Torque Controlled Active Steering for Electric Power Steering

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1. Introduction

The market for electric power steering systems (EPS) that help drivers to steer is expanding. This report introduces a new assist torque control method that can stabilize vehicles on a slippery road such as a snow-covered road, to improve the performance of the EPS.

2. Characteristics of Slippery Road Surfaces

Vehicle stability decreases on a slippery road (called a low-μ road hereafter), and may lead to spinning off the road. As shown in Fig. 1, the cornering force increases in proportion to the slip angle when the wheel slip angle is small (a). However, as the slip angle increases, the rate of increase of cornering force decreases and finally the cornering force saturates (b). On the other hand, lower road surface μ tends to lower the rate of increase of cornering force and the slip angle at which the cornering force saturates (c).

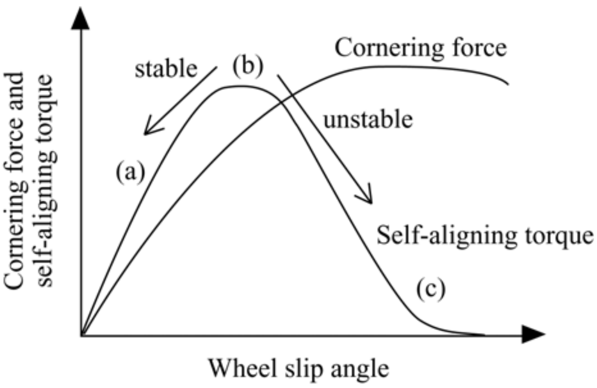

Fig. 1 Cornering force and self-aligning torque

The self-aligning torque also tends to increase linearly when the wheel slip angle is small. However, the self-aligning torque saturates at a smaller slip angle than that at which the cornering force saturates, and decreases further after reaching that point.

It is also known that the vehicle stability on a low-μ road is lower than that on a dry asphalt road (called a high-μ road hereafter). This matches the phenomenon of reduced maneuverability including driver performance on low-μ roads, indicating that vehicle stability and maneuverability are correlated.

3. Linear Analysis of Vehicles Equipped with EPS

This section discusses the linear analysis of the self-aligning torque feedback controller. Equations (1) through (3) shown below are dynamic equations of a vehicle equipped with EPS and Fig. 2 shows the model representation.

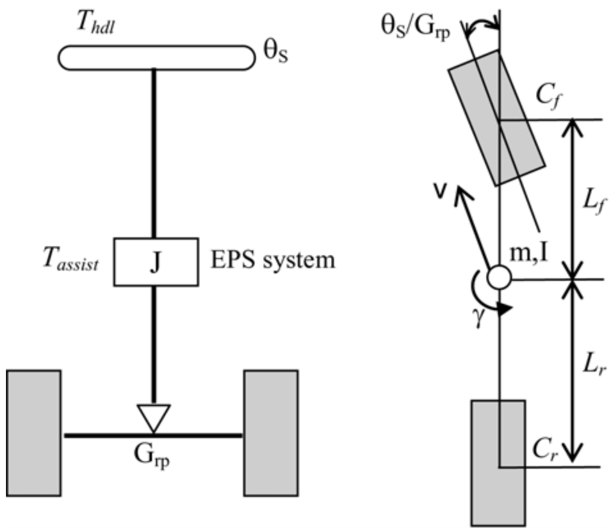

Fig. 2 Model of the vehicle and the steering system

$$J\ddot{\theta}_S + c\dot{\theta}_S = T_{assist} + T_{hdl} - \frac{\xi}{G_{rp}} C_f \left(\frac{\theta_S}{G_{rp}} - \frac{L_f}{V}\gamma - \beta \right) \tag{1}$$

$$mV\dot{\beta} = -2(C_f + C_r)\beta + \left\{ -mV - \frac{2}{V}(L_f C_f - L_r C_r) \right\}\gamma + 2Cf\frac{\theta_S}{G_{rp}} \tag{2}$$

$$I\dot{\gamma} = -2(L_f C_f - L_r C_r)\beta - \frac{2(L_f{}^2 C_f + L_r{}^2 C_r)}{V}\gamma + 2L_f C_f \frac{\theta_S}{G_{rp}} \tag{3}$$

T_{assist} by the controller mentioned above is defined by:

$$T_{assist} = -\alpha_1 \frac{\xi}{G_{rp}} C_f \left(\frac{\theta_S}{G_{rp}} - \frac{L_f}{V}\gamma - \beta \right) \tag{4}$$

Figure 3 shows the results of linear analysis of differential equations (1) through (4). According to the results, the pole position expands toward the negative direction compared to the pole position of a system without any control; hence, the vehicle stability has been improved by the controller.

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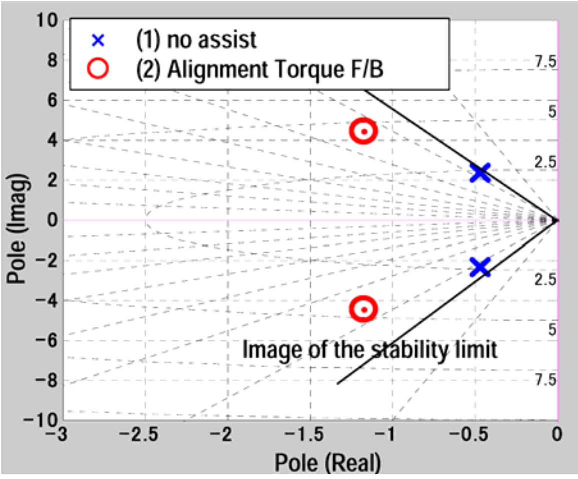

Fig. 3 Pole analysis of dynamics (Low μ)

4. Control Strategy and Self-Aligning Torque Estimator

We have built an EPS controller in accordance with the following strategies for assisting the maneuvering speed of the driver by adding steering return torque by means of self-aligning torque.

