Vibrations in Physical Systems Vol.26 (2014)

A Comparison of Human Physical Models Used in the ISO 10068:2012 Standard Based on Power Distribution
PART 2

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Abstract

This article is a continuation of the article entitled „A comparison of human physical models used in the ISO 10068:2012 standard based on power distribution – Part 1" [5], which presented a method of energy-based assessment of two human physical models. The first article revealed a discrepancy between the models in terms of three types of power and the total power. The focus of the present study was to determine the order of energy inputs in the dynamic structure and link different types of power to potential threats they pose to human health. Additionally, differences between the models were discussed.

Keywords: biomechanical system, energy flow, energy method, hand-arm vibrations

1. Introduction

Mechanical vibrations generated by vibrating systems of power tools or transport vehicles can have a negative impact on the human body. Long-term exposure to vibrations can cause many disorders in the operator's body, leading to permanent damage. The multitude of clinical symptoms is referred to as the hand-arm vibration syndrome [8]. In many countries, including Poland, HAVS has been classified as an occupational disease [1,7]. In Poland HAVS was added to the list of occupational diseases in 1968 [13], and was ranked 6th most commonly diagnosed ailment in the period 1985-1994 [10].

It is worth noting that lists of occupational disease have been revised to reflect the development of knowledge in the area of occupational health and safety and new ways of protecting people against the harmful effects of occupational hazards. Nowadays, according to the ordinance of the Council of Ministers of 30 June 2009 [14], HAVS is listed as a 22nd occupational disease. Additionally, because of its varied symptomatology, the list mentions different forms of the syndrome:

- vascular-nervous disorders,
- musculoskeletal disorders,
- mixed disorders: vascular-nervous and musculoskeletal.

Health hazards can be connected with a concentrated energy flow through the human body. This explanation is confirmed by physiological research in this area [8, 9, 11].

2. The influence of power distribution – changes in biological-mechanical systems

In the case of Human–Tool systems it is possible to determine the level of health hazard that a human operator is exposed to [2-4]. In the Table 1 has been shown the distribution of total power and different types of power in the two systems under investigation. [12]. Data analysis reveals that maximum power distribution for both models can be observed at low frequencies of operation, with the power distribution decreasing as frequency *f* increases. This observation indicates an interesting relationship that characterises Human–Tool systems, which can be used as a preventive measure: to protect tool operators from exposure to negative effects of vibrations only tools with a higher operating frequency, e.g. 60 Hz, should be used.

Table 1. Three types of power and total power for the two models specified in ISO 10068:2012 [12] in watts and percentages

ANALYZED MODEL ISO 10068:2012		**Model 1 (Annex B)** 2 points of reduction		**Model 2 (Annex C)** 3 points of reduction	
		W	%	W	%
Frequency *f*		**16 Hz**			
Average Power (RMS)	Inertia	21.27	28.28	21.27	11.24
	Dissipation	22.15	29.45	32.66	17.26
	Elasticity	31.80	42.28	135.3	71.51
Total Power		75.22	100	189.2	100
Frequency *f*		**30 Hz**			
Average Power (RMS)	Inertia	13.61	49.44	13.35	27.01
	Dissipation	7.93	28.80	11.84	23.96
	Elasticity	6.00	21.78	24.23	49.03
Total Power		27.53	100	49.42	100
Frequency *f*		**60 Hz**			
Average Power (RMS)	Inertia	6.82	81.78	7.00	54.89
	Dissipation	0.97	11.65	2.18	17.08
	Elasticity	0.54	6.49	3.57	27.99
Total Power		8.34	100	12.76	100
Frequency *f*		**90 Hz**			
Average Power (RMS)	Inertia	4.30	89.58	4.34	68.65
	Dissipation	0.34	7.08	0.85	13.39
	Elasticity	0.16	3.36	1.14	17.97
Total Power		4.80	100	6.33	100

The energy-based comparison of the two models produces a power distribution, which can be used to identify those elements of the biological structure that are exposed to the highest energy input. In this way, different types of power can be linked to specific effects in the human body [2-4].

