Research Report

Study of the Performance of a Driver-vehicle System for Changing the Steering Characteristics of a Vehicle

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Abstract

To improve the controllability, stability and safety of driver-vehicle systems in a wide range of driving scenarios, we undertook an investigation to determine the appropriate characteristics for an Active Front Steering system using a driving simulator and between 10 and 36 regular drivers. The control logic for the actual steering angle of the front wheels and for the reaction torque of the steering wheel were varied and the vehicle behavior and drivers' reactions were measured and analyzed for scenarios involving the drift-out and spin of a vehicle while cornering on a simulated low-frictional surface, as well as when braking on a so-called split μ road. Our findings allowed us to establish the appropriate steering system characteristics for the given cases.

Keywords: Steering assistance, Steering control, Driver-vehicle interface, Human workload, Perception and control

1. Introduction

Recent years have seen the development and marketing of several types of control systems for improving a vehicle's dynamic behavior and safety. At the same time, one of the most urgent and important problems the automobile industry faces are the reduction of the number of road accidents and the improvement of traffic safety. As it is said that almost all accidents are caused by human factors, the study of a driver-vehicle closed loop system is essential to the development of any control system. To date, however, there have been relatively few quantitative studies of the effects of such control systems on vehicle behavior in the hands of ordinary drivers.

This paper presents the results of our study into the appropriate characteristics of a steering system, which we undertook as part of the development of the control logic for an Active Front Steering System.[1, 2] Using a fixed-type driving simulator, a number of ordinary drivers were examined. We varied the control logic for the actual steering angle of the front wheels as well as that for the reaction torque of the steering wheel for a range of driving scenarios.

2. Configuration of the driving simulator

The configuration of the fixed-type (no vehicle dynamic motion) driving simulator that was used for this study is shown in **Fig. 1**. The drivers operate the vehicle in response to visual information that is projected onto the screen in front and based on the reaction torque of the steering wheel. The vehicle motion is calculated by the model based on the driver's steering angle inputs to produce real-time visual images. We used a relatively simple four-wheel vehicle model for which the tire characteristics are described by a brush type model. For the parameters, we used those for a mid-size passenger car in the model.

The actual steering angle and the reaction torque of the steering wheel were calculated by the control logic, based on the input steering angle and the vehicle motion.

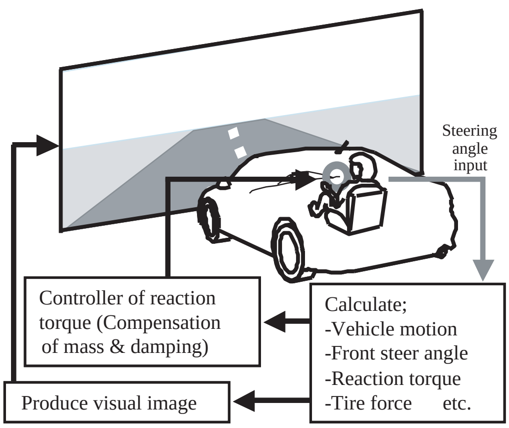

Fig. 1 Configuration of driving simulator.

3. Effects of actual steering angle and reaction torque control

The effects of both the actual steering angle of the front wheels ("front steering angle," below) and the reaction torque of the steering wheel ("steering torque," below) are described here. We can probably assume that the effect of active control of the front steering angle can be clearly verified by vehicle dynamics analysis but that the effect of the steering torque on the vehicle behavior will be rather difficult to understand because it is closely related to the driver's senses and recognition.

To clearly verify the control effects, situations approaching the maneuvering limits of the vehicle were chosen for the driving scenarios. Specifically, these were the drift-out of a vehicle and its tendency to spin in curves on a low frictional surface, and braking on a so-called split μ surface while traveling in a straight line. A total of 36 ordinary drivers (males in their 20s (7), 30s (7), 40s (7), and 50s (7) and females in their 20s (8)) took part in the experiment.

Figure 2 shows the circuit for the drift-out and

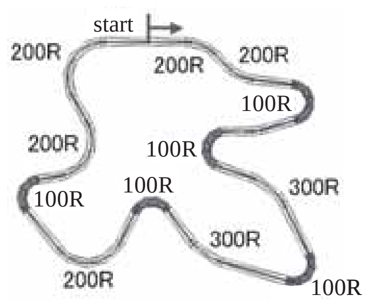

Fig. 2 Course layout for drift-out and spin test.

spin tests. For both tests, each driver drove three laps. As the vehicle speed was automatically set to 60 km/h by the simulator system, the drivers only had to operate the steering wheel. To simulate the drift-out and spin tendency of the vehicle, the maximum side forces (denoted as μ) of the front and rear tires were adjusted, such that at the corners with a 100-m radius (abbreviated to 100R below) in Fig. 1, the vehicle tends to drift-out or spin.

