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[1] THE RECOVERY OF THE OPTIMAL DAMPING CONSTANT BY THE MRF DAMPER

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UDC: 62-272.8:536.5
629.011.85

Abstract

What is studied in this paper is a method used in order to analyze the recovery of the optimal damping constant because of the temperature increasing in a shock absorber. The increase of a temperature leads to the decrease of that constant by means of such dynamic viscosity to modify the dynamic behavior of a 2DOF system built up by the sprung and unsprung mass.

The Magnetorheological damper was designed in accordance with the design of the desired optimal damping constant with the once fixed temperature. It has been seen that this constant is lost with the increase of a temperature. As Magnetorheological Fluids allow us to increase the viscosity, we use a control signal by a state feedback of a reduced order to create such a magnetic induction field to recover the optimal damping constant at higher temperature than to design one.

Key words: Index Terms — Optimal Damping Constant, Magnetorheological Fluid, State Feedback, Semi-Active Suspension.

OBNAVLJANJE OPTIMALNE PRIGUŠNE KONSTANTE POMOĆU MRF AMORTIZERA

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Rezime: U ovom radu je analizirano obnavljanje optimalne prigušne konstante usled porasta temperature u amortizeru. Porast temperature dovodi do smanjenja ove konstante pošto dinamička viskoznost utiče na promenu dinamičkog ponašanja 2DOF sistema oscilujućih masa.

Magnetorheological amortizer je projektovan u skladu sa optimalnom prigušnom konstantom pri konstantnoj temperaturi. Uočeno je da se sa porastom temperature prigušna

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konstanta smanjuje. Pošto Magnetorheological Fludi pružaju tu mogućnost da se viskozitet poveća, koristi se kontrolni signal koji daje informaciju o stepenu smanjenja kako bi moglo da se formira polje magnetne indukcije koje bi obnovilo optimalnu prigušnu konstantu pri temperaturama višim od onih pri projektovanju.

Ključne reči: Optimalna prigušna konstanta, Magnetorheological Fludi, odziv stanja, polu-aktivno vešanje.

THE RECOVERY OF THE OPTIMAL DAMPING CONSTANT BY THE MRF DAMPER

Gabriele Barbaraci[1], Gabriele Virzi' Mariotti

UDC: 62-272.8:536.5
629.011.85

INTRODUCTION

Real-time damping control of automotive suspension systems can reduce the low frequency vehicle body motions while enhancing the vehicle road holding characteristics. Other benefits of semi-active suspension systems having controllable damping are: reduced hardness from high frequency road disturbances (for a smoother ride) and better handling during transient maneuvers. The work presented in this paper was carried out with the purpose of making a theoretical study of the dynamic behavior of a 2DOF system using smart fluids [1]-[2] called Magneto-Rheological (MR). We considered the MR fluids which produce superior effects at voltages well below 12V and hence are more preferable for automotive use then the ER fluids which require very high electrical fields (on the order of 5kV/mm) to produce the desired effects. The Magneto-Rheological (MR) fluids are a class of controllable fluids having micrometer-sized magnetizable solids dispersed in a non-magnetic fluid such as synthetic mineral oil. The MR fluids are freely flowing in the absence of a magnetic field but they are changing into a paste-like substance in the presence of a magnetic field in a quick and completely reversible manner. The yield strength of a MR fluid can be continuously controlled by the applied magnetic field with response times in the range of milliseconds. This feature paved the way for the MR fluids as simple interfaces between mechanical systems and electronic controllers for fast, controllable actuators having valves without moving parts, especially in controllable dampers used in detail in the Magnetic Ride Control system.

2. MATHEMATICAL MODEL

Figure 1 shows a sketch of a 2DOF system used for this study

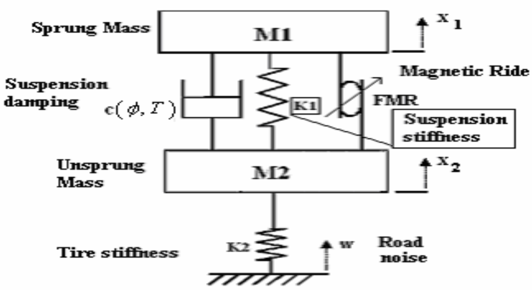

Figure 1: *A schematic view of a shock absorber for a 2DOF system*

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What is established due to the displacement along a positive direction x_1 is the sum of a reaction force acting in the sprung mass according to which it has its motion equation (1).

$$m_1\ddot{x}_1(t)+c(\phi,T)\dot{x}_1(t)+k_1x_1(t)-c(\phi,T)\dot{x}_2(t)-k_1x_2(t)-F_{MR}=0 \qquad (1)$$

The same procedure is applied to the unsprung mass owing to which it has (2)

$$m_2\ddot{x}_2(t)+c(\phi,T)\dot{x}_2(t)+k_1x_2(t)-c(\phi,T)\dot{x}_1(t)-k_1x_1(t)-k_2y(t)+F_{MR}=0 \qquad (2)$$

where $c(\phi,T)$ represents the damping constant varying with temperature and iron fraction particle volume of a fluid.
Both equations are shown in the following matrix form (3):

$$\mathbf{M}\ddot{\mathbf{q}}(t)+\mathbf{C}(\phi,T)\dot{\mathbf{q}}(t)+\mathbf{K}\mathbf{q}(t)+\mathbf{b}F_{MR}+\mathbf{g}w(t)=\mathbf{0} \qquad (3)$$

where

$$\mathbf{M}=\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix};\ \mathbf{C}(\phi,T)=\begin{bmatrix} c(\phi,T) & -c(\phi,T) \\ -c(\phi,T) & c(\phi,T) \end{bmatrix};\ \mathbf{K}=\begin{bmatrix} k_1 & -k_1 \\ -k_1 & k_1+k_2 \end{bmatrix};\ \mathbf{b}=\begin{bmatrix} 1 \\ -1 \end{bmatrix};\ \mathbf{g}=\begin{bmatrix} 0 \\ -k_2 \end{bmatrix}$$

$$\mathbf{q}(t)=\begin{bmatrix} x_1(t) & x_2(t) \end{bmatrix}^T$$

Carrying out a change of the variable we put:

$$\begin{cases} \mathbf{z_1}(t)=\mathbf{q}(t) \\ \mathbf{z_2}(t)=\dot{\mathbf{q}}(t) \end{cases} \Rightarrow \dot{\mathbf{z}}_\mathbf{1}(t)=\mathbf{I}\ \mathbf{z_2}(t)/\mathbf{I}$$

in order to obtain the state space model (4):

$$\dot{\mathbf{z}}(t)=\mathbf{A}\mathbf{z}(t)+\mathbf{b_z}F_{MR}+\mathbf{g_z}w(t) \qquad (4)$$

where

$$A=\begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C(T) \end{bmatrix};\quad b_z=\begin{bmatrix} 0 \\ -M^{-1}b \end{bmatrix};\quad g_z=\begin{bmatrix} 0 \\ -M^{-1}g \end{bmatrix}$$

3. ACTUATOR

The figure 2 shows the cross section of the comprehensive electromagnet coil in the hypothesis that this last one has a square section.

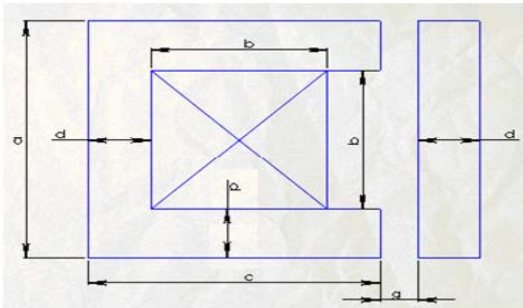

Figure 2: *A cross of the section of actuator and coil*

The mechatronic system that allows generating a damping force varying of the magnetic field at first depends on the circulation ampere's law (5):

$$N\ I = H_0 l_0 + \sum_i H_i l_i = \Phi\left(\frac{2l_0}{\mu_0 S_0} + \sum_i \frac{l_i}{\mu_r S_i}\right) \tag{5}$$

where l_0 and l_i are the length of a circulation in the gap and the iron space respectively, while S_0 e S_i are the cross section of the magnetic flow which in this case is the same as in the empty space or as in the iron one because of a small gap.
Since the reluctance in the iron is negligible with regard to the empty one ($\mu_r \ll \mu_0$) [3]-[4], we considered only the addend of the second member shown in an integral form such as (6), [5]:

$$\int \vec{H} \cdot \hat{n}\, dl = \int \vec{J} \cdot \hat{n}\, dA_C \tag{6}$$

where A_C is the coil cross section. The last step to carry out is to calculate the cross section of the polar expansion relative to the electromagnet. The realized magnetic field $\vec{B}$ obviously depends on the induction magnetic field $\vec{H}$ through the iron fraction particle volume of a fluid, [6]:

$$B(H) = 1.91 \cdot \phi^{1.133} \cdot \left[1 - e^{-10.97 \cdot \mu_0 \cdot H}\right] + \mu_0 \cdot H \tag{7}$$

the pathway of which is calculated by varying the iron particle fraction and induction magnetic field as shown in the figure 3.

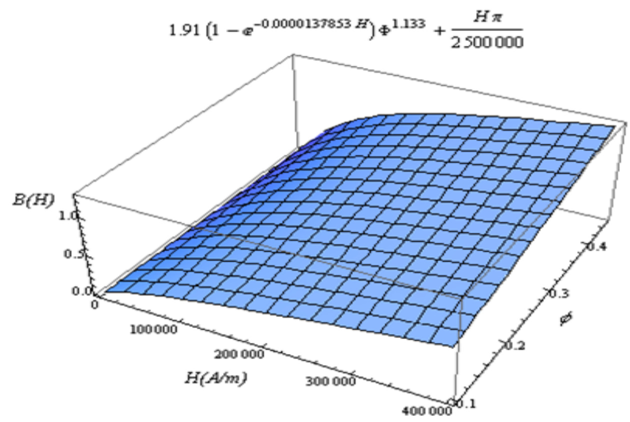

Figure 3: *A magnetic field B versus* ϕ and *H*

As we can see from the figure 3, the magnetic field increases with the increase of ϕ and of the induction magnetic field H as well. The yield strength equation (8), [6]:

$$Y_s = C_f \cdot 271700 \cdot \phi^{1.5239} \cdot Tanh\left(6.33\times10^{-6}\cdot H\right) \tag{8}$$

assumes the same behavior although what must be taken into account is another parameter called a carrier fluid constant C_f [6]. The figures 4 and 5 show the pathway of the yield strength varying with the magnetic field *H* in the two distinguished cases.

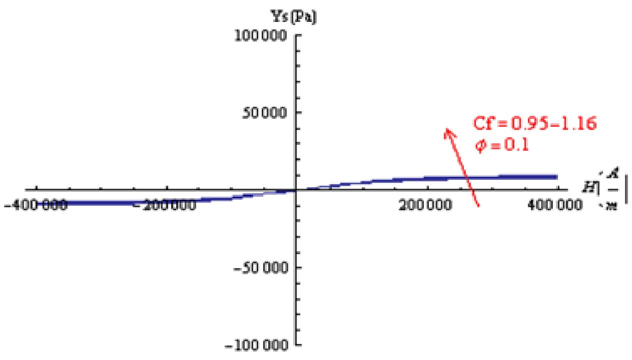

Figure 4: *The yield strength versus H varying carrier fluid constant* C_f *and fixed* $\phi = 0.1$.

What is shown in the figure 4 is the variation with the carrier fluid constant at $\phi = 10\%$. A small variation of $Y_S\left(C_f, H\right)\big|_{\varphi=10\%}$ can be seen there with regard to $Y_S\left(\phi, H\right)\big|_{C_f=0.95}$ whose data are plotted in the figure 5.

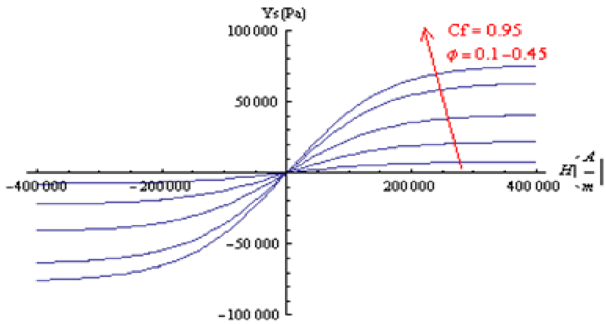

Figure 5: The yield strength versus *H* varying the carrier fluid constant ϕ and fixed $C_f = 0.95$

A similar behavior has $c(\phi,T)$ whereas ϕ and temperature *T* are changing. It depends on the dynamic viscosity as it is shown in (8), [7]:

$$\eta(\phi,T)=\eta_0\left(1-\frac{\phi}{\phi_{\max}}\right)^{-k\,\phi_{\max}} e^{\left[-\alpha(T-40)\right]} \tag{8}$$

whose a 3D plot is shown in the figure (6). We can see that $\eta(\phi,T)$ decreases with the increase of the temperature and while it increases with the increase of ϕ once *T* is fixed. In this application we fixed the iron fraction particle volume at the value $\overline{\phi}=0.4$ in order to have $\eta(\overline{\phi},T)$ as it is shown in the figure (7):

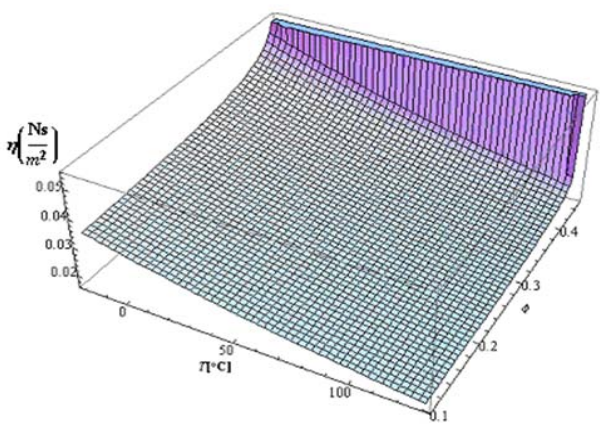

Figure 6: The dynamic viscosity η versus ϕ and T.

