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Biomechanical Model for Seat Comfort in Automobiles

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***Abstract* – The article proposes a simplified biomechanical model optimized by real world measurements of a passenger in an automobile passing over an obstacle (speed bump) at constant velocity. Samples of 15 male volunteers were used to obtain reliable overlay of acceleration data. The experiment uses an optoelectronic velocity sensor with analog accelerometers placed at key anatomical locations on the volunteers. The acceleration results represent the response (impulse) of the speed bump on the passengers. A biomechanical model using the average anthropomorphic values of the samples is then constructed in the Matlab/Simulink/Simmechanics software. Stiffness and damping parameters were then optimized until the best correlation between measured and simulated response was achieved. The results of the optimized model show good correlation of kinematic data for the head between measured and simulated (optimized) results. Thus the optimized model gives a good indication of the approximate vertical stiffness and damping parameters of a person's neck when driving over an obstacle in an automobile. The resonant frequencies of the head are obtained through FFT analysis and correspond well to other studies. Although the trunk of the model shows lower correlation to experiments, it still provides informative data but a more complex trunk model is suggested for future studies.**

***Keywords* – Automobile, Biomechanics, Measurement, Seat Comfort.**

I. Introduction

There are many different definitions of automobile seat comfort. The most sophisticated is that the automobile seat comfort is defined as a consensually held construction (i.e. a large group of representative subjects which perceive the seat in a similar manner) possessing a static and dynamic component that can be manifested objectively (i.e. consistently quantifiable) [1]. The factors affecting seat comfort are: (a) vehicle factors, (b) social factors, (c) individual factors, (d) seat factors. To fulfill the above definition we need to create performance measures for automobile seat comfort related to physiology and biomechanics [1]. For example, vibration can be quantified or measured with accelerometers. Vibration is one of the limiting factors of seat comfort and the vibration of the whole body causes many health (both physical and psychological) problems which, in turn, have a direct impact on the overall safety of the vehicle. Therefore many researchers are dealing with this problem.

The transmission of vibrations onto the seated human body has been of great interest to researchers dealing with the comfort and discomfort of human occupants [2]. The need of a comfortable seat requires more challenging designs. To predict the response of the coupled system consisting of the human body and the seat, we can apply numerical methods, experimental methods or a combination of both methods to obtain a favorable result. Analyzing this coupled system by a new experimental method proposed in [2] the basic resonant frequencies have been obtained. This study shows that the resonant frequencies are below 80 Hz for the coupled and uncoupled systems excited by road vibration, with resonant frequencies bellow 60 Hz. This means that key vibration attributes of the occupied seat structural resonant frequencies and mode shapes can be characterized and predicted from their corresponding unoccupied seat characteristics [2].

The effect of nonlinear biodynamics has been studied in [3]. The presented results indicate that the nonlinear properties of the coupled model significantly affect its dynamics and lead to quantitative deviations from the predictions of corresponding linearized models.

Therefore, many models are tested and verified by fitting experimental data. The models proposed in [4] reflect the sitting posture. The eight presented models are built from several masses, linear rotation/translation spring-dampers. The models differ from each other in the definition of joints and body segments. Analyzing these models, the best representation with resonance between 5.35 and 8.34 Hz are used. The selected model can more accurately depict apparent mass and head transmissibility simultaneously more so than other models, especially in rotational transmissibility [4].

The reaction of the human body to vibration is muscle activity. The muscle activity is highly correlated with lateral acceleration and significant differences are observed with respect to the direction of acceleration [5]. Therefore car manufactures should concentrate on chassis design, and seat structure.

Currently there exist numerous studies regarding the biomechanical model of a passenger in a vehicle. This passenger is often modeled in the postural plane of the biomechanical human model with 1, 2, or 3 DOF (Degrees Of Freedom) or a more complex biomechanical model with 9 DOF is used [6], [7]. Within these models the translational movement of each body segment is considered. Other studies assume a 4 or 5 DOF model which also considers the rotational components of the body segments. The 4 DOF model has been incorporated in to the standard ISO 7962 (1987). The difference between the 4 and 5 DOF model is that the prior model considers the head and neck as a single segment whereas the 5DOF model considers them to be independent [8]. All anthropomorphic parameters in these models are calculated using D. A. Winter [9]. However, many of these studies use experiments with controlled conditions

