METHODS FOR CALIBRATING HUMAN VIBRATION MODELS

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Introduction

Three methods (vibration transmissibility method, driving-point response method, and their combined method) have been generally used to calibrate human vibration models using frequency response functions. However, the theoretical basis for the methodology has not been sufficiently understood. As a result, these methods were not appropriately used in some studies, which generated some questionable results and conclusions. The objectives of this study are to enhance the understanding of the calibration methods and to help properly select and use them in the further development of the models.

Method

The methodology used in this study includes a novel theorem derived from a conceptual human vibration model[1], as shown in Fig.1. For clarity, only the accelerations and dynamic force responses in the *z* direction are represented in the figure. Based on Newton's second law, the relationship between the driving-point response functions (e.g., apparent mass, M_Z) and the distributed vibration transfer functions (T_Z) is derived and expressed as follows:

$$\sum M_Z = \int T_Z \cdot dm + \sum T_{Zb} \cdot (C_{Zb} / j\omega - K_{Zb} / \omega^2) \qquad (1)$$

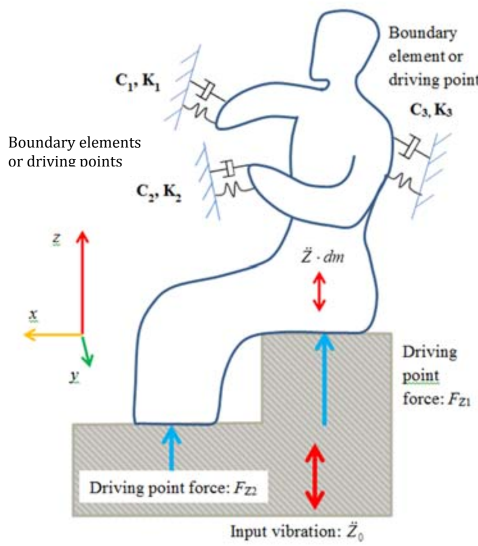


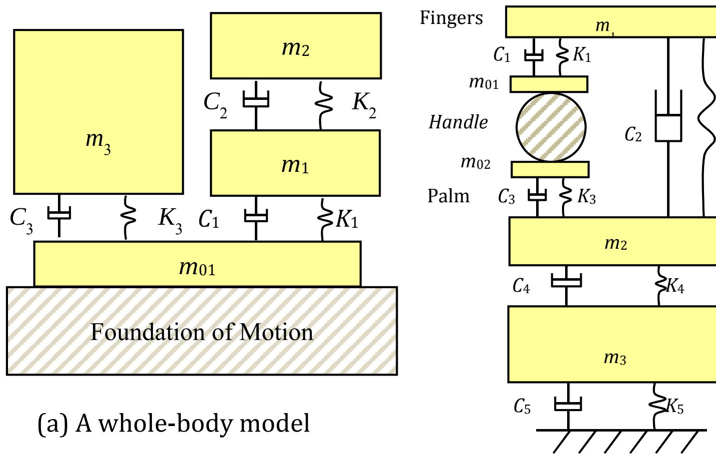
Fig. 1: A general human vibration model

This equation indicates that the sum of the driving-point apparent mass of any linear or non-linear system can be expressed as a linear combination of the motion transfer functions of the individual mass elements distributed throughout the system; the combination coefficient of each transfer function is the sum of its corresponding mass value and equivalent mass value related to boundary connecting stiffness and damping if applicable. Mathematically, the distributed mass can also be considered as a function. Therefore, this theorem reflects the relationships among the three types of functions. Interestingly, the combination of any two types of functions constitutes the basic requirement for each of the three typical methods for calibrating human vibration models. This theorem reveals that if any combination of two is given, the third can usually be determined as well. Thus, each method can result in the same solution if the provided functions are accurate, sufficient, and representative.

This study also used a numerical test method for the verification of the theoretical predictions and the exploration of the requirements for each method to achieve a unique solution of the calibration[1]. For this purpose, several human vibration models are considered in the evaluations, two of which are shown in Fig. 2. The driving-point response (DPR) functions and vibration transfer (VT) functions were assumed to be precise for each model in the numerical tests. They served as the reference functions in the calibration. If the calibrated parameter values can converge to the original parameters used to calculate the precise functions, the calibration method is considered valid for achieving a unique solution.

