

Relation between the Weave Mode in Low Speed Range and Slalom Running of Motorcycles

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ABSTRACT

Recently, our research has focused on the weave mode. This is a representative vibration mode of motorcycles and is important when considering maneuverability and stability. In a method of analyzing the weave mode, a disturbance is applied to the handle bars of the motorcycle during running and then the response waveform of the roll angle and other items at that time is used to perform estimations. However, when the motorcycle is driven at low speeds, the steering operations of the rider have a large effect on the running data and this makes estimation difficult. Therefore, it was assumed that weave mode data can be estimated from slalom running data since this possesses almost the same vibration frequency as the weave mode in low speed range.

In this research, a simulation was used to investigate the relationship between the weave mode and slalom running. The results of the investigation confirmed that slalom running at a specified speed around pylons placed apart at a specific interval resulted in the same vibration mode as the weave mode in low speed range. Furthermore, the data obtained from actually performing the slalom running was compared to the simulation results, and the same trends in the steering torque and roll angle, which are vital data when considering maneuverability and stability, were confirmed.

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INTRODUCTION

For a motorcycle, the maneuverability and the stability are difficult to express numerically though they are considered important. If the numeral values indicating the maneuverability and stability can be estimated from the vehicle design data without running an actual motorcycle, it is possible to design a vehicle in consideration of maneuverability and stability even at the design phase before the vehicle is completed. This is expected to contribute to the development process substantially. Evaluating the maneuverability and stability of a motorcycle quantitatively is much meaningful.

To quantitatively evaluate the maneuverability and stability of motorcycles, our research carried out measurements by mounting a posture measuring device on a motorcycle[1]. These measurement results confirmed that different trends are observed in the tire lateral slip angle and steering torque during steady-state cornering depending on the test conditions and riding posture. After the vehicle behaviors in steady state were thus identified, transient behaviors are now included in our research. The weave mode in a low speed range is examined, which is particularly

important in identifying the maneuverability and stability of a motorcycle.

One of the analysis methods for motorcycle vibration modes including the weave mode is the handle hit method that uses for estimation the roll angle and other response waveforms obtained when a disturbance is applied to the handle. However, it is difficult to analyze the vibration mode with the handle hit method at a low speed because the vibration damps quickly due to spontaneous handling and weight shift by the rider.

In this paper, the slalom running data were focused, which exhibit an equivalent frequency to the weave mode in low speed range, and a motorcycle simulation model was used to verify that the weave mode in low speed range is of the same vibration mode as slalom running. In addition, slalom running was performed in the simulation while varying the vehicle speed, pylon interval and slalom width, and a verification was made to see if the weave mode in low speed range can be estimated from these running data. Finally, the slalom running was performed with an actual motorcycle to see if an equivalent trend to the simulation was exhibited.

SIMULATION

Simulation model

The investigation used a simulation model of a large motorcycle with a displacement of 1300 cm³, as shown in Figure 1. The model has eleven degrees of freedom (DOF) and contains ten solid elements (the main frame, rider, engine, tank, front fork, front arm, front wheel, arm relay, rear arm, and rear wheel). Of these elements, the rider, engine, and tank are rigidly connected to the main frame. The MF-Tyre model was used for the tires. The coordinate system uses the ISO coordinate system, as shown in Figure 2. The rider control model is shown in equation(1). For a detailed explanation of the model, refer to the literature cited below[2].

$$\tau = -k_p(\phi - \phi_{ref}) - k_{d1}\dot{\phi} - k_{d2}\ddot{\phi}$$

τ : steering torque

ϕ : roll angle

ϕ_{ref} : target roll angle

α : steering angle

k : gain

(1)

