ADVANCED SIMULATIONS OF HUMAN PROTECTIVE DEVICES AGAINST TECHNOLOGICAL VIBRATIONS

Ana Picu [a), c)], Silviu Nastac [b), c)]

[a)] Regional Research Center for Vibro-Acoustics Polution and Ambiental Quality
[b)] Research Center for Mechanics of the Machines and Technological Equipments
[c)] Engineering Faculty in Braila, University "Dunarea de Jos" of Galati,
Calea Calarasilor 29, 810017 Braila, Romania
ana_picu@yahoo.com, snastac@ugal.ro
http://www.inginerieb raila.ugal.ro

Abstract: This work deal with the dynamic behaviour optimization of the protective devices for human protection against nocive shocks and vibration derived from technological processes. In this paper is described a computational model, based on visco-elastic linear rheological elements, useful for numerical simulation and dynamic behaviour analysis. It contains simulation components for the human body and for the protective device, thus that it offer the measures of the whole ensemble movements under the external intensive and various dynamic charges. Inovative trends of this study are sustained both from the unitary approach of the entire ensemble of human body - protection system - dynamic charges, with a behaviour approximation of visco-elastic characteristics for the essential components of the model, and from the spectral broach of the external charges, with transfer functions evaluation, involving Laplace's Transform and complex domain computations, and with FRF estimations of the system motions. The simulations based on this advanced numerical model, correlated with some available experimental information, provided the basis for a first approach on dynamics of protective devices behaviour. As a concluding remark, the stochastic approach assures a high accuracy level and provides a very good tool for initial estimation and validation of designing input data.

1 Introduction

It is a reason that make difficult to define a good model of shocks and vibration exposure risks, and this is that those exposed to these dynamic actions are usually also exposed to other hazards. Therefore it is very difficult to extract which of these factors caused a certain pain by using epidemiological methods. Exposure of whole-body vibration is one of several hazards that can result in injury manifesting as low back pain. Although a link between vibration and low back pain is generally accepted, methods of predicting which individuals are most susceptible to pain remain elusive [6].

A good method for evaluation of dynamics for whole-body vibration exposure and for protective systems is provided by experimental and instrumental tests performed on real ensembles. But sometimes, the direct acces to these systems is restricted. Thereby, a viable alternative to experimental evaluation is to approximate the human body and the protective device by a mathematical model and analyse the desired behaviour of the model through computer simulations.

A human body can be represented by a lumped system consisting of masses, and visco-elastic elements. ISO5982 [8] provided a two degree-of-freedom (2DOF) system, with the model parameters being determined by experiments. This 2DOF model is actually two independent SDOF systems rather than a 2DOF system because there is no connection between two masses except the rigid frame. This model suggests that the vibration of the human head and the upper torso is independent of the vibration of the rest of the body. Although this model provided two frequencies that match the measurements, this model is conceptually incorrect.

Nigam and Malik [7] proposed a 15DOF spring mass system. In general the difficulty with using this type of model is to determine the parameters of the system, such as mass, stiffness of spring and damping of each lumped mass.

Some researchers proposed continuum medium models. This kind of models appears to bring closer to the real ensemble behaviour, but it have more disadvantages amongst the opportunity to analyze only the human body in standing position (for a sitting position the model become very complex), the difficulties on simulation the complexity of linkage between the body components (it suppose to have only a limit conditions) and on determine the characteristics for each component of the model, a high simplification degree for the human body (two or three homogeneous masses for the entire body), the resorts absence for evaluation of protective elements and their linkage with the body and the main charges.

2 Computer simulation model

Taking into account the previously presented reasons, the authors developed a 3DOF lumped system with visco-elastic linkages between all the masses and between them and the ground (the insulation support of the ensemble). The model is simple, but by means of its complex structure can offer the opportunity to analyze more situations, such as the whole-body vibration exposure only, the body and the protective system behaviour, different parts of the human body exposed to dynamic actions, a single mass for the human body and decomposed isolation system. The particular configuration for each computer simulation model can be obtained through a proper structure and characteristic for the entire set of visco-elastic elements, and of course with a proper values for each masses according to the analysis case.

