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Development of a Low-Cost Steering System Simulator

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The Steering system is the most important system for a vehicle, in terms of safety and driving feel. But in many cases, experiments to improve the steering feel using a real vehicle are very difficult in the aspects of repeatability, safety and money. Repeatability in testing steering systems is very important because the steering feel for a driver varies according to the environmental conditions. In addition to that, steering tests using vehicle are so dangerous that the driver might not concentrate on the tests. In this paper, a new steering system simulator using the front part of a steering and suspension system is described. This simulator allows cheap, safe, and repeatable testing of the steering system compared with the real vehicle test.

Key Words : Steering Simulator, Steering System, Steering Torque, Self-aligning Torque

1. Introduction

Whenever a vehicle is moving or stationary, a driver feels the 'steering force' and the 'steering feel' through the steering wheel, thus these must be measured as accurately as possible to quantify (or qualify) the steering conditions (Kenneth, 1984 ; Kim et al., 1997). These may be obtained by using the data measured from real vehicle tests. However, it is very difficult to obtain the same conditions for every test, because of the considerable variations in the road, vehicle and other environmental conditions (Akinori and Takamasa, 1995 ; Sunao et al., 1998).

As a result, real vehicle tests lack the repeatability. Also it degrades the diver's concentration on safety during the test. Moreover, it needs a testing area that is at least 7 m wide and 1 km long, and so requires a considerable amount of costs. Thus, a steering simulator is normally used to overcome these drawbacks.

In most steering simulators, a steering system is connected to a spring and a damper for the imitation of self-aligning torque in driving conditions. The steering system usually consists of the steering wheel, the steering column, the rack-and-pinion, and the tie-rod (Yasuo and Toshihake, 1991 ; Nakayama and Suda, 1994 ; Kurishige and Kifuku, 2001). Although, this type of steering simulator is most widely used, it does not provide reliably repeatable results due to the lack of geometric considerations.

A HILS (Hardware In the Loop System) is often employed to solve this problem in practice (Sueharu and Shun'ichi, 1994 ; Noh et al., 1997 ; Tatsuya and Fumihiko, 1996). The HILS enhances the repeatability by considering the non-

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linear response caused by the effects of the vehicle's geometry and tires. However, finding the value of parameters for HILS is a difficult work.

Thus, in this research, a new type steering system simulator is developed to meet the academic requirement, while still considering the geometric effects. A lifter, which can be found in any typical garage, is used to reduce the cost. The steering simulator developed in this study uses a steering system, a suspension system, and tires as they are fitted in a real vehicle. This enables the steering test to be as similar as possibe to the real vehicle test. This simulator can also simulate the weight variations of a vehicle by controlling the normal force on the contact surface of the tires. It also enhances the repeatability of the driving test for various speeds by controlling the self-aligning torque.

In this paper, the structure of the developed steering system simulator is described, and the experimental reliability of the simulator is verified. This is done by comparing the data obtained from the simulator and the data from the real vehicle test, where the experimental data are the steering angles and the steering forces according to the driving speed.

2. Structure of the Steering System Simulator

A typical hydraulic steering system simulator is shown in Fig. 1. As shown in the figure, a typical steering system simulator uses a spring and a damper to realize the steering friction force and the self-aligning torque under its normal driving conditions, together with the steering wheel, the steering column, the rack-and-pinion and the tie-rod. This type of simulator ignores the nonlinear steering force caused by the geometric effects of parts such as the suspension system and the tire.

As a result, the steering force obtained by using the simulator is different from that obtained from a real vehicle test, especially when the friction force of the tire mostly contributes to the steering torque at low speeds. To overcome this, it is proposed to use not only the steering system but also