The braking tests were done on so-called "split-μ surfaces" where one half of the surface had a high μ value while the other half had a low μ. The vehicle was allowed to run in a straight line at 60 km/h and was automatically braked by the system, such that it would stop after about five seconds. The drivers only had to operate the steering wheel with the goal of keeping the vehicle pointing straight ahead. Each wheel was braked by a simulated ABS braking logic in the driving simulator system. The right and left tires were alternately run on the high μ and low μ surface and the braking tests were repeated four times for each driver and for each condition.

3. 1 Drift-out

To observe the control effect, the (instantaneous) steering gear ratio and the assist steering torque added to the normal reaction torque were changed as shown in **Fig. 3**. The value of the horizontal axis of the figure DRSTAT is defined as shown below by considering the difference between the actual and calculated yaw rate by a linear two-wheel vehicle model. A unit of DRSTAT expresses the steering wheel angle of the linear vehicle model that corresponds to the difference in the yaw rate.

The following conditions were applied to the drift-out experiment.

(a) Standard (fixed gear ratio of 16 and normal power steering)

(b) Change gear ratio only

(c) Change gear ratio and add assist torque

An example of the measured data for (c) above is shown in **Fig. 4**. From this figure, we can see that the steering torque becomes larger in the case of (c) as a result of the assist torque. In the figure, the front steering angle, the steering torque (target torque) and the actual response of the steering torque are plotted against the steering wheel angle. The actual response of the steering torque is also plotted in the figure. The cause of the hysteresis observed in the actual steering torque response is thought to be a result of the friction in the steering system, which cannot be cancelled by the controller.

If the driver is able to control the vehicle very precisely around a steering wheel angle of about 50 degrees, the vehicle is just able to clear the 100R corners. If the driver applies more and more steering, however, the vehicle travels further outside the corner as a result of a decrease in the side force of the vehicle front axle. So, the reason for setting conditions (b) and (c) was to reduce the front steering angle when the driver turns the steering wheel excessively in the case of drift-out.

Figure 5 shows the test results for the maximum

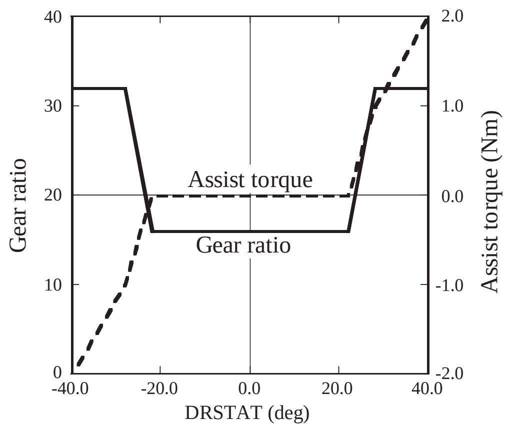

Fig. 3 Gear ratio and assist steering torque for drift-out test.

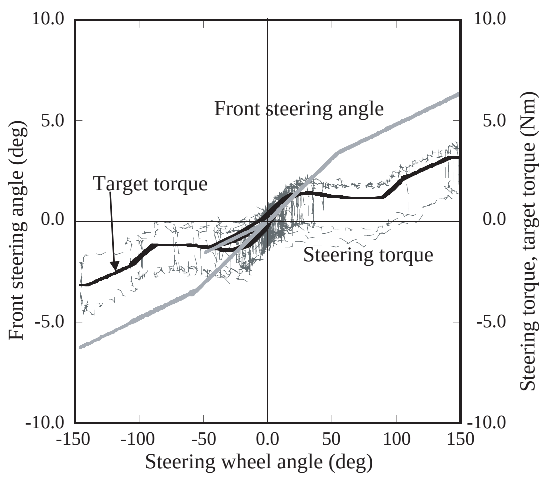

Fig. 4 Front steering angle and steering torque for drift-out test.

lateral deviation of the vehicle from the center line of the course. Through data analysis, it was found that there are some differences between drivers, as shown below. The percentage indicates the ratio to the total number of test drivers (36).

