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HAND-ARM VIBRATIONS. AN INTERDISCIPLINARY ENGINEERING AND MEDICAL STUDY

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Abstract: This work has been performed within a research project financially supported by the Romanian Ministry of Education, Research and Youth. The main objective is to develop technics, specifications and methodologies for thoroughly study the mechanical vibration phenomenon the human body is subjected to during practising a profession, potential sourse of occupational diseases. At the same time, it is intended to develop modern methods of dynamic (vibration) analysis and of active control advanced systems, for protecting the human body against vibrations.

1 INTRODUCTION

The occupational diseases due to vibrations represent nowadays one of the great concerns in the labour medicine. Workers from exposed fields of activity (Table 1) accuse symptoms on a large scale that could be associated to the vibration cause. It is still a problem for medicine to state that an identified disease is caused, to a great extent, by vibrations, since the contributing factors are usually several and interrelated. However, due to the problem complexity, presently there is a lot of research carried on by joint teams of engineering and medical researchers, at international level. Consequently, the vibrations influence can be clearly systematized in two distinct categories:

- whole body vibrations – with significant effects in the entire human body;
- vibrations on different sections of the body – that transmit significant accelerations and displacements only in some sections, such as the hand-arm system.

In the literature, the first category is referred to as WBV (***W**hole **B**ody **V**ibrations*), and the second one as HAV (***H**and **A**rm **V**ibrations)*. An overview of the state of the art in human body protection against vibrations, both at national and international level, is presented in [1].

Table 1. Fields of activity with high risk from the vibration exposure point of view [2]

Field of activity	Vibration category	Vibration source
Agriculture	WBV	Tractors driving
Constructions	WBV	Vehicles with heavy equipment
	HAV	Pneumatic drilling machines, pneumatic hammers, etc.
Forestry	WBV	Forestry vehicles (tractors) driving
	HAV	Chain saw
Mining	WBV	Mining vehicles driving
	HAV	Rock drill hammer
Metal cutting	HAV	Machine tools
Shipyard	HAV	Pneumatic hand tools
Textile	HAV	Sewing machines, looms
Transport	WBV	Vehicle driving

Due to the research carried on in this field, presently the critical frequencies that affect the human body are known [2]. Moreover, the research results led to several standards and regulations imposed both to the manufacturers of vibration generator equipment and to the employers whose employees are exposed to vibrations during the work. The most recent demonstration of the overall concern related to this subject is the European Parliament and the Europe Council Directive 2002/44/CE from July 25, 2002, regarding the security and health minimum requirements related to the workers exposure to the physical agents (vibrations) generating risks.

2. MEDICAL POINT OF VIEW REGARDING HAND-ARM VIBRATIONS

Within the area of vibration transmission into the human body, hand-arm vibration is the second large problem, different from whole-body vibration in the type of problems to which it gives rise. Whereas vibration transmitted into the standing or seated body normally generates problems of a general nature – motion sickness, discomfort, reduced-working efficiency, etc., vibration applied to the hand-arm may produce physical damage locally if the level and exposure times are sufficiently high [2].

Several tests proved that vibration levels encountered in many commonly used power tools are sufficiently high to cause damage when operated for durations common in industry. Typical of these power tools are chipping hammers, power grinders, hammer drills, and chain saws, found in widespread use in the mining, construction, manufacturing and forestry industries (see Table 1). Vibration may be transmitted into the body from a vibrating tool or hand-held workpiece via one or both arms simultaneously, causing, at lower levels, discomfort and reduced working efficiency. At higher levels and longer exposure periods, diseases affecting the blood vessels, joints and circulation occur. Severe exposure leads to a progressive circulation disorder in the part of the body suffering the highest level of vibration, usually the fingers or hand where hand-held tools are concerned. This is variously known as "dead hand", vibration-induced white finger, or Raynaud's disease. In extreme cases this leads to permanent damage or gangrene. These diseases and their causes are currently being extensively investigated both by medical and engineering researchers [2].

