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# Human Vibration

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## Introduction

Vibration is present everywhere in our environment. The two main characteristics of vibration are its frequency and magnitude (strength). Vibration is assigned to general categories based on frequency. Not all experts agree on the exact cut-off points for the categories, so any ranges given can vary from text to text. An approximation of frequency boundaries for each category is shown in Figure 1 (Paschold, in press). With regard to human exposure, the following descriptive categories are used ranging from low to high frequency:

- Motion
- Whole-body (WBV)
- Hand-Arm (HAV)
- Sound or noise
- Ultrasound

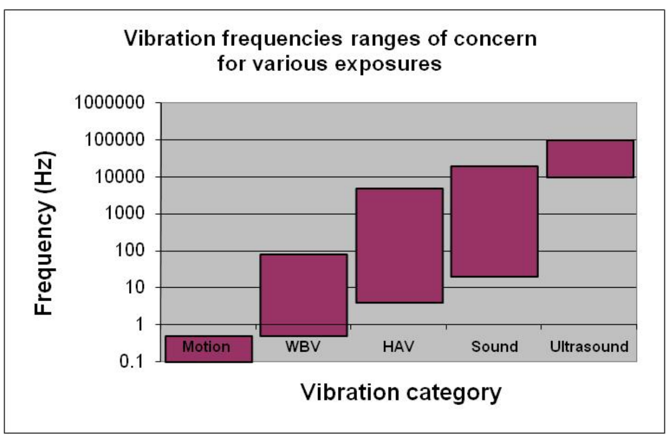


**Figure 1. Frequency boundaries for vibration categories**.

These categories have differing effects on the human body, including adverse health outcomes. The occupational illnesses resulting from vibration are dependent upon frequency, magnitude, and duration of exposure. Of the categories listed, the most familiar to the safety and health professional is noise, which will be not be emphasized in this report due to its extensive existing literature and knowledge by safety and health professionals.

This article will present the basics of vibration and for each category of vibration, the

- Frequency range,
- Sources,
- Adverse health effects, and
- Suggested controls.

## Vibration Basics

Vibration is a mechanical wave motion that can cause a transfer of energy from one object to another, traveling through solids, liquids or gasses. Vibration is typically represented by a ***sine*** wave, characterized by frequency and amplitude, shown in Figure 2. Frequency ranges determine the labeling of frequency type.

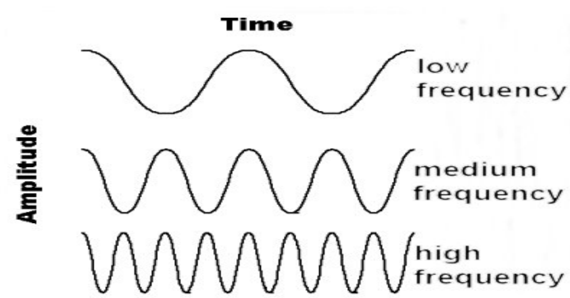


**Figure 2. Depiction of vibration sine wave.**

Frequency is generally expressed in ***Hertz*** (Hz), cycles per second, such as in household electric current – 110 volts, 60 Hz. In reality, our vibration wave exposures are complicated by numerous simultaneous waves as shown in Figure 3 (Mansfield 4). The magnitude or strength of vibration is the amplitude, height, of the wave depicted in Figure 4 as motion above and below a fixed reference line.

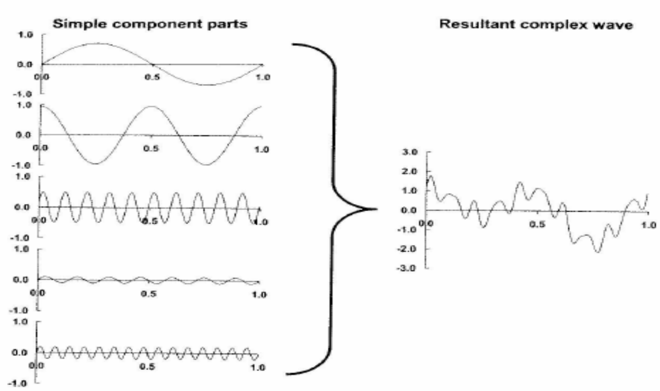


**Figure 3. Single waves and complex combined waves.**

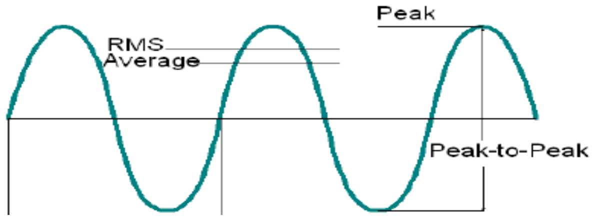


**Figure 4. Vibration amplitude.**

Vibration accelerations are expressed in meters per second squared, ($m\text{-}s^{-2}$), or sometimes in “g’s” (9.8 $m\text{-}s^{-2}$) which is the equivalent force to the exertion of gravity on earth. The amplitude of noise is usually reported in decibels, using an A-weighted dbA scale for measurements involving human exposure. If the wave distance is measured above and below the fixed reference line, adding the positive and negative values will equal zero. Therefore, vibration is measured by the root-mean-square (r.m.s.) method using units of $m\text{-}s^{-2}$. The r.m.s. is the mean of the *squared* individual vibration wave values reduced by the square root to eliminate the positive-negative canceling effect, which is similar in method to the statistical standard deviation function, shown in Figure 5.

