STUDY ABOUT EVALUATION OF HUMAN EXPOSURE TO HAND-TRANSMITTED VIBRATION

ANA PICU

„Dunarea de Jos” University of Galati, Engineering Faculty of Braila, 810017, Braila, Romania

Abstract. *This study investigates the perception of vibrations at the fingertip of the human hand. The study involved 10 adult male subjects, constant-velocity sinusoidal excitations at different discrete frequencies in the range of 16–315 Hz, covering the frequency range of three mechanoreceptors, the Merkel and Meissner receptors and the Pacini corpuscles, in the human hand. The results of the study suggest that the vibration energy absorption into the fingers is considerably less than that into the hand at low frequencies (16-25 Hz). The finger vibration energy absorption at high frequencies (100-315 Hz) is practically independent of the hand-handle coupling condition. The finger vibration energy absorption results suggest that the ISO standardized frequency weighting (ISO 5349-1/2001) may underestimate the effect of high frequency vibration on vibration-induced finger disorders.*

Keywords: *Hand-arm vibration syndrome, Vibration-induced white fingers, Human fingers and hand.*

1. INTRODUCTION

Transmission of vibration in hand is made via the somatosensory system, with its mechanoreceptors in the skin. There are four receptors located underneath the hand skin that react to mechanical action. These receptors are Merkel, Ruffini, Meissner and Pacini (Fig. 1).

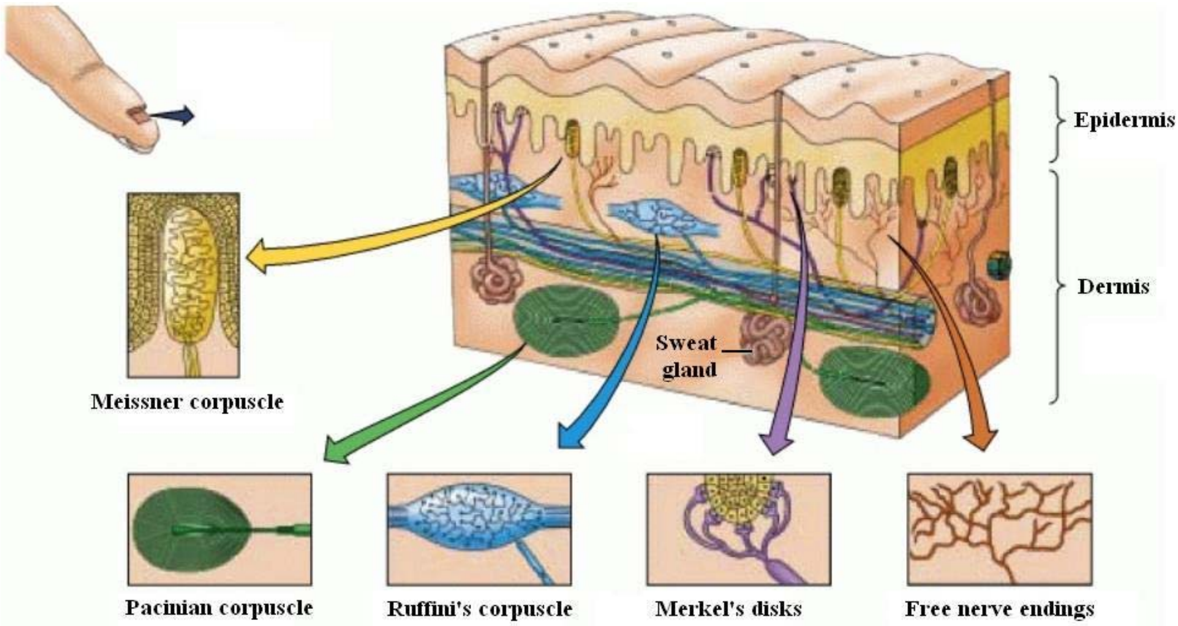

Fig. 1. The skin harbours a variety of morphologically distinct mechanoreceptors. This diagram represents the smooth, hairless (also called glabrous) skin of the fingertip. The major characteristics of the various receptor types are summarized in Table 1 [1].