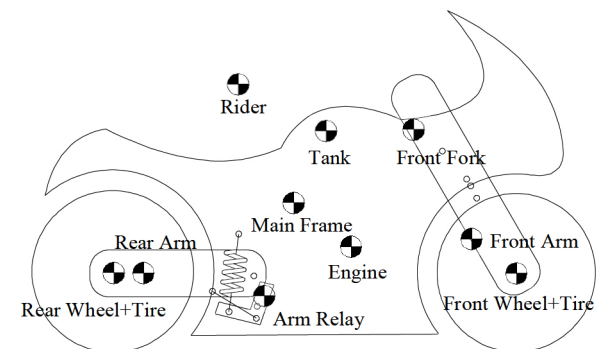


Figure 1. Simulation model

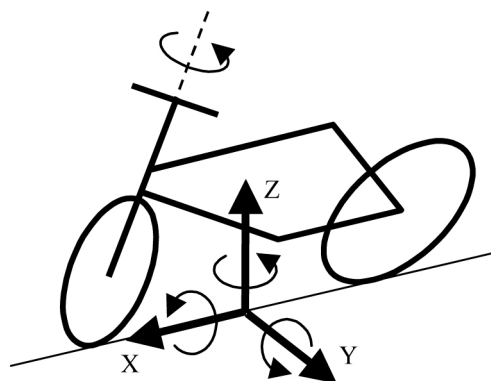


Figure 2. Coordinate System

Vibration frequency

With this model, an eigenvalue analysis was performed by running a straight line with various speeds. Figure 3 shows the eigenvalues representing a weave mode, which were extracted from the analysis results. The weave mode of a motorcycle is generally said to appear in a middle to high speed range with a vibration frequency from 1 to 4 Hz. In addition, The Figure 3 also indicates that it occurs in the low speed range, which has not been a focus of previous research. When the real part is 0, that is, the vibration continues without attenuation, the vehicle speed is around 25 km/h. The vibration frequency can be read in the imaginary part of the eigenvalue whose real part is 0 and is 2.3rad/sec(0.3Hz).

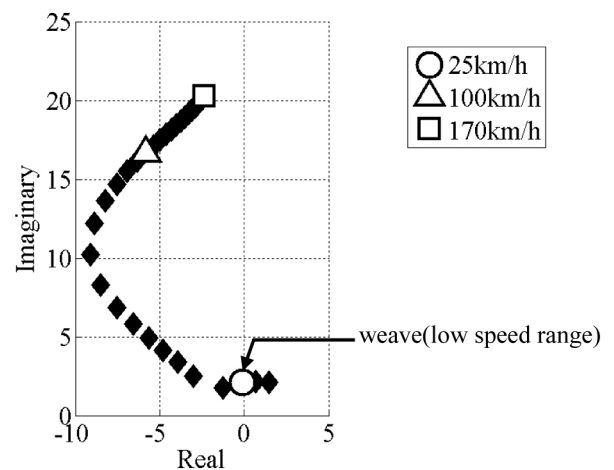


Figure 3. Eigenvalue of weave mode

Slalom running tests are as shown in Figure 4. The vehicle speed V , slalom width W , and pylon interval P were varied. Of the slalom running conditions, if the vehicle speed V is set to the same speed as the weave mode in low speed range, 25 km/h, and the pylon interval P is varied from 8 to 20 m, the resultant slalom frequencies vary from 0.2 to 0.4 Hz. The range is equivalent to that for the weave mode in low speed range.

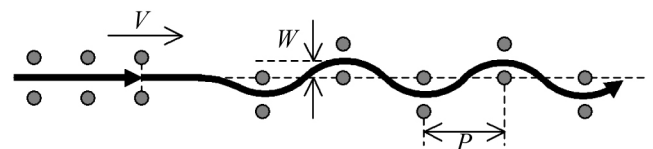


Figure 4. Slalom running test

Slalom simulation

The slalom running test was reproduced by simulation to investigate the correlation between the eigenvalue analysis results and the slalom running test results. The slalom running is carried out by giving the target roll angle of a sine wave in equation(1). Figure 5 shows an example of the results.

