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The Experimental Parameter Optimization Method of the Road Vehicles Suspension

Octav Dinu*, Ciprian Tabacu**, Dan Lucian Câmpan**

* Universitatea Petrol-Gaze din Ploieşti, Bd. Bucureşti 39, Ploieşti
e-mail: octavytza@yahoo.com

** Universitatea Politehnica Bucureşti, Splaiul Independenţei 313, Sector 6, Bucureşti
e-mail: tabacu_ciprian@yahoo.com; ludan840808@yahoo.com

Abstract

This paper presents some of the scientific research results obtained by the authors in the field of modeling and optimization of vehicle suspension in view of improving the vibro-comfort.

Key words: *model cars comfort, experimental optimization.*

Introduction

This paper presents some results of the doctoral scientific research on the current state of development of the modeling to perform analyzes and assessment of the vehicles suspension performance theory. The effervescent activity, worldwide, of scientific research in the field of improving the vibro-comfort needed to the vehicles passengers is justified by the increase of various land transport means in human activity in all the socio-economic areas. The vibration decrease of the suspended part of the vehicle has a dual purpose: to insure the vibro-confort and to decrease the wear of the vehicle construction caused by the presence of vibrations.

The main function of a vehicle suspension system is to provide comfort, through isolation of the vehicle’s body from the irregularities of the road and to increase handling capacity by producing a road-wheel continuous contact. The vibro-comfort problem arises only in the driving conditions when the road roughness is transmitted to the suspension meant to filter these irregularities to manifest in an improved form at the suspended part of the vehicle.

The filtering degree of these disturbances by the suspension depends on the constructive parameters of the vehicle suspension. The determination of these parameters values so as the vibro-comfort is optimal is a problem of grating the suspension. Because the car in dynamic mode has in reality a nonlinear dynamic system behavior with concentrated parameters, the testing and final adjustment of the damping system parameters is either experimental or on special test stands or in real road conditions [1].

Formulation of the Problem

Regarding the performance evaluation of the suspension system, in this paper we were inspired by the theory of automatic control systems destined for maintaining a physical size $y(t)$ to a given constant value, in the action terms of some external disturbances.

This theory treats the problem of granting the controller parameters in accordance with minimizing the standard deviation of the output quantity $y(t)$ from a given prescribed value y_0, in the conditions of a disturbance, $u(t)$ given.

Figure 1 shows the block diagram of the system ***road-vehicle*** where $u(t)$ shapes the perturbations caused by the road while walking and $y(t)$ expresses the vertical oscillations of the vehicle suspended mass while moving with the velocity ***v*** of the vehicle. The suspension design is based on mathematical models obtained considering the suspension as a linear system with concentrated parameters. These considerations make that the computer models describe just about the actual behavior of a vehicle's suspension system, as some of the suspension and body components (springs, dampers, tires, axles, etc.) have actually a slightly nonlinear behavior with distributed parameters.[2].

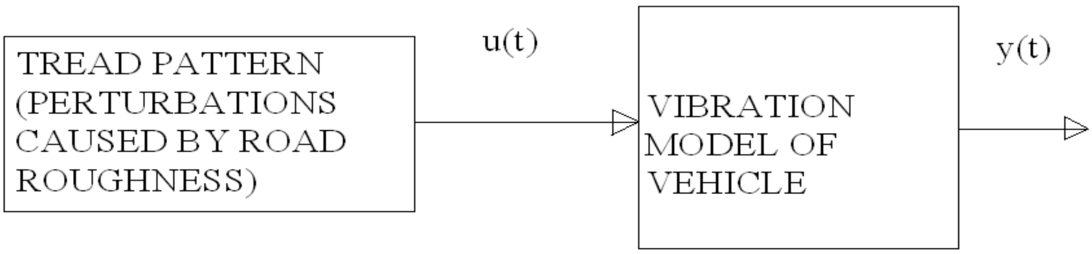


Fig. 1. Block diagram of a dynamic road-suspension system

For example, the suspended body weight is considered concentrated into a point while in reality its mass is distributed at the vehicle's gauge level. This makes that the finishing of the suspension parameters is made experimentally on special stands (fig. 2).