The properties of these receptors are presented in Table 1.

Table 1. The major classes of somatic sensory receptors

Receptor type	Anatomical characteristics	Diameters [μm]	Location	Function	Rate of adaptation	Threshold of activation
Free nerve endings	Minimally specialized nerve endings		All skin	Pain, temperature, crude touch	Slow	High
Meissner's corpuscles	Encapsulated; between dermal papillae	6–12	Principally glabrous skin	Touch, pressure (dynamic)	Rapid	Low
Pacinian corpuscles	Encapsulated; onion-like covering	6–12	Subcutaneous tissue, interosseous membranes, viscera	Deep pressure, vibration (dynamic)	Rapid	Low
Merkel's disks	Encapsulated; associated with peptide-releasing cells		All skin, hair follicles	Touch, pressure (static)	Slow	Low
Ruffini's corpuscles	Encapsulated; oriented along stretch lines	6–12	All skin	Stretching of skin	Slow	Low

The receptors react to different clues of a vibration stimulus (Table 2) and serve for different [2].

Table 2. Mechanoreceptors in the human hand

Receptor	Receptor Field/ Density	Cue
Merkel	2 mm/ ~100/cm^2	Skin Indention, Vibrations ~4 Hz
Ruffini	8 mm/ ~20/cm^2	Stretching
Meissner	5 mm/ ~150/cm^2	Velocity, Vibrations <~80 Hz
Pacini	Palm/ Finger/ ~20/cm^2	Acceleration, Vibrations ~40 to 500 Hz

Table 2 shows that through Merkel receptor, the overall feeling of touched object is felt. Through Ruffini receptor the mechanical tension is felt. The Meissner receptors are responsible for perception of the velocity of the skin deformation, used to control the strength or pressure with which a certain part of the skin touches a surface or grabs an object. The Pacini corpuscles are responsible for accelerations in the skin deformation with highest sensitivity at about 100-200 Hz and serve for the perception of roughness. All receptors contribute to the sensation of vibration perceived through the skin of the hand.

This paper determines the frequencies at which these stimuli react. This is achieved by choosing different working conditions: size of the contact surface with the vibrator, vibration frequencies and amplitudes etc.

2. THEORY

Today, all the activities are completely dependent on vehicles and in the 8 or more hours of production, drivers are subjected to HAV (hand arm vibrations). During their use the drivers are exposed to hand-arm vibration [3, 4]. These vibrations are due to rolling speed, cars' loading, the type of vehicle, the type of road, and the driver seat and tractor suspensions [6].

Because of all these factors the drivers suffer from different vascular and neurological disorders, skeletal and muscle disorders [5, 6]. The most often outcomes appear at 8–1000 Hz frequencies. Acceleration values from one-third-octave band analysis can be used to obtain the frequency-weighted acceleration a_{hw}. It shall be obtained using:

$$a_{1w} = \left[\sum_{j=1}^{n} (W_{hj} \cdot a_{hj})^2 \right]^{1/2} \qquad (1)$$

where a_{hj} is the acceleration measured in the one-third octave band in m/s², and W_{hj} is the weighting factor for the one-third-octave band.

In accordance with mentioned ISO standards, the three directions of an orthogonal co-ordinate system, in which the vibration accelerations should be measured, were as follows: z-axis, x-axis and y-axis. The evaluation of vibration exposure in accordance with ISO 5349/2001 [7] is based on a quantity that combines all three axes. This is the vibration total value a_{hw} or weighted acceleration sum (WAS) and it is defined as the root-mean-square of the three component values:

$$a_{hw} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad (2)$$

where a_{hwx}, a_{hwy}, a_{hwz} are frequency-weighted acceleration values for the single axes.

