The human body behavior under vehicle vibrations

RAUL MIKLOS KULCSAR, VERONICA ARGESANU, ION SILVIU BOROZAN, INOCENTIU MANIU
Mechanical Engineering Faculty, Mechatronics Department
“POLITEHNICA” University from Timisoara
1, Mihai Viteazu Blvd., RO-300222, Timisoara
ROMANIA
raul_k20@yahoo.com

Abstract: - The influence of vertical vibrations on the human body is analyzed on the basis of models, where the main components and their characteristic properties are made evident. As a function of position of the body, there are considered models, having concentrated masses, elastic constraints and dampers. For a few models that are presented, the matrix differential equations of motion are written and the mathematical input-state-output model (M-ISO-M) is specified. On the basis of the adopted mathematical models, computer block diagrams are defined. Thus, for the study of behavior of the mechanical systems, calculus diagrams are elaborated, in order to make evident the connections between the blocks and the developments with the help of Math Lab simulation of the system response to a harmonic input signal. Also with the help of the AnyBody Modeling System software, a driving simulation had been made, resulting intense muscle activities by subjecting the human body to the vehicle vibrations and external forces. The concrete cases that are studied refer to real situations for which the system parameters are deduced by a methodology, previously specified. In each case, fixed by the program running, for each mass, the amplitude-pulsation characteristics are determined, making evident the resonance possibilities.

Key-Words: - Vibration, human body, simulation, dynamic model, car seat.

1 Introduction
The influence of vehicle vibrations on the human body during the drive shows a distinctive importance because it inflicts a state of tiredness, especially to the driver who makes an additional effort in comparison the other passengers.
The forces are transmitted to the human body through the car seat, through the vehicle chassis and through the surrounding air that can be applied on one or more directions.
The main effort results from vertical vibrations of the seat but also postural stress, the effort made during the operation of different commands and the steering wheel, effort made for maintaining the balance in the seat while driving on uphill or downhill or following the road where the vehicle is driven.
Vehicle designers all around the world are trying to create functional seats that provide adequate physiological driving conditions. The creation of ideal driving condition implies a determination of the drivers efforts, its measuring and the response of the human body to each of these efforts, their comparison to normal physiological limits and as a result of this, the interventions on the driver’s seat for setting the drivers demand to his physiological possibilities [2, 3, 6].

The spine and internal organs are subjected to successive compressions and expansions. These unwanted movements produce on intervertebral disc side-compaction, a torsion of the spine, leading to neuralgias, sciatica, disc ruptures etc.
Due to the presence of soft tissues, of bones, of internal organs and also because of the configurationally particularities, the human body is a complex mechanical system. External vibrations can be transmitted to the human body in vertical, horizontal, sitting positions or through the hands while driving. The ways of transmitting these vibrations through the human body, show a special interest, and the influence that they have on internal organs and tissues [1, 9, 11].
Although, vibrations, under which the driver is subject to during the drive, are transmitted to him on a vertical, a vertical a horizontal plan, it is considered that vertical vibrations that are transmitted through the seat, lead in big proportions to the worsening of driving conditions.

2 Dynamic model of the human body
The problems of the influence of vibrations on internal organs and brain, as well as interactions of organs under vibration movements haven’t been yet analyzed in detail.
From a biodynamical point of view, the driver represents a distortionable body on whom mechanical and other kind of forces are acting. It also has to be mentioned that in the human body there are several formations which serve for stiffness and shock and vibrations dampers. Depending on the selection of the organs from abdominal cavity, the human body can include many rigid parts, connected with the aid of nonlinear springs and dampers, through which the stiffness and the damping capacity of the viscera (intestine), intervertebral discs, ligaments and conjunctive tissue etc. [3, 4, 5].

The way of obtaining a possible mechanical study in case of one driver is given in fig.1. In order to give an explanation regarding the vibration of the seat on internal organs and on the spine, there can be attached different other mechanical models. The mechanical model given in fig.2 consists of tree masses: head, thorax and hips, connected through flexible elements, which assure an elastic suspension. There is a simplified model for presenting the human body in a sitting position. The first step in the dynamical study of human body behavior is the introduction of such simplified and easy to use models. On the basis of the general anatomic portrait, the model from fig.2 was suggested. The simplified mechanical model of the driver sitting on a seat on a platform with vertical vibrations, includes the components shown in the scheme from fig.3.

