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Development of Techniques to Control Steering Feeling for Motorcycle

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ABSTRACT

As the feeling of riders while steering is one of the most important factors determining the characteristics of the motorcycles, we take special care with it in the vehicle development process.

In the past, the creation of steering feeling has been carried out through repeated trial and error based on only the rider's comments obtained from riding tests. Vehicle body development via such a process has been inefficient because it increases the cost of manufacturing and testing.

In this paper, a new technology that can effectively incorporate the steering feeling into the motorcycle design using riding simulator is developed. This paper also shows the specific example of applying the established process to the development of our latest model Z900RS.

Keywords: motorcycle, steering, rider feeling, riding simulator.

1 INTRODUCTION

We have been developing motorcycles based on RIDEOLOGY (Ride + Ideology) concept. It is necessary to investigate various factors related to the riding performance of a motorcycle, such as acceleration and deceleration performance and riding comfort; among these, we are strongly committed to developing the steering feeling, because it is a very important factor that determines the handling of a motorcycle and the enjoyment of steering operation.

Thus far, the creation of steering feeling has been repeatedly carried out through repeated trial and error based only on the rider's comments obtained from riding tests. In other words, based on the comments obtained, the geometry of motorcycle were changed relying on the experience and intuition of the engineer, and repeated production of a new prototype vehicle was performed to create a steering feeling. Prototype vehicle body development via such a process has been very inefficient because it takes time and cost to manufacture vehicles and perform riding tests.

Therefore, to create the desired feeling in the initial design stage, we attempted to identify the design parameters that have large impact on the steering feeling in steady turning by theoretical approach. Next, magnitude of the influence of such design parameters to steering torque is discussed.

We also developed an original riding simulator with the aim of creating steering feeling more efficiently, so we will describe this content as well.

Finally, we will introduce the specific example of applying the established design process to the development of our latest model Z900RS using new technology.

2 DEVELOPMENT OF TECHNOLOGY TO CREATE THE STEERING FEELING

2.1 Investigation of motorcycle property that determines vehicle behavior

Several previous researches show that the steering feeling during steady state turning has a strong correlation with rider's steering torque [1], [2]. In order to realize the targeted steering feeling efficiently, it is necessary to quantitatively grasp in early design stage the influence on the steering torque during turning given by the design parameters. Therefore, we derived these impacting parameters from theoretical formula on steering torque as follows.

The moment about the steering axis generated by the body during steady state turning is composed of the following six terms [1], [3]. For simplicity, the steering angle is treated as 0 degree and some other approximations are used.

1 Moment about the steering axis due to the weight force of the front section τ_1

$$\tau_1 = -b_f m_f g \sin\beta \tag{1}$$

2 Moment about the steering axis due to the centrifugal force on the front section τ_2

$$\tau_2 = b_f m_f \ddot{y} \cos\beta \tag{2}$$

3 Moment about the steering axis due to the vertical load on the front wheel τ_3

$$\tau_3 = (t_{side} \cos\beta \sin\varepsilon - t_{nor} \sin\beta \cos\varepsilon) N_f \tag{3}$$

4 Moment about the steering axis due to the lateral force on the front wheel τ_4

$$\tau_4 = (-t_{side} \sin\beta \sin\varepsilon - t_{nor} \cos\beta \cos\varepsilon) F_{yf} \tag{4}$$

5 Moment about the steering axis due to the twisting torque of the front tire τ_5

$$\tau_5 = M_{zf} \cos\beta \cos\varepsilon \tag{5}$$

6 Moment about the steering axis due to the gyroscopic effect of the front wheel τ_6

$$\tau_6 = I_{Wf} \omega_f \Omega \sin\varepsilon \cos\beta \tag{6}$$

b_f is the distance between the steering axis and the center of gravity position of the front section, m_f is the mass of the front section, g is the gravitational acceleration, β is the bank angle, $\ddot{y}$ is the body lateral acceleration, t_{side} is the side trail, ε is the caster angle, t_{nor} is the trail , N_f is the vertical load on the front wheel, F_{yf} is the lateral force on the front wheel, M_{zf} is the twisting torque of the front tire, I_{Wf} is the moment of inertia of the front wheel, ω_f is the angular velocity of the front wheel, and Ω is the yaw angular velocity of the body.