Results and Discussion

The VT method utilizes the measured transfer functions and distributed mass information as references in the calibration to determine the remaining element properties of a model. According to Eq.(1), this method uniquely determines the sum of the DPR functions and it can thus uniquely calibrate the remaining parameters of the model. The numerical test confirmed this prediction. The numerical test also demonstrated that Model-(b) shown in Fig. 2 can be uniquely calibrated if the two DPR functions in the entire frequency range of the major resonances are provided. Model-(a) can also be uniquely calibrated if the total DPR function and the distributed mass information are provided. These observations suggest that the DPR method can provide unique calibrations for many models if sufficient DPR functions and mass distribution information are provided. The combined (CTD) method utilizes the VT and DPR functions as references in the calibration. This method can theoretically provide a unique calibration, as proved using Eq.(1)[1]. However, the numerical test also revealed that the DPR and CTD methods are computationally not as robust as the VT method in some cases, e.g., Model-(a). This is because it is theoretically easier to use the distributed responses and properties (VT and mass) than to use the integrated DPR functions to predict the system properties. Practically, however, the VT method could be the worst one because it is very difficult to obtain adequate, accurate, and representative VT functions for the calibration. For this reason, the DPR method is the best choice if it is sufficient for the model of interest. If it is not adequate, some VT functions have to be used. Theoretically, the more references used, the more robust the calibration. Practically, however, the use of more references can lead to the introduction of inconsistent information. As a result, the curve fittings for the calibration have to compromise among the references, which may reduce the reliability of the model. If applicable, the VT functions should be used to calibrate only those components that cannot be uniquely calibrated using the DPR method. More weighting can also be applied to more reliable functions in the calibration. The baseline weightings based on Eq.(1) are also proposed to help properly apply the weighting. This study suggested that the best calibration method depends on the purpose of the model, the model structure, and availability, accuracy, and appropriate representation of the reference functions.



(a) A whole-body model

(b) A hand-arm system

Fig. 2: Examples of the human vibration models

REFERENCES

1. Dong RG, Welcome DE, McDowell TW, Wu JZ (2013). Theoretical relationship between vibration transmissibility and driving-point response functions of the human body. *J. of Sound and Vib.* 332(24): 6193-6202.

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Forward – Welcome Address

On behalf of my conference co-chairs, I am pleased to welcome you to Guelph, Ontario, Canada for the 5th American Conference on Human Vibration. The 5th ACHV is being co-hosted by the University of Guelph, Laurentian University, Western University and the University of Toronto. We are honored to be hosting this biennial conference on the University of Guelph campus. As the premier North American conference for human exposure to vibration, the conference provides a unique and convenient opportunity for researchers, engineers, medical professionals and industry representatives to exchange information on all aspects of vibration control and human responses to hand-transmitted vibration and whole-body vibration. The theme for this year's meeting is "Human Vibration - From Theory to Industrial and Clinical Applications".

Founded in 1827, Guelph was named after the British Monarch King George IV, who was from the House of Hanover. Selected as the headquarters of a British development firm called "The Canada Company", Guelph was designed by John Galt, who was a Scottish Novelist. The town was designed to resemble a European city center comprised of squares, wide main streets and narrow side streets. Guelph was home to Lieutenant Colonel John McCrae, the author of "In Flanders Fields". Its references to the red poppies that grew over the graves of fallen soldiers resulted in the remembrance poppy becoming one of the world's most recognized memorial symbols for fallen soldiers. Guelph was also the home of North America's first cable TV system. Fredrick T. Metcalf created MacLean Hunter Television (now part of Rogers Communications) and their first broadcast was of current monarch Queen Elizabeth II's Coronation in 1953. With a population of over 120,000, Guelph is part of a technology triangle which is comprised of the cities of Guelph, Kitchener, Cambridge and Waterloo. Guelph is consistently rated as one of Canada's best places to live because of its low crime rate, clean environment, high standard of living and low unemployment rate. Almost one quarter of Guelph employment is provided through the manufacturing sector with over 10% provided through Educational services. The City of Guelph has identified life science, agri-food and biotechnology, environmental management and technology companies as industries on which to focus future economic development activities.

Many thanks to Elyse Dubé from Conference Services at the University of Guelph for all of her hard work in helping to plan and sort through the conference logistics. We'd also like to thank Guelph Engineering students Gregor Scott and Dan Leto as well as School of Engineering technician Carly Fennell for their help in setting up the laboratory tours. We hope that your visit to the 5th ACHV and Guelph will be both educational and enjoyable.

Sincerely,

Michele Oliver, Jim Dickey, Tammy Eger and Aaron Thompson