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Aspects Regarding Stability of Vehicles Lateral Motion

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Abstract: The paper presents some theoretical and experimental aspects related to the stability of lateral motion, in case of vehicles equipped with Electronic Stability Control (ESC).The experimental research was conducted using a Volkswagen Touareg vehicle, equipped with ESC. The results are presented in graphical form. There will be presented some elements of control strategies and control algorithms used in practical experiments. These will be exemplified for an experimental research.

Keywords: Electronic stability control (ESC), vehicle stability, vehicle dynamics

I. INTRODUCTION

At present, vehicles are equipped with active systems for longitudinal and transversal stability control; for this purpose, rotational rolling and yaw motions control are assured separately by an integrated solution [4], [6], [7], [8], [9]. In modern solutions, longitudinal dynamics control is provided by systems like Adaptive Cruise Control (AAC) and Anti-lock Braking System (ABS).

The purpose of the present paper is to study lateral vehicle dynamics control of a vehicle, due to the use of ESC system. For that matter, there will be presented the main mathematical models of lateral dynamics, which are being used at ESC. Afterwards there will be shown the main elements specific to electronic control of stability, using control strategies and algorithms utilized and also using mathematical models for lateral dynamics.Finally, the paper presents the main theoretical elements of electronic control of stability specific to yaw motion and uses experimental data obtained during tests with the Volkswagen Touareg vehicle, equipped with ESC.

II. EXPERIMENTAL RESEARCH

For data acquisition, during experimental research with Volkswagen Touareg vehicle, there has been utilized dedicated software for Volkswagen group, Ross-Tech VCDS, an instrument whose role is to facilitate users professional communication with the vehicle`s command modules. VCDS software is used for required parameters selection, experimental data transfer in PC memory, different diagnosis procedures for vehicle parts, numerical display of the experimental data for all parameters and graphical display for up to 6 parameters. Afterwards, stored experimental data can be processed with MathLab software, resulting in graphical displaying.

III.MATHEMATICAL SIMULATION OF LATERAL VEHICLE DYNAMICS

The most used mathematical model for lateral vehicle dynamics is with two degrees of freedom, the bicycle model.

The two degrees of freedom for this model can be lateral position y and yaw angle □, or lateral slip body angle □ and angular velocity $□_z$ (figure 1), where:

$$\omega_z = \psi' \tag{1}$$

In figure 1 lateral forces are F_y^f for the front axle and F_y^s for the rear axle, longitudinal forces are F_x^f for the front axle and F_x^s for the rear axle, and □□ is the steering angle for the front axle.

$$\delta = \frac{\delta_v}{i_d} \tag{2}$$

where δ_v is steering wheel angle and i_d steering gear ratio.

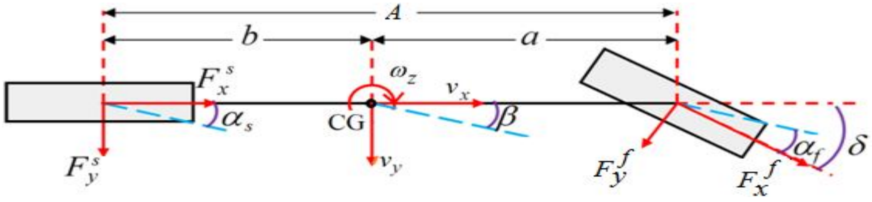

Fig. 1 Lateral vehicle dynamics

In figure 1 the center of gravity of the vehicle is marked as CG. The distances between front and rear axle and the CG of the vehicle are *a* and *b*, respectively. The wheelbase of the vehicle ($A = a + b$) is known. Also, in this figure, □$_f$ and □$_s$ are the slip angles for front and rear axle, and v_x and v_y are the longitudinal and lateral velocities.

The mathematical description of the model with lateral position *y* and yaw angle □□□as degrees of freedom is [2], [8]:

$$\begin{cases} m\left(y'' + \psi' v_x\right) = F_y^f \cos\delta + F_y^s + F_x^f \sin\delta \\ J_z \psi'' = aF_y^f \cos\delta - bF_y^s + aF_x^f \sin\delta \end{cases} \tag{3}$$

with J_z as inertial yaw moment.