- Type 1: Smallest deviation under condition (c) .. 41%
- Type 2: Smallest deviation under condition (b) .. 31%
- Type 3: Smallest deviation under condition (a) .. 28%

Type 3 implies that there is a negative effect (but not fatal) on the control of the steering system in the event of drift-out, but the deviation for test condition (a) is very small when compared to the other types. It may be said that the Type 3 drivers have the higher driving skill and a greater knowledge of vehicle maneuvers than the other drivers. As a result, the Type 3 drivers experienced a sense of incongruity for the steering control logic of (b) and (c). From Fig. 5, we can see that changing the gear ratio is effective for improving the drift-out phenomenon but that the effect of the assist torque is relatively small for many ordinary drivers.

3. 2 Spin

To investigate the control effect of the steering system in the event of a spin, a simulated Vehicle Stability Control (VSC) system, the like of which has been offered on many models in recent years to reduce the spin tendency, was introduced to the simulator's vehicle model. To determine the effect of the control, the additional front steering angle and the assist steering torque were changed as shown in **Fig. 6**. To prevent the vehicle from spinning, drivers should normally turn the steering wheel back. The front steering angle was reduced by subtracting the additional steering angle, which is a function of DRSTAT, from the steering angle corresponding to the driver's steering wheel input. The steering torque was increased by adding assist torque that is a function of the difference in the brake pressures of the two front tires while VSC is being applied. The following conditions were applied to the spin experiment.

(a) Standard (fixed gear ratio of 16 and normal power steering with VSC)
(b) Addition of extra front steering angle only
(c) Addition of assist torque only

Figure 7 shows example time histories for test condition (a). The data analysis area shown in the figure corresponds to the time from the vehicle entering a 100R corner to it's leaving the corner. As the index of the control effect in the event of a spin, the RMS values of the body slip angle in the data analysis area were used, because this value becomes very large in the event of a vehicle spin. **Figure 8** shows the test results for the three test conditions. In case of the spin test, all of the drivers exhibited the same tendency, so the results for all of the 36 drivers were averaged. From Fig. 8, it can be seen that applying control to both the front steering angle and the steering torque clearly improves the spin tendency of a vehicle, and that the effect of front steering angle control is greater than that of the steering torque.

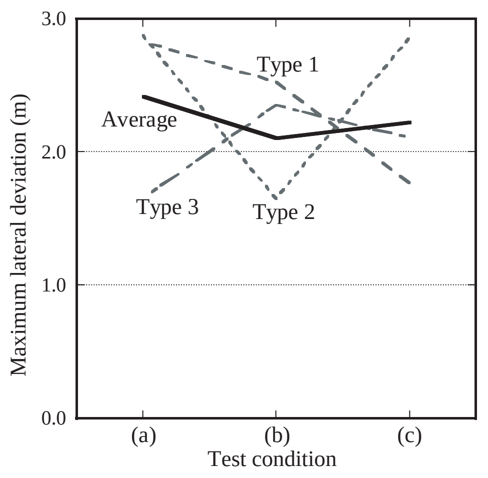

Fig. 5 Maximum lateral deviation for drift-out test.

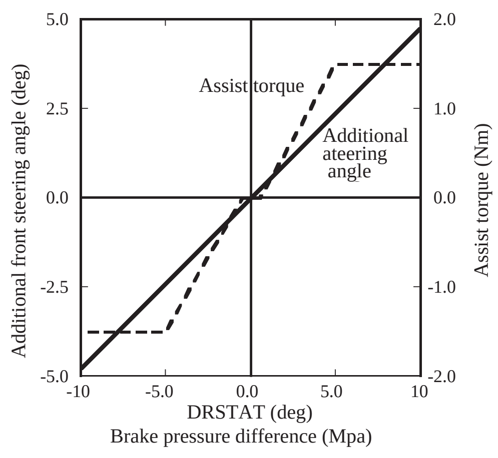

Fig. 6 Additional front steering angle and assist steering torque for spin test.

3. 3 Braking on a split μ surface

To investigate the control effect in the case of braking on a split μ surface, the test runs were performed under the following conditions.

(a) Standard (fixed gear ratio of 16 and normal power steering with ABS)

(b) Addition of additional front steering angle only

(c) Addition of assist torque only

Figure 9 shows the additional front steering angle and the assist steering torque. The horizontal axis of the figure indicates the brake pressure difference between the two front tires while braking. Both the angle and the torque were added to the direction that of the vehicle while running in a straight line. Upon the occurrence of test condition (b), the influence of the tire force and moment caused by the additional front steering angle was not reflected in the reaction torque of the steering wheel.

The indexes of the control effect under the condition of split μ braking are shown in **Fig. 10**. The RMS value of the vehicle lateral speed while braking is a factor affecting the vehicle lateral movement. By means of data analysis, it was found that the drivers can be classified into two types, as shown below. The percentage is the ratio to the total number of test drivers (36).

