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A comparison between a commercial WBV platform and an experimental prototype

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***Abstract* – There are many commercial WBV platforms for clinical applications but in literature very few have been tested to verify their actual amplitude, frequency spectra and waveform shape of vibration, although some clinical studies showed that these parameters can influence significantly the muscles performance. In this study the performances of a prototype WBV_1 designed by the authors are compared with a commercial platform WBV_2 typically used in clinical and rehabilitation investigations. Tests performed with four accelerometers in 3 different directions show the presence of transversal accelerations that in some cases exceeded the vertical one in WBV_2 while they were always lower than the 25% in WBV_1. Also the waveform shape of the vibration provided by WBV_1, evaluated by means of the SINAD parameter, show a better value compared to the commercial device: indeed secondary harmonics reaches the 30% of the fundamental in WBV_2 but they are always below the 25% in the prototype.**

Keywords – WBV, vibration, platform, comparison, acceleration measurement, frequency measurement, SINAD

I. INTRODUCTION

Vibrations provided to the human body may results in many health benefits . To this regard in many biomedical applications the whole body vibration (WBV) platforms are commonly used: they are characterized by an oscillatory motion in vertical or mediolateral direction [1-2] that is quantified by the displacement amplitude A (mm), frequency (Hz) of vibration, acceleration magnitude ($m \cdot s^{-2}$) and waveform shape [3]. An example of biological response produced by the WBV platform application to the human body is reported in [4], where an increasing concentration of testosterone and GH was discovered. Anyway, the most significant effects are reported for excitation frequency close to the natural muscles' one (muscle tuning). The natural frequencies of the leg muscles range from 10 to 50 Hz [5] but muscles activation is inhibited if the excitation frequency exceed 60 Hz [6-7]. Also the amplitude can provide specifics adaptation and muscles responses [8]. Actually, the common commercial *WBV* platforms don't allow a frequency modulation with a constant amplitude, among them:

- *Multibody Transmission platforms*. They are based on a mechanism with homokinetic transmission of one or more members providing sinusoidal vertical vibration. Amplitudes nominal range from 1 mm to 30 mm and frequency from 1 to 40 Hz. Acceleration reaches 2 g.
- *Rotor with unbalanced mass*. These devices use one or more eccentric rotating masses to provide vibrations reaching acceleration up to 8 g with a frequency range 1-60 Hz. This kind of WBV platform is used as reference standard in this study.
- *Magnetic WBV platforms*. These devices are based on the magnetic shaker principles but they typically show the acceleration amplitudes dependent on both frequency and load. The frequency range is usually limited up to 40 Hz.

Moreover, frequency and vibration waveform aren't usually monitored during biological applications.

A WBV platform prototype (WBV_1) has been designed to assess the optimal combination of amplitude (A) and frequency (f) for the highest muscle activation [9-13]. It can provide vertical vibrations with amplitude not depending on frequency. The operating range is from 20 to 60 Hz, with 0.1 Hz resolution and from 0.1 to 0.9 mm displacement nominal amplitudes. The prototype produces a vertical vibration by means of a slider-crank mechanism driven by an electric tri-phase motor. This device has been implemented by developing a slider-crank mechanism with adjustable crank length. At the moment, the total eccentricity of the system (i.e. the nominal displacement amplitude) is obtained by rotating an eccentric pin around the axis of another eccentric pin linked to the motor shaft. In this paper, the performance and limits of the WBV platform prototype have been assessed by comparing its outcomes with that from a common commercial platform used in many clinical studies and whose vibration mechanism is based on unbalanced rotating masses,

II. DESCRIPTION OF THE METHOD

In this section the platforms and measurement set-up used to assess the vibratory motion of the footboard are described.

A. Prototype (WBV_1)

The prototype proposed by the authors provides a sinusoidal vibration using an adjustable crank mechanism made up of two eccentric shafts inside each other: for the displacements considered in this application the alternative motion of the conrod can be considered sinusoidal [9-10]. The overall mechanism eccentricity can be manually set to different values. The motor speed, i.e. the vibration frequency, can be set with a 0,1 Hz resolution by means of an inverter connected to the motor. The platform is designed for a maximum load of 1000 N. Four vertical rods are used as vertical guides to assure the vertical vibration and attenuate the transversal motion. A scheme is reported in Figure 1.