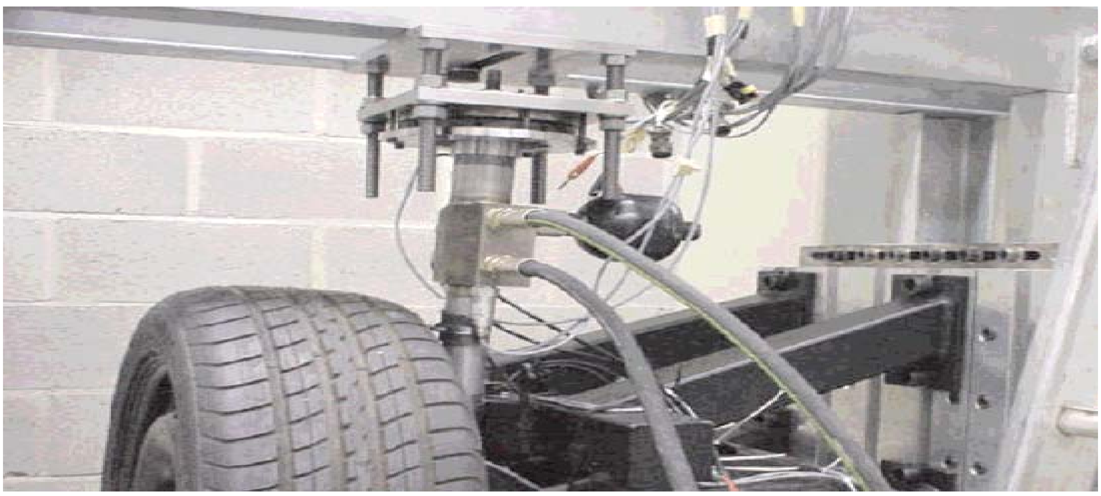


Fig. 2. Test stand for testing the quarter-car type suspension (1/4M)

The method proposed in this paper is to organize the experimental correction of the suspension system parameters.[3] In the simplest case where only two parameters are considered: the stiffness k and the damping coefficient c of a quarter car, then the testing is done by changing the parameters around the nominal values c_0 and k_0. The permissible variations of the parameters being of no more than 10% of the nominal value [4].

Description of the Proposed Method [5, 6]

The proposed method is shown for the experimental granting of a system with two granting parameters (β_0, β_1). These parameters are changed like in the network in Figure 3 where the central node of coordinates β_{10}, β_{00} corresponds to the nominal values of the parameters and Δ_1, Δ_2 - are variations of the parameters around their nominal values during the optimal behavior regime search of the suspension in the circumstances given by the road [1].

In case of testing, the suspension is subjected to the action of a given type of mechanical excitation $u(t)$ at the order given by the stand computer (Fig. 4). This figure simulates the road action on the moving vehicle. It causes vibration displacements $y(t)$ at the suspended mass level of the tested car.

