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EFFECTS OF VIBRATION ON HUMAN DURING CYCLING: HAND ARM VIBRATION EVALUATION

Leoncio Ladeira de Mendonça Neto
Maria Lúcia Duarte
Group of Acoustic and Vibration on Human Beings
UFMG - University of Minas Gerais - Mechanical Engineering
Av. Antônio Carlos, 6627, Zip Code 31.270-901 Belo Horizonte, Brasil.
leonciolmn@yahoo.com.br
mlduarte@dedalus.lcc.ufmg.br

Abstract. *Vibrations transmitted in cycling activities may cause injuries to the rider's body. In this paper, some factors related to human exposure to vibration during the cycling activity will be presented. Also the methodology described by the ISO 2631-1 and ISO 5349-1 standards for the evaluation of the vibration that the human body is subjected to during the practice of cycling is presented, focusing on vibrations transmitted to the hand-arm system. Conclusions are drawn on the best way to investigate the vibration influence on cyclists. At the end, suggestions to future works are given, so to increase the knowledge related to this subject.*

Keywords: Human exposure to vibration, Paving in cycle paths, Hand-Arm Vibration (HAV).

1. INTRODUCTION

The cycling activity is increasing in the past years, being performed as a means of transport, leisure or even as a physical activity. However, the human body during this cycling activity is exposed to vibrations which are transmitted through the bike to the body due to the irregularities over the path where the bike moves. which may be harmful.

The research of vibrations regarding the cycling activity is important because of the consequences it can cause to the cyclist's body. However, it is a complex research considering the variety of effects these vibrations may cause to the human body (discomfort, difficulty in performing the activity, etc), as well as due to parameters that can change the results of the research (the cyclist's position on the bike, the body and arms angles, the handlebars or the seat height). Tarabini et al (2014), for example, studied the whole body vibration influence in four different types of sports (kite surfing, alpine skiing, snowboarding and cycling) and showed that for different types of bikes (Mountain, City or Road Bike) the vibration felt by the cyclist is different. Moreover, the time to achieve the maximum acceptable level of exposure, that is, the ELV (Exposure Limit Value) according to the European Community (Directive 2002/44/EC), for all the bikes studied, was reached in less than 80 minutes. As interesting observation about their results is that, the bike characteristics were very important in the results. The time to reach the ELV decreased from the mountain bike (80 min) to the city bike (70 min), followed by the road bike (40 min).As mentioned by the authors, the bike mechanical characteristics, the tires pressure, the road pavement and the speed are also important parameters to be observed when analyzing the vibration influence on humans. Therefore, as one can see, many variables can influence the transmission of vibrations, which complicates the analysis of the vibrations’ responses to the human being.

The vibrations are transmitted to the cyclist through the points of contact with the bike: hands, feet and the region over the saddle. The consequences of the vibrations can be divided into three groups: comfort, activities’ interference or health. However, most of the times it is difficult to set limits to each of these groups, being necessary to consider several factors beyond the time of exposure. The vibration transmission to the human body can have various consequences such as wounds at specific parts of the body, discomfort, pain or even more serious injuries.

This work will discuss how to evaluate the vibration effects on cyclists. However, it will be given emphasis on the understanding of the effects of Hand-Arm Vibration (HAV).

2. THEORETICAL FOUNDATION

2.1 Human body’s exposure to vibration

The human body has inertia and elasticity characteristics which give it different values of natural frequency related to each of its parts. If an external frequency coincides with the natural frequency of the system, there will be resonance, which amplifies the movement. Thus, the energy of the vibration associated with this effect is absorbed by the body as a consequence of the attenuation caused by the tissues and organs of the body.

The human body can be modeled as a *mass-spring-shock absorber* system which is capable to absorb most of the vibration that it is subjected to. Depending on the points of contact of the cyclist with the structure that vibrates, the vibration that is transmitted to the body can be classified as a Whole Body Vibration (WBV) or Hand Arm Vibration (HAV). To facilitate the evaluation and the comparison of what are the acceptable vibration exposure levels, international standards were created to be used also in the case of bicycles.

The Whole Body Vibrations are transmitted to the body through the sustention area of a seated human being, such as feet, back, buttocks, or through the sustention area of a reclined person. They usually have low frequency and high amplitude, situated between 1 - 80 Hz, more specifically 1-20 Hz. These vibrations are specific for transport, such as truck, tractor, bus, train and others, according to the ISO standard 2631-1 (1997).

The Hand Arm Vibrations are the ones that reach specific parts of the body, particularly the hands and arms. These vibrations are the most studied and are between the frequency ranges of 6.3 to 1250 Hz, occurring very frequently during work activities that involves the use of hand tools. It is also the kind of vibration that may be present during cycling activity.

3. EVALUATION OF THE EXPOSURE OF HUMANS TO VIBRATION

In order to evaluate human exposure to vibration, quantitatively, there are several important parameters to consider, such as: type of excitation, direction, duration of the exposure, among others. Also, the way the results are presented is crucial; as the lack of such information may lead to very big errors. The amplitudes may be presented as peak, which indicates the value of greater vibration amplitude. There is also the peak-to-peak value, which represents the amplitude value between the maximum and minimum consecutive peaks. Also and constantly used for quantifying vibration, is the RMS (Root Mean Square) value, which represents the mean energy of the excitation.

