On the applications of biodynamic models of the human hand and arm

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Introduction

For experimental and analytical assessments of coupled hand-tool systems and vibration attenuation mechanisms, it is highly desirable to develop a hand-arm simulator and mechanical-equivalent models of the human hand and arm. For this purpose, a number of biodynamic models have been proposed to characterize the human hand and arm response to vibration (MIWA et al., 1979; GURRAM et al., 1995; ISO-10068, 1998, MISHOE et al., 1977). Although different models have evolved over the past 30 years, only minimal evidence exists regarding their applicability to either analytical or experimental studies of the coupled system (JAHN et al., 1986). A comparative analysis of the reported models can provide important information regarding their potential for applications in both experimental and analytical assessment methods.

Method

A total of 12 different models are evaluated. These include a distributed-parameter (WOOD et al., 1978), and 11 linear and grip-force dependent, lumped-parameter models. The lumped-parameter models range from a two-stage single-DOF (REYNOLDS et al., 1972) to four-DOF models. The suitability of the selected models is assessed on the basis of three different performance measures. The ability of a model to adequately describe the biodynamic response of the hand and arm under vibration forms the foremost requirement. The second requirement addresses the static deflections of model masses under a steady feed force of 50 N, which must be of reasonable magnitudes to ensure design feasibility of the model. The final measure examines the ability of the model to describe important aspects of vibration response of the human hand and arm, such as natural frequencies and damping ratios.

The first criterion is addressed by comparing the driving-point mechanical impedance (DPMI) magnitude and phase responses of the selected models with the limits of most probable values defined in ISO-10068 (1998). For the second criterion, the relative deflections of the contacting mass are evaluated with respect to the fixed support. In the case of semi-definite system models, the relative deflections between extreme masses are evaluated. The resulting deflections associated with each model are examined within the context of a potential application of the model to the design of a feasible mechanical simulator. The application of the last-cited criterion, however, poses difficulties, since there seems to be little quantitative knowledge on the vibration properties of the human hand and arm. A qualitative analysis of natural frequencies and damping ratios is thus performed, such that the modal frequencies and damping ratios lie within reasonable ranges that can be practically realized.

Results

The comparisons of response characteristics of selected models in terms their DPMI responses and compliance raise many doubts regarding their potential applicability to the development of mechanical simulators or to the analysis of coupled hand-tool system. The biodynamic responses of models based upon three- or four-DOF structures, in general, agree with the limits prescribed in ISO-10068 (1998). Many of these models, however, consist of very light masses, as low as 1.2 grams, and restoring elements with nearly zero stiffness resulting in low frequency natural modes (below 10 Hz) and excessive static deflections. The majority of the higher-order models yield excessive static deflections, ranging from 28mm to 975mm, which argue against their potential application. While the lower-order models yield reasonable static deflections, their DPMI responses differ from the proposed limits (Fig. 1). In view of the static deflection response, the models that could be considered suitable include: the three-DOF x_h-axis model of MISHOE et al. (1977); the two-DOF models of MIWA et al. (1979) for y_h- and z_h-axes; the two-stage single-DOF model of REYNOLDS et al. (1972) for all three-axes; and the distributed parameter model of WOOD et al. (1978) for y_h-axis with deflection of 1.1 mm of the skin and soft tissues within the hand. However, these models, with the exception of the model of MISHOE et al. (1977) for the x_h-axis alone, fail to characterize the DPMI responses of the human hand and arm within the recommended bounds.

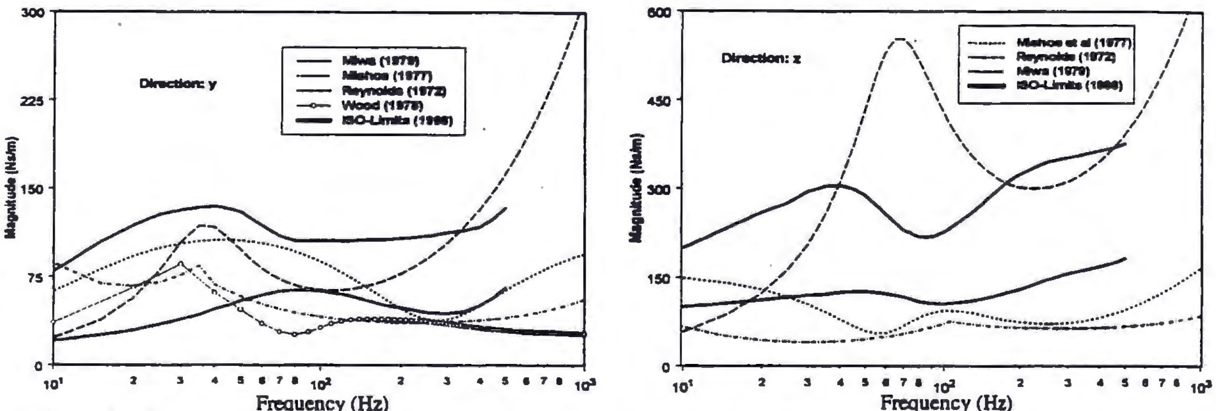

Figure1: Comparison of y_h- and z_h-axes DPMI magnitude responses of selected models.

Conclusion

From the results, it is concluded that vast majority of the reported models cannot be used as the basis for the development of a mechanical simulator or for the analytical design and assessment of the coupled hand-tool system. Further studies on characterization of the biodynamic response and modeling considerations are therefore suggested.

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Abstracts

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