Technical University of Civil Engineering Bucharest

MINISTRY OF NATIONAL EDUCATION

TECHNICAL UNIVERSITY OF CIVIL ENGINEERING BUCHAREST

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EFFECTS OF VIBRATIONS ON THE HUMAN BODY
Research Report No. 2

Scientific supervisor
Professor, PhD, Eng. Pavel Cristian

PhD Student
Eng. Ursache Robert-Ionuț

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Effects of Vibrations on the Human Body

1.Introducere:

Vibration is the oscillatory motion of different bodies. All bodies with mass and elasticity elements are capable of vibrating; therefore, most machines and structures, including the human body, experience vibrations to some extent. Two distinct categories of vibrations are identified in the literature. Free vibration occurs when the system oscillates only due to the action of internal forces. Forced vibrations are caused by the action of external forces. If the excitation frequency coincides with the system's natural frequency, resonance occurs. The result is the production of large oscillations in the structure, generating potentially harmful stress.

The human body is, both physically and biologically, an extremely complex "system." When viewed as a mechanical system, it can be considered to contain a series of both linear and non-linear "elements," and its mechanical properties differ considerably from one person to another [2].

From a biological standpoint, the situation is by no means simpler, especially when psychological effects are included. When considering the human response to vibrations and shocks, it is necessary to take into account both mechanical and psychological effects [2].

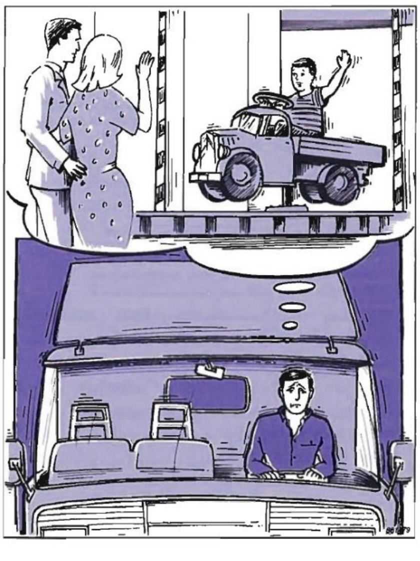


Figure 1. Daily activities with potential to generate vibrations

Vibrations can influence the human body in many different ways. The response to vibration exposure depends mainly on frequency, amplitude, and duration of exposure. Other factors may include: the direction of vibration input, the location and mass of different body segments, the level of fatigue, and the presence of external support.

During our normal daily lives, we are exposed to vibrations of one kind or another, e.g., in buses, trains, and cars. Many people are also exposed to other types of vibrations during their working day, for example, vibrations produced by hand tools, machinery, or heavy vehicles.

Just as sound can be either music to the ear or an irritating noise, vibrations on the human body can be pleasant or unpleasant. We enjoy and even create pleasant vibrations when we run, dance, or travel on a smooth road, but we try to avoid exposing ourselves to unpleasant vibrations, such as traveling on a rough road or using handheld power tools.

Extensive research has been carried out on the effects of vibration exposure on humans, particularly in their working environment. Some of the earliest studies involved research on individuals such as aircraft pilots, heavy vehicle operators, and hand-tool operators. Their ability to perform complex tasks under adverse vibration conditions was part of the initial investigations. Nowadays, research on human exposure to vibrations is also conducted in workplace environments, and the results are used to establish international standards that allow the assessment of vibration exposure.

1.1 Regulatory requirements for limiting vibrations transmitted to the human body

The reference documents regarding the maximum permissible limits are:

- Law 90 / 1996 on Occupational Safety
- General Occupational Safety Regulations, 2002
- SR ISO 2631-1 / 1994: Evaluation of whole-body vibration exposure
- SR ISO 5349: Guidelines for the measurement and evaluation of human exposure to hand–arm transmitted vibration
- ISO/DIS 8041: Instruments for measuring human body response to vibration
- ISO 7096: Measurement of operator seat vibration in earth-moving machinery
- ISO/DIS 7505: Measurement of hand–arm vibration exposure from chainsaw operation
- SR ISO 1030-2 / 2000: Hand–arm vibration. Guidelines for risk reduction. Part 2: Preventive measures at the workplace
- DIN 4150: Vibrations in buildings
- DIN 45669: Vibration measurement
- DIN 45671: Measurement of vibrations occurring in the workplace
- DIN 45675: Effect of mechanical vibrations on the hand–arm system
- VDI 2057: Effect of mechanical vibrations on the human body
- BS 6841: Measurement and evaluation of whole-body human vibration exposure
- BS 6842: Measurement and evaluation of hand–arm vibration exposure

- BS 6872: Evaluation of human exposure to vibration in buildings (1 Hz–80 Hz)
- JIS B4900: Descriptions and methods of measuring vibrations transmitted to the hand–arm system
- JIS C1510: Vibration level meters
- JIS C1511: Vibration level meters for hand-held tools

2. Generalities

2.1 General Concepts

Vibration is an oscillatory motion relative to a reference position. The vibration frequency, measured in hertz (Hz), represents the number of complete cyclic movements performed in one second.

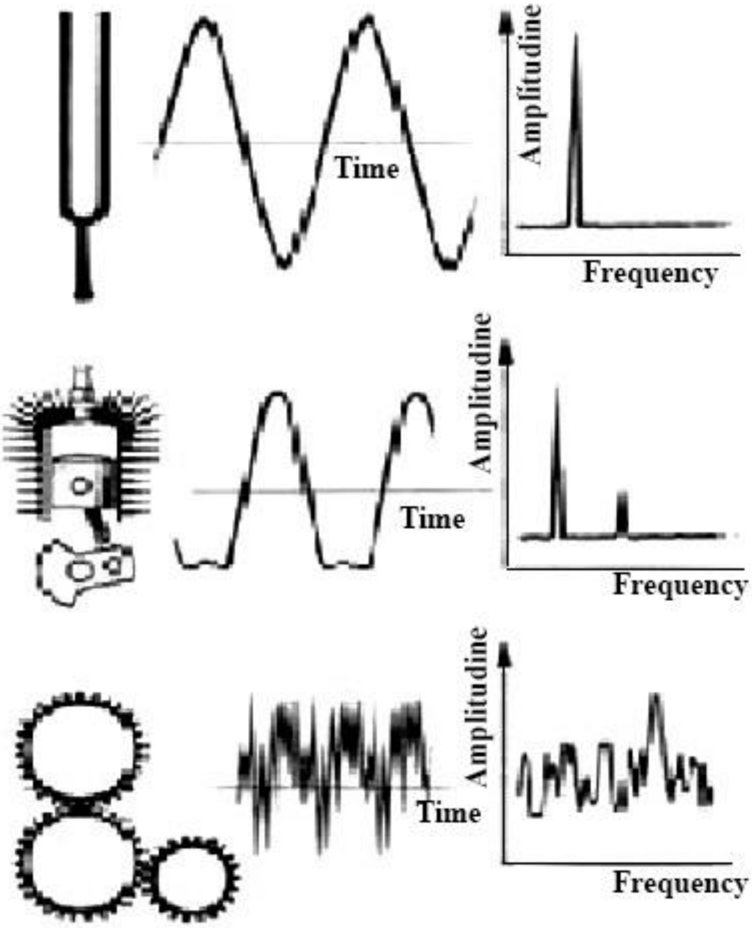


Figure 2. Vibration analysis

The vibration motion may have a single component, or multiple components occurring simultaneously but at different frequencies.

The decomposition of the vibration signal into its fundamental components according to their frequencies is called **frequency analysis**, and it represents the basis of any diagnostic process that uses vibration measurement.

2.2. Measurement Parameters and Quantification of Vibration Levels

The vibration amplitude is the parameter that describes the vibration intensity and can be quantified in various ways:

Peak amplitude is particularly used in the case of motions with a relatively short duration over time, such as shocks. However, as can be seen from the graph, the peak value indicates the maximum level reached, without considering the time evolution of the vibration signal.

Peak-to-peak amplitude is the value that indicates the maximum extension of the waveform, a necessary measure when, for example, the displacements of machine components during vibration can reach critical values corresponding to maximum allowable stresses or displacements.

