Broj rada: 166 – 2009 V7/4

A POSSIBLE MODEL FOR SHOCK ABSORBER BY USING "BLACK BOX" METHOD

Giovanni Belingardi, Full professor at Politecnico di Torino, Department of Mechanics, Italy

Miroslav Demić, Full professor at Faculty of Mechanical Engineering in Kragujevac - Serbia, and Visiting professor at Politecnico di Torino, Department of Mechanics, Italy

Shock absorbers are fundamental part of the vehicle suspension. Suspensions are needed to guarantee vehicle handling and passenger comfort. For good handling and braking performance of the vehicle, the tire-road contact forces need to be as stable as possible. Each wheel should always remain in contact with the ground. Comfort means that vibrations, induced by road profile during riding, are of a minimal nuisance to the passengers. When designing a new vehicle, a lot of development effort is focused on the optimal choice of the suspension parameters, stiffness and damping.

This paper presents some results of an experimental study conducted on shock absorbers for rear suspension of a vehicle that currently is on the market. Experimental tests were performed in conditions of repeated shock excitation. Based on the characteristic diagrams that correlate Force with the kinematic values (Displacement, Velocity, Acceleration), by means of the "black box" method, a mathematical model of the shock absorber response has been identified.

Key words: Vehicle, Shock absorber, Modelling.

INTRODUCTION

Automotive shock absorbers are part of the vehicle suspension. Suspension are needed to guarantee vehicle handling and passenger comfort, /15-18, 20, 21, 25, 26/. For a good handling and braking performance, the tire-road contact forces need to be as stable as possible. Each wheel should always remain in contact with the ground, /21/. Comfort means that vibrations, induced by road profiles during riding, are of a minimal nuisance to the passengers.

When designing a new vehicle, a lot of development effort is focused on the optimal choice of the suspension parameters, stiffness and damping. A first tuning can be achieved by implementing a full car model and simulating typical road profiles, /15-18, 20, 21, 25, 26/. The response from the simulations can give an idea about the quality of the suspension. However, the significance of the results strongly depends on the accuracy of the model.

The shock absorber is one of the most complex parts to model of the vehicle suspension, /1, 13, 14, 23, 22, 24, 27/. In general the shock absorber behaves in a non-linear and time-variant way. Dampers are typically characterized by a simple force-velocity diagram, also referred to as the damper characteristic diagram. Some information can also be extracted by plotting forces as a function of displacements resulting in a diagram, that in the automotive industry world is known as work diagram or resistance curve or control diagram, /13/.

The dependency of the shock absorber characteristics on time is due to the progressive rise of the oil temperature during the vehicle operation, which, in turn, is due to the conversion (dissipation) of kinetic energy connected with the oscillatory vertical movements of the vehicle into heat by viscous losses. Oil viscosity is a determining factor for the shock absorber characteristics and is strongly influenced by the temperature.

This paper presents some results of an experimental study performed with shock absorbers of the rear that suspension of a vehicle that currently on the market. The experimental tests were performed in conditions of random excitation. Based on the characteristic diagrams that correlates Forces with the kinematic values (Displacement, Velocity, Acceleration) and by means of the "black box" method a suitable mathematical model of the shock absorber response has been identified. The procedure and the obtained results will be discussed in detail in following text.

EXPERIMENT

Measurements were conducted in the Mechanical Engineering laboratories of the Politecnico di Torino at the Vercelli site with the Dartec testing machine. The used testing machine has an hydraulic actuator that, by means of a specific programming of the control unit, is able to provide repeated triangles excitation signals. During the tests the force and displacement values are acquired by the Dartec machine transducers and stored inside a connected PC. Relative velocity and acceleration were calculated by derivation of the relative displacement in respect to time (first and second order derivations).

A couple of car rear shock absorbers from free market were tested in this experiment (we will refer to them as A1, A2). In order to get only the shock absorber response they were tested without rubber joints.

For the shock absorber excitation, repeated triangle signals with 10mm and 20mm of displacement amplitudes were used. The

Table 1. Testing parameters

Shock absorber	Frequency, Hz	Magnitude, mm	Time history length, s	Sample size (points)
A1(Test 1)	0,5	10	20	5000
A1(Test 2)	1	10	10	5000
A1 (Test 3)	1	20	10	5000
A1(Test 4)	2	10	5	5000
A2(Test 5)	0,5	10	20	5000
A2(Test 6)	1	10	10	5000
A2(Test 7)	1	20	10	5000
A2(Test 8)	2	10	5	5000

excitation frequencies were 0.5, 1 and 2 Hz, and for illustrations, in table 1 the test parameters are given.

