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VIBRATION AND THE HUMAN BODY

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Abstract: *The paper contents a general presentation of the problems that could occur in studying of the human body vibrations.; they depend on the position of the person as well as on the support type.*

The internal organs vibrations are much more complicated than other parts dynamic behavior, because the internal system is complex and in relationship with the environment: neighbor organs, internal and external liaisons, friction etc. It has long been recognized that the effects of direct vibration on the human body can be serious.

Key words: *whole body vibration, exposure limit value, exposure action value, hand-arm vibration*

1. Introduction

Since man began to build machines for industrial use, and especially since motors have been used to power them, problems of vibration reduction and isolation have engaged engineers. Gradually, as vibration isolation and reduction techniques have become an integral part of machine design, the need for accurate measurement and analysis of mechanical vibration has grown.

Workers can be affected by blurred vision, loss of balance, loss of concentration etc. In some cases, certain frequencies and levels of vibration can permanently damage internal body organs.

Researchers have been compiling data over the last 30 years on the physiological effects of vibrating, hand-held power tools. The *white finger* syndrome is well known among forest workers handling chain saws. A gradual degeneration of the vascular and nervous tissue takes place so that the worker loses manipulative ability and feeling in the hands. Standards are at present under preparation which will recommend maximum allowable vibration spectra at the handles of hand-held power tools [1].

The first published international recommendation concerned with vibration and the human body is ISO 2631-1978 which sets out limitation curves for exposure times from 1 minute to 12 hours over the frequency range in which the human body has been found to be most sensitive, namely 1 Hz to 80 Hz.

The recommendations cover cases where the human body as a whole is subjected to vibration in three supporting surfaces, namely the feet of a standing person, the buttocks of a seated person and the supporting area of a lying person.

Three severity criteria are quoted [1] :

1. A boundary of reduced comfort, applicable to fields such as passenger transportation etc.
2. A boundary for fatigue-decreased efficiency, that will be relevant to vehicle drivers and machine operators, and
3. The exposure limit boundary, which indicates danger to health.

It is interesting to note that in the longitudinal direction, that is feet to head, the human body is most sensitive to vibration in the frequency range 4 to 8 Hz. While in the transverse direction, the body is most sensitive to vibration in the frequency range 1 to 2 Hz.

Exposure to vibration can cause health problems, such as low back pain. In addition vibration exposure can cause discomfort, which hinders work performance. Work machine operators have in general more health problems with back and neck than a reference group, which is not daily exposed to vibration. Because of this it is important to evaluate, understand and minimize the vibration exposure [2].

2. The European legislation

Exposure to vibration can cause health and comfort problems to humans. We can be exposed to vibration in work, commuting between home and work, in leisure travelling; basically in any situation where we are moving. In practice it is almost impossible to avoid vibration exposure in modern society. New technology has enabled more efficient and growing number of work machines and more effortless travelling, thus even greater number of people in future is potentially exposed to vibration. It is thus important to understand the effects of vibration and the procedures to minimize them in a practical manner [3].

The European legislation, concerning vibration exposure, requires employers to assess vibration levels in suitable intervals, and to reduce the risks. In theory the levels should not to be exceeded in any work day and for all employees, which is practically impossible for an employer to assure without continuously monitoring the vibration exposure of each worker [2]. Because it has not been practical to conduct large number of long term measurements before, the Directive and the standard ISO 26311 allows short term measurements to be made for evaluating the vibration exposure levels (ISO 2631 2004).

ISO 2631-1 (1997) gives the guidance on how to measure and calculate whole body Vibration levels (ISO 2631 2004). It gives the frequency weighting curves and analytical equations for calculating the necessary values.The standard does not give exact time for minimum or maximum measurement period, but it states that "*the duration of measurement shall be sufficient to ensure reasonable statistical precision and to ensure that the vibration is typical of the exposures which are being assessed.*" [6].
In a note the standard states that from the signal processing point of view the minimum measurement period should be 227 seconds for registering signals down to 0,5 Hz.

Different standards of whole body vibration give different guidelines for measurement period ranging from 60 to 227 seconds [4].

A typical research study, which has measured whole body vibration and then concluded the levels and probable health risks, has used measurement periods usually defined in minutes rather than hours. There are several examples of these kinds of studies [5]. Several challenges exist when analyzing the results of these studies. First of all the results will depend significantly on the conditions of the environment (e.g. surface type and condition, tire pressure, speed, etc) and the experience of the measurer, thus the vibration levels are most likely different in another day or with another measurer.

The short term measurements do not produce enough data to conclude the variability of the vibration levels in all circumstances, because there are so many factors changing the results. In medical point of view the problem is that, because the measurements are short term and not continuous, the results cannot be used to diagnose a link between vibration exposure and a back pain of a specific person [2]. This is because there is not enough data for generating exposure history of any person. In fact the operator is only used currently to give the right vibration response and to control the machine, thus the operator’s personal medical history is not linked to the measurement results.