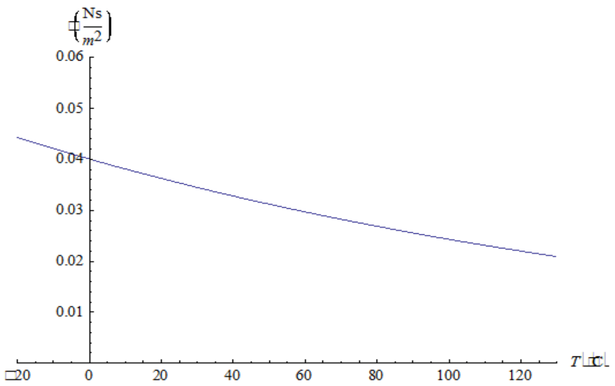

Figure 7: *The dynamic viscosity* $\eta(\bar{\phi},T)$ *versus* T

The equations (9), (10), (11) and (12) are the electromechanical relations through which the proportions of the magnetorheological damper have been determined. The force generated from the passive system turns out from the expression (9) from which the damping constant is extrapolated (10) and where V represents the relative speed between the sprung and unsprung mass, while (11) is the one relative to the MRF. The following represents the coil cross section whose axial dimension is equal to the square root of (12):

$$F_{pass}\left(V_d\right)=\left(\frac{6\,\eta\left(\bar{\phi},\bar{T}\right)\,a}{\pi r_m g^3}\right)\left(\pi r^2_{piston}-\pi r^2_{rod}\right)^2 V \tag{9}$$

$$c\left(\bar{\phi},\bar{T}\right)\Big|_{\substack{\bar{T}=40°C\\ \bar{\phi}=0.4}}=\left(\frac{6\,\eta\left(\bar{\phi},\bar{T}\right)\,a}{\pi r_m g^3}\right)\left(\pi r^2_{piston}-\pi r^2_{rod}\right)^2=\text{optimal damping constant} \tag{10}$$

$$F_y\left(H\right)=Y_s 2S_0=Y_s\left[2d\left(2\pi r_{piston}\right)\right] \tag{11}$$

$$A_C=\frac{H\,2g}{f_c J} \tag{12}$$

A short parenthesis must be opened for the meaning of the optimal damping constant. This term refers to the damping constant that must be realized at the minimum of the maximum acceleration of a system during its oscillation. It is equal to $c\left(\bar{\phi},\bar{T}\right)\Big|_{\substack{\bar{T}=40°C\\ \bar{\phi}=0.4}}=\sqrt{\frac{m_2\left(\frac{k_1k_2}{k_1+k_2}\right)}{2}}$ according to which the dynamic behavior response is characterized in a transient condition [8].

The cross section of the coil has been chosen in correspondence to the point of maximum magnetic permeability whereas this value is the one corresponding to the error of 10% between the linear and real pathway of the first magnetization curve. What has been said is on the Table 1 which leads to the Table 2 regarding the geometry of the electromagnet.

Table 1: *Initial data for electromagnet design*

Symbol	Quantity	Values (SI)
r_p	piston radius	0.03 m
r_r	rod radius	0.004 m
r_m	mean radius	0.017 m
A_p	piston area	0.0028 m^2
A_r	rod area	5×10^{-5} m^2
L_g	gap	1×10^{-3} m
$\overline{T}$	design temperature	+40 °C
k	Intrinsic viscosity	0.2750 Ns/m^2
η_0	dynamic viscosity at design temperature	0.0251 Ns/m^2
$\overline{\phi}$	design fraction volume of iron particles	40 %
$\phi_{\max}$	maximum fraction volume of iron particles	0.45 %
α	temperature coefficient	0.005 $°C^{-1}$
F_{yield}	design yield stress force in linearity range	100 N
C_f	carrier fluid costant	0.95
$c\left(\overline{\phi},\overline{T}\right)$	optimal damping costant	1000 N s/m
H	magnetic field	17840 A/m
J	density current	10^6 A/m^2
f_c	copper winding factor	50 %

Table 2: *Final data for electromagnet design*

Symbol	Quantity	Values (SI)
τ_{yield}	yield stress	7184 N
d	pole thickness	0.037 m
$A_{pole}(2S_0)$	pole expansion surface	0.014 m^2
a	piston axial dimension	0.0352 m
A_c	coil cross section	$7.13\times10^{-5}m^2$
b	Axial dimension of coil winding	0.0084 m

Once the data showed in the Table 2 are obtained, we have analyzed the plot of $C_d = c\left(\bar{\phi}, T\right)\Big|_{\bar{\phi}=0.4}$ varying with temperature as it is shown in the figure (8):

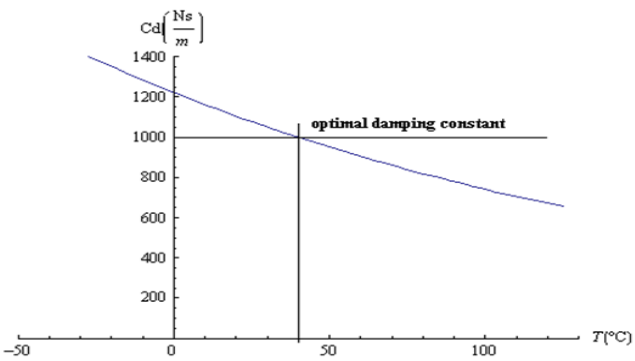

Figure 8: The damping constant C_d versus T once fixed $\bar{\phi} = 0.4$ with the optimal one which is shown as well

The figure (9) shows that $c\left(\bar{\phi}, T\right)\Big|_{\bar{\phi}=0.4}$ has a similar pathway of dynamic viscosity. This leads to a different dynamic behavior of the system varying with temperature. What has been said before is shown by plotting the real and imaginary part of eigenvalues produced by the dynamic matrix **A** of the system (4) varying the temperature in a range $-20 \le T \le 130\ °C$.

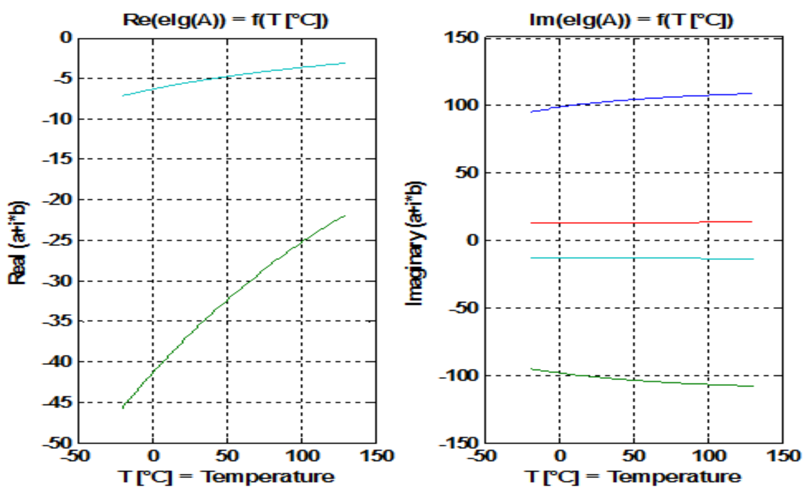

Figure 9: *The real and imaginary part of eigenvalues of the dynamic system varying with temperature*

We asked ourselves if the introduction of the MRF technology could recover the optimal damping constant varying with temperature. We know that in the optimal conditions and without the introduction of the MRF force, the expression of the force turns out from (13):

$$F_{tot(opt.)} = F_{pass.(opt.)}\left(\bar{\phi},\bar{T}\right) = c\left(\bar{\phi},\bar{T}\right)\Big|_{\substack{\bar{T}=40°C\\ \bar{\phi}=0.4}} \cdot V \tag{13}$$

If we assume an increase of the temperature beginning from $T = 40\ °C$ then the damping constant will decrease from the optimal value. Since the presence of the MRF involves an increase of the fluid viscosity, we can compensate the loss of a damping effect by means of the induction magnetic field *H* in the range $T > 40\ °C$.

Because of the presence of the magnetorheological fluid, this contribution must be added to the (13) in order to obtain (14), so that the same reaction force could be realized in the optimal conditions.

$$F_{tot(opt.)} = F_{MRF}\left(\bar{\phi},H\right) + F_{pass.}\left(\bar{\phi},T\right) \tag{14}$$

where

$$F_{MRF}\left(\bar{\phi},H\right) = C_f \cdot 271700 \cdot \bar{\phi}^{1.5239} \cdot A_{pole} \cdot \tanh\left(6.33\times10^{-6} \cdot H\right) \tag{15}$$

$$F_{pass.}\left(\bar{\phi},T\right) = c\left(\bar{\phi},T\right) \cdot V \tag{16}$$

From (14) we obtain the expression of the magnetic field $\vec{H}$ inorder to compensate decreasing of the damping constant, taking into account that with the increase of the temperature (14) must be verified.

By manipulating (14), (15), and (16) the value of the magnetic field is obtained (17):

$$H\left(T,V\right) = \frac{1}{6.33\times10^{-6}} \cdot \operatorname{arctan}^{-1}\left[\left(\frac{c\left(\bar{\phi},\bar{T}\right)\Big|_{\substack{\bar{T}=40°C\\ \bar{\phi}=0.4}} - c\left(\bar{\phi},T\right)}{\beta\left(C_f,\bar{\phi},A_p\right)}\right) \cdot V\right] \tag{17}$$

in order to induce a recovery of the optimal damping constant during the increase of the temperature ranging from $T > 40\ °C$ as a state feedback of the reduced order (in the sense that only the speed value is considered whereas the state vector contains displacements as well) such as to provide a time variant control signal with temperature.

The expression of the force generated to do what has been said so far (18):

$$F_{tot(opt.)} = \beta\left(C_f, \bar{\phi}, A_p\right) \cdot \tanh\left(6.33 \times 10^{-6} \cdot H\left(T, V\right)\right) + c\left(\bar{\phi}, T\right) \cdot V \tag{18}$$

where

$$\beta\left(C_f, \bar{\phi}, A_p\right) = C_f \cdot 271700 \cdot \bar{\phi}^{1.5239} \cdot A_{pole} \tag{19}$$

The magnetic field which provides the results presented above is dependent on the relative speed value of the unsprung mass with the once fixed temperature, as it is shown in the figure 10:

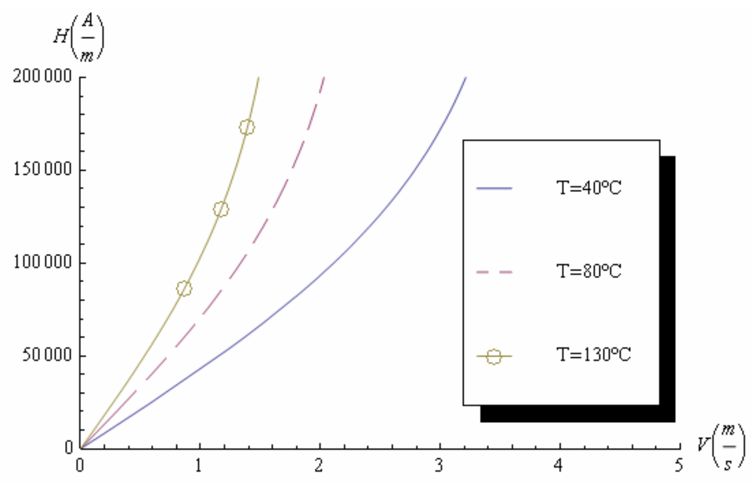

Figure10: *The force generated by the MRF to recover the optimal damping constant varying with temperature*

Once the temperature is fixed, as it is shown in the figure 10, we can see how to realize the compensation effect in order to recover the optimal damping constant. The electromagnets have to produce a magnetic induction field increasing the speed of the unsprung mass. This is a great problem because of the thermal limitation due to the copper wire whose electromagnets are built up. In fact, what we can also see from the figure is that, at very small speed, the value corresponds to the high induction magnetic field. However, if a compensation effect was feasible we would obtain a constant dynamic behavior varying with temperature.

The compensation of the optimal damping constant leads the system to have the same dynamic behavior varying with temperature as we can see from the plotting of the real and imaginary part of eigenvalues,as it is shown in the figure 11.

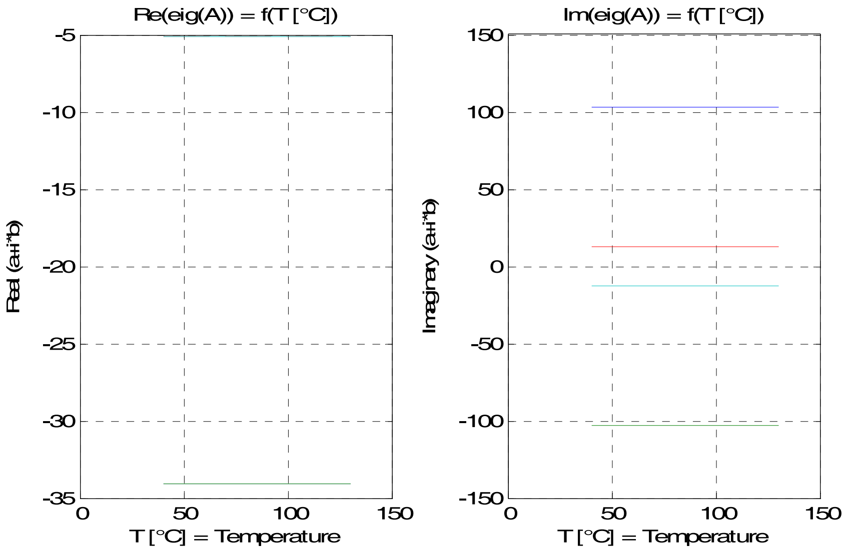

Figure 11: *The real and imaginary part of eigenvalues of a dynamic system with the MRF varying with temperature*

As we can see from the figure 11 the real and imaginary part of eigenvalues of the system are constant. This means that the equations of motion are characterized by the same linear combination of natural vibration varying with temperature for $T > 40\ °C$.

4. SIMULATIONS AND RESULTS

All simulations were performed by Simulink, a package of MATLAB. The figure (12) shows the block scheme through which simulations were performed while varying with temperature. Each block contains a sub-block, as it is shown in the figure (13), in which there is the dynamic system presented.

In this case they are considered within the blocks at $T = 40\ °C, T = 80\ °C,$ and $T = 130\ °C$ as a specified range of the temperature where the compensation is possible for our study. By simulating the system with a step input with the amplitude of $n = 0.02m$ at $\bar{t} = 2s$ in a simulation for $t \in [0,4]s$, see the figure (13-left), we can see that the overshoot increases by increasing of temperature, see the figure (13-right). This leads to a general modification of transient response in terms of settling times.