During cornering that can be regarded as steady state, the steering torque applied by the rider τ_{rider} is given by

$$\tau_{rider} = -(\tau_1 + \tau_2 + \tau_3 + \tau_4 + \tau_5 + \tau_6) \tag{7}$$

which is balanced with the moment generated by the body.

Figure 1 and Figure 2 shows the numerical calculation results of each terms. Based on Figure 1 and Figure 2, it was confirmed that the term 3, 4, and 5 (τ_3, τ_4, and τ_5) are the major constituents. In addition, Figure 2 shows that the proportion of the six constituents does not largely depend on the bank angle.

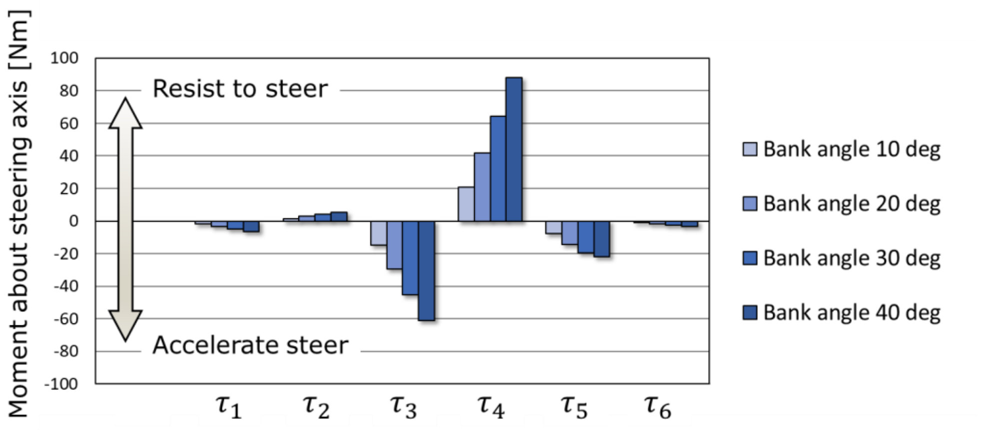

Figure 1. Magnitude of each constituent of steering torque.

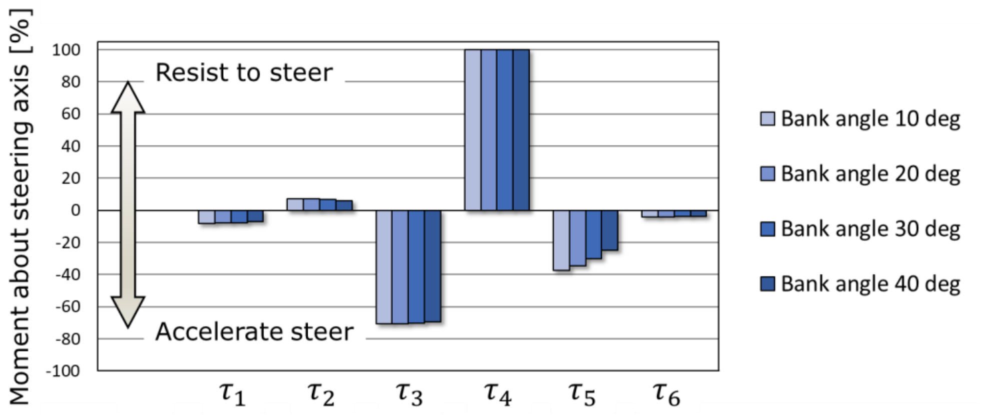

Figure 2. Magnitude of each constituent of steering torque.
(percentage based on $\boldsymbol{\tau_4}$)

Next, the controlling parameters of the body and the tire were extracted from the theoretical formulas of the constituents 3, 4, and 5 (Table 3). Based on Table 3, it was found that there are two body design parameters, caster angle and trail (Figure 3), which significantly affect the steering torque.

Table 1. Controlling parameters of the three major constituents of steering torque.