The RMS value (Root Mean Square) is the most relevant measure of vibration amplitude because it takes into account both its time variation and, at the same time, is directly related to its destructive energy:

$$v_{ef} = \sqrt{\frac{1}{T}\int_0^T v^2(t)\,dt} \quad (1)$$

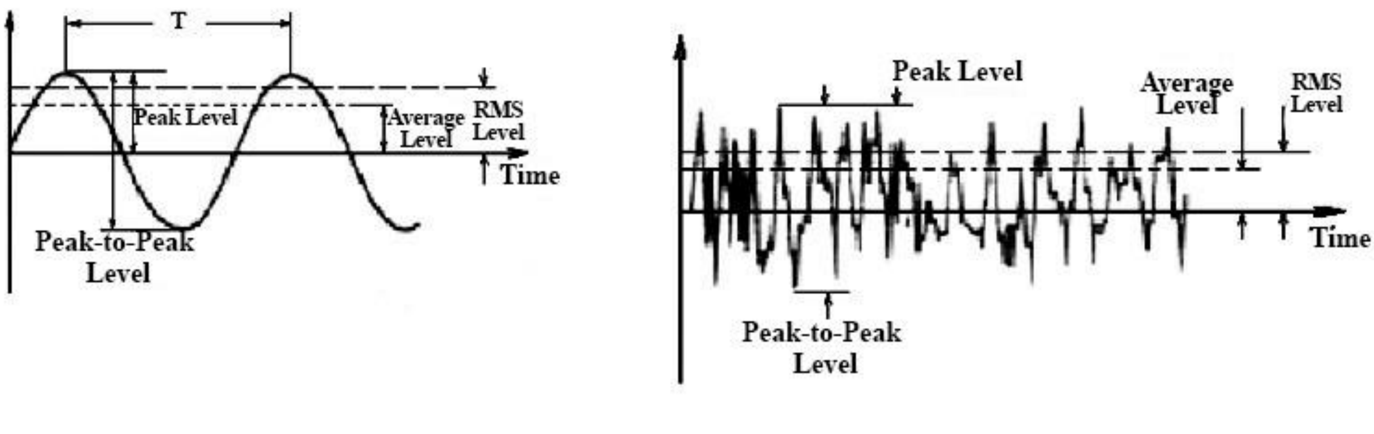
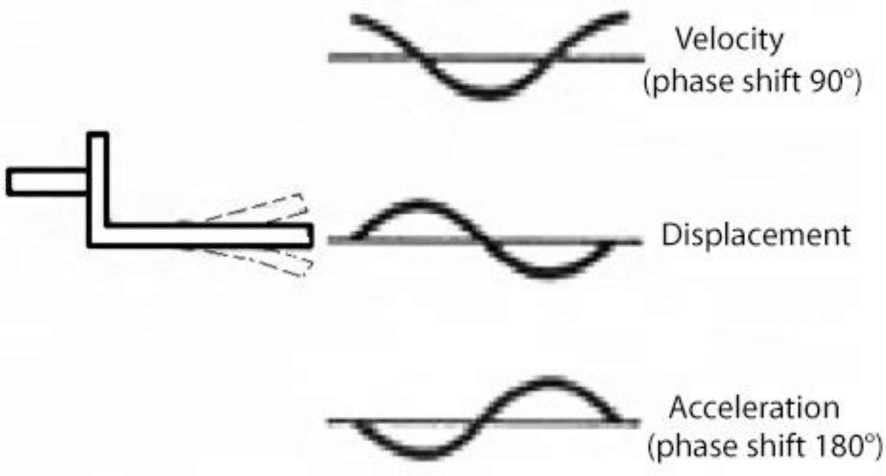


Figure 3. Quantification of Vibrations

Similarly, the same vibration motion can be described in terms of displacement, velocity, or acceleration, and for all three parameters the waveform and period remain the same. The difference between them lies in the phase shifts between their amplitude–time waveforms.



$$v = \frac{dx}{dt} \tag{2}$$

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2} \tag{3}$$

Figure 4. Velocity; Acceleration; Displacement

When the vibration signal contains components across a wide frequency spectrum, the choice of the parameter used to describe the vibration motion becomes important. Thus, while displacement emphasizes the response at low frequencies, acceleration highlights the response at high frequencies.

It is advantageous to select the parameter whose spectrum shows relatively constant values over the entire frequency range and which allows measurements to be performed across the full dynamic range of the measuring device (the difference between the smallest and largest value that can be accurately measured).

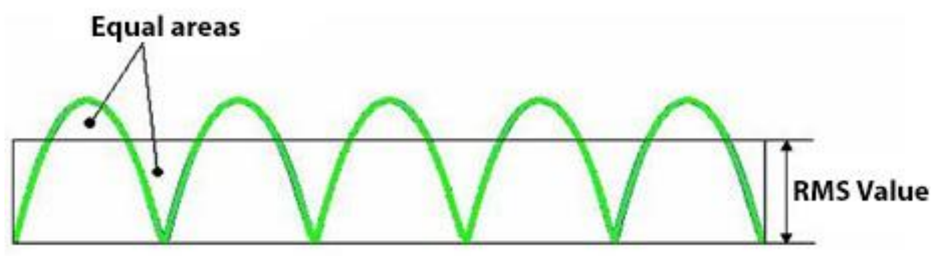


Figure 5. Choosing the correct parameter

2.3. Vibration Measurement

The ISO standards for measuring vibrations acting on the human body require acceleration to be the parameter used for measuring vibration levels.

It is essential that the vibration acting on the human body is measured accurately so that the following can be assessed:

(a) the discomfort caused by vibration, and

(b) the potential danger involved in exposure to vibrations,

so that the necessary measures can be taken to reduce these factors. If individuals exposed to vibrations are 'over-protected,' this could limit their freedom of movement, leading to reduced efficiency, while overexposure to vibrations may cause short-term accidents and/or physical damage after long-term exposure.

The accuracy of vibration measurements depends on the quality of the vibration transducer and the analysis and recording equipment used. The transducer now almost universally employed for vibration measurements is the piezoelectric accelerometer, due to its properties:

- it maintains its characteristics under all operating conditions;
- it has a wide frequency range in which measurements can be performed, and within this range its dynamic response remains highly linear;
- it is durable and maintains its properties over time;
- it is self-generating, requiring no external power source;
- it has no moving parts, thus avoiding wear issues;
- but perhaps the most important property of the piezoelectric accelerometer is that its output is proportional to the acceleration of the body to which it is attached, and the electrical signal can then be easily integrated to obtain velocity and displacement.

2.3.1. Transducer Characteristics

The main characteristics of accelerometers are:

- sensitivity
- mass
- dynamic range

The first characteristic to consider when selecting an accelerometer is its **sensitivity**. Ideally, we would like a high output signal, but this requires certain compromises, since high sensitivity usually involves a relatively large piezoelectric assembly and therefore higher mass.

The relatively large **mass** of an accelerometer mounted on a lightweight structure can lead to measurement errors by altering the natural frequencies and the dynamic response of that structure.

The choice of accelerometer according to the **dynamic range** must be made carefully when measuring in a low-frequency range (electrical noise induced) or very high-frequency range (limited by the physical properties of the accelerometer, specifically its resistance).

Since accelerometers are available in a wide variety of sizes and weights, it is possible to find one whose size and weight are small enough so that:

(a) the measured vibration is not altered by its presence, and

(b) it does not interfere with the operator’s grip on the power tool when used for measuring hand–arm vibration.

2.3.2. Transducer Installation

It is extremely important that when measuring vibrations acting on the human body, the measurement is taken as close as possible to the point or area through which they are transmitted into the body.

In the case of whole-body vibrations, the most common transfer zones to the operator are: floor–foot; seat–buttocks; seat–back. To measure the vibrations transmitted to the operator from the vehicle (Fig. 6), the operator may sit directly on the transducer or attach it to the back. To measure vibrations transmitted from the platform, the transducer is placed on the floor with a small weight on top to ensure good contact between the transducer and the vibrating surface.

Figure 6. Whole-body vibration transfer zones

When a vibrating object is held in the hand, it transmits vibrations to the hand–arm system through the palm. Therefore, the transducer must be mounted somewhere on the contact surface between the palm and the vibrating object (Fig. 7). Even a very small accelerometer placed at the hand–handle interface tends to interfere with the operator's grip, leading to inaccurate measurement. Several mounting methods have been suggested to overcome this problem. The most common method is to mount the accelerometer on the tool as close as possible to the hand (Fig. 7a). However, since tool handles are generally rounded, this requires machining the handle to provide a flat mounting base for the transducer. Therefore, this mounting method is not very practical or convenient.