3. Human exposure

Risks to workers from exposure to high levels of vibration include decreased performance and even permanent injury. Two common types of vibration exposure have been identified as deleterious: Hand-Arm vibration and Whole-Body vibration

Worker exposure to high levels of vibration from powered hand tools can cause vibration syndrome symptoms such as numbness, pain, tingling and blanching.

Vibration syndrome exposures induce adverse circulatory and neural effects in the fingers and hands that can become irreversible if left unchecked over as little as one year's time. Reduced tactile feeling and dexterity resulting from these exposures decreases workers' ability to perform critical tasks with precision. Often called vibration *white finger disease* (VWF), this condition is progressive and debilitating. Pneumatic and electric-powered hand tools are often the cause of these unacceptable exposure levels, and even hand tools that were initially selected to emit lower levels of vibration may degrade through typical use and lack of (or improper) maintenance, leading to increasing and ultimately unacceptable levels over the working life of the tool [7].

Table 1 gives an indication of typical human perception of vibration.

Table 1- Vibration and human perception of motion

Approximate vibration level (mm/s)	Degree of perception
0.10	Not felt
0.15	Threshold of perception
0.35	Barely noticeable
1.0	Noticeable
2.2	Easily noticeable
6.0	Strongly noticeable

Note: The approximate vibrations (in floors of buildings) are for vibration having frequency content in the range of 8 Hz to 80 Hz.

High levels of Whole-Body vibration exposure are common to workers who operate heavy machinery, material handling and transport equipment, or whose operator stations are in proximity to heavy rotating, stamping or reciprocating machinery. Physical effects to the worker can include damage to the spinal column, and can manifest as low back pain or back, neck and shoulder disorders. Some studies point to possible negative reproductive effects in female populations exposed to high levels of Whole Body vibration.

Until now, it has been difficult to quantify these exposures accurately and consistently. Vibration must be measured in three directions, or axes, simultaneously and this acceleration information must be integrated into useful values and scientific units of measure. Further, measuring the frequency range of the vibration is critical to assessing the potential for physical damage. For example, the frequencies of interest in determining potential injury from hand tools are as high as 2500 Hz, whereas Whole-Body vibration exposures are most damaging at lower frequencies - in the case of the spinal column, primarily from about 0.2 to 8 Hz [7].

Recent ISO standards have been promulgated that define measurement criteria and exposure limits that are useful and practicable for Safety and Industrial Hygiene professionals to implement. This methodology uses a broadband measurement of only the frequencies of interest for determining the severity of the two main types of exposures.

Figure 1 showing the mechanical model of the human body with resonance frequency –ranges of the various body section.

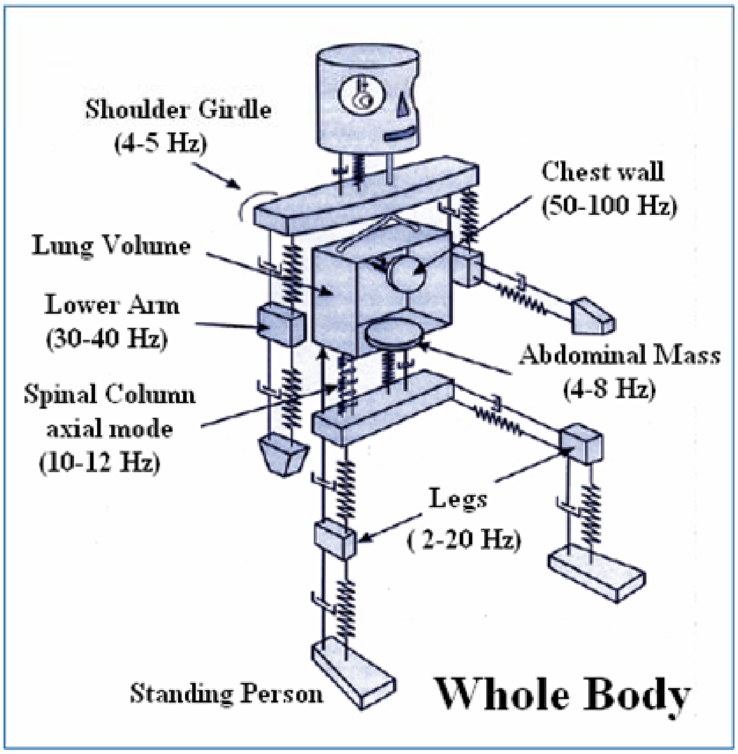

Fig.1- ***Simple theoretical model of the resonance frequencies of the human body [7]***