During experiment we used sampling time step between 0.001 and 0.004 s, sample size results to be of 5000 points, that ensures the suitability of the acquired results in the interval 500 to 125 Hz (the Nyquist frequency). The minimum frequency was between 0.05 and 0.2 Hz. These parameters are acceptable when we have in mind the aim of this study, /4-6/.

For illustration, Figures 1. and 2. show respectively the history of displacement and force in time, for shock absorber "A1" for magnitude 10 mm and frequency 0.5 Hz

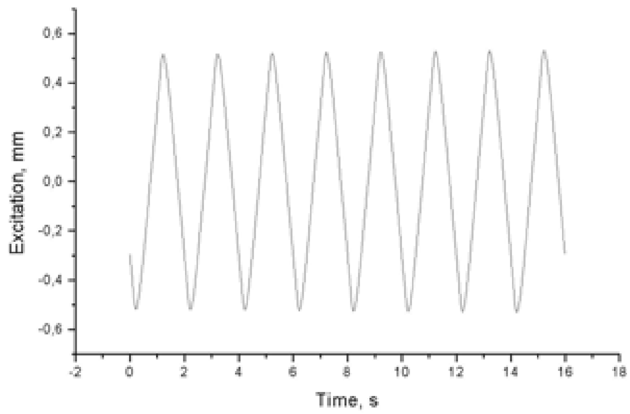

Figure 1. Displacement time history for test 1

The frequency content of the displacement history (see Figure 1.) is given in Figure 3. for example. We can see that the excitations are mainly in the interval from 0 to 2 Hz with smaller magnitudes of the harmonics at higher frequencies.

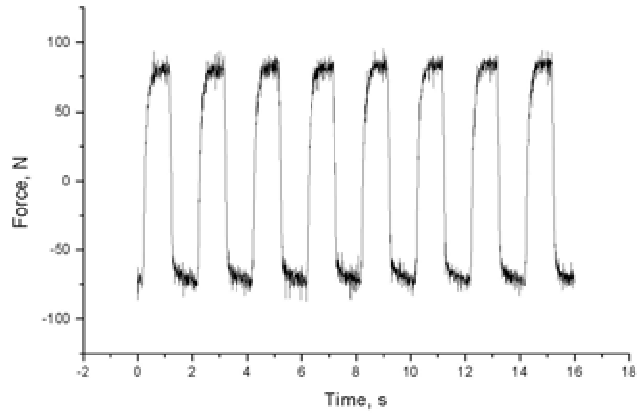

Figure 2. Force time history for test 1

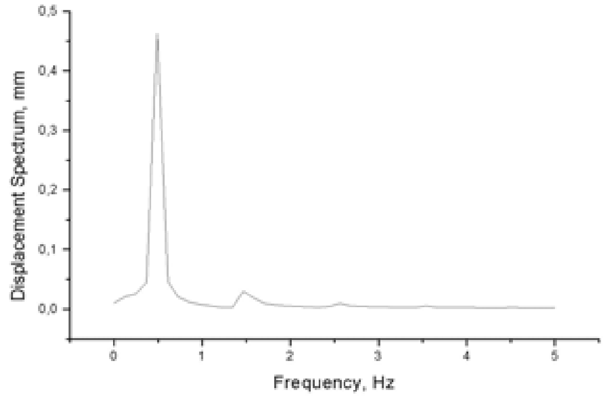

Figure 3. The spectrum of shock absorber displacements for test 1

For illustration in Figures 4. to 6. the forces as functions of displacement, velocity and acceleration, acquired during the experimental test of the shock absorber “A1” in the test case with amplitude 10 mm and frequency 0.5 Hz, are given.