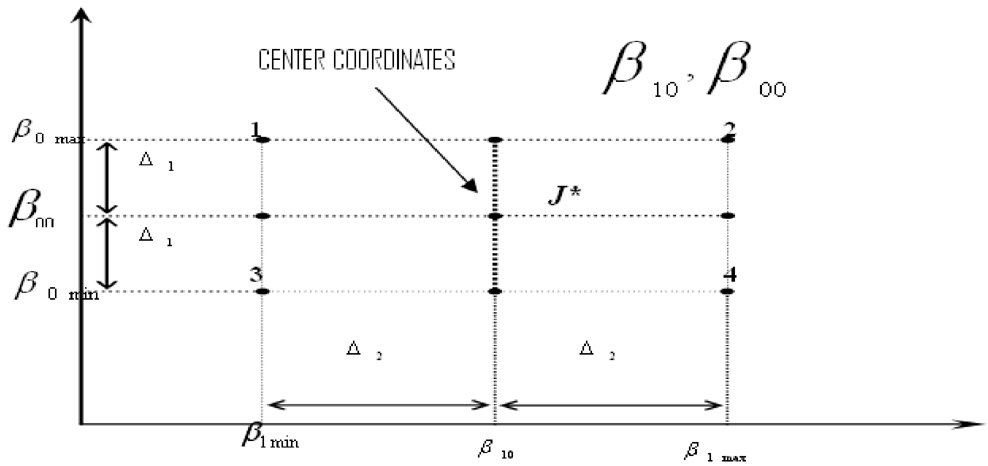


Fig. 3. Parameters variations in the optimum granting process

During the testing, the computer also controls the parameters change (β_0, β_1) of the vehicle suspension from the stand and also records the time evolution of the given disturbing signal $u(t)$ and of the suspension response (suspended mass vibrations) $y(t)$ on a required period of time T. These records are used to calculate the square standard deviation of the vibration displacement $y[t(\beta_0, \beta_1)]$ from a constant value y_0 under the values required of the parameters (β_0, β_1) for granting the suspension system on a time imposed horizon T.

The square standard deviation (AMP) is a function that for a given signal $u(t)$, depends only on the suspension parameters values:

$$J(\beta_0, \beta_1) = \frac{1}{T}\int_0^T [y(t) - y_0]^2 \, dt \tag{1}$$

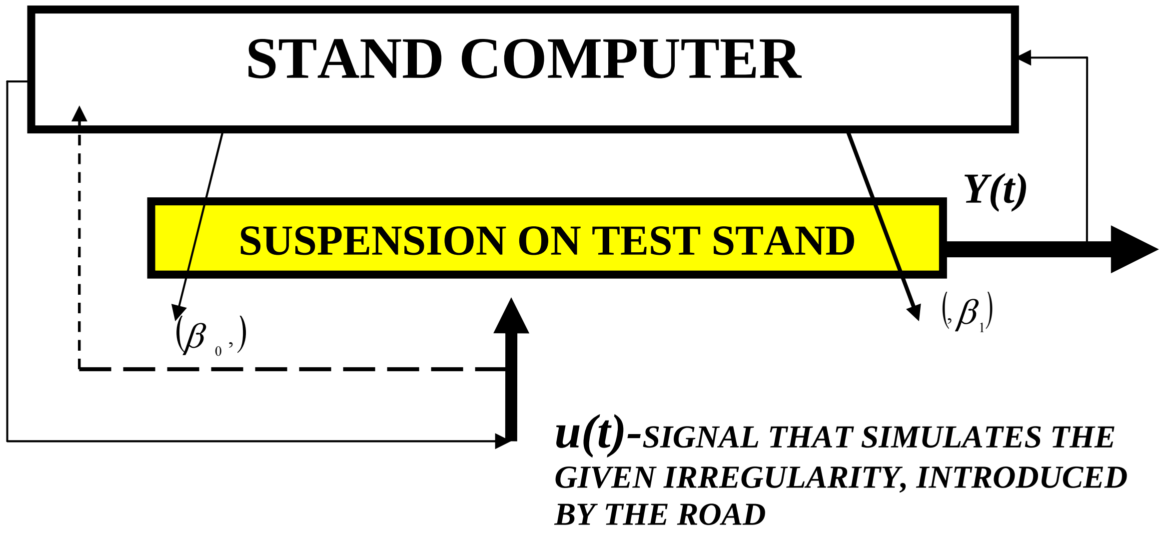


Fig. 4. Conexions between the test stand computer and the suspension subjected to the testing on the stand

Search for the best involves solving the following optimum problems:

$$\min_{\beta} J(\beta) = J_{\min} \qquad (2)$$

where $\beta = [\beta_0, \beta_1]$ is the suspension parameters vector.

To solve this problem experimentally we go through the search steps related to the search algorithm in Figure 5 where is deemed known the baseline value J^* in the node from the network center in Figure 3.

