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CONSTRUCTION OF A NEW STAND
FOR INVESTIGATING THE INFLUENCE
OF WHOLE BODY VIBRATION ON MAN

BUDOWA NOWEGO STANOWISKA
DO BADAŃ WPŁYWU WIBRACJI OGÓLNYCH
NA CZŁOWIEKA

Abstract

In this paper, the way of construction, adaptation and testing of a new stand for whole body vibration built on the base of a Heckert electro-hydraulic shaker was presented.

Keywords: *Whole body vibration (WBV), Construction of low frequency vibration stand*

Streszczenie

W artykule zaprezentowano budowę i adaptację stanowiska badawczego do badania wibracji ogólnych zbudowanego nas bazie wzbudnika elektrohydraulicznego Heckert oraz badania testowe prezentowanego stanowiska.

Słowa kluczowe: *wibracje ogólne, konstrukcja stanowiska do badań niskoczęstotliwościowych*

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1. Introduction

Different approaches exist to assess the effects of whole body vibration (WBV) on men. Research on the influence of vibrations on humans in a standing position requires the employment of a test platform which can be controlled by different low frequency signals. In such tests, powerful and low frequency shakers can be used [1, 2]. Different types of shakers have been described in [3]. Until now, various versions of shakers [4–8] have been used to evaluate vibrations of different sections of the human body and to model and estimate the passage of vibrations through the human body. Electro-hydraulic shakers are suitable for tests where all aforementioned exigencies need to be taken into consideration The Heckert shaker is a good example of such a device, but it must be adapted for standing human operators. Such an adaptation was the aim of the work presented in the paper. The new stand was built and tested in the laboratory at the Department of Dynamics of Material Systems of Cracow University of Technology.

2. Stand construction

The stand was designed as a system composed of a vertical frame and platform joined together by a horizontal axle. The axle supported by bearings was joined with the horizontal beam of the frame placed on the piston of the electro-hydraulic Heckert SHA 140 shaker by two vertical bars. The dimensions of the platform are suitable for vibration investigations of humans in sitting and standing positions. Two versions of the stand (primary and final) are shown in Figures 1a, 1b. In the first version, the platform was constructed as a truss made of welded bars held in place by screws fixed to the rigid, rectangular frame.

a)
b)
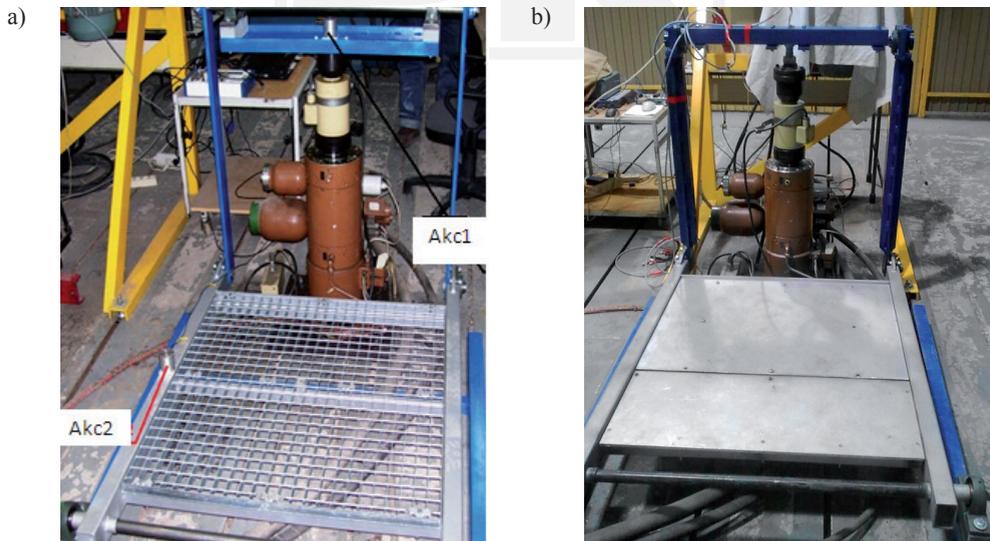
Fig. 1. Primary (a) and final (b) version of the stand

