with the same problems and solutions. In most cases, contacting the nearest Local Authority and establishing the correct department will allow a dialogue on the topic in hand.

7.3 OTHER SOURCES

a) Trades Unions

Several Unions have taken close interest in the health aspects of vibration exposure. If claims for compensation arising from vibration induced health damage are being considered, an approach to the relevant Trades Union may be worthwhile.

b) Consultants

There are a number of specialist vibration consultants and consultancy practices that can measure and prescribe actions arising from the measurements of vibration. Many of these are also Acoustic Consultants, and care needs to be taken that a consultant selected really does know vibration fully, as many are new to this area of operation.

There is no registered list of knowledgeable vibration consultants at present. The ANC and IOSH are understood to have information on members with special interest with respect to human response to vibration. They can be contacted at:

Post: The Institute of Occupational Safety & Health (IOSH).
The Granges, Highfield Drive, Wigton, Leics. LE18 1NN
Phone: 0116 257 3100
Website: www.iosh.org.uk.

Post: The Association of Noise Consultants (ANC)
6 Trap Road, Guilden Morden, Royston, Herts. SG8 0JE
Phone: 01763 852958
Website: www.association-of-noise-consultants.co.uk

c) The Institute of Acoustics

The Institute of Acoustics operates a Certificate course in the Management of Occupational Exposure to Hand-Arm Vibration. This can be studied at a number of centres in the UK. The measurement of hand-arm vibration is covered to give the delegates an appreciation of the equipment, skills and experience needed to make meaningful measurements.

This is the only known qualification that includes human vibration measurement, and is mostly acquired by health and safety professionals, engineers and others who need to help employers control vibration risks.

The Institute can be contacted at:

Post: 77A St Peter's Street, St Albans, AL1 3BN
Phone: 01727 848195
e-mail: education@ioa.org.uk
Website: www.ioa.org.uk

d) Academic Institutes

A number of Universities have vibration measuring expertise in a variety of guises. The probable leader in this field is the Institute of Sound and Vibration Research (ISVR) at Southampton University who can be contacted at:

Post: ISVR Human Factors Research Unit,
The University, Highfield, Southampton SO17 1BJ.
Phone: 023 8059 2162
Website: www.humanvibration.com

Other Universities who have Departments that may be able to assist specialist requirements, where problems of vibration exposure require dedicated solutions include:

Loughborough University,
Post: Acoustics and Vibration Research Unit, Loughborough. LE11 3TU.
Phone: 01509 227216
Website: www.lboro.ac.uk/departments/tt/research

University of Salford,
Post: School of Acoustics and Electronic Engineering,
Brindley Building, Salford. M5 4WT.
Phone: 0161 295 5582
Website: www.acoustics.salford.ac.uk

Cranfield University,
Post: School of Engineering, Cranfield. MK43 0AL.
Phone: 01234 754631
Website: www.cranfield.ac.uk/soe/engmechanics

ANNEX A

PUBLICATIONS AND STANDARDS THAT PROVIDE MORE INFORMATION ON SPECIFIC TOPICS RELATED TO VIBRATION

All British, European or International Standards can be usually purchased from:

British Standards Institution (BSI)
389 Chiswick High Road,
London, W1 4AL
Phone 0208 996 9001,
Fax: 0208 996 7001
E-mail: orders@bsi-global.com

British Standard BS EN 1032:2003 Mechanical vibration – Testing of mobile machinery in order to determine the vibration emission value.

European Standard EN 1033:1995 Hand-Arm vibration – Laboratory measurement of vibration at the grip surface of hand-guided machinery – General
NOTE: This standard is currently being revised and will be issued as EN ISO 20643:200X Mechanical Vibration – Hand-held and hand-guided machinery – Evaluation of vibration emission.

International Standard ISO 8041:1990. Human response to vibration – Measurement Instrumentation.

NOTE: THIS WILL BE REPLACED BY EN ISO8041:200X, POSSIBLY BEFORE THIS GUIDE IS PUBLISHED.

International Standard ISO 2631-1:1997. Mechanical vibration and shock – Evaluation of human exposure to whole body vibration. Part 1: General Requirements.

This Standard also has Parts 2 & 4 which define additional weighting curves.

British Standards BS EN ISO 5349-1:2001 and BS EN ISO 5349-2:2002. Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration.
Part 1: General requirements
Part 2: Practical guidance for measurement at the workplace.

International Standards Report CR 12349:1996 Mechanical Vibration – Guide to the health effects of vibration on the human body.

British Standard BS EN 14253:2003 Mechanical vibration – Measurement and calculation of occupational exposure to whole-body vibration with reference to health – Practical guidance.

British Standard BS6841:1987 Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock.

European Standard EN 8662-X.Hand-held portable power tools – Measurements of vibrations at the handle.
This comes is many parts (=X), part 1 is general requirements, parts 2 – 14 apply to specific types of tools.

International Standard ISO 5348:1998 Mechanical vibration and shock – Mechanical mounting of accelerometers.

Directive 2002/44/EC The Physical Agents (Vibration) Directive. European Union, Brussels.

Hand-Arm Vibration HS(G) 88 (1994) produced by the Health and Safety Executive and available from HSE Book, Phone 01787 881165.
NOTE: This will be withdrawn when guidance to accompany the new Regulations is published by the HSE in 2005.

