A MULTI-BODY DYNAMIC BIOMECHANICAL MODEL OF A SEATED HUMAN EXPOSED TO VERTICAL WHOLE-BODY VIBRATION

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Introduction

Ethical concerns of in-vivo procedures and poor repeatability of non-invasive techniques have been major limitations in estimating vibration-induced spine loads through experiments. The biodynamic models of seated human body exposed to whole-body vibration (WBV) have evolved for defining the frequency-weightings, enhancement of human responses to WBV, and developing anthropodynamic manikins for seating assessment activities. The widely reported mechanical-equivalent models, solely based on through- or to-the-body biodynamic response functions, do not seem to resemble the biomechanical structure and do not yield information on the dynamic loading and deflections of segments of concern, namely the spine. On the other hand, biomechanical models with representative anatomical structure and anthropometry are being attempted to simulate segmental movements and the coupling effects, using Finite elements (FE) or multi-body dynamics (MBD) formalisms, which could provide important insights into the inter-vertebral forces [1]. While the FE models pose considerable complexities primarily related to characteristics of the bio-material properties, the MBD technique with discrete rigid bodies offers the flexibility to create multi-segment models with relative ease and lower computational cost. In this study, a preliminary multibody dynamic model of a seated human body exposed to WBV along the vertical direction is formulated using MSC/ADAMS software. The model validity is demonstrated by comparing selected responses with the available measured data.

Methods

The seated human is represented by nine rigid body segments, including: head, neck, thoracic and lumbar torso, pelvis, hands and thighs, as shown in Fig. 1. The rigid bodies are coupled through different rotational and translational joints, some of which are force elements to allow vertical translations and sagittal–plane rotations of the segments. The measurements of transmission of vertical vibration through-the-body generally require subjects to voluntarily maintain a vertical head position to reduce head-accelerometer orientation errors. The head–neck–shoulder joint is thus considered to be rigid. The shoulders are assumed to be rigidly attached to the thoracic segment.

The torso is made up of three (upper, middle and lower) segments connected by visco-elastic revolute and translational joints to permit relative pitch and vertical motions. The forces and torques generated by the joints are derived assuming linear stiffness and damping properties, which were identified from published studies. The pelvis is connected to the rigid seat by similar elements representing the visco-elastic properties of the buttock tissues. The two thighs are rigidly connected to the pelvis, while the segment masses are chosen from the anthropometric data for the 50th percentile male subject.

The initial model parameters for the joints were obtained from [2]. The model was analyzed to determine the force-motion relationship at the buttock-seat interface expressed in terms of apparent mass (AM) and through-the-body vibration transmission, expressed in terms of seat-to-head acceleration transmissibility (STHT), under a swept-sine vertical acceleration. Normal mode analysis was also performed to study the segment motions and resonant frequencies.

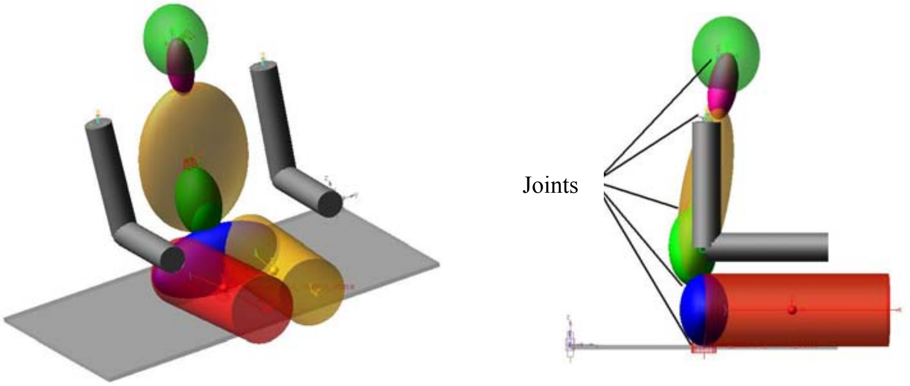

Fig. 1: A multi-body formalism of the seated body.

Results and Discussion

The model validity was initially examined by comparing the AM and STHT magnitude and phase responses with those reported in ISO 5982 [3] and Paddan and Griffin [4]. The results showed poor agreements between the model and reported responses, while the frequencies corresponding to the peak magnitudes were quite close. Normal mode analysis revealed two significant modes: upper-body pitch near 2 Hz, thoracic translation and pitch about the lumbar near 6.6 Hz. Both the AM and STHT responses showed peak magnitude near 4 Hz, while a relatively smaller magnitude peak was observed near 2 Hz. These frequencies agree well with those observed from the biodynamic responses under vertical and horizontal WBV, respectively. The discrepancies in the response magnitudes, however, suggested the need for verification and/or identification of suitable parameters for all the joints. An optimization-based parameter identification technique is thus applied with limit constraints around the reported values to enhance the validity of the model. The results suggest that the model parameters could be identified to match the AM and STHT responses, reasonably well. The feasibility of the resulting model in predicting the relative movements of segments and spine loads could then be explored.

References

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