3. Stand tests

The preliminary tests were done using two KB12 accelerometers fixed on the horizontal beam and the frame of the platform as shown in Fig. 1a. The accelerometers, the NI SC 2345 conditioner, and the NI USB 6251 measurement card were linked to a computer. The source input signals used during tests were preprogrammed on the Heckert SHA 140 shaker. The time histories of accelerations measured on the horizontal beam and platform were registered. After the analysis of the registered results, some new modifications of the stand were introduced. The rigid connection between the horizontal beam and the piston of the shaker was substituted with a ball-and-socket joint to eliminate horizontal forces. The plate, made of a non-corrosive lightweight alloy, was fixed to the truss to increase the rigidity of the platform (Fig. 1b). The preliminary tests showed that some modes of vibrations of the platform were at frequencies different from that which is generated by the shaker. These modes were identified by tests with use of the Bruel & Kjaer 8202 impact hammer, the B&K 8200 force sensor and the bi-channel vibration analyzer B&K 2035. The stand and recording arrangement used for taking test measurements is shown in Fig. 2. The application of the impact hammer allowed for the input shock motion of the object to be investigated. Simultaneously, the hammer output signal was recorded and analyzed by the piezoelectric force sensor, the line drive amplifier and the first channel of the analyzer. The transient window of the analyzer allowed for the choice of location and the choice of the length of the window displaying the time history of one full impulse of impact force. The shock duration is dependent upon the shape of the chosen hammer-face. The generated frequencies are dependent upon both the shock duration and upon the shape of the chosen hammer-face. In the presented tests, a steel hammer tip was used. The B&K piezoelectric accelerometer, which was secured at the chosen point, and the second channel of the analyzer were used for concurrent measurements of the stand response. The decay of acceleration was recorded by application of the exponential window. After some preliminary calibrating impacts, the analyzer automatically fixed the gain for both measurement circuits. The following measurements were designed to obtain the estimation of power spectral densities of both channels and their cross-spectral density from the analyzer.

Fig. 2. Stand arrangement during tests

Using the registered signals, the analyzer screened the chosen transfer function calculated according to formula (1):

$$H_1(f) = \frac{G_{xy}(f)}{G_{xx}(f)} \tag{1}$$

where $G_{xx}(f)$ power spectral density of input signal, $G_{xy}(f)$ cross-power spectral density of time input $x(t)$ and time output $y(t)$ signals. The coherence function between random input and output signals given by formula (2) was also calculated and projected on screen. It allowed for the assessment of a linear relationship between $x(t)$ and $y(t)$ at the given frequency where one vibration can be exactly predicted from the other.

$$\gamma_{xy}^2(f) = \frac{\left|G_{xy}(f)\right|^2}{G_{xx}(f)G_{yy}(f)} \tag{2}$$

Configuration of the analyzer's screen is shown in Fig. 3.

Fig. 3. Analyzer configuration

Downward short-duration impacts of the impact hammer on the structure were applied to the horizontal beam above the point where the ball-and-socket joint was secured (Fig. 4a). The responses of the structure were measured by the accelerometers fixed to the plate and to the frame of the platform (Fig. 4b). The final test results were presented as the mean value of five impacts of the impact hammer for each test. The obtained illustrations allowed for the evaluation of the resonance frequencies of the structure and for the validation of the executed measurements.

a)

b)
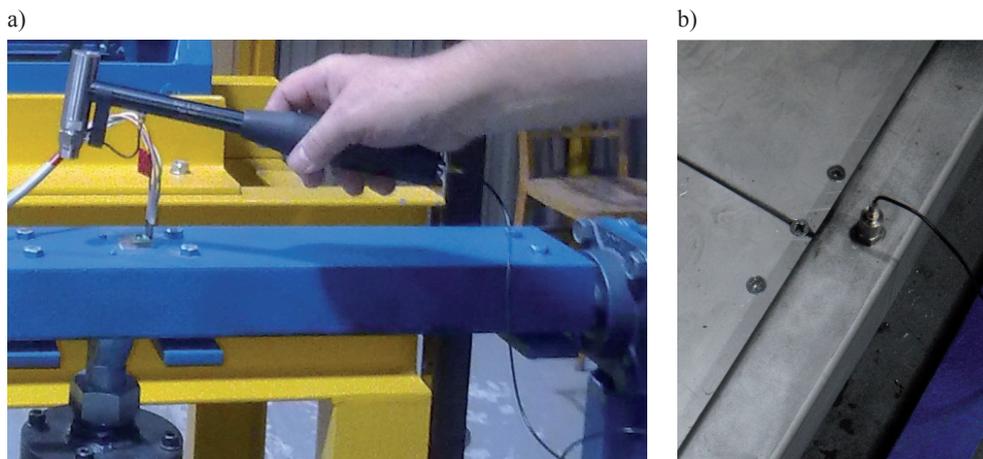
Fig. 4. Impact hammer used as source of excitation (a) and accelerometer used for the respose recording of the system (b)