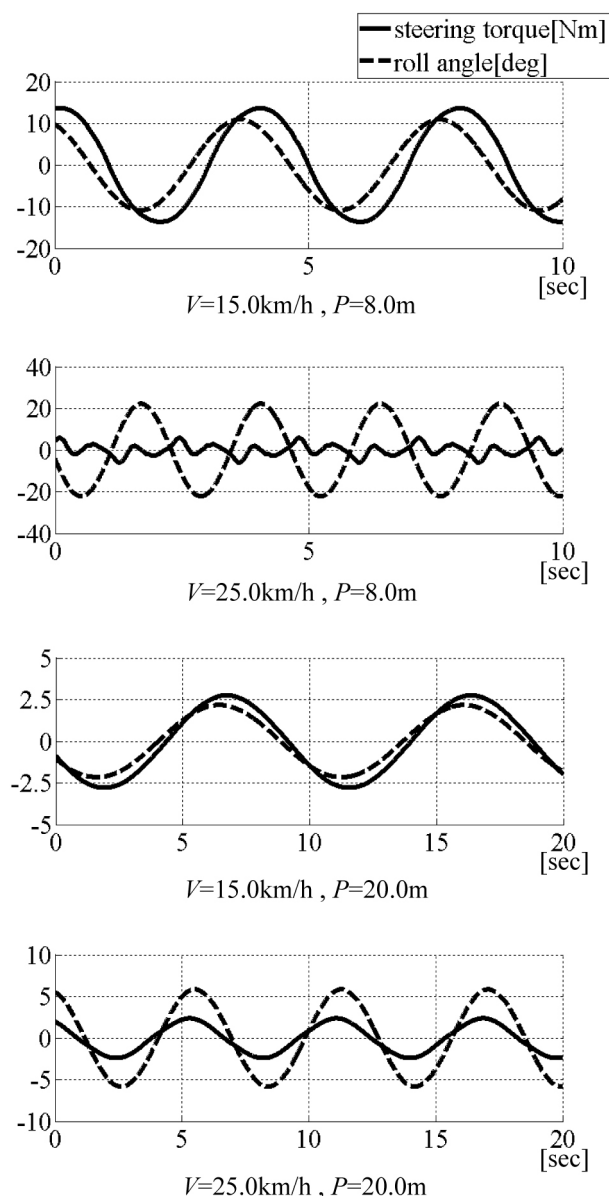


Figure 5. Steering torque and roll angle

Generally, a rider applies steering torque inputs during slalom running. Due to the influences of these steering torque inputs by the rider, the vibration mode of the motorcycle itself cannot be analyzed from the slalom running data waveforms. However, there may be a situation where the applied steering torque is relatively small, as indicated by the data with $V = 25$ km/h and $P = 8.0$ m.

Therefore, vehicle speed and vibration frequency conditions were calculated for the slalom running simulation to form a weave mode eigenvalue with a zero real part. It was assumed that a simulation performed under these conditions would enable sustained vibration without steering inputs, except during the initial period. These conditions would eliminate the influence of the rider and express the weave mode of the motorcycle itself in the slalom running results.

Comparison between the weave mode in low speed range and slalom running

Based on the results of the investigation described in the previous section, the slalom running simulation was performed under conditions calculated from an eigenvalue with a zero real part (vehicle speed V_0 and pylon interval P_0). The simulation showed that the same vibration mode as the low-speed weave mode was obtained.

First, the slalom conditions (vehicle speed V_0 km/h and pylon interval P_0 m) offering an equivalent vibration frequency to the weave mode in low speed range are calculated. Vehicle speed V_0 is calculated from eigenvalue λ_0 with 0 real part from Figure 3. Pylon interval P_0 is calculated by the following formula: $P_0 = (V_0 / 3.6) / (b / 2\pi) / 2$, b : Imaginary part of λ_0 . The results were $V_0 = 24.3$ km/h and $P_0 = 10.1$ m.

Next the eigenvector for each of the weave mode in low speed range and slalom running was calculated. Both were compared according to the following procedure.

- From the eigenvalue analysis results, the eigenvector corresponding to the weave mode eigenvalue λ_0 with 0 real part was calculated (Figure 6). The amplitude ratio can be read in the length of eigenvectors, and the phase difference can be read in the angle formed by eigenvectors. They are shown in Table 1.
- The slalom running with the conditions (vehicle speed V_0 and pylon interval P_0) calculated was performed in simulation and the respective state quantities during drive were measured (Figure 7). The slalom width W was set to 0.8 m by referring to the data of actual vehicle running tests. Then the amplitude ratios and phase differences between the respective state quantities were calculated (Table 1) and represented by a vector (Figure 8). Figure 8 also includes the vector representation of state quantities calculated with vehicle speeds other than V_0 (15 km/h and 35 km/h) for reference.

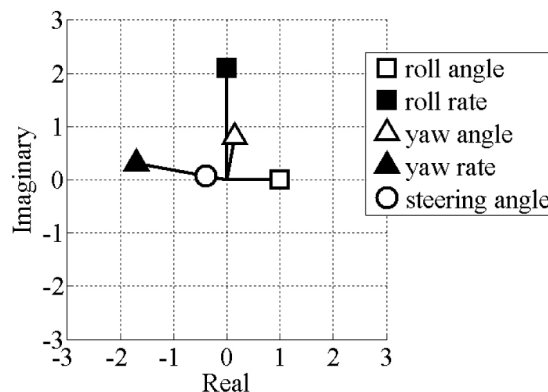


Figure 6. Eigenvector (weave mode)