Background to Vibration as a Hazard

- Everything vibrates!

- Vibrations cause problems when passing through the air
  - Perceived as sound or noise

- Vibrations cause problems through solids too
  - Perceived as uncomfortable or dangerous
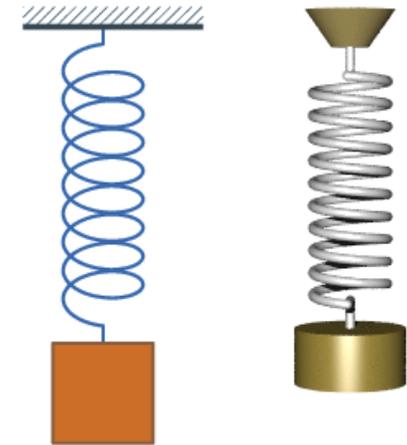
Vibrations through solid materials

- Energy is transmitted from one place to another

- Characterized by speed of transmission

- By the amplitude of the waves

- By the speed of vibration changes

- By the direction of the vibrations
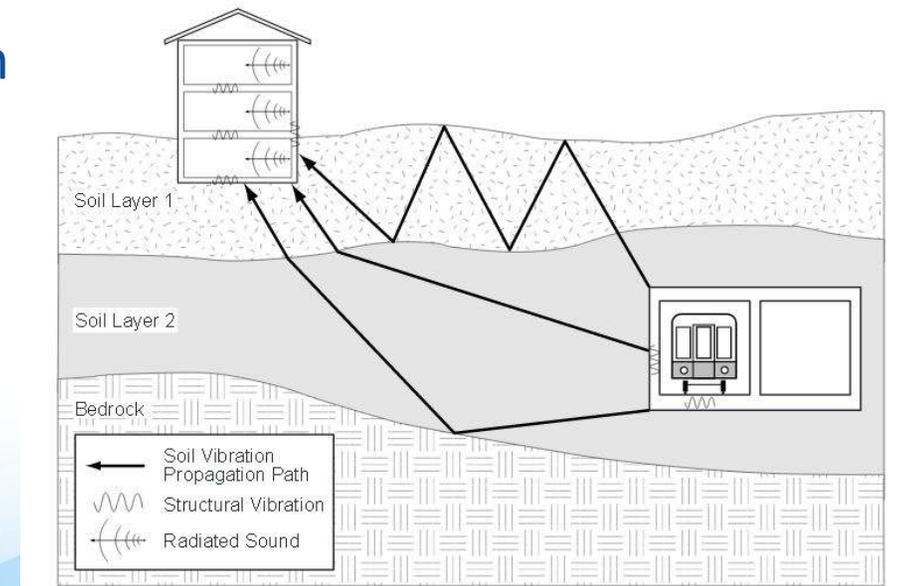
Vibration sensors used for measurements

- Unlike sound where we can measure with a single omni-directional transducer (a microphone) the transducer we use for detecting vibration is only responsive in a main single axis through the body of sensor

- To gain a complete picture we need to be able to measure in three perpendicular axes to obtain the vector sum

- Vibration has both a magnitude and a direction

Vibration in three dimensions

- Usually have three accelerometers set at right angles to each other

- Measure an X, Y and Z component

- Calculate the vector sum by squaring the three components, summing then finding the square root

- True vibration amplitude

  $$= [X^2 = Y^2 = Z^2]^{1/2}$$
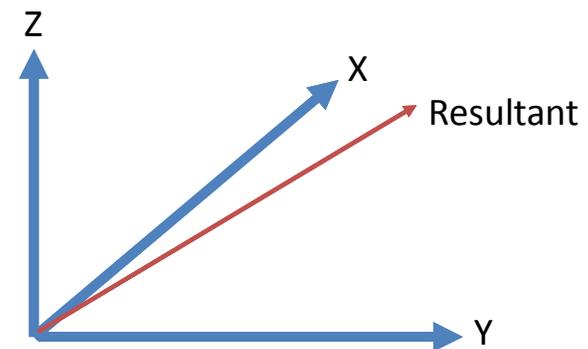
How do we refer to vibration characteristics

- **Peak value**
  - Can be positive or negative amplitude

- **Peak to peak value**
  - Highest positive to lowest negative value

- **RMS value**
  - Equivalent energy average over time

- **Period of oscillation**
  - How long for one complete cycle

- **Frequency of oscillation**
  - How many cycles per second

Simple 60 Hz Sine Wave
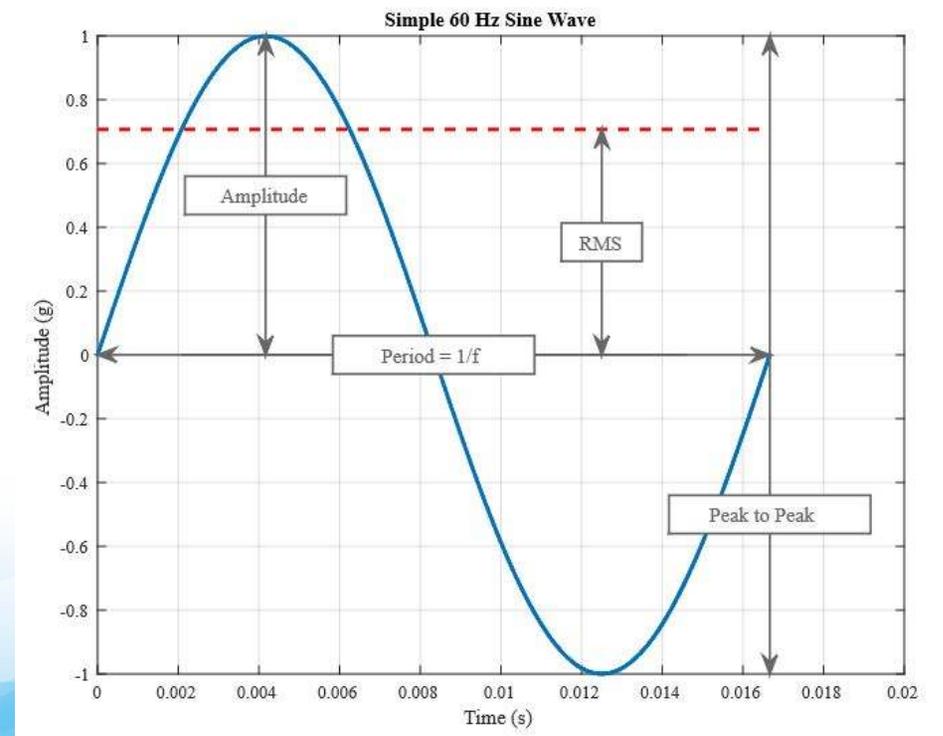
Vibrations in the real world