The two models exhibit a high degree of similarity only at operational frequency $f =$ 16 Hz. Simulation data show an almost identical order of energy input experienced by the biological structure. At this frequency, it is the spring elements that are exposed to the highest energy input levels. This can lead to upper limb dysfunction and result in tendon, muscle and joint damage. Under these circumstances one can observe a rise in temperature due to the dissipation of energy over time – the power of dissipation, and blood circulation disorders resulting from increased accelerations – the power of inertia. It is worth pointing out that for the model with two points of reduction (model 1) values of the three types of powers are similar. This means that the resulting changes in the body will be nearly equally manifested in all the elements of the biological structure. In contrast, the model with three points of reduction (model 2) exhibits a different intensity of changes. While the order of energy input into the biological structure remains largely identical, the contribution of the power of elasticity is much higher than that of the other two types. It can therefore be concluded that it is the elastic elements of the human body that will be exposed to the highest levels of energy input and most likely to be affected first. Only later will changes be manifested in the other two systems: nervous and vascular.

Energy input levels experienced by the dynamic structure at frequency of 30 Hz are quite different. In the case of the model with three points of reduction the energy analysis revealed the highest energy input levels for spring elements, as evidenced by the power of elasticity, followed by mass elements, as measured by the power of inertia, with dissipation elements being least under energy input, as indicated by the loss power. An entirely different order of harmfulness of vibration could be observed in the case of the model with two points of reduction, with the biggest contribution of the power of inertia, followed by power of dissipation and elasticity.

Further differences can be observed in the order of energy input levels for the remaining frequencies. The energy comparison of the two models revealed high levels of energy input applied to mass elements, as measured by the power of inertia. There is also a discrepancy between the order of energy input levels in the dynamic structure in terms of the two other types of power.

The energy analysis shows partial similarity between the models in terms of the energy input experienced by the human biological structure. Nonetheless, the study provides the basis for a comparative evaluation of different construction variants of tools used – in this case estimating the impact of vibration on the human body depending on the operational frequency of the tool.

3. The impact of mechanical vibrations on the human body – differences between the models

Mechanical stimuli (vibrations) affect receptors, whose sensitivity varies depending on their location: on the skin, tendons, periosteum and internal organs. The intensity and the degree to which vibrations are transmitted depends on other factors, the most important ones being intensity and frequency of vibrations and the place, time and rate of their propagation. Another significant factor is the damping capacity of body tissues which are in contact with the vibrating source. The influence of vibration at a certain frequency can induce resonant vibration in individual tissues or whole organs, which is a very destructive phenomenon [8]. Resonant frequency values for different parts of the human body have been determined statistically based on detailed studies. However, these frequencies are only an approximation, since they depend on an individual's physical characteristics [6]. The model of the human body developed by R. R. Coerman and shown in Figure 1 specifies resonant frequency values for different body parts.