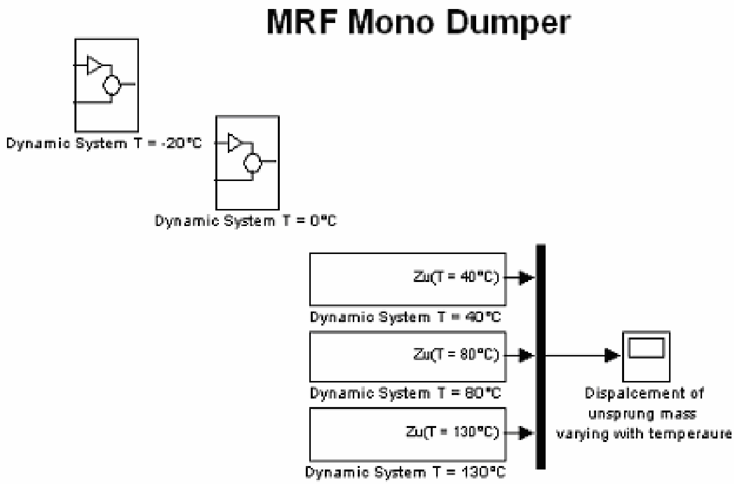

Figure 12: *A block scheme of the dynamic system with the MRF varying with temperature*

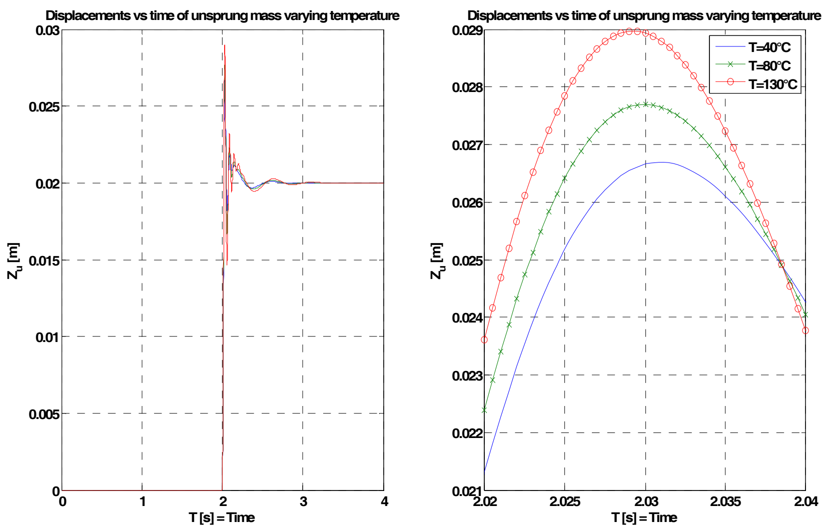

Figure 13: *Displacements of the unsprung mass without MRF varying with temperature*

By the introduction of MRF technology for example in the system having temperature $T = 80\ °C$, there is a small variation in a dynamic behavior. The figure (14-left) shows a simulation during which the system is analyzed in the case it has a temperature $T = 40\ °C, T = 80\ °C,$ and $T = 80\ °C$ with the MRF compensation. From the figure 14-right we can see how the introduction of the compensation effect reduces the overshoot corresponding to the simulation at $T = 80\ °C$ well below than the one at temperature $T = 40\ °C$

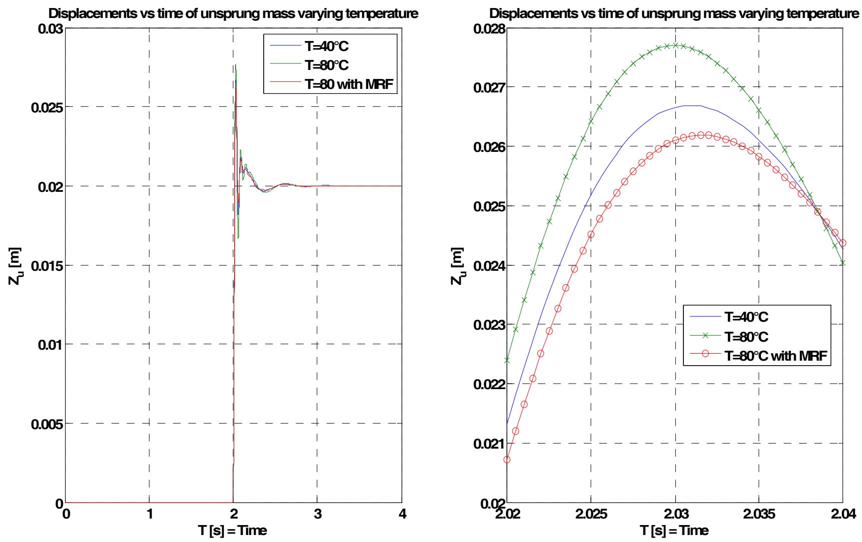

***Figure 14:** Displacements of the unsprung mass with the MRF compensation varying with temperature*

5. CONCLUSIONS

After a short introduction to magnetorheological fluids and their advantages as for the power supplied with regard to the electrorheological ones, we have analyzed the behavior of the magnetic field $\vec{B}\left(\vec{H},\phi\right)$ and $Y_{\mathrm{S}}\left(\text{yield strength}\right)$ whereas $Y_{\mathrm{S}}\left(\phi,H\right)\Big|_{\mathbf{C_f=0.95}}$ makes higher contributions than $Y_{\mathrm{S}}\left(C_f,H\right)\Big|_{\boldsymbol{\varphi}\mathbf{=10\%}}$. According to the analysis of dynamic viscosity, which decreases with the increase of the temperature, it was seen that the optimal damping constant is not held in such a manner to induce a higher oscillation of the unsprung mass in transient response. The oscillations are characterized by the overshoot which increases with the increase of the temperature because of decreasing of the damping constant. We have also seen that in the case of the real yield strength expression, obtaining a gain as independent on the unsprung mass speed is not feasible. However, if a nonlinear expression is used, there would be a great value of the induction magnetic field in a range of the speed where another contribution to the increase of the temperature is a joule dissipation effect. This leads to a higher and more complicated design of the electromagnet because it has to support high values of the induction magnetic field and produce low dissipation of thermal energy.

Moreover, decreasing of the damping constant was compensated by the introduction of a magnetic field whose value was considered in a range of a linear response of the yield strength produced by the actuator in order to obtain an equivalent damping constant $c_H\left(\bar{\phi},T\right)$. This constant represents a gain to generate a control signal by a state feedback of a reduced order which can maintain the same transient response within a range of the unsprung mass speed with the once fixed temperature. The future development will deal with the influence of this study upon the lateral dynamic behavior due to the force developed in a full car during turning and maneuvering whereas the centrifugal force produces such a virtual increasing and decreasing of the sprung mass to modify the optimal damping constant for the inner and outside part of a vehicle respectively.

LIST OF SYMBOLS

m_1	Sprung mass
m_2	Unsprung mass
x_1	Degree of freedom of the sprung mass
x_2	Degree of freedom of the unsprung mass
w	Road noise pattern
k_1	Suspension stiffness
k_2	Tire stiffness
T	Temperature
$c\left(\phi,T\right)$	Suspension dumping versus temperature
F_{MR}	Magnetic-Ride force
ϕ	Fraction volume of iron particles
$\phi_{\max}$	Max fraction volume of iron particles
C_f	Carrier fluid constant
k	Intrinsic viscosity
a	Axial length of the electromagnet

L_g	gap
$\mathbf{M}$	Mass matrix
$\mathbf{C}(\phi, T)$	Damping matrix
$\mathbf{K}$	Stiffness matrix
$\mathbf{A}$	Matrix of dynamic
$\mathbf{b}$	Vector for the sign of F_{MR}
$\mathbf{g}$	Noise tire stiffness vector

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[1] CONTRIBUTION TO TIRE / ROAD FRICTION ESTIMATION

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UDC: 629.113:625.85
629.012.551.3:531.43

Abstract:

This paper presents a method to tire-road frictional parameter estimation in real driving condition. The procedure is based on the relationship between longitudinal wheel slip and frictional coefficient. Theoretical basis for forming identification model is an appropriate combined vehicle-wheel dynamics simulation model. The used experimental system has been designed with more sensors of typical measured variables, such as wheel angular velocity, vehicle linear velocity, steering whee angle, (torque, velocity), vehicle linear deceleration, (acceleration),, braking hydraulic pressure etc. The experimental data has been processed as relation friction – slip, at different affecting factors. As typical parameters of these relation are selected curve shape, friction – slip slope, curve maximum, slip optimum. The importance of these parameters to assessment of vehicle-environment interaction with respect to influence on the traffic active safety is pointed out.

Key words: Tire, road, friction, slip, braking, experiment, typical parameters.

PRILOG ODREĐIVANJU TRENJA PNEUMATIKA I KOLOVOZA

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Rezime: U radu je prikazana metoda za određivanje parametara trenja pneumatika i kolovoza u uslovima realne vožnje. Procedura je bazirana na relaciji između podužnog klizanja točka i koeficijenta trenja. Jedan prikladan kombinovani simulacioni model dinamike vozilo-točak je baza za formiranje identifikaciong modela. Korišćen eksperimentalni sistem projektovan je sa više senyora tipičnih mernih veličina, ugaona brzina točka, translatorna brzina vozila, ugao zaokretanja točka upravljača, (odgovarajući obrtni moment, ugaona brzina), usporenje (ubrzanje) vozila, pritisak u kočnoj instalaciji itd. Eksperimentalni podaci su obrađeni kao relacije trenje – klizanje, pri različitim uticajnim faktorima. Kao tipični parametri ovih relacija su izdvojeni oblik krive, gradijent trenje-klizanje, maksimum, optimalno klizanje. Istaknut je značaj ovih parametara na procenu interakcije vozilo-okruženje sa aspecta uticaja na aktivnu bezbednost saobraćaja.

Ključne reči: Pneumatici, kolovoz, trenje, klizanjue, kočenje, eksperiment, tipični parametri.

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CONTRIBUTION TO TIRE / ROAD FRICTION ESTIMATION

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INTRODUCTION

To increase vehicle active safety it is necessary to estimate tire/road friction reliable. The vehicle performance can be significantly improvement if the parameters of the tire/road friction are available as input information to system of vehicle active control.Various methods to estimate the tire/road friction characteristics have been developed and used. These methods can be divided into two groups; first, " cause-based", second, "effect-based". Namely, the first approach detect factors which affect the friction coefficient, the second based on the effects that are generated by friction [1].

Many factors affects on the relation tire/road friction, for example, road condition, tire condition such as tire type, tread pattern, tread depth, tire pressure and temperature [2, 3]. Moreover, directly measurement of the relevante variables either is impossible or requires the use of the special sensors. From these reason, currently, different definition, methods and tools can be used, such as virtual sensors, estimation theory, optimal filtering, adaptive filtering and change detection etc. With a virtual sensor can to estimate any parameters which cannot be measured directly, or at least would require very costly sensors, by only using available measurement information from in the vehicle implemented standard sensors [4]. The base of this approach is forming an appropriate model which couples measured and estimated parameters. The basic identification model can be formed either for whole vehicle or particularly for wheels with correct interconnections.

1. TIRE / ROAD FRICTION

Key points of model forming is relation of the vehicle dynamic parameters and tire / road friction parameters. Based on the tire frictional characteristics, actual modeling and estimation problems can be pointed out on Figure 1, with plots : a/ lateral force F_y versus longitudinal force Fx, upper plot b/ lateral force Fy versus side slip angle α, right plot, c/ longitudinal force F_x versus longitudinal slip s, lower plot.

The tire complex characteristic in Fig. 1a, can be fitted from the experimental data or/and simulated by different physical – mathematical models and methods. The assumption that the tire tread sliding friction properties are isotropic permits definition a non-directional sliding friction coefficient in relation to full friction force vector. This force vector can be divided on the longitudinal and the lateral component according to given or adpotet friction distribution, as circle or ellipse [4]. The examples shown in Fig. 1, lower and right are partial friction curves, corresponding to components of the friction force vector.

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As can be see from Fig.1 lower plot, and Fig.2, typical form of the tire – road longitudinal friction curves is nonlinear. The curve initial segment, which in relation to tire longitudinal stiffnes, can be approximated by straight line. The second segment is domain optimal slip with peak value of the friction coefficient and third segment defines the domain intensive slip with locked value at 100% slip. Direction change of plot μ = μ (s) depending from influential parameters are shown in Fig. 2a.

Tire performances in Fig. 1 , presented as field operating tire characteristics, can be obtained for steady state driving condition, simulated on the testing drum or in real driving environment at different vehicle maneouvres, tire working condition, road state etc, what will cause significant data distribution from smooth curve shape [1], [4]. From these reason, it is search, recently, new approaches to identification of the tire – road interaction based on the modern scientific – technical areas. In order to contribute the previously point out problems solution, in following sections a approach to choice and use identification methods to tire/road friction is proposed.

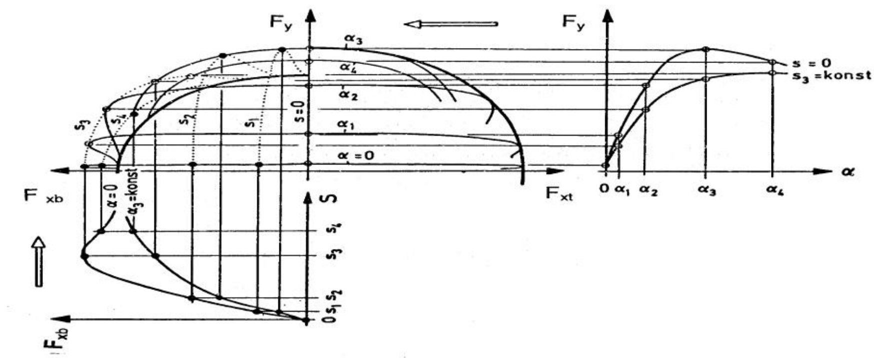
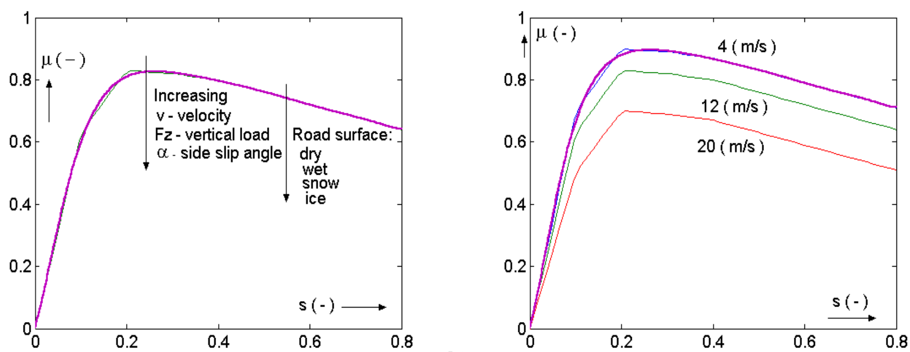


Figure 1: *Schematic plots of tire frictional characteristics, a/ complex, $F_y=F_y(F_x,s\,,\alpha)$, b/ lateral, $F_y=F_y(\alpha,s)$, c/ longitudinal, $F_{xb}=F_{xb}(s,\alpha)$, [6]*

a)



b)

Figure 2: *Estimated plots of friction coefficient, μ - longitudinal wheel slip, s: a) influential parameters, b) vehicle velocity as prameter, [Measurement samples from this study]*

2. VEHICLE SIMULATION AND IDENTIFICATION MODEL

A simplified vehicle – wheel longitudinal dynamics model, presents in Fig. 3 a,b, is adapted as basic for experimental investigation in this study, [4], [7]. This model includes one – wheel rotational dynamics, linear vehicle dynamics and interactions between them. The equations of the wheel and vehicle motion are given as the following respectively according to signs in Fig. 3,

$$m_t(dv/dt) = F_x \quad (1) \qquad J(d\omega/dt) = F_x r - M_k \quad (2)$$

$$F_x = F_x \mu(s, v, F_z, \alpha....) \quad (3) \qquad s = (v - r\omega)/v \quad (4)$$

$$M_k = K_b p \quad (5) \qquad F_{z1} = (mgb - mjh)/l \quad (6)$$

with additional denotation and comments, m_t – wheel mass, J – wheel moment of inertia, M_k – braking torque, K_b – braking system gain, p – braking cylinder pressure, j = dv/dt – vehicle linear deceleration.