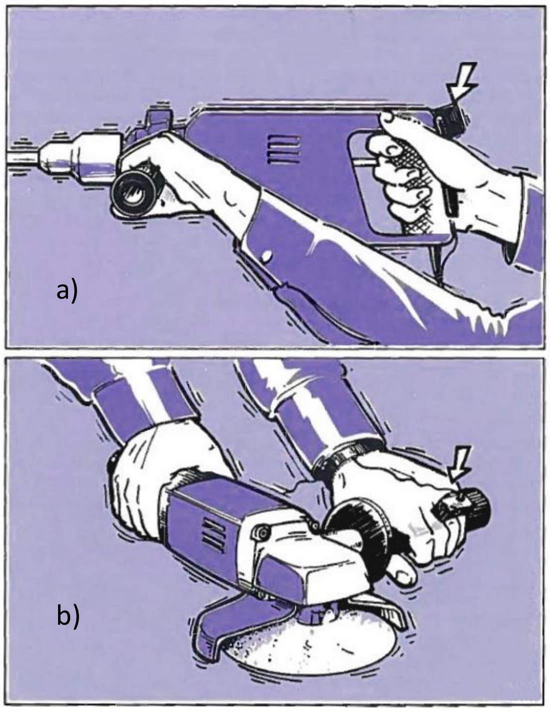


Figure 7. Transfer Zones of Hand–Arm System Vibrations

A practical solution for on-site measurements is mounting an accelerometer on an adapter, which is then kept in contact with the handle–hand interface by the operator's natural grip (Fig. 7b). Both the adapter and the accelerometer must be lightweight to reduce the risk of introducing resonances.

When measuring vibrations transmitted to the hand–arm system in working conditions, the cable connecting the accelerometer to the recording equipment must be properly protected.

2.3.3. Vibration Levels in Different Situations

RMS acceleration values (a_{eq}) associated with occupational exposure to hand–arm vibrations normally range between 2–50 m/s², while whole-body vibrations fall within 0.1–40 m/s². Some typical work and leisure situations are illustrated in Figure 8, along with their value ranges. The white area of the diagram highlights situations of particular interest for measuring human vibrations. By taking measurements in these types of situations, it is possible to assess the effect of vibration exposure.

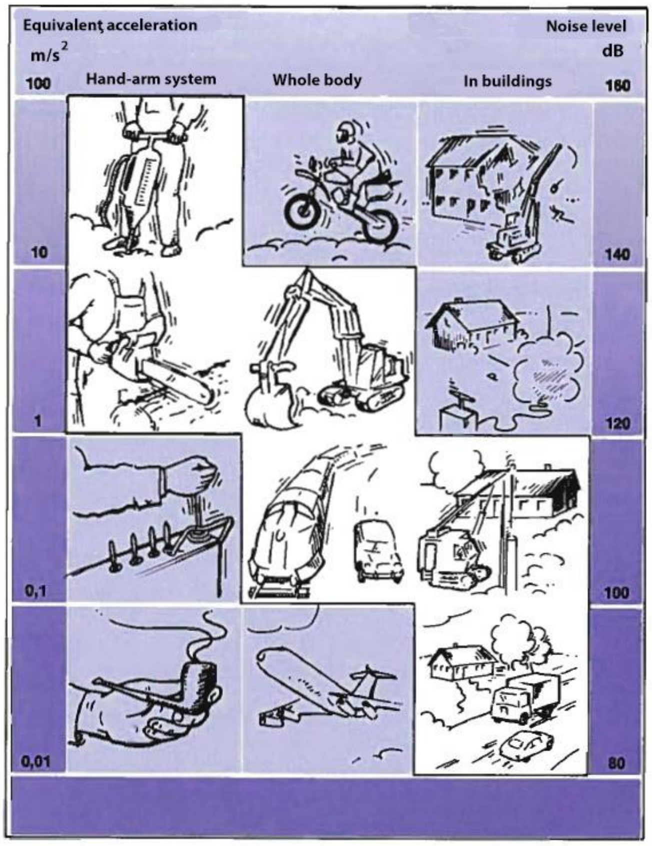
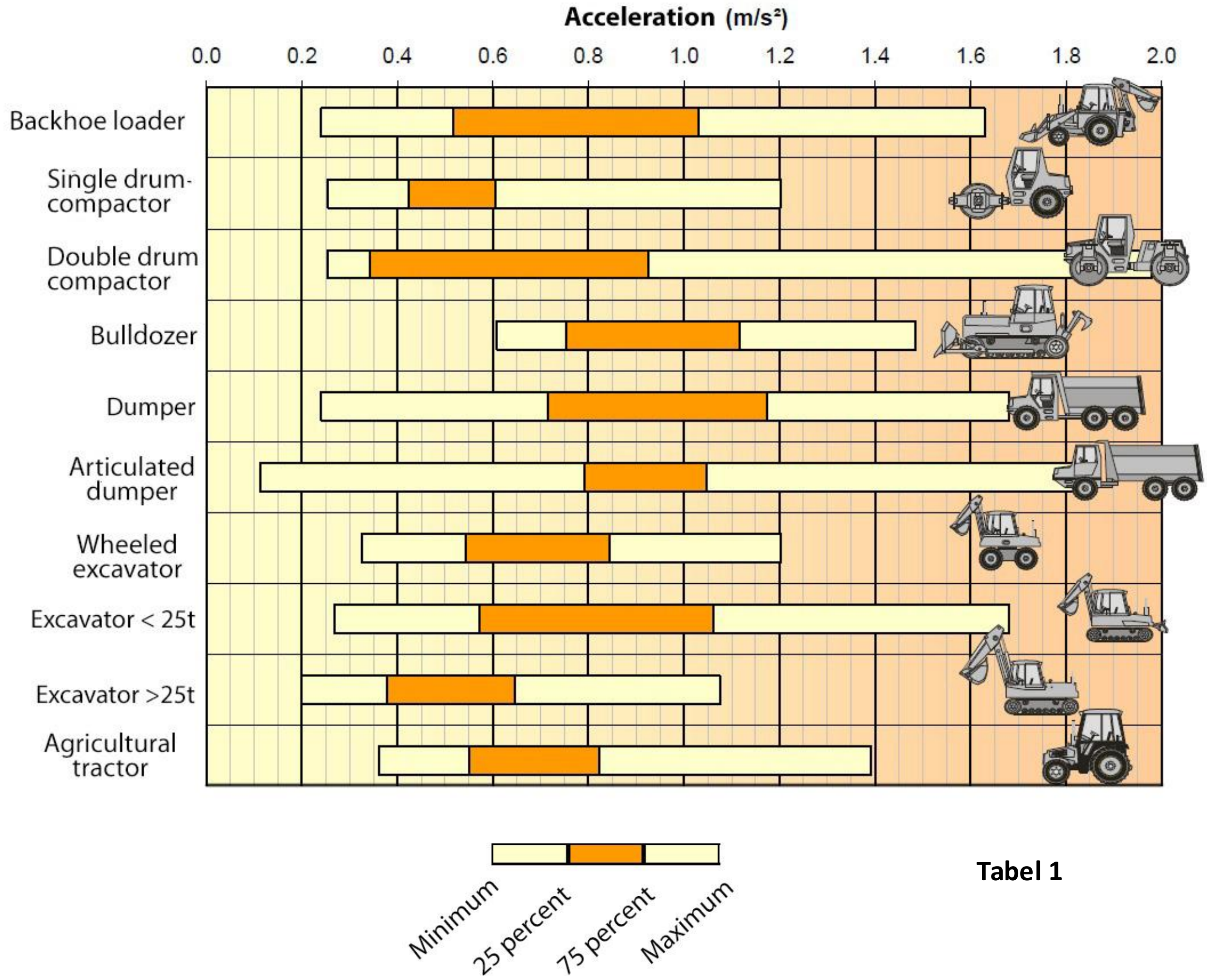