When exposed to frequencies between 20-200 Hz, the hand-arm system may register the following types of affections:

1. The osteo-musculo-articular syndrome
2. The vascular (occupational Raynaud) syndrome
3. The neurological syndrome.

2.1 Description of the most common affections

1. The musculoskeletal syndrome consists of typical injuries that affect especially the following areas: scapulo-humeral, acromio-clavicle, elbow and carpal region. The pain, knuckle tumefaction and movement limitations are registered, together with the knuckle spaces shrinking – put into evidence during the radiological examination. Inflammatory phenomena are present at the level of tendons, muscles and fasces, as different diseases: tenosinovite, miozite, Dupuytren disease.
2. The vascular (occupational Raynaud) syndrome is considered the most characteristic for this category of affections. It develops itself as knuckle spasm crises, increasing in intensity during three phases: 1- *the aura period*: finger pain and paresis; 2- *the state period*: one or more fingers bleakness, hypo-/ anaesthesia and decrease of cutaneous temperature in the affected region – with variable duration between a few minutes and

2 hours; 3- *recovery period*: pain at the finger level, which is extended to the hand and arm, finger tumefaction and cyanosis, cutaneous temperature retrieval.

A positive association has been established between the Raynaud syndrome and the hearing disorder registered at the exposed persons, having as explanation the sympathetic vasoconstriction mechanisms that affect the cohlear blood flux [3].

3. The neurological syndrome consists of sensitive, motor and trophic disorders, in addition to neural-vegetative disorders, such as insomnia, cephalalgia, asthenia.

2.2 The HAV syndrome

A special attention should be given to the medical entity named Hand-Arm Syndrome, caused by vibrations. The syndrome incidence is not known, at the population sector that works in high risk environment; however, the studies related to this subject appreciate that this affection is underestimated and usually wrongly diagnosed as carpal channel disease [4]. Therefore the difference should be done between the Hand-Arm Syndrome and the occupational Raynaud Syndrome described above. Whereas the second one strictly refers to the vascular disorders at hand (finger) level, the first one includes vascular, neurological and muscle-skeleton disorders produced as a consequence of vibration exposure. The HAV syndrome was described for the first time in 1986 by the Stockholm working group, who also conceived an evaluation scale [5]. Aiding this scale, both the vascular and neurological components can be assessed, by ranking from 0 to 4. The 3 stage (vascular or neurological), according to the Stockholm scale, contraindicates the subject exposure and to continue to work in the vibration environment. The disease severity increases together with the exposure period. The medium exposure time that causes the HAV syndrome varies in terms of epidemiological studies, from 9.1 to 23.3 years); this variation is probably due to the heterogenic study batches [6].

The most exposed occupational groups are related to activities in which vibratory machines and tools are manipulated: forestry workers, farmers, workers in mining industry, machine building industry, constructions, dental technicians. The clinical panel is described in the literature [4]. The physiological-pathological mechanisms the HAV syndrome is based on are not completely known, however it can be surely stated that following changes are present: vasospasm at vascular level, organic microangiopathy with the vascular wall hypertrophy and endothelial cells alteration, occlusive arterial thrombosis, diffused neuropathy that affects the Pacini corpuscles (the mecano-receptors at fingers level) [4].

2.3 The research approach

The research performed by a joint team of engineering and medical specialists from University Transilvania of Brasov, in the framework of the CNCSIS grant 393/2006, revealed the serious affections that HAV syndrome may cause to the exposed categories of workers, and has led to the idea to develop advanced models of the vibration phenomenon and its influence on the human body, in order to further propose active control systems for protection against vibrations.

The research method, from the medical point of view, is presented in Fig.1. The target group consists of workers from activity fields exposed to vibrations, accusing different affections that are identified by medical consultation performed by labor medicine staff. In terms of the diagnosis, the patient is referred to a specialist (member of the research team) who develops the patient profile, feed the database with information

related to the affection and monitor the patient evolution before and after the use of active vibration systems designed for diminishing the vibration exposure.