Human sensitivity to vibration also depends on (Griffin, 1996):

(i) Frequency;

(ii) Direction of vibration, both translation and rotation;

(iii) Posture of the body.

The curves of frequency weighting consider all these aspects and are included in the standards mentioned below.

3.1 ISO 2631-1: 1997 - Evaluation of human exposure to whole-body vibration

This standard is one of the most important in order to study vibrations in the human body. It provides important information in the study of human exposure to whole-body vibration presenting the acceptable levels guidance for comfort and health during the activities. The ISO 2631-1 (1997) standard distinguishes three kinds of exposure to vibration, but focuses mainly on one of them: vibrations transmitted to the whole body through support areas. This type is applied normally when using vehicles, the type of exposure to vibration that a cyclist is subject to.

The ISO 2631-1 (1997) standard is applied only to the frequency range between 1 Hz and 80 Hz. Previously, the version of this standard of 1985 defined acceptable limits for three situations: fatigue, which is also referred in this document as the reduced level of efficiency (in terms of work); the comfort and the limit of exposure (already at the level that causes injuries to human health). However, since that distinction was not supported by further research, the fatigue levels were dropped in the ISO version of 1997.

3.2 ISO 5349-1:2001 - Evaluation of human exposure to hand arm vibration

The ISO 5349-1 (2001) standard specifies general methods for measuring and reporting the vibration exposure transmitted to the hand at the three orthogonal axes in the one-third of octave range having central frequencies between 8 Hz and 1,250 Hz. The vibration is calculated by instruments linked to an acceleration transducer, called accelerometers, which must follow the specifications of the ISO 8041 and ISO 5349-1 standards. The accelerometer is the element that captures the vibratory movement, turning it into an electrical signal proportional to the acceleration, which will be taken to a vibration meter, the instrument responsible for processing the data captured by the accelerometer.

In the measurement of Hand Arm Vibration, the accelerometer must be on the vibrating surface, with the appropriate adapters, especially the hand and block adapters. The vibration shall be measured in three orthogonal axes, and any analysis performed should be based on the highest value obtained considering these axes.

The evaluation of the vibration exposure considers the daily exposure time T, defined as the total time that the hands are exposed to the vibration during the performance of an activity, and T_0 is a time of reference of 8 hours.

$$A(8) = a_k \sqrt{\frac{T}{To}}$$

The daily vibration exposure $A(8)$ is the total amount of vibration, weighted in frequency and expressed in terms of an equivalence of 8 hours daily exposures. All the accelerations considered in this standard are weighted in frequency, according to W_h curve shown in Figure 1 (Annex A of the ISO 5349-1 (2001) and ISO 8041 (2005) standards).

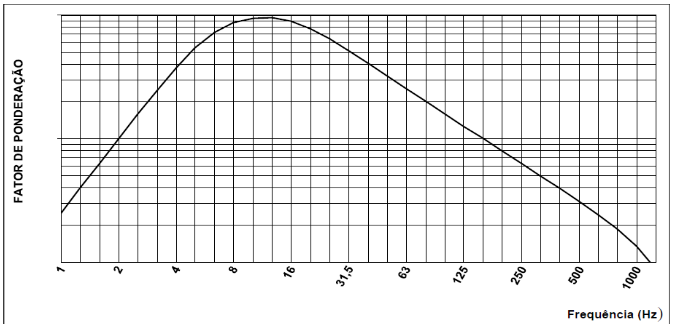

Figure 1. Frequency Weighting Curve

The ISO 5349-1 (2001) standard establishes the daily exposure values of acceleration $A(8)$, estimating to produce the "white finger syndrome" in 10% of the people exposed to a certain number of years (D). The relationship between $A(8)$ and D is established by the following equation:

$$D = 31{,}8\,[A(8)]^{-1.06}$$

3.3 European Directive 2002/44/EC

The safety limit values for $A(8)$ to a certain daily exposure, suitable also to cycling activity, are established by the Directive 2002/44/EC (2002). The value of ELV sets the maximum amount of vibration that the cyclist may be exposed to in a single day, showing the highest risk which the cyclist should not be exposed to. The value of EAV is the amount of vibration which the cyclist must stop his activity in order to prevent setting the exposure limits. The limits for WBV and HAV are different, as shown in Table 1. Generally, these levels are considered regarding health.

Table 1. Directive 2002/44/EC values

Type of Value	WBV	HAV
(*ELV*) *Exposure Limit Value*	1.15 m/s^2	5 m/s^2
(*EAV*) *Exposure Action Value*	0.5 m/s^2	2.5 m/s^2

3.4 **Quantifying the Cyclist Comfort**

Comfort during cycling activity is related to the bike vibration levels. High vibration levels result in less comfort for the cyclist. The cyclist contacts the bike in three locations: the handlebars, the seat and the pedals. It is assumed that the worst discomfort for the cyclist is felt near the handlebars, while riding along an irregular surface (for example cobblestone). So, from this point onwards, vibration level on the handlebars is used to completely quantify cyclist comfort regarding the hand-arm system.