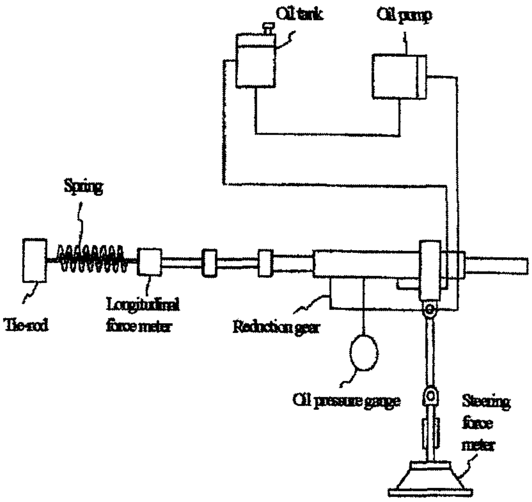


Fig. 1 Example of hydraulic steering system simulator

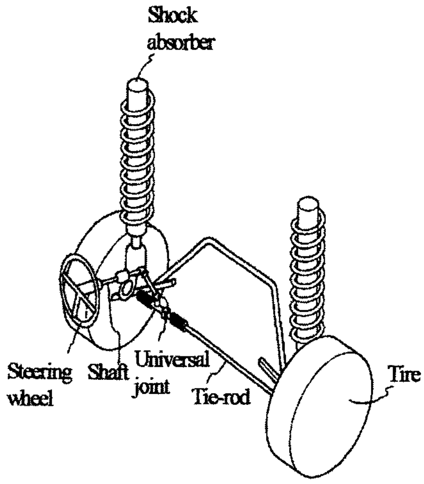


Fig. 2 Parts of steering system simulator : steering system

the front suspension of a real vehicle as shown in Fig. 2.

The supporting rig for the simulator is shown in Fig. 3, and a rotating plate to realize the steering restoration force is shown in Fig. 4. Thus, in this study, the steering system simulator can be constructed in two parts in order to match the result of the real vehicle as closely as possible.

The first part simulates the stationary condition, which does not use the rotating plate, the other is for the driving condition which uses the rotating plate. The whole system is shown in

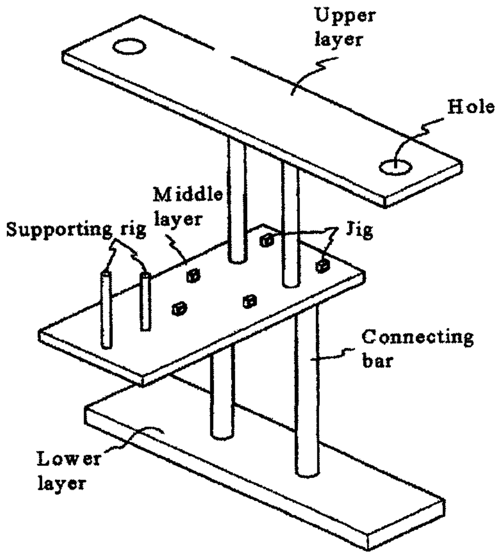


Fig. 3 Parts of steering system simulator : jig system

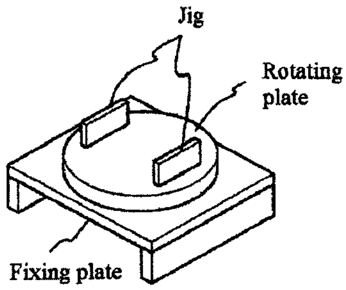


Fig. 4 Parts of steering system simulator: rotating plate

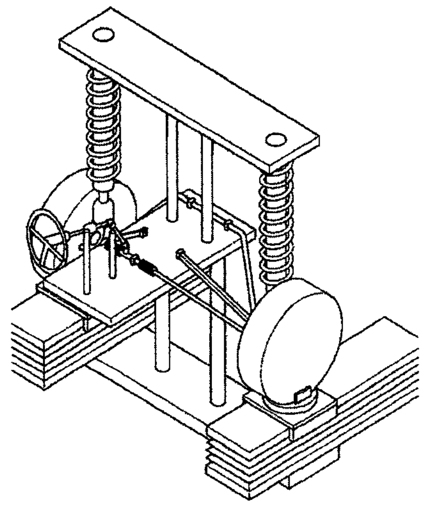


Fig. 5 Assembly of steering system simulator

Fig. 6 Photo of steering system simulator

Fig. 5 and Fig. 6, and is composed of four modules, i.e., the supporting rig, lifter, vehicle components and rotating plate.

