INFLUENCE OF TIRE DYNAMICS ON A BRAKING PROCESS WITH ABS

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ABSTRACT

This article analyzes the influence of the proper modeling of the anti-lock brake system control loop components. Both the use of a stationary tire model and not considering the delays due to measurement, estimation, and actuation tend to be overlooked. Therefore, this affects the efficiency of the control algorithms developed through simulation. Thus, this work proposes to analyze the influence of the modeling of the components by performing experimental tests on a flat-track test bench. These tests demonstrate the need for taking these effects into account.

1. INFLUENCE OF TIRE DYNAMICS ON A BRAKING PROCESS WITH ABS

Correct modeling of the anti-lock brake system (ABS) components is crucial in the process of setting and optimizing a control algorithm through simulation. Therefore, this paper models all the components and analyzes their influence on the controllability of the braking system. The ABS control loop (Fig. 1) is composed of 4 main components: The system to be controlled, also called plant (tire-road interaction), the actuator (braking system), the measurement and estimation system (speed sensing), and finally the control algorithm.

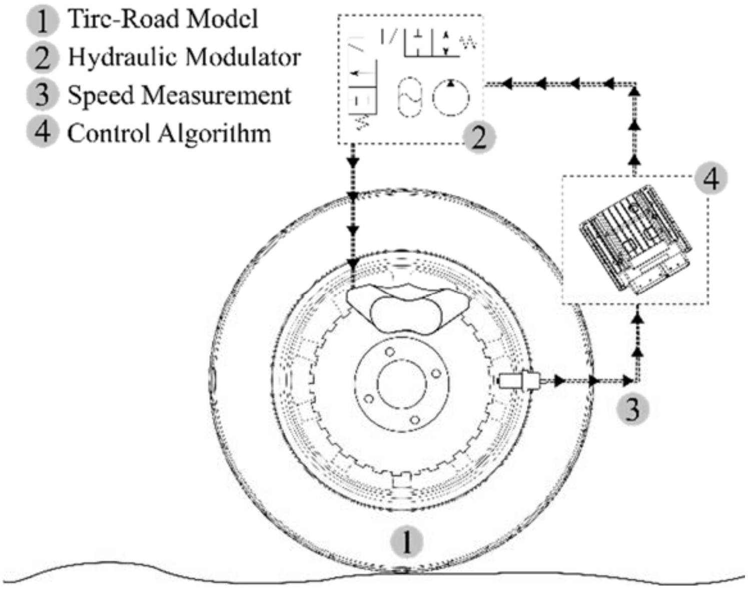

Figure 1: ABS Control Loop

First of all, the most commonly used tire model is the well known Pacejka's Magic Formula in its steady-state formulation (Pacejka, 2012). This model (1) relates the friction coefficient (μ)defined as the coefficient between the longitudinal and vertical forces to the slip ratio (κ) according to expression (2).

$$\mu = D_x sin[C_x\ arctan\{B_x\kappa - E_x(B_x\kappa - arctan(B_x\kappa))\}] \quad (1)$$

$$\kappa = -V_{sx}/|V_x| = (R_e\omega - V_x)/|V_x| \quad (2)$$

Where R_e is the wheel effective radius, ω the wheel angular speed, V_x the vehicle speed and (B_x, C_x, D_x, E_x) are the stationary parameters of the tire obtained on a test bench.

Since wheel locking occurs in a short time and with large variations in the contact forces (Arrigoni et al., 2017), a transient model (3) has to be used (Pauwelussen et al., 2003). This model uses the relaxation length (σ_κ) to add a delay between the transient longitudinal slip (κ') and the corresponding longitudinal force.

$$\kappa\sigma_\kappa \cdot d\kappa'/dt + |V_x|\kappa' = \sigma_\kappa\dot{\kappa}' + |V_x|\kappa' = -V_{sx} \quad (3)$$

Because the tire model parameters are obtained at a constant speed in test benches, it does consider the speed variation during braking processes. In Cabrera et al. (2018), this dependence is analyzed and is included in the tire model (4):

$$\kappa\lambda_{\mu x} = P_{x1} + P_{x2}exp(-P_{x3}\kappa'\,V_x) \quad (4)$$

Where (P_{x1}, P_{x2}, P_{x3}) are the parameters that describe the increase in adherence. All this modifies the adherence and optimal slip ratio (Ružinskas & Sivilevičius, 2017) throughout the braking process.

