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On optimal motorcycle braking

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Abstract

The optimal braking strategy in a high-performance motorbike is discussed. First, the control strategy using the front brake only is analyzed, highlighting the role of aerodynamics and studying how to select and modify the control objective during braking. The importance of the brake modulation in the very first part of the braking maneuver is also discussed. The role played by the rear brake is then analyzed. Finally, the attention is shifted to the damping ratio of the front suspension, which is probably the single motorbike parameter with the largest impact on vehicle dynamics during braking. A possible policy for semi-active suspension control during braking is sketched.

Keywords: Motorbike; Brake control; Semi-active suspension; Vehicle dynamics; Automotive systems

1. Introduction and motivation

In this work a simulation-based study of the braking maneuver in high-performance (racing) motorcycles is presented.

The starting point of this work is the analysis of a typical hard-braking maneuver performed by a professional driver. An example is given in Fig. 1, where the measured front-wheel speed, front-brake pressure and suspensions elongation are displayed (the measurements are made on the MY05 Aprilia RSV1000 Factory). During this braking maneuver, the driver makes no use of the rear brake. Notice that the brake pressure has a ramp (of about 250 ms), followed by a small brake release (probably due to an over-slip phenomenon sensed by the driver); then the brake pressure is kept almost constant until the end of the braking maneuver. By inspecting the elongation of the front and rear suspensions, it is interesting to observe that the suspension hard-limit is reached in both cases; notice that this means that the rear-wheel is at the contact limit; apparently, this may induce the driver to avoid turning the vehicle before the braking maneuver is ended.

Among pilots and race engineers it is common opinion that the braking phase is the most critical and sensitive maneuver. The ability of a driver to achieve an "optimal braking" can make the difference on the lap-time. Even few milliseconds per braking hence can be crucial. In this work, optimality simply means minimum time to decelerate the motorbike from the initial speed to a target speed. A broader range of performance parameters will be discussed in Section 4, where the sensitivity to the front-suspension damping will be analyzed.

The objective of this paper is to deeply analyze a single braking maneuver, trying to understand what the optimal maneuver should be, and the main parameters which can influence it.

The analysis is developed in the following setting:

- A pure braking maneuver is assumed, on a straight line (no lateral forces are engaged).
- An ideal driver is assumed; the concept of the ideal driver can be recast into an automatic closed-loop control system, following a reference signal (e.g., a target slip or a target load). The design of the reference signal is clearly a key issue for the optimality ("ideality") of the driver.

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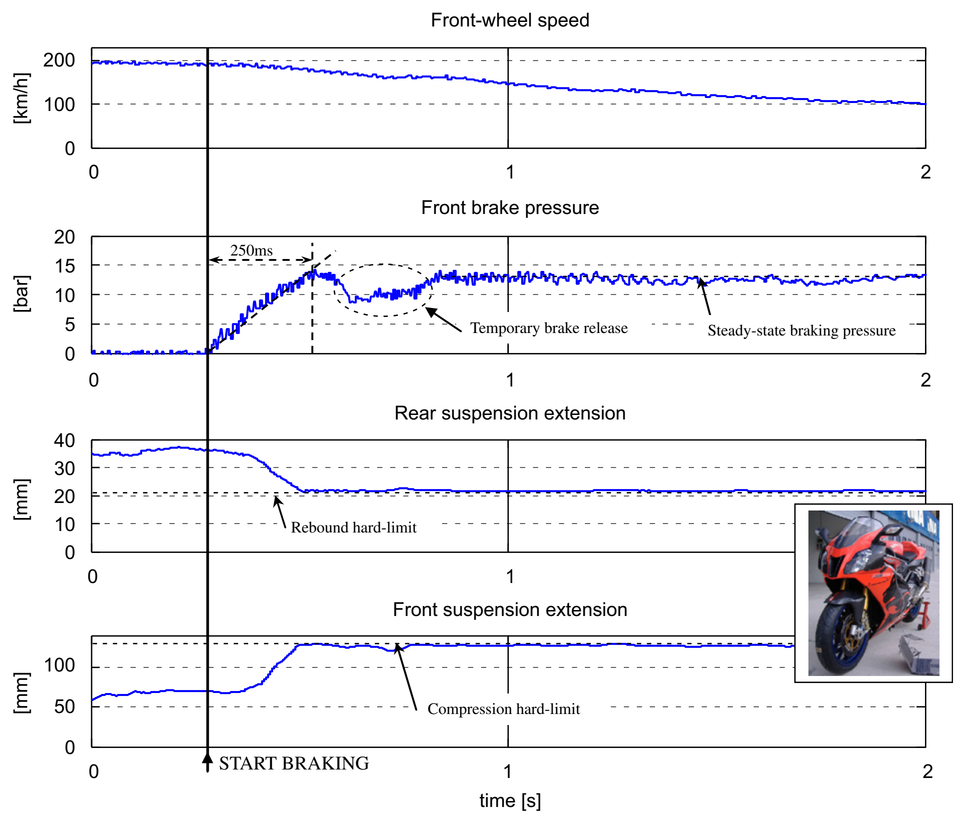