Some testing with different placements of the accelerometer measuring the output signal were carried out. Figure 5 shows sample results.
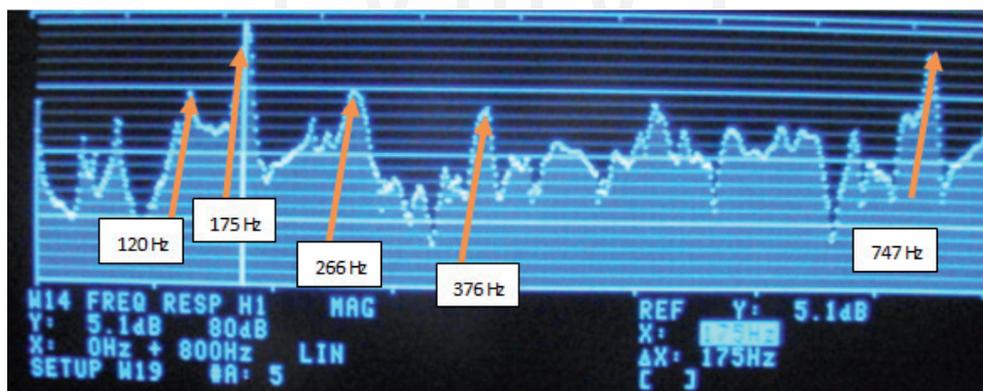
Fig. 5. Exemplary frequency response

In general, the coherence function is bounded at all frequencies by zero and unity, where $\gamma^2_{xy}(f) = 0$ means there is no linear relationship between $x(t)$ and $y(t)$ at frequency f and $\gamma^2_{xy}(f) = 1$ means there is a perfect linear relationship between $x(t)$ and $y(t)$ at frequency f.

The exemplary coherence function from the test is shown in Fig. 6, where at low frequencies, a lack of clear dependencies between signals $x(t)$ and $y(t)$ can be noticed.

Finally, in Fig. 5, only frequencies verified by Fig. 6 were shown. Preliminary testing confirmed the existence of many resonant frequencies of the stand. To eliminate these frequencies, the following upgrades of the stand were carried out:
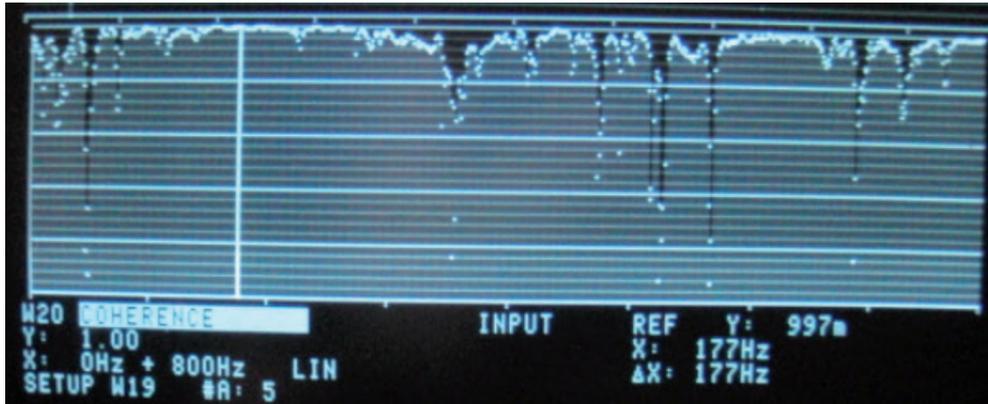
Fig. 6. Exemplary coherence function

1) the platform plate was cut into two sections,
2) the rubber pads were put under each of the sections.
    The following summarizes the frequencies identified during the carried out tests:
– The accelerometer placed on the plate of the stand: 120, 175, 266, 376, 747 [Hz].
– The accelerometer placed on the frame of the platform: 120, 177,232, 265, 747 [Hz].
– The accelerometer placed on the loaded plate of the platform: 122, 178, 234, 270, 541, 743 [Hz].
– The accelerometer placed on the half plate with rubber pad: 170, 449, 735 [Hz].
– The accelerometer placed on the frame after platform modification (division and with rubber pad): 118, 170, 443 [Hz].