STEP 1: ***we test the suspension as shown above for values of the vector*** $\beta = [\beta_0, \beta_1]$ ***coresponding to the 4 nodes in the corners 1,2,3,4 , of the did network***
STEP 2: ***we calculate the AMP values for the nodes in the corners of the network J1,J2,J3,J4:***

- **IF,**

$$\bigcap J1 \bigcap J2 \bigcap J3 \bigcap J4 < \mathbf{J^*}$$

- THEN the solution of the problem (6) is found, meaning Jmin =J*
- OTHERWISE is executed,

STEP 3 we chose as a center of the experimenting the smallest value of the four,
J*=min{J1,J2.J3,J4}
and we build a grid (fig.3) around the new center, then we repeat the execution from step 1.

Fig. 5. Experimental search algorithm of the AMP minimum

The Suspension Dynamics Model for a Quarter Car

Simulink is a block diagram based simulator of dynamic systems models representation by standard Input-Output elements (input/output) of modeling [7, 8]. Such standard instruments (amplifiers, integrators, recorders, etc.) are available in an Editor Library. With these simple elements can be built other input/output instruments, more complex or models of some complex systems represented by the graphic of some similar model schemes with the representation schemes on analog computers of the dynamic systems models, described by input-output differential equations. For the simplicity of presentation, we consider the simplified structure of the quarter car suspension (1/4 M) in Figure 6, where there were neglected the non-suspended mass or the elasticity parameters of the tire obtaining a simplified model 1/4 M only characterized by two parameters: elasticity coefficient *k* of the suspension arc and the viscous friction coefficient *c* of the damper. Considering a single degree of freedom of vertical movement is obtained the known second order differential equation of the suspension system dynamics 1/4 M.

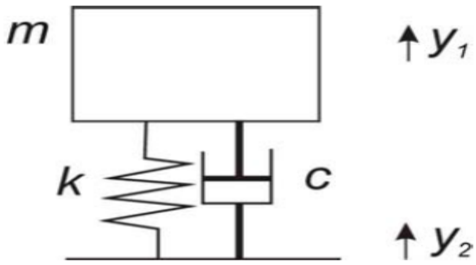


Fig. 6. Simplified structural scheme of the try-out stand 1/4M of the figure 2

Considering only one degree of freedom (of the movement vertically) are obtained three forces acting in the system: ***inertia force*** of the suspended mass m, $F_1 = m\frac{d^2y}{dt^2}$; ***viscous friction force***, $F_2 = c\frac{dy}{dt}$; ***elastic force developed by the spring***, $F_3 = k(y-u)$.

The forces balance leads to the known second order differential equation of the suspension system dynamics 1/4 M:

$$m\frac{d^2y}{dt^2} + c\frac{dy}{dt} + k(y-u) = 0 \quad \text{or} \quad m\frac{d^2y}{dt^2} + c\frac{dy}{dt} + ky = ku \tag{3}$$

This simplified model type 1/4M we use as example to verify the experimental method of suspension optimization (fig. 5) by model simulation (3). This model has three parameters: ***m, c*** and ***k***. Since the suspension parameters are only ***c*** and ***k*** during the experiment will remain constant the suspended mass ***m*** as parametric optimization of the suspension is wanted. Exit *y(t)* of the SIMULINK model resulting in double integration of the equation (4) deduced from (3):

$$m\frac{d^2y}{dt^2} = ku - c\frac{dy}{dt} - ky \tag{4}$$

after the double integration of the equation (4) results:

$$my = k\iint(u-y)dt^2 - c\int ydt \tag{5}$$

Testing the Method by Simulation in Matlab - SIMULINK of the Suspension Dynamics for a Quarter-Car

