

Support Effects of the Haptic Throttle Grip by the Friction Circle on the Driving Wheel

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ABSTRACT

Recently, there have been many reports about development of Human Machine Interface (HMI) which used a visual or auditory display to improve driver assist. For a motorcycle, it is suitable to use a haptic display for rider assist, since there are many disturbances in open-air situation such as sunshine and surrounding noise. Therefore, a test vehicle based on a large motorcycle equipped with the haptic throttle grip that is connected to a motor by gear, an original ECU to control the motor, and a lean angle sensor to calculate the lateral force of the motorcycle was developed. To inform surplus driving force warning, the throttle grip, a haptic display outputs additional return torque estimated by the friction circle and ellipse with the lateral force of the motorcycle. One of the purposes of this torque is that it informs the rider to decelerate when the motorcycle state of movement is around the limit of tire grip, and another purpose is that it leads to return the throttle grip to decelerate. For both purposes, the intuitive signal which adds return torque was selected to avoid misunderstanding. As the result of riding tests, all of the riders were able to recognize the signal and understood the request from the motorcycle. It became clear that this system was able to offer the information of surplus driving force warning, and to support the throttle grip operation.

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INTRODUCTION

There are many HMI inside the cabin on production automobiles, such as meters, indicators and navigation system with audio assist. There are also many reports on haptic devices, which were tested with modified production automobiles or a simulator such as a haptic gas pedal to make deceleration [1], [2], [3], [4], [5] and a haptic steering wheel to inform lane departing with vibration or with additional steering torque [6], [7], [8]. These reports clearly state that the drivers can perceive the haptic signals and there are few disturbances to communicate on the channel between the driver and the car. Therefore, a haptic display was considered to match to motorcycle than applying a visual or auditory display.

To make a haptic device on a motorcycle, it is the most reasonable to use hand and throttle grip as a communication interface between the rider and the motorcycle from the following reasons. The rider's hand and the throttle grip are always in contact while riding, and there are many sensory receptors on a hand than the other parts of the body. But haptic displays have less information than visual or auditory displays. Therefore, as a haptic display, letting the throttle

grip output only intuitive information to avoid misunderstanding. To use an intuitive signal is important for perception and usability from HMI point of view [9]. In addition, it became more difficult for the riders to operate the throttle grip of large displacement motorcycles like super sport models, due to increasing of engine torque year by year with technology innovation. To improve throttle grip controllability around the limit of tire grip, it is necessary to add some of function.

In order to satisfy two purposes mentioned previously, the haptic throttle grip equipped with a motor which is connected by the gear was developed; it is able to add the return torque to communicate between the rider and the motorcycle, and to improve the throttle grip controllability. In this paper, the detail of the haptic system on the motorcycle and its riding test results are reported.

HAPTIC SYSTEM

Haptic Throttle Grip

Figure 1 shows the haptic throttle grip which is used in this research. It consists of a throttle grip with a return spring to close itself, a gear, a one-way clutch, and a motor. This

throttle grip is connected to the motor by the gear and the one-way clutch, it can output haptic signals to the rider by controlling the motor.

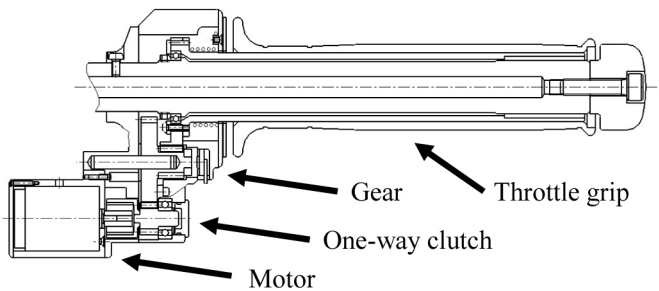


Figure 1. Haptic throttle grip

The one-way clutch is set between the motor and the gear, and the motor can only add torque to closing direction of the throttle grip for a safety reason. Therefore, even if the motor is locked due to breakdown, the rider can close the throttle grip to decelerate.