The following text is an abstract of Directive 2002/44/EC of the European Parliament and of the Council dated June 25, 2002 [9]. The directive lays down minimum requirements for the protection of workers from the risks arising from vibrations. Manufacturers of machines and employers should make an adjustment regarding risks related to exposure to vibration.
The directive lays down the following limit values- table 2 [8]:

Table 2- ***Exposure Limit and Action Values[8]***

	Hand-Arm Vibration	Whole-Body Vibration
Exposure Action Value	**2.5 m/s²**	**0.5 m/s²**
Exposure Limit	**5 m/s²**	**1.15 m/s²**

Once the *exposure action value* is exceeded, the employer shall establish and implement a program of technical and and organizational measures intended to reduce to a minimum exposure to mechanical vibration, taking into account in particular [ ]:

- Other working methods that require less exposure to mechanical vibration
- Appropriate work equipment of ergonomic design, producing the least possible vibration;
- Provision of auxiliary equipment that reduces the risk of injuries, such as protective gloves or special seats;
- Appropriate maintenance programs for work equipment;

- Design and layout of workplaces;
- Adequate information and training to instruct workers to use work equipment correctly and safely;
- Limitation of the duration and intensity of the exposure.

In any event, workers shall not be exposed above the *exposure limit value*. If this should be the case, the employer shall take immediate action to reduce exposure below the exposure limit value.

The methods used may include sampling, which must be representative of the personal exposure of a worker to the mechanical vibration in question.

The assessment of the level of exposure to vibration is based on the calculation of *daily exposure A(8)* expressed as equivalent continuous acceleration over an eight-hour work period. For the determination of A(8) it is not necessary to measure over eight hours. It is sufficient to make short-term measurements during representative work steps. The results are normalized to eight hours. Daily exposure is calculated as follows:

$$A(8) = a_{we}\sqrt{\frac{T_e}{T_0}} \qquad (1.1)$$

where

a_{we} -is the energy equivalent mean value of the frequency weighted acceleration during the exposure;

T_e - is the total duration of exposure during one work day;

T_0 - is the reference duration of 8 hours.

If a daily exposure consists of more than one activity with different vibration magnitudes, daily exposure is calculated [8]:

$$A(8) = \sqrt{\frac{1}{T_0}\sum_{i=1}^{n} a_{wi}^2 T_i} \qquad (1.2)$$

where

a_{wi} - *i*s the energy equivalent mean value of the frequency weighted accel. of activity ***i;***

n- is the number of activities;

T_i - is the duration of activity ***i;***

For *hand-arm vibration* the energy equivalent mean value awe is calculated to ISO 5349. It is the square root of the sum of the squares (vector sum) of the interval *rms* values a_{wx}, a_{wy} and a_{wz}. The interval *rms* values are measured as the accelerations in three orthogonal directions with the weighting filter W_h.

This vector sum is often called *Total Vibration Value* -a_{hv} [8]:

$$a_{we} = a_{hv} = \sqrt{a_{wx}^2 + a_{wy}^2 + a_{wz}^2} \qquad (1.3)$$

In the case of machines which need to be held with both hands, measurements must be made on each hand. The exposure is determined by reference to the higher value of the two.

For *whole-body vibration* the energy equivalent mean value of acceleration awe (interval rms) is measured separately on three orthogonal axes to ISO 2631-1 [9]. For seated persons the following weighting filters and multiplying factors are to be used:

X axis: Filter Wd Multiplying factor k_x = 1,4

Y axis: Filter Wd Multiplying factor k_y = 1,4

Z axis: Filter Wk Multiplying factor k_z = 1

The highest one of the three values is inserted as awe in the calculation of A(8). If no dominant axis of vibration exists, the energy equivalent mean value of acceleration awe may also be calculated as vibration total value a_{hv}, where the multiplying factors k_x, k_y and k_z are to be used:

$$a_{we} = a_{hv} = \sqrt{k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2} \quad (1.4)$$

4. Discussion

The *human body* may be regarded as a complex mechanical system consisting of a large number of interlocking visco-elastic elements, or sub systems (see fig. 1).

The mechanical system will exhibit a dynamic response to an externally imposed vibratory force. The response will depend on:

- The nature of the forcing vibration (i.e. frequency, amplitude and point of application);
- The mechanical constants of the system (or sub systems), i.e. body composition, (weight, tissue distribution, mass of organs, elastic and viscous properties of connective tissue);
- The configuration of the mechanical system, (*i.e.* posture: standing, seated);
- The point at which the response of the system is measured (*e.g.* pelvis, shoulder, head, hand.

Each element of the system has its own natural frequency of vibration - or resonant frequency. Hence at different forcing frequencies, different elements may be more or less affected - more prone to damage, pain, discomfort, and impaired performance.

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