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(usually performed on shake tables etc) and few experiments, if any to date, incorporate real measurement inputs from everyday driving as excitation into the biomechanical model. This study aims at using experimental data to construct and optimize a simplified 2DOF biomechanical model from measurement data obtained under real driving conditions

II. Experiment

According to STN EN 30326 the method, procedure, and limitations in the measurement of mechanical vibration are described. These vibrations are important in building a suitable biomechanical model of a human passenger in a vehicle (whereby these vibrations are used as excitation of the model). Within the aforementioned standard the exact type, number, and placement of sensors are defined to accurately measure vibrations on the passenger's seat. The first of these sensors (accelerometers) is required to be placed on the floor of the vehicle within a circle whose diameter is 200mm. The center of this circle must be placed directly under the second sensor which is placed on the sitting part of the passenger seat. The last sensor is placed on the lumbar support of the seat according to fig(1).

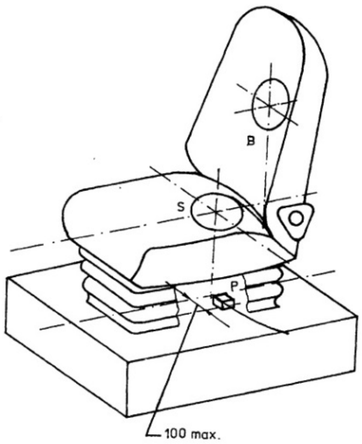

Fig. 1. Placement of accelerometers on the passenger seat [11]

The sensors are placed at the above mentioned positions by mounting them on a disk with a diameter of 250mm. The thickness of the disk must not be greater than 12mm. the mounting disk is made of semisolid rubber or plastic with a hardness factor of 80-90 according to Shore [10]. In the center of the disk, a cavity holds the actual sensor which must be mounted on a thin steel disk which has a diameter of 75mm and a thickness of 1,5mm. The measurement directions must correspond to the general coordinate system of the vehicle (parallel to the direction of vehicle travel). [11]

For the purposes of the experiment and verification of the model, it was necessary to place accelerometers directly on the human body. No studies or standards dictate the placement of these sensors for this specific measurement, therefore the sensors are placed at key anatomical locations of interest (Hip, Trunk, and each hemisphere of the head) fig(2).

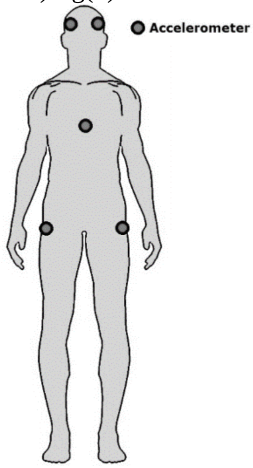

Fig. 2. Location of accelerometers on the passengers (subjects)

All measurements were performed according to the ethical codex AREA (American Educational Research Association) and BERA (British Educational Research Association).

In order to obtain an accurate characteristic of accelerations occurring on the human body, a sample of 15 male subjects with an average age of 24.1 years, height 178.8 cm, and weight 80.2 kg volunteered to participate in the experiment. Each subject was instructed to sit in the passenger seat of the vehicle while 8 individual measurements (impulses) were recorded. The basic physical parameters of the measured subjects can be seen in tab.(1).

Subject	Age (years)	Weight (Kg)	Height(cm)
1	25	76	179
2	25	83	176
3	23	78	177
4	24	82	177
5	24	80	181
6	25	85	182
7	25	78	178
8	24	79	176
9	24	85	180
10	23	81	181
11	25	75	176
12	25	79	178
13	23	83	182
14	23	75	179
15	24	84	180

Tab. 1. The basic physical parameters of the measured subjects

Altogether, 120 measurements were performed then statistically processed to obtain a reliable overlay of acceleration data to obtain a general response characteristic of each segment.

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III. Apparatus

The measurement uses a common passenger vehicle (automobile) conforming to the standard in [12]. The vibrations are measured by accelerometers as the vehicle passes over a speed bump seen in fig(3), at a constant speed of 40km/h. To ensure constant velocity of the automobile, an optoelectronic velocity sensor (correvit HF-250C) is mounted on the vehicle and the data is recorded on an onboard laptop located in the rear seats of the vehicle. In the measurements, tri-axial accelerometers from Analog Devices (ADXL 325) were used to measure accelerations.