The most common lifter in the automotive industry which is widely found in any typical vehicle garage is used. The supporting rig consists of the upper, middle and lower parts. A jig is installed between the upper part and the lower part to maintain the geometry of the main components and to support the upper part of the shock absorbing device.

The lower part of the supporting rig is fixed under the lifter to support the whole simulator, and so it provides the same conditions of road friction force to the tires when the upper plate of lifter is raised up.

The weight acting on a tire can be controlled from 0 kg to 450 kg by lifting up the upper part of the lifter. Tires are placed on the upper part of the rotation plate which is fixed on the upper part of the lifter. The number of springs inside the rotation plate varies from one to ten as the driving speed increases. This provides the self-aligning torque for the driving condition of a vehicle.

3. Experiments

This section describes both the steering simulator experiments and real vehicle experiments.

They are performed under the same conditions to obtain the reliability of the simulator.

For the real vehicle experiments, the 'Tico DX' model made by the Daewoo Motor Company is used, which is also the basis of the steering system simulator. At the stationary condition, the tire has a twisting deformation at the beginning of steering due to the tire's elasticity, and so a slip occurs when it exceeds the static friction force.

The steering torques are shown in Fig. 7 according to the weight on the tires-from 150 kg to 300 kg per tire at increments of 50 kg, while the steering wheel is arbitrary steered between angles of −720 and +720. As shown in the figure, the steering force increases proportionally as the weight increases due to the increase of friction force, and the friction force increases as the steering angle increases due to the increase of length between the tire contact point and the kingpin. The ripple in the figure may be caused by the universal joint. It also shows a sudden increase of the steering force at both ends of the steering system due to the geometrical boundary condition of the steering system.

To simulate driving conditions, the rotating plate is used and the weight on the tire and the spring on the rotating plate are appropriately adjusted. Drivers usually feel the steering state largely by the steering force and its slope, and so the weight and the springs are appropriately

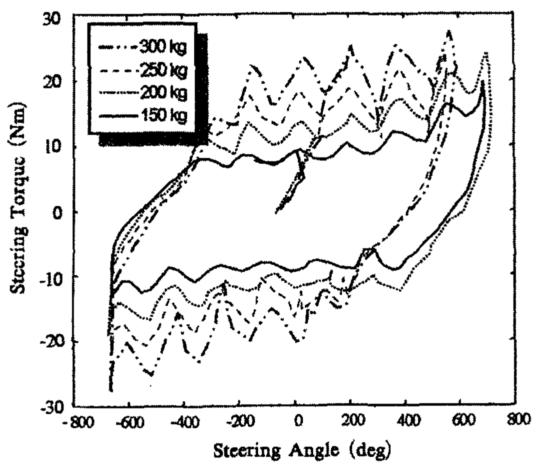


Fig. 7 Steering torque according to the front tire load simulator

adjusted according to the feeling. The experimental results using the simulator are verified to ensure their reliability by comparing them to results of the real vehicle test. Steering force hysterisis, steering stiffness and returning stiffness are chosen as important parameters for the steering force. Since the steering feel, which a driver feels at steering state, usually depends on the magni tude of steering force and its variations, the reliability is verified using the above three parameters.

The steering force hysterisis (H) shows the difference between the maximum value and the minimum value of the steering force with respect to the center point, i.e., 0°.

The steering stiffness (Sz) is the slope when the steering force increases, thus, at a stationary condition, it is related to the static rotation friction force and the geometric shape of the suspension system.

The returning stiffness (Sr) is the slope when the steering force decreases, thus it mainly depends on the stiffness of the tire.

These three values can be calculated at the graph by using the linealization method. The error between the simulator experiment and the real vehicle experiment is expressed as below, where the results obtained from the
real vehicle are assumed to be true values.

$$\text{error }(\%)=\frac{|\text{real vehicle experiments}-\text{simulator experiments}|}{\text{real vehicle experiments}}\times 100$$

4. Results and Discussion

The experimental results for the steering force at the stationary condition are shown in Fig. 8 and Table 1. The same front weight is applied to both the real vehicle and the simulator under the same geometrical shape, and so there is little error in the steering force hysterisis (4.3%) and the steering stiffness (1.3%).

