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SHORT COMMUNICATION

VIBRATION – HAZARDOUS FACTOR IN PROFESSIONAL ENVIRONMENT

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Abstract: The detrimental influence of vibration on particular systems and organs of the human body was presented in the study. The influence of vibration encountered in aviation was discussed, taking into account their nature and harmful effect concerning the circulatory and nervous system in particular. The European Union Directive from 2002 determining standards is mentioned.

Keywords: vibration, vibration resonance frequency, acceptable vibration levels, disorders caused by vibration, European Union Directive

INTRODUCTION

Vibration is one of various hazardous factors exerting negative influence on the human body present in the contemporary professional environment. The development of technology and mechanization in the 20th century enabled people to make use of these achievements. However, because of that, people nowadays have to stay within the range of vibration induced by a particular machine, technical device or vehicle more frequently and for longer periods of time. Detrimental effects of vibration are encountered today more frequently due to common use of modern means of transport in everyday life. We are exposed to vibration while travelling by train, car, and tram or while staying at home in the range of vibration caused by particular elements of the building. From the biological point of view, vibration induced in the surrounding environment is

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transmitted by hands. However, they also affect the whole body. The outcomes of vibration intensity measurements indicate that significant percentage of vibration energy is attenuated within particular organs while being transmitted through the whole body. Numerous studies indicated that the influence vibration exerts on the human body is in its nature the same as the impact of energy. The criterion that allows researchers to determine functional changes caused by vibration is the amount of energy transmitted to the organism. It can be calculated using the following equation:

$$Q = IS_t$$

Q - the amount of energy
I - vibration intensity (N/S)
S - contact surface area (m^2)
t - time of intensity (sec.)

It was determined that all kinds of vibration, even cyclic vibration of less than 0.5 Hz frequency, can be classified as a shock. Basic vibration includes sinusoid (harmonic, simple) and stochastic (random) vibration. The latter type is encountered most frequently in aviation [11]. Vibration can also be classified as whole-body vibration and hand-arm vibration. Whole-body vibration is transmitted to the human body through the lower extremities if a person is in supine position, and through the sitting area if a person remains in sitting position. Hand-arm vibration is transmitted through hands. Independent of its type, vibration is transmitted through tissues to remote areas within the body [2]. The frequency, for which human body resonance is observed, can be determined on the basis of impedance charts. This phenomenon is characterized by sudden increase in the oscillation of elastically mounted mass, in which maximum oscillation is observed at a particular frequency. This phenomenon is encountered extremely rarely in aviation, as resonance is observed along with harmonic vibration. Stochastic (random) vibration is usually observed in aviation.

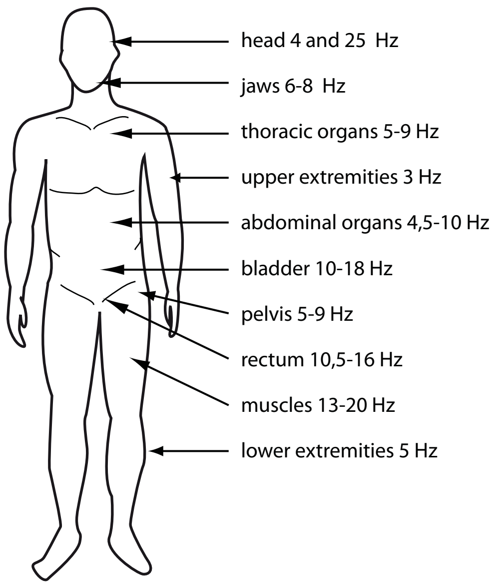

Fig. 1. Comparison of resonance frequency values of selected organs and human body parts.

Vibrations within an aircraft develop due to aerodynamic loading of different types, during the movement of the aircraft, in air masses, as well as due to various loading of propulsion systems. The pilot is subjected to both hand-arm and whole-body vibration. The nature of vibration is changed by its transmission from the source to the body due to factors as air resistance, altitude change, and vibration of particular aircraft steering elements. The nature of aircraft vibration, particularly at low altitudes and at high velocity, is influenced mainly by: the weight of the wings, wind velocity, aircraft size, structural module curvatures, weather conditions, terrain type, and air velocity [5]. Turbulence disturbances constitute the main source for aircraft vibration at high altitudes, especially for jet aircraft. Vibration in helicopters is related mainly to weather disturbances and mechanical features of the aircraft. Low-frequency vibrations (25-75 Hz), which are complex in nature, are observed in helicopters.

