CONTRIBUTION TO TIRE / ROAD FRICTION ESTIMATION

Rajko Radonjić [1]

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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.

[1] Corresponding author e-mail: rradonjic@kg.ac.rs, University of Kragujevac - Faculty of Mechanical Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia

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.

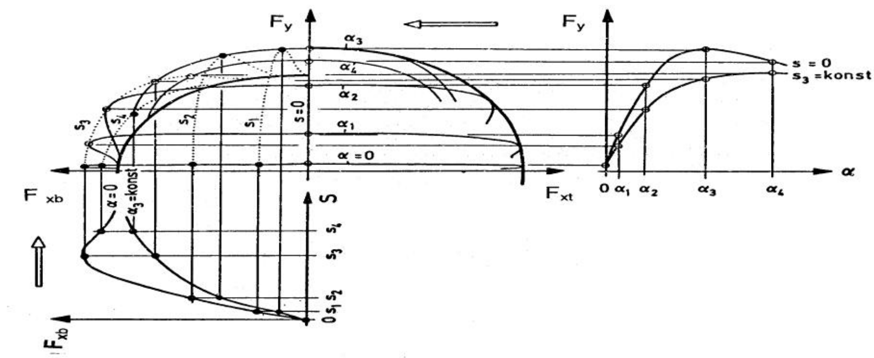

Figure 1: *Schematic plots of tire frictional characteristics, a/ complex, $F_y=F_y(F_x,s\,,\alpha)$, b/ lateral, $F_y=F_y(\alpha,s)$, c/ longitudinal, $F_{xb}=F_{xb}(s,\alpha)$, [6]*

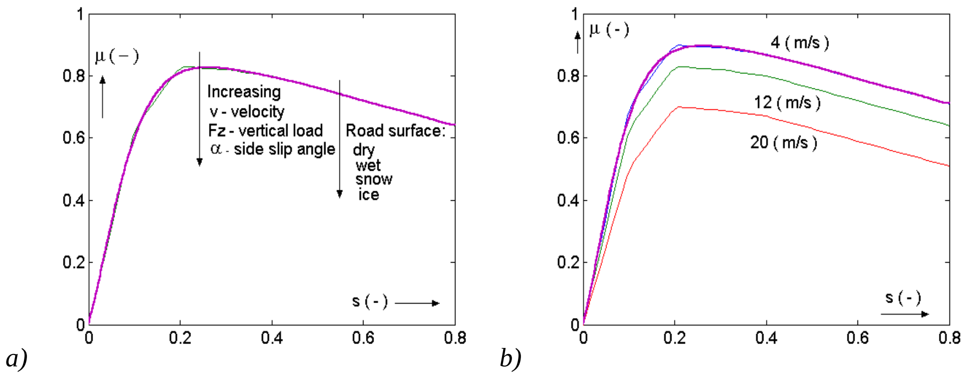

Figure 2: *Estimated plots of friction coefficient, μ - longitudinal wheel slip, s: a) influential parameters, b) vehicle velocity as prameter, [Measurement samples from this study]*

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.

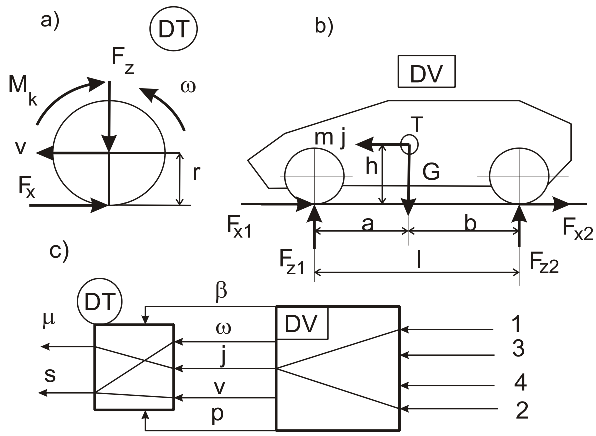

Figure 3: *Vehicle system models, a),b) simulation models, c) identification model*