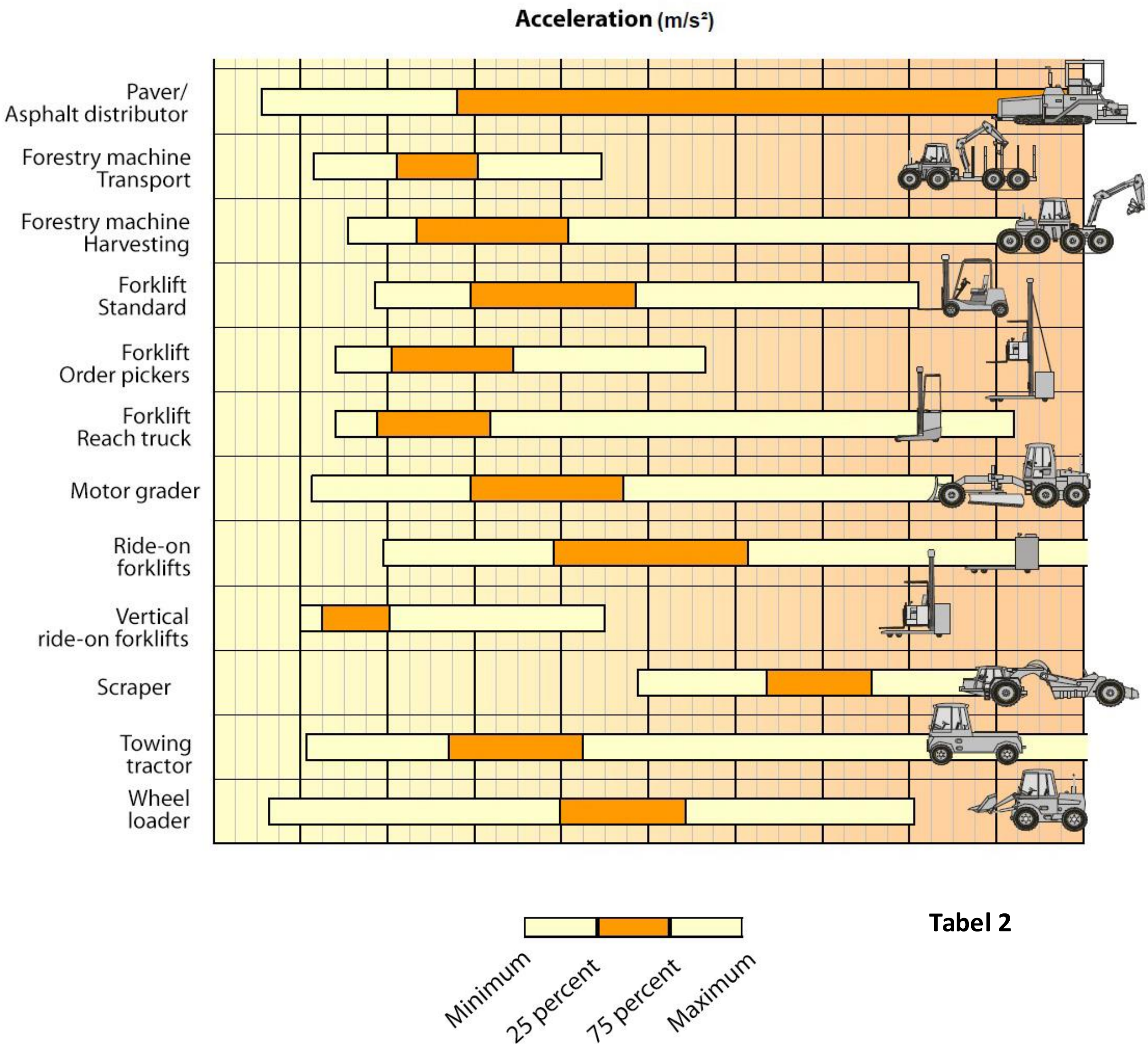
Figure 8. Vibration levels in different situations

Vibration exposure situations vary greatly, and therefore different criteria are needed to correctly assess acceptable exposure limits. For example, acceptable exposure to vibrations during a long train journey would depend on whether: (a) the evaluation concerns the reduced performance of the train driver due to fatigue caused by vibration exposure, or (b) the assessment concerns the comfort of the train passengers.

In the following table, several examples of vibration magnitudes for common machines will be illustrated [8].



Tabel 1



Tabel 2

Note: The 25% and 75% values show the vibration level below which one quarter and three quarters of the measurements fall.

3. Disorders Caused by Prolonged Exposure to Vibrations

For a long time, it has been recognized that the direct effects of vibrations on the human body can be severe. Workers may suffer from blurred vision, loss of balance, lack of concentration, etc. In some cases, certain frequencies and levels of vibration can permanently damage the internal organs of the body.

Regardless of the industrial activity from which it originates, vibration acts upon the human body and may cause discomfort to the operator, alter their performance, or even have more or less serious effects on the health of the person exposed to a vibration-producing activity.

From a medical perspective, it is known that prolonged exposure to vibrations can lead to four types of conditions, namely:

1. musculoskeletal disorders;
2. digestive disorders;
3. Raynaud's syndrome;
4. nervous system disorders.

In Romania, in 1997 and 2010, occupational diseases caused by noise and vibrations had the following percentage distribution.:

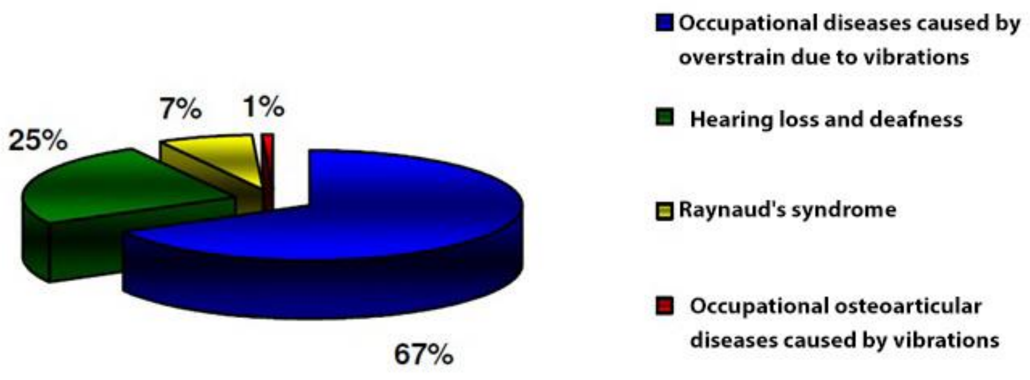


Figure 9. Percentage distribution of occupational illnesses associated with noise and vibration exposure

In the case of accelerations and frequencies exceeding 6g and 25 Hz, injuries to the inner wall of the intestines may occur, while at frequencies above 30 Hz and high velocities, the cerebral, pulmonary, and cardiac areas are endangered, with the possibility of lesions developing.

There are also other severe disorders that the human body may develop as a result of exposure to mechanical vibrations, such as:

- changes in metabolism due to stimulation of the nervous system and hormonal activity;
- nausea, headache, changes in pulse, and alterations in respiratory function.

R. Rossegger and S. Rossegger presented an analysis of pathological spinal deformations caused by prolonged use of vibrating tools or by sitting on vibrating platforms (such as tractor drivers), depending on the average age:

- miners (average age 51), tractor drivers (average age 26), and truck drivers show 70–80% spinal column impairment;
- factory workers (average age 45) and bus drivers (average age 40) have around 43% spinal column impairment;
- construction workers (average age 51) present spinal deformities in about 37% of cases.

Professor J. Krumer showed in 2006 that vibration-related diseases, for different occupations, have the following average latent periods:

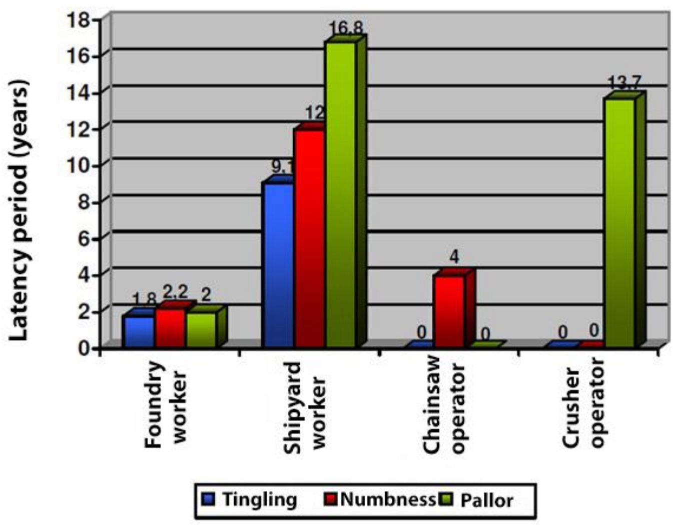


Figure 10. Latency period for different occupations

Vibrations cause involuntary contraction of all muscles without triggering oxidative stress, commonly known as "muscle soreness." This soreness is caused by the buildup of lactic acid in the muscles, which leads to the familiar painful sensation after physical effort, especially in people who are not used to exercise.

