Investigating The Applicability Of Biodynamic Models To Account For Whole-Body Dynamics On Automotive Seats

S. Rakheja* and P.-É. Boileau**

**CONCAVE Research Centre, Concordia University, 1455, De Maisonneuve West, Montréal, (Québec) H3G 1M8, Canada*

***IRSST, 505 De Maisonneuve West, Montréal (Québec) H3A 3C2, Canada*

1. INTRODUCTION

Automotive seating comfort is strongly influenced by the perception of whole-body vibration, which is related to body posture, static and dynamic properties of the seat, and nature of vibration. The dynamics of the coupled seat-body system is highly complex due to nonlinear response of the seat cushion and the human body to vibration input. The assessment of vibration related comfort performance of automotive seats are thus mostly achieved through laboratory or field experiments involving representative subjects sample and test conditions. This approach, however, raises some ethical concerns associated with vibration exposure of human subjects, and complexities due to inter- and intra-subject variations. In view of the above and significant contributions of the occupant, considerable efforts have been made to develop analytical models of seats and the occupants (PATTEN, 1998; GRIFFIN, 1990). A review of reported seated occupant models suggests that most of these models are derived from biodynamic response measured under excitations and conditions that do not represent automobile driving [ISO/FDIS 5982, 2001]. The validity of these models for automotive seats is thus doubtful. In this study, different occupant-seat models are explored for vibration comfort analyses of automotive seats. A nonlinear model of a seat cushion and its support mechanism is developed on the basis of measured static and dynamic characteristics. Subsequently, analyses and experiments are performed to examine the applicability of some selected linear occupant models.

2. AUTOMOTIVE SEAT MODELING

The static and dynamic properties of a polyurethane foam (PUF) cushion and its support depend upon the material, construction, seated body weight and nature of vibration. An automotive seat cushion is thus characterized in the laboratory under different preloads, representing seated weights of 5^{th} percentile female to 95^{th} percentile male population, and displacement excitations ranging from 2.5 mm to 19 mm at frequencies upto 15 Hz, using a force indentor recommended in SAE J1051 (1988).

The measured force-deflection data revealed nonlinear visco-elastic behavior arising mostly from non-linear stress-relaxation and stress-strain properties of PUF. A constant static stiffness value corresponding to a selected preload could be evaluated assuming small variations around a selected preload. The dynamic stiffness coefficient of a seat, however, differs from its static value. The dynamic stiffness constants are computed from mean force-deflection data measured under sinusoidal excitations of varying amplitudes in the vicinity of a selected preload (Fig. 1). The results suggested that dynamic stiffness is similar to the static value at low frequencies but increases considerably with increase in excitation frequency and decreases with increase in excitation amplitude. The damping properties of the PUF cushion are also derived from the measured data using the principle of energy similarity. The results showed high damping at low frequencies, which decreased rapidly with increase in frequency. The results also showed almost insignificant influence of excitation amplitude.

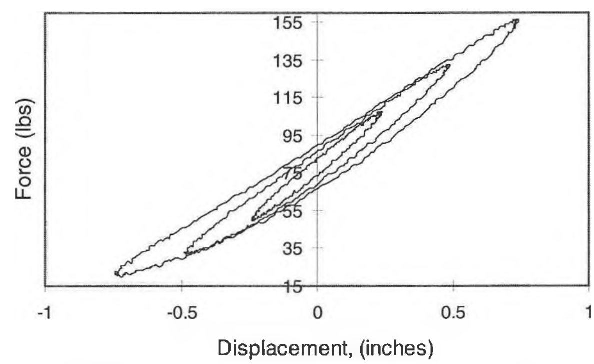

Fig. 1: Dynamic force-deflection of a seat cushion under different excitation amplitudes at 1.5 Hz.

A nonlinear model of the seat is developed on the basis of dynamic stiffness and damping coefficients as functions of excitation and seated body weight. The vibration transmission characteristics of the seat with a passive load are measured in the laboratory and the data is used to validate the seat model and the test methodology. The model results agreed very well with measured data in 0.5-4.5 Hz frequency range. Considerable deviation between the model results and measured data, however, was observed at higher frequencies, which was attributed to hopping of the passive load on the seat.

3. OCCUPANT-SEAT MODELLING

Three different occupant-seat models are derived upon integrating selected biodynamic models of seated occupants to the validated cushion model. The linear occupant models included a single-DOF model (GRIFFIN, 1990), a two-DOF model (SUGGS and STIKELEATHER, 1970) and a four-DOF model (BOILEAU, 1995). These models were derived from the biodynamic responses of subjects in the mass ranges of 58-81 kg, 57-85 kg and 58-90 kg, respectively.