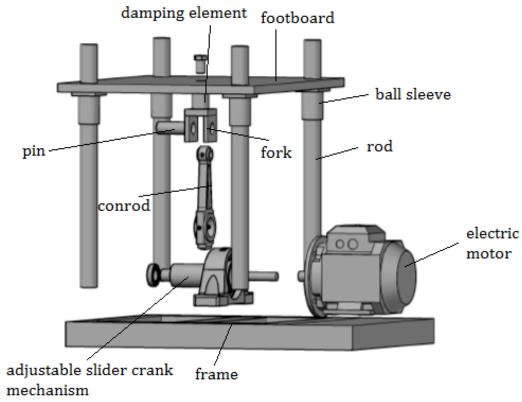

Fig. 1. Scheme of the prototype WBV_1. The fork joins the plate by means of a screw and the adjustable crank is coaxial with the connecting rod head.

B. Reference WBV platform (WBV_0)

The device has an electric motor under the footboard with an unbalanced rotor by means of two eccentric masses: although the vibration frequency depends on the angular speed of the motor, the displacement amplitude is load dependent, i.e. a function of the subject's bodyweight. The footboard is placed on four dumping supports fixed to the chassis by means of screws. Therefore the system allows to set the footboard vibration frequency (by means of the motor speed) but not its displacement amplitude.

Measurement chain

Acceleration amplitudes, displacement and frequency are very important parameters and should be measured, as they are related to the maximum muscle activation response. To this aim, following the example of other studies [4, 9, 10, 14-16], the accelerations have been measured by piezoelectric accelerometers and displacements have been derived from the double integration of the acceleration data: this has been achieved with a *LabVIEW* routine that fixed the offset error due to the integration by applying a high pass filter to the data. As in other works on dynamic performances of biomedical systems [17-19], the vibration frequency spectrum is obtained by a Fast Fourier Transform algorithm. Moreover the system has been equipped with four mono-axial I.C.P.® accelerometers (Integrated Circuit Piezoelectric accelerometers) to measure both the accelerations and displacements of the footboards: two of them (Piezotronics PCB 338B335) have been placed close to the contact zone between feet and the footboard (i.e. near the toes) to detect the vertical vibrations, while the others (Piezotronics PCB 352A56) have been placed on the footboard middle axes to measure the transversal accelerations, i.e. along the X-axis and the Y-axis. All the accelerometers have been supplied by an I.C.P.® power supply (Piezotronics 482A05). The measurement system allows the assessment of the vertical accelerations that are transmitted to the subject feet, since both of the platforms WBV_0 and WBV_1 should provide a sinusoidal excitation mainly along the vertical direction, as shown in Table I. The measurement data have been collected by a Digital Acquisition System *National Instruments* NI USB 6251 and processed by *LabVIEW* software, also to evaluate the excitation frequencies, displacements and the SINAD to determine if the footboard vibration may be considered sinusoidal. Indeed, a real electro-mechanical system is usually characterized by a complex dynamic behavior and signal distortions due to its frequency response should be evaluated [9, 20-22]. The SINAD is here obtained from the ratio of the RMS signal amplitude to the mean value of the root-sum-square (RSS) of all other spectral components, apart from DC.

Table I. Technical specifications of the prototype and the reference WBV platform.

