Static Steering-Control System for Electric-Power Steering

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Electric-power steering (EPS) systems have attracted much attention for their advantages with respect to improved fuel economy and have been widely adopted as automotive power-steering equipment in recent years. The article introduces a new EPS control system that reduces steering torque during static steering (i.e., while a vehicle is at rest) as a means of further improving EPS control performance.

Required Control Performance During Static Steering

An EPS system controls the current of a motor to generate assist torque based on the output of a steering-torque sensor. The assist torque is set so that it is nearly proportional to the sensor output. Increasing this proportional gain (i.e., map gain) has the effect of reducing steering torque, but in the vicinity of 30Hz the control system may oscillate, causing a driver to feel unpleasant steering-wheel vibration. In general, drivers tend to prefer a low level of steering torque during static steering. Accordingly, the challenge is to suppress steering-wheel vibration while at the same time reducing steering torque.

Damping Control System Design Incorporating an Observer

Fig. 1 shows a model of a steering mechanism equipped with EPS. We linearize this model and perform frequency analysis[1] to elucidate the oscillation mechanism during static steering. As shown in Eq. (1), this model can be represented as a balance between the motor inertia, the steering torque applied by the driver T_{hdl}, the assist torque produced by the motor T_{ASSIST} and the reaction torque of the steering mechanism T_{tran}. During static steering, the area of contact between the front tires and the road surface does not change in the region of small steering-wheel angles. Since the torsion of the tires acts as a spring, the steering angle and reaction torque have a proportional relationship with nearly constant gain.

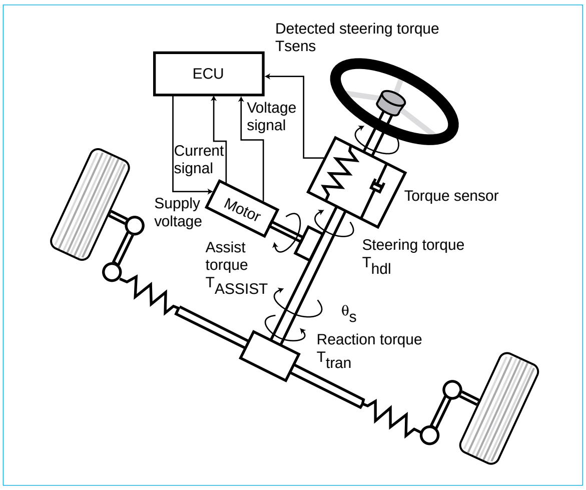

Fig. 1 A steering mechanism with EPS.

$$J \cdot d^2\theta s/dt^2 = T_{ASSIST} + T_{hdl} - T_{tran} \quad \text{Eq. 1a}$$

$$T_{ASSIST} = G_{gear} \{K_T \cdot I_{mtr} - T_{fric} \cdot \mathrm{sgn}(d\theta_s/dt)\} \quad \text{Eq.1b}$$

$$T_{hdl} = K_{TSEN} (\theta_{hdl} - \theta_s) + C_{TSEN} (d\theta_{hdl}/dt - d\theta_s/dt) \quad \text{Eq.1c}$$

where

K_T	motor-torque constant
I_{mtr}	motor current
T_{fric}	motor-friction torque
K_{TSEN}	spring constant of the torque sensor
C_{TSEN}	damping coefficient of the torque sensor
θ_s	angle of steering-column shaft
θ_{hdl}	steering-wheel angle
G_{gear}	motor-gear ratio
J	motor moment of inertia

The calculated frequency characteristics of the linearized model are shown by the solid lines in Fig. 2. The control system has been designed with a phase margin in the vicinity of the crossover frequency where the gain is 0dB. However, when the map gain is increased, the crossover frequency shifts to the high frequency side and the phase margin decreases, which tends to induce control-system oscillation.

An effective way of suppressing steering-wheel vibration is to incorporate a control measure that applies damping at the frequency where oscillation occurs, but an EPS system does not have a motor-speed sensor. Previously, the motor speed has been estimated in the low-fre-

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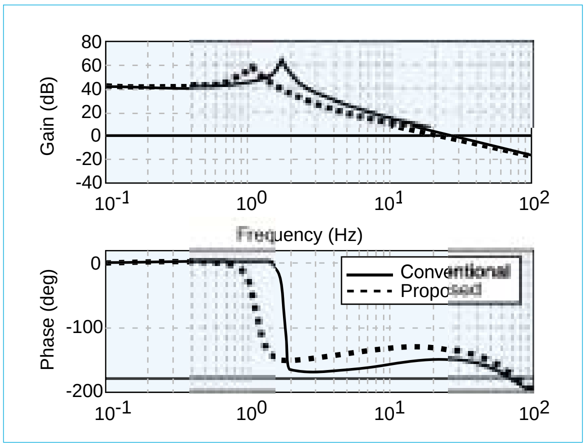

Fig. 2 Frequency characteristics of a steering mechanism with EPS.

quency region below 5Hz, but it has been difficult to estimate the motor speed in the vicinity of an oscillation frequency of 30Hz.

To overcome this problem, we have devised a method of estimating the motor speed by using an observer[2] and have developed a damping compensator that provides compensation based on the estimated motor-speed signal. This has resulted in comfortable static steering performance free of steering-wheel vibration.