	Controlling parameters	
	Vehicle body	Tire
τ_3	Caster angle Trail	—
τ_4	Caster angle Trail	Lateral force property
τ_5	Caster angle	Self-aligning property

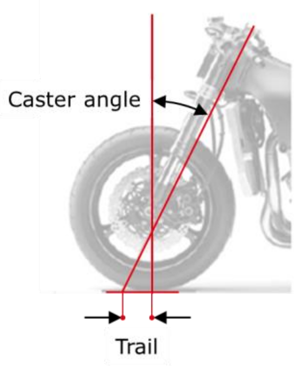

Figure 3. Caster angle and trail.

2.2 Analysis of relationship between motorcycle and vehicle behavior

To quantitatively understand the contribution of caster angle ε and trail t_{nor} to the steering torque τ_{rider}, following examination were performed.
First, the steering torque is expressed by the approximation below because the constituents 3, 4, and 5 are the main constituents.

$$\tau_{rider} \cong -(\tau_3 + \tau_4 + \tau_5) \tag{8}$$

Following that, to calculate the amount of change in the steering torque against the amount of change in the caster angle and trail, partial differentiation of the above approximation results in:

$$\frac{\partial}{\partial \varepsilon}\tau_{rider} \cong -(t_{side}\cos\beta\cos\varepsilon + t_{nor}\sin\beta\sin\varepsilon)N_f \\ -(-t_{side}\sin\beta\cos\varepsilon + t_{nor}\cos\beta\sin\varepsilon)F_{yf} \\ +\cos\beta\sin\varepsilon\, M_{zf} \tag{9}$$

$$\frac{\partial}{\partial t_{nor}}\tau_{rider} \cong \sin\beta\cos\varepsilon\, N_f + \cos\beta\cos\varepsilon\, F_{yf} \tag{10}$$

Figure 4 quantitatively shows the sensitivity of the caster angle and trail to the steering torque as calculation results using the above two equations. As mentioned above, the sensitivity of the caster angle and trail was able to be quantitatively shown using a theoretical formula.
The validity of this theoretical examination has been confirmed from running tests.
We established a technology that sets the steering torque during turning to the ideal value and produces an ideal steering feeling by properly adjusting the caster angle and trail.

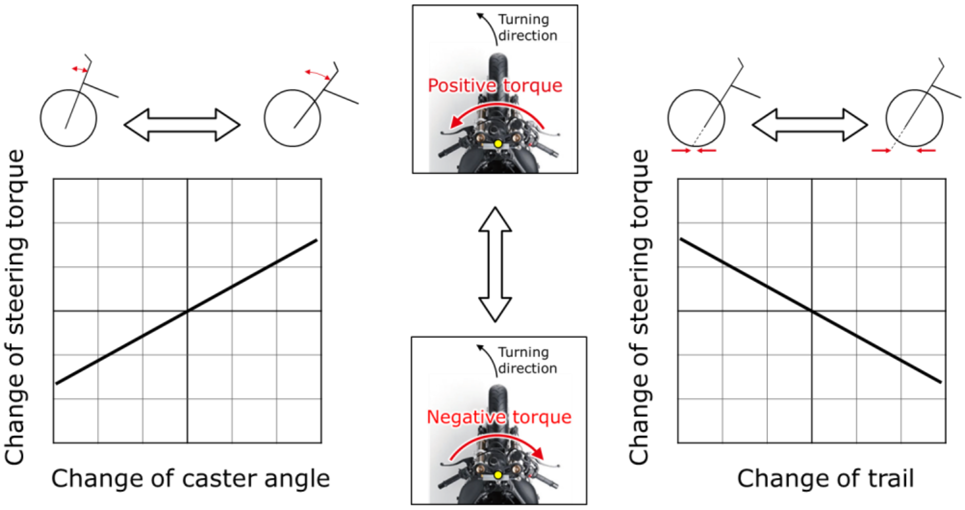

Figure 4. Influence of changes in caster angle and trail on steering torque.

2.3 Development of a riding simulator

Aiming at further development efficiency, we developed a riding simulator as shown in Figure 5 [4]. This riding simulator is a device that can simulate the vehicle dynamics in real time based on the rider's operations such as steering, acceleration, and braking similar to that of a real vehicle, and reproduce the behavior of roll and pitch by sway of motion platform. Even at the conception stage, when there is no prototype vehicle, this riding simulator can be used to provide a riding experience similar to that of a real vehicle. In addition, it is also advantageous because we can easily compare and study many specification items between modified models.