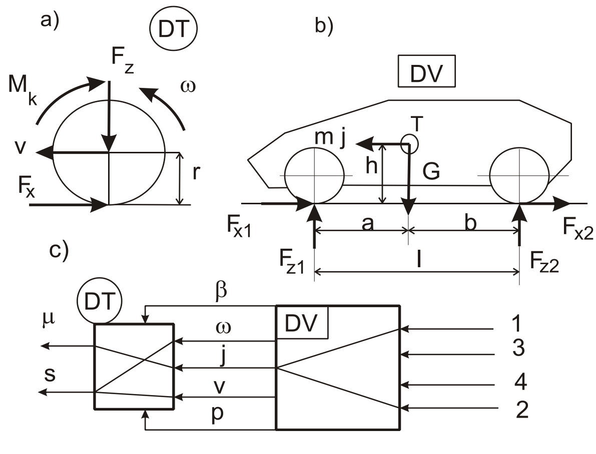


Figure 3: *Vehicle system models, a),b) simulation models, c) identification model*

The structure and parameters of the tire/road friction identification model, proposed in this study is shown on the block diagram in Fig. 3c. The system input in Fig. 3c, includes one of the possible braking combination with number signs of braking wheels 1 3 4 2. The system state variables are: β – steering wheel angle, ω - wheel angular velocity, j – vehicle linear deceleration, v – vehicle velocity, p – braking cylinder pressure. The system output variables are : μ - longitudinal friction coefficient , s – longitudinal slip. Generally, all above denoted state variables can be measured in real driving condition by means experimental system presented in next section. The output variables, friction, μ → slip, s, are denoted in this study as estimted variables related to above mentioned state variables, before all with j – deceleration, v – linear velocity, ω - angular velocity.

3. EXPERIMENTAL SYSTEM AND RESULTS

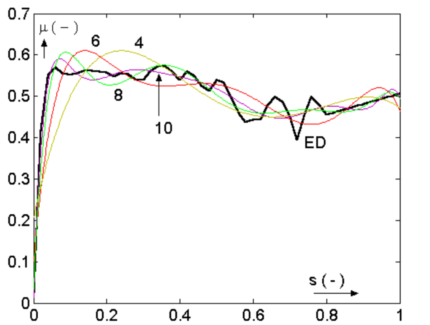
The experimental investigation presented in this paper were realized with two system s whose segments are shown in Fig.4 as follows: upper row, from left to right – 1) chassis cab vehicle for traction and support of the measured devices or measured vehicle, 2) sensors combination of wheel angular velocity – vehicle linear velocity, 3) steering wheel measured device for steering torque, steering angle and steering angular velocity measurement; lower row, from left to right – 1) sensors combination of longitudinal – lateral vehicle velocity components, 2) braking system hydraulic pressure sensor, 3) detail of connecting of the angular velocity sensor support with vehicle wheel.

By using experimental system in Fig. 4, in the first phase of the study, measured data of vehicle linear velocity and wheel angular velocity has been collected and processed by means corresponding algorithms according to mathematical model (1) – (6) and determined data of variables, vehicle deceleration and wheel longitudinal slip. Then, a structural filter, as relation between deceleration and longitudinal friction coefficient is formed and used during identification procedure.

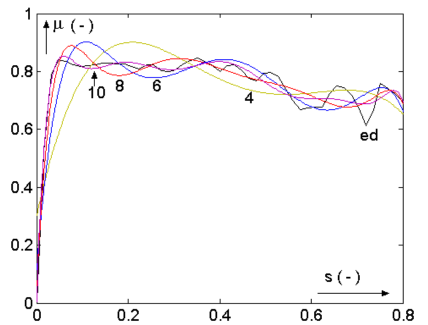
The ilustrative samples of experimental results are presented in Figure 5 and 6 as follows below. Fig. 5a, shows the raw experimental data related to vehicle deceleration during braking which are used for identification of the tire/road frictional curve in Fig. 5b. The used signs on these Figures are: ed – experimental data, 4, 6, 8, 10 – number and degree of the curve fitting iteration. Fig. 5c, d, shown segments of the frictional curve in Fig. 5b, but presented in the narrow band of the longitudinal slip, 20% and 10%, respectively. These segments give more information about curve shape, friction – slip slope, friction coefficient maximum value, optimum value of the longitudinal slip, denotation in Fig. 6c, also, information about curve fitting acuracy. For given examples in Fig. 5c, d, the best curve fitting is realized with 10 th degree approximation according to presented differences of estimated and fitted values in Fig. 6a, b.

After the curve shape and fitting error determination can be typical parameters selected, denoted in Fig. 6c, by means procedure of differential criteria specificied in Fig. 6d. The plots of parameters in Fig. 6d is obtained for raw upper curve in Fig. 2b, as ilustrative example curve with more straight consitutive segments. On this way defined typical parameters and procedure for their search give possibilities to evaluation of the vehicle – enviroment.

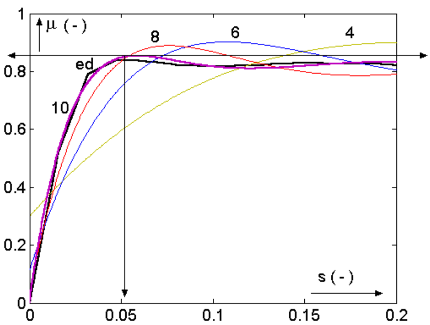
***Figure 4:** Vehicle experimental systems for tire/road friction estimation*



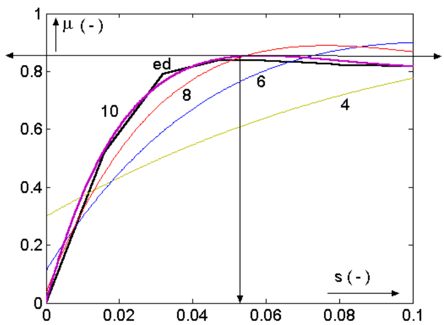
a)



b)



c)



d)

***Figure 5:** Identification results of the tire /road friction, a) starting plot related to vehicle deceleration, b) result of processed plots, c),d) results in narrow band of longitudinal slip, 20%, 10%, respectively, ed – experimental data, 4, 6, 8, 10 – number and degree of the curve fitting interpolation.*

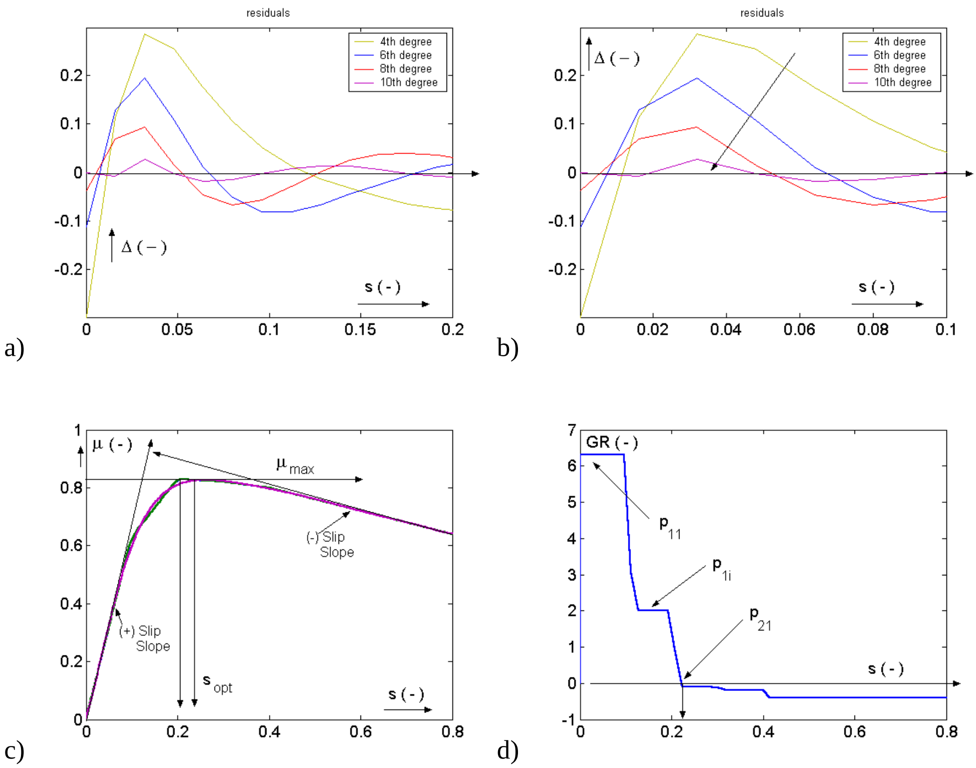


Figure 6: *Accuracy of the curves fitting and typical parameters,*
a), b) difference of estimated and fitted values of $\mu \rightarrow s$ *– curves in Fig. 5 c, d, respectively, c) typical parameters of* $\mu \rightarrow s$ *– curves, friction - (+) Slip Slope positive, friction - (-) Slip Slope negative,* μ_{max} *– maximum values of friction coefficient,* s_{ot} *– optimum values of the longitudinal slip related to* μ_{max}*, d) differential criteria to search typical parameters of the curves* $\mu \rightarrow s$*,* p_{1i} *– curve slops,* p_{2i} *– curve extremum*

Condition with respect to many affecting factors on the braking process. In real driving condition, during braking, for example, above mentioned factors affect simultaneous, such as the change of vehicle velocity, wheels load, lateral and longitudinal slip, road state and condition etc, what cause that road frictional properties must be considered as time variables with stochastical quantity [4]. In this sense, defined and indentified parameters, before all, friction – slip slope, at coordinate origin, as effects tire longitudinal stiffnes and the maximum of friction coefficient at optimum slip, as need for good braking control, can be appropriate assessment criterion the stochastical relation of tire/road interaction.

CONCLUSIONS

To increase vehicle active safety it is necessary to estimate tire/road friction reliable. Many factors affects simultaneous on this relation, such as road condition, vehicle driving state, tire/road interaction. The basic model to identification of the tire/road longitudinal friction during vehicle braking can be formed on the different ways. One combination of the vehicle longitudinal dynamics model and single wheel rotational dynamics model used in this paper give acceptable results. Proposed procedure and defined quantity contribute to assessment of the vehicle – environment interaction on the traffic active safety.

ACKNOWLEDGMENTS

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[1] SECOND HAND VEHICLE MAINTENANCE FRAUDS

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UDC: 629.114:343.537
629.114:343.533+343.72

Abstract

With the globalization of automotive industry all related automotive business activities are becoming global – automotive fraud, and in particular vehicle maintenance, associated with insurance fraud is a good example. Like many other supplier-to-customer based processes, vehicle maintenance fraud is almost always being significantly represented in the international trade of goods and services. The price of new cars has climbed steadily over the past few years (excluding last year and a half) making used cars more attractive than ever. Buying a used car is a great way to make money economy, particularly in the case of less developed market. On the other hand, there are scam artists all around the world working hard to take advantage of unsuspecting buyers. This is particularly the case of imported second hand cars from one (more developed) to another (less developed) country.

A number of automotive frauds was elaborated in this paper with the particular emphasis of automotive maintenance frauds. Some typical examples are demonstrated.

Key words: automotive fraud, automotive maintenance fraud, used vehicles.

PREVARE U ODRŽAVANJU POLOVNIH VOZILA

UDC: 629.114:343.537
629.114:343.533+343.72

Rezime: Prateći globalizaciju automobilske industrije svi prateći aspekti automobilskog biznisa takođe su postali globalni – prevare sa vozilima, a posebno prevare u održavanju i osiguranju vozila su odličan primer. Slično drugim procesima u kojima su povezani dobavljač i korisnik i prevare u održavanju vozila su oduvek bile značajno zastupljene u međunarodnom prometu roba i usluga. Cene novih vozila znatno su rasle poslednjih godina (izuzimajući poslednjih godinu i po dana) zbog čega su u jednom periodu polovna vozila bila interesantnija nego ikada ranije. Kupovina polovnih vozila je dobar način da se uštedi, posebno u zemljama sa slabije razvijenim tržštem. Sa druge strane, na celom svetu postoje

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«umetnici» koji ne biraju sredstva da bi na neopreznim kupcima steknu profit. Ovo se posebno događa na relaciji uvoz vozila iz razvijenije u manje razvijenu zemlju.

U ovom radu je opisan izvestan broj automobilskih prevara, sa posebnim osvrtom na prevare u održavanju vozila. Prikazani su i neki karakteristični slučajevi.

Ključne reči: automobilske prevare, prevare u održavanju vozila, korišćena vozila.

SECOND HAND VEHICLE MAINTENANCE FRAUDS

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UDC: 629.114:343.537
629.114:343.533+343.72

1. INTRODUCTION

With the help of modern body repair techniques everything is possible - even vehicles in a bad overall condition may have a nice look. The auto industry and their dealers are rife with scams and fraud and the potential buyer needs to be armed with the knowledge of how these scams work and how to avoid them. There are many dealers that run reputable businesses and can get buyers into a vehicle without using fraudulent means**,** but there are always those individuals or companies that are looking for ways to take consumers for a ride.

In many countries, it is illegal to sell a new vehicle that has sustained some form of body, structural, collision, or other damage up to a certain percentage of the manufacturer's suggested retail price for the vehicle without first disclosing the prior damage to the buyer. It is also generally considered illegal to sell an unsafe vehicle**,** to make affirmative misrepresentations about a vehicle, new or used, or to lie to a consumer in response to questions asked about a vehicle. Few things are more annoying in the purchase of a vehicle than to find out that it has sustained prior accident damage**.**

Therefore, even if fraudulent maintenance activities were performed in a certain country, there exist fraud internationalization process supported by the exchange of vehicle parts and components (new genuine, new but non-genuine, repaired or used – "second hand"), maintenance tools, repair materials and technologies, etc. between countries. In addition to that there exist an intentional flow of goods and services normally starting in highly developed countries towards the direction of less developed countries. No matter what aspect of internationalization of this process is in question it is always seriously related to safety risks associated with the used vehicle market, and in particular with the importation of such vehicles.