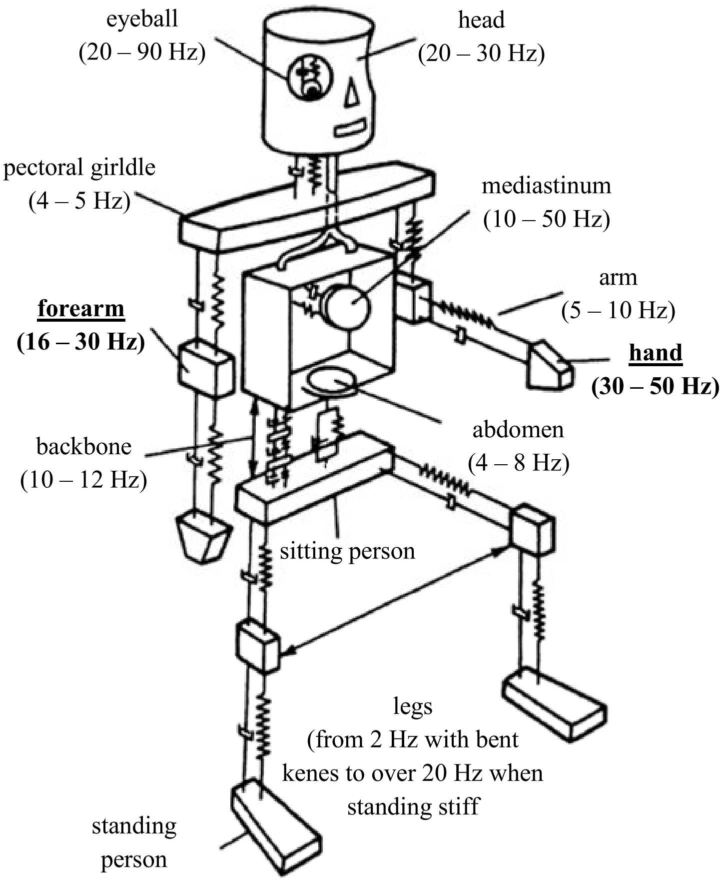

Figure 1. A model of the human body according to R. R. Coerman [6]

The model suggests that frequency is a critical factor considering the energy input into the dynamic structure of a mechanical-biological system. Human–Tool systems can differ with respect to frequencies of their subsystems – which are represented by mathematical models (3) and (4) in this study [5]. Our analysis also addresses this question.

Table 2 presents resonant frequency values for the human physical models at particular points of reduction.

Table 2. Resonant frequencies for the human physical models from the ISO 10068:2012 standard at different points of reduction

human physical model from **ISO 10068:2012**				
Model 1 (Annex B) 2 points of reduction		**Model 2 (Annex C)** 3 points of reduction		
j = 1	j = 2	j = 1	j = 2	j = 3
Resonant frequency of a subsystem [Hz]				
31,28	**14,44**	35,71	247,88	**30,27**

frequencies depending on the tool mass m_N

As can be seen in Figure 1, in the case of the Human–Tool system based on model 1 – Annex B from the ISO 10068:2012 standard [12], resonant frequencies are similar to the resonant frequencies of the hand and forearm. For model 2 – Annex C, the corresponding values are also similar to the reference values for the upper limb. Additionally, this model exhibits another frequency of almost 248 Hz, which represents resonant vibrations of the whole upper limbs [6]. Studies have also shown the possibility of deformations occurring in other internal organs, since local effects of vibrations can cause systemic disturbances [8]. In such cases, resonant vibrations can be induced in other parts of the body, such as the upper torso and backbone at 10÷14 Hz, the chest at 7÷11 Hz, the head at 20÷30 Hz, muscles at 13÷20 Hz, eyeballs at 20÷90 Hz, etc.

Different values of resonant frequencies for the models are due to dynamic parameters specified in the ISO 10068:2012 standard [12] – tables 1 and 2 in [5]. This relationship is especially visible in the case of resonant frequencies obtained for the model with three points of reduction. The differences result from the third point of reduction added to the system, in particular, the way it is attached to the rest of the model by spring and damping systems – Fig. 3 in [5]. In this case large values of spring parameters k_3 and k_4, which significantly contribute to one of the resonant frequencies for this model. It should be noted that not all computed values are constant. Resonant frequencies computed for both Human–Tool systems depend on the tool mass m_N –frequencies dependent on the tool mass m_N are indicated 2. This situation results from the impact of mass on the dynamic characteristics of one point of reduction in each system and the dynamic reaction of the whole Human–Tool system.

Energy analysis is a synchronic method of analysis, in which results of conventional dynamic analysis {mathematical models (3) and (4) in [5]} of amplitudes of kinematic quantities are used for energy analysis {energy models (5) and (6) in [5]} – of energy flows. This implies that an analysis conducted in a new domain, i.e. power distribution, is very sensitive to the adequacy of the model used to describe the system's dynamic structure. Undoubtedly, the development of the HAVS syndrome depends mostly on the intensity of vibrations and the amount of vibration energy introduced into the human body. For this reason, it is necessary to determine amplitude values, since the models in question can differ in this respect. Amplitude values of kinematic quantities for the models in question at specific points of reduction are shown in Table 3.