- Most vibration signals are much more complex than a single sine wave

- Shows a pump bearing raw time waveform with spikes due to damaged bearings
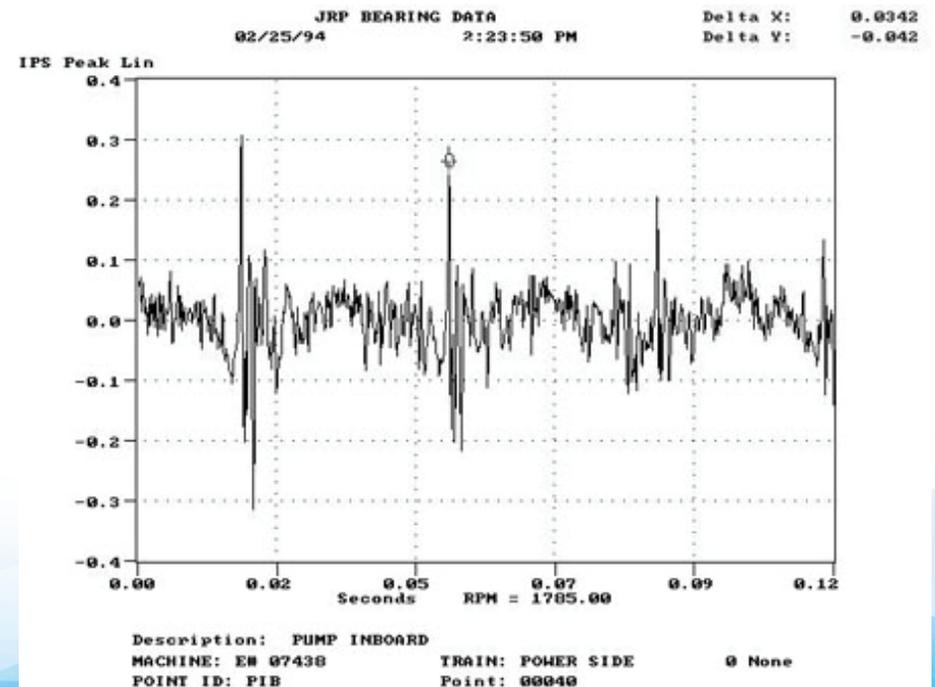
Extra information contained in frequency analysis

- Even complex vibration signals like the pump bearing can be measured using frequency analysis

- At least 1/3 octave band analysis
  - Normally interested in a lower range than for noise measurements
  - Typically 1 Hz to 5 kHz is sufficient

- Often narrower band or FFT analysis is useful to identify tones and harmonics
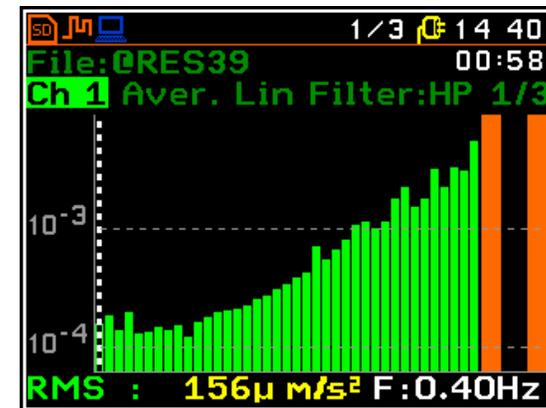
34 x 1/3 octave bands + 2 overall values
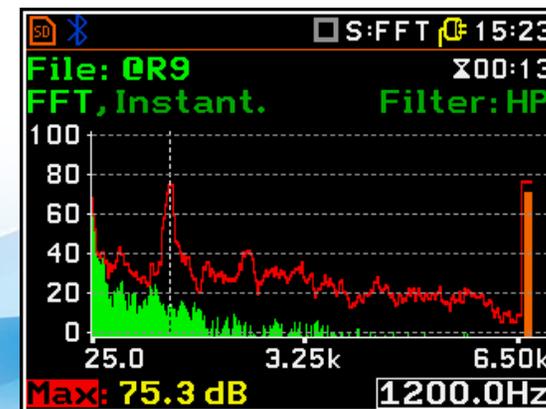
Narrow band FFT + overall value

Single number overall readings

- Recording the vibration signal as a time history is useful to show trends and changes

- Three popular units to measure include;
  - Acceleration in m/s^2 (or g)
  - Velocity in m/s (or ips)
  - Displacement in m (or mil)
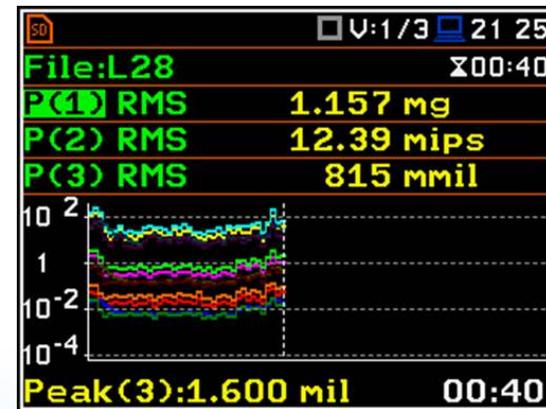
P1 is accel, P2 is vel, P3 is disp

Alternative display units

- ⊙ Sometimes useful to display vibration in decibel units
  - For acceleration 10^{-6} m/s² is taken as 0 dB acc
  - So acceleration of 1 m/s² is 120 dB acc

  - For velocity 10^{-9} m/s is taken as 0 dB vel
  - So velocity of 1 mm/s is 120 dB vel

  - For displacement 10^{-12} m is taken as 0 dB disp
  - And displacement of 1 microm is 120 dB disp

Consider vibration effects on man

- Specifically consider hazards of vibration in the workplace

- Primarily there is vibration affecting the hand and arms

- Also vibration affecting the whole body

- Finally nuisance vibration affecting delicate machinery at work

- Let's look at each of these in more detail

Hand arm vibration sources

- Can adversely affect workers who use hand operated power tools for their job

- Examples are;
  - Grinding tools,
  - Polishing tools,
  - Road breakers,

Hand arm vibration sources 2

- ⊙ More examples of potential hand arm vibration sources at work
  - Chain saws,
  - Cutting tools

Who else might be affected?

