

Studies of Shimmy Phenomenon by Statistical Approaches

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ABSTRACT

There have been a number of attempts to clarify the relationship between motorcycle specifications and shimmy phenomenon. Some of such efforts are based on equations of motion. The methods used in those efforts are suitable for analyzing motions in a fundamental structure. However, when the degree of freedom is large, it is extremely difficult to deliver an equation of motion. Therefore, a practical method cannot be found generally when applying the methods employing equations of motion.

We also conducted the analysis of shimmy using multi-body dynamics simulation. The yielded results were useful only for clarifying the differences in shimmy levels among motorcycles. However, they were not helpful to understand the relationships between specifications and shimmy phenomenon.

In this study, we focused clarifying these relationships and we took four study steps shown below:

1. Narrowing down the motorcycle specifications affecting shimmy
2. Determining physical parameters influential to shimmy
3. Investigating how a change of physical parameters affects shimmy using simplified model
4. Analyzing how the changes of motorcycle specifications affect the shimmy

Following these steps, we clarified the relationships between motorcycle's specifications and shimmy by using only three physical parameters.

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INTRODUCTION

Shimmy is one of the modes that affect the straight-running stability of a motorcycle. It is often treated as the similar phenomenon as wobble, which is one of the three modes defined by R.S.Sharp [1]. A number of past studies have looked at the shimmy or the wobble mode [1], [2], [3], [4], [5], [6], [7], [8], [9]. In particular, Kageyama et al. pointed out the difficulties that shimmy was hardly simulated accurately by a conventional simulation model having four degrees of freedom. Consequently, they showed that shimmy phenomenon can be accurately simulated by adding lateral and torsional stiffness of tires [8]. We have simulated performance differences among a number of motorcycles by applying Kageyama's principle to a multibody dynamics (MBD) model [9]. Thus the methods for the precise simulation of the shimmy phenomenon have been developed. However, the simulation model turned into the Black Box because it needed a lot of parameters for the execution of the simulation at the same time. It is difficult to establish effective

design guidelines based on considerations of the mechanism of shimmy. Accordingly, it is necessary to clarify how the motorcycle specifications affect the shimmy. Some of the attempts include the studies of wobble mode by Katayama et al. using the energy-flow method [3]. This method made it possible to explain the interactions between elements. When a model is composed of a basic structure, this method is effective to simplify the description of the phenomenon. On the other hand, it is difficult to apply the energy-flow method when the MBD simulation is composed of a lot of elements. Keeping in mind the aforementioned, we tried to derive a simplified manner to describe the relationship between the motorcycle specifications and the shimmy without expanding the equation of motion. Consequently we decided to use multiple regression analysis.

The analysis procedures are:

1. Narrowing down motorcycle specifications affecting shimmy using the multiple regression analysis

2. Determining physical parameters influential to shimmy using the multiple regression analysis
3. Investigating how a change of physical parameters affects shimmy using simplified model
4. Analyzing how the changes of motorcycle specifications affect the shimmy clarifying how motorcycle specifications affects physical parameters

SIMULATION MODEL USED IN ANALYSIS

The authors developed a simulation model, shown in Figure 1, in a past studies [9]. We used the same model in this study as well. In the model, we applied flexible bodies to the frame and to the steering assembly. Heavy objects excluding the frame and the steering assembly (i.e. tire, wheel, swingarm, engine and loaded object etc.) were laid at the location of their centers of gravity (CG). Those parts were fastened via springs and dampers to their fixing structures. To the connections at steering stem, swingarm pivot, front axle and rear axle, rotational joints were applied. Regarding the rider model, the one in the literature [10] was used. The tire model was based on the MF-MC tire [11]. In that model, the degree of freedom of lateral movement was taken into account as shown in Figure 2. The steering friction and the spring and damper characteristics in various connecting points were determined from experiments.

