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Some Investigations on the Wobble Mode of a Bicycle

Chr. Ott, B. Angrosch, J. Edelmann, M. Plöchl

Institute of Mechanics and Mechatronics
Vehicle System Dynamics and Biomechanics
Vienna University of Technology
Wiedner Hauptstraße 8-10, 1040 Vienna, Austria
e-mail: manfred.ploechl@tuwien.ac.at

Abstract

Learning how to ride a bicycle demands courage. After some unfortunate experiences with a bicycle toppling over at low speeds, taking a risk to speed-up will be rewarded, as the bicycle may stabilize its motion on its own. Some more practice, and we have learnt how to handle two potentially unstable modes of the bicycle – weave and capsize.

There remains a further mode, wobble, which is – once experienced in its unstable form – at least unpleasant if not hazardous at all. Wobble is related to the more general class of wheel-shimmy, which is a self-excited motion of the wheel about the steering axis, and thoroughly treated in [1, 2]. The experience and main findings from detailed analysis of this phenomenon at motorcycles, e.g. [3], can hence be transferred to the bicycle. Although key issues on the wobble mode at bicycles are given in [4], little else can be found in scientific literature on this topic.

This paper aims to contribute to the analysis of the wobble mode by examining a specific bicycle, that shows an unstable wobble mode at certain speeds, both on the basis of a mathematical model and by experiment. The considered bicycle is equipped with measurement devices (GPS-sensor, 6 degree of freedom inertial measurement unit for accelerations and angular velocities, steering angle potentiometer, wheel-speed sensor) and is depicted in Figure 1.

Figure 1. Test bicycle with measurement equipment.

The nonlinear equations of motion for bicycle and rider are derived by hand applying d'Alembert's principle. The model considers the roll and steering angle of the bicycle, yaw rate and lateral velocity, and moves at a constant longitudinal speed. The flexibility of the frame is modeled by introducing a rotational degree of freedom, allowing the steering assembly to twist about an axis normal to the steer axis in the plane of symmetry, restrained by a spring-damper combination. The rider has just a lean degree of freedom, which is represented by the relative roll angle of the upper torso with respect to the bicycle. The applied linear tyre model considers sideslip and camber angle of the respective tyre, and accounts for the time lag in a transient condition of the tyre. Details on the derivation of the system equations and the corresponding system model are presented in [5].

Figure 2 shows a time-sequence of the steering angle of a typical test run. The rider was sitting tight in an upright position, hands-off, and did not pedal after attaining the initial speed of about 7 m/s. The dominant frequency in the signal is about 6 Hz. At the end, intervention of the rider was inevitable.

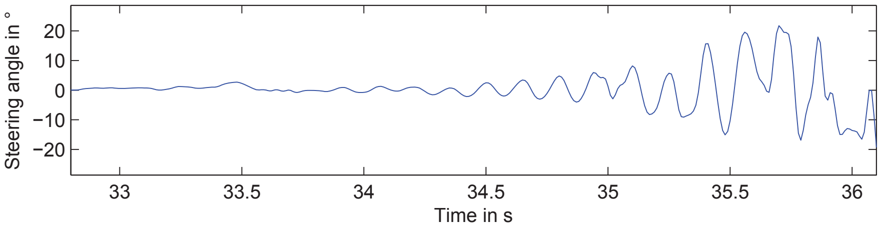

Figure 2. Measured steering angle of the bicycle with initial speed of about 7 m/s.

For stability analysis the system equations are linearized with respect to the straight running condition at constant speed, and eigenvalues are analyzed.

Mass and geometric properties of the bicycle have been measured, as well as the lateral stiffness of the main frame assembly. Other crucial parameters for the standard configuration of the bicycle, like the damping coefficient of the frame and some tyre parameters, have been estimated within the system model to meet the transition-velocity from stable to unstable wobble mode and the corresponding frequency found by test runs. Subsequently, the sensitivity and influence of various design parameters of the bicycle on the on-set of the unstable wobble mode are discussed and compared with measurements if possible.

Preliminary results give evidence that the key design parameters that influence the wobble mode are frame damping coefficient, mass distribution, geometric properties of the front frame assembly and tyre parameters in the mentioned order.

References

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