INFLUENCE OF DETERIORATION OF VIBRATION PARAMETERS ON MOTOR VEHICLE'S VIBRATION COMFORT

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1. INTRODUCTION

Dynamic simulation based on modeling of designed systems has an important role in motor vehicles development process. In practice, a whole range of vehicle models is used [4, 5, 7-13, 23]. Let's assume that a mechanical model of the observed motor vehicle is described, in general, by differential equation [5, 6]:

$$\dot{Z} = \dot{Z}\left(Z, A, U, L, Q, t\right) \tag{1}$$

where:

Z - is a vector of generalized coordinates of the vibration system,

A - is a vector of system vibration parameters,

U - is a vector of control functions,

L - is a function that considers random variations of vibration parameters characteristics during vehicle exploitation,

Q - is excitation time function (originating from road roughness, engine operation, unbalanced masses, tire nonuniformity) and

t - is time.

General solution of the differential equation (1) may be written in the following form [3]:

$$Z = Z(A, U, L, t) \tag{2}$$

A simple case is when there are no control functions (U=0) and changes in vibration parameters during exploitation are not considered (L=0):

$$Z = Z(A, t) \tag{3}$$

Simplification given by equation (3) is most frequently used in practice - the influence of the length of exploitation on change of vehicle's vibration parameters is neglected. However, it represents a major simplification, because data from [21] show that deterioration of the mentioned vibration parameters does exist.

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2. SELECTION OF A MODEL

Structure of a vehicle model is selected depending on the quantities that should be observed. In this case, an oscillatory model from [8] is used that is acceptable because it includes influences of all vibration parameters, as well as parameters of tire nonuniformity, during a vehicle straight line drive.

The observed model is presented in Figure 1 and it enables the analysis of:

- longitudinal, q(1), lateral, q(2), and vertical vibrations, q(3), as well as roll, q(4), pitch, q(5), and yaw, q(6), of the vehicle body,
- tire vertical vibrations, q(7), q(8), q(9) and q(10),
- propulsion group vertical vibrations, q(11),
- driver's seat vertical vibrations, q(12) and
- radial, r, tangential, t, and axial, n, vibrations of the steering wheel.

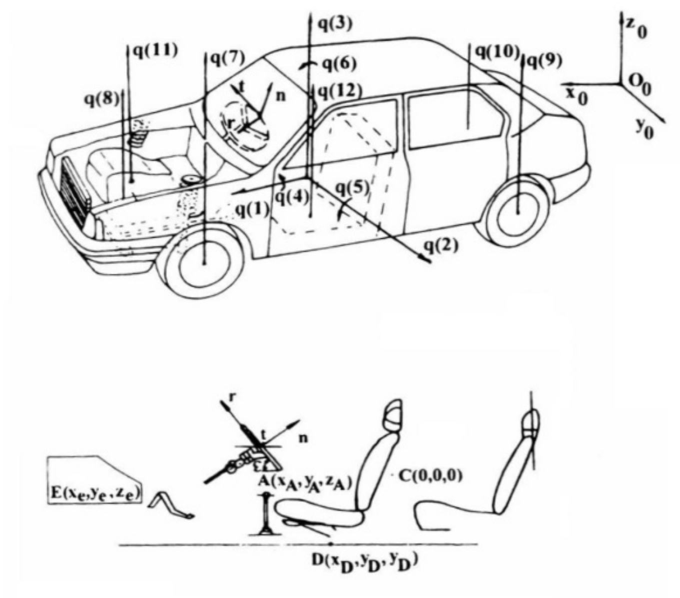

Figure 1: *Vehicle model [8]*

Here should be stated that differential equations of vehicle motion may be obtained in a classical way or by using software, and the motion is described by ordinary nonlinear differential equations like [18, 19, 21, 22, 24-26, 29, 30]:

$$M\ddot{q} + Kq = QE \tag{4}$$

where:

M - is a matrix of inertial parameters with dimensions NDFxNDF (NDF - number of degrees of freedom),
K - is a vector of Coriolis and centrifugal forces with dimensions 1xNDF,
QE - is a vector of generalized forces with dimensions 1xNDF,

$q, \ddot{q}$ - are matrices of generalized coordinates and accelerations, respectively, with dimensions NDFxNDF.

Matrices *M*, *K* and *QE* are calculated by classical procedure and are known form [8], so here they will not be presented here.

Vehicle vibrations originate from its motion over uneven roads with stochastic roughness, unbalanced operation of the engine and nonuniformities of the wheels and tires. Details may be found in [8-12].

Excitation forces originating from road roughness, engine operation and tires nonuniformity are introduced by vector *QE* (with dimensions 1xNDF) in which nonuniformity forces denoted with VVF_{11}, VVF_{12}, VVF_{21}, VVF_{22}, VLF_{11}, VLF_{12}, VLF_{21} and VLF_{22}, act beside known forces presented in Figure 2 (radial, tangential, lateral forces) and stabilization moments not presented in the Figure 2.