Test Vehicle

The haptic system is constructed with the haptic throttle grip, an original sensor to calculate the lean angle of the

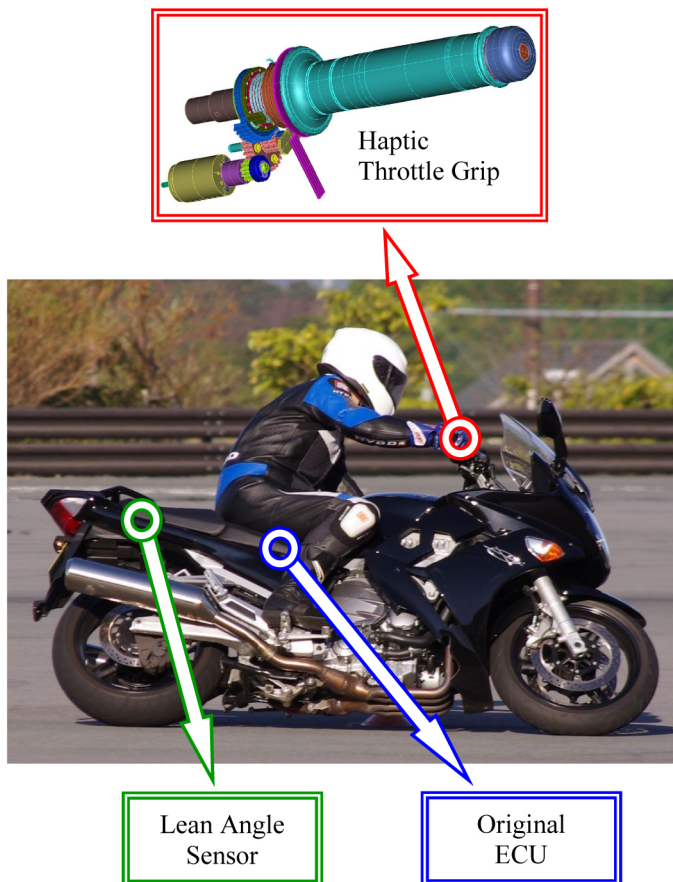


Figure 2. Test vehicle and parts

motorcycle, and an original ECU to control the motor of the haptic throttle grip. Figure 2 shows our company's large displacement motorcycle (equipped with the system), and the location of its components parts.

In addition to these parts, a permission switch and a mode switch are equipped. The permission switch allows the rider to activate or deactivate the control, and the mode switch allows the rider to change the level of additional return torque in five steps while riding. It is effective to use these switches for the development of the system. A logger is also equipped to the motorcycle to log data such as throttle grip position named accelerator position, engine speed, gear position, lean angle, vehicle speed, and additional return torque of haptic throttle grip. It became easy to analyze test results and to develop the system by using this system.

Friction Circle & Ellipse

One of the purposes of this system is to inform the rider to decelerate when surplus engine torque is at the edge of tire grip. The theory of friction circle is used to estimate the surplus engine torque. Figure 3 shows the image of friction circle, ellipse, and the forces on the driving wheel.

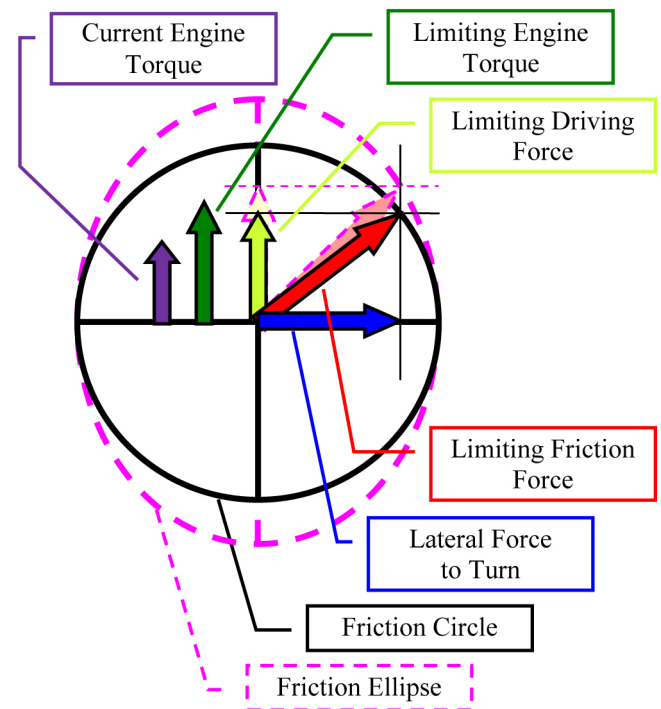


Figure 3. Image of friction circle & ellipse

As a premise, if the total force on the driving wheel does not exceed the friction circle, the wheel will not lose the tire grip. There are two forces on the driving wheel; lateral force and driving force. The lateral force is calculated from the acceleration which is created by turning movement of the motorcycle, the limiting friction force is calculated with the lateral force and the friction circle, and the limiting driving

force is calculated as a longitudinal component of the limiting friction force.