2.1 The dynamic model

In Figure 1 is depicted the basic schematic diagram for the 3DOF dynamic model. The symbols denote masses (m_i), stiffnesses (k_{ij}), dampings (c_{ij}), displacements (x_i) and dynamic excitation (h). The index (i) denote the mass at first tag of the linkage, and the index (j) denote the other tag (for the ground it was supposed null index).

For a first approach it was considered linear characteristics both for stiffness, and for viscous damping. It answers to the most current analysis cases. Furthermore, a non-linear approach increase the difficulty of estimation for number of specific parameters and for theirs value.

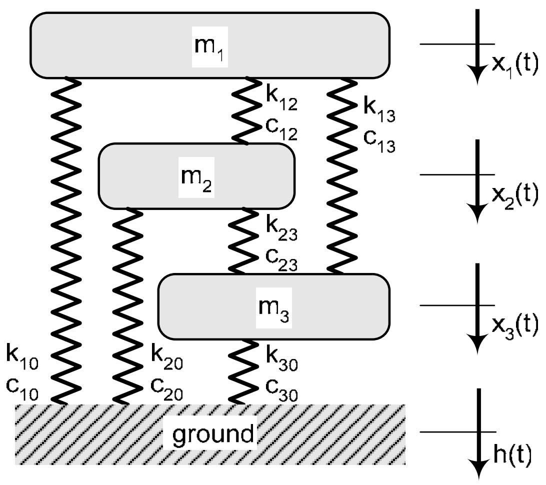

Figure 1. Schematic diagram of dynamic model. Supposed springs having stiffness k_{ij} and damping c_{ij}.

2.2 The mathematical model

The mathematical model for the system depicted in Figure 1 is

$$M\ \ddot{X} + C\ \dot{X} + K\ X = F_{ex} \tag{1}$$

where *M* is the masses array, *C* is the dampings array, *K* is the rigidities array, and

$$X = \begin{bmatrix} x_1 & x_2 & x_3 \end{bmatrix}^T \tag{2}$$

is the vector of displacements, with velocities $\dot{X}$ and accelerations $\ddot{X}$ associate vectors. The external charges have the next final form according to kinematic excitation *h(t)*

$$F_{ex} = \begin{bmatrix} F_{ex\_1}(t) & F_{ex\_2}(t) & F_{ex\_3}(t) \end{bmatrix}^T = \begin{bmatrix} k_{10} & k_{20} & k_{30} \end{bmatrix}^T h(t) \tag{3}$$

Performing the computations and applying the Laplace's transform to the motion equations system (1), result the transfer matrix *H(s)* as follows

$$H(s) = \begin{bmatrix} m_1 s^2 + c_1 s + k_1 & -c_{12}s - k_{12} & -c_{13}s - k_{13} \\ -c_{12}s - k_{12} & m_2 s^2 + c_2 s + k_2 & -c_{23}s - k_{23} \\ -c_{13}s - k_{13} & -c_{23}s - k_{23} & m_3 s^2 + c_3 s + k_3 \end{bmatrix}^{-1} \tag{4}$$

where new condensed terms have the expressions

$$\begin{aligned} c_1 &= c_{10} + c_{12} + c_{13}; \quad c_2 = c_{20} + c_{12} + c_{23}; \quad c_3 = c_{30} + c_{13} + c_{23}; \\ k_1 &= k_{10} + k_{12} + k_{13}; \quad k_2 = k_{20} + k_{12} + k_{23}; \quad k_3 = k_{30} + k_{13} + k_{23}; \end{aligned} \tag{5}$$

This formulation, in complex domain, have two main advantages, such as: first, it allow the acces to partial transfer functions and this fact can lead to identify the modal shapes, and second, it enable the utilization of more complex excitation signals - stochastic transient signals, stationary or nonstationary random signals - by means of theirs spectral composition [1,3,4]. It has to be mentioned that is relative simple to synthesize a composite input signals with specified but arbitrary power spectrum. This can be stationary or slowly time varying, and it can be described with any mix of deterministic and stochastic attributes. Conceptually, generating stochastic signals with a specified power spectra (or correlation function) is accomplished by filtering a white noise signal with a filter exhibiting the desired power spectrum [2].