Notations:
- \( m_1 \) – head and first vertebra;
- \( m_2 \) – spine;
- \( m_3 \) – thoracic cavity;
- \( m_4, m_5 \text{ and } m_6 \) – internal organs;
- \( m_7 \) – pelvis and legs;
- \( k_1...8 \text{ and } c_1...7 \) – linear springs and dampers representing the stiffness of the different parts of the human body.

Mechanical models describe that interaction between driver and vehicle reflect only certain particular aspects without being able to give an answer to all the problems that might appear.

### 3 Mathematical input-state-output system

Initially, the differential equations of the movement of the 7 masses were determined, assuming that the supporting platform has a constant harmonic vibrating movement. Initially, the differential equations of the movement of the 7 masses were determined, assuming that the supporting platform has a constant harmonic vibrating movement \( y_f = y_{0f} \sin \omega t \). If marked \( y_i \ (i = 1, 2...7) \) the system of differential equations of movement, written in form of a matrix, becomes:

\[
\begin{bmatrix}
\frac{d^2y_1}{dt^2} \\
\frac{d^2y_2}{dt^2} \\
\frac{d^2y_3}{dt^2} \\
\frac{d^2y_4}{dt^2} \\
\frac{d^2y_5}{dt^2} \\
\frac{d^2y_6}{dt^2} \\
\frac{d^2y_7}{dt^2}
\end{bmatrix} =
\begin{bmatrix}
k_1 & -c_1 & 0 & 0 & 0 & 0 & 0 \\
0 & k_2 & c_2 & 0 & 0 & 0 & 0 \\
0 & 0 & k_3 & c_3 & 0 & 0 & 0 \\
0 & 0 & 0 & k_4 & c_4 & 0 & 0 \\
0 & 0 & 0 & 0 & k_5 & c_5 & 0 \\
0 & 0 & 0 & 0 & 0 & k_6 & c_6 \\
0 & 0 & 0 & 0 & 0 & 0 & k_7
\end{bmatrix}
\begin{bmatrix}
y_1 \\
y_2 \\
y_3 \\
y_4 \\
y_5 \\
y_6 \\
y_7
\end{bmatrix} +
\begin{bmatrix}
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
0
\end{bmatrix}
\]
\[ [A] \{\dot{y}\} + [C] \{\ddot{y}\} + [K] \{y\} = \{F\} \] (1)

with the notations:

\[ [A] = \begin{bmatrix}
  m_1 & 0 & 0 & 0 & 0 & 0 & 0 \\
  0 & m_2 & 0 & 0 & 0 & 0 & 0 \\
  0 & 0 & m_3 & 0 & 0 & 0 & 0 \\
  0 & 0 & 0 & m_4 & 0 & 0 & 0 \\
  0 & 0 & 0 & 0 & m_5 & 0 & 0 \\
  0 & 0 & 0 & 0 & 0 & m_6 & 0 \\
  0 & 0 & 0 & 0 & 0 & 0 & m_7 \\
\end{bmatrix} \]

\[ [C] = \begin{bmatrix}
  c_1 & -c_1 & 0 & 0 & 0 & 0 & 0 \\
  -c_1 & (c_1 + c_2 + c_3) & -c_3 & 0 & 0 & 0 & -c_2 \\
  0 & -c_1 & (c_1 + c_2) & -c_4 & 0 & 0 & 0 \\
  0 & 0 & -c_4 & 2c_5 & -c_6 & 0 & 0 \\
  0 & 0 & 0 & -c_6 & c_7 & 0 & 0 \\
  0 & 0 & 0 & 0 & -c_7 & c_8 & 0 \\
  0 & 0 & 0 & 0 & 0 & -c_8 & (c_2 + c_3) \\
\end{bmatrix} \]

\[ [K] = \begin{bmatrix}
  k_1 & -k_1 & 0 & 0 & 0 & 0 & 0 \\
  -k_1 & (k_1 + k_2 + k_3) & -k_3 & 0 & 0 & 0 & -k_2 \\
  0 & -k_1 & (k_1 + k_2) & -k_4 & 0 & 0 & 0 \\
  0 & 0 & -k_4 & 2k_5 & -k_6 & 0 & 0 \\
  0 & 0 & 0 & -k_6 & k_7 & 0 & 0 \\
  0 & 0 & 0 & 0 & k_7 & 0 & 0 \\
  0 & 0 & 0 & 0 & 0 & -k_8 & (k_2 + k_3) \\
\end{bmatrix} \]

Where:

- \([A]\) – inertia matrix;
- \([C]\) – amortization matrix;
- \([K]\) – stiffness matrix;
- \(\{y\}\) – displacements vector;
- \(\{F\}\) – disruptive force vector.