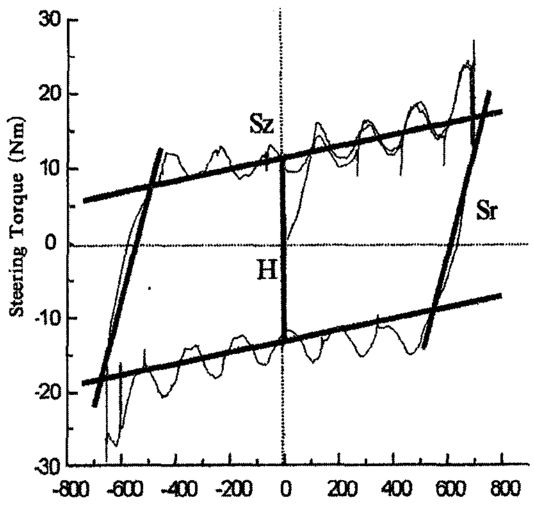
The results for the steering force while driving at 10 km/h are shown in Fig. 9 and Table 2. Similar to the case of the stationary condition, there is little error in the steering force hysterisis (3.4%) and the steering stiffness (4%).

Table 1 Comparison of steering torque parameter at stop state

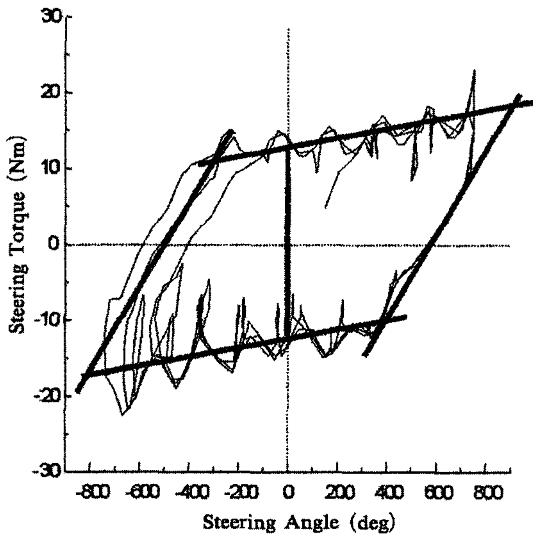
Parameter	Real vehicle	Simulator	Error
H (Nm)	23	24	4.3%
Sz (Nm/deg)	0.0075	0.0074	1.3%

Table 2 Comparison of steering torque parameter at 10 km/h state

Parameter	Real vehicle	Simulator	Error
H (Nm)	5.8	6.0	3.4%
Sz (Nm/deg)	0.025	0.024	4.0%