Table 3. Maximum amplitude values of kinematic quantities at specific points of reduction from the ISO 10068:2012 standard

Point of reduction	**kinematic quantity (maximum)**	**Operational frequency *f* [Hz] of the tool**							
		16		30		60		90	
		the model from ISO 10068:2012 standard							
		Model 1 (Annex B)	Model 2 (Annex C)	Model 1 (Annex B)	Model 2 (Annex C)	Model 1 (Annex B)	Model 2 (Annex C)	Model 1 (Annex B)	Model 2 (Annex C)
j=1	a $[m/s^2]$	31,79	31,73	36,20	38,26	15,77	18,31	8,45	9,24
	v [m/s]	0,316	0,316	0,192	0,203	0,042	0,049	0,015	0,016
	z [m]	3,15 $\cdot10^{-3}$	3,14 $\cdot10^{-3}$	1,02 $\cdot10^{-3}$	1,08 $\cdot10^{-3}$	1,11 $\cdot10^{-4}$	1,29 $\cdot10^{-4}$	2,66 $\cdot10^{-5}$	2,90 $\cdot10^{-5}$
j=2	a $[m/s^2]$	28,08	28,76	30,42	30,95	33,86	33,97	33,44	34,34
	v [m/s]	0,279	0,286	0,161	0,164	0,090	0,090	0,059	0,061
	z [m]	2,78 $\cdot10^{-3}$	2,85 $\cdot10^{-3}$	8,56 $\cdot10^{-4}$	8,71 $\cdot10^{-4}$	2,38 $\cdot10^{-4}$	2,39 $\cdot10^{-4}$	1,05 $\cdot10^{-4}$	1,08 $\cdot10^{-4}$
j=3	a $[m/s^2]$	–	28,36	–	29,92	–	34,08	–	33,48
	v [m/s]	–	0,282	–	0,159	–	0,090	–	0,059
	z [m]	–	2,81 $\cdot10^{-3}$	–	8,42 $\cdot10^{-4}$	–	2,40 $\cdot10^{-4}$	–	1,05 $\cdot10^{-4}$

Based on the maximum amplitude values of kinematic quantities shown in table 3, it can be concluded that the results generated by the models are very similar. Moreover, amplitude values of kinematic quantities for the model with three points of reduction are almost identical at the second (j = 2) and third (j = 3) point of reduction. A very similar level of energy input at these two points of reduction raises an interesting question of whether this model actually needs to be so complex.

Finally, an important conclusion should be drawn from the study. The comparative analysis suggests that health hazards for the tool operator predicted on the basis of the dynamic analysis can be completely different from those indicated by the energy analysis. The examples presented in the study lead to a more general conclusion that the similarity of models in terms of their dynamics by no means implies their energy identity.

4. Conclusions

The study demonstrated a partial compatibility between energy levels observed in two models of the human biological structure. The method of energy analysis enabled a comparative evaluation of different structural variants of tools – in this particular case, the impact of different operational frequencies. Moreover, with the method of energy analysis it was possible to assess the health hazard for the tool operator depending on the characteristics of the source of vibration. The order of energy inputs based on types of powers can also be determined when operating an impulse tool, e.g. a demolition hammer.

In addition, the study analysed the relationship between resonant frequencies of subsystems and those of the human bodies. It was possible to determine those points of the biological structure, where resonant vibrations can be induced, above all, the hands and forearms. Finally, amplitude values of kinematic quantities for both models were presented and found to be similar. It can therefore be concluded that the human physical models specified in the ISO 10068:2012 standard exhibit both similarities and discrepancies.

Acknowledgments

The investigations were made possible owing to partial funding by the Ministry of Science and Higher Education in research project: The flow of energy in mechanical and biomechanical systems 21-431/2013 DS-MK.

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