Development of Auxiliary Power Supply System for Electric Power Steering

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When employing an electric power steering (EPS) system on a large vehicle, issues include an increase in the electric power load of the vehicle during stationary steering (steering while parked), and lowering of assist torque responsiveness due to lack of electric power.

An auxiliary electric power supply system for EPS is being developed to solve these issues.

The purpose of this system is to achieve a high power output EPS system which compensates momentarily required electric power with an auxiliary power supply.

This report describes an outline of the higher power output system and vehicle test results of the auxiliary electric power supply system, as well as application development to lower the vehicle power supply load and ensure safety within the redundant power supply system.

Key Words: *electronics and control, electric power steering, auxiliary power supply system, high power output*

1. Introduction

Motorization of automobiles has progressed in recent years due to environmental concerns. In electronic power steering (EPS) as well, demands are increasing for installation on large size vehicles (SUVs, minivans, etc.) in addition to small size vehicles. As steering axial force increases with increased vehicle weight, however, the installation of EPS on large size vehicles requires consideration of increased load on the vehicle power supply during stationary steering (steering maneuvering when parking), as well as reduction in responsiveness of the assist torque during rapid steering action. Furthermore, if for example the input electric power of EPS were to be temporarily cut off in a large size vehicle, it would cause a massive and immediate change in steering force, and therefore safety assurance during reduced maneuverability is considered as one of the issues regarding EPS.

Due to these reasons, we are currently engaged in the development of an auxiliary power supply system for EPS that achieves the following three functions.

1) EPS with high power output (Ensures responsiveness of assist torque during rapid steering action)
2) Peak shaving of electric power (Levels vehicle power supply load during stationary steering)
3) Power supply backup (Maintains EPS function through redundant power supply)

This paper first describes the details of the development of EPS with high power output using an auxiliary power supply system, and the results of its evaluation. It then introduces the practical application of the developed technology in an overview of peak shaving of electric power and power supply backup.

2. Issues regarding EPS installation on large size vehicles

2. 1 Increased load on vehicle power supply

The configuration of the EPS system is shown in **Fig. 1**. The electronic control unit (ECU) controls the motor based on the values of steering torque and motor angle that are detected by the sensor, and outputs the appropriate assist torque for steering in order to lessen the steering burden on the driver. The electric power necessary for EPS is, as for other electrical equipment for automobiles, supplied by the vehicle power source (alternator and battery).

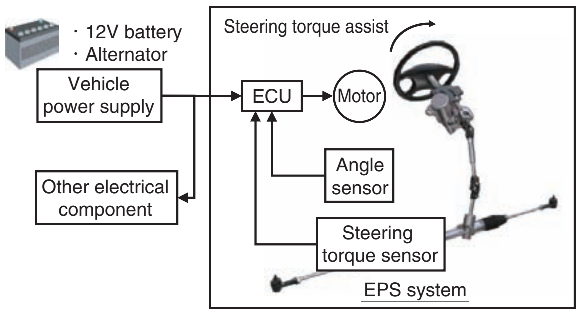


Fig. 1 EPS system block diagram

The results of measured maximum electric power consumption of electronic equipment for automobiles are shown in **Fig. 2**. These results show that among the equipment, EPS has the smallest maximum power consumption when driving in a straight line, but has the largest during stationary steering. Power consumption temporarily increases during stationary steering as more assist torque is required for larger and heavier vehicles. This causes increased load on the vehicle power supply, and as such is an issue within EPS installation on large size vehicles that must be resolved.

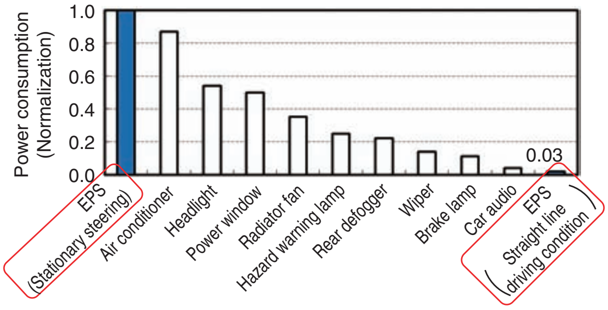


Fig. 2 Comparison of maximum electric power consumption[1), 3)]

2. 2 Decrease of assist torque responsiveness

To check the responsiveness of assist torque, we conducted a test using an actual vehicle. The test involved turning the steering wheel (SW) left and right during stationary steering, and measuring steering angle speed and steering torque while gradually increasing steering angle speed. The results, displayed in **Fig. 3,** show that an increase in steering angle speed causes the absolute value (for example, ①, ②, and ③) of the maximum amplitude of steering torque to increase as well. The results of an evaluation of this relationship are shown in **Fig. 4**. From these results, we can see that the SW becomes difficult to maneuver if the steering angle speed of the driver exceeds a certain value, inhibiting the ability to steer comfortably. This is caused by a decrease in assist torque responsiveness to the fast steering maneuvers of the driver. This phenomenon is highly likely to occur in large size vehicles and it is therefore imperative that the design of EPS takes into account assist torque responsiveness in order to reduce the steering burden on the driver.