    The aforementioned tests carried out using the impact hammer, accelerometer and analyzer showed that all resonant frequencies of the stand are in a range above 100 [Hz]. This means that the presented direct drive mechanical vibration machine has had all mechanical resonances removed from the operating frequency range shown below in Table 1.

4. Application of stand to WBV measurements

    Resonace frequencies of the various body sections submitted to vertical vibration are mainly in a low frequency range as shown in Table 1.
    To show these resonances, the excitations developed by the designed test bench must have the adequate range. The used apparatus with piezosensors does not allow for measurements at lower frequencies, thus, in the next stage of the research, other measuring circuits and other excitations were applied. The stand was excited by the electro-hydraulic shaker controlled by its internal signal generator operating in the sine function with adjustable amplitude and frequency. Two laser displacement sensors from Mikro Epsilon were applied to measure the displacement of the shaker and platform. The measuring track uses a National Instruments measurement card (USB 6251) along with LabView Signal Express software. Figure 7 shows the location of the laser sensors.

Body sections	Resonace frequency ranges of the various body sections submitted to vertical vibration in [Hz]
Head	4 – 6, 20 – 30 (axial mode)
Chest wall	50 – 100
Chest organs	5 – 9
Jaw	6 – 8
Spinal column (axial mode)	10 – 12
Spinal column (lower part)	4 – 6
Spinal column (upper part)	10 – 14
Eyeballs	20 – 25, 60 – 90
Shoulder girdle	4 – 5
Abdominal mass	3 – 3.5, 4 – 8
Arm	5 – 10
Lower arm	16 – 30
Hand	30 – 50
Knee	20
Legs	2 – 20
Muscles	13 – 20
Bladder	10 – 18
Diaphragm	5 – 8
Pelvis	5 and 9
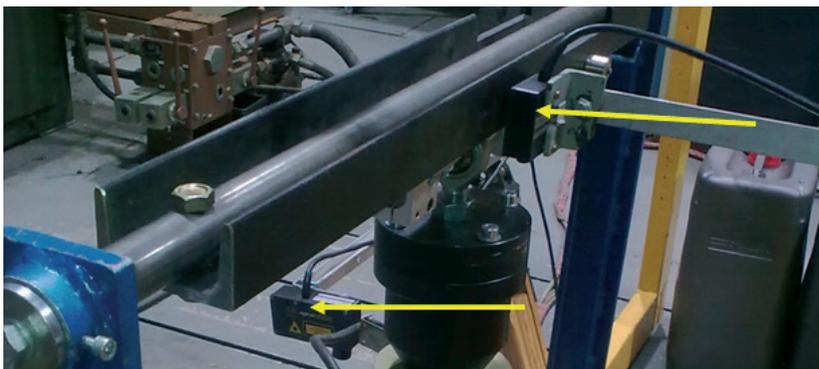
Fig. 7. Location of the laser sensors