To evaluate cyclist comfort, two methods are considered. The most used method is the one which evaluates the accelerations of whole-body and hand-arm vibration. Accelerations on the seat can be evaluated regarding the ISO 2631-1 (1997) standard, while the ISO 5349 (2001) standard is used for measurements on the handlebars. The second method to quantify vibration comfort is the absorbed power method, as used in the work by Vanwalleghema et al (2012) and Pelland-Leblanc (2014). The Average Power Absorbed (*PMA*) is the rate of energy dissipated as heat by the vibrating parts of the human body in contact with the bike. This measurement can be made considering both time and frequency. Both works claim that PMA has advantages over the other methods as it does not require the use of ISO filter besides the fact that noise can be eliminated (since it is based on energy).

For time, the Average Power Absorbed (PMA) is calculated for the entire duration of the test, at only one contact point and one direction, as below:

$$\boxed{\overline{P_{Abs}} = \frac{1}{T}\int_0^T F(t)\cdot v(t)\,dt}$$

Average Power Absorbed (*PMA*)

Next, a representative case study performed in order to evaluate the vibration transmission to the cyclist is presented in order to illustrate the points discussed.

4. CASE STUDY

4.1 Vibrations Transmission to Cyclists in Different Pavement Types

Some cities are investing the infrastructure of cycling paths. That is relevant in cycling routes projects, since they have to consider the most appropriate type of pavement, so to improve the comfort and safety of the cyclists.

The purpose of comparing the vibration transmission between different types of pavements is to allow an objective analysis of the vibration impact produced by them so to choose the one that transmits less vibration to the cyclist's body.

It needs to be observed that the cyclist do not conduct the bike in the axis mentioned at the ISO standards (Pelland-Leblanc, 2014). The vibration transmitted increases at the same time the irregularity of the pavement increases, because uneven surfaces have higher rolling resistance (Rr) than flat pavements, and that is a big source of energy dissipation for bicycles. Comfort during cycling increases as the rolling resistance decreases.

A measurement and evaluation study of human exposure to vibration transmitted to the hand-arm system during cycling activity was carried out by Savionek (2010), who compared the vibration measurements on three different types of pavement: asphalt (AS) molded plates of concrete (PC) and concrete blocks (BI).

Comparing the results presented, it turns out, that the most appropriate type of pavement for cycling activity is asphalt (AS), followed by molded plates of concrete (PC) and then concrete blocks (BI). The comfort levels found were below the limits set in the standards. However, as seen in this study, many factors could change the results, as the influence of the torso position, the angle that the arms have with the handlebars or the seat height, which are the main causes to improve when considering comfort for the cyclist. Also, as mentioned by

5. WAYS TO REDUCE THE EXPOSURE TO VIBRATIONS

5.1 Anti-vibration gloves

Figure 2. Anti-vibration gloves

The use of anti-vibration gloves is considered by many people an efficient way of protection for the effect of the vibrations transmitted to the hands of the cyclist. However, due to the nature of the insulating materials, all gloves are more effective when isolating high frequency than low-frequency vibrations, which are the most harmful to the human body. Padded cloth gloves can be used as protection because they can soften the vibration, improving the comfort over long distances, which reduces the risk of damage to the hand-arm system when they are used for the practice of cycling. However, these anti-vibration gloves may not provide complete protection. Padded cloth gloves also have a thermal effect on the hands, which makes it possible to keep heated the blood circulating in the fingers, reducing the risk of whitening the fingers in response to a restricted blood supply. To improve the quality of the gloves in the market, the ISO 10819 standard has been edited, establishing standardized procedures for testing the gloves.

5.2 **Suspension systems**

In order to the cycling activity becomes a more comfortable experience, many bicycles are equipped with a lifting system which can be on the front and/or on the back. The systems can effectively reduce the vertical vibration transmitted to the human body, especially at frequencies above 10 Hz, so that the cyclist would not be subjected to high frequency vibration in a more irregular paving, having then a more comfortable driving experience.

6. CONCLUSIONS AND FUTURE WORKS

During the research to write this article, it was possible to notice that only recently people became concerned about the transmission of vibrations during cycling activities. Then, the objective was to draw attention to a very common source of vibration which is most of the times mislead. With the dissemination of this activity, either as transport or leisure, it is necessary to invest and study more about the construction of bicycle routes for a proper implementation of these paths, in order to avoid vibrations that may have certain effects on the cyclist's body, especially at the comfort level.

As well as studying the most appropriate type of paving, other aspects related to the transmission of vibrations to cyclists need to be deeper studied and evaluated, like the effects of the movements in the cyclist's torso position, the angle that the arms have with the handlebars or the seat height as these influence the vibration transmission. Another interesting direction of research would be related to the attenuation of the vibrations transmitted to cyclists through protective elements such as the anti-vibrating gloves, appropriated to the practice of cycling. Most sophisticated projects, such as a structural design of a lifting system, capable of attenuate efficiently these vibrations on points of contact of the cyclist on the bike in order to keep the comfort levels within the standard limits may also be a solution.

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