The configuration of the observer is described next. This observer has been constructed by linearizing the model in Eq. 1, and has the steering torque and motor current as its inputs. To validate the operation and estimation performance of the observer, an estimate was made of the motor speed when static steering oscillation occurred. The results are shown in Fig. 3

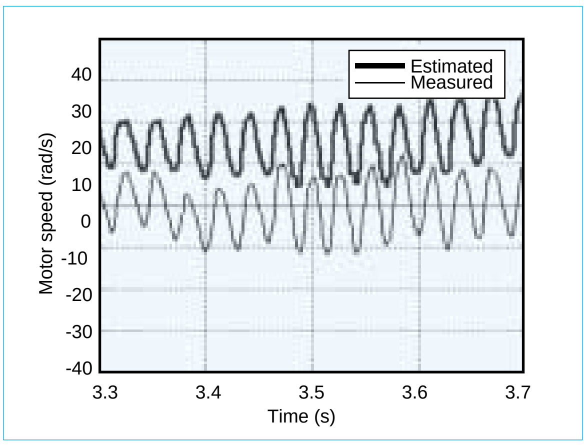

Fig. 3 Estimation of motor speed using an observer.

where the thicker line indicates the motor speed measured with a rotary encoder and the fine line shows the speed estimated by the observer. The estimated results agree well with the measured data in terms of both the amplitude and phase of the motor speed.

The input signal is filtered with the aim of applying damping only at the frequency where steering system oscillation occurs, so the estimated motor speed fluctuates near a value of zero. Therefore, when oscillation damping control is performed based on the motor speed estimated by this observer, there is no feedback of the steering velocity component. Accordingly, since damping control does not manifest itself as steering resistance, it is possible to achieve comfortable steering behavior.

A block diagram of the new controller that performs feedback of the estimated motor speed is shown in Fig. 4, and its frequency characteristics are indicated by the dashed lines in Fig. 2. Although the phase margin is larger than that of the previous system, the control system is not affected by high-frequency mechanical resonance because the high-frequency gain does not change.

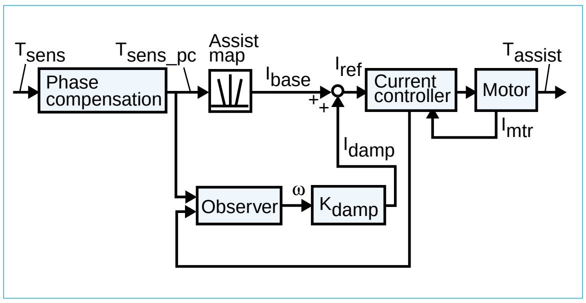

Fig. 4 Block diagram of the contoller with damping compensation.

Vehicle testing

To verify the performance of the proposed controller, tests were conducted with an actual vehicle using the DSP-CIT controller development tool that is capable of generating a control program seamlessly from the controller model constructed with MATLAB/SIMULINK. The map gain was increased 3.3-fold over the conventional level. While oscillation occurred with the conventional controller, see Fig. 5 (a), no oscillation occurred with the proposed controller, Fig. 5 (b). These

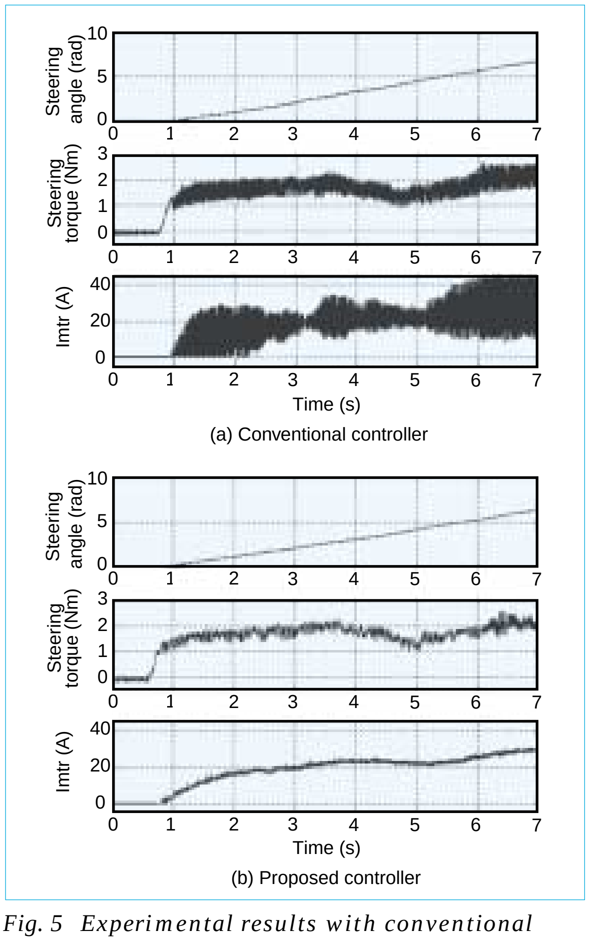

Fig. 5 Experimental results with conventional and proposed controllers.

results confirm that the application of an observer and damping control to the EPS control system have improved static steering performance.

In future work, efforts will be made to apply this control system to a high-output motor and to improve the control performance further. Technologies will be developed for applying EPS widely to small and midsize cars with the aim of contributing to the further development of such vehicles. ❑

References

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2. D. G. Luenberger, "Observing the state of linear system," IEEE Trans. Mil. Electron, MIL-8, 74-80 (1964).