Car maintenance deficiencies may be intentional or unintentional, conscious or unconscious. Maintenance and repair is becoming now-a-days a set of very complex technological procedures that sometimes are even more complex compared to those used in vehicle production.

Used vehicles have an unknown history of ownership. The best used car buy is one that has been well taken care of and well maintained. In the less developed countries there is an unwritten rule assuming "vehicles coming from developed countries" are with no doubt "always better" then those available at the local markets, and "even much better then that". This "inferiority complex" position in fact is not often true, but it opens a challenging playground for different individuals and companies to benefit significant profit by

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enhancing the flow of bad and/or unsafe second hand vehicles over the borders between “developed” and “less developed” countries, obviously in the direction of the second ones.

Such a believe is also enabling some parties to additionally benefit from the fact that while importing second hand cars to other countries there normally is no any particular vehicle inspection performed over such vehicles aside from documentation verification for customs and latter vehicle registration purposes. That is why vehicle documentation is also often subject to forging.

On the other hand, legislation in less developed countries often does not deal with the automotive fraud issues, i.e. there are no appropriate laws designed to protect consumers from the many deceptive and unsavory practices and fraudulent means used in connection with purchasing and financing an automobile.

In theory, it is illegal to sell an unsafe vehicle, or a vehicle with disclosure of the true mileage, but …? That is why it may be considered typical that things not to be considered legitimate in a developed country might be assumed “legitimate” in less developed countries, simply due to missing legal frame which would ban the fraudulent behaviour.

In addition to that, purchase of used cars is often "as is" with no warranty, but in developed countries there are legal protections, and these may also apply in the case of "as is" sales [6].

2. WHAT IS FRAUD?

Fraud [1] is often defined using a four-part test to determine whether an act is fraudulent or not by asking whether the act is :

- The false representation of a material fact,
- Intended to be relied upon by others,
- Knowing it was false, and
- Relied upon by the victim to their detriment.

3. WHAT IS AUTOMOTIVE FRAUD?

Automotive fraud is a very broad area. In general, the sale or leasing of cars with forged documentation and/or without a proper disclosure of known defects or dangerous conditions with the vehicle constitutes automotive fraud. There are many different types of automotive fraud**,** and the defendants include: insurance companies, car dealers and manufacturers, extended warranty companies, service contract companies and car finance companies.

Automotive fraud can come in a variety of forms when purchasing a used car, like inappropriate vehicle documentation, sales of salvage**,** flood and former rental cars without disclosure of their past history, odometer rollbacks, yo-yo sales, credit consolidation sales, and resale of damaged vehicles without full disclosure [2]. One of the most common forms of auto fraud is the practice of misrepresenting the true condition of the vehicle. There is a rule in some countries that a vehicle should be labeled if it “has been inspected for collision damage and collision repairs and has been found to be free of collision damage or repairs", like the case was in the US, but not in a number of other countries.

The NHTSA estimates, for example, that customers lose billions of dollars a year to odometer fraud, due to odometer readings rolled back or documents were forged. Making miles disappear helps increase the car's value to the seller, but can mean increased maintenance and repair costs to the buyer.

Typical dealer fraud that can be perpetrated on a used car buyer, for example, include lying about the previous ownership history, rolling back or replacing the odometer, falsifying figures or terms on a sale and/or lease, forging vehicle documentation, and other. The last thing an auto buyer should expect after buying a new or used car are problems that result from auto fraud, which occurs when the seller of the vehicle either fails to disclose the complete history of the car he is selling, or alters or destroys evidence pertaining to any part of the vehicle's age, condition or inherent or acquired defects.

All these things make used car customer not being ever sure that he/she is buying a legitimate vehicle that he/she can truly own. This lack of knowledge facilitates fraud, and some dealerships will indeed defraud customers by (falsely) telling them that their vehicle is OK. Customers should avoid being fooled by a freshly detailed car and a steam cleaned engine compartment, because it is essential to know the true condition of the vehicle before buying it.

One of the most common types of lemon fraud in US encountered by clients is used car being sold which later turns out to have extensive presale collision damage. The way of fighting this problem is to impose requirements that vehicle should be labeled "not been returned to a dealer or manufacturer because of lemon law defects or complaints."

Automotive frauds are hard to detect. These are usually associated with the Insurance frauds and/or typically maintenance frauds that may be discovered under accident reconstruction analyses, damaged vehicle value estimation or massive vehicle repairs. Therefore, insurance, or maintenance or automotive frauds in general are not easy of being documented and illustrated because these are not easy to identify in public.

4. WHAT IS MAINTENANCE FAILURE - MAINTENANCE FRAUD & RELATED SAFETY RISKS?

Auto repair problems make up the largest group of consumer complaints. While most repair shops are honest, undercover car repair stings can be found at dishonest auto mechanics and shops all over the world. [3] According to Leonhardt and Rozon [4], one in three used cars has something to hide. Usually it's nothing major, perhaps the owner was a little lazy and failed to get maintenance done as frequently as he should have. In other cases, it could be that the car has been in a serious accident, flood damaged, or in fact stolen.

Deficiencies are immanent to the maintenance process, but the problem arises from that only when deficiencies are directed consciously by intention. In fact, any maintenance deficiency is safety related, although not all such things should be ranked to the same level of vehicle safety risk caused by maintenance fraud.

This paper does not deal with poor or low quality vehicle maintenance and repair. Besides, it neither relates to conscious and intentional maintenance deficiencies committed in order to make fraud but to those deficiencies resulting from the fact that both maintenance shops and/or technicians do not apply appropriate maintenance procedures or do not possess appropriate knowledge on the technology built in a vehicle they are repairing.

This particularly applies to installation of inappropriate spare parts, and application of inappropriate materials and/or repair technologies in the case of some specific vehicle failures.

At the Faculty of Mechanical Engineering of the University of Belgrade we are working on the development of a method for estimation of vehicles safety rate based on its condition [5]. It also includes study of some specific fraudulent cases, like the following:

- Intentional mislead to vehicle identification in the form of inappropriate (forged) engine number, VIN number, year of vehicle production, vehicle color, hiding real vehicle condition due to previous serious accident damage, etc.,

- Forging of vehicle maintenance and service documentation,

- Misuse of vehicles that have been declared "total loss" or "totally damaged", and then re-built in the country of origin or exported in the form of secondary raw material to the customer in another county where it will be rebuilt and marketed as "normally" used vehicle,

- Misuse of vehicle components removed from damaged vehicles, or declared damaged by the vehicle manufacturer (due to corrosion, fabrication failures, etc.) and therefore disposed to the recycling storage from where taken away and built-in a vehicle intended to be repaired and sold out in another country or directly exported to another country,

- Misuse in the form of dismantling of original parts and components from the vehicle intended of being exported and replacing of those with parts and components of unknown origin,

- Importation of vehicles of a given type and purpose (like vans) and their adaptation to become vehicles another purpose (like passenger cars) by means or unoriginal parts and non-standard repair technologies, etc.,

- Incomplete or inoperative vehicle with respect to its auxiliary equipment, like ABS, air-bags, GPS etc., that may not be inspected by inexperienced drivers.

Some of those may be illustrated by means of the cases presented in the Annex to this paper, while they also may be further elaborated in the following way:

Vehicle reconstruction after flood damage

If a vehicle was involved in a collision or otherwise sustained damage, it will be deemed either a total loss or eligible for repair[2]. If the amount of damage exceeds 75% of the car's fair market value, the owner is entitled to have the car declared a total loss.

In some cases, like in North Carolina, USA, if the vehicle is five years old or newer and the repairs exceed 25% of the vehicle's fair market value, the damage should be disclosed to prospective buyers. Diminished vehicle value occurs when a car sustains damage which is not a total loss in an accident that was the fault of another driver.

After the repairs are completed, such vehicle's fair market value is almost always less than it was before the damage. Some countries require this diminished value to be told to a potential buyer, but some countries don't and that is where fraud may occur.

Even if the vehicle was not stolen, it may be reconstructed after flood damage and/or older than it appears.

A salvaged and/or rebuilt vehicle is one that has been damaged so severely that the insurance company of the previous owner of the vehicle considered it a total loss. Vehicles that have been wrecked, declared a total loss by an insurance company, or rebuilt have what is called a salvage title**.** The title of the vehicle (and registration) must disclose that the vehicle is a salvage. In US it is unlawful to sell a salvaged vehicle without telling the buyer. The price of a salvaged vehicle is generally much less than an equivalent non-salvaged vehicle**.** Salvaged vehicles may have major safety defects depending on how well it was rebuilt. It is usually not very difficult to find out whether or not a vehicle is a salvage.

Other vehicles may have been wrecked and rebuilt, but were not declared a total loss by an insurance company. These types of vehicles are much harder to identify because they do not carry the salvage title.

Some companies will then take the vehicle and have it rebuilt and restructured, however, rarely if ever is the vehicle restored to a safe condition. To that end, every state in the US, for example, has a law regarding the disclosure of the salvaged history on the title of the vehicle (known as a "branded title") and requires that certain notification of that history be given to the potential consumer in writing before the actual sale of the vehicle. Any failure to disclose a salvage or rebuilt history is a violation of law.

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2 Rebuilt titles are issued when the car has sustained damage as a result of one or more incidents. A rebuilt title may be issued if a vehicle sustained damage and was rebuilt or reconstructed, then placed back on the road.
Salvage titles are issued by the state when an insurance company takes possession of a vehicle as a result of a claim. This usually occurs when a vehicle has been declared a total loss.
Junk titles are issued when a vehicle is not road worthy and cannot be titled again in that state.

But this is not the case in many European countries, and that is why such fraudulent behavior is not rare. There are even cases that vehicles used for performing crash tests following EuroNCap procedure were afterwards recollected, reconstructed and marketed in SE Europe, for example.

There are cases that a car rebuilt after a wreck was equipped with engine not properly lined up in the chassis, while these parts of the car had been welded together where bolts normally are used. During a court suit it was proven that the wrecked car had been purchased by backyard mechanic from one country who had tried to fix it up and then sold it to a repair shop in another country.

Used vehicles are often coming from rent-a-car service. These vehicles are subject to driving by numerous different people with different habits. With no pride of ownership, people tend to abuse these vehicles and treat them in ways they would not treat their own car. Thus, they tend to be of lesser value than another vehicle of the same age and make that was owned by an individual, but this must not be disclosed (in writing, for example). On the contrary, dealers typically try to hide this information, or even misrepresent the vehicle's history in an effort to make the sale.

Counterfeit Car Parts - Using counterfeit car parts instead of high-quality replacement parts.

The old used part switcheroo is another common car part related scam. Used parts are a viable option for many repairs, however, some mechanics charge customers for new, premium parts after installing sub-standard or used car parts.

The customer was told and billed by repair firm with the price of new replacement part having high quality, but counterfeit part was in reality built in the vehicle. This practice can actually put vehicle owner in danger because counterfeit auto parts are often of inferior quality. In addition to that, there is a substantial risk for the driver because he may never even know that some parts in his vehicle do not have appropriate quality level. i.e. the quality he is assuming they have. Besides being potentially unsafe, counterfeit parts generally wear out sooner than genuine parts. Detecting counterfeit auto parts is difficult because the counterfeiters often duplicate trademarks or alter them so slightly that it takes an experienced eye to notice the difference.

Many collision service centers are repairing damaged vehicles with used replacement parts but are charging consumers the cost for new parts. This is unlawful. Even more outrageous, many collision shops are repairing collision damage by "pounding out" the damages and using a "bondo" spackling agent but instead are charging the customer for new parts and materials. This is not only unlawful, but it negatively affects the vehicle's warranty agreement with the manufacturer and decreases the vehicle's resale value. Contact us immediately if you suspect you have been a victim of these unlawful business practices.

Cannibalization

Cannibalization is very famous maintenance technology in which spare parts necessary to perform given maintenance operation are collected from other vehicles of the same kind and type, or even from any other vehicle source on condition this part "fits" to the vehicle being repaired. It is well know that vehicle junk heaps and second hand vehicle shops exist all around the world, and it seems like installation of parts provided from these sources to a vehicle in use is approved by the authorities in these countries. There are countries, even within the EU, in which such market operation is very developed.

Making of clone vehicles:

Typically, car cloning is the case when cloners find a vehicle identification number or VIN from a legitimate vehicle and slap it onto a stolen, or rebuilt car. Each VIN is unique, so the stolen vehicle becomes a clone of the original one associated with the lifelike paperwork so that an illegal clone looks perfectly legitimate.

There are evidence of cases in which a loose (and often previously disposed or sold out due to significant manufacturing failures or damages while being in the stock) vehicle body is subject to substantial body repair work, performed by the specialized shop. Having in mind that most advanced body repair and paining technologies are used, such a body gives look of the brand new original, particularly to the individuals not being professionals in the subject area, and those normally represent 99,9% of potential customers of such products.

During the rebuilding process, such a vehicle is provided with all relevant symbols (like VIN mark and others) previously removed from another vehicle which, for example, was taken from disposed vehicles plant, and being totally damaged in a car accident. There are also cases that such marks were forged, and that is how there are few vehicles bringing "the same" manufacturing marks but running one in Europe, another in Australia, and the third one in the US, for example. The body is then equipped with all other vehicle components taken away from different disposed vehicles or from another second hand vehicle, or from the unoriginal spare part suppliers, or, finally equipped even with the original spare parts.

And that is how the clone vehicle was born. It is rather clear that such operation would not be financially very efficient on condition it was applied to low class vehicles, but in the case of higher vehicle classes, the benefit may be very substantial.

Missing or False Maintenance and Warranty Records and Disclose of Prior Vehicle Damage History:

It is always illegal to sell an unsafe vehicle, and if you asked specific questions about a vehicle, new or used, the dealer is obligated to provide truthful responses (to the best of his knowledge). Vehicles sold as Certified Pre-Owned vehicles**,** meanwhile, must live up to the dealership's advertised certification standards**.**

It is also illegal to sell a new vehicle with any unrepaired damage, any structural damage or even if repairs were made costing more than 3% of the vehicle's value.

Virtually every used car on the market will be said never been damaged or involved in any previous accidents. In fact, only in the case of an individual used car sale the salesperson knows whether vehicle really was previously damaged or not. Therefore, every used car vehicle on the market should go through some inspection but that normally is not the case.

Maintenance and Warranty records may be of particular importance for inexperienced customers not only because they represent a good way to see if the car was stolen, but also will giving a hint of how well the car has been taken care of. It is essential these document are official, otherwise they also may be fraudulent.

The same apply to the mileage over time on the maintenance records, which may represent a good step to ensure that the seller did not tamper with the odometer. Most trained technicians can identify certain damage to a vehicle by noting re-painting, welding, or even replacement parts, but there are no standard procedures of such inspection that are applied on a compulsory bases.