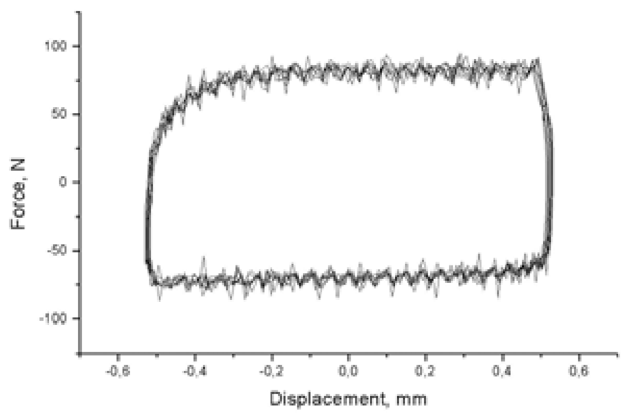

Figure 4. Force as function of displacements for test 1

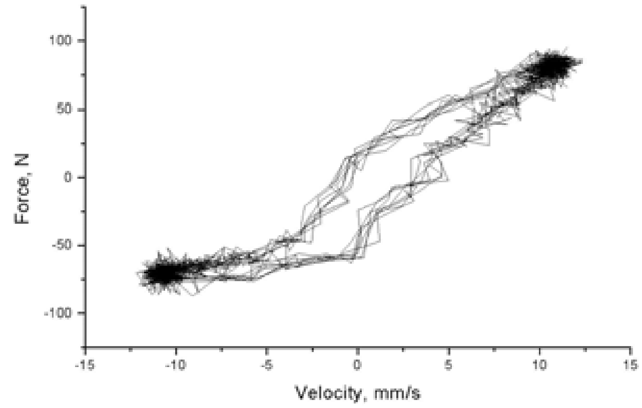

Figure 5. Force as function of velocity for magnitude for test 1

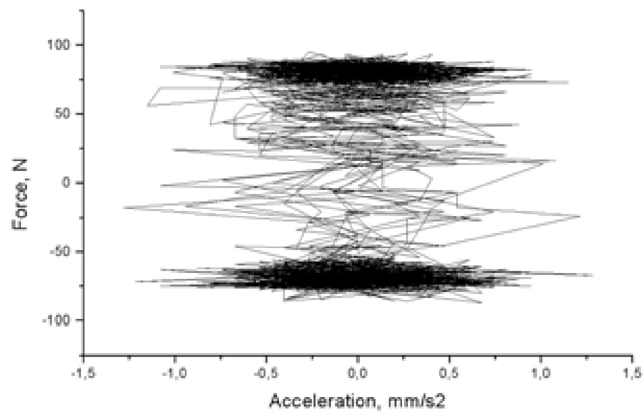

Figure 6. Force as function of acceleration for test 1

SHOCK ABSORBER MODELING

In our research, we knew only the functional dependence of the forces in respect to displacements, velocities and accelerations. Analysis of the diagrams force-displacement, force-velocity, and force-acceleration have shown that displacement, velocity and acceleration affect the force in shock absorber, and that should be in mind during its modeling.

Since we will not attempt to model the interior devices of the shock absorbers, our approach is generally defined as a "black box" problem, /8/. Namely, we knew input signals (displacements, velocities and accelerations) and output variable (forces restituted by the shock absorber). The goal is to define the best mathematical model of the shock absorber behaviour. The problem was divided into two parts:

1. defining the structure of the model (influential parameters: displacement, velocity, acceleration) and

2. identify the parameters of the model. The first task is solved by using of the same model as in /2,3/, given by expressions (1):

$$F = [x[1] + x[2,3]\cdot v + x[4]\cdot v^2 \mathrm{sign}(v)]\cdot[x[5] + x[6]\cdot \mathrm{th}(\frac{d}{3\cdot\sigma_d})]\cdot[x[7] + x[8]\cdot \mathrm{th}(\frac{a}{3\cdot\sigma_a})] \quad (1)$$

where:
x[i], i=1,9 - parameters of model that should be identified,
d,v,a – relative displacement, velocity and acceleration, respectively, and
σ_d, σ_a - standard deviation of displacement and acceleration, respectively.
The second task is solved by using the optimisation method, which will be briefly the described below.

As it is well known, the method of 'stochastic parametric optimisation' is based on the methods of non-linear programming. In the optimisation process, where constraints for design parameters are present, the problem is solved by the introduction of 'external' or 'internal' penalty functions. In the specific case, for the identification of the parameters of the shock absorber, a method of 'stochastic parametric optimisation' was applied /7-9, 10-12/ based on the Hooke Jeeves method and "external" penalty functions, /7/, the block scheme of the procedure is given in Figure 7. /8-9, 12-14/. Since this optimisation method has been already described in details elsewhere, see in /7-9, 14-16/, its description will not be repeated here. The optimisation procedure was programmed in Pascal language.