	Reference WBV_0 platform	Prototype WBV_1
Nominal Frequency [Hz]	20 – 55 Hz	20 – 60 Hz
Nominal Amplitude [mm]	2 mm	0.1 – 0.9 mm
Actual frequency range (loaded[(1)]) [Hz]	19.7 – 48 Hz	19.9-59.5 Hz
Actual amplitude range (loaded[(1)]) [Hz]	0.1 – 0.7 mm	0.2 – 0.7 mm

[(1)] 800N load

III. RESULTS AND DISCUSSIONS

The tests have been carried out by loading the prototype footboard with 800N (i.e. man with a mass of 80 kg). The accelerations spectra have been obtained for frequencies from 20 Hz to 55 Hz at increasing steps of 5 Hz and eccentricity values from 0.1 to 0.9 mm (WBV_1). The results have been compared with the measurement data from the commercial reference platform (WBV_0) at a similar frequency range (i.e. 20 - 55 Hz). From the spectra analysis of data in figure 2 the secondary harmonics of WBV_0 are about 30% of the fundamental frequency (Figure 2e, 2g) but they remain below the 25% in WBV_1. On the other hand, the acceleration spectra also reveal that the transversal accelerations in the commercial platform is 600% of the vertical ones (Figure 2a), while the transversal accelerations remain below 25% of the vertical accelerations in WBV_1. Moreover in Table II the experimental data analysis shows that the vertical accelerations (i.e. right and left foot) detected on WBV_1 are related to higher SINAD values than those on WBV_0. On the other hand, WBV_0 has higher SINAD values along longitudinal directions, i.e. vertical accelerations exhibit more signal distortions than longitudinal ones. It's important to point out that these platforms are designed to perform vertical vibrations, that should be an order greater than the transversal ones to prevent crosstalk problems and discomfort. Anyway in both of the devices a significant difference is observed in the vertical accelerations experienced by the feet for few frequencies. This is likely due to the fact that the accelerations from WBV_0 and WBV_1 are not homogeneous across the whole footboard. To this aim an in-depth study could be conducted after a feedback control of the patient posture on the footboard is added to the device [15, 23].

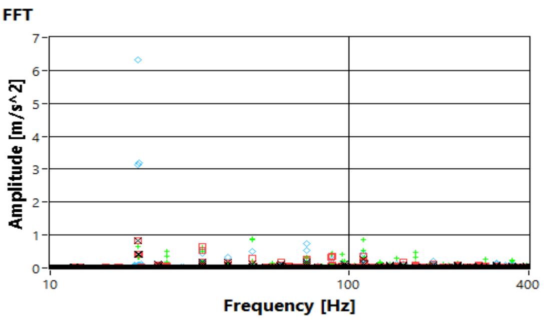

Fig. 2a frequency spectra of the commercial platform at 20 Hz: × right foot vertical acceleration, ◻ left foot vertical acceleration, + X-axis acceleration, ◊ Y-Axis acceleration