Workers exposed to vibrations for long periods may experience muscle weakness, pain in the hands and arms, and a decrease in muscle strength. It has also been observed that vibration exposure is linked to reduced hand grip strength. In some individuals, muscle fatigue can even lead to work incapacity.

Heavy equipment and vehicles used in mining can expose operators to significant levels of shock and vibration over long periods of time. These effects on the human body are usually addressed by considering human vibration as either **whole-body vibration (WBV)**, which occurs when the body is supported on a vibrating surface, or **hand-arm vibration (HAV)**, which occurs when the hand is in contact with a vibrating surface, such as power tools. These two systems are mechanically different and are therefore studied separately.

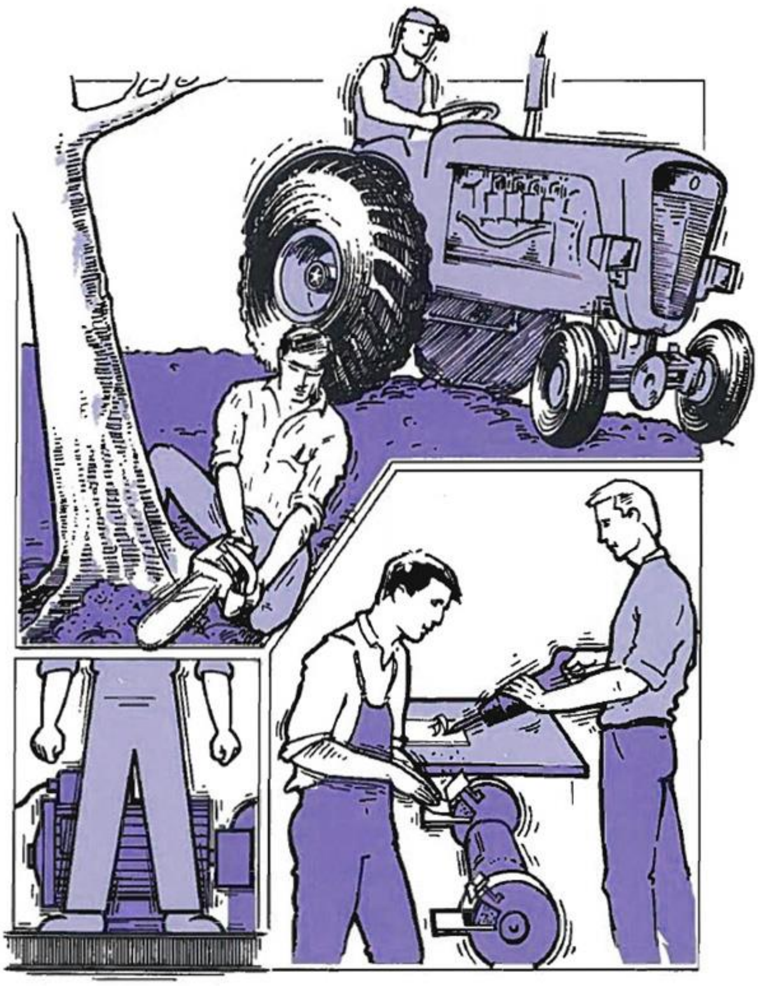


Figure 11. Activities that expose the human body to high levels of vibration

Equipment that generate shock and vibration

Industrial equipment	Others
Cranes	Jackhammers
Control station equipment	Handheld power saws
Presses	Mills
Hammers	Vibrating screens
Cutting machine tools	Bulldozers, excavators
Grinding machines	Plastering machine
Cutting machines	Concrete cutters
Drilling machines	Tamping rammers
Mixers	Concrete vibrators
Vibrating plates	Stone guillotines

Tabel 3

3.1. Whole-body vibration (WBV)

Whole-body vibration (WBV) is a general term used when vibrations (mechanical oscillations) of any frequency are transferred into the human body. Such vibrations can occur in daily life, whether while traveling by car, standing on a moving train platform, using a power tool, or through countless other devices.

Figure 12. Equipment causing whole-body vibration

3.1.1. Disorders caused by whole-body vibration

Daily exposure to whole-body vibrations over many years can lead to serious physical damage, such as ischemic lumbago, a condition affecting the lower spine. Exposure may also impact the circulatory and/or urological systems of the affected person. Individuals who suffer from the long-term effects of whole-body vibration are usually exposed to this harmful condition in connection with specific occupational tasks.

In some cases, an increased prevalence of gastrointestinal complaints, peptic ulcers, and gastritis has been reported among drivers of vibrating vehicles. Whole-body vibration also appears to be a contributing factor, together with prolonged sitting posture, to the development of varicose veins and hemorrhoids. Some studies have reported evidence of effects on the digestive system, female reproductive organs, and peripheral veins. One study showed a higher-than-expected incidence of women in the transport sector giving birth to infants with complications [8].

Another problem caused by vibration exposure is disruption of the central nervous system. Symptoms of this disorder usually occur during or shortly after exposure, taking the form of fatigue, insomnia, headaches, and tremors. Many people have experienced these nervous symptoms after long car or boat journeys. However, the symptoms usually disappear after a period of rest.

Both mechanical and acoustic vibrations can become dangerous beyond certain limits. Studies on the harmful effects of vibration on the human body show that they produce a wide range of damaging effects, both physiological and physical. For example, long-term exposure to low-frequency vibrations between 5 and 15 Hz may cause relative displacements of internal organs, pulmonary hemorrhages, and other complications [5].

Effects of prolonged exposure to vibration (G. Rasmussen, 1966)

Symptom	Frequency of occurrence
Shortness of breath	4-8 Hz
General discomfort	4-9 Hz
Muscle contraction	4-9 Hz
Abdominal pain	4-10 Hz
Lower jaw complaints	6-8 Hz
Chest pain	5-7 Hz
Urgent need to urinate	10-18 Hz
Sensation of a lump in the throat	12-16 Hz
Speech problems	13-20 Hz
Increased muscle tone	13-20 Hz
Headaches	13-20 Hz

Tabel 4

3.2. Hand-arm vibration (HAV)

Vibrations transmitted through the hand or the hand-arm system are mechanical vibrations that occur during technological processes or are caused by various vibrating tools, entering the human body through the fingers, palm, or hands.

Figure 13. Hand-arm transmitted vibrations [3]

Many industrial activities expose people to this type of hazard through the tools they use.

According to estimates, about 1.7% to 3.6% of workers in European countries and the United States are exposed to harmful hand-transmitted vibrations (ISSA, 1989).

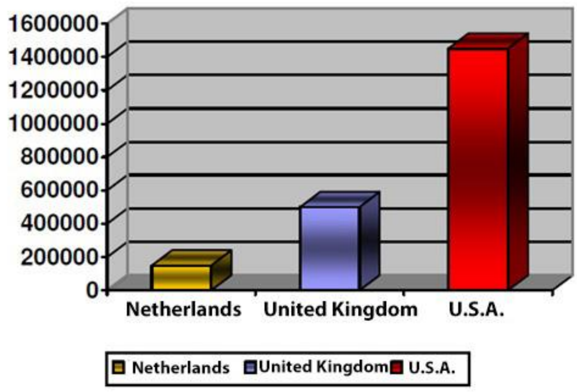


Figure 14. Number of workers exposed to hand-arm vibration

3.2.1. Disorders caused by hand-arm vibration

The Hand-Arm Vibration (HAV) syndrome refers to the following symptoms that occur as a result of vibration exposure (through the hand):

- Vascular disorders;
- Peripheral neurological disorders;
- Muscular disorders;
- Joint and bone disorders;
- Central nervous system disorders.

Figure 15. Vascular system of the upper limb

Daily exposure to hand-arm vibrations over many years can cause permanent physical damage, commonly known as “white finger syndrome,” or it may damage the joints and muscles of the wrist and/or elbow.

In its advanced stages, white finger syndrome is characterized by whitening of the fingertips (Fig. 11), caused by damage to the arteries and nerves in the soft tissues of the hand. The syndrome usually begins with one finger but will spread to the others if hand-arm vibration exposure continues. In the most severe cases, both hands are affected.

In the early stages of white finger syndrome, symptoms include tingling, numbness, and loss of sensation and control in the affected fingers. These symptoms are serious because they affect not only work activities but also leisure activities, and they are largely irreversible.