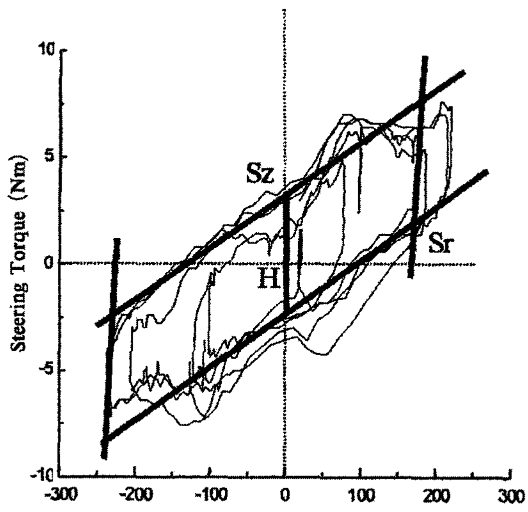


(a) Real vehicle

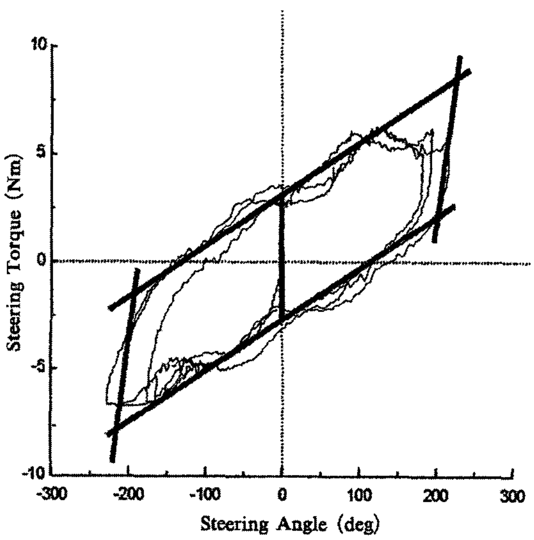


(b) Steering system simulator

Fig. 8 *Steering torque at static state*



(a) Real vehicle



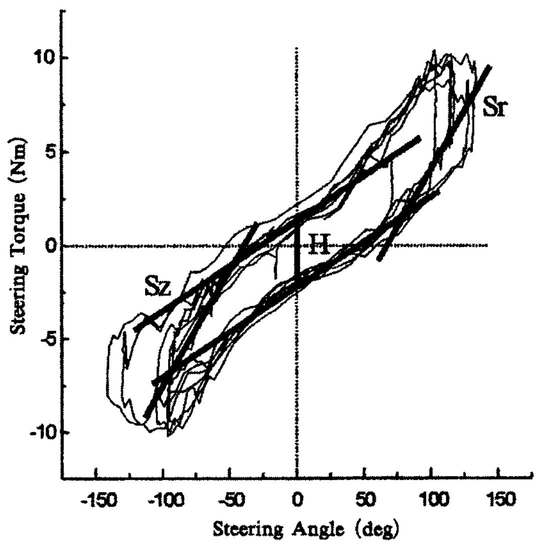
(b) Steering system simulator

Fig. 9 *Steering torque at 10 km/h state*

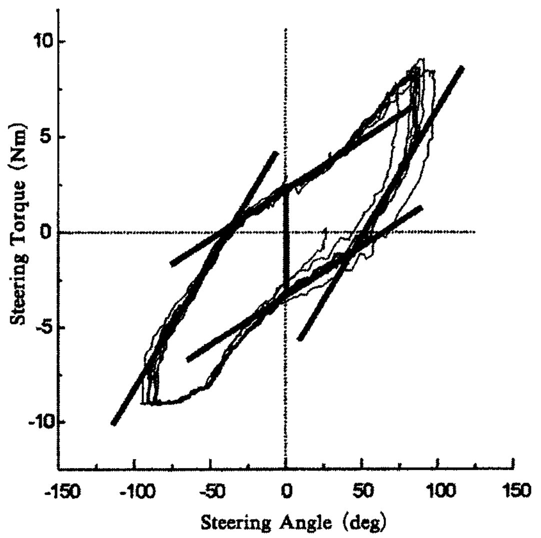
The steering forces while driving at 30 km/h are shown in Fig. 10 and Table 3. It shows that the results of the simulator agree well with those of the real vehicle experiments within 10% of error for all three parameters. As a result, at low speed (30 km/h), it is shown that the rotation plate of the simulator has been well applied. This is due to the fact that the returning force of the tire itself has a larger effect than the friction force of the tire at this speed.

Table 3 Comparison of steering torque parameter at 30 km/h state

Parameter	Real vehicle	Simulator	Error
H (Nm)	5.2	5.7	9.6%
Sz (Nm/deg)	0.05	0.049	2.0%
Sr (Nm/deg)	0.100	0.091	9.0%



(a) Real vehicle



(b) Steering system simulator

Fig. 10 Steering torque at 30 km/h state

5. Conclusion

The following conclusions are made from the experimental results.

(1) At the stationary condition and at extreme low speed, it has been shown that the simulator realizes the steering characteristics of a real vehicle within 5% of error for the steering force hysterisis and the steering stiffness.

(2) At low speed (30 km/h), it has been shown that the steering simulator realizes the real vehicle characteristics within 10% of error for all parameters.

(3) In this paper, the new type of steering system simulator using exist lifter has been developed.

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