- Landscape gardeners

- Industrial automotive polishers

- Dentists using drills and teeth cleaning tools

- Tattoo artists using small drills

Common sources in industry

Examples of occupational vibration exposure		
Industry	Type of Vibration	Common Source of Vibration
Boiler making	Hand-arm	Pneumatic tools
Construction	Hand-arm	Pneumatic tools, Jackhammers
Diamond cutting	Hand-arm	Vibrating hand tools
Forestry	Hand-arm	Chain saws
Foundries	Hand-arm	Vibrating cleavers
Furniture manufacture	Hand-arm	Pneumatic chisels
Iron and steel	Hand-arm	Vibrating hand tools
Lumber	Hand-arm	Chain saws
Machine tools	Hand-arm	Vibrating hand tools
Mining	Hand-arm	Rock drills
Rivetting	Hand-arm	Hand tools
Rubber	Hand-arm	Pneumatic stripping tools
Sheet Metal	Hand-arm	Stamping Equipment
Shipyards	Hand-arm	Pneumatic hand tools
Shoe-making	Hand-arm	Pounding machine
Stone dressing	Hand-arm	Pneumatic hand tools
Textile	Hand-arm	Sewing machines, Looms

How many workers are affected?

Number of workers by main industry segment in USA

No. of Workers	Industry	Type of Tool
500,000	Construction	Handtools
200,000	Farming	Gasoline chain saws
14,000	Metal working	Handtools
54,000	Steel	Furnace cleaning using powered handtools
30,000	Lumber and wood	Gasoline chain saws
34,000	Furniture manufacturing	Handtools
100,000	Mining	Pneumatic drills
250,000	Truck and auto manuf'	Handtools
64,000	Foundries	Handtools

How many US workers at risk?
About 1.25 million

Source – NIOSH http://www.cdc.gov/niosh/docs/83-110/default.html

What are the problems?

⊙ Loss of sensation in the finger tips, then whole fingers

⊙ Fingers turn white as blood vessels are damaged and die

⊙ Difficulty holding small objects due to irreparable nerve damage

⊙ Ultimately may need amputation in worst cases

More examples of HAVS issues

How long does it take to get HAVS?

Average latent periods for vibration-induced diseases in different occupations		
Occupation	Stage of VWF	Latency (years)
Foundry worker	Tingling Numbness Blanching	1.8 2.2 2.0
Shipyard worker	Tingling Numbness Blanching	9.1 12.0 16.8
Chain saw operator	Numbness	4.0
Grinder	Blanching	13.7

Scale of the problem

⊙ In 1997, the UK High Court awarded £127,000 (approximately $200,000) in compensation to seven coal miners for vibration white finger. Over $28,000 each individual claim.

⊙ A UK government fund set up to cover subsequent claims by ex-coalminers had exceeded £100 million ($160 million) in payments by 2004.

⊙ Since the 1970's there have been many successful claims for compensation for hand arm vibration syndrome.

Estimating the risk

- ⊙ Use manufacturer's stated vibration values per operation
  - − Studies have shown variation of about 12 % between users of same tool
  - − Also variation between tools of the same type and condition and age
  - − Tests carried out under no load conditions may not be representative

- ⊙ Tool timers to measure exposure duration (so called trigger time)

- ⊙ Calculate separate exposure contributions and sum for daily exposure

- ⊙ Prone to large errors and can have wide tolerances

Source - http://www.cdc.gov/niosh/docs/2006-140/
pdfs/2006-140.pdf page 87

Standards for the instruments

- Instruments used for assessments of HAV should comply with
  - ISO 8041:2005 Human response to vibration -- Measuring instrumentation

  - ISO 5349-1:2001 Mechanical vibration -- Measurement and evaluation of human exposure to hand-transmitted vibration -- Part 1: General requirements

  - ISO 5349-2 :2001 Mechanical vibration -- Measurement and evaluation of human exposure to hand-transmitted vibration -- Part 2: Practical guidance for measurement at the workplace

  - ISO 15230 :2007 Mechanical vibration and shock -- Coupling forces at the man--machine interface for hand-transmitted vibration

How do we measure HAV?

- Measure at the point of contact of the hand and the tool

- Ideally measure both hands if possible (6 ch) or use worst case (3 ch)

- Measure in X, Y and Z directions

- Measure for whole time tool is used in a workday or for a representative period for later calculation using known usage times
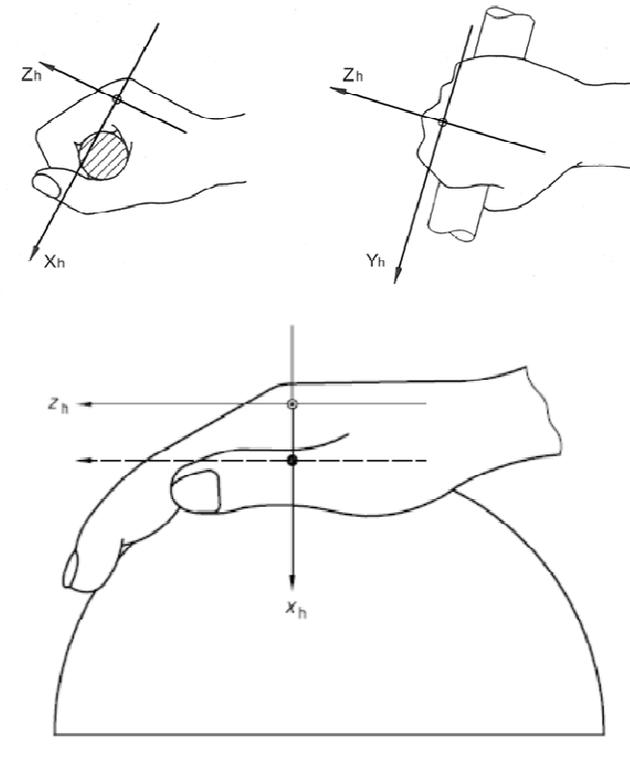
ISO 15230:2007 Standard overview

- ISO 15230:2007 describes the coupling parameters between the hands of a machine operator and a vibrating surface of the machine. The coupling between the hand and the vibrating surface can be described using different parameters and component parts of these parameters: force parameters, such as push, pull and grip; parameters such as pressure exerted on skin.