During the identification of unknown parameters of proposed models, we had set goal that the models should be acceptable for all tests given in Table 1. The objective function is defined by the expression:

$$\phi = \sum_1^N (F_{model}[i] - F_{exper}[i])^2 \quad (2)$$

where:

- F_{model} , F_{exper} are respectively the values of the force given by the model (1), and those of the force measured during the experimental tests, which features are reported in Table 1,
- N – is the sample size (5000 points).

Since in practice there are parameter constraints, the optimisation was carried out taking into account a pre-defined domain for the parameter values:

$$x[s]_{\min} = -5000,\ x[s]_{\max} = 5100 \quad *$$

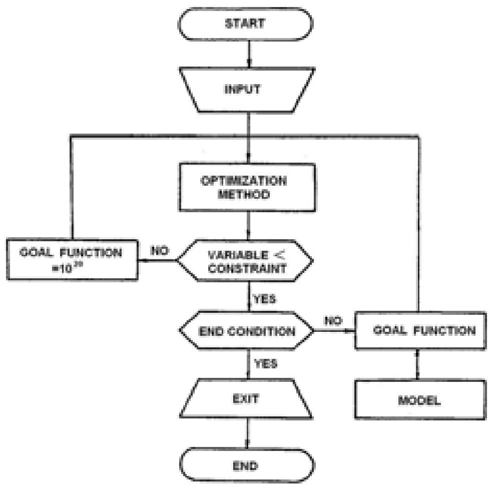

Figure 7. - Block diagram of the developed procedure for calculation of the model parameters

As stated in /7-9, 10-12/, a global (absolute) minimum of the objective function is defined in such a manner that optimal parameters lead to the minimum value of the objective function. Unfortunately, there are no generally accepted procedures for definition of the global minimum of the objective function. Thus, procedures based on optimisation with different initial values of the parameters to be optimised are used in practice. The global minimum is searched by beginning the optimisation process with several different initial values of parameters to be optimised, /8,9,10-12/. In this case, the optimisation process has begun with three different initial values of those parameters. Preliminary analysis showed that only the initial values of model parameters chosen in the central part of the considered interval allow for unimpeded iterative process, and we used only these initial values.

Table 2. Optimal Model Parameters

Test	Minimum Value of the Objective Function given by expession (2)	Model parameters used in expression (1)
1	7.663272427096059E+001	5.329265645275645E+001 -3.079856594600424E+001 3.503593994192684E-001 1.559597582511905E+000 -2.872927951080395E+001 9.553926553977170E-001 1.191322585812703E-002 1.063802865148775E-003
2	1.211715971313970E+003	-1.161058507263718E+002 6.695506265593554E+000 8.669291709249167E-001 -9.942434585976698E-002 1.950380332541989E+001 -5.258954576693077E+000 2.382645170138932E-002 -4.995268910092536E-003
3	1.559936519357628E+004	-1.968267401791522E+003 -8.154760451135606E+001 7.799187555104614E+000 2.388133798205556E+000 5.278469681942854E-001 2.631068018442423E-001 7.862729058038975E-002 -1.237614133739231E-002
4	1.363320434362736E+004	7.494717827601531E+001 4.701857609221350E+000 3.843317199777364E-001 4.873742447642190E-002 5.596883651915817E+000 1.285055615617692E+001 6.194877439982133E-002 -6.589834539401536E-003
5	6.171584443168152E+001	6.159606998269102E+001 -3.452521404028452E+001 4.384651840493174E-001 1.770143256147256E+000 -2.651554429055205E+001 1.733896094548289E+000 1.191322585812703E-002 -9.706875076480548E-004
6	1.033914523793413E+003	-5.542883377968612E+001 7.509240411051994E+000 4.106840807865125E-001 -1.247678065751552E-001 3.276252313132660E+001 -6.246798131478588E+000 2.144380653273685E-002 3.633542607290172E-003
7	1.469884994041402E+004	-3.611424227704235E+003 -1.311726727884517E+002 1.441442386379451E+001 4.031559750750461E+000 6.282989944556443E-001 3.385074210023099E-001 3.573967754465829E-002 5.240858070110497E-003
8	1.183154037061039E+004	9.085140880642845E+001 5.671981285760362E+000 3.440094329578690E-001 2.729295771723727E-002 6.118096995726527E+000 1.537281821812534E+001 5.956612923116900E-002 1.152254534541185E-002