One of the most common forms of auto fraud is failing to disclose preexisting and/or known problems with the vehicle. Cars often have documented histories of mechanical problems**.** Some dealers try to sell vehicles with known mechanical problems by either misrepresenting the car's condition or simply by not telling the prospective buyer about these problems. Do not be fooled just because a vehicle appears cosmetically clean and mechanically sound. If the vehicle you are interested in comes without a warranty or "as is," you should be extra cautious.

One form of hiding a vehicle's history is called "lemon laundering." Many states, including California, have lemon laws, which essentially require a manufacturer to repurchase a defective vehicle**.** Lemon laundering is the resale of these defective vehicles without disclosing their prior history. A possible sign of lemon laundering is when a car that is close to new is being sold as used.

Other forms of this type of fraud include misrepresentations about prior owners or prior use. For example, dealers often tell consumers that a car has only had one owner, when in fact it has had multiple owners. Dealers may also conceal the fact that a vehicle was a rental car. Dealers may also hide a vehicle's history as stolen and recovered; stolen vehicles sometimes have undetected and un-repaired problems.

Many unsuspecting consumers purchase from car dealers used vehicles that are represented to be one owner vehicles but are in fact prior daily rental vehicle, (cars used as rental cars by car rental firms). Many of these cars have prior accident damage or mechanical problems. Under California Law an auto dealer has the legal obligation to identify and disclose former taxi cabs, rental vehicles, publicly owned vehicles, insurance salvage vehicles and revived salvage vehicles at the time of and prior to sale. Besides, a dealer has an obligation to perform a legal sufficient safety inspection of all used cars offer for sale and must perform repairs or disclose collision damage revealed by the inspection [7].

Missing or false Registration Papers :

The registration papers also give customer clues about the vehicle, and that is why these are sometimes subject to forging. Besides, the license plate on the car should indeed match the numbers on the registration papers, and there is also fraud possibility if the owner's name does not matches the seller's one. Meeting seller at the address listed on the papers may also prevent ideas about fraudulent behavior.

5. CONCLUSIONS

In this paper vehicle maintenance fraud was elaborated. It was demonstrated that there is a large variety of possibilities to make pre-sale forge of the vehicle condition and/or relevant documentation.

It may be concluded that missing legal environment is in favor of those who are preparing and ready to commit automotive frauds.

It may also be concluded that automotive frauds are often hard to discover, but there are methods and organizations capable of performing the task of inspection condition of vehicles on the used car market.

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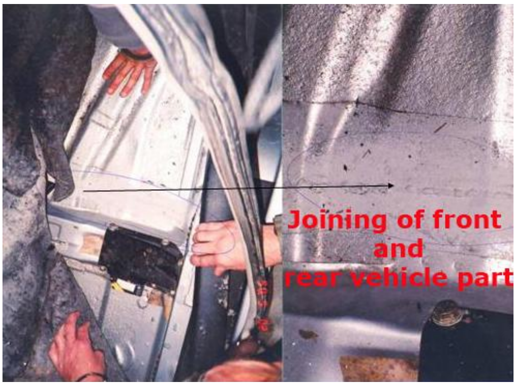
ANNEX

Case 1 : Volkswagen Golf IV

After first accident vehicle declared “total loss”

After second accident vehicle declared “total loss” again

Vehicle cloning



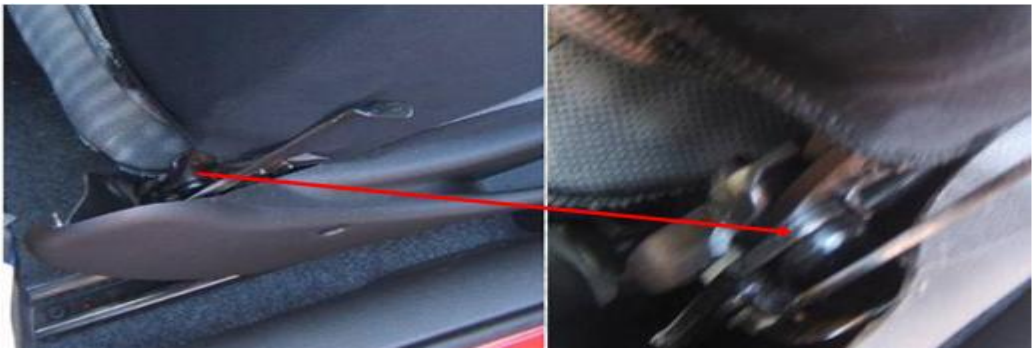
Case 2 : Imported used vehicle Audi A4

Spare part with no manufacturer mark

Removed catalysts (converters)

Welding traces at front axle

Case 3 : Converting van to car



Non – genuine seat folder device

Non – genuine seat fixation elements

Vehicle manufacturer built-in LPG device replaced with un-original one

[1]BUS DRIVERS' CHRONIC MORBIDITY

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UDC: 616-057-036.8:656.132-051

Abstract

Traffic is one of the most important economic branches here. A physically and psychologically healthy driver is an important factor for traffic safety. A bus driver's work place is limited to a small space and work consists of sitting on mostly uncomfortable seats. The drivers are exposed to unpleasant microclimatic factors, noise, vibrations, exhaust gases and often stressful situations.

The work aim is the analysis of chronic morbidity and presence of work – related diseases among bus drivers.

A group of 169 bus drivers was examined. Data from periodical driver examinations and data from general medicine charts were used. The control group consists of 65 mechanics. All data were processed using the statistical program SPSS.

The general morbidity rate in the basic group is 85.8%. The most common diseases with bus drivers are bone-muscle system diseases with 24.8%. In second place there are the cardiovascular diseases (22.7%). The third place is taken up by psychological disorders (21.4%), which are statistically significantly more frequent when compared to the control group ($p<0.05$).

The leading disease with drivers is the lumbal syndrome (16.6%). On the second place there are the neuroses (15.4%), which are significantly more frequent when compared to the control group ($p<0.05$). In third place there is the arterial hypertension (8.3%). In fourth place there are ulcus ventriculi and ulcus duodeni (5.3%). In fifth place there are eye refraction anomalies (4.7%).

The four leading diagnoses for bus drivers are from the work – related disease groups. It can be concluded that: the lumbago, neurosis, hypertension and ulcus ventriculi et duodeni are dominant diseases in the specific morbidity of bus drivers.

Key words: chronic morbidity, bus, driver, work.

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HRONIČNI MORBIDITET VOZAČA AUTOBUSA

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Rezime: Saobraćaj je jedna od najvažnijih privrednih grana. Fizički i psihički zdrav vozač je važan činilac za bezbednost saobraćaja. Radno mesto vozača autobusa je u ograničenom prostoru, a rad se odvija sedeći na, najčešće nekomfornom sedištu. Vozači su izloženi nepovoljnim mikroklimatskim faktorima, buci, vibracijama, izduvnim gasovima i često, stresnim situacijama.

Cilj rada je analiza hroničnog morbiditeta i bolesti u vezi sa radom kod vozača autobusa.
Ispitivanu grupu činilo je 169 vozača autobusa. Korišćeni su podaci sa periodičnih pregleda i iz kurativnih kartona. Kontrolnu grupu je činilo 65 mehaničara. Svi podaci su statistički obrađeni pomoću SPSS programa.

Stopa opšteg morbiditeta u ispitivanoj grupi iznosila je 85,8%. Najčešća oboljenja bila su oboljenja koštano-mišićnog sistema sa 24,8%. Na drugom mestu bila su kardiovaskularna oboljenja 22,7%. Psihološki poremećaji su na trećem mestu sa 21,4%, što je statistički značajno u odnosu na kontrolnu grupu ($p<0,05$).

Vodeće oboljenje vozača autobusa bio je lumbalni sindrom 16,6%. Na drugom mestu bile su neuroze 15,4%, što je statistički značajno značajno u odnosu na kontrolnu grupu ($p<0,05$). Na trećem mestu bila je arterijska hipertenzija 8,3%, na četvrtom mestu, čir na želucu i dvanaestopalačnom crevu 5,3% i na petom mestu, refrakcione anomalije 4,7%.

Prve četiri vodeće dijagnoze pripadaju grupi bolesti u vezi sa radom. Može se zaključiti da su lumbago, neuroze, arterijska hipertenzija i čir želuca i dvanaestopalačnog creva dominantne bolesti specifičnog morbiditeta vozača autobusa.

Ključne reči: hronični morbiditet, vozač, autobus, rad.

BUS DRIVERS' CHRONIC MORBIDITY

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UDC: 616-057-036.8:656.132-051

INTRODUCTION

Traffic is one of the most important economic branches here. The main factor for safe traffic flow is a driver. An important precondition for working as a professional driver, besides knowing traffic regulations and having a high quality driving training, is the health condition of the drivers. A physically and psychologically healthy driver is an important factor for traffic safety.

Monitoring of the health condition from the aspect of chronic morbidity presents an important indicator of the driver's health condition. An analysis of chronic morbidity in a certain population or in the part of the population (a company, a shop), especially an analysis of frequency and a form of professional diseases can indicate the presence and intensity of risk factors arising from conditions or work processes.

A bus driver's work place is limited to a small space and work consists of sitting on mostly uncomfortable seats. The drivers are exposed to unpleasant microclimatic factors, noise, vibrations, exhaust gases and often stressful situations.

Working hours and shifts of professional drivers often vary, so the necessary rhythm of work and rest is disturbed.

The feeling of responsibility for lives of passengers during driving is strongly expressed among bus drivers. [2, 7]

WORK AIM

The work aim is the analysis of chronic morbidity and work – related diseases among bus drivers.

EXAMINEES AND WORK METHODS

The group of 169 "Autosaobracaj" bus drivers was examined. Data from periodical driver examinations which were used – contained diagnoses of psychologists, neuro-psychologists, ophthalmologists and specialists of occupational health. The control group consisted of 65 mechanics from the same company that have never worked as drivers.

All examinees were examined in Zastava Institute of Occupational Health Kragujevac where workers of Autosaobracaj Company realize full preventive and curative protection.

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Morbidity was analyzed according to ISCDRH (X revision). [10] All data were processed using the statistical program SPSS.

An average age in the examined group was 43.1 ± 8.5. An average age in the control group was 41 ± 7.3. Regarding the age difference both groups were comparable because there was not a statistical age difference (t=1.75; p>0,05).

An average length of total working years (TWY) for drivers was 19.4 ±8.3 and for mechanics 18.7 ± 8.3 and there was not a significant statistical difference in lasting of TWY (p>0,05).

An average length of exposition working years (EWY) of examined drivers was 14.5 ±7.2. EWY of most of the drivers were between 15 – 19 (29%).

RESULTS

In the examined group of 169 drivers, 77 (45.6%) did not have any diseases, while 92 (54.4%) had one or more diseases. In the control group of 65 mechanics, 25 (38.5%) did not have any diseases and 40 (61.5%) had some diseases.

Table 1*: A comparative overview of the number of sick workers in both groups*

	Basic group		Control group		χ^2
	N	%	N	%	
Without disease	77	45.6	25	38.5	
With disease	92	54.4	40	61.5	0.68 (p>0.05)
Σ	169	100.0	65	100.0	

There was not a significant statistical difference (p>0.05) between the numbers of sick workers in the exposed group and in the control group.

In the exposed group there were a total of 145 registered diseases. The general morbidity rate of bus drivers was 85.8%.

Table 2: *A comparative overview of the chronic morbidity structure per disease groups (IDC) in both groups*

Disease group		Basic group		Control group		χ^2 test
		N	%	N	%	
II	neoplasm	1	0.7	2	3.6	ns
IV	endocrine diseases	1	0.7	1	1.7	ns
V	psycholog.disturbances	31	21.4	4	7.1	4.57 ; p<o,o5
VI	nerv.syst. dis.and sen.org	12	8.3	1	1.7	ns
IX	cardiovascular diseases	33	22.7	12	21.4	ns

Disease group		Basic group		Control group		χ^2 test
		N	%	N	%	
X	respiratory system diseas.	2	1.4	1	1.7	ns
XI	digestive system diseases	18	12.4	7	12.5	ns
XII	skin disease	1	0.7	2	3.6	ns
XIII	bone-muscle system	36	24.8	16	28.6	ns
XIV	urogenital diseases	10	6.9	10	17.8	4.12 ; p<0,05
Σ		145	100	56	100	ns

Most common diseases of bus drivers were the bone-muscle system diseases with 24.8%. The second place took cardiovascular diseases with 22.7%. In third place there were psychological disturbances with 21.4%, which were statistically much more frequent when compared to the control group ($p<0.05$). In fourth place there are diseases of the digestive system with 12.4%.

In the control group, 56 diseases were registered. The general morbidity rate in the control group was 86.1% and there was not a significant statistical difference between the general morbidity rate between drivers and mechanics. (X^2 test = 0.22; $p>0.05$).

The most common diseases among mechanics were the diseases of the bone-muscle system with 28.6%. In second place there were cardiovascular diseases with 21.4%. Urogenital diseases with 17.8%, were in third place, which were statistically significantly more frequent among mechanics ($p<0.05$). In fourth place, there were digestive system diseases with 12.5%.

Table 3: *The most common diseases in the examined group*

Order	Disease	N	rate
I	Lumbal syndrome	28	16.6
II	Neurosis	25	14.8
III	Hypertension	14	8.3
IV	Ulcus ventriculi; ulcus duodeni	9	5.3
V	Refractive anomalies of the eye	8	4.7

100 examinees rate

Table 4: *The most common diseases in the control group*

Order	Disease	N	rate
I	Lumbal syndrome	12	18.5
II	Hypertension	7	10.8
III	Ulcus ventriculi; ulcus duodeni	5	7.7
IV	Prostatis chr.	4	6.2
IV	Nephrolithiasis	4	6.2

The most common disease of bus drivers was lumbal syndrome. In second place there was the neurosis (15.4%), which is statistically much more frequent when compared to the control group ($p<0.05$). In third place, there was arterial hypertension (8.3%).

The most common disease in the control group was lumbal syndrome (18.5%). In second place there was arterial hypertension (10.8%). In third place, there were ulcus ventriculi and ulcus duodeni (7.7%).

Through the analysis of the distribution of chronic morbidity done according to the age of bus drivers and mechanics, the following results, which were received, are shown in the Tables 5. and 6.

Table 5: *Chronic morbidity and the age of examined group*

Age group	20-29	30-39	40-49	50 and more	Total
N	12	45	64	48	169
w/o disease	11	28	27	11	77
% w/o dis.	91.7	62.2	42.2	22.9	45.6
Disease total	1	22	52	70	145
Rate (%)	8.3	48.9	81.2	145.8	85.8
Dis.per.work	0.1	0.5	0.8	1.5	0.9

The connection between the age of bus drivers and the increase of the general chronic morbidity rate can be noticed from the Table No. 5, in a way that the disease rate was the highest in the 50 + age group (145.8%), meaning 1.5 illnesses per worker.