- In addition, informative annexes provide guidelines for measuring procedures, the measurement of the force and pressure parameters, and information on the requirements for measuring instrumentation, as well as a calibration method.
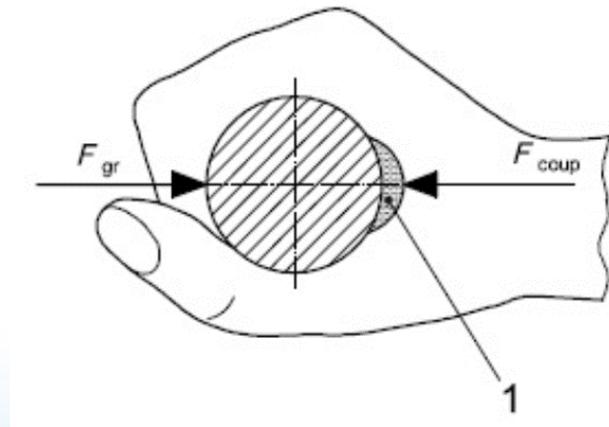
Alternative mounting methods

- Accelerometer should be mounted in appropriate position to suit the task

- Clamped to the tool handle enables tool vibration to be measured

- Will not be the same as vibration at the palm of hand/tool handle interface

- Can be significant differences
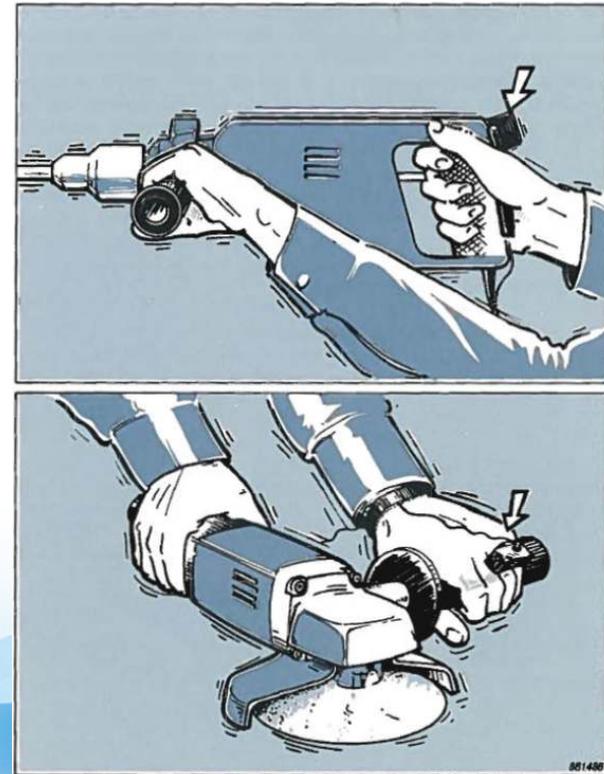
What do we need to measure?

- The vector sum of the three axes of measurement

- Apply special frequency filters to correlate with range of damage risk (1 to 1250 Hz overall, main sensitivity 8 to 16 Hz)

- Wh filter designed to take account of the region of highest sensitivity

The **Wh** filter is used for the assessment of the influence of the vibration signal on the human body. It conforms to the ISO 2631-1-97 and ISO 8041:2005 standards.

	0.5	1	2	4	8	16	31.5	63	125	250	500	1k	2k	4k Hz
	-44.0	-32.0	-20.0	-8.6	-1.5	-0.1	0.0	0.0	0.0	0.0	-0.1	-1.5	-8.8	-30.4 dB
	-44.0	-32.0	-20.0	-8.5	-1.2	-1.0	-5.7	-11.8	-17.9	-24.0	-30.1	-37.5	-50.9	-72.5 dB
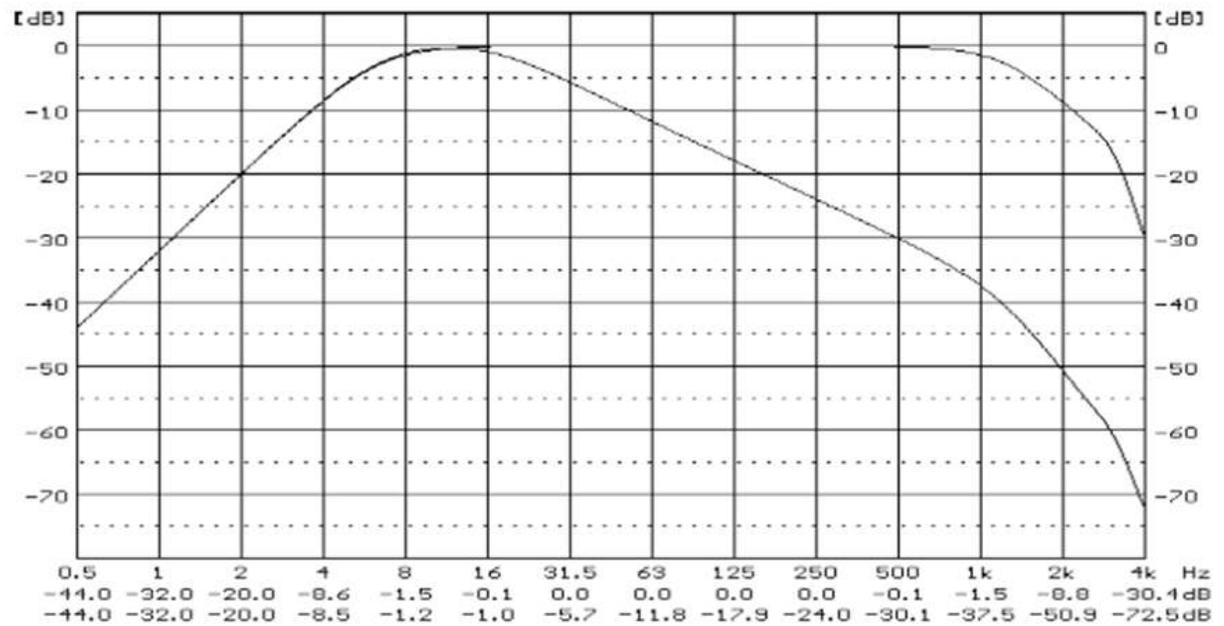
Characteristics of the BL-Wh and Wh digital filter implemented in the instrument

How do we deal with it - 1?

- Have to measure the dangerous vibration levels

- Three axes of measurement needed (6 ch = two inputs for L & R hand simultaneously)

- Use suitable instrument with appropriate setups and calculation methods

- Measure for a representative period of time – each tool type

- Include all partial exposures from different sources

How do we deal with it - 2?

- Can measure the vibration levels with personal hand arm vibration dosimeter

- Three axes of measurement (3 ch = one hand at a time)

- Use suitable instrument with appropriate setups and calculation methods

- Measure for a representative period of time – all day

- Include all partial exposures from different sources

What are the limits?

