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OPTIMAL ISOLATION SYSTEMS INCORPORATING HUMAN SENSITIVITY TO VIBRATION

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ABSTRACT
The presented paper is composed of three parts: the ways of description of human sensitivity to vibration including mathematical models of human vibration discomfort, the procedure of synthesis of optimum vibration isolation system (VIS) for the sitting human-operator body incorporating human sensitivity to vibration (HSV) and the numerical examples of application of this procedure.

1 - WAYS OF DESCRIPTION OF HUMAN SENSITIVITY TO VIBRATION (HSV)
There are several ways of description of human sensitivity to vibration. Almost all them are based on various tests and experiments with human beings. The results of these tests are expressed by means of tables, formulae and standards.
The ways of description of human sensitivity to vibration can be divided into two groups: linguistic and mathematical. The linguistic group consists of discomfort definitions, tables and charts with degrees of discomfort feelings, descriptions of symptomatic components of Reynaud's disease and VWF phenomena [3], [4]. The new definitions of functional and subjective discomfort and a new way of modelling of discomfort feelings with application of "fuzzy logic theory" were proposed by Ksiazek in [6] and [7]. The chosen part of this approach is presented in Fig. 1, where the degree of comfort was illustrated as the function of frequency and acceleration. The mathematical group consists of weighting curves, doses of vibration, absorbed energy, power and all diagrams basing on mathematical formulae and expressions.

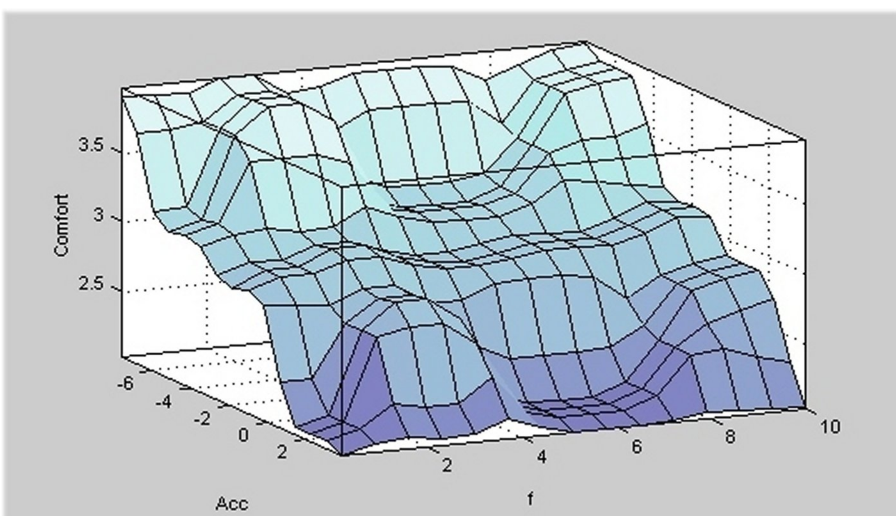

Figure 1.

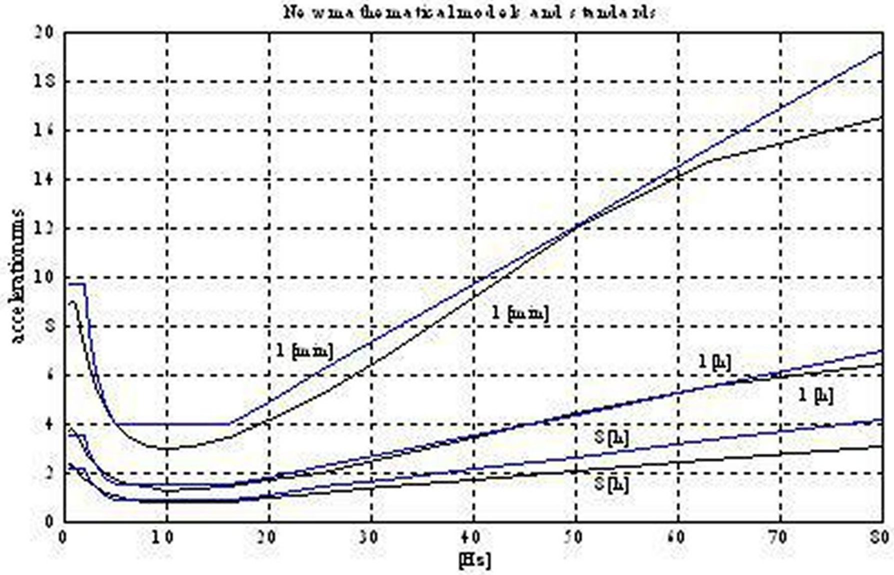

Figure 2.