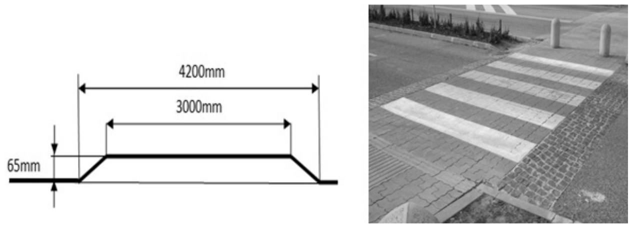

Fig. 3. Obstacle used in experiment

These ADXL sensors allow for the accurate measurement of accelerations within a range of ±5g. For better measurement resolution the sensors are analog, therefore the apparatus incorporates an analog to digital converter from National Instruments (NI USB-6221 DAQ). The converted signals are then recorded using the accompanied software from National Instruments (Signal Express) on a laptop in the back seat of the vehicle. Both correvit and ADXL sensors were set to sample at a frequency of 1kHz to ensure sufficient data to accurately describe the response characteristic and speed of the vehicle. To reduce the effects of unwanted noise the signals were filtered in post processing in the program MATLAB by implementing a second order low pass Butterworth filter with a cutoff frequency of 15Hz [13]. After filtering, the statistical averages of the acceleration characteristics for all 120 measurements were then used in the optimization algorithm of the biomechanical model.

IV. Modelling and Optimization

Due to the nature of the measurement (a vehicle passing over an obstacle at constant velocity), a 2DOF biomechanical model was sufficient to obtain the desired parameters of the experiment. The model was intended for the verification of seat comfort when driving over a speed bump at constant velocity, thus the rotational effects of the segments were neglected. The maneuver that the vehicle performed introduced a significant vertical impulse into the system, which can have negative effects on the human spine [14], [15]. This impulse is used as excitation into the system. The model assumes the principles of Newton's second law (equation 1).

$$\sum \bar{\boldsymbol{F}} = m.\bar{\boldsymbol{a}} \quad (1)$$

$$\bar{M}\ddot{q} + \bar{B}\dot{q} + \bar{K}\bar{q} = \bar{f} \quad (2)$$

Applying Newton's law on the system in fig.(4) we obtain the 2DOF mathematical description (equation 2) of the head and core (trunk).

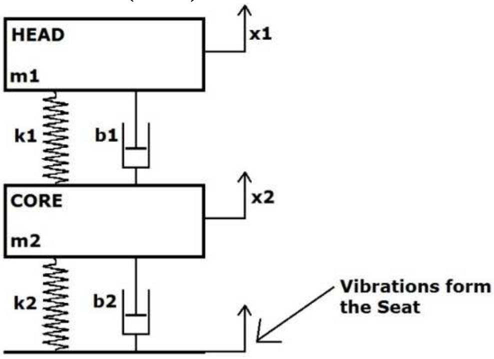

Fig. 4. 2 DOF model of the Passenger

The mass of each body segment was calculated with respect to D. A. Winter (9). Random stiffness parameters k1, k2 and damping parameters b1, b2 were selected as initial conditions for the model. The numerical behavior of the system is described with differential equations defined in the MATLAB program. The simulation itself, which describes the behavior of the system, is performed in MATLAB\SIMULINK. The graphical representation of the results is performed in the MATLAB\SIMULINK\SIMMECHANICS program intended for the graphical interpretation of the acceleration of each body segment which made it possible to immediately identify key events when the vehicle encountered the speed bump. The initial poor correlation between the accelerations obtained from the simulation and the experimental acceleration data were expected, since the initial stiffness and damping parameters were only approximated in order to verify the kinematics of the model in the MATLAB program. Therefore the initial results of the simulation do not represent the measured accelerations of the body segments. In order to overcome this problem and find the likely stiffness and damping parameters of the numerical model, we used an optimization algorithm which varies the stiffness and damping parameters of the segments until the best correlation of kinematic results obtained by the experiments is found (16). The principle of the optimization algorithm was to find the best parameters of stiffness and damping such that the correlation of accelerations obtained from the simulation were comparable to the accelerations obtained from simulations. Therefore it was necessary to write a script in the MATLAB environment which would efficiently and accurately apply the aforementioned optimization principle. In order to increase optimization efficiency without compromising accuracy, the algorithm was written with progressively finer steps in parameter variation. Resonant frequencies of the segments were then calculated using the FFT (Fast Fourier Transformation) analysis of the model under the optimized conditions.

