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# EXPLORING FRICTION IN PRISMATIC JOINTS: A STUDY ON NON-IDEAL FRONT SUSPENSION DYNAMICS

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## 1. INTRODUCTION

The front suspension of motorcycles plays a crucial role in their dynamic behavior. Throughout history, various types of front suspension have been employed in numerous motorcycles [1,2], including telescopic fork, front rocker arm (telelever), four-bar mechanisms (Girder, Hossack), leading link, etc. The most widely used and the only one currently employed in high-performance motorcycles is the telescopic fork.

Traditionally, these types of suspensions featured a thicker lower part, housing the wheel axle and brake caliper support in a single piece, while the upper part consisted of a cylindrical bar. This design, known as conventional fork, evolved over time into inverted forks. In these, the larger diameter part is attached to the chassis through the triple trees, while the smaller diameter part is positioned at the bottom. This configuration allowed for minimizing the unsprung mass and improving overall stiffness by increasing the diameter of the bars.

This work focuses on the bending moments and friction generated in the front suspension system during braking, where the non-ideal behavior, attributed to internal friction, significantly influences the system's response. Forces in the front suspension mechanism during braking are analyzed, identifying various sources of these forces (see Figure 1).

On one hand, external loads on the tire and brake system create forces and moments at the bottom end of the front suspension. Some of these forces are compensated by normal reactions in the friction bushings connecting the lower and upper parts of the suspension. Regarding forces in the axial direction of the suspension, these are compensated by the spring and damper, typically. However, the friction of the bushings (and seals) may not be negligible, especially under severe conditions such as uneven terrain or during ABS operation.

In this work, a motorcycle in-plane model is presented, emphasizing the modeling of friction forces in the front suspension and analyzing their impact on planar dynamics.

## 2. MODELING

For this purpose, Simscape Multibody was used, and a motorcycle with which the University of Malaga team participated in the 2023 Motostudent competition was modeled. Relevant inertial parameters were obtained from Solidworks CAD software or through measurements. Damping curves of the front and rear suspension were obtained from a manufacturer, considering a nonlinear model. The tire model was obtained from one of the very few models present in the literature. [3].

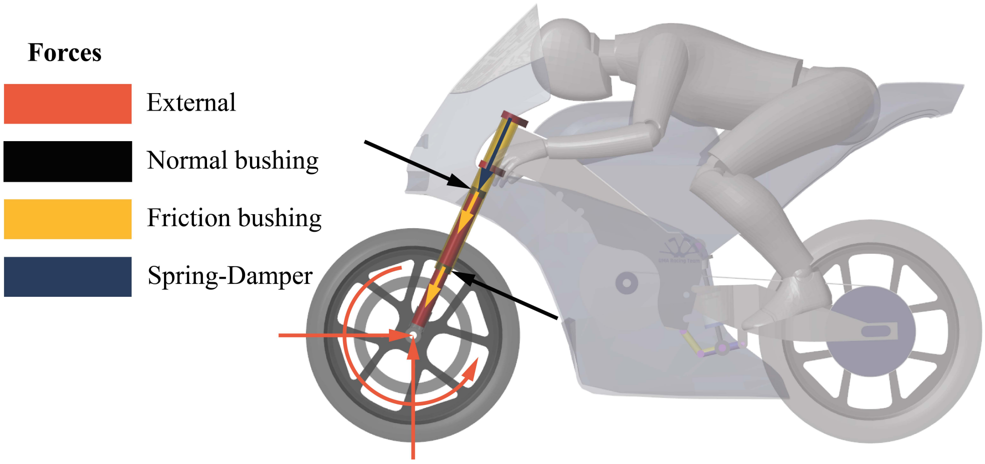

Figure 1. Force equilibrium in the front suspension considering their origin.

Regarding the friction model, the geometry of the front suspension was detailed to obtain the correct distances between the bushings. A prismatic joint was used to model the kinematic pair between the upper and lower parts of the front suspension. Simscape Multibody allows us to calculate the constraint torque compensating for this kinematic pair. Knowing the bending moment of the front suspension and the separation between the bushings, normal reactions can be obtained. To determine the tangential friction forces, the Brown and McPhee model [4] was employed (equation 1). This model is suitable for real-time simulations and adequately models friction between two rigid metallic elements, in the absence (or presence) of a lubricating fluid. Additionally, system characterization is straightforward, requiring only three (or five) parameters to model the system, all of which have physical significance. In this work, static and dynamic friction coefficients of 0.10 and 0.08 respectively, and a transition velocity of 0.1 m/s, were assumed.

$$f_t = f_c \tanh\left(4\frac{v_t}{v_s}\right) + (f_s - f_c)\frac{v_t/v_s}{[0.25\,(v_t/v_s)^2+0.75]^2} \qquad (1)$$

## 3. RESULTS

Once the motorcycle was modeled, various simulations were conducted. Below are the results of simulating an aggressive acceleration process up to 50 km/h and subsequent severe braking down to 5 km/h, on uneven terrain. The studied road profile is described as a sinusoidal wave with an amplitude of 10 mm and a wavelength of 2 m.

