

Effects of Equivalent Steering Torque Characteristics Derived from the Coupling Structure of Steering System and Vehicle Dynamic Characteristics on Handling Quality Evaluation

Jun Ishio ¹⁾ Reon Suzuki ²⁾ Masato Abe ²⁾ Ikuo Kushiro ²⁾ Masaki Yamamoto ²⁾ Makoto Yamakado ²⁾

1) Honda R&D Co., Ltd.

4630 Shimotakanezawa, Haga-machi, Haga-gun, Tochigi, 321-3393, Japan (E-mail: jun_ishio@jp.honda)

2) Kanagawa Institute of Technology

1030 Shimoogino, Atsugi-shi, Kanagawa, 243-0292, Japan

KEY WORDS: Vehicle dynamics, Steering system, Driver Model, Equivalent Steering Torque, Electric Power Steering [B1]

1. Introduction

The restoring moment arising from vehicle motion acts on the steering torque through the coupling with the steering system, and its characteristics vary with vehicle speed. In a previous report, the authors presented a framework that associates the equivalent stiffness and equivalent damping of the restoring moment with the steering-angle-proportional and steering-rate-proportional control of an electric power steering (EPS) system. However, the policy for setting the EPS control quantities according to vehicle characteristics, including its mechanical rationale, has not been clarified. In this report, a compensation-setting policy is derived from the equivalent correspondence between the restoring moment and EPS control, and is verified through driving simulator (DS) experiments using an evaluation method based on driver steering characteristics.

2. Equivalent Steering Torque Characteristics and EPS Control

Representing the steering-system friction by an equivalent stiffness K_{FS} and an equivalent damping C_{FS} , the equivalent stiffness and equivalent damping on the output side of the steering system, including the restoring moment and EPS control, are given as follows.

$$K_{eq} = K_{FS} + K_v - G_{a3} \quad (7)$$

$$C_{eq} = C_s + C_{FS} + C_v - G_{a2} \quad (8)$$

Here, K_v and C_v are the equivalent stiffness and equivalent damping of the restoring moment; K_v is small at low speed and increases with vehicle speed, whereas C_v is large at low speed and becomes negative at high speed. Within the controllable direction, G_{a3} increases the equivalent stiffness and G_{a2} increases the equivalent damping. Accordingly, the policy is to compensate the stiffness with G_{a3} at low speed and to compensate the negative damping with G_{a2} at high speed.

3. DS Experiment and Evaluation Method

The coupling model was implemented in the DS steering-reaction model, and lane-change tests were conducted at 40, 70, and 140 km/h. G_{a3} at 40 km/h and G_{a2} at 70 and 140 km/h were each varied over five levels. Two participants performed seven trials under each condition. Handling quality was evaluated by the previously reported method based on driver steering characteristics, focusing on the first-order lag time constant τ_L ; a larger value indicates steering with greater margin.

4. Results and Discussion

Fig. 1 shows the relationship between G_{a2} and τ_L at 70 km/h. A range in which τ_L becomes relatively large was observed, and the same tendency was confirmed at the other vehicle speeds. While the base-assist characteristic modifies the static gain $\tilde{K}$, the low-frequency characteristic of the equivalent steering torque can be approximated as follows.

$$\frac{T_{det}}{\theta_h} \approx \tilde{K}(1 + \tau_s s) = \tilde{K} \left(1 + \frac{C_{eq}}{K_{eq}} s \right) \quad (11)$$

$$\tau_s = \frac{C_{eq}}{K_{eq}} = \frac{C_s + C_{FS} + C_v - G_{a2}}{K_{FS} + K_v - G_{a3}}$$

Fig. 2 shows τ_s under the compensation condition that maximizes τ_L and under the no-compensation condition at each vehicle speed. Without compensation, τ_s decreases as the vehicle speed increases, whereas under the condition that maximizes τ_L , τ_s remains approximately constant regardless of vehicle speed.

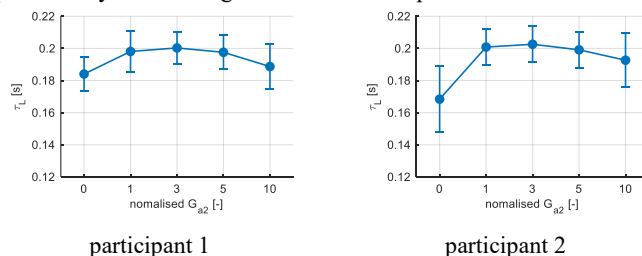


Fig. 1 Relationship between normalized G_{a2} and τ_L at 70 [km/h]

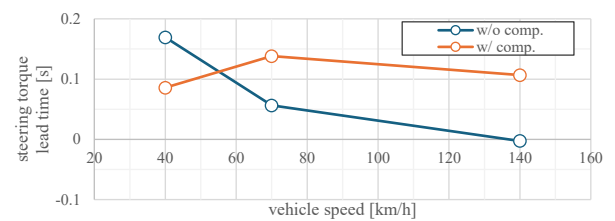


Fig. 2 Speed dependence of equivalent steering torque lead time constant

5. Conclusions

The restoring moment was represented by equivalent stiffness and damping, and the compensation effect of the corresponding EPS control was verified through DS experiments. A range of compensation quantities was found in which the driver model's first-order lag time constant becomes relatively large, and under that condition the first-order lead time constant of the equivalent steering torque became approximately equal across speeds. These results indicate that suppressing the speed dependence of the equivalent steering torque dynamics can serve as an index for setting the EPS compensation quantity.