Generating method of steering reaction torque on driving simulator

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1. Introduction

The development of the driving simulator is intended to imitate the running condition of a vehicle in the limited space of a laboratory [1–4]. The driving simulator consists of the vehicle dynamic simulation system, the visual system, the motion system and the reaction force system for handling operations. The steering reaction torque is important for the driver to get information about the contact condition between the tires and road. Therefore, this feeling should be generated by the reaction force generating system of a driving simulator.

The steering reaction torque has been generated by a hydraulic actuator or an electric servo motor. Recently, a lot of systems have been equipped with an electric servo motor which is more flexible than a hydraulic actuator [5,6]. The purpose of this study is to develop the generating system of the steering reaction torque on the driving simulator. This paper describes the analysis of steering reaction torque by computer simulation and the development of a system which applies the generated torque to the steering wheel of the driving simulator.

2. Generating method of steering reaction torque

The steering reaction torque is generated as a result of the desire of a vehicle to restore straight line running on a road. This restorative torque is mainly created by the self-aligning torque and the effect of side force combined with caster of the front tires. First, we have studied the generating mechanism of steering reaction torque by making computer simulations.

Figure 1 shows the steering system model used in the simulation. Taking the power steering mechanism into consideration in this model, the opening area of the control valve of the power steering system is determined by the twist angle of a torsion bar in the steering gear box. Figure 2 shows the vehicle model describing lateral and yaw motion. In this model, the cornering force and the self-aligning torque are assumed to have linear characteristics. The driver's behavior while steering this vehicle is supposed to be a fixed control model. In this control system, the steering angle is determined by an integrating and proportional model using feedback.

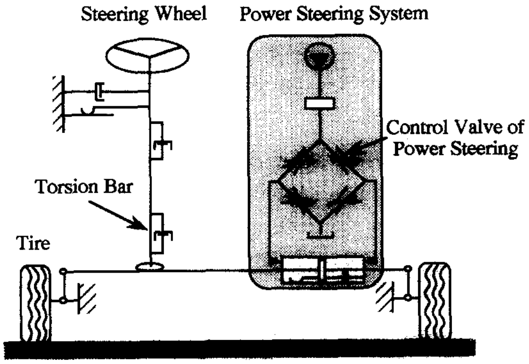

Fig. 1. Steering system model.

Figure 3(a) shows the simulated steering reaction torque, and Fig. 3(b) shows the same result on an actual vehicle. The test condition is slalom running; vehicle speed is 11.1 m/s, maximum steering angle is about 2.1 radians and steering interval is about 3 s. In these figures, the simulated steering reaction torque almost corresponds with that of an actual vehicle.

The total force in the power steering system is composed of the driver's steering force and hydraulic assistant force. Equation (1) shows the relation of these three forces:

$$F_t = F_d + F_a \tag{1}$$

where F_t is the restorative force, F_d is the driver's steering force and F_a is the hydraulic assistant force respectively. Calculation of the hydraulic assistant force by using the detailed model requires a sampling period of a few microseconds.

In the driving simulator, the calculation time is limited so a simpler model of the power steering system should be used. A simple model has been developed which uses a weighting function based on the slip angle of the front tires for approximating the steering

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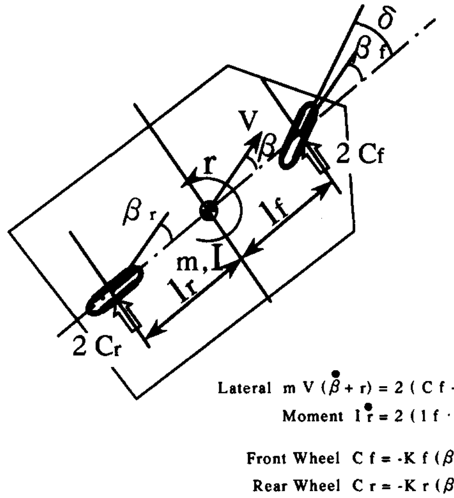

Fig. 2. Vehicle model.

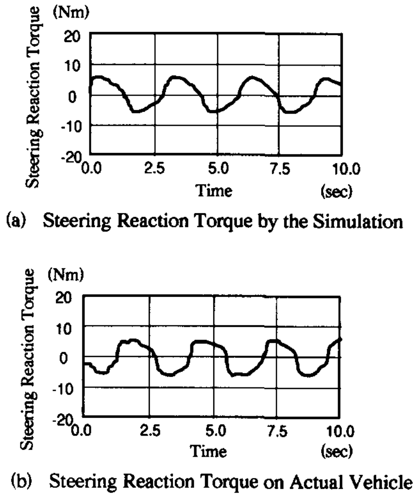

Fig. 3. Comparison of steering reaction torque by simulation and the actual vehicle.