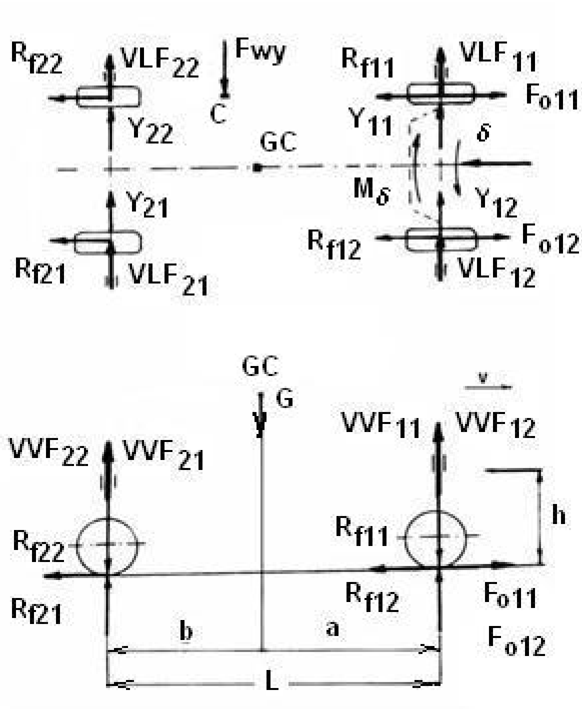

Figure 2: *Forces acting on the observed vehicle model*

As it is well known, vehicle dynamic parameters depend on the type of the road, vehicle speed and vehicle loads. Having this in mind, an analysis is conducted in the case of a vehicle with two passengers driving on a good asphalt road with speeds of 25 ms^{-1} and 40 ms^{-1}. The detailed description of definition of excitation functions from road roughness, engine operation and tires nonuniformity is given in [6-12], so it will not be presented here.

During analysis, the first three harmonics of tire nonuniformity were used [8]. Considering that there is statistical coupling between harmonics, the higher harmonics are expressed with the first harmonic of the radial (lateral) force.

The analysis is conducted for "ZASTAVA 1100" vehicle, with parameters obtained from the vehicle producer.

3. THE METHOD

The three groups of parameters were used for analysis of changes in vehicle dynamic characteristics in function of variations in vibration parameters during exploitation, with corresponding factors to take into account these variations. More precisely, any change is defined by the expression (5):

$$oscpar(\tau) = oscpar_0 \bullet k_i \quad (5)$$

where:

$oscpar(\tau)$ - is a value of any oscillatory parameter after τ kilometres of exploitation,

$oscpar_0$ - is a value of any oscillatory parameter at the beginning of exploitation and

k_i - is a factor that takes into account degradation of oscillatory parameters during exploitation.

Analyses have shown that stiffness and damping of elasto-damping elements decrease during exploitation [21], while it is assumed (based on experience) that parameters of non-uniformity increase with longer exploitation.

In order to take into account the influence of deterioration on vehicle dynamic characteristics in exploitation, corrective factors are adopted based on [21] and own experience [7] and presented in Table 1. Factor k_1 is related to springs, factor k_2 to dampers, factor k_3 to seats, drive unit mounts and tyres and factor k_4 to tyre non-uniformity. Three groups of factors were observed: at the beginning of exploitation (group 1), after 10.000 km of exploitation (group 2) and after 100.000 km of exploitation (group 3). All analyses were performed assuming that, in the observed period of exploitation, one complete change of tyres was performed, while other systems and elements were not replaced.

Table 1: *Corrective factors*

	k_1	k_2	k_3	k_4
Group 1	1	1	1	1
Group 2	0,95	0,83	0,50	0,50
Group 3	0,95	0,83	1	1

Differential equations that describe the oscillatory motions of the vehicle are solved numerically, using the Kutta-Merson method, with initial integration step of 0,01 s, for 256 points. During numerical integration, there were different integration step sizes, but the software written in Pascal [8] enabled the forming of sequences with integration step of 0,01 s, ensuring reliability of the results in the range between 0,4 Hz and 50 Hz that is quite acceptable for these types of analyses [1-3, 6-15, 17]. Since the results of the frequency analysis will be used only for mutual comparison, it was not necessary to calculate statistical errors, according to theory from [1-3].

4. DATA ANALYSIS

Based on acquired time series of passenger, seat and steering wheel accelerations, amplitude spectra are calculated using software [16] and shown in Figures 3 to 7.