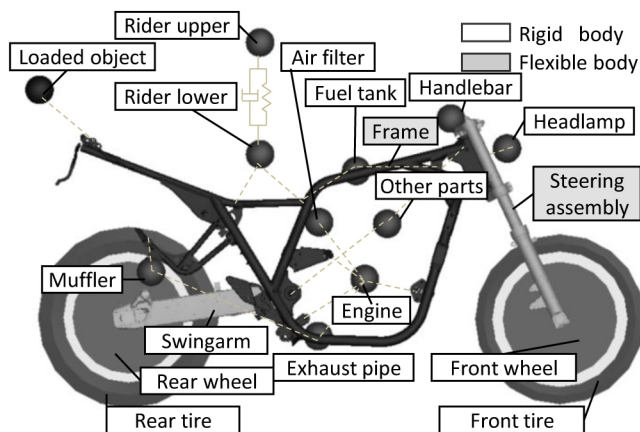


Figure 1. Simulation model

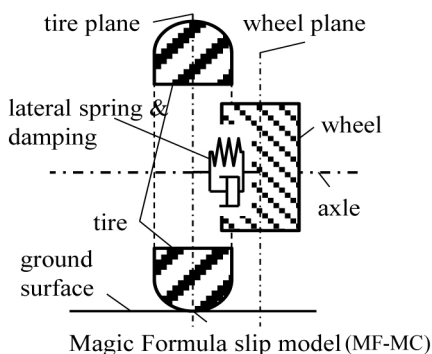


Figure 2. Tire model

Table 1. Specifications of simulation model

Wheelbase (mm)	1510
Trail (mm)	99
Caster angle (deg.)	25
Weight of motorcycle (kg)	273.2
Weight of steering assy. (kg)	33
Longitudinal distance between CG to rear wheel (mm)	760
Height of CG from ground (mm)	512
Roll inertia moment (kg m ²)	20.3
Yaw inertia moment (kg m ²)	58.4
Steering inertia moment (kg m ²)	0.805
Front tire	120/70ZR17
Rear tire	180/55ZR17

The maximum steering angle of shimmy is used as an index that represents the shimmy phenomenon in the literature [9]. However, we considered that the process through which the steering angle reaches to maximum amplitude when shimmy is generated is important. Accordingly, we decided to describe the index value for representing the shimmy phenomena by using a steering angle variation ratio (hereafter StrAgl-VR). StrAgl-VR is defined as the amplitude of the third wave divided by the amplitude of the first wave after the input of the external disturbance.

Table 1 shows the major specifications of the base motorcycle.

NARROWING DOWN OF THE MOTORCYCLE SPECIFICATIONS AFFECTING SHIMMY

Table 2 is a summary of the motorcycle specifications that affect shimmy, taken from the literatures [2][3][4][5][6][7].

We conducted the shimmy simulations on the basis of the Design of Experiments (DOE). 170 sets of specifications were created from 13 specification parameters, each of which has three valuable levels. The caster angle and the trail were independently varied with the fork offset varying dependently. When it is tried to change the stiffness of frame and steering assembly, the structure of those parts are generally changed. However, in that case, the mass of those parts is changed as well. To avoid this mass change, we changed the Young's modulus instead to adjust the stiffness to the target value. Using the simulation results, a multiple regression analysis was conducted. The objective variable was StrAgl-VR and the explanatory variables were the motorcycle specifications. Thus, we conducted the analysis to narrow down the influential motorcycle specifications. Stepwise regression was used for selection of the variables in the multiple regression analysis. The selection criteria were such that the number of variables

was eight or less, and the multiple correlation coefficients were 0.9 or higher. With eight variables selected, the multiple correlation coefficients were 0.94, and the P-value, which represents the significance of the regression equation, was less than 0.01. Figure 3 shows the motorcycle specifications in descending order of variance ratio, which represents contributions of each variable.