Figure 5. Riding simulator.

To exploit this riding simulator for investigation of the steering feeling, the following devices are installed.

2.3.1 Reproduction of steering reaction torque

As shown in Figure 6, a servo motor is installed to reproduce the steer angle around the steering axis. This system enables the rider to feel the same steering reaction torque as a real vehicle.

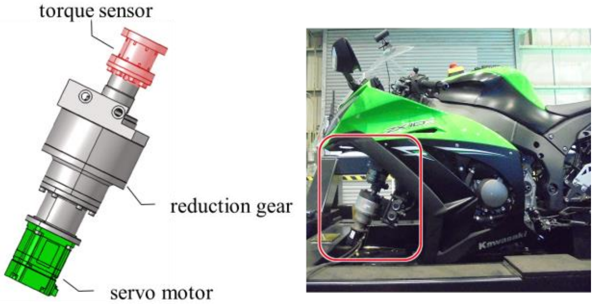

Figure 6. System to reproduce steering reaction torque.

2.3.2 Detection of changes in riding posture

Since the changes in riding posture have significant influence on the motorcycle's dynamics, we thought that a system to detect it was necessary to investigate the steering feeling. As a solution, we adopted a system in which two markers were attached to the rider's back and tracked by a stereo camera behind them (Figure 7). Rider's lateral movement and lean angle are calculated from the coordinate of the markers and are reflected in the real time simulation.

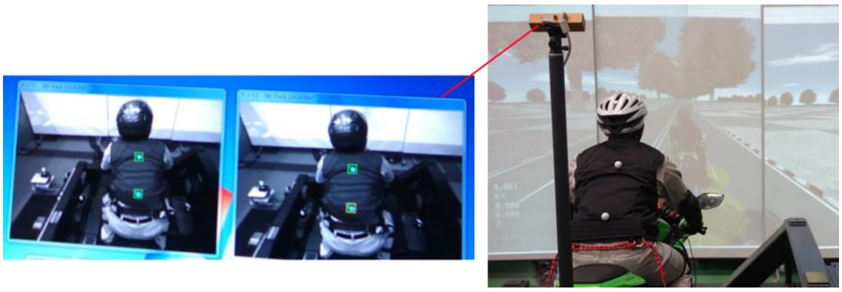

Figure 7. System to track the rider's posture.

2.3.3 Reproduction of sense of speed

In general, it is difficult for rider on simulator to feel accurate sense of speed due to the lack of reproducibility about field of view, engine vibration, and wind and so on. This defect tends to make it difficult for the rider to evaluate the steering feeling accurately. Therefore, to improve the sense of speed, we introduced a VR (Virtual Reality) system. By using VR, rider's immersion has been considerably enhanced.

In addition, we also devised a method to give a more accurate sense of speed by generating an engine sound that changes according to the engine RPM from the speakers.

Figure 8 VR system for reproducing sense of speed.

3 APPLICATION TO THE DEVELOPMENT OF Z900RS

We will introduce specific case where the steering feeling built-in technology described in Chapter 2 was applied to development of our latest model Z900RS.

The steering feeling of Z900RS is developed by following steps.

Step 1: Determination of product concept

Step 2: Determination of ideal steering torque while turning

Step 3: Determination of motorcycle geometry

Step 4: Confirmation on the riding simulator

Step 5: Test ride on a prototype vehicle

Step 1: Determination of product concept

As a result of market research, we decided to develop a neutral steering feel that allows the rider to turn at corners as intended so that a wide range of customers can go for a relaxing ride.

Step 2: Determination of ideal steering torque while turning

Measured data and rider's comments obtained at repeated running tests in the past shows that the steering torque while turning should be in the range from -5 Nm to +5 Nm in order to achieve neutral feeling. Thus, in the case of Z900RS, we aimed for steering torque to be in this range under various riding conditions (turning with bank of from 20 deg to 40 deg) in order to enable all the customers to experience neutral steer feeling regardless of their skill or riding style.

Step 3: Determination of motorcycle geometry

The sensitivity of the caster angle and trail to steering torque has been theoretically obtained as Figure 4. Based on this map and consideration about tire property, the two parameters of Z900RS prototype are set to the values shown in Table 2.