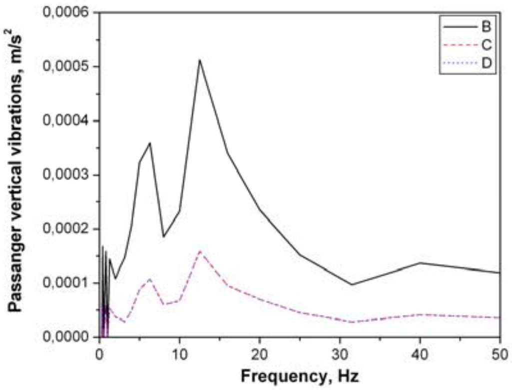

Figure 3 *Passenger vertical vibrations (B - group 1, C - group 2, D - group 3)*

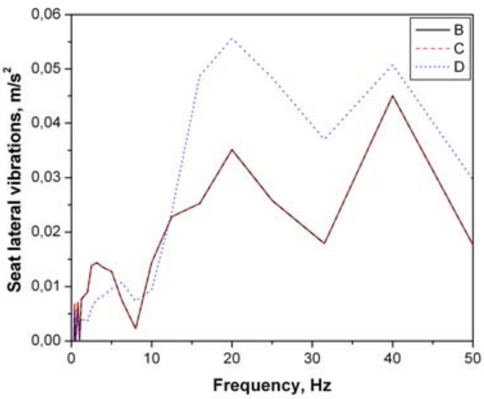

Figure 4 *Seat lateral vibrations (B - group 1, C - group 2, D - group 3)*

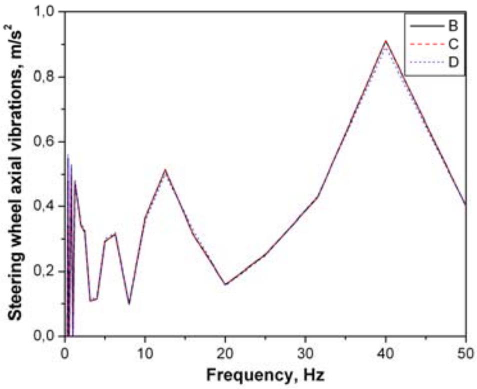

Figure 5 *Steering wheel axial vibrations (B - group 1, C - group 2, D - group 3)*

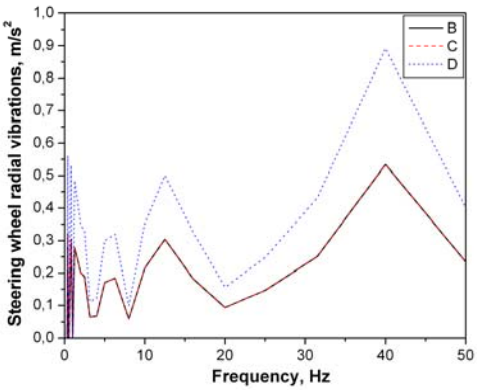

Figure 6 *Steering wheel radial vibrations (B - group 1, C - group 2, D - group 3)*

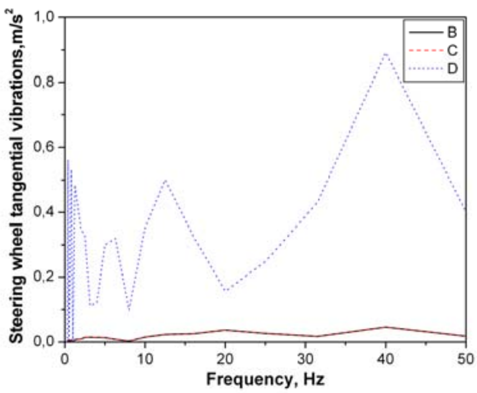

Figure 7 *Steering wheel tangential vibrations (B - group 1, C - group 2, D - group 3)*

Analysis of data in Figures 3 to 7 shows that the influence of oscillatory parameters deterioration on vehicle dynamic characteristics can be established. Detailed analysis determines that the influence is not unambiguous and that it depends on acceleration of the observed point and on the type of parameter deterioration. Besides, differences are very distinctive in frequency ranges where the humans are very sensitive to vibrations [13-17].

It may be established from Figure 3 that there are very small differences between passenger vertical vibrations for parameter groups C and D, but the differences are considerable for vibrations obtained for group B parameters.

Data in Figure 4 point to the fact that there are very small differences between seat lateral vibrations for parameter groups B and C, while there are considerable differences for group D parameters.

Regarding the steering wheel vibrations (radial, tangential and axial), Figures 5, 6 and 7, there are very small differences obtained for parameter groups B and C, but there are significant differences for vibrations obtained for group D parameters.

Previous discussions show that the influence of deterioration of vibration parameters is not unambiguous for all characteristic vehicle points, so there is a need to conduct separate analysis for each case. It should be noted that the influence of deterioration of vibration parameters must be considered during model development in the initial stages of vehicle design.

CONCLUSIONS

The following conclusion may be stated based on conducted research:

- Deterioration of vibration parameters during vehicle exploitation has considerable influence on changes of characteristics important for motor vehicle's vibration comfort.
- The influence of deterioration is not unambiguous in all characteristic points of the vehicle and there is a need to conduct separate analysis for each concrete case.
- The influence of deterioration of vehicle vibration parameters must be taken into account during model development in the initial phases of vehicle design.

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