Table 2. Motorcycle parameters which affect shimmy, from the literature

	Reference-literature number					
	[2]	[3]	[4]	[5]	[6]	[7]
Stiffness of frame		x		x	x	
Stiffness of steering assy.		x		x	x	
Damping of steering	x					x
Roll inertia moment of body						x
Yaw inertia moment of body			x			x
Steering inertia moment	x		x			
Fore-and-aft location of CG of motorcycle						x
Height of CG of motorcycle						x
Caster angle						x
Trail						x
Front tire cornering power	x		x			x
Front tire lateral stiffness	x		x			x
Front tire relaxation length	x		x			

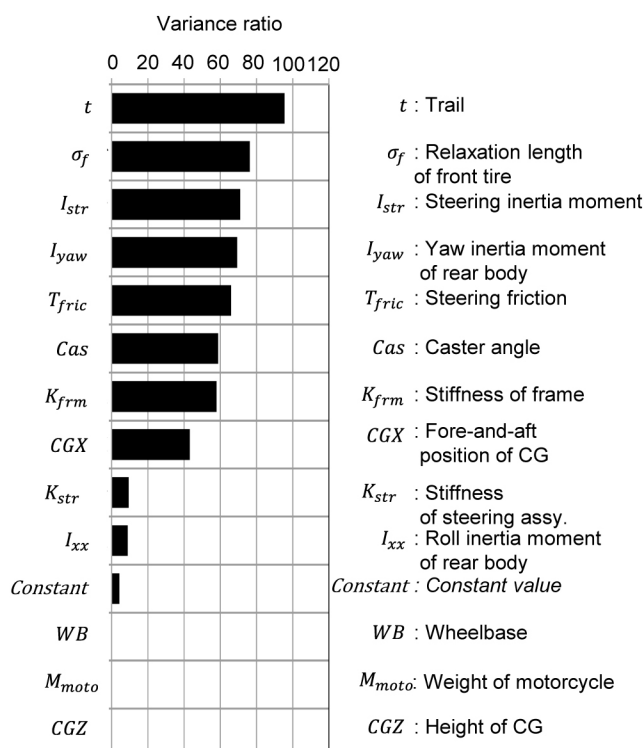


Figure 3. Variance ratio of motorcycle specification to steering angle variation ratio

From the above-mentioned analysis, we chose the following eight influential parameters: the steering inertia moment, rear body inertia moment, trail, relaxation length of front tire, steering friction, frame stiffness, fore-and-aft position of rear body CG and caster angle.

MECHANISM OF SHIMMY

Preconditions and Hypothesis on Shimmy

In the analysis on how the motorcycle specifications affect the shimmy, two preconditions were set.

The first precondition we presumed was that “the external forces to the vehicle body are applied only to its tires.” We consider this reasonable because the shimmy is generally experienced while the vehicle is travelling in an almost strait trajectory with a constant velocity. In this strait travelling, it experiences only a little influence from longitudinal accelerations, centrifugal forces, aerodynamics factors or the influences from the load variations originating in the rider's mass.

Secondly, we focused that the deformations of the steering assembly, frame, and tires are extremely smaller than the motions of the entire motorcycle. We decided “to have the motions of steering assembly represented by the behavior of the front tire, and the motions of rear body by the behavior of the rear tire.”

Moreover, the loads conveyed between the road surface and a motorcycle are only transmitted via front and rear tires. Accordingly, we considered that variations in behaviors of a motorcycle depend on the amplitude ratio and the phase difference of the forces occurring in front and rear tires. Based on this principle, we set our hypothesis as “shimmy characteristics may be explained by the amplitude ratio and phase difference of the lateral forces on the front and rear tires and those of motions.”

Figure 4 shows typical waveforms of the lateral force on the front and rear tires from the 170 calculated results. For the amplitude ratio, we used the first wave of the front after the external disturbance divided by that of rear. For the phase difference, the delay in the front compared to the rear is defined as a positive phase difference. That is, when the rear is ahead, a positive value is taken, and when the front is ahead, a negative value is taken.

Based on the preconditions, it was assumed that the motions in longitudinal, vertical and pitch movement directions were trivial. Through our experiences, it was also considered that the yaw moment and the roll moment had a small influence on shimmy. Therefore, the eight parameters shown below were defined as “physical parameters.”

1. Lateral force amplitude ratio (F_{y_AR})
2. Lateral force phase difference (F_{y_PD})
3. Yaw angle amplitude ratio ($\dot{\psi}_{y_AR}$)