V. Result

The outcome of the study represents the optimization of the kinematic results between experiments and simulations in order to obtain the optimal stiffness and damping parameters for the biomechanical model. These parameters were found by writing an optimization script which varied stiffness and damping parameters in order to obtain good correlation between accelerations in the virtual model (simulation) and accelerations obtained statistically by experiments. The 2 DOF biomechanical model was designed for the quantitative evaluation of vertical head and trunk accelerations, whose anthropomorphic parameters were defined by D. A. Winter (9). Fig.(5) and Tab.(2) show the average values and standard deviations of stiffness and damping parameters in the neck and trunk.

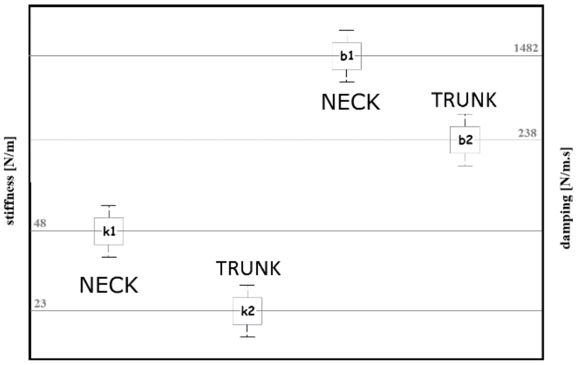

Fig. 5. Mean and STD of the stiffnes and damping parameters

Parameter ater optimalization	MEAN	STD
Stiffnes K1 [N/m]	48	4
Damping B1 [N/ms]	1482	36
Stiffnes K2 [N/m]	23	4
Damping B2 [N/ms]	238	7

Table 2. The average values and standard deviation of the stiffness and damping parameters in the neck and trunk

Fig (6) represents the values of the accelerometer placed on the head. The head accelerations from the biomechanical model, after optimization of neck stiffness and damping parameters, correlated to within 79.34 - 91.85% to the experimental results. Fig (6) represents the best correlation between experimental and optimized head accelerations after the stiffness and damping parameters of the neck were optimized. Fig (6) also shows the simulated head acceleration prior to optimization. Similarly fig(7) shows the same relation for trunk (core) accelerations which correspond to within 63.87% - 65.34% to the experimental results. The resonant frequencies of the head were found from the FFT of the signals which resulted in resonance at 3.1Hz with SD (Standard Deviation) of ±0.15Hz, 6.9Hz with SD ±0.19Hz, and 13.5Hz with a SD of ±0.23Hz.