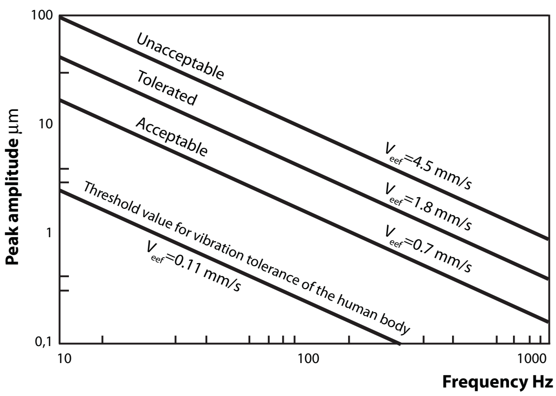

Fig. 2. Acceptable vibration levels.

Two frequency ranges can be distinguished in vibration charts:

– Basic frequency with values between 6 and 8 Hz, resulting from the functioning of the rotor,
– Carrier frequency, exhibiting values between 50-75 Hz, related to the helicopter aerodynamics.

Transport aircrafts are characterized by vibration within the range of several dozen to 150 Hz. The greatest vibration intensity in supersonic jet aircrafts is observed for the frequency range exceeding 100 Hz. Vibration amplitude is an important parameter in cases in which the body is exposed to frequency values outside the resonance range. In these cases mechanical injury of several organs follows the function of frequency at constant spectrum amplitude [20]. The difference in muscle activity of both upper extremities should be taken into consideration when discussing the transmission of vibration through the hands. [1]. The most significant vibration attenuation was always observed in those areas of the body that remained in direct contact with vibrating elements [4]. The results of measurements concerning the transmission of whole-body vibration through the pilot's body indicated that significant percentage of vibration energy is attenuated during the process. Vibration that affects the pilot's trunk is generally complex in nature – it results from the superimposition of vibration originating from the work of the engine and the functioning of the rotor in helicopters. Comprehensive examination of staff who fly different helicopter types was performed at the Military Institute of Aviation Medicine [11,12]. The evaluation included vibration intensity measurements in different helicopter types, e.g. at the joystick, floor and the seat. In some helicopter types (Mi-24) values exceeding acceptable limits were observed. After appropriate safety measures provided by the manufacturer were implemented (attenuation of floor vibration and the use of supplementary pilot seat cushion) vibration values were within acceptable limits. Special anti-vibration gloves were used in order to attenuate the vibration of the joystick. The examination of the personnel included a detailed interview, as well as thermometry, pletismography and palestesiometry (i.e. the examination of vibration sensitivity threshold). These examinations were conducted in response to complaints made by pilots concerning tingling and numbness within distal fragments of extremities, increased skin humidity and occasional pain after flights [12]. Mean number of hours flown by pilots does not exceed 200 hours annually. Significant severity of subjective complaints was observed in pilots in whom the mean number of hours flown annually exceeded 600 hours (agroaviation). Complaints reported by patients concerning numbness or pain in fingers and increased palm and foot skin humidity observed most frequently after flights, may indicate that these symptoms result from functional changes observed in small vessels of hands and feet due to nervous system tension that leads to constriction of these vessels and, consequently, a decrease in blood supply and temperature in these areas [10,17,18,21]. It was shown on the basis of the physical examination of the peripheral circulatory system (pletismography and skin thermometry) that blood vessel reactivity, established in a temperature provocation test using volumetric pletismography, exhibited greater increase in pule volume (expressed in percent) in the control group. The reaction of blood vessels in particular thermal phases of the examination indicates that blood vessel reaction is regulated more favorably in the control group than in pilots exposed to vibration [11].

Long-lasting exposure to vibration environment leads to general fatigue that causes a decrease both in attention and in the effectiveness of performed professional tasks. Concentration deficits lead to psychomotor function impairment. It is suspected that the negative influence of vibration on cognitive processes is caused by its detrimental effect on the cerebral cortex. Following symptoms may occur when a person is exposed to vibration: decreased visual acuity, decreased perception speed and disorders in color discrimination test. From the mechanical point of view, it makes no difference whether the observed object vibrates, the human body vibrates, or whether both entities vibrate together. Movement of the image on the retina is always observed. It can lead to the creation of a blurred image, which can lead to sad consequences, including a catastrophe.

