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Journal of Biomechanics 40 (2007) 1493–1503

JOURNAL OF BIOMECHANICS

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Measurement and modelling of *x*-direction apparent mass of the seated human body–cushioned seat system

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Accepted 26 June 2006

Abstract

For modelling purposes and for evaluation of driver's seat performance in the vertical direction various mechano-mathematical models of the seated human body have been developed and standardized by the ISO. No such models exist hitherto for human body sitting in an upright position in a cushioned seat upper part, used in industrial environment, where the fore-and-aft vibrations play an important role. The interaction with the steering wheel has to be taken into consideration, as well as, the position of the human body upper torso with respect to the cushioned seat back as observed in real driving conditions. This complex problem has to be simplified first to arrive at manageable simpler models, which still reflect the main problem features.

In a laboratory study accelerations and forces in *x*-direction were measured at the seat base during whole-body vibration in the fore-and-aft direction (random signal in the frequency range between 0.3 and 30 Hz, vibration magnitudes 0.28, 0.96, and 2.03 ms^{-2} unweighted rms). Thirteen male subjects with body masses between 62.2 and 103.6 kg were chosen for the tests. They sat on a cushioned driver seat with hands on a support and backrest contact in the lumbar region only.

Based on these laboratory measurements a linear model of the system-seated human body and cushioned seat in the fore-and-aft direction has been developed. The model accounts for the reaction from the steering wheel. Model parameters have been identified for each subject-measured apparent mass values (modulus and phase). The developed model structure and the averaged parameters can be used for further bio-dynamical research in this field.

Keywords: Human body; Whole-body vibration; Fore-and-aft direction apparent mass; Seated human body–cushioned seat system modelling

1. Introduction

The biodynamic response of human body to vibration and shocks is a complex problem, which is of permanent interest for decades. The hitherto most comprehensive description of all the aspects can be found in (e.g. Balandin et al. (2001) and Griffin (1990) and in an abridged way in Mansfield (2005). One of the permanent problems is a faithful but reasonable simple modelling of the human body in various practical positions, e.g. sitting in a suspended cushioned driver's seat in working environment or in an unsuspended cushioned passenger car seat leaned back. Much work on this issue has been done for the vertical (z–axis) direction, e.g. Meltzer et al. (1986), Griffin (1990), Fairley (1990), Griffin (1998), Griffin (2002), Boileau et al. (2002), Mansfield (2005) and Wölfel and Rützel (2005) to name but a few. Mathematical models of the vertical apparent mass of the upright sitting human body are developed for example in Fairley (1990), Wei and Griffin (1998) and Boileau et al. (2002). In the fore-and-aft and lateral directions not much work has been hitherto reported. Probably the hitherto most comprehensive human body response measurements in the fore-and-aft direction (x–axis) and in the lateral direction (y–axis) have been reported in Fairley and Griffin, (1990); Holmlund and

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0021-9290/$ - see front matter
doi:10.1016/j.jbiomech.2006.06.012

Lundström, (1998) and Mansfield and Lundström, (1999), and recently by Fleury (2004), Nawayseh and Griffin (2005b), Mandapuram et al. (2005), Mansfield and Maeda (2005), Hinz et al. (2006). The papers (Fairley and Griffin, 1990; Holmlund and Lundström, 1998; Mansfield and Lundström, 1999) are concentrated on measurement of human body sitting upright on a rigid seat in a well-defined biodynamical position without interaction with controls or the seat back. This approach is well justified for biodynamical research purposes, however does not bring full answers to some practical problems. Only very few papers are concerned also with influence of the seatback support (Fairley and Griffin, 1990; Fleury, 2004; Nawayseh and Griffin, 2005a; Mandapuram et al., 2005; Mansfield and Maeda, 2005). Other papers deal with cushioned car passenger seats (Wu et al., 1999; Rakheja et al., 2002; Hinz et al., 2004; Rakheja et al., 2005); however the driver's/passenger's posture is somehow different from the one observed in industrial environment and the reported excitation intensities are much lower than in the latter case. Despite of some similarities these two seat classes are treated more-or-less separately.

Driven by practical problems, also in view of the EC Directive 2002/44/EC, a European project, with acronym "VIBSEAT", dealing also with analysis and mitigation of fore-and-aft, as well as lateral vibrations has been initiated. One specific problem tackled within this project was a development of a cushioned seat upper part–upright sitting human body model accounting for:

- Interaction with vehicle controls and there-from resulting force reactions,
- Influence of sitting posture,
- Influence of cushioned seat in contrary to a hard support, assuming a contact with both soft seat cushion and soft seatback embedded in a rigid frame.

There are no reliable models of human body or of the system cushioned seat upper part–seated human body for the fore-and-aft direction. Hence a first attempt has been made to propose a reasonable simple mechano-mathematical model, which provides a faithful representation, which is justified from physical and biodynamical point of view. Below the proposed linear translatory model of the system: upright seated human body—cushioned seat upper part is described and model parameters are identified, based on x-direction apparent mass measurement with a cohort of test subjects sitting in a defined position in the upper cushioned part of a typical driver's seat. This model is proposed for further use in biodynamical research of cushioned seats as one possible approach to modelling of this rather complex problem.

2. Description of apparent mass

The apparent mass method is one method of measuring the dynamic response of the human body and indicates presence of resonances (Mansfield, 2005). The apparent mass of the human body in the vertical direction has been used for long time to predict dynamics of vehicle seats, to provide target dynamic response characteristics for the design of seat vibration test dummies. It is a well-established descriptor in biodynamics and in human influence of vibrations research as thoroughly described by Griffin (1990) and Griffin (1998), as well as by Mansfield (2005). International standardization in this field is well advanced. Within the ISO TC 108/SC4 the standard ISO 5982 (2001) has been developed amalgamating most of the hitherto reported laboratory measurements. Idealised values of various human body characteristics under vertical vibration are described and critically analysed by Boileau et al. (1998) and Boileau et al. (2002). A national standard DIN 45676 (2003) exists too, which ought in more exact way than ISO 5982 (2001) approximate the hitherto z-direction apparent mass laboratory measurements (Wölfel and Rützel, 2005); however its scope is somehow limited. These models are representative of an upright sitting human on rigid support, without back support under rather high acceleration intensities. They are not suited for the backward inclined automobile posture situations.

The basic definition of human body apparent mass in vertical direction $\mathbf{M}_a(\omega)$ as a function of positive angular frequency $\omega = 2\pi f$ within a given frequency range is defined in following way according to the Standard ISO 5982 (2001) and Mansfield (2005). The apparent mass $\mathbf{M}_a(\omega)$ is the complex ratio of an applied excitation of a system (force $\mathbf{F}(\omega)$) to its response (acceleration $\mathbf{a}(\omega)$) in the same point and the same direction, both being complex quantities:

$$\mathbf{M}_a(\omega) = \frac{\mathbf{F}(\omega)}{\mathbf{a}(\omega)}. \quad (1)$$

Various approaches to modelling of seated human body in the vertical direction are used (e.g. Griffin, 1990; Wei and Griffin, 1998; Fairley, 1990; Smith, 2000; Boileau et al., 2002; Nawayseh, 2002). The modelling of the human body in the backward inclined automobile posture is widely treated too (White et al., 1999; Nishiyama et al., 2000; Rakheja et al., 2005). Fleury and Mistrot (2006) describe a x-direction human body model using rotary and translatory mechano-mathematical elements used for prediction of x-direction vibration suppression by a driver's seat equipped with a fore-and-aft suspension system. Here another approach will be followed: the rather complex problem will be simplified a little to arrive at a simple mechano-mathematical model, which would still reflect the main