Figure 16. Raynaud’s syndrome (white finger syndrome) [6]

Loss of sensation and control in the fingers, even for short periods of time, can pose a direct and immediate danger. For example, this occurs when periods of exposure (using vibrating hand tools) alternate with tasks requiring precise manual work. Such a work situation is often found in slaughterhouses, where butchers use both circular saws and sharp knives.

Joint damage in the wrist or elbow is often caused by prolonged exposure to vibrations from poorly balanced percussion tools (such as jackhammers and drills). This damage leads to pain in the joints and forearm muscles and is accompanied by reduced control and muscle strength in the forearm.

In 1987, in Stockholm, a classification scale for white finger disease was adopted [3][7].

Stage	Degree	Symptoms
0	-	No symptoms
1	Mild	Occasional attacks affecting only the tip of one or more fingers
2	Moderat	Occasional attacks affecting the middle (rarely proximal) phalanx of one or more fingers
3	Severe	Frequent attacks affecting all phalanges of several fingers
4	Very severe	As in stage 3, with trophic changes in the skin tissue at the fingertips

Tabel 5

4. Human body response to different frequency values

The mechanical vibrations of a machine are caused by the movement of its components. Each moving part has a specific frequency associated with its motion, so the total vibration transmitted to a human body in contact with the machine is made up of different vibration frequencies occurring simultaneously. This is an important aspect to consider when measuring vibrations, since the human body is not equally sensitive to all vibration frequencies.

To understand why humans are more sensitive to some frequencies than others, it is useful to consider the human body as a mechanical system. This system is complicated by the fact that: (a) each part of the body has its highest sensitivity in different frequency ranges; (b) the human body is not symmetrical; and (c) no two people respond to vibrations in the same way. Nevertheless, suitable biomechanical models have been developed to simulate the human body's response to vibrations.

This illustration shows a highly simplified mechanical model of the body (Fig. 15), where each section is represented by a mass, spring, and damper unit. The human body is a strongly damped system and therefore, when a part of it is excited at its natural frequency, it resonates over a range of frequencies rather than a single one (see the broad rounded peaks in Figure 16). The human body is not symmetrical, and thus its response to vibration also depends on the direction in which the vibration is applied.

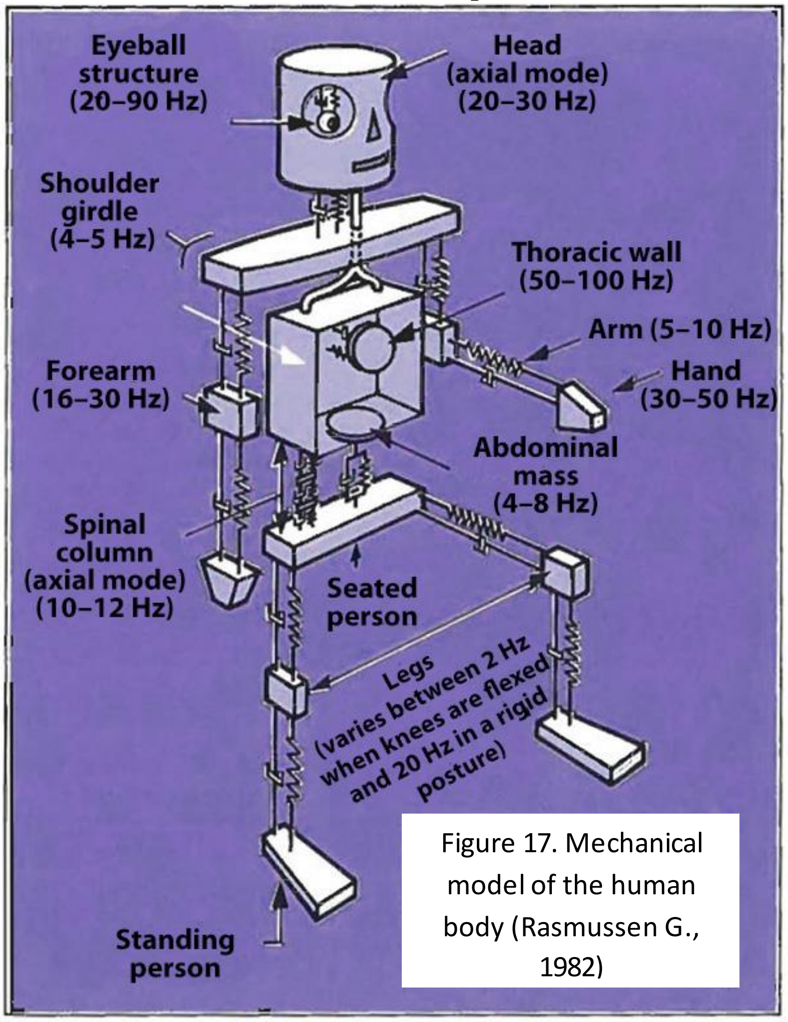


Figure 17. Mechanical model of the human body (Rasmussen G., 1982)

The sensitivity of the human body to mechanical vibrations depends on both the frequency and the direction of excitation. These factors must be considered when evaluating the harmful effects of vibration. ISO (International Organization for Standardization) has developed three weighting curves, shown here, which can be used to account for the above factors when assessing vibration-related risks (see ISO standards 5439 and 2631 Part 1).

When vibration is measured in a particular direction, its level is recorded across all frequencies within the range of human sensitivity. Frequencies to which the human body is more sensitive are given a much heavier weighting than those to which it is less sensitive. This weighting provides a good correlation between the measured vibration level and the subjective feeling or impact produced by the vibration.

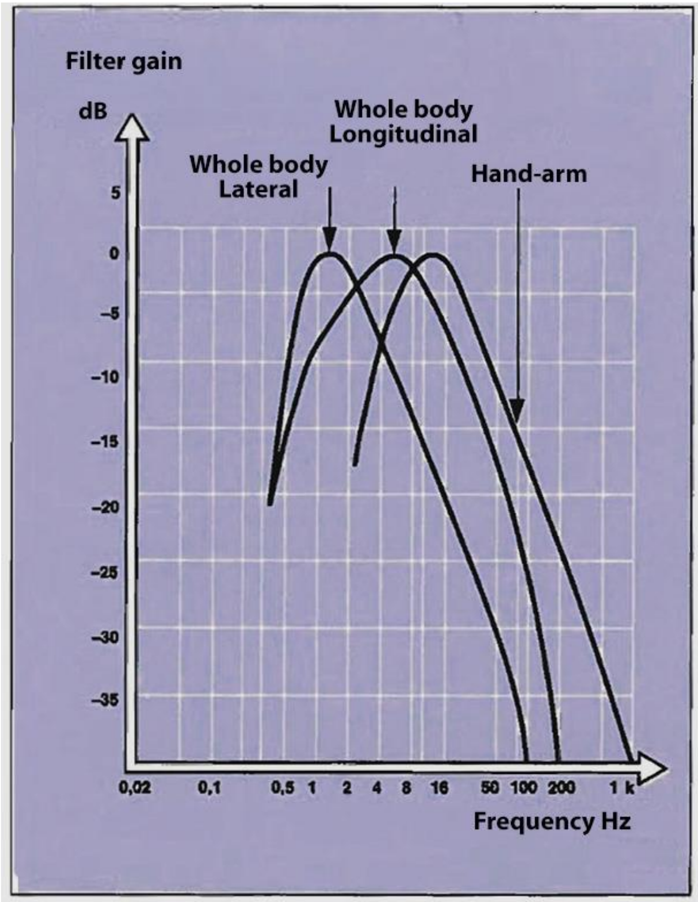


Figure 18. ISO weighting curves for whole-body and hand-arm vibration

5. Vibration control

Vehicles that operate on rough terrain (for example, on construction sites, open fields, or in forests) are subjected to vibrations caused by the uneven surfaces they move across. Without a suspension system, every bump the vehicle passes over would be transmitted directly to the operator as vibration. Adding a suspension system to the vehicle absorbs some of the most harmful vibrations. However, a damping system also introduces its own resonance frequency for the vehicle, meaning that the vibration magnitude at this resonance frequency will be higher.

Figure 19. Working on rough terrain

Hand tool vibrations are mainly generated by the moving parts of the tool. There are various methods to reduce tool vibrations, but these damping methods sometimes also introduce new resonance frequencies into the tool. Therefore, it is very important to ensure that: (a) the method used to dampen the vibrations of a machine or tool only introduces resonance frequencies outside the range to which the human body is sensitive, and (b) the vibration frequencies of the machine/tool that fall within the human sensitivity range are effectively dampened.