Figures 8 and 9 show the time histories of displacements of the shaker and platform for excitation frequency 2 [Hz] and 5 [Hz].
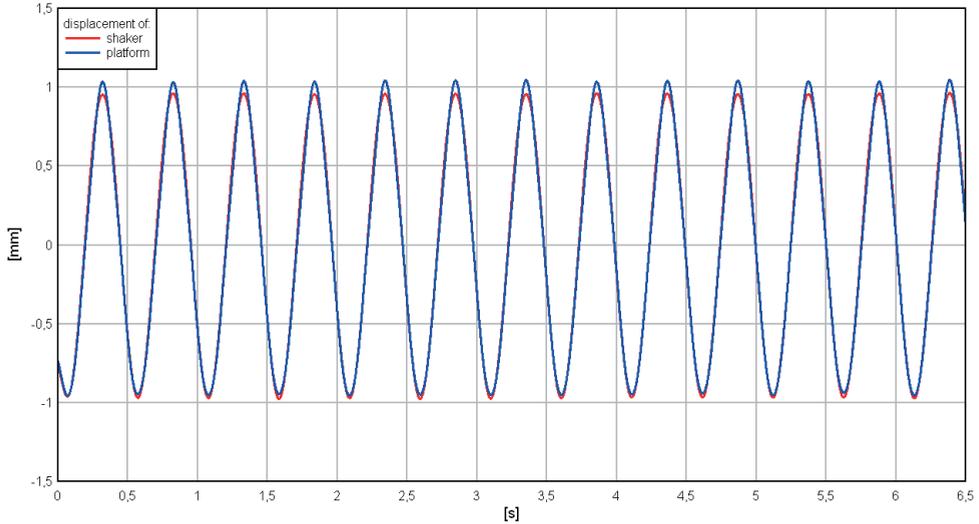
Fig. 8. The time histories of displacements of the shaker and platform for excitation frequency 2 [Hz]
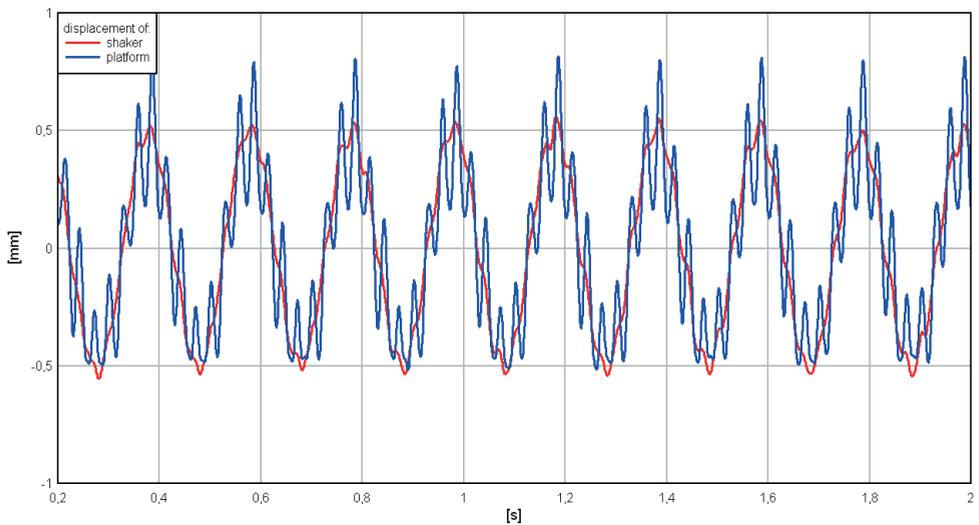
Fig. 9. The time histories of displacements of the shaker and platform for excitation frequency 5 [Hz]

In Fig. 9, one can see additional vibration with higher frequencies that have been set up on the platform. The frequencies of these vibrations are identified by the displacement spectrum in Fig. 10.
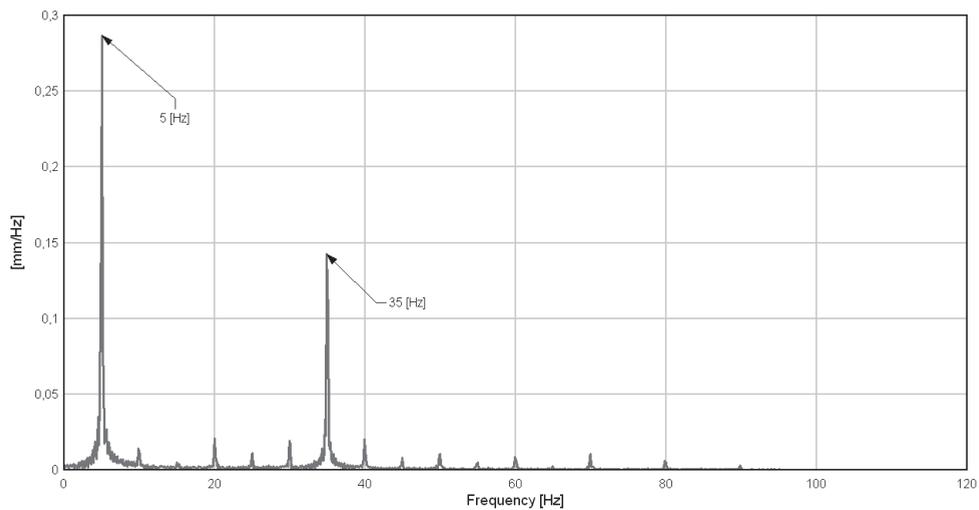
Fig. 10. Spectrum of displacement of the platform for excitation frequency 5 [Hz]