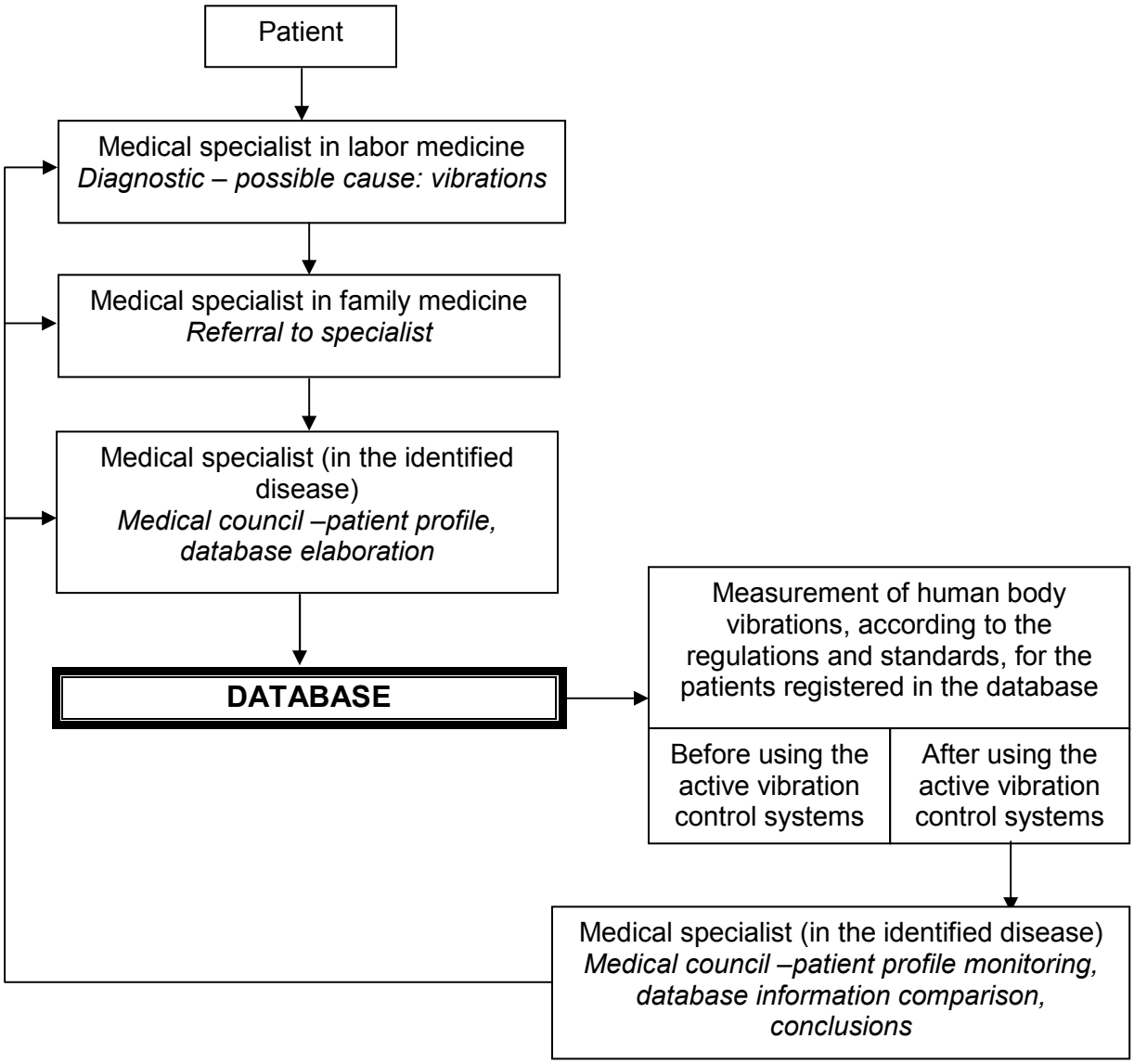

Fig. 1 Research method from the medical point of view

3. HAND-ARM EXPOSURE ASSESSMENT

3.1 Relevant information

When trying to identify the hand-arm vibrations and how they influence on the human health, one has to assess the information related to so called 'hand-arm exposure'.