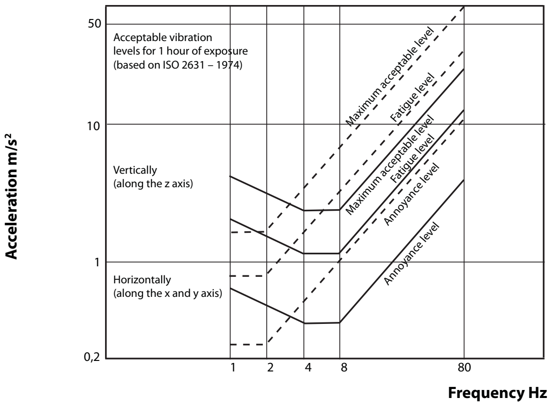

Fig. 3. Acceptable levels.

CHANGES IN THE HUMAN BODY CAUSED BY VIBRATION

Vibration affecting the whole organism constitutes a factor that contributes to the development of pathology within the lumbar spine. It occurs particularly frequently in tractor, bulldozer and lorry drivers. Pain in the spine is also a symptom that is observed frequently in helicopter pilots. Direct measurements of lumbar spine movements (performed using markers mounted on the spinous processes) indicated that the greatest amplification of not only vertical movement, but also sagittal and rotary movements, is observed at a frequency of 4 Hz. At this frequency major body resonance is observed – it is probable, then, that in these conditions the mechanical loading of the spine should exhibit the highest values. Epidemiological studies conducted on tractor and bulldozer drivers showed that degenerative changes within the spine develop earlier in these groups of patients, and that their etiology is related to vibration. The frequency that dominates in helicopters is usually higher than the major body resonance frequency, and the pain within the spine can be more probably attributed to the necessity of keeping the same, slightly inclined, strained body position. Any final conclusions cannot be drawn on the basis of the observation that higher frequency of pathology in the lumbar spine was seen in the x-rays.

Different sources of resonance manifest themselves at different vibration frequencies. Although the maximum oscillating airflow develops at vertical frequencies of 3-4 Hz, speech in these cases is not distorted – provided that the level of vibration is not too high [18]. In the frequency range between 6 and 20 Hz, oscillating airflow influences the volume of speech and the comprehensibility of speech may be lost at certain frequencies. As vibration frequency increases, smaller structural units of the human body may resonate. Resonance is observed at lower frequencies (4-8 Hz) in muscle groups of the lower extremities, at higher frequencies (15-20 Hz) in soft tissues of the face, which leads to a disturbing tremor [16]. The possibility of mechanical eyeball resonance was studied. The studies showed impaired visual acuity in cases in which the whole body was exposed to vibration of 20-40 Hz and 60-90 Hz.

Exposure of the whole body to vibration of moderate intensity does not cause any permanent changes within the circulatory system.

In the first phase of exposure to vibration an increase in heartbeat and small rise in blood pressure and changes in cardiac rhythm are observed [3,7,8]. Vibration of high intensity can lead to anxiety causing hyperventilation [8,9]. Lung stretch receptors can be stimulated by vibration, which, in turn, may activate ventilation. Individual differences in vibration-induced hypocapnia can be related with individual reaction to CO2.

Apart from a local injury caused by vibration, generalized disorders and various organ reactions can be observed. Such a complex of symptoms is known as the vibration syndrome of the vascular type. In the beginning, paresthesia during rest period can be observed, i.e. numbness and tingling and, rarely, pain affecting distal parts of extremities. In the second period subjective disorders concerning upper extremities intensify. When exposed to cold, fingers become numb, the pain increases and they turn blue or pale [13,14]. The temperature of skin in the fingers decreases significantly. Increased threshold for the feeling of vibration is observed, particularly within the higher range of frequency. In the next phase, the “white finger syndrome” develops. Contemporary views suggest that paroxysmal vasomotor constriction expresses a compensatory tension in the sympathetic system with hyperergic features, whereas tension within the parasympathetic system dominates in the periods between seizures [15].

Whole body vibration of 0.2 Hz can induce the symptoms of motion sickness in sensitive people. This phenomenon is encountered, though less frequently, in case of vibration characterized by frequencies lower than 0.7 Hz.