In the software of this system, all data are calculated based on the engine torque, since the additional return torque is estimated from the quantity of the difference of the limiting engine torque and the current engine torque. For this, first the current engine torque must be calculated from the engine speed and throttle valve position, and the limiting engine torque must be calculated from the limiting driving force and the reduction gear ratio each gear positions. If the difference becomes small, it means that the total of friction forces on the driving wheel is becoming close to the friction circle. In this condition, there is a possibility of slipping down with losing the tire grip. Therefore, it informs the rider to decelerate by increasing the return torque of the haptic throttle grip.

In different research of our company shows the friction circle of a same test motorcycle is estimated that the longitudinal axis is about 8% bigger than the lateral axis. From this, the haptic system control is made with the friction ellipse of dashed line in addition to the friction circle in figure 3.

Based Torque Control

This haptic throttle grip is equipped with a motor to make haptic signals. Rotating the motor by the throttle grip creates counter electromotive force: V_{emf} (1) and inertia torque: T (2) of the rotor. These forces give negative influences in operation of the throttle grip, such as becoming heavy or a delay. These forces are calculated with the following equations in order to compensate.

$$V_{emf} = K_t \frac{d\theta_1}{dt} \quad (1)$$

$$T = J_1 \frac{d^2\theta_1}{dt^2} + J_2 \frac{d^2\theta_2}{dt^2} \quad (2)$$

$$V_I = \frac{R}{K_t} T \quad (3)$$

K_t : Motor Constant
 J_1 : Moment of Inertia of the Rotor
 J_2 : Moment of Inertia of the Gear
 θ_1 : Rotating Angle of the Rotor
 θ_2 : Rotating Angle of the Gear
 R : Electric Resistance of the Motor
 V_I : Voltage equivalent to inertia torque

The total voltage of V_{emf} and V_I is added to reverse direction in which they are generated by the motor. As the result, it can neutralize the negative influences, and the haptic throttle grip can offer natural feeling equivalent to a production motorcycle.

Additional Torque Control

Proportional control

Figure 4 shows the relation between the additional return torque of the proportional control and the difference between the limiting engine torque and the current engine torque. The difference of the limiting engine torque is estimated from the friction circle or ellipse minus the current engine torque which is indicated in the solid line, the additional return torque is proportional to the difference which is indicated in dashed line. If the difference comes bigger than the margin or when the current engine torque is negative, the system outputs no additional return torque on the throttle grip. In this situation, there is no wheel spin coming from the acceleration, and therefore, it is not necessary to inform any caution. If the difference comes smaller than the margin and when the current engine torque is plus, the system adds some return torque on the throttle grip to inform only the surplus engine torque. The point where the margin is same as the difference is the control starting point, the torque is estimated from there with the proportional coefficient: a/margin . The limit of return torque is provided to prevent harder throttle grip operation for the rider. This strategy is presented in (4). From this strategy, the rider can perceive the modulation and is led to decelerate to create the margin.

$$\text{ART} = (\text{CET} + \text{Margin} - \text{LET}) \times \text{PC}$$

(4)

ART : Additional Return Torque
 CET : Current Engine Torque
 LET : Limiting Engine Torque
 PC : Proportional Coefficient

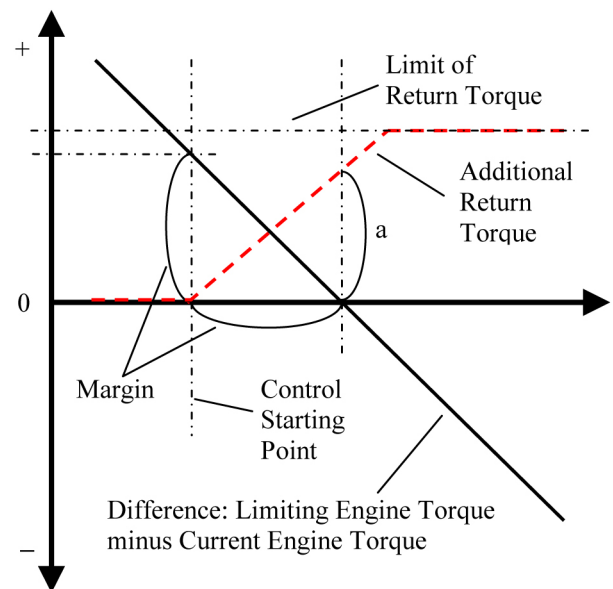


Figure 4. Relation between driving forces and additional return torque of proportional control

Figure 5 shows the example of return torque character of a conventional throttle grip and the proportional control. The