By immediate algebraic transformation, the equations system (1) transform in input-status-output equations:

\[ \dot{x} = A \cdot x + b_u \cdot u \]

\[ y = C \cdot \dot{x} \] (2)

\(A\) – the systems state matrix;

\(y = \{x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}\}\) – state vector;

\(u = \{0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0\}\) – vector of input quantities;

\(b_u = 1/m_1;\)
4 Simulation of the human body’s dynamic behavior

4.1 Simulation using Mathlab software

In case of the vertical vibrations, the resonance frequency for the system thorax-abdomen is 3-4 Hz, for the head 18–30 Hz, for the shoulders 4-5 Hz, for the chest cavity 4–6 Hz and for the viscera from the abdominal cavity taken as a compact system 3-5 Hz.

The construction of the mechanical model for the study of dynamics of the human body sitting on a seat requires the specification of the elastic and mass features of the human body. As a consequence, the main parameters of the organism are set in this paper, starting with some well-known data from standards and experiments regarding distribution of the masses and resonance frequencies [6, 7, 8].

The initial data have been taken from specialist literature. It has been taken into consideration a standard model subject with its mass of 80 kg and the mass distribution that can be specified on the basis of previous researches. In addition to this, according to the assumed simplified hypothesis, it is supposed that the equation is equal: $k_5 = k_4$ and $k_6 = k_7$.

While determining the parameters of the model, it had been used well-known resonance frequencies for different parts of the human body, that are obtained in an experimental way.

The features amplitude-pulsation for the masses $m_1…m_7$, obtained on the basis of the created program, are shown in fig.4.(a.b.c.d.e.f.g.). By overlapping of the features amplitude-pulsation for the 7 masses, a more suggestive presentation has been obtained in fig.5.

A representing of all 7 features in linear coordinates is shown in fig.6. So it is determined that the resonance edges of the amplitudes overlap, where each mass presents a resonance with the same pulsation-values, but more or less prominent.

4.2 Simulation using AnyBody Modeling System software

The AnyBody Modeling System is a software system for simulating the mechanics of the live
human body working in concert with its environment. In this case the simulation was driving in to an “S” curve with 60m radius, at the speed of 12m/s, by subjecting the human body to high frequency vibrations.

The body models are available in the standard demo package that can be used in conjunction with the AnyBody human body simulation software. Starting from a standing human model, using pre-defined muscles and bone attachments, and building the seated driving postures scenarios, have been developed.

For the seated position, the car seat was added virtually through a node that offers a stable platform for the pelvis region. The angles for the legs were obtained from an ideal theoretical position for the purpose of minimizing their involvement in the general muscle activity of the body system.

All activities include certain tensions in the hands given by the steering wheel load. Because of this factor, the model has forces attached to the nodes belonging to each of the hands. This ensures that the data output is similar to that which would be obtained from a real life model and further adds to the accuracy of the model [10].

All movement patterns were carefully studied for muscle collision and kinematical correctitude; after all data was considered viable, the next phase of the study – using inverse dynamics, was conducted (fig. 7). The data was then extracted from the output of the program for the various muscle groups that were of interest (trunk muscles and general muscle activity). The most relevant data was considered the trunk muscle fatigue. Muscle fatigue (Activity) is defined by the AnyBody solver as muscle force divided by strength. The results are presented in graphical form in fig. 8 and 9.
4 Conclusion
While the program for the behavior simulation of the model under vibrations is running, the features amplitude-pulsation and amplitude-frequency are obtained corresponding to the mass of the components. It is found that for each mass, edges of the amplitude appear on the right side of its own vibrating pulsations, namely in situations of resonance. The systems own pulsations are smaller than the pulsation of component masses taken separately. As for small pulsations the amplitude of the movement of each mass is big, comparable to the amplitude of the disruptive movement or even bigger, results the importance of the design and utilization of devices necessary for eliminating the negative effects on the human body. Generally, calculating programs use as input data obtained through experimental ways and according to the basic algorithm that serve as a base for implementation, processing of these data obtaining in the end the final results wanted.

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