The mathematical description for model with body slip angle □ and yaw velocity □□as degrees of freedom is [2], [8]:

$$\begin{cases} mv_x\left(\beta' + \omega_z\right) = F_y^f \cos\delta + F_y^s + F_x^s \sin\delta \\ J_z \omega_z' = aF_y^f \cos\delta - bF_y^s + aF_x^f \sin\delta \end{cases} \tag{4}$$

Within mathematical description (3) and (4), the two variables are lateral forces on axles F_y^f and F_y^s.

IV. EXPERIMENTAL RESULTS

In figure 2 and figure 3 there are presented values for some parameters for the experimental research with Volkswagen Touareg vehicle.

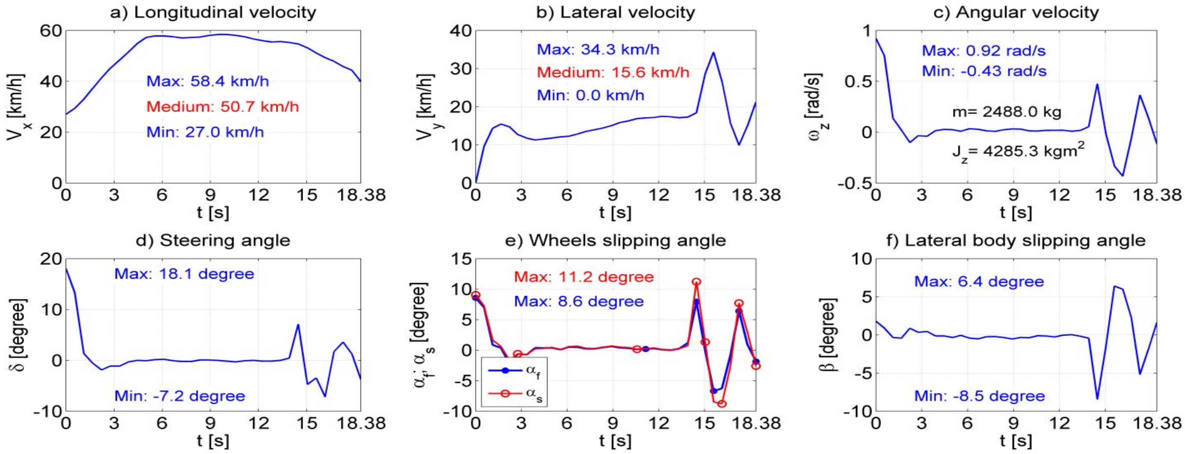

Fig. 2 Kinematics vehicles motion parameters

In these charts steering angle values □ were calculated with mathematical expression (2) and steering wheel angle values □$_v$ were measured. Extreme values for parameters, vehicle weight *m* and inertial yaw moment J_z are also marked in charts. Lateral forces on wheels were calculated using mathematical relations (3) or (4), where longitudinal forces result from traction balance.

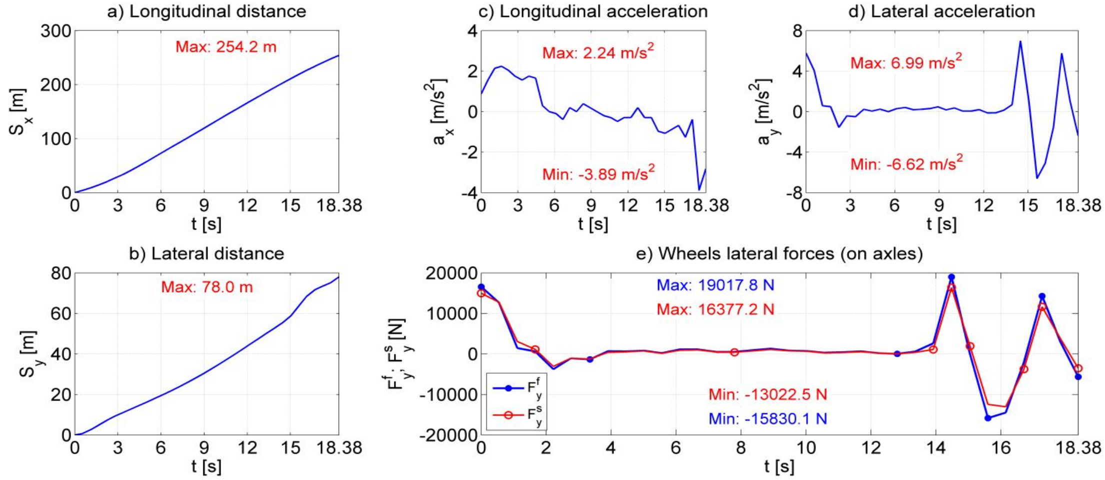

Fig. 3 Kinematics and dynamics parameters specific to vehicle motion

V. CONTROL OF LATERAL VEHICLE DYNAMICS

In practice, control algorithms for lateral dynamics stability (yaw motion control) are classified [1], [3], [5]:

1) *Linear Control:* with feedback loop control, with PID controller and adaptive control;
2) *Nonlinear Control:* On–off control, MPC - Model Predictive Control, SMC - Sliding Mode Control, Intelligent control (based on various artificial intelligence computing approaches like neural networks, fuzzy logic and genetic algorithms.
3) *Robust Control:* H_2 control and H_∞ control;
4) *Optimal Control:* optimal linear control; optimal PID control; optimal robust control (H_2 optimal control; H_∞ optimal control);
5) Fault Tolerant Control.

Yaw motions stability architecture control contains two controllers, first one for the yaw moment M_ψ, and the second one for the braking pressure p_f. If the two parameters controlled are angular velocity ω_z and slid body angle β, then it is used mathematical model (4). In this case required values (imposed or of reference) for the parameters are:

- for angular velocity ω_z:

$$\omega_{zd} = \frac{2C_\alpha^f C_\alpha^s v_x}{2AC_\alpha^f C_\alpha^s + \left(m_f C_\alpha^s - m_s C_\alpha^f\right) v_x^2}\delta \qquad (5)$$

with C_α^f, C_α^s as tire lateral stiffness for front and rear axles, and m_f, m_s weights on vehicles axles.

- for lateral body slid angle β:

$$\beta_d = \frac{C_\alpha^f\left(2bAC_\alpha^s - amv_x^2\right)}{2C_\alpha^s A^2 + \left(2m_f C_\alpha^s - 2m_s C_\alpha^f\right)Av_x^2}\delta \qquad (6)$$

For the experimental research, when it is considered wheels selective braking, using parameters from figure 2 and figure 3, are obtained the yaw moment values M_ψ from figure 4a and the braking pressure values p_f from figure 4b. Therefore, in figure 4b, initial braking pressure is p_0=27.24 bar.