The identification was performed on a Pentium-4 computer (Intel 1.8 GHz, 1 Gb RAM), and the iteration process was interrupted when the difference between two adjacent values of the objective function reached ***1e***$^{-09}$. Duration time of the identification was approximately less than one hour per combination. The resulting minimum values of the objective function are given in Table 2. for all the test cases given in Table 1., together with the identified values of the model parameters.

DISCUSSION

Analysis of data from Table 2. shows that the test parameters from Table 1., affects the minimum value of the objective function. Also, from Table 2. it is clear that the design of the shock absorbers (A1,A2) affects the parameters of the model given by expression (1).

For analysis purpose, some signals have been processed with softwares "Analsigdem" and "Demparcoh", /28, 29/. For illustration, in figures from 8 to 15 some results for shock absorber (A1) are shown.

From the analysis of all data, which are partially shown in the figures from 8 to 14, we can conclude that there is good coincidence between results obtained by experiment and model.

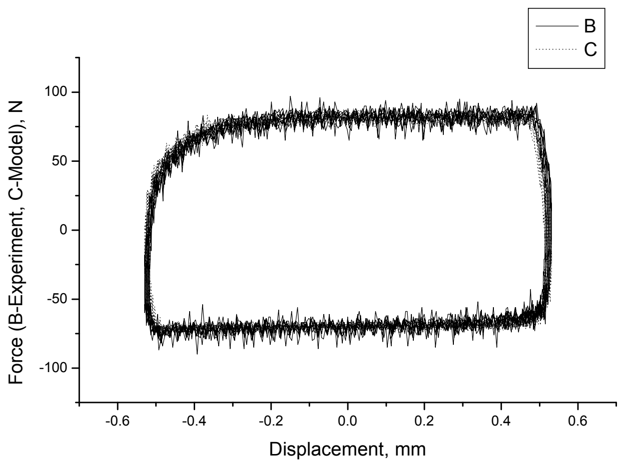

Figure 8. Comparison between forces measured in experimental tests and forces computed with the identified model in respect to displacement for test 1

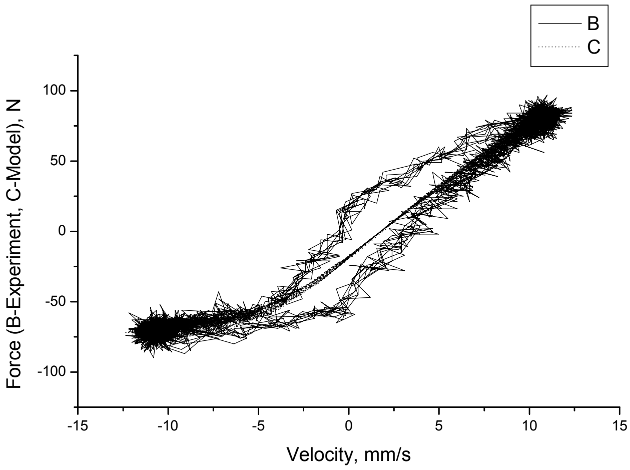

Figure 9. Comparison between forces measured in experimental tests and forces computed with the identified model in respect to velocity for test 1

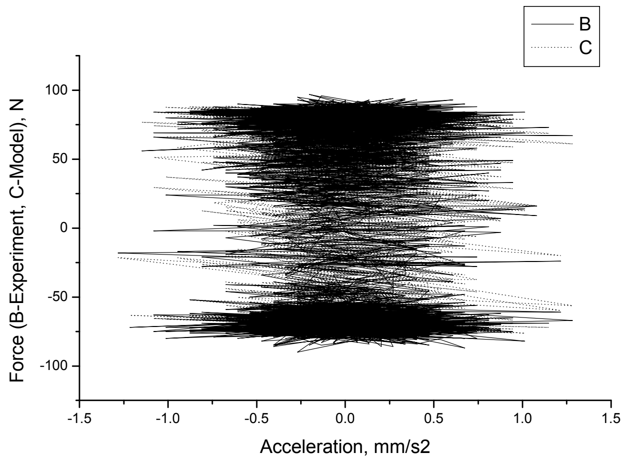

Figure 10. Comparison between forces measured in experimental tests and forces computed with the identified model in respect to acceleration for test 1