Vibration Solutions HS(G) 170 (1997)) produced by the Health and Safety Executive and available from HSE Book, Phone 01787 881165.

Handbook of Human Vibration, M.J.Griffin 1990. Academic Press Ltd. London. ISBN 0-12-303040-4.

Bell, Stephanie. A beginners guide to Uncertainty of Measurement. Measurement Good Practice Guide no. 11, 1999, National Physical Laboratory, London.

Darlington, Paul. Measurement Uncertainty in Human exposure to vibration. Proceedings of "Shake, Rattle and (the) Role", Institute of Acoustics, 7th July 2004.

ANNEX B

INFORMATION ON DOSE-EFFECT RELATIONSHIPS

A very brief overview of the Health risk information known about Hand-Arm and Whole Body vibration exposures

Ba) Hand-Arm Vibration Risks

Significant exposure can cause disturbances in finger blood flow and in motor, vascular and neurological functions of both the hand and arm. Hand-arm vibration syndrome (HAVS) is often used to describe any disorder arising from exposure to hand-arm vibration. This may include bone and joint abnormalities in some cases. All these symptoms, if caused by hand-arm vibration, are included in a European list of recognised occupational diseases, and as such are potentially subject to compensation from employers who permit excessive exposures and damaging work practices.

One of the more commonly experienced effects when subjects are exposed to hand-arm vibration is known as Raynaud's Phenomenon or Vibration White Finger. This takes the form of interruption of the blood circulation to the fingers, which results in them being pale or white, having little or no sensation of feel, and is usually induced by exposure to cold temperatures. During an attack, the loss of sensation and of manipulative skills is potentially dangerous to anyone working in areas requiring manual dexterity. During recovery, which can usually be accelerated by warmth, the fingers may turn a bluish hue, and tingling or pain and excessive redness may all be experienced. Attacks can last between minutes and an hour.

The restrictions in the blood flow are caused by digital vasoconstriction, induced by prolonged vibration exposure. There is the medically recognised Stockholm Workshop scale which grades the severity of impairment and is often used for assessing compensation claims. Many factors affect the influences and onset of Raynaud's Phenomenon, but evidence of correlation between exposures and symptoms is very vague. However, there are some reports that the effects can diminish slowly if exposure to vibration is stopped for long periods.

The sensorineural component of HAVS is now considered to be the principal cause of disability. It generally involves a reduced sense of touch and temperature, which can develop independently of the vascular condition.

Other noted effects include carpal tunnel syndrome, a disorder resulting from compression of the median nerve in the wrist, wrist and elbow osteoarthritis

and degenerative bone and joint disorders in the upper limbs. Muscular weakness and diminished hand grip strength have also been attributed to hand-arm vibration exposure, and many other peripheral disorders have been claimed to be induced, but the case for many of these is not proven.
More information on these symptoms and their relationship between exposure and effects on health can be found in ISO 5349-1:2001. The likelihood of vascular symptoms being experienced by people is expressed as the vibration exposures causing problems with 10% of exposed people over a number of years. This appears to be an approximately doubling relationship, with 8 hour vibration exposure levels of 3.7 m/s^2 requiring 8 years to induce problems, 7 m/s^2 4 years and 14 m/s^2 2 years. The values set in the PA(V)D of 2.5 m/s^2 and 5.0 m/s^2 can therefore be seen to look reasonable in the light of this tentative information.

Bb) Whole Body Vibration Risks

The reported effects of whole body vibration are much less well-defined than those for hand-arm vibration, as studies are always very long-term and it is often difficult to separate work-type exposures and normal lifestyle activities. Exposure to whole-body vibration and shock is associated with an increased prevalence of pain in the lower-back, but other occupational factors, such as poor or constrained posture and manual handling tasks are often also present.

Spinal injuries of varying sorts are the principal concern, and it has been shown that anyone suffering from osteoporosis or other spinal disorders will be more susceptible to whole body vibration injuries. Shocks can cause compression of the spine, leading to diffusion of disc tissue and degeneration of lumbar segments. The intervertebral disc can change internal pressure and soften, tear or buckle with exposure, and trunk muscles can overcompensate under certain conditions, which can prove uncomfortable, and muscle fatigue is not unknown, especially those concerned with supporting the head.

Measurement of vibration exposures alone should not be regarded as providing all data, as the many other potential causes of lower-back injury must be given full consideration, and judgements made on the relative importance of all factors.

Tests have shown a correlation between peak acceleration levels and compressive stress in the spine. Posture has also been shown to influence the effects, and a bending forward or twisting stance is likely to increase the vibration effects.

Unlike hand-arm vibration, no quantitative correlation between vibration exposure and health effects has been established for whole body vibration. Drivers of tractors and earth moving machinery, and helicopter pilots appear to be among the most likely people to be affected, but the careful application of correct seating and posture can alter the exposure so much, that any study into cause and effect is very difficult to get meaningful data from. The use of VDV as opposed to r.m.s. measurements for whole body vibration is suggested as giving a clearer response to potentially damaging levels as VDV gives greater importance to peaks in the received vibration. With so little concrete evidence linking vibration levels and health effects, it will be a long time before either method can be shown to be more appropriate to the assessment of whole body vibration.

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