The vibration exposure depends on the duration of the exposure and on the magnitude of the vibration total value. Daily exposure duration is the total time for which the hands are exposed to vibrations during the working day. The daily vibration exposure should be expressed in terms of the 8 hour energy-equivalent acceleration or frequency-weighted vibration total value:

$$A(8) = a_{hw} \sqrt{\frac{T}{T_0}} \qquad (3)$$

where T the total daily duration of the exposure [s], and T_0 is the reference duration of 8 h.

3. MEASUREMENTS

Six subjects were chosen aged 21-35 years, men, two of whom have static activities and four have dynamic activity. Of these latter four, two are smokers. In order to determine the accelerations transmitted through hand, the assembly in Fig. 2 was used.

Fig. 2. Excitator and measuring system.

Fig. 3. Hand locations.

Subjects placed each distal phalanx (fingertips) on the driver. Contact points with the driver are shown in Fig. 3.

A contact forced was provided with a small weight add to the counterweight.

The experiment was conducted in a quiet room, where the subject was seated and had the arm resting on an arm support.

The measurements were made using NetdB - Complex system for analysis and measurement of remitted vibration to human body with dBFA Suite - Software for acquisition command and data post-process and PCB Piezotronics triaxial piezoelectric accelerometers.

Vibration magnitudes were expressed as root-mean-square acceleration, frequency-weighted using frequency weighting W_h in accord with ISO 5349/2001. In addition, unweighted acceleration magnitudes were obtained over the same nominal frequency range (16 - 400 Hz).

The measurement time for every test set was 10 minutes with 15 s integration period.

Working frequencies were 16, 20, 25, 31.5, 40, 50, 63, 80 100, 125, 160, 200, 250 315 and 400 Hz.

4. RESULTS

Measurement results are shown in Fig. 4.