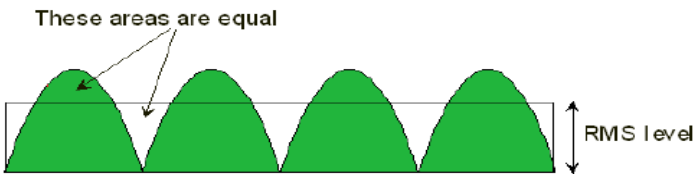


**Figure 5. Use of r.m.s. method for magnitude measurement.**

Objects possess a property call *natural frequency*, a function of their composition and mass. Natural frequency is also known as the inherent frequency of a spring-mass system. When an external vibration equal to the natural frequency is applied to an object, a synergistic effect known as *resonance* occurs. The human body as a whole and its individual organs has natural frequencies that can resonate.

This resonance is suspected to cause adverse health effects, especially with chronic exposure based mainly on epidemiological evidence for loser frequencies. Greater amounts of data are available for illnesses occurring at higher frequency ranges.

Vibrations from the external environment are transmitted to the human body

- From floors or platforms when standing,
- Through seats when sitting,
- Along the length of the body when reclining
- By grasping or holding vibrating objects with the hands, or
- Through mediums such as air or water.

## Lower Vibration Ranges

Included in the lower ranges of frequency are the categories of motion, WBV, and HAV. While grouped as lower frequency vibrations, each has profoundly different impacts on the human body. As previously stated the effects are dependent on frequency, magnitude and duration of exposure.

### Motion

Motion sickness usually comes about from travel on the sea, in vehicles, or in aircraft. People on water-bound vessels are subject to mostly vertical up and down motion, low frequency with high amplitude. In ground vehicles, drivers and passengers are subjected to lower frequencies with mostly horizontal amplitude from starting, stopping and turning. Passengers on aircraft are subject to turbulence of low frequency and in any direction of magnitude.

The most likely explanation for motion sickness is the sensory conflict or what is known as the sensory rearrangement theory. With this, humans have a conflict between signals that are expected and experienced. People walking with reading glasses can feel effects similar motion sickness due to the distortion of the visual (expected) and motion while walking. Humans have the ability to adapt and reconcile the expected and experienced, reducing or eliminating the effects of motion sickness. In some cases, people who have been exposed to sea motion, such as on a cruise, experience a wave motion afterwards on the ground, a condition known as *mal de debarquement*.

Other symptoms of motion sickness include:

- Nausea,
- Body warmth,
- Dizziness,
- Headaches,
- Lethargy, or
- Pallor.

Control of motion sickness can be attempted in several ways. Most effective is the avoidance of motion or sensory conflict. For example, on a ship, focus on the distant horizon instead of nearby waves. Anti-motion-sickness drugs such as Dramamine or Scopolamine are effective for many. Traditional folk remedies are generally ineffectual. Many individuals can adapt by acclimation or desensitization.

### WBV

WBV vibration exposures are most commonly found among operators of large equipment. Truck drivers, locomotive engineers, pilot of fixed wing and rotary aircraft, mining equipment operators, loggers, forklift operators, and construction equipment operators are among the many occupations most likely to have WBV health issues.

Frequencies between 1 and 20 Hz are of greatest concern, with some effects noted as high as 80 Hz. As previously discussed, the issue of resonance is the likely cause of adverse human health effects, as WBV frequency ranges correspond with the natural frequencies of the body, Figure 6a, and its organs, Figure 6b (Paschold 54, 2008). As the WBV approaches the body’s natural frequency, resonance will cause numerous voluntary or involuntary muscle contractions. This increased muscle activity, in turn, can cause fatigue or diminished motor performance ability.

| Body - Whole, Part or Organ | Resonant Frequency (Hz) |
|---|---|
| Whole body – standing | 12.3 +/- 0.1 |
| Whole body – seated vertically | 4 to 6 |
| Whole body, prone | 3 to 4 |
| Whole trunk (vertical) | 4 to 8 |
| Lumbar disks | 4.5 to 5.5 |

**Figure 6a. Natural frequency of the whole body.**

| Body - Whole, Part or Organ | Resonant Frequency (Hz) |
|---|---|
| Head relative to body | 20 to 30 |
| Eyes | 20 |
| Shoulder girdle | 5 |
| Stomach | 4 to 5 |
| Cardiovascular system | below 20 |

**Figure 6b. Natural frequency of body organs.**

Besides the frequency, WBV adverse health effects are dependent on the magnitude of vibration and duration of exposure (usually months to years). In Europe, standards suggest an *action level* of 0.50 m-s$^{-2}$ and an exposure limit value of 1.15 m-s$^{-2}$. Other considerations need to include jolts which are used in the calculation of a crest factor. If the crest factor is sufficiently high, WBV measurements are less reliable.