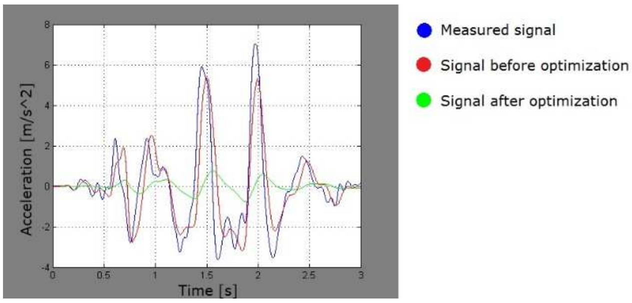

Fig. 6. Acceleration of the Head

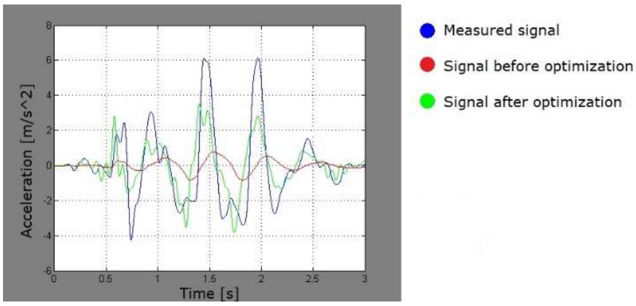

Fig. 7. Acceleration of the Trunk

VI. Conclusion

As can be seen, the virtual model incorporated in the study can be used only for the simulation of a vehicle passing over an obstacle (speed bump). The results show good correlation for head accelerations; however the trunk accelerations correlated less. This is likely due to the trunks more complex construction which, for future studies, should not be considered as a solid mass. In the future it would be advantageous to use Hills nonlinear muscle model in the simulations [17]. It is also necessary to expand the model into a more complex 9DOF system if we are to incorporate more complex (significant movement in all three directions) vehicle maneuvers (turning, uncontrolled sliding, etc…). However for simple cases such as the one presented, a 2 dimensional model is often enough and offers the best compromise between computational efficiency and accuracy. Although the correlation of trunk accelerations between simulated and experimental results were low compared to the head, the optimization algorithm was able to accurately determine stiffness and damping parameters in the neck which corresponded to other studies [6],[7],[8].

References

[1] Kolich, M.: A conceptual framework proposed to formalize the scientific investigation of automobile seat comfort, Vol. 39, 2008, pp. 15-27

[2] Lo, L. – Fard, M. – Subic, A. – Jazar, R. : Structural dynamic characterization of a vehicle seat coupled with human occupant, Journal of Sound and Vibration, Vol. 332, 2013, pp. 1141-1152

[3] Papalukopoulos, C. – Natsiavas, S.: Nonlinear Biodynamics of passengers coupled with quarter car models, Journal of Sound and Vibration, Vol. 304, 2007, pp. 50-71

[4] Kim, T.H. – Kim, Y.T. – Yoon, Z.S.: Development of a biomechanical model of he human body in sitting posture with vibration transmissibility in the vertical direction, Industrial Ergonomics, Vol. 35, 2005, pp. 817-829

[5] Farah, G. - Petit-Boulanger, C. – Hewson, D.J. – Duchene, J.: Surface electromyography as a tool to assess the responses of car passengers to lateral acceleration, Part II. Objective comparison of vehicles, Journal of electromyography and kinesiology, Vol. 16, 2006, pp. 677-684

[6] Yong Ch., Yong-San Y., Biomechanical model of human on seat with backrest for evaluating ride quality, International Journal of Industrial Ergonomics 27(2001) 331-345

[7] Wei L., Griffin M. J., Mathematical Model for the Apparent Mass of the Seated Human Body Exposed to Vertical Vibration, Journal of sound and Vibration (19980 212(5), 855-874

[8] Yasunao M., Michael J. G., Modelling the dynamic mechanism is associated with the principal resonance of the seated human body, Clinical Biomechanics 16 Supplement No. 1(2001) S31-S44

[9] Ethier, C. Ross. Simmons, Craig A. Introductory Biomechanics: From Cells to Organisms, University of Toronto, Cambridge University Press, pp. 332-471, 2007.

[10] STN EN ISO 868, Plastics and ebonite. Determination of indentation hardness by means of a durometer (Shore hardness)

[11] STN EN 30326, Mechanical vibration, Laboratory method for evaluating vehicle seat vibration.

[12] STN EN ISO 6813, Road vehicles. Collision classifikation. Terminology.

[13] ButterworthFilters,http://www.mathworks.com/matlabcentral/fileexchange/38584-butterworth-filters

[14] Stephan M, Nasser B. Radivoj M.V., David. I.M and Broje R. Does Dailyw xposure to Whole-Body vibration and Mechanics Shock Relate to the Prevalence of Low Back and Neck Pain in a Rural Workforce. Ann OccupHyg (2012) 56(1): 10-17

[15] Adurey H., Frederic R., Pascal D., Herve G., Hevre H. Determination of pre-impact occupant posture and analysis of consequences on injury outcome-Part II: Biomechanical study, Volume 43, Issue1, January 2011, pages 75 -81

[16] Michael I.J., Zoubin G. Tommi S. J., Lawerence K.S. An Introduction to Variational Metods for Graphical Models, Machine Learning, 34, 183-233 (1999).

[17] Hof A.L et. Al. EMG to forceprocessing I. An electrical analogue of the hill muscle model. Volume 14. Issue 11, 1981, Pages 747-753,755-758.

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