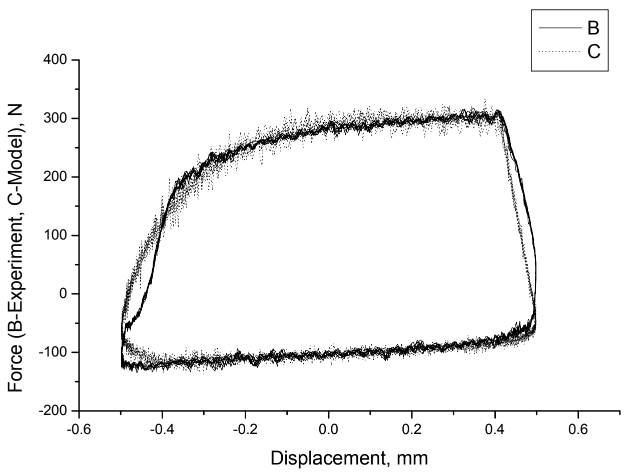

Figure 11. Comparison between forces measured in experimental tests and forces computed with the identified model in respect to displacement for test 2

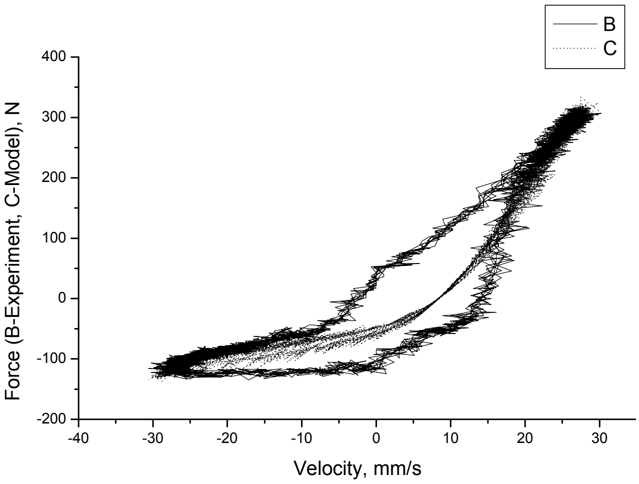

Figure 12. Comparison between forces measured in experimental tests and forces computed with the identified model in respect to velocity for test 2

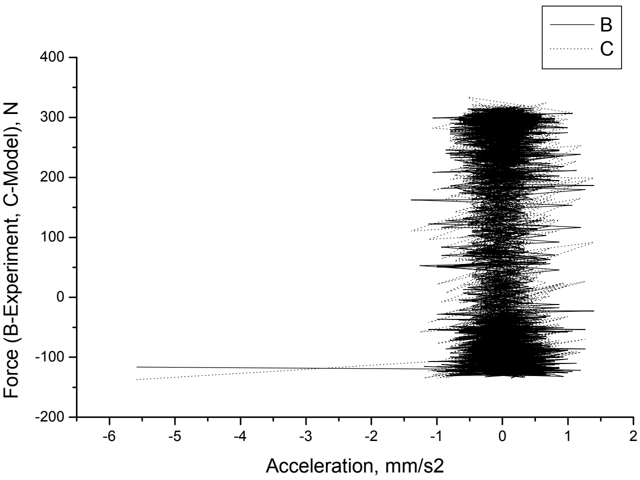

Figure 13. Comparison between forces measured in experimental tests and forces computed with the identified model in respect to acceleration for test 2

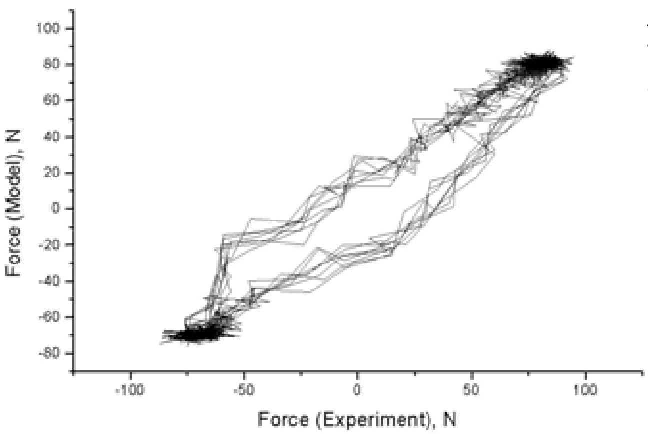

Figure 14. Comparison between forces measured in experimental tests and forces computed with the identified model for test 1