The new mathematical models of perception thresholds feelings of man for vertical whole-body vibration obtained by Ksiazek in [6] and [7] are presented in Fig. 2 where the new mathematical models are compared with the standards.
The third way of the illustration of HSV can be described by the standard frequency weightings shown in Fig. 3 where two chosen weightings obtained in British Standards (W_b) and ISO (W_k) were compared.

2 - PROCEDURE OF SYNTHESIS OF OPTIMUM VIBRATION ISOLATION SYSTEM (VIS) INCORPORATING HUMAN SENSITIVITY TO VIBRATION (HSV)

Examples of design of suspension incorporating human sensitivity to vibration can be found in [2] and [6]. In this paper the synthesis of optimal isolation systems of the sitting human body subjected to random vertical vibration was presented. Human sensitivity to vibration were represented by chosen frequency weighting curve W_b. The general scheme of HSV and *VIS* is presented in Fig. 4. The problem was solved for two types of excitations $\ddot{x}_0(t)$: white and narrow band noises, with the power spectral densities of acceleration given by the formulae (1) and (2)

$$S_{\ddot{x}_0}(s) = \frac{\sigma_0^2}{2\pi} \tag{1}$$

and

$$S_{\ddot{x}_0}(s) = \frac{\gamma\sigma_0^2}{\pi}\frac{\Omega^2 - s^2}{\left(\Omega^2 + s^2\right)^2 - 4\gamma^2 s^2} \tag{2}$$

where: $s -$ complex variable $\sigma_0^2 -$ variance of acceleration in $[m^2/s^4]$, γ and $\Omega -$ constants in $[rad/s]$. These two power spectral densities can be considered as two extreme cases of excitation between pure random and harmonic (single frequency) signals. Let us suppose that the force acting on the sitting human body of mass m can be expressed by the formula

$$F(s) = m\ddot{z}(s)W(s) \tag{3}$$

where: $W(s) -$ one of the frequency weightings of acceleration presented in Fig. 3 depicting hypothesized relations between vibration frequency and the human responses reflecting its sensitivity to vibration. As the criterion of synthesis of the optimal *VIS*, the following expression was assumed:

$$J = \sigma_\delta^2 + \lambda\sigma_{\ddot{x}}^2 \tag{4}$$

Where σ_δ^2 is the mean square value of the relative displacement $\delta(t) = x(t) - x_0(t)$, λ is a Lagrangian multiplier, $\sigma_{\ddot{x}}^2$ is the mean square value of the acceleration of the point of contact between *HBM* and *VIS*. Applying the procedure presented in [5] we obtain