The results in the control group were similar to the results in the examined group. The increase in the number of illnesses with age and the decrease of the number of workers without disease can be noticed.

The Table 7. shows the distribution of chronic morbidity in relation to the length of EWY of the drivers.

Table 6: *Chronic morbidity and the age in the control group*

Age group	20-29	30-39	40-49	50 and more	Total
N	3	26	27	9	65
w/o disease	1	18	5	1	25
% w/o dis.	33.3	69.2	18.5	11.1	38.5
Disease total	2	12	30	12	56
Rate (%)	66.7	46.2	118.6	133.3	86.2
Dis.per.work	0.7	0.5	1.1	1.3	0.9

Table 7: *Chronic morbidity and the length of EWY*

EWY – intervals	0-4	5-9	10-14	15-19	20-24	25-29	Total
N	22	25	36	49	15	22	169
w/o dis.	21	14	16	19	1	6	77
%w/odis.	95.4	56	44.4	38	6.7	27.3	45.6
Dis. total	1	16	31	42	25	30	145
Rate (%)	4.5	64	86.1	85.7	166.7	136.4	85.8
Dis.perwork	0.04	0.6	0.9	0.9	1.7	1.4	0.9

The Table 7. shows that the number of diseases increased with the length of EWY, while the number of examinees not having any diseases decreased. In that sense, the groups of 20-24 and 25-29 EWY had the highest number of diseases per one driver 1.7 and 1.4.

DISCUSSION

The analysis of chronic morbidity and work – related diseases found in 169 bus drivers employed in Autosaobracaj Kragujevac Company gave the following results.

Practically, the same general morbidity rate was found in the examined (85.8%) and the control group (86.1%). It is also important to notice that within the examined group, a much better professional orientation and medical and psychological selection was conducted, resulting in the fact that when employed, drivers have a very low general morbidity rate (the Table 5; the Table 7.). When the diseases from the Regulation book on medical condition for motor vehicle drivers [9] are diagnosed during work, they are usually reassigned to other work places or they retire, meaning that they could not be included in this study.

Within the examined group, bone-muscle system diseases were the most common with a rate of 24.8%. The most common disease in this group and also, in the examined group, was lumbal syndrome with a specific morbidity rate of 16.6% (the Table 2; the Table 3.).

Sitting position while driving, an action of general vibrations, frequent temperature changes around the driver with air drafts and increased sweating in the lumbal back area, complete with uncomfortable seats, led to such a high rate of degenerative spine diseases.

In second place, there were the cardiovascular diseases with 22.7%. The leading disease in this group was arterial hypertension, which was in third place with a rate of 8.3% in the specific morbidity. Hypertension as a psychosomatic disease was partly connected to the stressogenic factors to which the drivers were almost continuously exposed. Noise is the most common factor of the physical work environment. Working in shifts and irregular work – rest regimes increased the risk of cardiovascular diseases.

In third place, there were the psychological disturbances with 21.4%. The leading illness in this group were neuroses, which took up a second place with a rate of 15.4% in the specific morbidity, which were statistically much more frequent when compared to the control group ($p<0.05$). Chronic professional stress to which the drivers were exposed, contributed to the presence of neuroses in a greater percentage in the examined group.

In fourth place, there were the diseases of the digestive system with 12.4%. The leading diseases in this group were ulcus ventriculi and ulcus duodeni with a rate of 5.3%, which were in fourth place in the specific morbidity. Chronic professional stress, working in shifts and a way of nourishment led to the appearance of ulcus among professional drivers.

In fifth place, there were the diseases of the nervous system and of sense organs with 8.3%. The main diagnoses in this group were refraction eye anomalies, which took the fifth place with a rate of 4.7% in the specific morbidity.

In the control group, as well as in the examined one, in first place there were the diseases of the bone-muscle system with 28.6%. The leading disease in this group as well as in the specific morbidity was lumbal syndrome with a rate of 18.5%. The position during work, lifting of heavy objects during replacements and repairs, unfavorable microclimatic conditions in shops and in the field, led to a high rate of the lumbal syndrome disease among car mechanics.

In second place, there were the cardiovascular diseases with 21.4%. The leading disease in this group and in the specific morbidity was arterial hypertension with a rate of 10.8%.

In third place, there were urogenital diseases with 17.8%, which were statistically more frequent when compared to drivers ($p<0.05$). The diagnoses in this group were chronic prostatis and nephrolithiasis, which shared the fourth place with a rate of 6.2% in the specific morbidity. Working in pits and unfavorable microclimatic conditions led to the high frequency of urogenital diseases among mechanics.

In fourth place, there were the digestive system diseases, with a rate of 12.5%. The leading diseases in this group were ulcus ventriculi and ulcus duodeni with a rate of 7.7%, which took the third place in the specific morbidity.

In fifth place, there are the psychological disturbances with 7.1%.

A similar order and percentage of most common diseases of traffic workers have been noticed in foreign and domestic literature. [1, 3, 4, 5, 8]

The chronic morbidity rate increased with the age. The lowest was in the youngest group (20-29 years) with only 8.3% and the highest – in the 50 + years group with 145.8%, or 1.5 diseases per worker. Those are the expected results considering the fact that healthy candidates are usually being employed and that the registered diseases are also present in the general public within the older age (Table 5.).

The chronic morbidity rate increased with the length of EWY. The reason for a higher rate of illnesses in the group with a shorter EWY (20-24 years) when compared to the group with the longer EWY (20-29) was probably because the group was smaller (the Table 7.).

CONCLUSION

The leading disease among bus drivers was lumbal syndrome, with the specific morbidity rate of 16.6%.

In second place there were the neuroses (15.4%), statistically significantly more frequent when compared to the control group ($p<0.05$).

In third place, there was arterial hypertension (8.3%).

In fourth place, there were ulcus ventriculi and ulcus duodeni (5.3%).

In fifth place, there were the refraction anomalies of the eye (4.7).

None of the professional diseases was registered. The four leading diseases of bus drivers were diseases from the work – related group. It can be concluded that work-related diseases were dominant in the specific morbidity of bus drivers. [6]

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[1] THE DYNAMIC ANALYSIS OF A VEHICLE'S MOTION AT THE POINT OF CORNERING

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UDC: 629.113.3:[531.38:531.232

Abstract

The dynamics of a vehicle's circular motion is being elaborated throughout the work itself, complete with the analysis of all relevant parameters necessary for monitoring vehicles' stability and steering systems.

What has been examined is the spatial model of vehicles displaying characteristics inherent in the sprung mass (such as mass, the moment of inertia and the position of the center of gravity), complete with the characteristics regarding a vehicle wheelbase, a lateral characteristic of a pneumatic tyre and the influence of a steering system (steering gear ratio and the tyre slip angles).

What is obtained as a result of this, is a lateral and longitudinal displacement, complete with a rotation and the velocity of the sprung mass rotation about the vertical axis, and then, the velocity and a direction of the sprung mass velocity, the slip angles of all tyres and the instantaneous center of rotation.

On the basis of these parameters, it is possible to determine vehicles' stability and steering systems under the given motion condition.

The work itself is provided with an elaborated example of a circular vehicle motion substantiated with the input values of a single home made vehicle and the results of all relevant parameters.

Key words: vehicle dynamics, circular motion.

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DINAMIČKA ANALIZA KRETANJA VOZILA U KRIVINI

UDC: 629.113.3:[531.38:531.232

Rezime: U radu se obrađuje dinamika kružnog kretanja vozila sa analizom svih relevantnih parametara za praćenje stabilnosti i upravljivosti vozila.

Posmatran je ravanski model vozila sa karakteristikama oslonjene mase (masom, momentom inercije i polžajem težišta), osovinskim rastojanjem, bočnom karakteristikom pneumatika i uticajem sistema upravljanja (prenosni odnos upravljanja i uglovima zaokretanja točkova).

Kao rezultat imamo poprečno i podužno pomeranje i rotaciju i brzinu rotacije oslonjene mase oko vertikalne ose kao i brzinu i pravac brzine oslonjene mase, uglove skretanja svih točkova i trenutnog centra rotacije.

Na osnovu ovih parametara moguće je odrediti upravljivos i stabilnos vozila pri datom režimu kretanja.

U radu je urađen primer kružnog kretanja vozila sa ulaznim veličinima i rezultatima svih relevantnih parametara.

Ključne reči: Dinamika vozila, kružno kretanje.

THE DYNAMIC ANALYSIS OF A VEHICLE'S MOTION AT THE POINT OF CORNERING

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UDC: 629.113.3:[531.38:531.232

INTRODUCTION

A vehicle's circular motion entails a kind of motion which is performed by a vehicle along the circle of a specific radius all the way to the point of cornering which corresponds to the real conditions, with the presence of lateral forces depending on the centrifugal force and longitudinal forces in the form of braking and accelerating.

Apart from this, a significant influence is exerted by a driver himself / herself, because he / she is the one who alters the magnitude and character of external forces which have an influence upon a motor vehicle. The magnitudes of a driving force and braking force are also under the influence of a driver's use of specific controls, and it is the steering wheel that enables a driver to maintain the circular course of a vehicle's motion.

What is being examined in this work is the spatial model of a medium class passenger vehicle of a conventional construction which is used for observing the parameters, on the basis of which a vehicle's behaviour is defined depending on the forces resulting from the circular motion of a particular vehicle.

The two axis systems have been introduced: a system of earth – fixed axis and the one with non – fixed axis, which is related to a vehicle's position oxyz where:

the X – axis represents the lateral axis of a vehicle's gravity center;

the Y – axis represents the longitudinal axis of a vehicle's gravity center and

the Z – axis represents the yaw axis of the gravity center.

1. A MATHEMATICAL MODEL

Taking into account the aim of this work, what has been done – is a complex model of a vehicle which enables the following parameters to be analyzed:

x – a body displacement along the x – axis,

y – a body displacement along the y – axis,

ψ – a sideslip, oscillations about the x – axis,

a, b – a vehicle wheelbase,

h – the height of center of gravity and

2s – a wheel track.

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The Figure 1 represents the vertical dynamics of a vehicle provided with the analysis of forces and displacements depending on the center of gravity displacement.

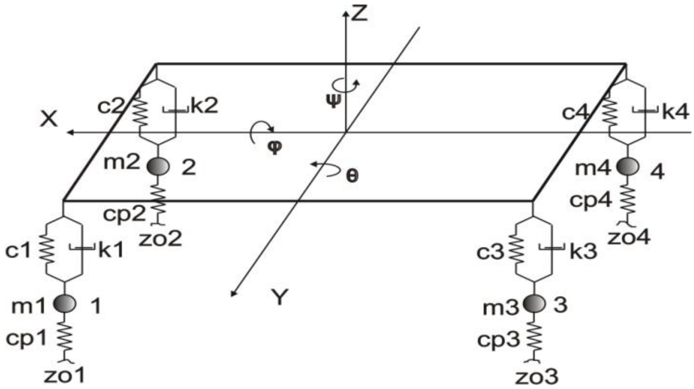

Figure 1: *The vertical dynamics of a vehicle*

The Figure 2 represents the horizontal dynamics of a vehicle while cornering provided with the analysis of forces and displacements.

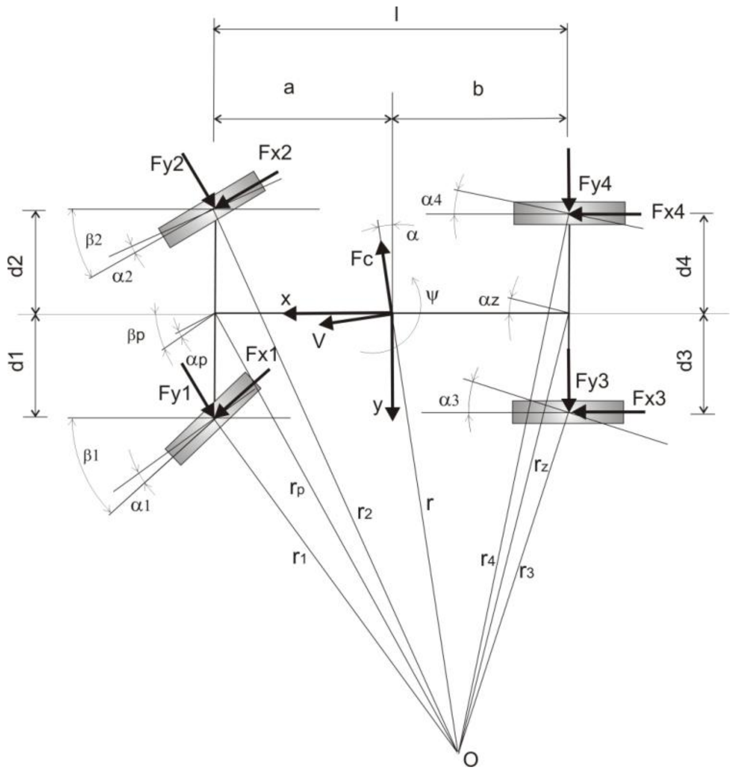

Figure 2: *The horizontal dynamics of a vehicle*

The angles relevant for the horizontal dynamics as shown in the Figure 2 – are to be defined in the following manner:

$$\beta = \frac{\beta_1 + \beta_2}{2} \qquad \alpha_1 = \beta_1 - \frac{y' + a \cdot \psi'}{x' - d_1 \cdot \psi'} \qquad \alpha_2 = \beta_2 - \frac{y' + a \cdot \psi'}{x' + d_2 \cdot \psi'}$$

$$\alpha_3 = -\frac{y' - b \cdot \psi'}{x' + d_3 \cdot \psi'} \qquad \alpha_4 = -\frac{y' - b \cdot \psi'}{x' - d_4 \cdot \psi'} \qquad \alpha_p = \beta_p - \frac{y' + a \cdot \psi'}{x'}$$

$$\alpha_z = -\frac{y' - b \cdot \psi'}{x'} \qquad \alpha = \frac{y'}{x'}$$

Differential equations of a vehicle's motion are the following:

$$\begin{aligned}
m_1 \ddot{z}_1 &= c_1 (z_5 + a\theta - s\varphi - z_1) + k_1 (\dot{z}_5 + a\dot{\theta} - s\dot{\varphi} - \dot{z}_1) - c_{p1z}(z_1 - z_{01}) \\
m_2 \ddot{z}_2 &= c_2 (z_5 + a\theta + s\varphi - z_2) + k_2 (\dot{z}_5 + a\dot{\theta} + s\dot{\varphi} - \dot{z}_1) - c_{p2z}(z_2 - z_{02}) \\
m_3 \ddot{z}_3 &= c_3 (z_5 - b\theta - s\varphi - z_3) + k_3 (\dot{z}_5 - b\dot{\theta} - s\dot{\varphi} - \dot{z}_3) - c_{p3z}(z_3 - z_{03}) \\
m_4 \ddot{z}_4 &= c_4 (z_5 - b\theta + s\varphi - z_4) + k_4 (\dot{z}_5 - b\dot{\theta} + s\dot{\varphi} - \dot{z}_4) - c_{p4z}(z_4 - z_{04})
\end{aligned}$$