- Different countries around the world have adopted different limits for HAVS

- In the EU there are 2 values

  - Exposure limit value ELV
    - $A(8) <= 5.0$ ms^{-2}
  - Exposure action value EAV
    - $A(8) <= 2.5$ ms^{-2}

Concept of HAVS Dose value

- In Europe there is the concept of HA vibration dose

- 2.5 m/s^2 equivalent to 100 % daily action level

- So called "exposure points" (1 Point = 1% dose)

- Similar in principle to noise dose concept

Limits in the USA

SENSIDYNE®
Industrial Health & Safety Instrumentation

- ⊙ ANSI S2.70-2006*
    - – 2.5 m/s² DEAV
    - – DEAV = Daily Exposure Action Value

    - – 5.0 m/s² DELV
    - – DELV = Daily Exposure Limit Value

    - – For an 8 hr work day

⊙ DEAV is vibration dose sufficient to produce abnormal signs, symptoms in vascular, bone or joint systems

⊙ DELV identifies levels above which a high proportion of workers are considered to have "high health risk" to vibration problems

* Guide for the Measurement and Evaluation of Human Exposure to
Vibration Transmitted to the Hand

ANSI S2.70 vibration risk

- permissible vibration total values for time periods other than 8 hours

- "Health Risk Zone"
  - sufficient to produce abnormal signs, symptoms, and laboratory findings in the vascular, bone or joint, neurological, or muscular systems of the hands and arms in some exposed individuals

- "High Health Risk Zone"
  - sufficient to produce abnormal signs, symptoms, and laboratory findings in the vascular, bone or joint, neurological, or muscular systems of the hands and arms in a high proportion of exposed individuals.

Recommendations in USA

SENSIDYNE
Industrial Health & Safety Instrumentation
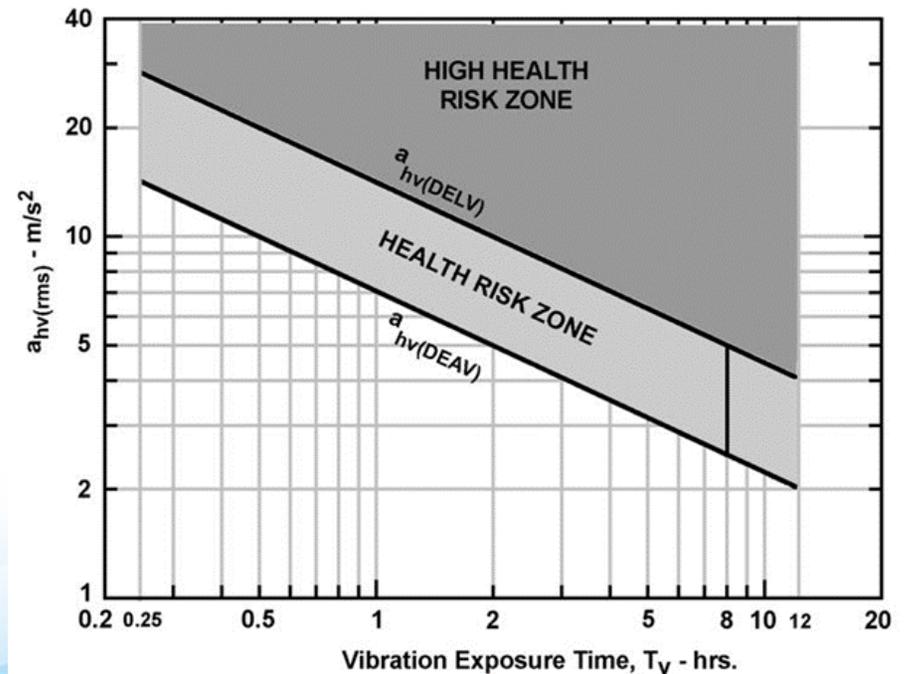
- ⊙ ACGIH* has issued TLVs for HAV
  - < 4 m/s^2 for 4 to < 8 hrs/day

  - < 6 m/s^2 for 2 to < 4 hrs/day

  - < 8 m/s^2 for 1 to < 2 hrs/day

  - < 12 m/s^2 for < 1 hr/day

- ⊙ Have to consider both steady state and intermittent sources of vibration at the hand

- ⊙ Time average value Aeq m/s^2 of the dominant axis

- ⊙ In any one of the 3 axes

*ACGIH = American Conference of Governmental Industrial Hygienists

What are some typical values?

Tool / Equipment	Acceleration (a$_{h,w}$) m/s²			Recommended Maximum Exposure Time		
	Good	Typical	Poor	Good	Typical	Poor
Angle grinders	1	5	10	> 24 hours	2 hours	30 minutes
Jackhammers	5	18	30	2 hours	9 minutes	3 minutes
Rotary Hammer Drills	5	8	18	2 hours	46 minutes	9 minutes
Rotary Sanders	1	5	10	> 24 hours	2 hours	30 minutes
Strimmers	3	6	15	5 ½ hours	1 ½ hours	13 minutes
Floor Polishers	1	2	4	> 24 hours	12 ½ hours	3 hours
Impact Wrenches	1	4	16	> 24 hours	3 hours	11 minutes
Nut Runners	3	4	8	5 ½ hours	3 hours	46 minutes
Power Screwdrivers	1	3	8	> 24 hours	5 ½ hours	46 minutes
Rotary Drills	2	4	8	12 ½ hours	3 hours	46 minutes
Lawnmowers	2	5	10	12 ½ hours	2 hours	30 minutes

How do we calibrate equipment?

- Use a suitable vibration calibrator

- Frequency in the range of the Wh – BL filter (1 Hz to 1.25kHz)
  - Typically 80 or 160 Hz

- Level 1 or 10 m/s^2

Mounting the accelerometer

- Use a suitable mounting adapter

- Measure in all three axes separately

- Perform "field check"

- Annual calibration to verify whole system

Potential solutions for HAV

- Keep hands warm to maintain good circulation

- Keep tool handles warm in cold weather use

- Keep cutting tools sharp

- Use low vibration tools where ever possible

- Maintain tools properly to minimize vibration due to excessive wear

- Wear anti vibration gloves (Personal protective equipment)

- Don't smoke as it reduces blood flow in fingers

- Rotate jobs between workers to minimize individual risk

Measurements in action

Typical results using a hand drill

Whole body vibration

⊙ Can adversely affect workers who drive a lot or operate certain types of machinery

- Truck drivers,
- Train drivers,
- Power rescue boat drivers,
- Earth moving equipment drivers,
- Helicopter pilots,
- Seamen onboard ships,
- Farmers on tractors,
- Concrete crusher operators

What are the problems?

- ◉ Whole-body vibration (WBV) is transmitted through the seat or feet of employees who drive mobile machines, or other work vehicles, over rough and uneven surfaces as a main part of their job.

- ◉ Large shocks and jolts may cause health risks including lower back-pain.

- ◉ How many workers at risk?
  – Up to 6.8 million in USA

Regular exposure to WBV from heavy equipment can lead to lower back pain in equipment operators

WB claim and award in the USA

A whole body vibration claim in the U.S.