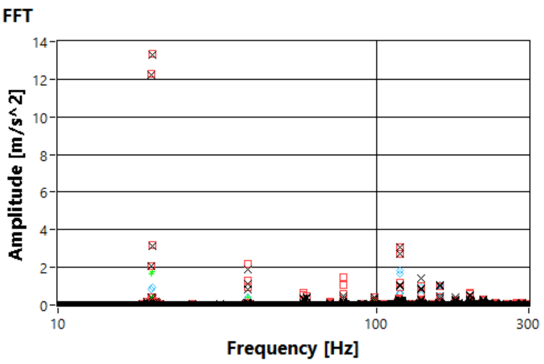

Fig. 2b frequency spectra of the prototype at 20 Hz and 0.9 mm nominal amplitude

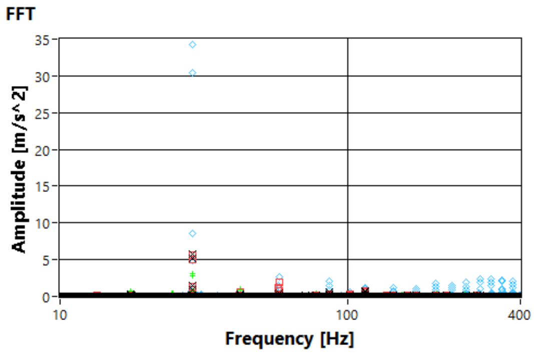

Fig. 2c frequency spectra of the commercial platform at 30 Hz

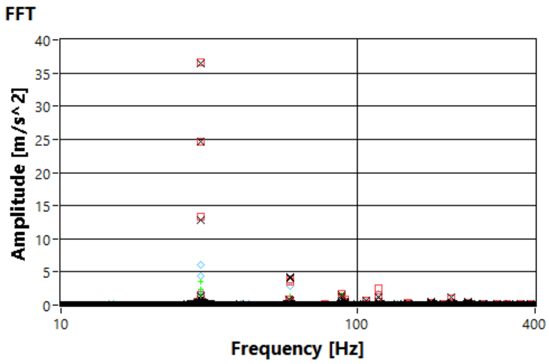

Fig. 2d frequency spectra of the prototype at 30 Hz and 0.9 mm nominal amplitude

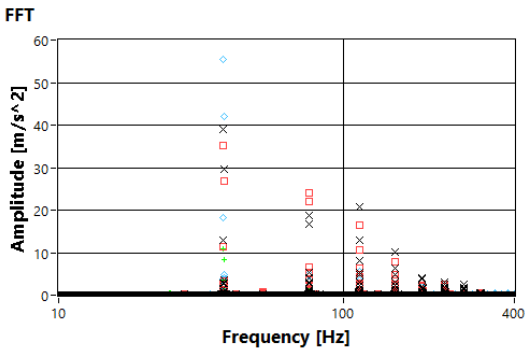

Fig. 2e frequency spectra of the commercial platform at 40 Hz

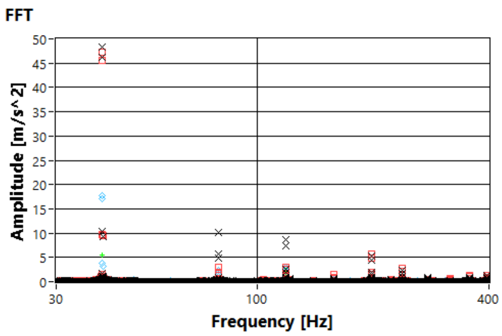

Fig. 2f frequency spectra of the prototype at 40 Hz and 0.9 mm nominal amplitude

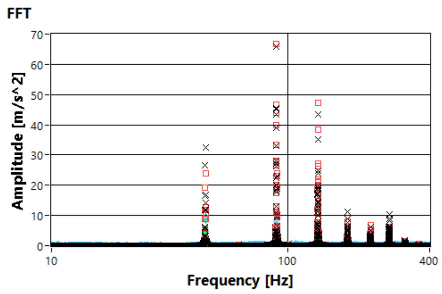

Fig. 2g frequency spectra of the commercial platform at 50 Hz.

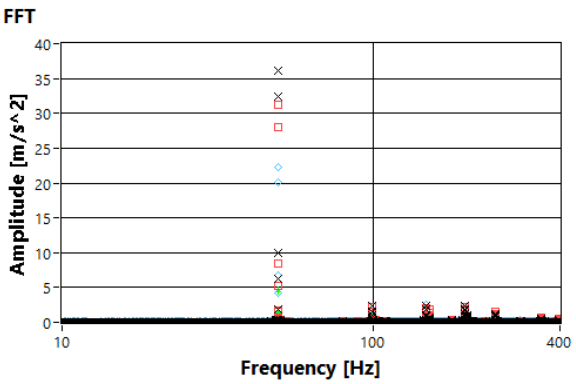

Fig. 2h frequency spectra of the prototype at 50 Hz and 0.3 mm nominal amplitude

Table II. Acceleration, displacement amplitude and SINAD from the vibration data in Fig.2 a, b, c, d, e, f. The measurement chain uncertainty is 4% but prototype data are affected by a 22% uncertainty for the test carried out in the same operating conditions (load, nominal amplitude and frequency).