reaction torque. The steering reaction force is derived by subtracting assistant force from restorative force of the front tires. The driver's torque shown in Eq. (1) is expressed as Eq. (2). The weighting function is the

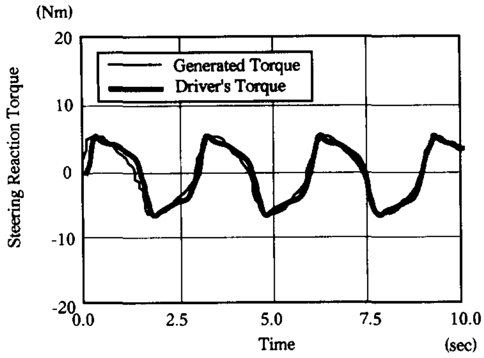

Fig. 5. Comparison of generated steering reaction torque and driver's torque.

assistant force subtracted from the restorative force divided by the restorative force.

$$\begin{aligned} F_d &= F_t - F_a \\ &= F_t\left(\frac{F_t - F_a}{F_t}\right) \\ &= F_t W_f. \end{aligned} \tag{2}$$

Because the restorative force depends on the slip angle of the front tires, the weighting function W_f is approximated as a function of the slip angle. Figure 4 shows the shape of the weighting function. It is possible to calculate the restorative force and slip angle of the simple vehicle model shown in Fig. 2 within a few milliseconds. By using this model in combination with the weighting function based on the slip angle, the steering reaction torque of a power assisted steering system can be generated within the sampling period of a few milliseconds.

Figure 5 shows the comparison of the generated steering reaction torque by this simple method with the torque calculated by doing a detailed simulation. As is clearly shown in this figure, the steering reaction torque generated by the first method closely corresponds to that of the second.

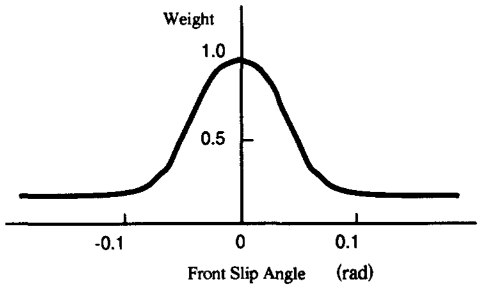

Fig. 4. Weighting characteristics.

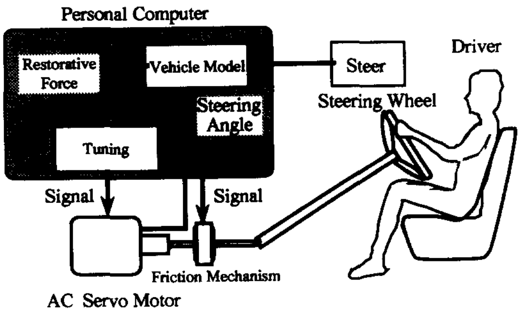

Fig. 6. System construction of generating the steering reaction torque.

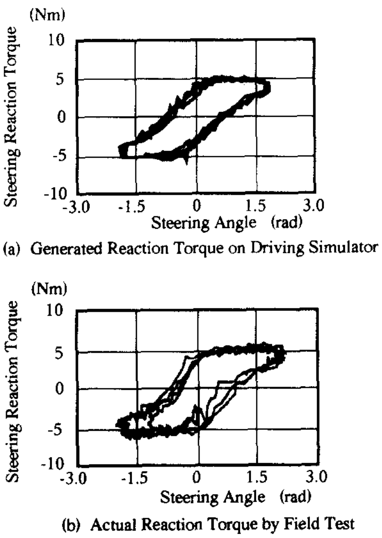

Fig. 7. Comparison of generated steering reaction torque and actual vehicle torque.

3. Generating system of steering reaction torque and experimental results

Figure 6 shows the construction of the system that generates the steering reaction torque. The reaction torque is generated by the AC servo motor. The friction of the steering system is controlled by an electric power brake. The personal computer in this figure uses the vehicle model to calculate the reaction torque and operates the AC servo motor and the friction mechanism within a period of 10 milliseconds.

Figure 7 shows the generated steering torque versus steering angle on the driving simulator as well as the actual torque on an real experimental vehicle. By using the power steering system, the required steering torque is limited by the hydraulic assistant force. In the case shown in Fig. 7, the maximum value of the required steering torque is about 5 Nm. From these figures it can be concluded that the characteristics of the generated steering torque is quite similar with the steering torque of the actual vehicle.

4. Conclusion

We have developed a system to generate the steering reaction torque on the driving simulator. The steering torque generated by this system is remarkably similar to the actual steering torque measured in a real vehicle. A weighting function which uses the front slip angle values is introduced into this system to generate the steering reaction torque. The system is able to generate the steering torque of a vehicle with power steering by controlling an AC servo motor and a friction mechanism.

We are planning to study the effects of steering reaction torque on driving behavior by using this system.

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