5.1. Damping of whole-body vibrations

One of the most important features of many work vehicles is their ability to handle heavy loads. This requires the vehicle to have a stiff suspension, which means that bumps are not absorbed very effectively. In this situation, the usual method of protecting the operator from harmful or disturbing vibrations caused by rough terrain is to equip the operator's seat with a suspension system that can effectively dampen these vibrations.

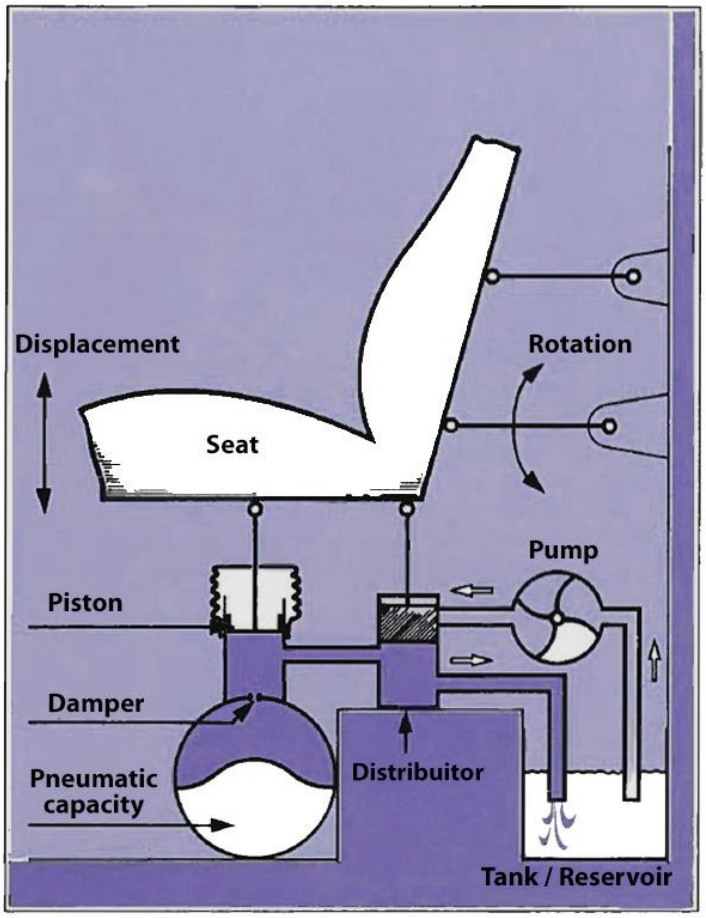


Figure 20. Working principle of an oleo-pneumatic seat

One of the simplest methods to absorb harmful vibrations transmitted through a vehicle seat is to place a soft cushion between the driver and the seat. Another common method is mounting the seat on a suspension system made of spring and damper elements. A more advanced solution is the use of an oleo-pneumatic seat with automatic position correction. The working principle of such a seat is shown in the figure above.

The main objective is once again to reduce the amount of harmful vibrations experienced by the driver by damping the existing resonances in the vehicle, without introducing new frequencies within the human sensitivity range. The required damping depends to some extent on the operator's weight, and some seats are available with individual adjustment to match the operator's weight. ISO 7096 specifies a standard method for testing seat vibrations.

5.2. Damping of hand-arm vibrations

There are four main ways to dampen vibrations acting on the operator's hand:

1. By internal damping of the tool
2. By adding damping between the tool housing and the operator's hand
3. By operating the tool remotely
4. By reducing the operator's exposure time to vibrations through a job rotation schedule

It is important to note that it is often difficult, and in some cases impossible, to dampen vibrations in a tool that has already been manufactured. Therefore, when selecting new hand tools, it is necessary to check whether the tool produces harmful vibrations that are not dampened. In addition, it should be remembered that well-maintained tools not only operate more efficiently but also generate lower levels of vibration.

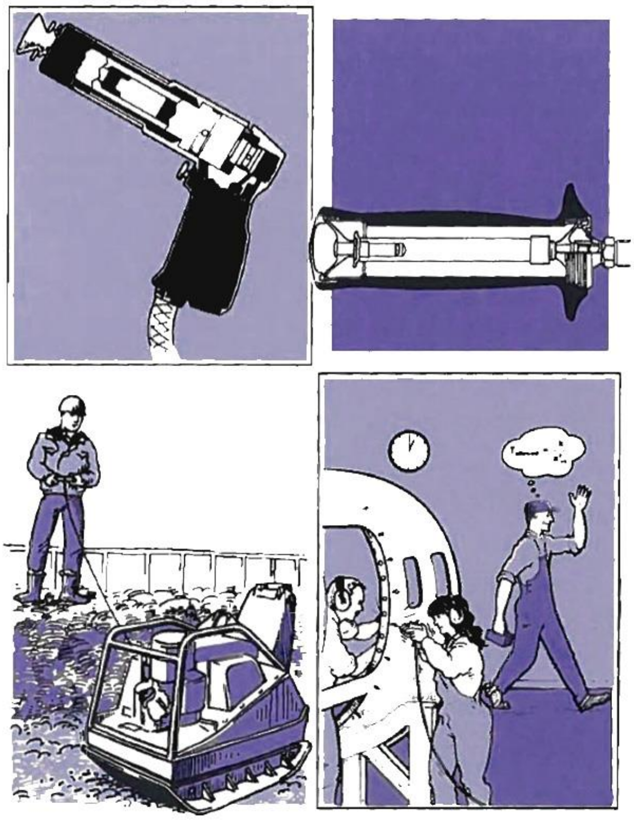


Figure 21. Main methods of vibration damping

5.2.1. Internal damping of the tool

Internal damping of tools is an effective method through which harmful vibration levels can be minimized, and it is the most common damping approach used by tool designers.

A well-established method for damping percussive tools is pneumatic damping, which has been developed and implemented by many manufacturers. The principle involves adding an extra gas chamber and a piston behind the driving piston's gas cavity. By properly balancing the two gas flows, the recoil from the driving piston can be significantly reduced (dampened). The same effect can also be achieved using a spring assembly.

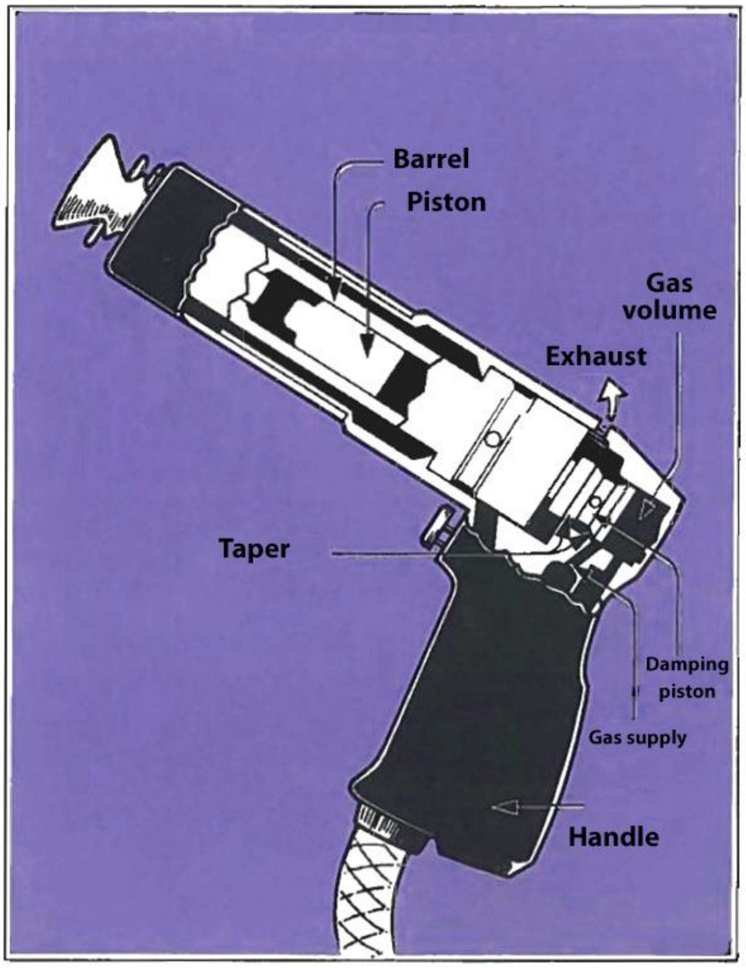


Figure 22. Internal vibration damping solution

5.2.2. Damping between the housing and the operator’s hand

Adding damping material between the tool housing and the hand is an effective and widely used method to reduce the level of vibration transmitted to the hand. This damping can be introduced by:

1. Placing damping material between the tool housing and the tool handles
2. Covering the handles with rubber
3. Using rubber gloves when handling the tool

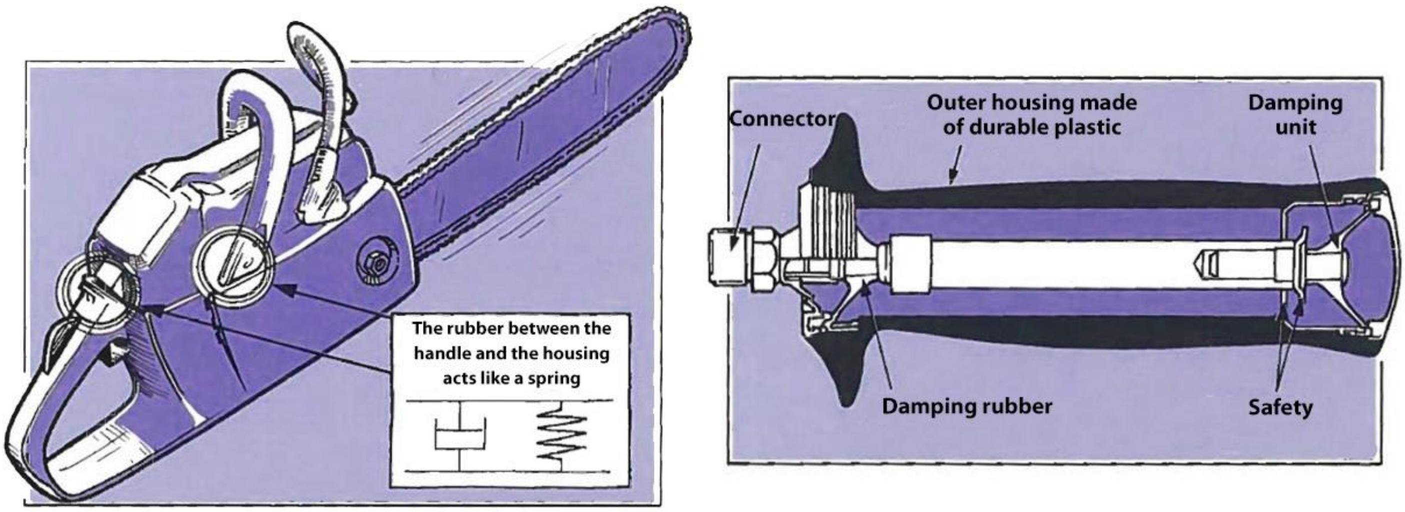


Figure 23. External damping solution for the tool handle

The vibrations produced by the engine and chain in most modern chainsaws are isolated from the handle by a rubber suspension. This damping method can reduce vibration levels by up to 70%, for example, from 10 m/s² to 3 m/s²—a substantial decrease. The main drawback of this method is that the damping material itself tends to wear out faster than the chainsaw, and therefore it must be replaced regularly during its service life.

In general, rubber and other elastic materials are commonly used to dampen high-frequency vibrations. However, they can also introduce a low-frequency resonance. Tools with fast-moving parts that generate mainly high-frequency vibrations can therefore be effectively dampened using elastic materials, while tools that produce predominantly low-frequency vibrations are not effectively dampened by adding an elastic layer of material between the hand and the handle.

5.2.3. Remote operation

Undoubtedly, the most effective—but unfortunately also the most expensive—method of damping is to operate tools remotely. Remotely controlled tools are often more efficient and precise than manually operated ones. However, remotely controlled tools are generally larger, more specialized, and more complex than their manually operated equivalents.

There are many work situations where remotely controlled tools are used, for example, a rock drill mounted at the end of a hydraulic arm, a jackhammer mounted on a small manually operated vehicle, or a plate vibrator controlled remotely via a cable (as illustrated here).

Figure 24. Remote operation

5.2.4. Reducing exposure time

The final method of reducing vibration exposure is to limit daily exposure time. This is the only remaining solution when all other damping methods have failed or are not considered feasible.

Jobs that involve exposure to high-frequency accelerations should therefore be shared among several workers to reduce individual exposure to harmful vibrations. This can be achieved by introducing job rotation, as shown here. However, this method of reducing exposure requires extensive planning and is not always easy to implement.

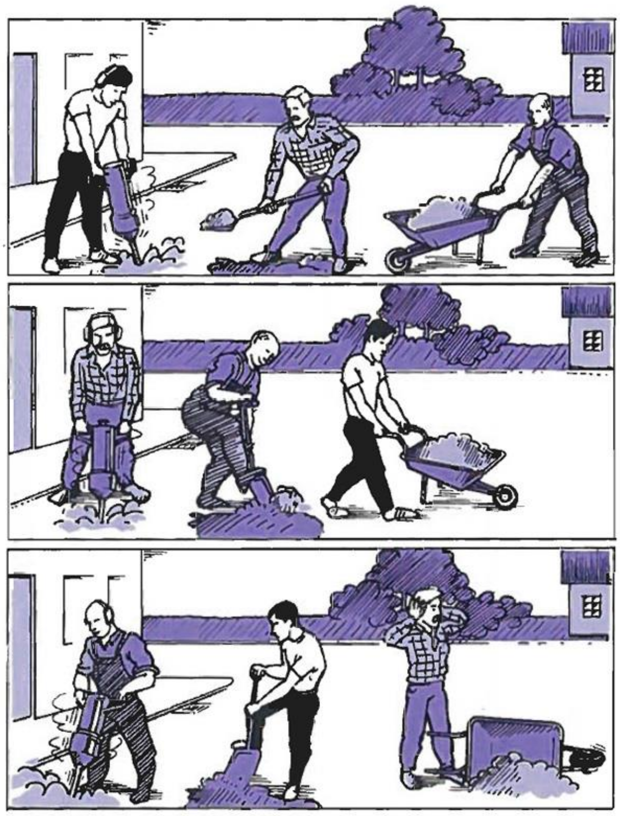


Figure 25. Reducing vibration exposure time

6. Beneficial effects of vibrations on the human body

In 1989, research began at the State University of New York – Department of Biotechnology, focusing on the reversibility of osteoporosis. Scientists at this prestigious university started from the premise that unused bones atrophy, explaining that stem cells in the bone marrow detect movement and transform into bone tissue to better withstand vibrations.

The studies showed that, similar to astronauts who lose about 2% of their bone mass after space flights, people over the age of 35 experience the same loss over a period of 10 years.

Experiments conducted on two groups of test animals (with identical diets), where one group was exposed to vibrations for 15 weeks, 15 minutes per day, revealed the following effects of vibration:

- Body fat decreased by 28%
- Triglycerides decreased by 43%;
- Free fatty acids in the liver decreased by 39%
- Bones became stronger (increase in bone mass).

From there, it was only a small step to the development of devices through which vibrations could be transmitted into the bone structure.

Studies on the beneficial influence of vibrations on metabolism were carried out even before 1949, when the positive effects of vibrations induced by an oscillating bed were observed in patients immobilized with plaster casts.

It was also noted that vibrations at 50 Hz with accelerations of 10g, applied for two to five hours per day, led to an increase in muscle cross-section and a reduction of fat content in muscle tissue.

The observations that vibrations applied to muscles and tendons cause involuntary contractions are highly significant in the case of patients with different forms of paresis (when combined with physical exercise).

Such techniques have started to be used not only in neurophysiology and physiotherapy but also in sports training in general, and particularly in sports that involve intense effort over short periods of time.

Conclusion

Current evidence suggests that whole-body vibration can be an effective exercise intervention for slowing down the aging process in musculoskeletal structures. However, further studies are needed to better understand the neurophysiological mechanisms involved in muscle activation through vibration, in order to design safe and effective training programs. Not only must the optimal frequency and amplitude be identified, but also the level of muscle activation that benefits most from vibration stimulation.

With current technology, it appears that the procedure is generally safe when subjects stand on vibrating platforms for a relatively short period of time with their knees slightly bent, to limit vibration transmission to the head. However, when the vibration transmission frequency is too high, some individuals may experience motion sickness-like symptoms. As occupational medicine has shown that prolonged vibration exposure can have major negative health effects, proper care must be taken when prescribing such exercise programs to ensure safety [17].

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