Fig. 1. Typical hard-braking maneuver (measured on the MY05 Aprilia RSV1000 Factory). The convention used for the suspension extension is that the maximum value is taken at full compression, the minimum at full extension.

The main challenge in the development of the "optimal maneuver" is due to the fact that a complete analytical model of a motorcycle is very complex, and it can hardly be used for the direct closed-form calculation of the optimal solution. On the other hand, reduced order models can indeed offer analytic solutions, but they cannot be really useful to find the optimum for the real target vehicle. This classical dilemma is solved according to the objective and the perspective of the specific research work; in this paper, since the objective is to analyze the very details of a braking maneuver, the simulator-based approach has been the natural choice (Fig. 2).

The analysis developed in this work is based on a full-fledged motorcycle simulator (the Mechanical Simulation Corp. *BikeSim*® simulation environment, based on the AutoSim symbolic multi-body software (Sharp, Evangelou, & Limebeer, 2004, 2005), which takes into account all the motorcycle dynamics, and accurately models the road–tire interaction forces (Sharp et al., 2004). See also Cossalter and Lot (2002), Donida, Ferretti, Savaresi, Schiavo, and Tanelli (2006), Frezza and Beghi (2005), Lin, Chyuan-Yow, and Tsai-Wen (2006), Sayers (1999), and Sharp and Limebeer (2001) for other state-of-the-art simulation environments suitable for this kind of analysis. The complete set of parameters used in the simulator is listed in Appendix A.

Solving the problem of the "optimal" maneuver is very attractive, since it allows to decouple the intrinsic performance of the vehicle from the driver behavior. In 2-wheel vehicles, these two aspects are so strictly interleaved that it is hard to predict the effect of a parameter change on the vehicle. This is a well-known problem, which sometimes has the picturesque effect of transforming the tuning of a racing motorbike from a rigorous model-based procedure into a sort of fine (or "magic") art.

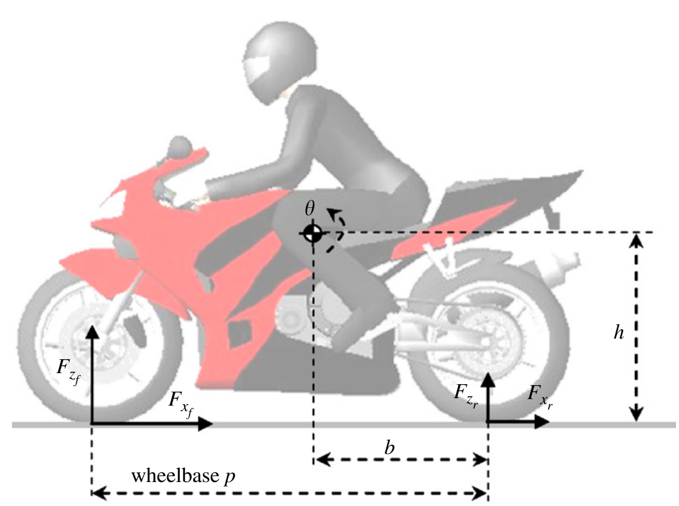

Fig. 2. Notation and GUI of the hypersport-class motorcycle used in the SW simulator Bikesim.