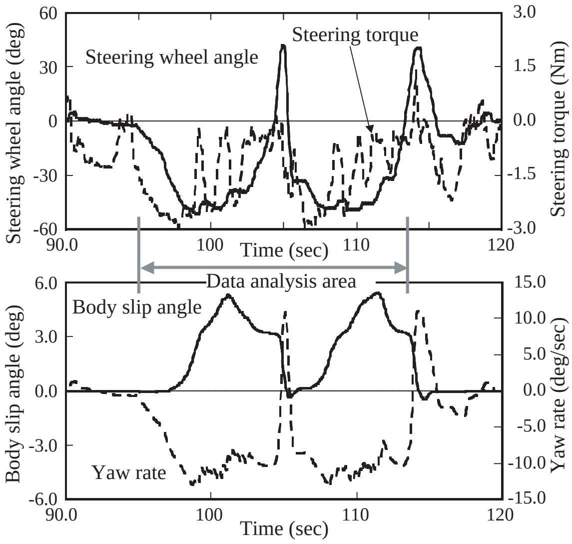

Fig. 7 Time histories of spin test.

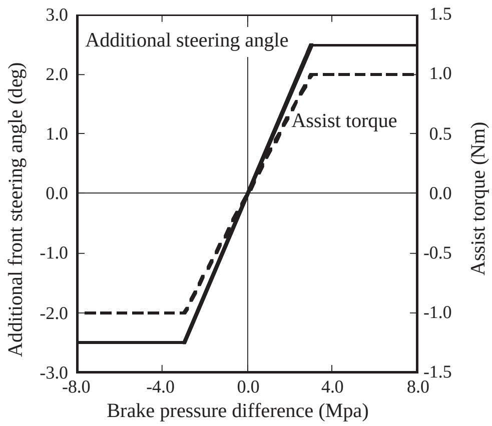

Fig. 9 Additional front steering angle and assist steering torque for split μ braking test.

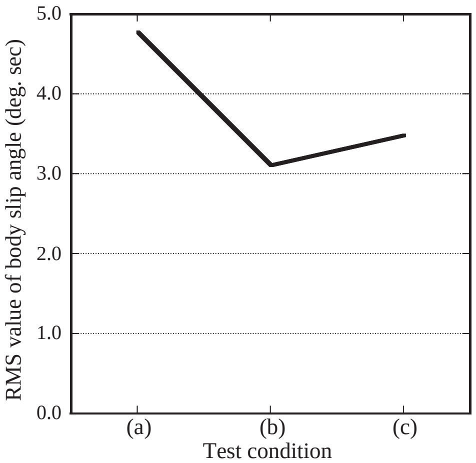

Fig. 8 RMS values of body slip angle at spin test.

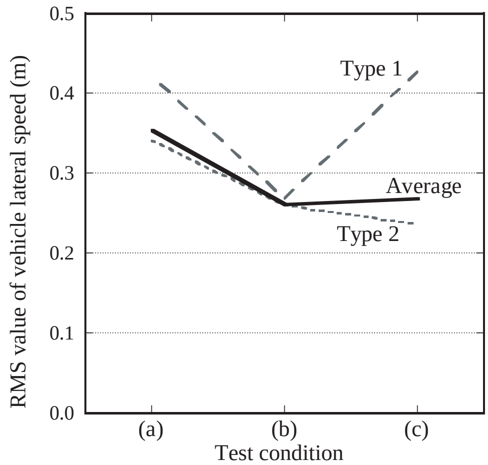

Fig. 10 RMS values of vehicle lateral speed for split μ braking test.

- Type 1: Steering torque control has almost no effect. .. 16%
- Type 2: Others .. 84%

From these figures, we can conclude that the front steering angle control has a considerable effect because it reduces the driver's work load, and that the steering torque control also has a remarkable effect for many drivers.

4. Conclusion

We examined the characteristics of a steering system for a driver-vehicle system. Our findings were as follows.

(1) The effects of both the actual steering angle of the front wheels and the reaction torque of the steering wheel on the drift-out and spin tendency of a vehicle on a low frictional road, as well as on braking on a split μ road were studied. A change in the gear ratio is effective for improving the drift-out phenomenon, but assist torque is of negligible benefit to many ordinary drivers.

(2) The control of both the front steering angle and the steering torque has a clear effect on improving the spin tendency of a vehicle and the effect of the front steering angle control is greater than that of the steering torque.

(3) The front steering angle control has a dramatic effect in that it reduces the driver's work load, and the steering torque control also has a notable effect for many ordinary drivers.

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