As mentioned in paragraph 1, Europe Council Directive 2002/44/CE foresee the exposure limit values and the exposure values able to trigger the occupational disease. For the hand-arm vibrations, the daily exposure limit, standardized to a reference time period of 8 hours is 5 m/s^2. The daily exposure limit, that may trigger the disease action, standardized to a reference time period of 8 hours is 2.5 m/s^2.

Exposure level assessment is based on the calculus of the daily exposure value, standardized to a reference time period of 8 hours and expressed as root mean square

(rms) of the frequency weighted component accelerations determined on the three orthogonal axes, a_{hwx}, a_{hwy}, a_{hwz} - as defined by the ISO 5349-1 standard (2001).

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \quad (1)$$

Exposure level assessment is performed both by estimations based on information provided by equipment manufacturers and by measurements. The accuracy depends on:

- measurements accuracy
- estimated exposure period (provided by operator)
- estimated working cycles per day.

Daily vibration exposure, $A(8)$, for a worker carrying out one process or operating one tool can be calculated from a magnitude and exposure time, using the equation [7]:

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \quad (2)$$

where a_{hv} is the vibration magnitude (in m/s²), T is the daily duration of exposure to the vibration magnitude a_{hv} and T_0 is the reference duration of eight hours. Like vibration magnitude, the daily vibration exposure has units of meters per second squared (m/s²).

Partial vibration exposures are determined in the case of a person exposed to more than one source of vibration; they are calculated from the magnitude and duration for each source. The overall daily vibration exposure can be calculated from the partial vibration exposure values, as follows [7]:

$$A(8) = \sqrt{A_1^2(8) + A_2^2(8) + \cdots + A_n^2(8)} \quad (3)$$

where $A_1(8)$, $A_2(8)$, …, $A_n(8)$ are the partial vibration exposure values for the different vibration sources.

3.2 Different assessment methods

The research performed in this field revealed several methods available for hand-arm exposure assessment, which is systematized below [7].

- **Daily exposure graph**

The graph presented in Fig. 2 gives an alternative method for daily exposures or partial vibration exposures monitoring. A simple look is needed, on the graph for the $A(8)$ line at or just above where the vibration magnitude value and exposure time lines meet. The green area in indicates exposures likely to below the exposure action value. These exposures must not be assumed to be “safe”. There may be a risk of hand-arm vibration injury for exposures below the exposure action value, and so some exposures within the green area may cause vibration injury in some workers, especially after many years of exposure.