$$\begin{aligned}
& m_5 \ddot{z}_5 = -(c_1 + c_2 + c_3 + c_4) z_5 - ((c_1 + c_2)a - (c_3 + c_4)b)\theta - (c_1 + c_4 - c_1 - c_3) s\varphi + \\
& + c_1 z_1 + c_2 z_2 + c_3 z_3 + c_4 z_4 - (k_1 + k_2 + k_3 + k_4)\dot{z}_5 - ((k_1 + k_2)a - (k_3 + k_4)b)\dot{\theta} - \\
& - (k_2 + k_4 - k_1 - k_3) s\dot{\varphi} + k_1 \dot{z}_1 + k_2 \dot{z}_2 + k_3 \dot{z}_3 + k_4 \dot{z}_4
\end{aligned}$$

$$\begin{aligned}
& I_x \quad \ddot{\varphi} = (c_1 - c_2 + c_3 - c_4) z_5 \quad s + \\
& +(a \quad c_1 - a \quad c_2 - b \quad c_3 + b \quad c_4)\theta \quad s - (c_1 + c_2 + c_3 + c_4) \quad s^2 \varphi + \\
& +(-c_1 \quad z_1 + c_2 \quad z_2 - c_3 \quad z_3 + c_4 z_4) s + \\
& +(k_1 - k_2 + k_3 - k_4) \quad \dot{z}_5 \quad s + ((k_1 - k_2) \quad a - (k_3 - k_4) \quad b) \quad \dot{\theta} \quad s - \\
& -(k_1 + k_2 + k_3 + k_4) \quad s^2 \dot{\varphi} + (-k_1 \dot{z}_1 + k_2 \dot{z}_2 - k_3 \dot{z}_3 + k_4 \dot{z}_4) s
\end{aligned}$$

$$I_y\ddot{\theta} = z_5(-a(c_1+c_2)+b(c_3+c_4)) + ((c_1+c_2)a^2-(c_3+c_4)b^2) \quad \theta +$$
$$+((-c_1+c_2)sa + (-c_3+c_4) \quad sb) \quad \varphi$$
$$a(c_1 \quad z_1 + c_2 \quad z_2) + b(c_3 \quad z_3 + c_4 z_4) +$$
$$+(a(k_1+k_2)+b(k_3+k_4)) \quad \dot{z}_5 +$$
$$+((k_1+k_2) \quad a^2-(k_3+k_4) \quad b^2) \quad \dot{\theta} +$$
$$+(\ (-k_1+k_2)s \quad a + (-k_3+k_4)s \quad b) \quad \dot{\varphi} - (a(k_1\dot{z}_1+k_2\dot{z}_2)+b(k_3\dot{z}_3+k_4\dot{z}_4))$$

$$m \cdot x'' = F_{1x} \cdot \cos\beta_1 + F_{2x} \cdot \cos\beta_2 - c_{y1} \cdot \left(\beta_1 - \frac{y'+a\cdot\psi'}{x'-d_1\cdot\psi'}\right) \cdot \sin\beta_1 -$$
$$- c_{y2} \cdot \left(\beta_2 - \frac{y'+a\cdot\psi'}{x'+d_2\cdot\psi'}\right) \sin\beta_2 + F_{3x} + F_{4x} + F_c \cdot \sin\left(\frac{y'}{x'}\right)$$

$$m \cdot y'' = F_{1x} \cdot \sin\beta_1 + F_{2x} \cdot \sin\beta_2 + c_{y1} \cdot \left(\beta_1 - \frac{y'+a\cdot\psi'}{x'-d_1\cdot\psi'}\right) \cos\beta_1 +$$
$$+ c_{y2} \cdot \left(\beta_2 - \frac{y'+a\cdot\psi'}{x'+d_2\cdot\psi'}\right) \cdot \cos\beta_2 + c_{y3}\cdot\alpha_3 + c_{y4}\cdot\alpha_4 - F_c \cdot \cos\left(\frac{y'}{x'}\right)$$

$$J_z \cdot \psi'' = \begin{pmatrix} F_{1x} \cdot \sin\beta_1 + F_{2x} \cdot \sin\beta_2 + c_{y1} \cdot \left(\beta_1 - \frac{y'+a\cdot\psi'}{x'-d_1\cdot\psi'}\right) \cos\beta_1 + \\ + c_{y2} \cdot \left(\beta_2 - \frac{y'+a\cdot\psi'}{x'+d_2\cdot\psi'}\right) \cdot \cos\beta_2 \end{pmatrix} \cdot a -$$
$$-\left(c_{y3}\cdot\alpha_3 + c_{y4}\cdot\alpha_4\right)\cdot b - F_{1x}\cdot\cos\beta_1\cdot d_1 + F_{2x}\cdot\cos\beta_2\cdot d_2 + F_{3x}\cdot d_3 - F_{4x}\cdot d_4 +$$
$$+ c_{y1} \cdot \left(\beta_1 - \frac{y'+a\cdot\psi'}{x'-d_1\cdot\psi'}\right) \cdot \sin\beta_1 \cdot d_1 - c_{y2} \cdot \left(\beta_2 - \frac{y'+a\cdot\psi'}{x'+d_2\cdot\psi'}\right) \cdot \sin\beta_2 \cdot d_2$$

$$F_c = \frac{m\cdot v^2}{R} \qquad\qquad \alpha = \frac{y'}{x'}$$

$c_{yi} \quad i = 1,4$ cornering stiffness.

A lateral force:

$$F_{1y} = c_{y1}\cdot\alpha_1 \qquad F_{2y} = c_{y2}\cdot\alpha_2 \qquad F_{3y} = c_{y3}\cdot\alpha_3 \qquad F_{4y} = c_{y4}\cdot\alpha_4$$

A longitudinal force can be expressed as a braking force or driving force. It can be displayed through the axle coefficient K , the sign of which can be positive or negative.

F_p - a front axle,

F_z - a rear axle and

F_x - a resultant longitudinal force.

$$F_p = K_o \cdot F_x \qquad F_z = (1 - K_o) \cdot F_x$$

where:

$$K_o = 0 \qquad F_{px} = 0; \; F_{zx} = F_x$$
$$0 < K_o < 1 \qquad F_{px} = K_o \cdot F_x; \; F_{zx} = (1 - K_o) \cdot F_x$$
$$K_o = 1 \qquad F_{px} = F_x; \; F_{zx} = 0$$

A front wheel distribution:

$$0 \le K_{tp} \le 1 \qquad F_{1x} = K_{tp} \cdot F_{px} \qquad F_{2x} = (1 - K_o) \cdot F_{px}$$

A rear wheel distribution:

$$0 \le K_{tz} \le 1$$
$$F_{3x} = K_{tz} \cdot F_{zx}$$
$$F_{4x} = (1 - K_{tz}) \cdot F_{zx}$$

2. THE CALCULATION RESULTS

INPUT DATA

m1=25; m2=25; m3=25; m4=25; m=1000;

c1=42000; c2=42000; c3=60000; c4=60000;
cp1z=170000; cp2z=170000; cp3z=170000; cp4z=170000;
c1bocno=600; c2bocno=600; c3bocno=600; c4bocno=600;

k1=42000; k2=42000; k3=42000; k4=42000;

a=1.2; b=1.3; s=0.7; d1=s; d2=s;d3=s;d4=s; l=2.5; h=0.6;

Ix=1680; Iy=570; Iz=2000;

m=1000 kg;
v=10 m/s;
R=20 m

Input for circular driving

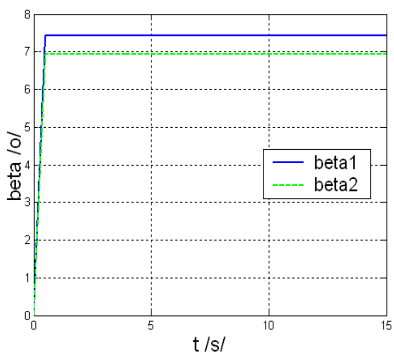

Figure 3*: The slip angles of front wheels*

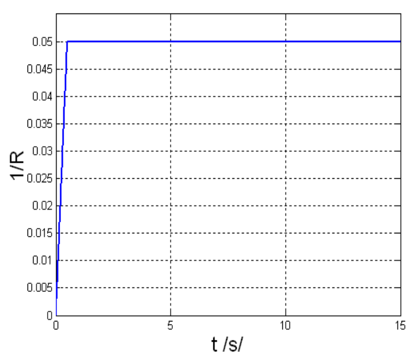

Figure 4: *The reciprocal value of the corner radius*

OUTPUT RESULTS

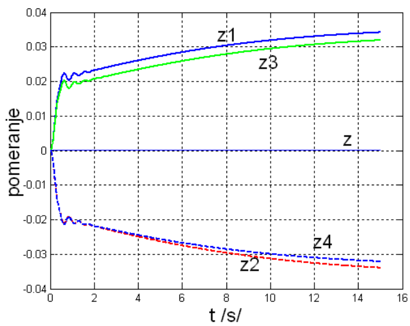

Figure 5: *A vertical wheel displacement*
z1 – the front left – hand drive wheel
z2 – the front right – hand drive wheel
z3 – the rear left – hand drive wheel
z4 – the rear right – hand drive wheel

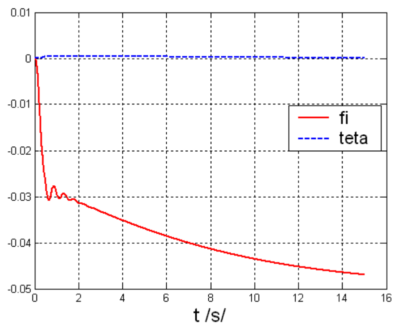

Figure 6: *The rotation of the sprung mass center of gravity*
fi – around the longitudinal axis
teta – around the lateral axis

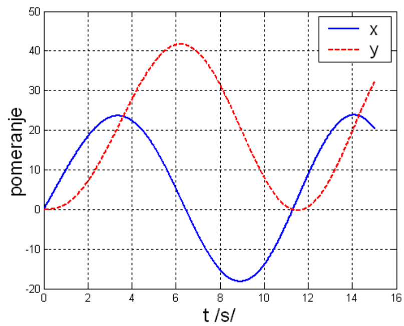

Figure 7: *The displacement of a vehicle's center of gravity in the lateral (y) direction and longitudinal (x) direction*

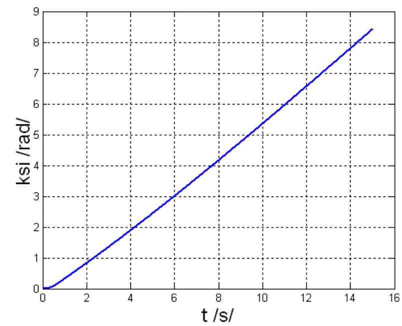

Figure 8: *The angle of the vehicle's rotation around the vertical axis*

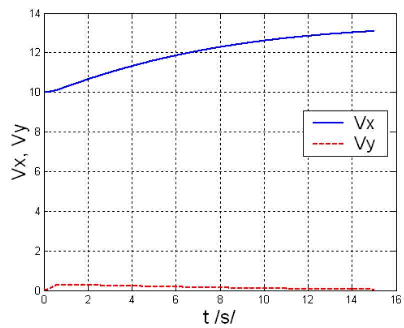

Figure 9: *The velocity of the center of gravity displacement in the lateral (Vy) and longitudinal (Vx) direction*

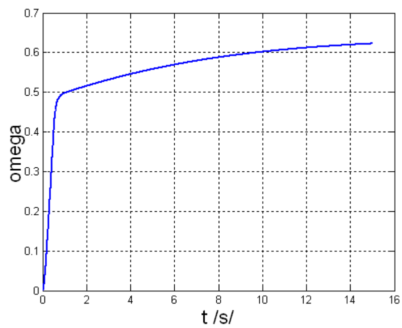

Figure 10: *The angular velocity of the rotations around the vertical axis*

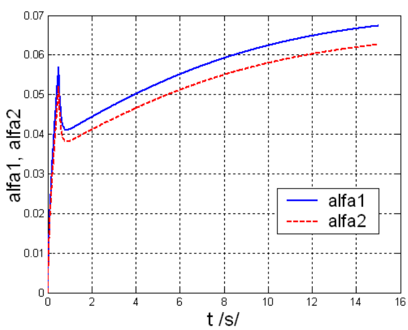

Figure 11: *The lateral slip angles of front wheels*

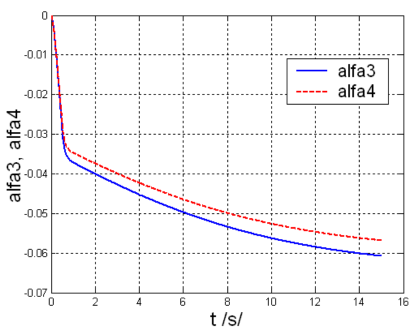

Figure 12: *The lateral slip angles of rear wheels*

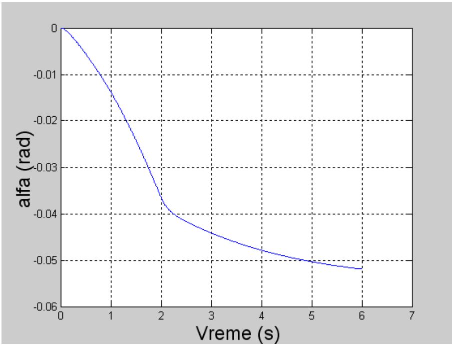

Figure 13: The angle of the sprung mass motion with respect to the longitudinal axis of a vehicle

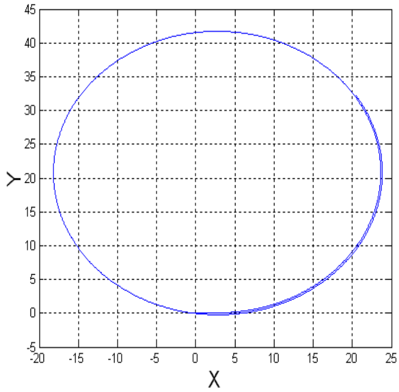

Figure 14: The motion path of a vehicle's center of gravity

CONCLUSION

Dynamics equations presented in this paper provide an analysis of a vehicle's movement along the curvature. The spatial model includes the translations and angular displacements. The model is compared with the well-known Reimpell's models, which are similar to this one.

The results obtained using numerical simulation methods and techniques are presented in a digital and graphical form and provided to make a conclusion about stability and control.

The object of our research was the domestic vehicle, the experimental car where we change the tyres characteristics and load of the vehicle. This model verifies the experimental research made in the previous papers and experimental investigation on road as regards the same vehicle.

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