According to the block diagram in Figure 1 of the *drum-suspension* dynamic system and the model expressed by the equation (5), the structure in Simulink of the model contains two distinct parts: ***the subsystem that models the disturbance induced by the road*** and ***the subsystem that models the suspension itself***. From equation (5) results that the development in time of the suspended mass displacement, *y(t)*, depends not only on the parameters ***k*** and ***c*** of the suspension but also on the suspended mass ***m*** and the road surface allure ***u(t)*** which in the testing process will not be changed. So for testing the method ***m*** will have a constant given value and ***u(t)*** will be a given function of time, following that the optimal performance of the suspension is valid only in the imposed conditions of the road surface. The test of the proposed method we present on an example of road with a bump in the form of a rectangular trench (fig.7) 1m wide and 0.15 m deep. On this road a vehicle is running with a speed of 20 km/h. The distance run from origin to the trench being of 450 m. The vehicle's wheel diameter being of 0.3 m.

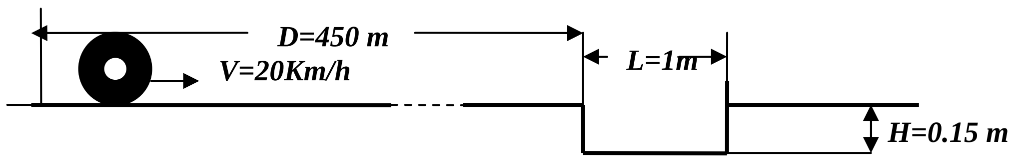


Fig. 7. Graphical representation of road deviation of type trench

SIMULINK Model of Trench-Shaped Road Deviation

In Figure 8 is shown interconnection MATLAB optimization program.