Texas Jury Awards $1.9 Million to Train Driver for "Whole Body Vibration" Spinal Injuries.

On Friday February 18, 2011, a Tarrant County jury awarded Mr. James Phillips $1.9 million for career-ending spinal degenerative disc injuries following a four week trial in Fort Worth, Texas. Mr. Phillips, a Locomotive Engineer, worked for the BNSF Railway Company for thirty years, the last eighteen years of which were spent on freight trains operating between Clovis and Belen, New Mexico.

How do we deal with it?
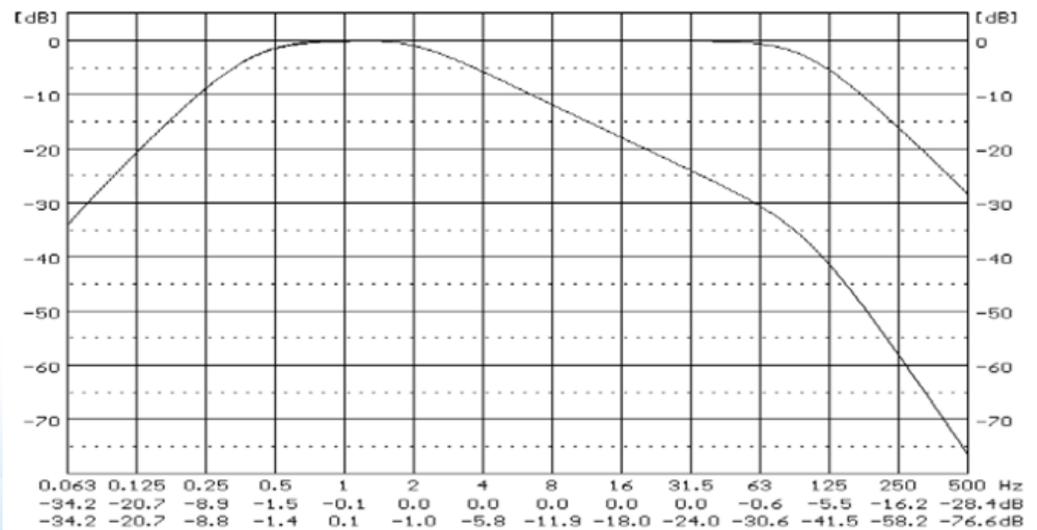
- Have to measure the actual vibration levels

- Three axes of measurement needed

- Use suitable instrument with appropriate setups and calculation methods

- Measure for at least 20 minutes for representative sample

What do we need to measure?

- The vector sum of the three axes of measurement

- Apply special frequency filter to correlate with range of damage risk (0.5 to 80 Hz overall, 0.5 to 2 Hz main sensitivity)

- Wd filter for the X (front to back) and Y (side to side) directions

- Measure A(8) & VDV

The **Wd** filter is used for the assessment of the influence of the vibration signal on the human body in the x and y directions and for horizontal recumbent direction. It conforms to the ISO 2631-1-97 and ISO 8041:2005 standards.


	0.063	0.125	0.25	0.5	1	2	4	8	16	31.5	63	125	250	500 Hz
	−34.2	−20.7	−8.9	−1.5	−0.1	0.0	0.0	0.0	0.0	0.0	−0.6	−5.5	−16.2	−28.4dB
	−34.2	−20.7	−8.8	−1.4	0.1	−1.0	−5.8	−11.9	−18.0	−24.0	−30.6	−41.5	−58.2	−76.6dB

Characteristics of the BL-Wd and Wd digital filters implemented in the instrument

What do we need to measure?

- The vector sum of the three axes of measurement

- Apply special frequency filter to correlate with range of damage risk (0.5 to 80 Hz overall, 4 to 12 Hz main sensitivity)

- Wk filter for the Z direction (foot to head)
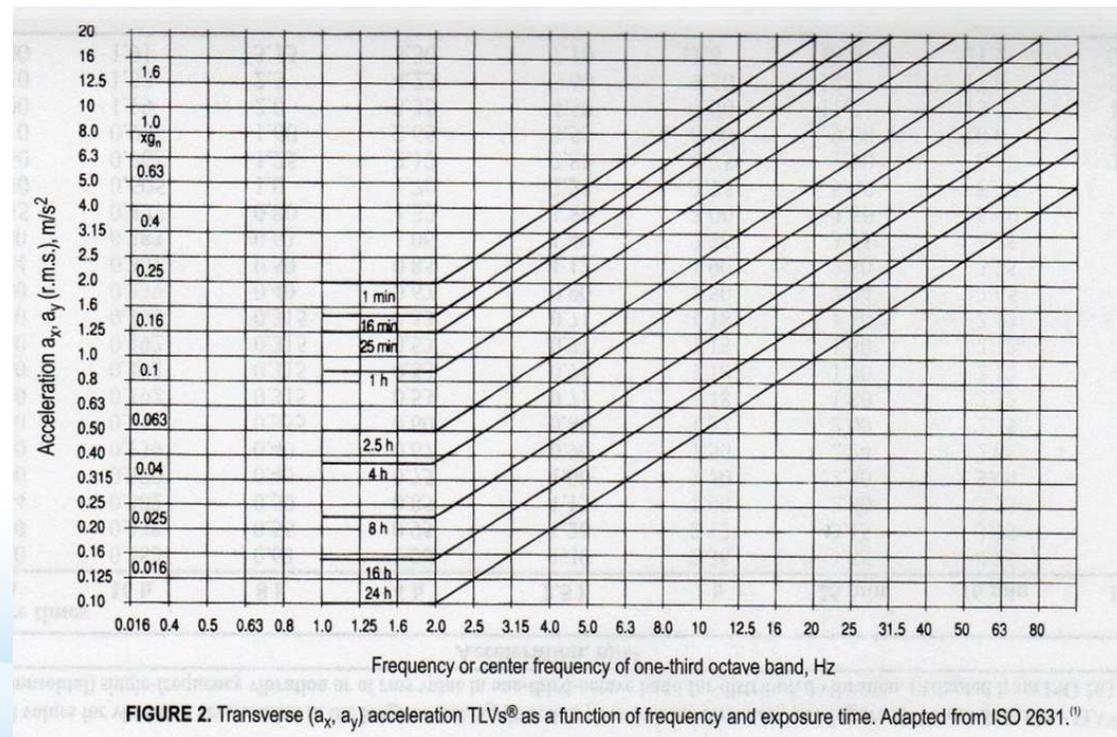
- Measure A(8) & VDV