The primary concerns of injury or illness from WBV exposure are lower back pain. Other possible illnesses involve abdominal pain, hearing impairment, blurred vision, or respiratory distress (Paschold 54-55, 2008). However, WBV is also currently being used and studied as a means of body strengthening for athletes and people with disabilities due to its stimulation of muscle activity.

Control of WBV is best achieved by elimination. Elimination steps often include engineering design to eliminate or reduce vibration in equipment. Reduction of WBV can be achieved by:

- Eliminating unnecessary job steps,
- Adequately maintaining equipment,
- Job rotation,
- Maintaining roadways smooth, reducing travel speed, using train instead of trucks for shipping, or
- Use of vibration-reducing seating.

HAV

Industrial sectors with HAV exposures include manufacturing, construction, mining, agriculture, or any other occupation requiring vibrating hand tools. Tools contributing to HAV health issues include drills, grinders, chain saws, jack hammers, etc.

Frequencies between 10 and up to 3000 Hz comprise the range for HAV. HAV primarily differs from WBV by the greater amount of vibration magnitude directly to human body parts, primarily the hands. The ACGIH suggests a maximum limit of 4 $m\text{-}s^{-2}$ for 4 to 8 hours of operation, a vibration magnitude much higher than for WBV.

A frequently occurring adverse health effect from continual HAV exposure at high magnitudes is Raynoud's Syndrome. This syndrome is characterized by reduced blood flow and depleted oxygen in the hands. This can be exasperated by cold environments, making occupations such as logging in higher latitudes more vulnerable.

Methods of reducing HAV exposure and subsequent injury include:

- Optimizing tools
    - Sharpening, maintenance, or lubrication,
- Job design,
- Administrative controls,
- Medical surveillance,
- PPE, or
- Training.

## Higher Vibration Ranges

Noise

Exposure to noise is found in virtually all occupations. Lower magnitudes may simply cause distraction or communication interference. Higher levels are known to cause hearing loss in excess of the natural loss of hearing due to aging. Current research suggests a possible link to high noise levels and cardiovascular disease (Gan).

The extreme ranges of frequency for sound are reported between 10 and 20000 Hz. The main concern is generally centered about 3000 Hz. Sound intensity is measured in decibels using the dbA weighted scale. OSHA establishes an action level of 85 dbA for the initiation of a Hearing Conservation Program. 85 dbA is a noise level that will generally require a person to speak in an elevated voice level to be heard at arm's length.

An interesting application of high-frequency sound was broadcasting high pitched noise through speakers outside a convenience store in Great Britain. The frequency was above the audible range for most persons over 18 and served to "annoy" and drive off younger persons loitering about the store. Now, this has been used to the advantage of younger people by using a high-pitched ring tone for cell phones that cannot be heard by older teachers, parents, etc. This application is known as the "Mosquito Tone". Low-frequency high-intensity sound has been explored for possible military or police use based on its ability to disrupt or disorient humans.

Methods of sound reduction include:

- Engineering to eliminate or reduce magnitudes,
- Isolation barriers,
- Improved maintenance of equipment,
- Noise dampening applications,
- Administrative controls, or
- PPE.

### Ultrasound

Ultrasound does not appear to have as many or common potentials for human adverse health effects as do other vibration categories. Some of the adverse health effects of human exposure to ultrasound include:

- Annoyance,
- Ear discomfort,
- Fatigue,
- Nausea,
- Tinnitus, and
- Headaches.

Ultrasound is generally categorized at 10000 to 50000 or 100000 Hz.

Direct contact with ultrasound cleaning liquids may course localized heating on skin. An indirect increased health hazard due to ultrasound my result from ultrasonic cleaners utilizing solvents. The decrease in surface tension by the ultrasound allows increased vaporization of the solvent, increasing air concentrations. On the other hand, it is commonly known that ultrasound is used for medical diagnostics, especially for fetal examinations. The frequencies used for medical scanning are in the megahertz range.

Control of ultrasound is generally much easier than control of sound. Because it is highly directional, barriers are very effective in blocking ultrasound waves. Also, ultrasound has high transmission loss in most materials.

## Summary

Regardless of frequency, vibration has the potential to cause human injury or illness. All frequencies become more dangerous with greater magnitude and duration of exposure. However, most vibration exposures can be reduced by common hazard-abatement approaches.

## References

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