Table 2. Caster angle and trail determined for Z900RS

Caster Angle	25 deg
Trail	98 mm

Step 4: Confirmation on the riding simulator

Using the riding simulator, it was considered if we could achieve the intended steering feeling during turning.

As a result of the test ride on the simulator, it was confirmed that the vehicle of the specifications determined in Step 3 was able to realize a neutral steering feeling during cornering as intended by both perceptive evaluation and simulation result on steering torque, with minimum time and cost.

Step 5: Test ride on a prototype vehicle

A prototype vehicle of the specifications determined in Step 3 was manufactured, and a riding test was conducted to confirm the steering feeling. The specification of the test is as shown in Table 3.

Table 3. Running test specification.

Vehicle	Z900RS prototype
Running mode	Steady turning
Turning radius	50 m
Target vehicle speed	3 steps (50 km/h, 60 km/h, 70 km/h)
Riding position	2 patterns (lean with, lean in)
Turning direction	2 patterns (clockwise and counterclockwise)
Measurement item	Steering torque, Vehicle speed, Vehicle angular speed and translational acceleration, and so on.

The steering torque was gained by calculation from the measured value of strain gauges attached to the handle bar. Figure 9 shows an example of the steering torque at each vehicle speed obtained by the measurement. From Figure 9, it was confirmed through actual riding test that the intended steering torque was realized.

In addition, the rider's sensory evaluation was simultaneously obtained in the test and it is shown that the neutral characteristics of the targeted steering feeling can be realized.

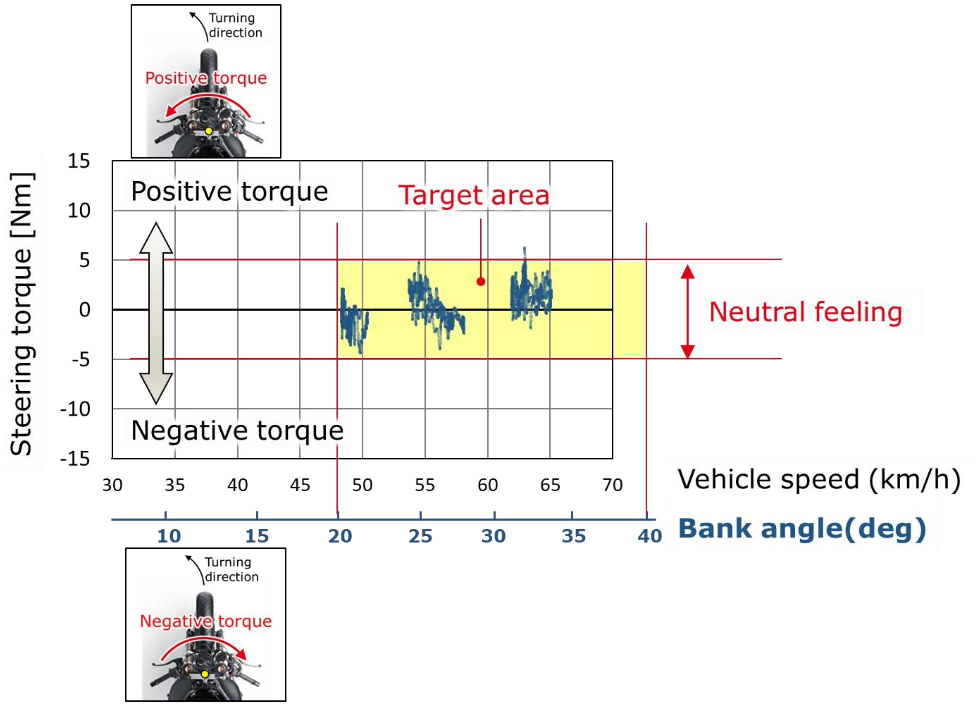

Figure 9. Steering torque measured on the running test.

By means of the above procedure and riding test, ideal steering feeling was efficiently created in a limited period of development.

4 CONCLUSIONS

In this paper, the following efforts were made to establish technology to efficiently create a steering feeling while turning in vehicle development process.

- Quantitative evaluation about sensitivity of motorcycle properties for steering torque based on the theoretical equation.
- Development and application of riding simulator

In addition, the example case of applying new technology to the development of our latest model was introduced.

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