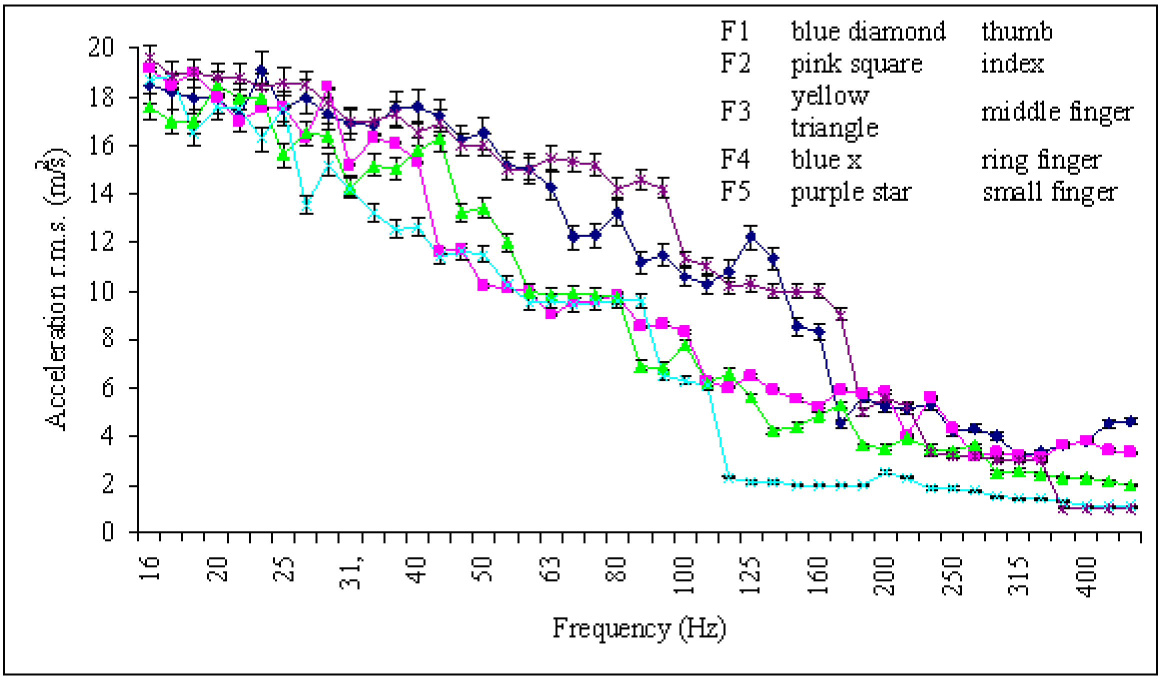

Fig. 4. The r.m.s acceleration variation as a frequency function for the 5 fingers.

Fig. 4 shows that the decrease of the r.m.s. acceleration as a function of frequency can be approximated by a straight line, as follows:

- For the thumb:

$a_{r.m.s} = -1,2327\nu + 21,861$ ($R^2 = 0.9286$)

- For the index finger:

$a_{r.m.s} = -1,2111\nu + 19,782$ ($R^2 = 0.9431$)

- For the middle finger:

$a_{r.m.s} = -1,2761\nu + 19,855$ ($R^2 = 0.9611$)

- For the ring finger:

$a_{r.m.s} = -1,4271\nu + 19,984$ ($R^2 = 0.9464$)

- For the small finger:

$a_{r.m.s} = -1,3668\nu + 22,974$ ($R^2 = 0.9448$)

Representing these lines on the same graph, it obtained Fig. 5.

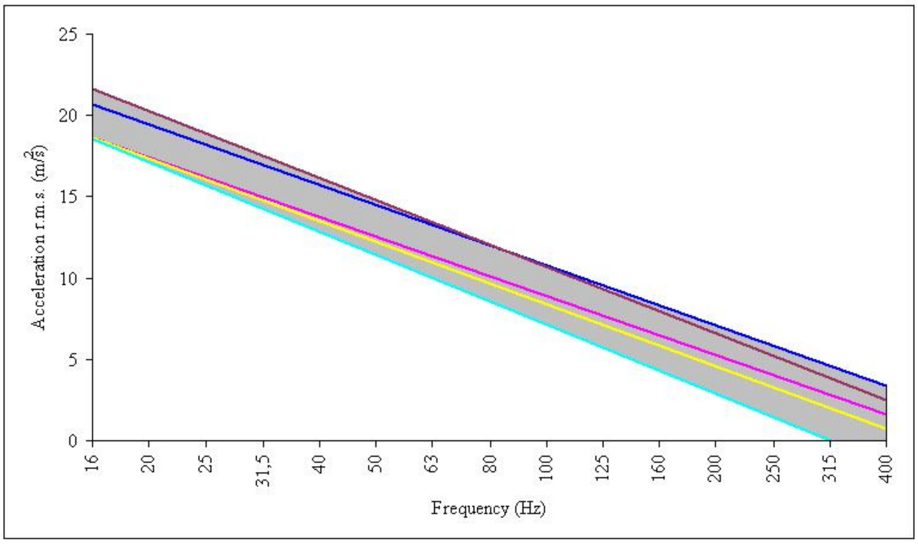

Fig. 5. Perception areas of the fingers transmitted vibrations in terms of frequency.

Fig. 5 shows that was obtained an area where the vibrations are easily perceived by the fingers. Thus, the human body easily tolerates vibrations whose accelerations are below this area, and those whose accelerations are above this zone, are perceived as very disturbing.

5. CONCLUSIONS

The daily vibration exposure was calculated according to the equation (3), where T=10min of exposure, and results were represented in Fig. 6. According to H.G. 1876/2005 [8] on minimum health and safety requirements regarding the exposure of workers to risks arising from vibration, art. 5, the value of the daily exposure to vibrations that triggers the actions on the human body, calculated for a reference period of 8 hours, is 2.5 m/s^2. From calculations with the experimentally obtained values, it was found that for frequencies up to 25 Hz, the daily vibration exposure A(8) is greater than the maximum permissible value of 2.5 m/s^2 (value represented by the black line in Fig. 6. In conclusion, it is necessary to avoid as possible the hands exposure to these frequencies and limiting the exposure time to vibration with these frequencies.