The actuator commonly used is a hydraulic control valve system (Tavernini et al, 2019) which, by increasing or decreasing the pressure, changes the contact force between the brake pads and the disc. This control system has an opening and closing time modeled using a first-order system including the fluid and friction dynamics (5) with a time constant (τ).

$$\tau\, dT_b/dt = \tau\, \dot{T}_b = K_b P_b - T_b \tag{5}$$

The torque applied (T_b) by the braking system is proportional (K_b) to the brake pressure (P_b). The measurement of the variables to be controlled is either carried out by sensors in a direct mode or by estimating their value in an indirect mode. The main variables in a braking control system are the speed of the vehicle and the speed of the wheel to be controlled. The latter is measured using a sensor that produces a wave whose frequency is proportional to the rotation speed. Both the variable resolution and the delay of the wheel speed sensor have to be considered to fit the one used in the vehicle. On the other hand, the speed of the vehicle is obtained indirectly as the technology that allows its direct measurement for commercial vehicles is costly. Therefore, the estimator used has to be implemented in the simulation in order to include the delays associated with estimation. Finally, the last of the four main components are the control algorithm that regulates the pressure to maximize the adherence preventing the wheel from locking. The simulation of an ABS optimizes this component to maximize braking. The main contribution of this research is to ensure that the simulation is accurate, so it behaves in the same way as the real. Therefore, it is proposed to keep the control algorithm fixed, with a simple control logic (6), (7) and analyze how the model of the other components influences the simulation and the real experimentation.

$$P_b = \{[P_{max} \quad \kappa' < \kappa_{opt}], [P_{min} \quad \kappa' > \kappa_{opt}]\} \tag{6}$$

$$\kappa_{opt}(\lambda_{\mu x}) = \lambda_{\mu x} \cdot P_{C_x}\, P_{D_x}\, tan\left(\frac{\pi}{2\, P_{C_x}}\right) / P_{B_x} \cdot \ \kappa = -V_{sx}/|V_x| = (R_e\omega - V_x)/|V_x| \tag{7}$$

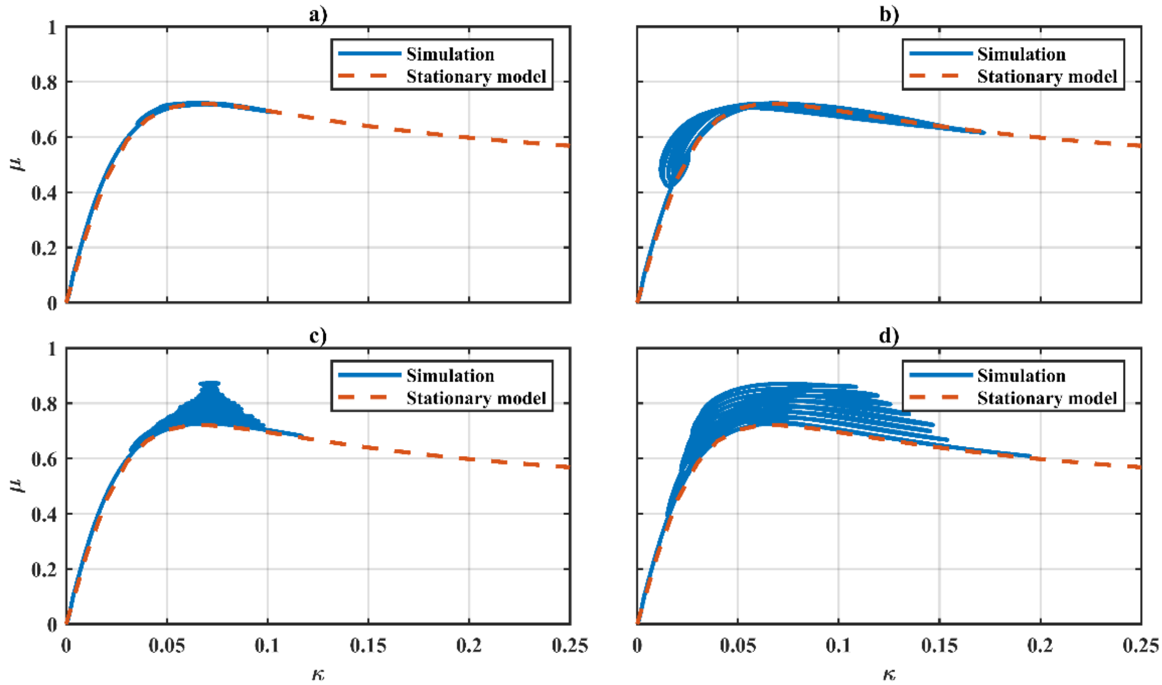

Figure 2: Influence of increasing adherence and measuring time in simulation: none (a), only measuring time (b), only increasing adherence (c), both (d).

2. CONCLUSIONS

The following conclusions can be drawn after analyzing the modeling of the different components of the ABS control loop. Both the adherence dependence with speed and the delays due to the measurement or estimation of variables are the ones that cause more fluctuations in the system response (Fig. 2). These introduce large oscillations, as well as affect the friction coefficient obtained throughout the simulation. In addition, both components tend to go overlooked in most of the literature that develops control algorithms for ABS systems. Usually, they are not supported by experimental tests or they do not show a proper fit with the simulation. This paper tries to emphasize the importance of the proper modeling of the ABS control loop components as well as to highlight the importance of experimental validation when developing control algorithms.

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