(1) Vehicle stability shall be improved by assisting the steering wheel torque even on a low-μ road.

(2) The controller configuration shall be built without adding new sensors.

(3) No other EPS compensation function shall be affected.

Figure 4 shows the block diagram of our newly developed controller. First, the self-aligning torque is estimated from the steering torque supplied by the driver and the assist torque of EPS. Then, the steering return torque is assisted based on the estimated value of the self-aligning torque.

The self-aligning torque estimator obtains the estimated value of the self-aligning torque by eliminating nonlinear elements such as friction torque and the like by using a filter in accordance with the vehicle state values. Figure 5 shows the self-alignment torque values estimated by the estimator, confirming the accuracy of the values from low to high frequencies.

5. On-vehicle Test Results

We conducted slalom testing on a snow-covered testing road using an actual car to evaluate the maneuverability including driver performance and vehicle stability.

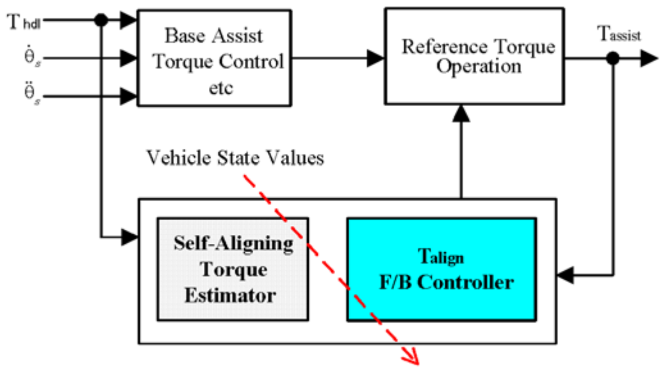

Fig. 4 Block diagram of the new controller

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Figure 6 shows that the delay time during steering wheel return is improved by approximately 0.5 seconds by using the control algorithm of this paper, compared to the conventional control, and that the vehicle instability due to the delay in return was reduced. In short, the algorithm improves maneuverability including driver performance and vehicle stability.

We will continue to develop EPS technologies to improve value-added mechanisms, which will not only help EPS as actuators but also significantly contribute to vehicle stability.

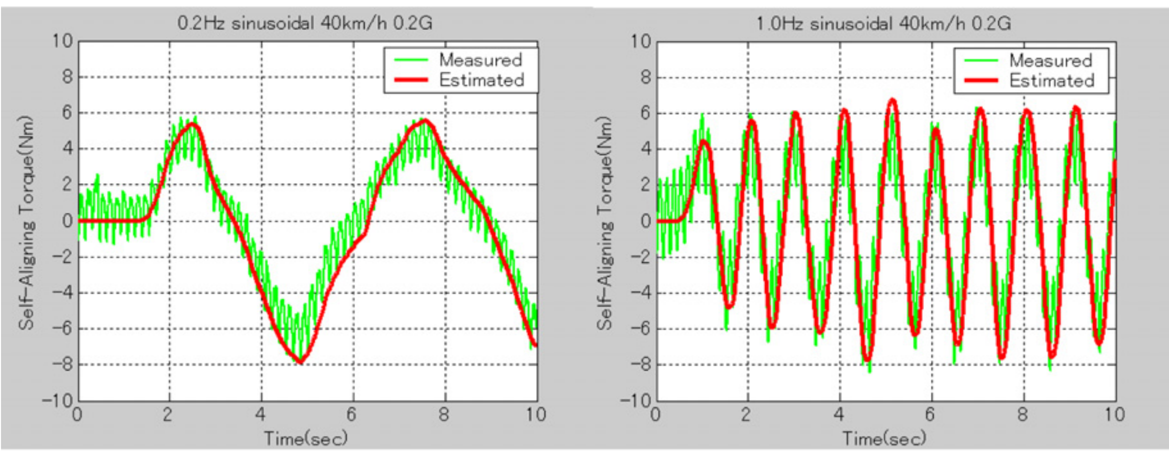

Fig. 5 Estimation results of the self-aligning torque

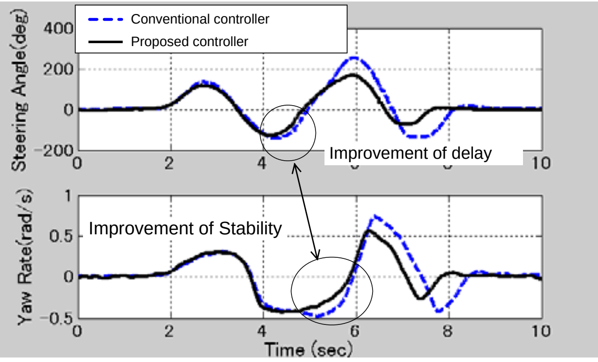

Fig. 6 Test of slalom steering

Reference:

(1) Tanaka H. et al., Torque Controlled Active Steering for EPS, In Proc. International Symposium on Advanced Vehicle Control, 501-506, 2004