4. MEASUREMENTS

The vibration transmission characteristics of the seat with 6 male human subjects were investigated in the laboratory under sinusoidal and road-measured excitations. The subjects mass ranged from 68 to 80 kg (mean mass of 73 kg). Each subject was seated with feet supported on the vibrating platform and hands on a steering wheel.

5. RESULTS

The acceleration transmissibility characteristics of the seat model employing three different seated occupant models, evaluated under sinusoidal excitations, are illustrated in Fig. 2, together with measured mean and envelope curves. It should be noted that the total masses of models considered are comparable with the mean seated mass of the test subjects (73% of mean body mass). The measured data, attained with human subjects, exhibits considerable attenuation of base vibration at frequencies above 4 Hz, while the resonant frequency of the coupled system lies near 3 Hz. The responses attained with three occupant models differ considerably among themselves and from the measured data. The seat with single-DOF occupant model yields better agreement with the measured mean transmissibility at frequencies close to and below resonace frequency. At frequencies higher than 3.3 Hz, however, the single-DOF model underestimates the measured response by as much as 50%. The responses of the seat-occupant model employing two- and four-DOF occupant models differ considerably from the mean measured response in the entire frequency range.

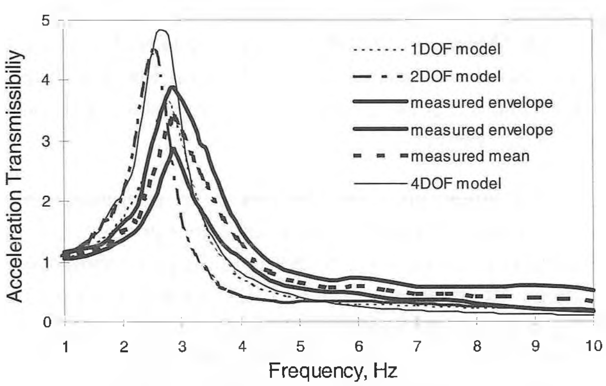

Fig. 2 : Comparison of computed and measured acceleration transmissibility of the seat-occupant system.

The responses of the seat-occupant models were also evaluated under road-measured excitation. The comparisons with mean laboratory measured data further revealed considerable differences between them, irrespective of occupant model employed. Figure 3 shows, as an example, a comparison of PSD of acceleration response of seat- model with a single-DOF occupant model with the mean measured data. In the low frequency range (below 2 Hz), all the three models demonstrated good agreement with the measured response, which is most likely attributed to negligible contributions of occupant dynamics in this range. In the 2-5 Hz range, responses of all models deviated from measured mean response. The models yielded considerable errors in near the resonannce frequency in the 3-3.5 Hz band.

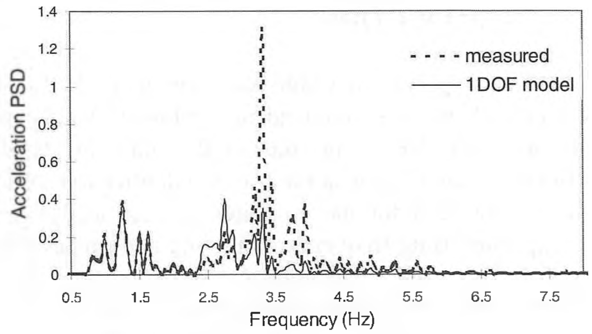

Fig. 3 : Comparison of acceleration PSD of seat model with single-DOF occupant model with mean measured response

6. CONCLUSION

From the study, it is concluded that the response characteristics of reported seated occupant models, when applied to automotive seats, differ considerably among themselves and from the measured data. The combined seat-occupant models yield considerable errors in magnitude responses and resonant frequency of the coupled system, specifically under random excitations. Under deterministic excitations, all the models yield poor estimation of vibration attenuation performance of automotive seats, while that involving the single-DOF occupant model yields somewhat better estimate of the response near the resonant frequency.

REFERENCES

BOILEAU, P.-E., A study of secondary suspension and human driver response to whole-body vehicular vibration and shock, Ph.D. Thesis, Concordia University, 1995.

GRIFFIN, M.J., Handbook of human vibration, Academic Press, 1990.

INTERNATIONAL STANDARDS ORGANIZATION ISO/FDIS 5982, Mechanical Driving Point Impedance and Transmissibility of the Human body, 2001.

PATTEN, W.N., A vibration model of open celled polyurethane foam automotive seat cushions, J. of Sound and Vibration, 217(1), 1998.

SAE J1051, Force deflection measurement of cushioned components of seats for off-road work machines, 1988.

SUGGS, C.W. and STIKELEATHER, L.F., Application of a dynamic simulator in seat testing, Trans. ASAE, 1970, 13, pp. 378-381.