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*

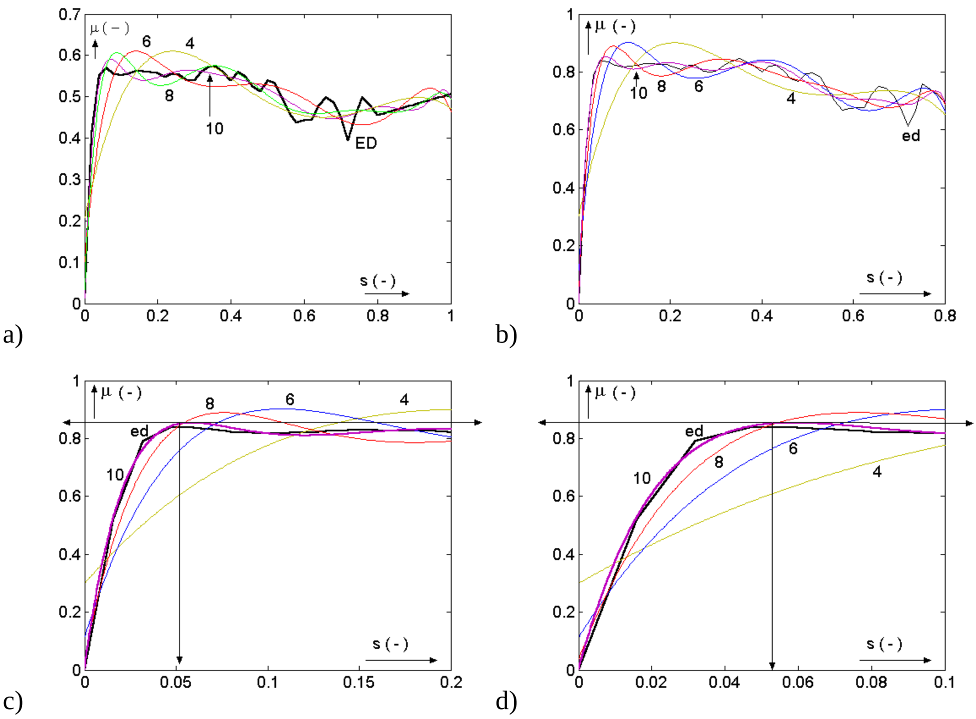

Figure 5: *Identification results of the tire /road friction, a) starting plot related to vehicle deceleration, b) result of processed plots, c),d) results in narrow band of longitudinal slip, 20%, 10%, respectively, ed – experimental data, 4, 6, 8, 10 – number and degree of the curve fitting interpolation.*

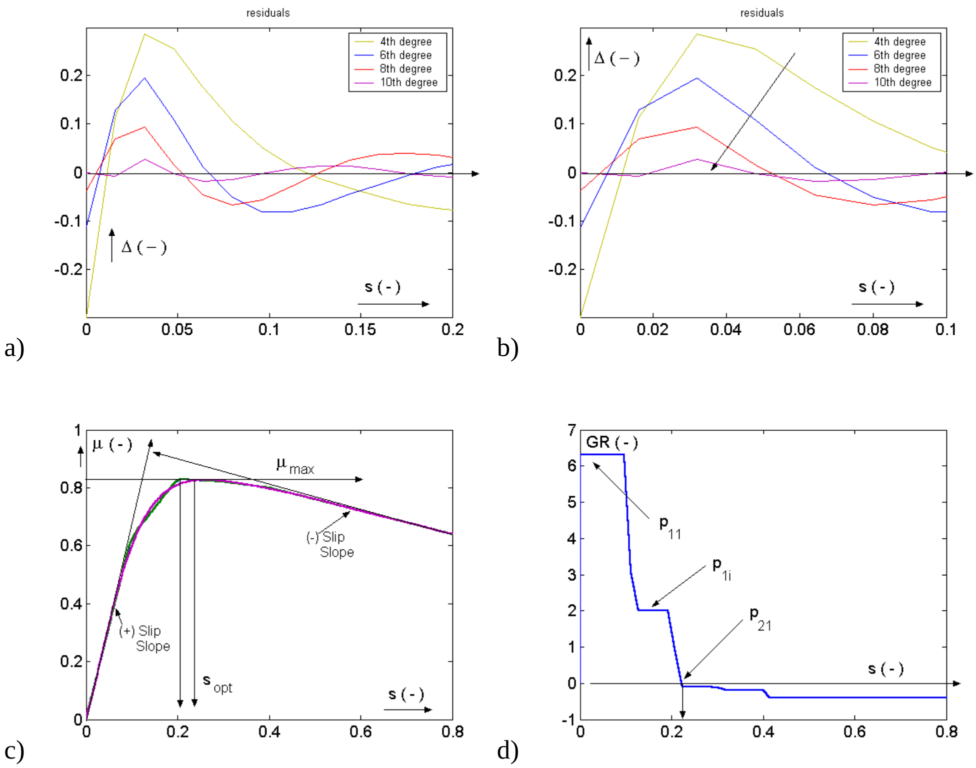

Figure 6: *Accuracy of the curves fitting and typical parameters,*
a), b) difference of estimated and fitted values of $\mu \rightarrow s$ *– curves in Fig. 5 c, d, respectively, c) typical parameters of* $\mu \rightarrow s$ *– curves, friction - (+) Slip Slope positive, friction - (-) Slip Slope negative,* 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.

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