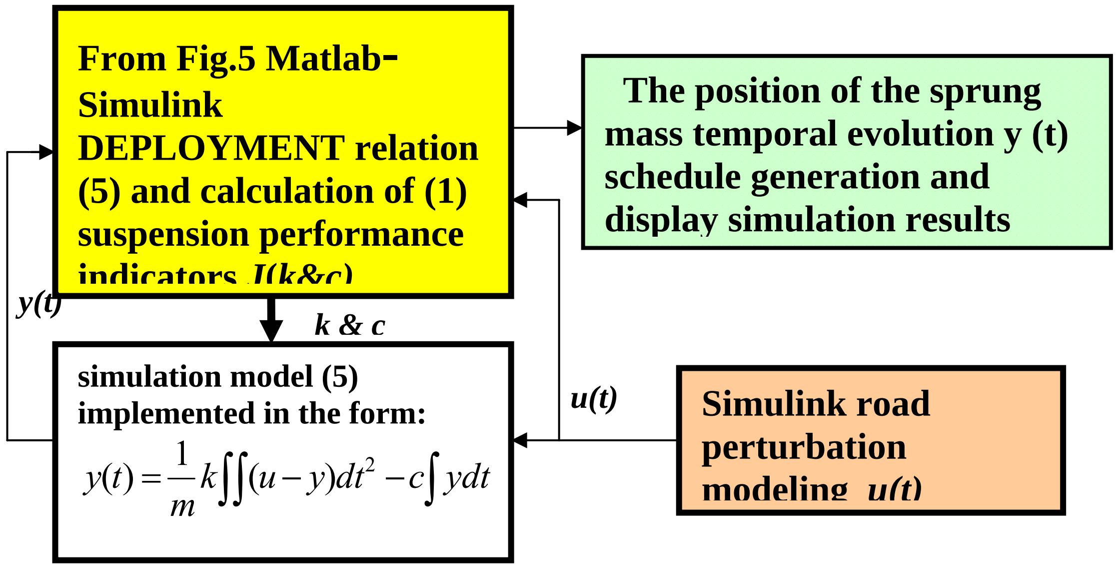


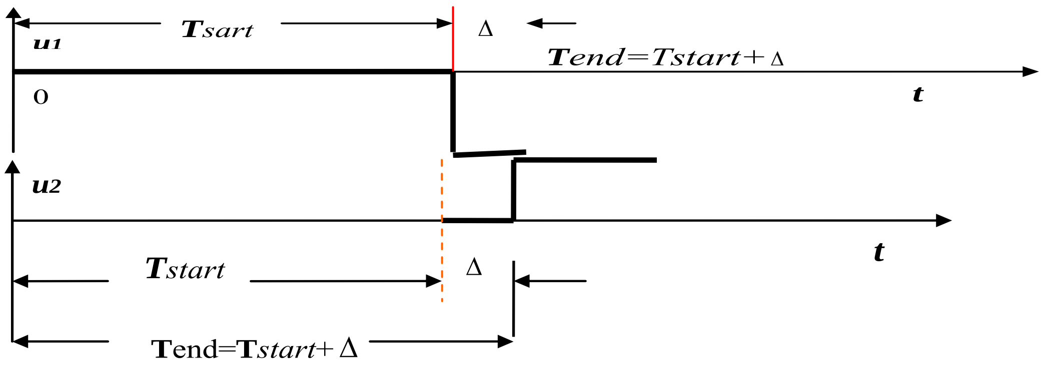
Fig. 8. Matlab-Simulink system structure optimization method for testing

The library building blocks for computing implementation schemes continue system dynamics models are present in only signal sources compartment labeled by ***step***, step function. A block next step is characterized by 4 parameters presented in Table 1:

Table 1. Simulink block type parameters of a step

Step Time	Initt val	Fin val	Sample time
Jump Amplitude =A	Ttime Jump = Tstart	Over time jump =Tend	Sampling step =.001

The significance of these parameters resulting from step chart shown in Figure 8 in which, for example, considered these parameters have the values: ***T**start=450/V=450/20* and ***T**end=(450+ trench width)/V* where *V=20 m/sec* speed car driving on the road with deep trench *A=-0.15 and trench width =1m.*



The SIMULINK Model for Signal Generation Shapes the Way

To generate the signal u (t) that simulates the road unevenness Simulink are used as the ditch generating step2 step1şi two blocks signals u1 (t) and u2 (t) represented in figure 9 the time constants which is based on spatial data in Figure 7 with relations:

$$Tstart=D/V\ ;\ \ \Delta=1/V\ ;\ \ Tend=Tstart+\Delta\ ;\ A=0.15 \qquad (6)$$

TheSIMULINK model of temporal signal *u (t)* is obtained using step1 and step2 two blocks (which generates two steps *u1(t)* and *u2(t)*) and a Simulink block type SUM (Fig.9).

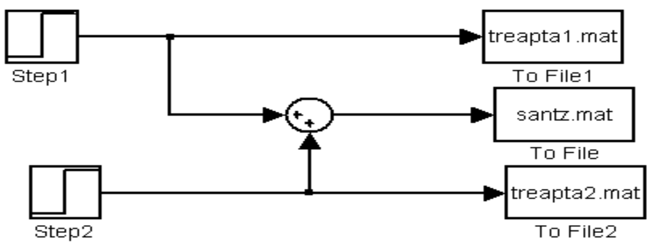


Fig. 9. SIMULINK model for signal generation scheme that shapes the way

To analyze and process the signal u generated by MATLAB blocks STEP1, STEP2 and SUM of Simulink block output to be sent to a Simulink block, for this purpose, called to file.(Fig.10).

Experimental Method for Suspension 1/4 M Testing in SIMULINK-Matlab

Transposition into simulink model of 1/4 M shall be in accordance with relation (5). According to this model to obtain Simulink model of Figure 11. Input *u*(*t*), taken from the blocks in Figure 9, which simulates road irregularities. As output signal is *y*(*t*) that simulates the sprung mass movement which is transmitted through ***to file*** Simulink-blok to Matlab Figure 11.Transposition into simulink model of suspension shall be doing that when drawing the road model in Figure 11.

Road-suspension model scheme for testing by Matlab-Simulink simulation of experimental optimization method of figura11 implements system structure shown in Figure 8.

