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The Spectral Response of Hand–Arm System

R. Barański* and W. Batko

Department of Mechanics and Vibroacoustics, Faculty of Mechanical Engineering and Robotics

AGH University of Science and Technology, al. A. Mickiewicza 30, 30-059 Kraków, Poland

Recently we have used better solution to protect hand tool operators. In spite of our good intentions there is still endanger on high level vibration. For that reason we need to improve protection constantly. One of the most important properties of hand–arm system is knowledge about spectral response. In this article we try to obtain spectral response in narrow band-pass filters in accordance with IEC 1260:1995 and ANSI S1.11-2004 standards (implemented in LabVIEW software). To measure signals we used accelerometer placed on a wrist and on a tool. Of course the vibrations are attenuated by hand (cartilage, muscular tissue) but the question was what the shape of envelope in measurement range is. Our research used measurement on two different systems. The one was based on vibration inductor (laboratory environment), the second one used drill (real environment). This research is a part of a wider project to make virtual model of hand–arm system.

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1. Introduction

The research presented in this paper was designed to set a vibration transfer function value in vibration on hand–arm system. This article shows the result of first part of the program, where we make research only on one operator. We want to be sure that measurement system gives comparable result to other institute, e.g. Central Institute for Labour Protection — National Research Institute (CIOP-PIB) [1]. But the main purpose is to develop a dynamic model of hand–arm system [2].

Presently, published research are based on one direction measurements [3–7]. Due to the complexity of the problem the solution seems right. However our purpose was to see how it works for three directions hand–arm system. All research was made by using one system with one operator and two sources of input function. One of these has stationary signal (shaker), second generated pseudostationary signal (hand drill). The parameters of measurement were selected as follows: the time — 30 s, the sampling frequency — 4 kHz and the triaxial accelerometers.

Types of vibration source:

a) shaker — main signal frequency 100 Hz with harmonics, possible to change amplitude of signal.

b) hand drill (55 W) — measuring during standard work without load, with constant turnovers and hand grip force.

To make statistic analysis we have previously prepared signals in few steps:

- All signals were filtered by third-octave filters.
- For all bands and all axis root mean square(RMS) parameter has been obtained.
- Formula (1.1) has been used to obtain module of acceleration vector for all bands.

$$a_{T\_P} = \sqrt{a_x^2 + a_y^2 + a_z^2}\,, \tag{1.1}$$

where a_{T_P} — module of acceleration vector for tool, a_x — RMS value for x direction, a_y — RMS value for y direction, a_z — RMS value for z direction.

To obtain module of acceleration vector for hand (a_{H_P}) we made the same operation. To compute a vibration transfer function (W_{P_i}) we used formula (1.2):

$$W_{P\_i} = \frac{a_{H\_P}}{a_{T\_P}}\,. \tag{1.2}$$

After applying all of above we have received coefficient of vibration transfer function for all third-octave filters from range 20–1600 Hz.

In this research we made 126 measurements in 8 measurement series.

2. Statistic analysis

Now we obtained one mean coefficient of vibration transfer function for each of third-octave filters [8]. But first we must prove no significant differences between means from our measurements. In this case we have used ANalysis Of VAriance (ANOVA). ANOVA is described more precisely in [9, 10]. In all statistics tests coefficient statistically significant was accepted on level 0.05. To do this we had to make sure if the basic assumptions of the variance analysis had been met [10]:

* corresponding author; e-mail: robertb@agh.edu.pl

a) The variable is measurable. This condition has been met as we have used measurable acceleration values m/s^2.

b) The dependent variable should be normally distributed within groups.

In this case our distribution are vibration transfer function (W_{P_i}) for each 8 series and for bands. Now we have 20 bands in 8 series.

At first, we rejected outlier value. From 126 measurements for each frequency band we reduced them to 100. The rest of measurements were tested in groups to check their normal distributions. In Table by X we marked series in a band that has significant statistics and we should reject this series.

For series 2, 6, 7 and 8 we should have rejected part of measure for few bands.

c) The distribution has homogeneity of variances.

We have used Levene and Brown–Forsythe tests for homogeneity of variances with null hypothesis like formula (2.1) and alternative hypothesis like formula (2.2) (with statistical significance 0.05)

$$H_0 : \mu_1^2 = \mu_2^2 = \ldots = \mu^2, \tag{2.1}$$

$$H_1 : \text{ there are differences between any two means.} \tag{2.2}$$

In Table mark O means that there is no performed condition homogeneity of variances. That is the reason we cannot obtain variance analysis (ANOVA).

TABLE

Normal distribution test (X) and homogeneity of variances (O).

	Frequency Hz																			
Series	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600
1	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
2	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	X	O	O	O
3	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
4		O	O	O																
5	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
6														O	O	O	O	XO		X
7	X	O	XO	O	O							O	O					O	O	
7a												X	XO							

The blank area in Table means that there is no reason to reject variance analysis (ANOVA). Additionally, in this case it means variance analysis was not statistically significant, so that there are no mean differences between groups or treatments in the population.

Only for the 315 Hz band we cannot even find two series for which homogeneity of variances has been met. In spite of this we made variance analysis and it also was not statistically significant.

3. Coefficient of vibration transfer function

The average coefficients of vibration transfer function were computed only using measurement series where analysis of variance was not statistically significant. Figure 1 shows the result of our research. We can see a different shape of vibration transfer function for different source of vibration.

Coefficients for shaker are almost of the same value for full band spectrum. Only for high and low frequency coefficients they are a bit higher.

For hand tool transfer function is a bit different. In this case differences between low and high frequency are significant, and for high frequency were near 0.001.

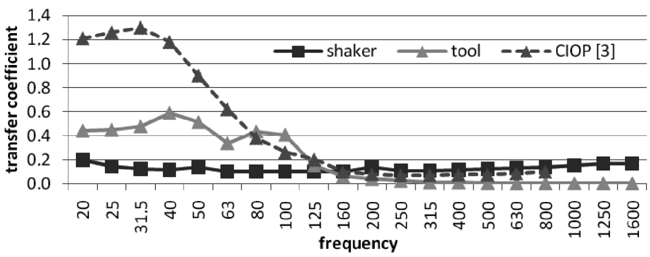

Fig. 1. Transfer function.

Figure 1 shows third transfer function which is the result of research made in Central Institute for Labour Protection — National Research Institute in Warsaw [9]. In CIOP measurements were performed using one horizontal axis. In spite of this difference we can see some similarity between hand tool and CIOP transfer function. For frequency below 125 Hz we can see a higher value. For other frequencies coefficients of transfer functions are small.

4. Conclusions

This article was describing another trial to set a vibration transfer function for hand–arm system. This kind study could be very helpful to protect our life against vibration [11].

We have used two different sources of vibration. The results of our research confirm very strong relationship between computed vibration transfer function and study system.

On the ground of presented studies the most important element in this type of research is a handle material. This conclusion is similar to other research [7].

The most popular method bases on measure vibration on hand and on a tool [12–14]. Generally, a system of connection has been placed between sensors, which consisted of hand and handle. In presented research only handle was changed. That implies a handle stood as a main reason for differences between characters of transfer function.

In fact, our shaker used a flexible material for a better grip. Hand tool had a handle made of a kind of plastic material. It is the reason why in this case of study any information about measurement and examined system is so crucial.

In the most leading research centers parameter characterizing energy transmitted by the handle of tool is the driving point mechanical impedance of the hand–arm system [15]. Research presented in this paper is based on transfer function computed using acceleration on tool and operator (wrist). There is no way we could compare our result. In future, we are going to change measurement method to enable comparison.

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