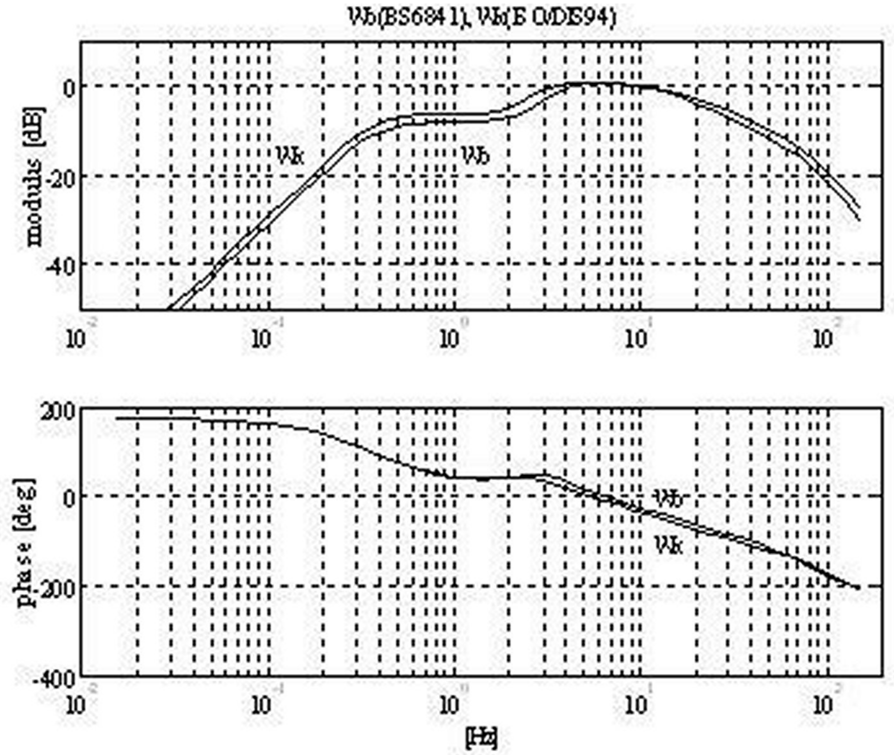

Figure 3.

$$\Phi(s) = \frac{\phi(s)}{m} = \frac{W(s)}{R(s)\,\psi(s)}\left[\frac{\psi(s)}{R(-s)}\right]_{+} \qquad (5)$$

where: $\Phi(s)$ $-$ is the normalized function describing the optimal *VIS*, $[\ ]_+$ $-$ represents the part of expression in brackets having poles in the left-hand side of the s plane, $R(s)$ and $R(-s)$ are the functions having poles in the left-hand side and the right-hand side of the s plane respectively, which must be calculated for the supposed model of human body, (*HBM*). $\psi(s)$ is the result of factorization of the power spectral density of excitation $S_{\ddot{x}_0}(s)$.

3 - EXAMPLES OF OPTIMUM VIBRATION ISOLATION SYSTEMS

It was assumed that the human sensitivity to vibration can be depicted by the frequency weighting curve W_b. The analytical form of the weighting W_b shown in Fig. 3 can be written as follows

$$W_b(s) = H_{fb}(s)\ H_b(s) \qquad (6)$$

where the forms of $H_{fb}(s)$ and $H_b(s)$ are given in [2]. For the W_b given by (6) moduli and phases of $\Phi(s)$ for white noise and narrow band excitation were presented correspondingly in Fig. 5. (0 $-$ without isolation system, 1 $-$ vibration isolation system for $\lambda = 0.0001$ $[s^4]$, 2 $-$ vibration isolation system for $\lambda = 10000$ $[s^4]$) and Fig. 6. (0 $-$ without isolation system, 1 $-$ vibration isolation system for $\lambda = 0.0001$ $[s^4]$, $\Omega = 0.5$ $[Hz]$, 2 $-$ vibration isolation system for $\lambda = 10000$ $[s^4]$, $\Omega = 0.5$ $[Hz]$, 3 $-$ vibration isolation system for $\lambda = 0.0001$ $[s^4]$, $\Omega = 5.5$ $[Hz]$, 4 $-$ vibration isolation system for $\lambda = 10000$ $[s^4]$, $\Omega = 5.5$ $[Hz]$, 5 $-$ vibration isolation system for $\lambda = 0.0001$ $[s^4]$, $\Omega = 8.0$ $[Hz]$, 6 $-$ vibration isolation system for $\lambda = 10000$ $[s^4]$, $\Omega = 8.0$ $[Hz]$).

4 - CONCLUSIONS

As it was shown in Figs. 5 and 6, the moduli of $\Phi(s)$ have got in principle, independently of the type of excitation, less values in the considered band of frequency than the corresponding moduli of $\Phi(s)$ for the systems without any isolation. The greater value of the coefficient λ, the greater difference between the moduli. These differences are smaller for the small values of λ, ($\lambda = 10^{-4}$) and frequencies below 2 $[Hz]$ (curves 1 and 2 in Fig. 5 and curves 1 and 5 in Fig. 6). In the other cases the optimal vibration isolation systems are clearly better in all band of frequencies than the systems without any isolation.

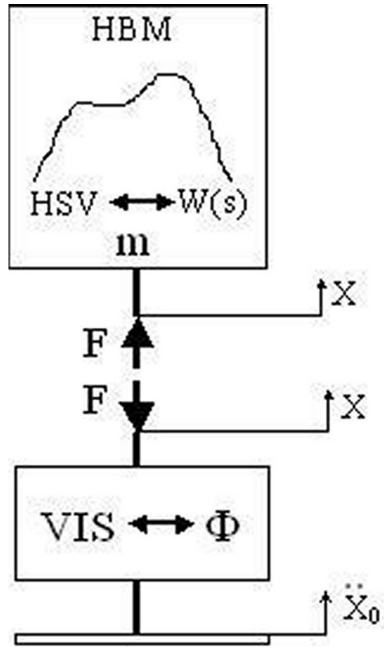

Figure 4.

