# HAND FORCE-DEPENDENT MODELING OF THE HAND-ARM UNDER $Z_H$-AXIS VIBRATION

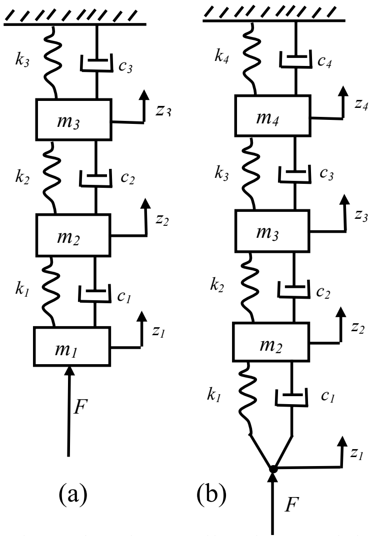
Y. Aldien[1], S. Rakheja[1], P. Marcotte[2], P.-E. Boileau[2]
[1]CONCAVE Research Center, Concordia University, Montréal, Canada
[2]Institut de recherche Robert-Sauvé en santé et en sécurité du travail, Montréal, Canada

## Introduction

A number of biodynamic models of the hand-arm system have evolved on the basis of measured driving-point mechanical impedance (DPMI) responses to facilitate analyses of the coupled hand-tool system [1]. The parameter identifications in such models are based upon minimization of an error function of the model and the target impedance data, which may not yield a unique solution. Consequently, a number of model structures and parameter sets could be realized that would equally satisfy the target curve. Moreover, the vast majority of the reported models exhibit acute deficiencies due to excessive static deflections of model masses, presence of a low frequency mode and very light masses in the order of 1.2- 4.8 grams. The models also do not characterize the dependency of the biodynamic responses on many factors, namely the hand forces, hand-arm posture and vibration intensity. This study aims at development of a hand-arm biodynamic model with considerations of the hand forces, and both the DPMI and power absorption measures, to enhance the uniqueness of the model.

## Methods

Two different model structures are chosen for identifying the model parameters on the basis of measured DPMI and absorbed power characteristics of the hand-arm system under $z_h$-axis vibration over a range of hand-grip and push forces. Owing to the strong influence of the hand-handle coupling forces, the models were initially derived for fixed hand forces, namely 30 N grip and 50 N push forces, as suggested in the ISO 10068 standard [2]. The equations of motion for the model are formulated and solved to compute both the DPMI and absorbed power responses. A constrained minimization function comprising weighted errors of both the DPMI and absorbed power is formulated and solved to identify the parameters. Alternate functions corresponding to different combinations of hand forces are then applied to identify hand-force dependent model parameters.



(a) (b)

Fig. 1: hand-arm vibration models

Variations in the model parameters are investigated as functions of the grip, push and coupling forces through linear regression analysis. Regression-based models are formulated for deriving the hand-handle forces dependent model parameters. The validity of the model is also examined under selected combinations of hand forces.

## Results and Discussions

Comparisons of models results with the measured data suggested that both model structures could predict the DPMI as well as absorbed power reasonably well, when variations in the hand forces are neglected. The model with the visco-elastic interface (b), however, provided relatively poor agreements and large static deflection under a static push force. The model stiffness and damping parameters identified on the basis of measured responses for nine different combinations of hand forces revealed linear variations with the hand forces, particularly the coupling force. The model masses, however, revealed only minimal sensitivity to variations in the hand forces. The resulting relationships between the model parameters and the coupling force (*CF*) were thus used to formulate a hand force-dependent mechanical-equivalent model of the human hand-arm system using model (a). These relationships suggest linear increase in stiffness and damping coefficients with increasing coupling force, and assume the general form:

$$k_i = a_1 CF + a_0 \text{; and } c_i = b_1 CF + b_0 \quad \text{for } i\text{=1,2,3}$$

where $a_0$, $a_1$, $b_0$ and $b_1$ are constant coefficients. Multiple linear regressions between parameters and the grip and push forces ($F_g$ and $F_p$) as independent variables, were also performed, which resulted in higher correlation factors (>0.88). These are expressed as:

$$k_i = a_2 F_p + a_1 F_g + a_0 \text{; and } c_i = b_2 F_p + b_1 F_g + b_0 \quad \text{for } i\text{=1,2,3}$$

Comparisons of model responses with the measured data revealed reasonably good agreements in both the DPMI and absorbed power magnitudes for the hand forces combinations considered. Consideration of parameters as functions of grip and push forces would also be more desirable than that based upon the coupling force only.

While the DPMI magnitude is known to exhibit negligible sensitivity to variations in excitation magnitude, the absorbed power increases considerably under a higher vibration magnitude. The validity of the resulting model under different magnitudes of excitation was thus explored by comparing the model results with the data acquired under $a_{h,w}$= 2.5 and 5 m/s$^2$. The model results revealed reasonably good agreements with measured absorbed power and the DPMI under both levels of excitations.

The vibration properties of the proposed models could be considered appropriate in view of the practical issues related to model implementation, namely static deflection, damping ratio and resonant frequencies. The eigen-frequencies of the proposed model also revealed good agreements with the frequencies corresponding to the peaks observed in the DPMI magnitude data, while the static deflections of masses were relatively small.

## References

[1] Rakheja, S., Wu, J.Z., Dong, R.G., Schopper, A.W. and Boileau, P.E. 2002: A comparison of biodynamic models of human hand-arm system for applications to hand-held power tools, *Journal of Sound and Vibration*, 249, pp. 55-82.

[2] ISO 10068, 1998: Mechanical vibration and shock – Free, mechanical impedance of the human hand-arm system at the driving point, *International Standard Organization*, Geneva, Switzerland.