The expression (4) of transfer matrix provide a partial transfer functions and, supposing the general matrix form of the motion equations

$$X(s) = H(s)\ F(s) \tag{6}$$

it can be shown that the modal parameters can be identified from any row or column of the transfer matrix *H*, except those corresponding to components known as node points. In other words, it is impossible to excite a mode by forcing it at one of its node point (a point where no response is present).

2.3 Some remarks about the model charging

In practice is simpler to use the frequency response function (FRF). Note that since *s* is complex, the transfer function has a real and an imaginary part. The FRF is a Fourier transform of a time signal and is obtained by merely substituting in eqn. (6) $j\omega$ for *s*, where

ω denote angular velocity. In other words, The Fourier transform is merely the Laplace trasform evaluated along frequency axis $j\omega$ [4,5].

According to the previous paragraph suppositions, in eqn. (6) the input *F* and the output *X* are the linear Fourier spectrum of corresponding time signals. Usually is available the power spectrum of the signals (e.g. the excitation signal), and in this case it is necessary to use the next form of motion equation

$$G_{XF}(j\omega) = H(j\omega)\, G_{FF}(j\omega) \tag{7}$$

where $G_{XF}(j\omega)$ denotes the cross power spectrum between the input *F* and the output *X*, and $G_{FF}(j\omega)$ denotes the auto power spectrum of the input *F*.

3 Conclusion

The concluding remarks framed the advantages of the proposed model relative to the most used at this moment. First, the complexity of the linkage elements leads to various possibilities to analize the dynamic behaviour. Second, the linear characteristics of visco-elastic elements answer to the most practical cases and assure a high performance with minimum computational resources involved. Third, by means of complex formulation of motion equations, it is simple and suitable to analyze each mode of vibration. Also, by using auto and cross power spectrum for input and output signals it can be simulated a large area of excitation signals, according to the real supposed situations.

This study is a first step from a suite of researches concerning the whole-body vibration exposure and the technical measures to reduce it. Hereby, the entire set of theoretical suppositions previously denoted will be benefit by the instrumental data calibration and experimental validations. But the simplicity and the power of the model recomanded as a useful tool for analysis.

References

[1] Bendat, J.S., Piersol, A.G., (2000): Random Data: Analysis and Measurement Procedures, 3rd Edition, Wiley, New York.

[2] Elliot, D.F., (1987): Handbook of Digital Signal Processing. Engineering Applications, Academic Press Inc., ISBN 0-12-237075-9.

[3] Harris, C.M., Piersol, A.G., (2002): Shock and Vibration Handbook - 5th Edition, McGraw Hill, ISBN 0-07-137081-1.

[4] Istvan, L.V., Beranek, L.L., (2006): Noise and Vibration Control Engineering. Principles and Applications, 2nd Edition, John Wiley & Sons, Inc., ISBN-13:978-0-471-44942-3, ISBN-10:0-471-44942-3.

[5] Josephs, H., Huston, R.S. (2002): Dynamics of Mechanical Systems, CRC Press, ISBN 0-8493-0593-4.

[6] Mansfield, N. J. (2005): Impedance methods for assessment of the biomedical response of the seated person to whole-body vibration, *Industrial Health* 2005, 43, 378-389.

[7] Nigam, S. P., Malik, M. (1987): A study on a vibratory model of a human body, *Journal of Biomechanical Engineering*, 109, 148-153.

[8] International Organisation for Standardisation, (1981): Vibration and shock - Mechanical driving point impedance of the human body, ISO 5982.