	R. foot	**L. foot**	**X-axis**	**Y-axis**
Fig. 2a WBV_0 at 20 Hz				
Frequency [Hz]	19.7			
Acceleration [m/s^2]	0.8	0.8	1	6.3
Displacement [mm]	0.11	0.10	0.35	0.41
SINAD [dB]	2.7	1.7	0.7	11.7
Fig. 2b WBV_1 at 20 Hz				
Frequency [Hz]	19.7			
Acceleration [m/s^2]	13.3	13.4	1.8	0.9
Displacement [mm]	0.88	0.88	0.10	0.07
SINAD [dB]	8.6	8.1	6.1	0.9
Fig. 2c WBV_0 at 30 Hz				
Frequency [Hz]	28.9			
Acceleration [m/s^2]	6.5	6.2	3.5	34.6
Displacement [mm]	0.20	0.19	0.10	1.16
SINAD [dB]	11.7	8.5	3.5	5.4
Fig. 2d WBV_1 at 30 Hz				
Frequency [Hz]	29.7			
Acceleration [m/s^2]	37.5	37.7	3.7	6.4
Displacement [mm]	1.07	1.08	0.10	0.18
SINAD [dB]	14.0	14.1	0.7	2.5
Fig. 2e WBV_0 at 40 Hz				
Frequency [Hz]	38			
Acceleration [m/s^2]	39.0	35.2	10.9	55.4
Displacement [mm]	0.68	0.62	0.20	0.97
SINAD [dB]	3.8	3.3	7.9	5.8
Fig. 2f WBV_1 at 40 Hz				
Frequency [Hz]	39.6			
Acceleration [m/s^2]	49.3	46.8	5.5	8.0
Displacement [mm]	0.79	0.75	0.09	0.12
SINAD [dB]	10.7	12.6	0.5	1.7
Fig. 2g WBV_0 at 50 Hz				
Frequency [Hz]	44.9			
Acceleration [m/s^2]	32.5	24	11	9.8
Displacement [mm]	0.4	0.3	0.13	0.12
SINAD [dB]	0.4	0.4	0.5	0.1
Fig. 2h WBV_1 at 50 Hz				
Frequency [Hz]	49.6			
Acceleration [m/s^2]	36.2	31.3	4.7	22.3
Displacement [mm]	0.37	0.32	0.05	0.23
SINAD [dB]	7.7	7.3	0.2	5.4

IV. CONCLUSIONS

A comparison between the vibrations provided by a prototype of WBV platform and a commercial one has been performed: the frequency and displacement amplitudes have been evaluated for some tests on both platforms. Preliminary outcomes showed that waveforms from the devices can differ significantly from sinusoid (i.e. high order harmonics are not negligible) and transversal acceleration amplitudes can be 6 times higher of the vertical ones in the commercial platform: therefore crosstalk effects can be observed and may affect the biological responses. The issue is likely due to the reference platform design, as this device uses two unbalanced masses driven by a motor coupled to the footboard in order to generate vibrations. The forces provided by the motion act in all directions and the sum of the transverse ones is not exactly zero. Moreover, the results suggest that the commercial platform could provide accelerations with accuracy in frequency and amplitude lower than the prototype. On the other hand the SINAD analysis suggests that the prototype is affected by vertical vibrations closer to a sinusoidal wave than the commercial one (i.e. the reference platform reaches 12dB in the best case, while the worst one is equal to 0.4 dB; the prototype reaches 14dB but all data remains above 7 dB). Moreover the difference between the actual and the nominal frequency increases with frequency (up to 10%) in the reference platform, while it is always less than 2% in the prototype. Anyway both of the devices are affected by a significant difference in the vertical accelerations experienced by the feet for few frequencies: this would seem to confirm the hypothesis that the accelerations produced by the two WBV platforms may be not homogeneous across the whole footboard. This issue should be studied in the near future: it could be interesting to place a couple of sensors near the feet of the subject in order to assess whether a WBV platform is able to produce homogeneous vertical vibrations through the whole footboard or at least near the subject's feet. Moreover the determination of how specific muscle groups are affected by vibrations provided by the WBV platform could be interesting (i.e. by means of stereo-photogrammetry or other techniques) and useful for a better design of the devices.

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