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Review

Synchronous brake analysis for a bicycle

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ABSTRACT

This paper presents an investigation on the braking performance and safety for a bicycle riding on a straight and an inclined paths. The equations of motion for a wheel model as well as the model for ideal synchronous braking are derived to acquire the shortest braking distance and improve the riding stability. The optimal design of the bicycle braking is obtained based on the simulation results with various bicycle geometries, ratios of brake force, and road friction.

Contents

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Nomenclature

F_t (N)	total braking force
μ_b (–)	coefficient of friction of the tire
W_0 (N)	the load of a wheel axle
μ_r (–)	rotation friction coefficient of the tire w.r.t. ground
T_b (N m)	braking torque
F_d (N)	friction force applied from the calipers to the disk
μ_d (–)	friction coefficient between the caliper and the disk
R_0 (m)	radius of the wheel
a (m/s^2)	acceleration
g (m/s^2)	the gravity acceleration
L (m)	distance from front wheel center to rear wheel center
L_1 (m)	distance from the front spindle to the center of mass
L_2 (m)	distance from the rear spindle to the center of mass
W_f (N)	vertical force of the front wheel
W_r (N)	vertical force of the rear wheel
W (N)	total vertical force
h (m)	height of the center of mass
F_{bf} (N)	braking force of the front wheel
F_{br} (N)	braking force of the rear wheel
μ (–)	friction coefficient of the road

1. Introduction

The increased market demands have resulted in disk brakes being a mainstream in high-end bicycles. It is evident that the disk brakes can enhance the performance and added value of a bicycle. Except for a number of patents [1–6], only a few research papers and some related articles in automotive and motorcycle periodicals are available on the topic of disk brakes for bicycles. In the field of vehicle dynamics and control, some researchers have investigated the riding dynamics and stability of motorcycles [7–10]. In their researches, the driver was simulated as a feedback controller and provided with the correct factor by the preview error with the control angle analysis. Shladover et al. [11] compared more parameters to derive the model. In 1996, Young and Kim [12] studied the lateral dynamics of a motorcycle using the curved path and conducted a stability analysis by the root-trace method to derive the effects of the speed, curvature and gain factor of the control loop for driving safety, a theory that has always been used by tire manufacturers. Bernard et al. [13] used a first-order delay model and the massless string model to discuss the dynamic behavior of the tire when the brake was applied. Vittore et al. [14] analyzed the effects of speed and curvature on the handle control. Qu and Liu [15] applied approximate analytical methods to study the nonlinear influences of tires on the steady-state steering behavior, dynamic response and handling stability. Chou and D'Andrea-Novel [16] designed a nonlinear control law to allow the stopping vehicle follow the desired trajectories at specific yaw rates and longitudinal accelerations by using both braking torques and suspension forces. Vangi and Virga [17] presented a methodology, which employed fuzzy logic approach on the basis of the data obtained from on-site measurements and/or published by technical press, to permit the evaluation of the coefficient of friction and stopping capability of a car.

2. Basic theories of the disk brake system for a single wheel

Braking performance is the most important index of bicycle safety. When an emergency happens while riding a bicycle at high speeds on a muddy road, and the friction torque between the tire and the ground is much smaller than that between the calipers and the disk, this will result in tire "lock" and sliding of the bicycle. Therefore, when designing a safe braking mechanism, one must consider the torque ratio of the brakes to the tires. The larger the friction between the tire and the ground, the better the control over the bicycle by providing more deceleration to shorten the braking distance and so enhance the safety of the bicycle.

When the disk brake is applied, the friction force applied from the calipers to the disk will make the wheel slow down. However, it is the friction force between the tire and the ground that slows down the speed of the bicycle, and is a crucial factor for stopping the bicycle safely without slipping. The braking performance depends mainly on the optimum torque distribution between the braking torque and the torque produced by the friction between the tire and the ground.

Fig. 1 shows a wheel model that is used to illustrate the braking conditions. The braking force of the bicycle takes place between the tire and ground, which is the contribution from two forces: the friction force applied from the calipers to disk, F_d, and the rolling friction force of the tire, $\mu_r \frac{W_0}{R_0}$, as shown in Fig. 1, the total braking force F_t can be written as follows:

$$F_t = \frac{T_b}{R_0} + \mu_r \frac{W_0}{R_0} = \frac{r}{R_0} F_d + \mu_r \frac{W_0}{R_0} \quad (1)$$