. The **Wk** filter is used for the assessment of the influence of the vibration signal on the human body in the **z** direction and for vertical recumbent direction. It conforms to the ISO 2631-1-97 and ISO 8041:2005 standard.
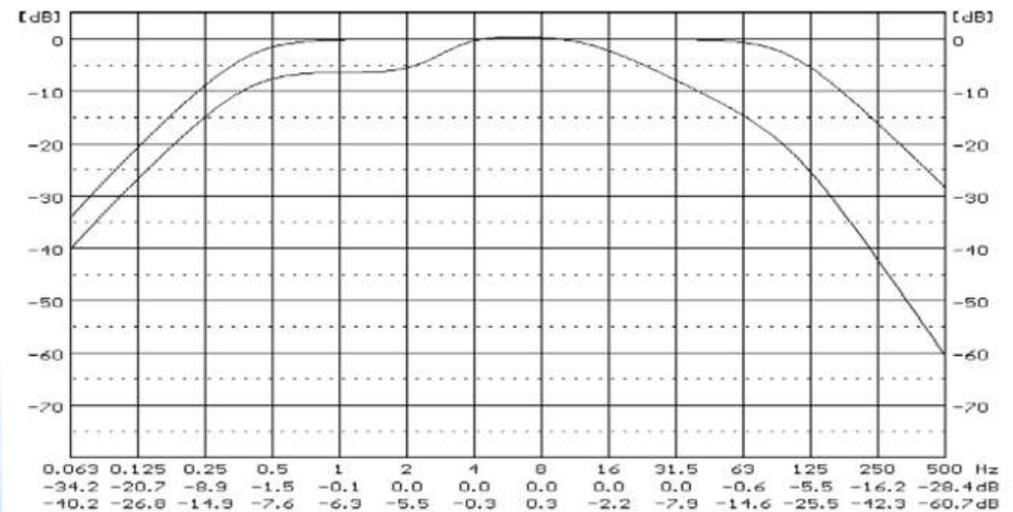
Characteristics of the BL-Wk and Wk digital filters implemented in the instrument

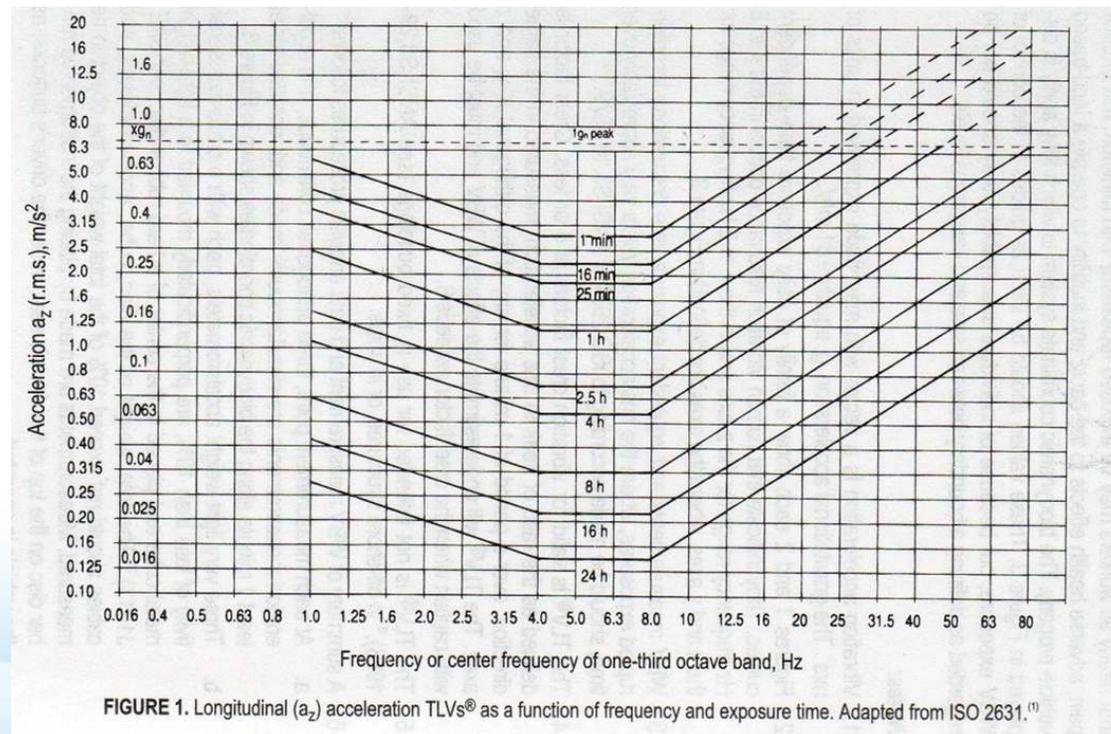# Can measure in 1/3 octave bands

- For the X and Y axes

FIGURE 2. Transverse (a_x, a_y) acceleration TLVs® as a function of frequency and exposure time. Adapted from ISO 2631.[1]

Source – ACGIH TLV recommended limits for WBV in X & Y axes

Can measure in 1/3 octave bands

- For the Z axis

FIGURE 1. Longitudinal (a_z) acceleration TLVs® as a function of frequency and exposure time. Adapted from ISO 2631.[1]
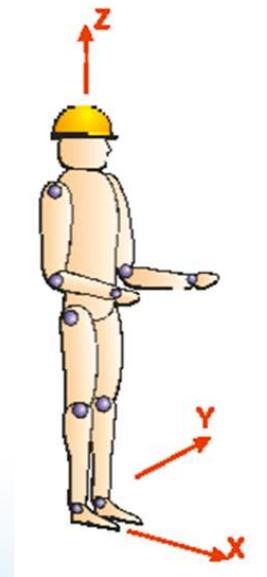
Source – ACGIH TLV recommended limits for WBV in Z axis

How do we measure WBV?

- Seat pad sensor is placed under buttocks for seated operators

- Floor sensor for operators who stand on vibrating surfaces

- Need to obtain the resultant overall average daily vibration acceleration level as the A(8) where

A(8) = $\sqrt{[(1.4 \times Ax)^2 + (1.4 \times Ay)^2 + Az^2]}$

- May also need the Vibration Dose Value (VDV)

What is the VDV?

- The vibration dose value (or VDV) provides an alternative measure of vibration exposure to the daily average A(8) value.

- The VDV was developed as a measure that gives a better indication of the risks from vibrations that include shocks.

- Shocks or very impulsive vibrations are considered more harmful where the crest factor during the measurement >6. (Crest factor = Peak/RMS)

- The units for VDV are meters per second to the power 1.75 ($m/s^{1,75}$), and unlike the average A(8) r.m.s. vibration magnitude, the measured VDV is a cumulative value, i.e. it increases with measurement time(i.e. the vibration <u>Dose</u> value).