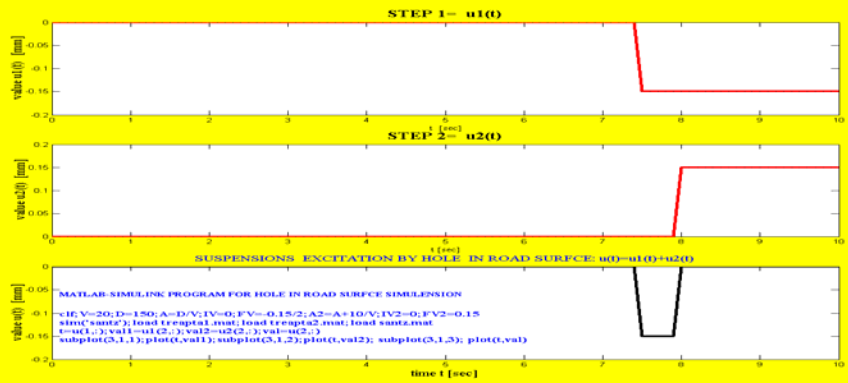


Fig. 10. Matlab-Simulink program for hole in road surface simulension

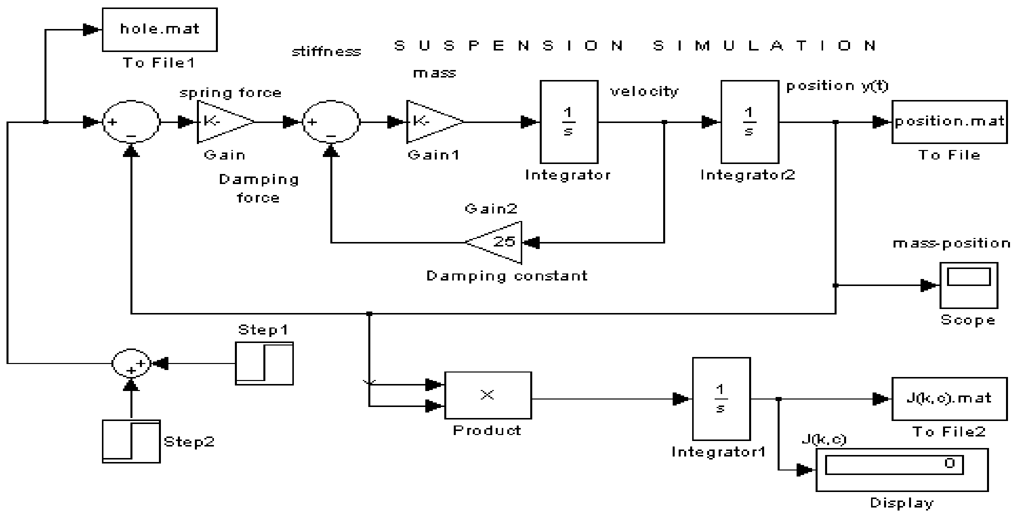


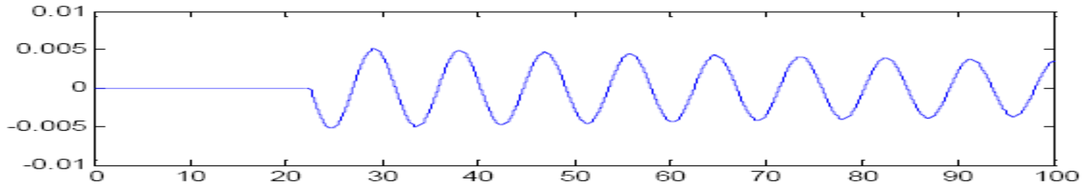
Fig. 11. A method of autovehicles ¼ M suspension experimental optimization testing by simulation in Matlab-Simulink

A method of Autovehicles 1/4M Suspension Experimental Optimization Testing by Simulation in Matlab-SIMULINK, rezults:

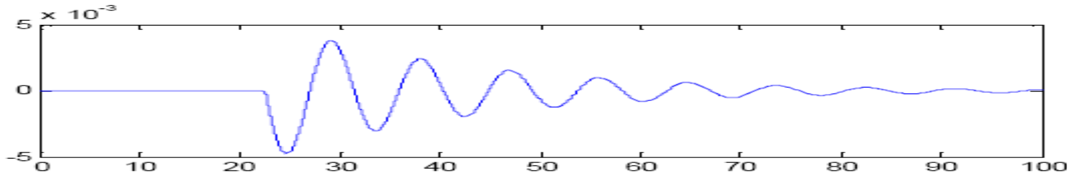
Road-suspension model scheme for testing by Matlab-Simulink simulation of experimental optimization method [6],of Figure11 implements system structure shown in Figure 8.

$$J_4(k = 500, c = 3000) = \frac{1}{T}\int_0^T [y_4(t)]^2 \, dt = 0.01[mm^2] \qquad (7)$$

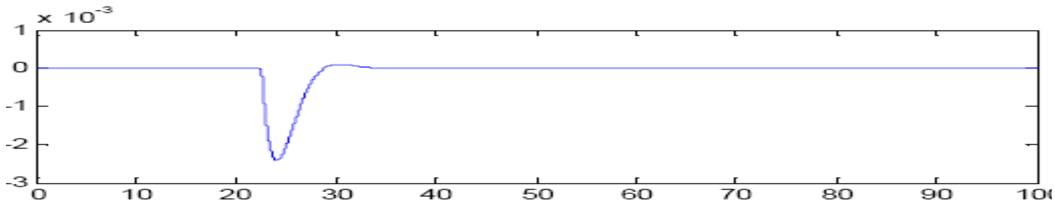
This can be confirmed by visual inspection of the four types of graphs in Figure 12.



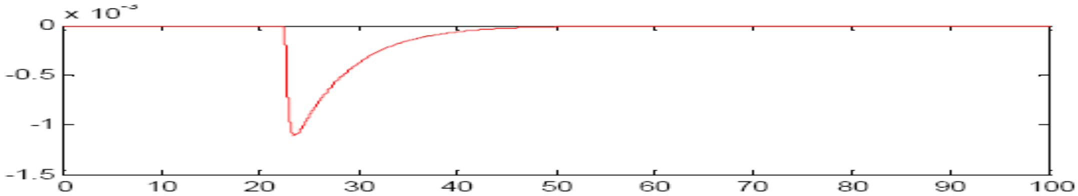
a) $J_1(k = 500, c = 10) = \frac{1}{T}\int_0^T [y_1(t)]^2\,dt = 0.1[mm^2]$



b) $J_2(k = 500, c = 100) = \frac{1}{T}\int_0^T [y_3(t)]^2\,dt = 0.05[mm^2]$



c) $J_3(k = 500, c = 1000) = \frac{1}{T}\int_0^T [y_3(t)]^2\,dt = 0.02[mm^2]$



d) $J_4(k = 500, c = 3000) = \frac{1}{T}\int_0^T [y_4(t)]^2\,dt = 0.01[mm^2]$

Fig. 12. Simulation results of road-suspension system testing

Conclusions

The method for optimizing the vibrant comfort has as a justification the fact that the suspension design is based on approximate mathematical models where there are not reflected the distributed nature of the suspended mass and of other physical and mechanical peculiarities of the suspension system components.

The proposed method is inspired from the optimal granting techniques of the automatic control systems parameters and was adapted for adjustment to some modifiable parameters of the suspension system of the vehicles. The criterion function adopted for optimization is the square standard deviation of the response signal of the suspended mass position (from a constant value).

In the aspect of further doctoral scientific research on this subject, we will continue the scientific research on experimental testing of the method on an example system simulated of quarter-car type suspension and still the method validation by testing on a trial stand or in actual road conditions.

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Metodă experimentală de optimizare parametrică a suspensiei autovehiculelor rutiere

Rezumat

Lucrarea prezintă câteva din rezultatele obținute de autori prin cercetare ştiințifică în domeniul modelării şi optimizării suspensiei autovehiculelor în vederea ameliorării vibroconfortului.