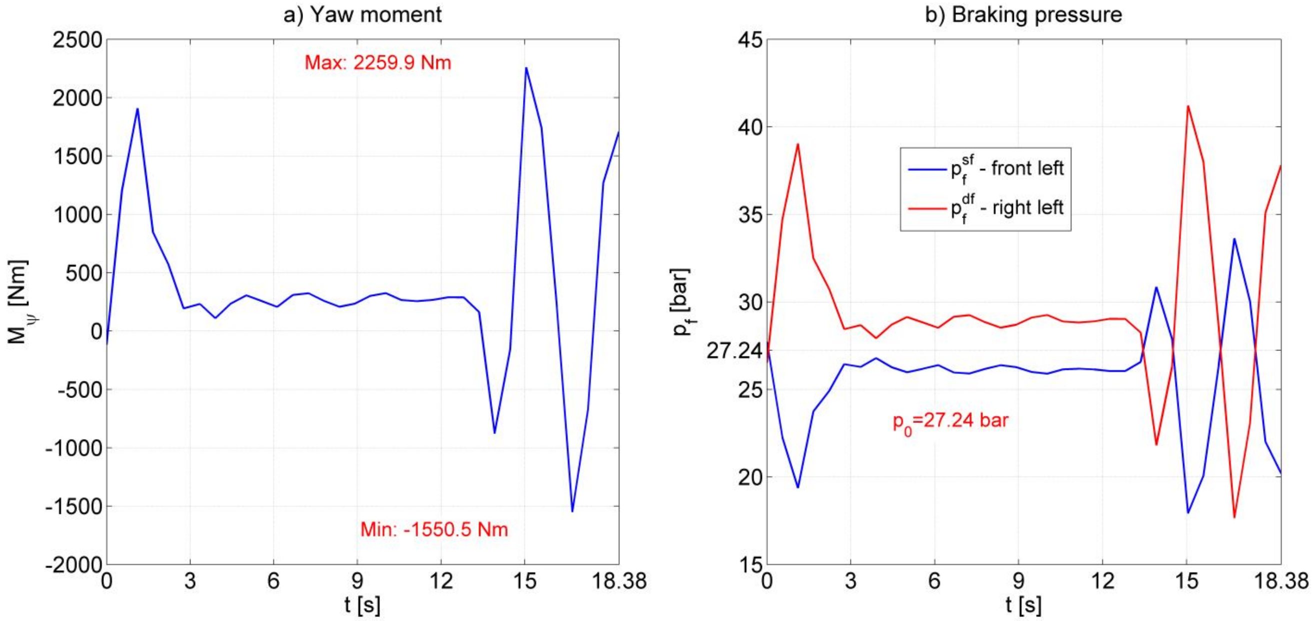

Fig. 4 Yaw moment and braking pressure

Analyzing figure 4 it turns out that the left wheel braking pressure is increasing while the right wheel braking pressure is decreasing when the yaw moment is positive, meaning that the vehicle has to steer left (trigonometrically), acording to ISO coordinating axles. Meanwhile, when the yaw moment is negative, meaning that the vehicle has to steer right (clockwise), according to ISO coordinating axles, the breaking pressure is increasing for the right wheel and decreasing for the left one.

In this case, using Sliding Mode Control, it is obtained the response time for the system in figure 5, while vehicle speed is V_x=80 km/h and steer radius is R=100 m.

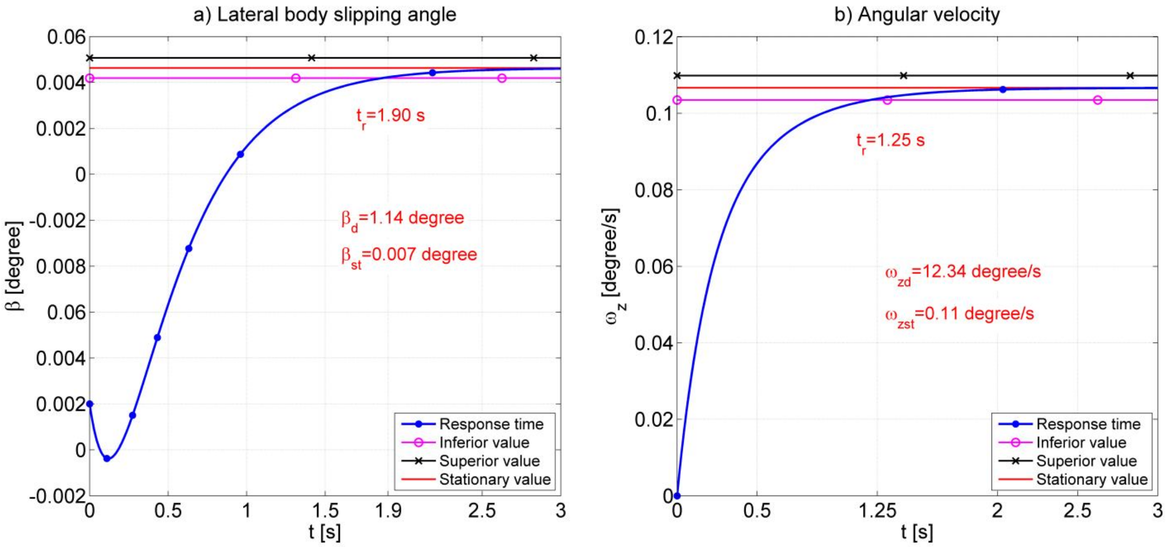

Figure 5. The response time for a system while vehicle speed is V_x=80 km/h and steering radius is R=100 m

From figure 5 can be observed that the system response times are 1.9 s for □ and 1.25 s for ω_z. There can also be observed that stationary values for both parameters (□$_{st}$ and □$_{zst}$) are way below the imposed one (□$_d$ and □$_{zd}$).

VI. CONCLUSIONS

At present, vehicles equipped with sensors, actuators and electronic command units in manufacturing process, allows complex research with complete access to all high speed dynamical processes privacy, characteristics to motions electronic stability control.

Lateral vehicles dynamic stability control require access to control strategies and algorithms which can meet the expectations not only in dynamics and economics performances, but also in systemic performances such as time response, overriding and phase and amplitude margins of stability.

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