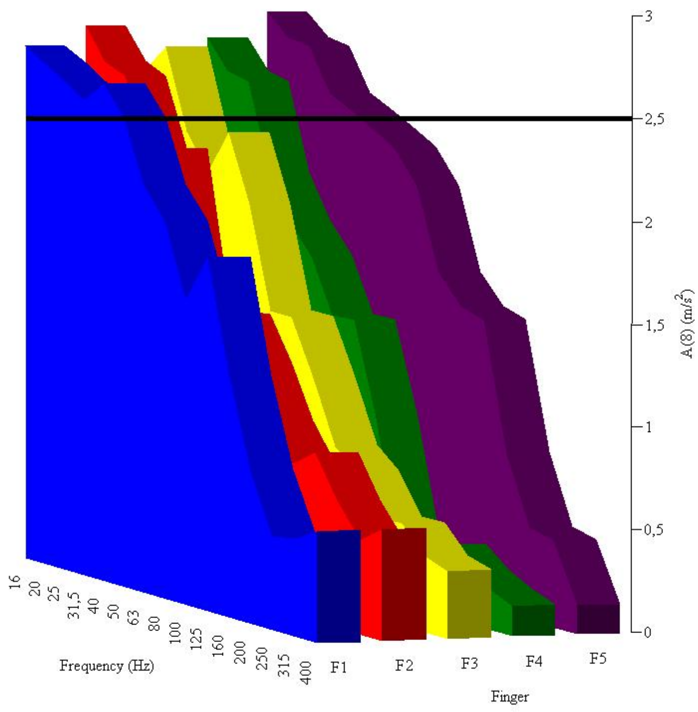

Fig. 6. The daily vibration exposure representation for each finger in terms of frequency where F1 (blue) – thumb; F2 (red) – index; F3 (yellow) – middle, F4 (green) – ring, F5 (purple) – small.

REFERENCES

[1] Kennedy, W.R., Wendelschafer-Crabb, G., *Journal of the Neurological Sciences*, **115**(2), 184-190, 1993.

[2] Oey, H., Mellert, V., *Vibration thresholds and equal vibration levels at the human fingertip and palm*, ICA 2004 4-9 April, Kyoto, Japan, *Th.P2 Noise and vibration (NSP01)* http://wwwsoc.nii.ac.jp/asj/ICA2004/home.htm

[3] Bovenzi, M., Franzinelli, A., Mancini, R. et al., *Occup Environ Med*., **52**, 722–730, 1995.

[4] Griffin ,M.J**.,** Standards for the evaluation of hand-transmitted vibration and the prevention of adverse effects. In: Lundström R, Lindmark A, eds. *Proceedings of the 8th International Conference on Hand-Arm Vibration*, 9–12 June 1998, Umeå, Sweden, 2000. Arbetslivsrapport Nr 2000:4, 243–259, 2000.

[5] Bovenzi, M., Lindsell, C.J., Griffin, M.J., *Occup Environ Med.,* **58**, 185–193, 2001.

[6] Palmer, K.T., Haward, B., Griffin, M.J. et al., *Occup Environ Med.,* **57**, 237–241, 2000.

[7] International Organization for Standardization. *Measurement and evaluation of human exposure to hand-transmitted vibration—Part 1: General guidelines*. ISO 2001:5349-1. Geneva: ISO, 2001.

[8] H.G. 1.876/22.12.2005 privind *Cerinţele minime de securitate şi sănătate referitoare la expunerea lucrătorilor la riscurile generate de vibratii*, 2005.

Manuscript received: 30.04.2010
Accepted paper: 05.09.2010
Published online: 04.10.2010