Similarly, for higher frequencies in the displacement spectrum, one can notice vibration with a frequency of 35 [Hz] (see Fig. 11).
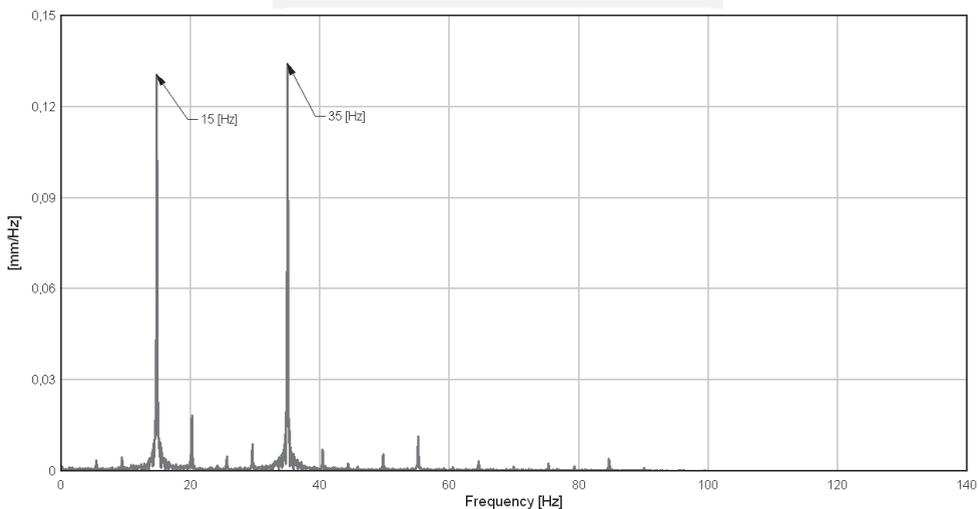
Fig. 11. Spectrum of displacement of the platform for excitation frequency 35 [Hz]

The load on the platform due to a standing man changes the displacement time history of platform vibrations as shown in Figure 12.
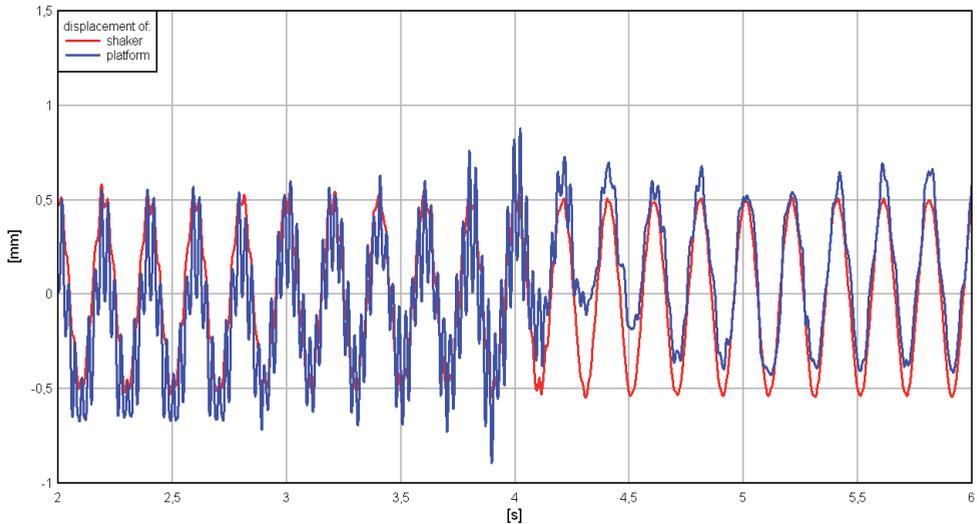
Fig. 12. Influence of the stand load on platform displacement

The presence of a man on the platform largely eliminates pulse-frequency vibrations of 35 [Hz]. During subsequent trials, the platform was loaded with a human operator body in standing position. A lack of components with higher frequencies can be noticed. After the aforementioned tests were completed, the design of the stand platform was changed by loading it with a thick and hard metal plate. This resulted in further elimination of vibration components with higher frequencies in the range important for WBV tests for both sitting and standing positions.

5. Conclusions

The presented laboratory stand allows for the study of vibration acting on a human operator body in both standing and sitting positions. The stand also enables the study of other complex dynamic systems involving higher weights. All of these design and manufacturing solutions that emerged during the implementation of the stand have a unique, leading prototype character. The built stand has been positively tested with an unbiasedly weighted platform and a biasedly weighted platform. Tests showed that the stand should work under load and can be used in scientific research as well as in studies combining whole body and local vibrations acting simultaneously on man.

R e f e r e n c e s

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