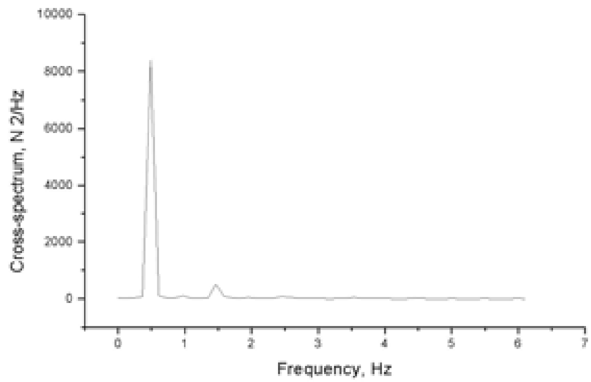

Figure 15. Cross-spectrum between the forces measured in experimental tests and computed with the identified model for test 1

Finally, we analysed Cross-spectrum functions, one of these functions is shown in Figure 15. Analysis showed that there is acceptable value of the aforementioned functions, so that the model (1) can be suitably used in vehicle dynamic simulations.

CONCLUSION

An experimental test campaign has been developed to characterise the mechanical behaviour of some vehicle shock absorber.

The "black box" procedure was used to obtain a mathematical model that represents in a suitable way the relationship that exists between the kinematic variables (displacement, velocity and acceleration) and the restituted damping force. It is worth of note that the force values depend also on acceleration, and not only, as it is usually accounted, on velocity and displacement.

An optimisation procedure has been used for the identification of the model parameters.

The "black box" method and the optimisation procedures adopted for identifying of parameters of the shock absorber model lead to suitable results. For the aim of this study the model described by expression (1) is acceptable for vehicles dynamic simulation.

REFERENCES

/1/ Audenino, A., Belingardi, G., Garibaldi, L.: An application of the restoring force mapping method for the diagnostic f vehicular shock absorbers dynamic behaviour, 2nd Int. Machinery monitoring and diagnostic conference & exibit, LA, 1990, pp. 560-566.

/2/ Belingardi, G., Demić, M.: A contribution to shock absorber modeling by using „black box“ method, (in press), Scientific Bulletin, University of Pitesti, 2009.

/3/ Belingardi, G., Demić, M.: A contribution to shock absorber modelling and analyses of its influence to vehicle features, (in press), Journal of Mechanical engineering, Slovenia.

/4/ Bendat J.S.: Nonlinear Systems-Techniques and Applications, John Wiley and Sons, London, 1998.

/5/ Bendat J.S., Piersol A.G.: Random Data Analysis and Measurement Procedures, John Wiley and Sons, London,2000.

/6/ Bendat J.S, Piersol A.G.: Engineering Applications of Correlation and Spectral Analysis, John Wiley and Sons, London, 1980.

/7/ Bunday, P.: Basic Optimization Methods, Spottiswoode Ballantyne, Colchester and London, 1984.

/8/ Demić M.:Identification of Vibration parameters for Motor Vehicles, Veh. Syst. Dyn. Vol. 27, 1987, pp. 65-88

/9/ Demić M.: Optimization of Characteristics of Elasto-Damping Elements from Aspect of Oscillatory Comfort and Vehicle Handling, Int. J. of Veh. Des. Vol. 17, № 1, 1996, pp. 76-91

/10/ Demić, M.: Optimization of Vehicles Elasto-Damping Elements Characteristics from the Aspect of Ride Comfort, Veh. Syst. Dyn. Vol. 23, 1994.

/11/ Demić, M.:A contribution to optimization of vehicle seats, Int. J. of Veh. Des. 5/6, 1991, pp. 618-629.