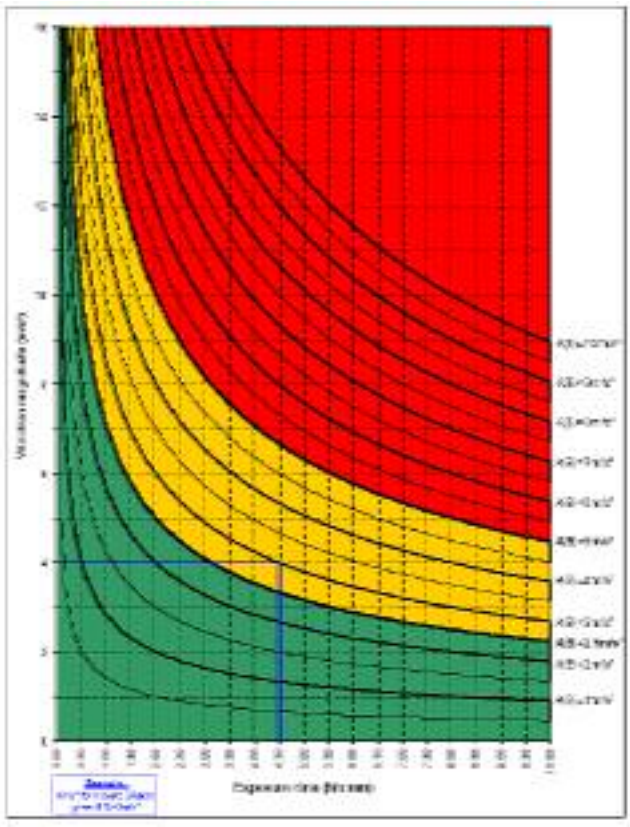

Fig. 2 Daily exposure graph method [7]

- **Daily exposure nomogram**

The nomogram (see more details in [7]) provides an alternative method of obtaining daily vibration exposures, without using the equations. It consists of the following operations: 1-Draw a line from a point on the left hand scale (representing the vibration magnitude) to a point on the right hand scale (representing the exposure time); 2-Read off the partial exposures where the lines cross the central scale; 3-Square each partial vibration exposure value; 4-Add the squared values together; 5-Take the square root of the result to give the overall *A*(8) daily vibration exposure value.

- **Exposure points system**

Hand-arm vibration exposure management (see more details in [7]) can be simplified by using an exposure "points" system. For any tool or process, the number of exposure points accumulated in an hour ($P_{E,1h}$ in points per hour) can be obtained from the vibration magnitude a_{hv} in m/s² using the following relation:

$$P_{E,1h} = 2a_{hv}^2 \quad (4)$$

Exposure points are added together, so one can set a maximum number of exposure points for any person in one day. The exposure scores corresponding to the exposure action and limit values are:

- exposure action value (2,5 m/s²) = 100 points;
- exposure limit value (5 m/s²) = 400 points.

- **Traffic light system**

It has been developed a "traffic light" system (see more details in [7]), where each tool is clearly marked with a hand-arm vibration color coding, dependent on the expected in-use vibration magnitude of each machine. The success of the traffic light system is dependent on the quality of data used to determine the color rating of each machine. The green area indicates exposures likely to below the exposure action or limit value. These exposures must not be assumed to be "safe". There may be a risk of hand-arm vibration injury for exposures below the exposure action value and other management controls must be used to ensure that workers are trained to understand and operate the system correctly, that the systems are actually correctly used and that workers at risk do not develop symptoms of hand-arm vibration syndrome.

4. ACKNOWLEDGEMENT

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REFERENCE

[1]. Lache, S., *Upon State Of The Art in Human Body Protection against Vibrations in the View of Developing an Integrated Research Program Related to the Subject*, in Mecatronica Journal, No. 1, 2005, pp.39-44.
[2]. Rasmussen, G., *Human Body Vibration Exposure And Its Measurement*, http://www.zainea.com/body.htm, 2006-07-13.
[3]. Palmer, K.T., Griffin, M.J., Syddall, H.E., Pannett, B., Cooper, C., Coggon, D., *Raynaud's phenomenon, vibration induced white finger, and difficulties in hearing*, Occup Environ Med, 2002; 59, pp. 640-642.
[4]. ***, *Hand-arm vibration syndrome*, CMAJ Apr. 12, 2005, 172(8).
[5]. Cherniack, M., Brammer, A., Meyer, J., Morse, T., Peterson, D., Fu, R., *Skin temperature recovery from cold provocation in workers exposed to vibrations: a longitudinal study*, Occup Environ Med. 2003, 60, pp. 962-968.
[6]. McGeoch, K.L., Gilmour, W.H., *Cross sectional study of a workforce exposed to hand-arm vibration: with objective tests and the Stockholm workshop scales*, Occup Environ Med. 2000, 57, pp. 35-42.
[7]. ***, *Guide to Good Practice on Hand-Arm Vibrations V5.3*, December 2005.