

Modal Analysis of a Simplified Motorcycle Model During Turning Motion

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This study aims to develop a simplified model of a motorcycle. Since Sharp's two-wheeled vehicle model, which assumes straight-line motion near the upright position, is limited in its ability to analyze the dynamics of a motorcycle during cornering, a novel model is developed for a motorcycle negotiating a turn at a prescribed reference roll angle. Modal analysis is then conducted using the proposed model.

The analysis of motorcycle dynamics can be traced back to the four-degree-of-freedom (4-DOF) model proposed by Sharp in 1971, and the vibration modes identified in that study have served as the basis for subsequent analyses. In this model, the motorcycle is represented by two rigid bodies corresponding to the front and rear frames. The equations of motion are derived using the Lagrangian formulation, followed by modal analysis to identify the principal vibration modes.

Because the kinetic and potential energies associated with the centers of gravity of the front and rear frames must be determined, the model requires a substantial number of geometric and mass-related parameters. Although Sharp's original paper provides specific parameter values and numerical results, one example of publicly available data that comprehensively covers the vehicle specifications required for the 4-DOF model is a technical report published by the Society of Automotive Engineers of Japan (JSAE), which summarizes the specifications of four motorcycle models without disclosing their specific vehicle names. However, this report was published in 1997, and the characteristics of the motorcycles described therein may differ from those of modern vehicles.

Furthermore, the parameters required by the 4-DOF model include not only quantities that can be measured relatively easily on a complete motorcycle, such as wheelbase and total vehicle mass, but also parameters that cannot be determined without disassembling the motorcycle. For example, the location of the center of gravity of the rear frame including the rider is required. These measurement requirements make it difficult to obtain all the parameters necessary to construct and validate the 4-DOF model for a contemporary motorcycle.

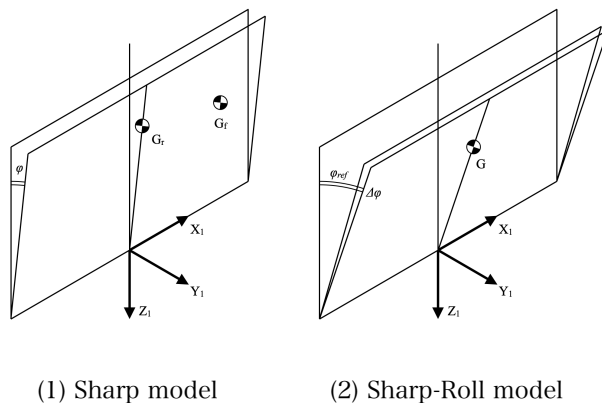
For the analysis of four-wheeled vehicle dynamics, a simplified bicycle model has been established in which the front and rear wheels are each represented by a single wheel located at the center of the corresponding axle. This model enables qualitative discussions of fundamental steering characteristics, such as understeer and oversteer. Naturally, more detailed analyses can be performed by constructing models with additional degrees of freedom and carrying out numerical computations with the aid of a computer.

The authors' research is motivated by the question of whether motorcycle dynamics can likewise be described using a mathematical model, analogous to the bicycle model for four-wheeled vehicles, that provides a concise explanation of the fundamental dynamic characteristics. In light of the aforementioned situation, the authors have continued their research with the aim of developing a simplified mathematical model of motorcycle dynamics.

Following the formulation of Sharp's equations of motion, four degrees of freedom are introduced, and the four governing equations for lateral displacement, yaw angle, roll angle, and steering angle are formulated as a coupled system.

$$M\ddot{q} + C\dot{q} + Kq = (0 \quad 0 \quad 0 \quad \tau)^T$$

The SR model does not explicitly model the front-wheel steering system; however, the steering angle appears explicitly in the governing equations because it is included in the expression for the lateral tire force.



(1) Sharp model

(2) Sharp-Roll model

Fig.1 Treatment of the coordinate system and the positions of the centers of mass

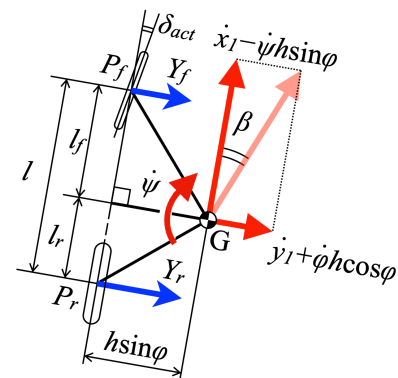


Fig.2 Schematic diagram of the simplified motorcycle model viewed from the Z₁ direction