Figure 2 presents a comprehensive view of the dynamics within the front suspension system. The top panel illustrates the relative position and velocity between the upper and lower parts of the suspension mechanism, providing insights into their motion during braking and acceleration. In the central panel, the total force generated by the suspension is depicted, showcasing its three primary components: the elastic force exerted by the spring, the damping force from the shock absorber, and the force attributed to the studied friction. This breakdown offers a clear understanding of the contribution of each component to the overall suspension behavior. Lastly, the bottom panel visualizes the bending moment experienced by the front suspension bushings, highlighting the structural stresses it encounters under different conditions. Together, these three figures offer a comprehensive analysis of the complex interplay between forces, motion, and structural integrity within the front suspension system.

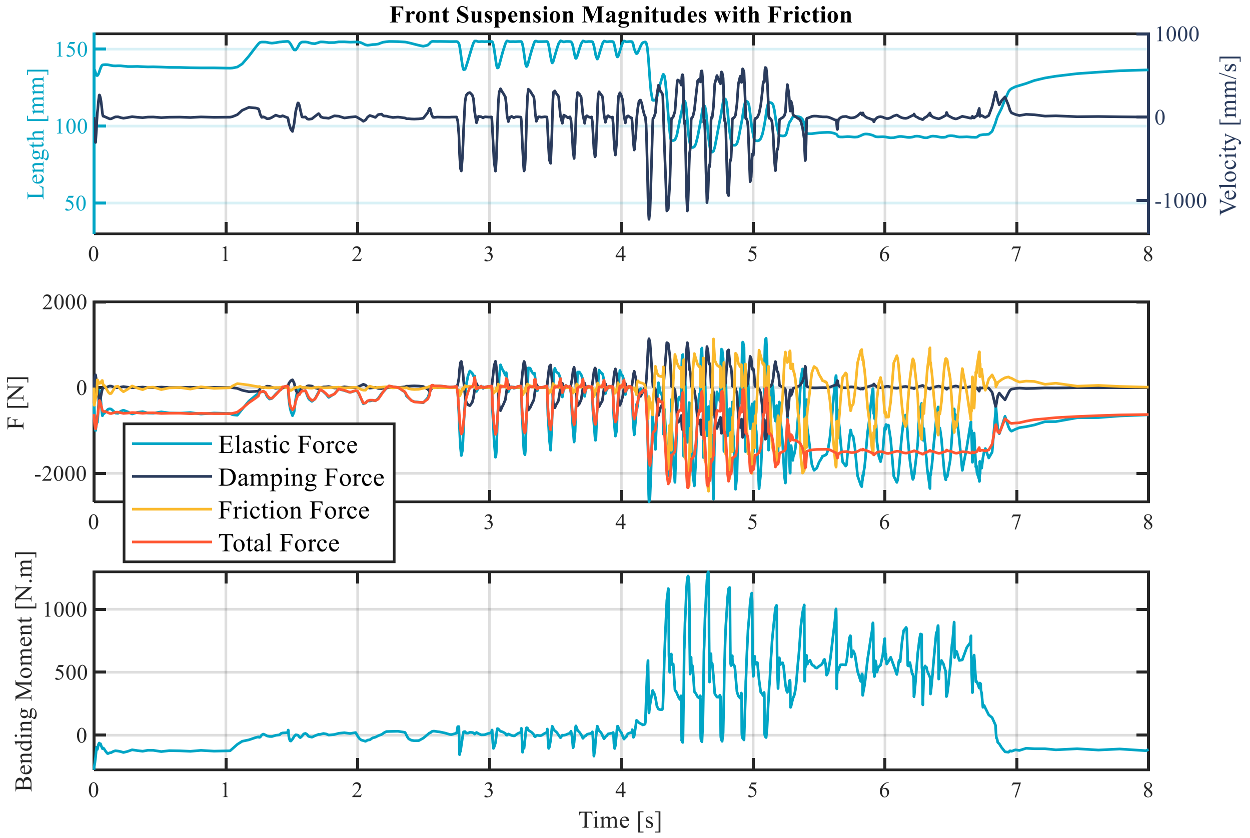

Figure 2. Results of the simulation. Top: Position and relative velocity of the upper and lower parts of the suspension. Middle: The different described forces and their values. Bottom: Bending moment supported by the suspension bushings.

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