- It is therefore important for any measurement of VDV to know the period over which the value was measured.

- It is the highest of three orthogonal axis values ($1.4 \times VDV_{wx}$, $1.4 \times VDV_{wy}$ or $1 \times VDV_{wz}$) that is used for the risk assessment.

What are the limits?

◉ In the UK & European Union there are 2 WBV limits

Description		A(8) m/s²	Vibration Dose Value m/s$^{1.75}$
Exposure Limit Value	The daily exposure limit value standardised to an eight-hour reference period	1.15	21
Exposure Action Value	The daily exposure level value standardised to an eight-hour reference period	0.5	9.1

What are some typical values?

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Industrial Health & Safety Instrumentation

Vehicle / Process	Acceleration (a_w) m/s²			Based on Median Value Time to reach Criteria	
	Low	Median	High	EAV 0.5 m/s²	ELV 1.15 m/s²
Agricultural Tractor	0.6	1.0	2.0	2 hours	10 ½ hours
Quarry Dumper	0.2	1.0	2.2	2 hours	10 ½ hours
Small car	0.2	0.4	0.5	12 ½ hours	> 24 hours
Lorry	0.4	0.7	1.0	4 hours	21 ½ hours
ATV (Quad)	0.5	1.2	2.0	1 ½ hours	7 ½ hours
Rigid Body Truck	0.4	0.9	1.1	2 ½ hours	13 hours
Articulated Truck	0.4	0.4	0.6	12 ½ hours	> 24 hours
Milk Float	0.7	0.9	0.9	2 ½ hours	13 hours
Large Bus	0.4	0.6	0.7	5 ½ hours	> 24 hours
Small Bus	0.4	0.5	0.5	8 hours	> 24 hours
1 ton Van	0.3	0.5	0.6	8 hours	> 24 hours

How do we calibrate equipment?

- ⊙ Use a suitable low frequency vibration calibrator

- ⊙ Frequency in the range of the Wd/Wk – BL filter (0.5 Hz to 80 Hz)

- ⊙ Level 1 m/s^2 at 16 Hz

Mounting the accelerometer

- Use a suitable mounting adapter that can accept the whole transducer

- Measure in all three axes separately

- Perform "field check"

- Annual calibration to verify whole system

Potential solutions for WBV

- Purchase newer lower vibrating technology and equipment and install vibration dampeners on equipment and vehicles.

- Maintain equipment properly or redesign equipment, vehicles or road surfaces.

- Fixing the problem e.g. filling in pot holes in the rough road

- Remote control of the equipment when possible or use transportation alternatives.

- Adding seat suspension systems to vehicles.

WBV control may include the following administrative tasks:

- Job rotation to reduce individual exposure times.

- Removal of employees completely from WBV environments.

Human vibration - conclusions

- Many US workers are potentially affected, up to 8 million

- There are more workers at risk from Whole Body Vibration (6.8 m) than from Hand Arm Vibration (1.2m)

- Both are serious risks to health and enjoyment of life

- Regulations exist around the world in industrialized and developed countries to limit these risks

- Regular monitoring needs to be carried out to assess the likely risk to workers

- Appropriate monitoring instruments and methods exist to perform these measurements properly

Nuisance vibration

- Primarily concerned with low levels inside buildings

- Shaking the floor or walls

- Upsetting delicate machinery
  - X-ray machines,
  - MRI machines,
  - micro balances,
  - photo etching processes etc

Potential solution for measurement

- ⊙ **Need highly sensitive sensor**
  - – 1000 mV/g output

- ⊙ **Need three directions**
  - – X, Y and Z axes measurements
  - – Find vector sum

- ⊙ **Compare with limits for different applications**
 - – Vibration Criteria (VC) curves are popular

Required results

- Usually require peak particle velocity (PPV)

- Also frequency information is very important at least 1/3 octave band
  - Dominant frequency if present using narrow band FFT analysis

- Range of frequencies of interest 1 to 80 Hz

- Time history is useful to show changes with the environment

- Weather proof solution useful for outdoor measurements at same time as indoor to measure transmission loss in foundations

Vibration Criteria curves used for building vibration measurements

- Measured in 1/3 octave bands

- Measure rms velocity in each band

- Used in microelectronic industry for increasingly sensitive equipment
  - VC-A limit 50 microm/s
  - VC-B limit 25 microm/s
  - VC-C limit 12.5 microm/s
  - VC-D limit 6 microm/s
  - VC-E limit 3 microm/s

Figure B.2 Example of vibration criteria

NOTE For key to graph, see Table B.3.
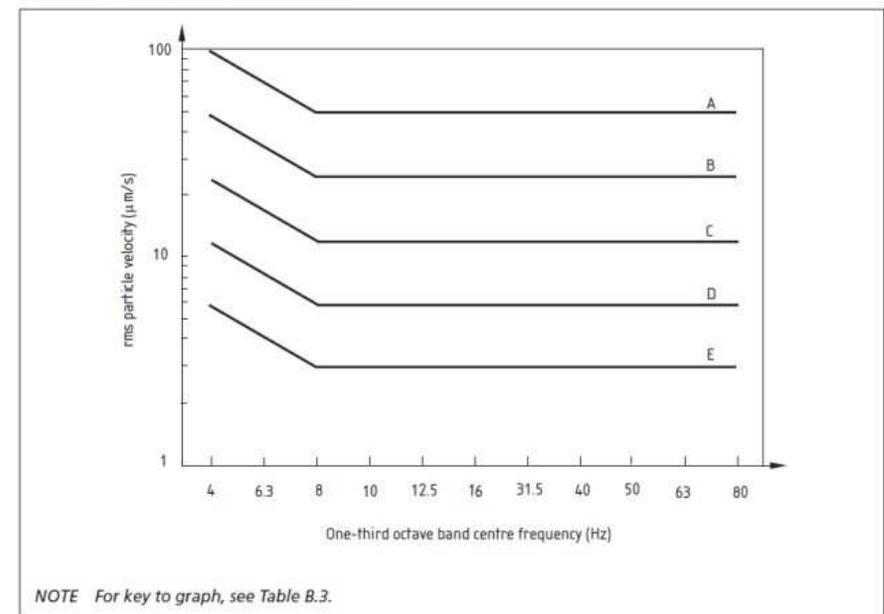
For additional information

- Contact RAECO Rents (866 736-8347 – www.raecorents.com) to rent or obtain suitable Svantek instruments for all these applications

- Contact Sensidyne (Bob Selwyn – 603 203 7471 – bselwyn@Sensidyne.com for purchase or technical information)

- Thank you.

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