Susceptibility is most probably higher for stimuli that operate in the Gx axis. The range of frequencies that induce the symptoms of motion sickness is significantly lower than internal body resonance. Therefore, there are no direct causes that would lead gastric symptoms that are characteristic of motion sickness.

European Parliament Directive 2002/44/EG was published in July 2002. This document on the minimum health and safety requirements concerns the exposure of workers to the risks arising from physical agents (vibration). The directive determines acceptable levels of vibration to which workers can be exposed within their workplace. According to this Directive, the employer is responsible for protecting the worker against the harmful influence of vibration and for establishing a safe vibration level. The worker should determine the accepted duration time and the level of vibration. The daily limit value is determined for a work day (8 hours). According to this document, the employer is obliged to have detailed knowledge of equipment and emitted vibration levels affecting the worker, and to act in cases that require the introduction of actions limiting the emission of vibration.

EUROPEAN DIRECTIVE

DIRECTIVE 2002/44/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 June 2002

The communication of the Commission concerns the plan of action related to the introduction of the Community Charter of Fundamental Social Rights of Workers, and it involves the introduction of minimum requirements in healthcare and safety of exposure of workers to risks caused by physical agents. The European Parliament accepted the regulation concerning this action plan, in which its members address the Commission, particularly concerning the preparation of a detailed directive concerning the risks caused by noise and vibration. It is believed that it is crucial in the first phase to introduce measures protecting workers from the risks arising from vibration owing to its effects on the health and safety of workers, in particular muscular/bone structure, neurological, and vascular disorders.

This Directive lays down minimum requirements, thus giving Member States the option of maintaining or adopting more favorable provisions for the protection of workers, in particular the fixing of lower values for the daily action value or the daily exposure limit value for vibration. The implementation of this Directive should not serve to justify any regression in relation to the situation which already prevails in each Member State.

Employers should make adjustments in the light of technical progress and scientific knowledge regarding risks related to exposure to vibration, with a view to improving the safety and health protection of workers.

In the case of sea and air transport, given the current state of the art it is not possible to comply in all circumstances with the exposure limit values for whole-body vibration; provision should therefore be made for justified exemptions in some cases.

In some cases, means crucial for the implementation of this directive should be applied according to the Council decision 199/468/WE from 28.06.1999 setting the requirements for executing the executive tights given to Commission.

The following directive, sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC, provides minimum requirements concerning the protection of workers from health and safety hazard resulting (or potentially resulting) from exposure to mechanical vibration. According to the Directive, 'hand-arm vibration' is defined as the mechanical vibration that, when transmitted to the human hand-arm system, entails risks to the health and safety of workers, in particular vascular, bone or joint, neurological or muscular disorders. The "whole-body vibration' is on the other hand defined as the mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine.

Daily exposure limit value standardized to an 8-hour reference period is 5 m/s2 and 2.5 m/s2. For whole-body vibration it is set at 0.5 m/s2 – 1.15 m/s2. According to this Directive the employer should fulfill the following requirements:

- Control the level, type and duration of exposure
- Limit values and exposure action values, effects concerning the health and safety of workers at particularly sensitive risk and information provided by the manufacturers of work equipment in accordance with the relevant directives, the existence of replacement equipment designed to reduce the levels of exposure to mechanical vibration, ensuring specific working conditions such as e.g. low temperatures, appropriate information obtained from health surveillance.

The employer is obliged to establish risk at given posts and to pay close attention to the following factors:

- other working methods that require less exposure to mechanical vibration
- choice of appropriate work equipment
- provision of auxiliary equipment that reduces the risk of injuries caused by vibration, such as seats that effectively reduce whole-body vibration and handles which reduce the vibration transmitted to the hand-arm system
- appropriate maintenance programs for work equipment
- the design and layout of workplaces and work stations
- information and training of the workers
- limitation of the duration and intensity of the exposure
- appropriate work schedules (rest periods)
- provision of clothing to protect exposed workers from cold and damp

The regulation, which is the applicable act in Poland determining safety requirements and work hygiene in jobs associated with such hazardous factors as vibration and noise, is the Regulation of the Minister of Economy and Labor of 5th August 2005 concerning safety and work hygiene in jobs related with exposure to noise, mechanical vibration.

AUTHORS' DECLARATION:

Study Design: Bronisław Turski; **Manuscript Preparation:** Bronisław Turski; **Funds Collection:** Bronisław Turski. The Author declares that there is no conflict of interest.

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