/12/ Demić, M.: A contribution to the optimization of the characteristics of elasto-damping elements of passenger cars, Veh. Syst. Dyn. Vol. 19,1990, pp. 3-18

/13/ Duym, S., Stiens, R., reybrouck, K.: Evaluation of shock absorbers models, Vehicle System Dynamics, Vol. 27, 1997, pp. 109-127.

/14/ Gardulski, J., Warczek, J.: Investigation of forces in frictional kinematic pairs to acces their influence on shock absorber characteristics, Transport problems, Tom 3, 2008, pp. 19-24.

/15/ Genta, G.: Motor Vehicle Dynamics, Verlag, 2003.

/16/ Ellis, J.R.: Vehicle Handling Dynamics, Mechanical Engineering Publications Limited, London, 1994.

/17/ Gillespie T (1992) Fundamental of Vehicle Dynamics, SAE

/18/ Hačaturov, A.A. et al.: Dinamika sistemi: Doroga – Šina – Avtomobilj - Voditelj, Mašinostr., Moscow (in Russian), 1976.

/19/ Lee, C. T., Moon, B, Y.: Simulation and experimental validation of vehicle dynamic characteristics for displacement sensitive shock absorber using fluid-flow modelling, Mechanical Systems and signal processing, Vol. 20, 2006, pp. 373-388.

/20/ Miliken, W., Miliken, D.: Race Car Dynamics, SAE,1995.

/21/ Mitschke, M.: Dynamik der Kraftfahrzeuge, Springer,1972.

/22/ Ping, Y.: Experimental and mathematical evaluation of dynamic behaviour of an oil-air coupling shock absorber, Mechanical Systems and signal processing, Vol 17, 2003, pp. 1367-1379.

/23/ Ping, Y.: Testing and mathematical approach on dynamics of Cymene-Si-Oil shock absorber for structural integrity in vibration and impact protection, Int. J. Materials and structural integrity, Vol. 1, Nos 1,2,3, 2007, pp. 1-15.

/24/ Pracny, V., Meywerk, M., Liona, A.: Hybrid neural network model history-dependent automotive absorbers, Vehicle System Dynamics, Vol. 45, 2007, pp. 1-14.

/25/ Rotenberg, V.: Vehicle suspension, Mašinostr. Moscow (in Russian), 1972.

/26/ Simić, D.:Motor vehicle dynamics, Naučna knjiga, Begrade (in Serbian),1988.

/27/ Yang, P., Liao, N., Yand, J.: Design and test and modelling of a novel Si-oil absorber for protection of electronic equipment in moving vehicles, Mechanism and Machine Theory, 2007, pp. 18-32.

/28/ Demić M.: "ANALSIGDEM" – Software for signal analysis, 2003. www.ptt.yu/korisnici/i/m/imizm034/

/29/ Demić, M.:"DEMPARCOH": Software for partial coherence function calculation, www.ptt.yu/korisnici/i/m/imizm034/, 2003.

JEDNA MOGUĆNOST ZA MODELIRANJE AMORTIZERA UZ KORIŠĆENJE METODE „CRNE KUTIJE“

Rezime: *Amortizeri su osnovni element sistema za oslanjanje vozila. Sistem za oslanjanje treba da obezbedi upravljanje vozilom i udobnost putnika. Kontakt točka i puta treba da bude što bolji, jer se time obezbeđuje lako upravljanje i dobre kočne performanse vozila. Pri tome, svaki točak, ponaosob, mora imati dobar kontakt sa podlogom. U cilju poboljšanja udobnosti, uticaj pobude puta se mora minimalno prenositi na putnike. Tokom projektovanja vozila, velika pažnja se posvećuje optimalnom izboru parametara sistema za oslanjanje (koncepcija, krutost opruge, prigušenje amortizera). U ovom radu su prikazani rezultati eksperimentalnih istraživanja sprovedenih na amortizerima zadnjeg sistema za oslanjanje jednog vozila koje se nalazi trenutno na tržištu. Eksperimentalna ispitivanja su izvedena u uslovima pobuđivanja ponavljajućim udarnih opterećenja.. Na osnovu dijagrama koji povezuju sile sa kinematskim parametrima (pomeranje, brzina, ubrzanje), uz korišćenje metode "crne kutije" identifikovan je matematički model amortizera.*

Ključne reči: vozila, amortizeri, modeliranje.

Rad poslat na recenziju: 18.11.2009.

Rad spreman za objavu: 18.12.2009.