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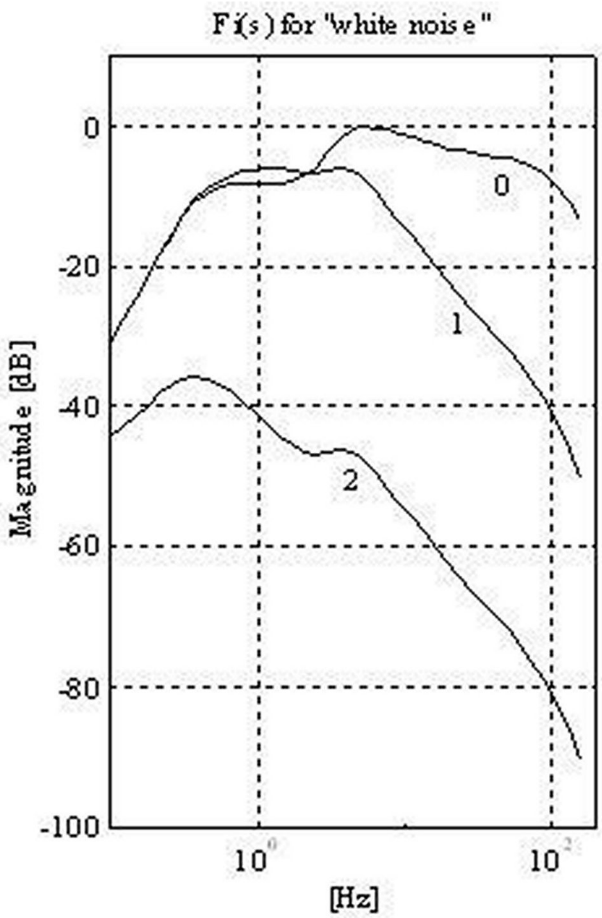
Fi(s) for "white noise"
0
-20
-40
-60
-80
-100
Magnitude [dB]
0
1
2
10^0
10^2
[Hz]

Figure 5.

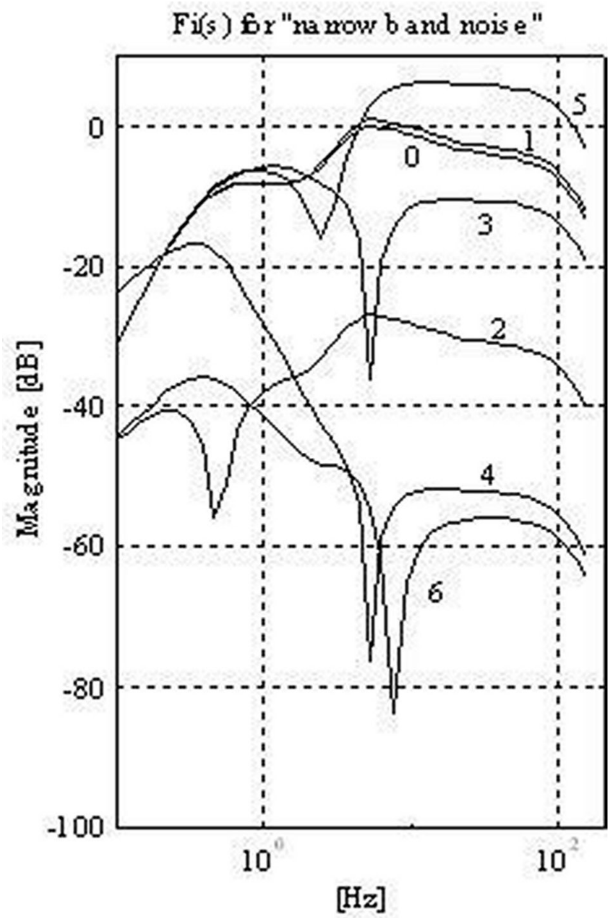
Fi(s) for "narrow band noise"
0
-20
-40
-60
-80
-100
Magnitude [dB]
10^0
10^2
[Hz]
5
1
0
3
2
4
6

Figure 6.