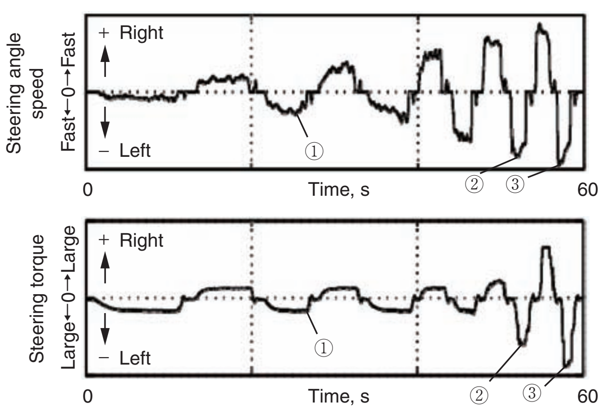


Fig. 3 Steering angle speed and steering torque transition[3)]

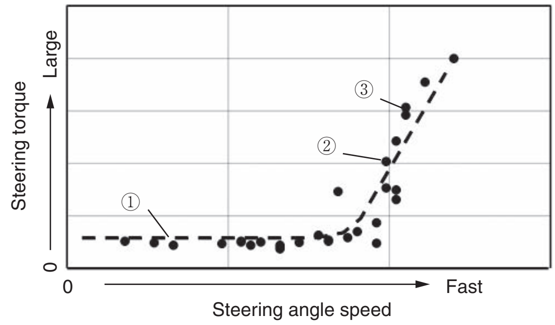


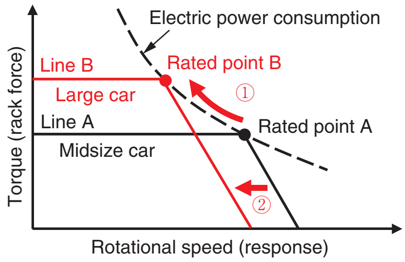
Fig. 4 Peak value plot of steering torque against steering angle speed[3)]

3. Auxiliary power supply system

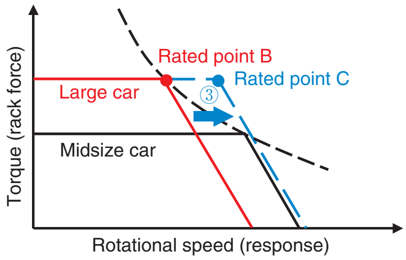
3. 1 Principle of high power output

The following is an explanation on the phenomenon of steering torque increase due to decreased assist torque responsiveness, using characteristics diagrams (N-T characteristics diagrams) of the rotational speed of the EPS motor and the torque. In **Fig. 5** (a), the point (rated point A) where the N-T characteristics of the EPS motor for midsize cars (line A) intersects with the maximum electric power able to be supplied by the vehicle power supply (dashed line) is the maximum rotational speed at the rated torque. When rated torque is increased (line B) in order to support larger vehicles, rated point A changes to rated point B (arrow ①). As a result, assist torque responsiveness in large cars decreases in comparison to midsize cars due to a reduction in maximum rotational speed (arrow ②) at the rated torque. This in turn causes steering torque to increase.

In general, motor rotational speed is dependent on induced voltage, and it is therefore possible to create a method to increase motor input voltage (higher voltage) in order to improve assist torque responsiveness. A characteristics diagram with increased input voltage is shown in **Fig. 5** (b). When voltage is increased, rated point B changes to C (arrow ③), allowing rotational speed to be increased while still maintaining rated torque. Through this, we have enabled a countermeasure against decreased assist torque responsiveness within faster steering ranges.



(a) Basic characteristics[3]



(b) Characteristics with addition of electric voltage[3]

Fig. 5 N-T characteristics of EPS assist motor

3. 2 System configuration

To achieve higher voltage, we may at first consider increasing the voltage of the actual power supply of the vehicle. However, in consideration of demands for EPS with high power output (high voltage) at the present 12 V vehicle power supply, we decided to install a separate auxiliary power supply solely for EPS, without modifying the vehicle power supply. A block diagram of this system is shown in **Fig. 6**. The system is configured with the ECU, which controls the auxiliary power supply as well as charging and discharging, located on the power supply line between the vehicle power supply and EPS.

The charge-discharge ECU monitors the power supplies of EPS and the vehicle. If EPS power is insufficient, the discharge circuit is activated, immediately supplementing the EPS input power with the power of the auxiliary power supply. To prevent insufficiency of the power from the auxiliary power supply, the charge circuit is activated when the voltage of the auxiliary power supply decreases, and charges the auxiliary power supply system using the vehicle power supply. This resolves the two issues of the previously stated increased load on vehicle power supply, and decreased assist torque responsiveness.

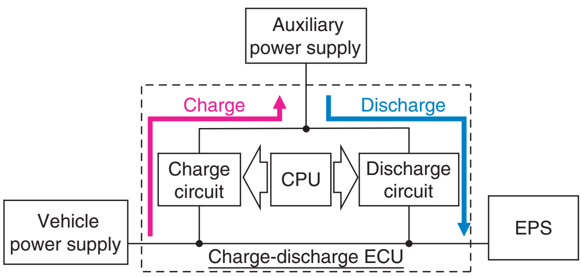


Fig. 6 Block diagram of auxiliary power supply system for EPS[3]

3. 3 Selection of auxiliary power supply

Stationary steering is performed mainly when parking and entering a garage. These actions involve rapid steering angle speed and often involve consecutive steering maneuvers. To implement steering force assist continuously in these situations, it is necessary to utilize an electric power storage device that enables quick charging on the auxiliary power supply. We conducted a comparative study on three types of electric power storage devices with good results in automobiles, including a lead battery, lithium-ion battery, and capacitor. **Table 1** shows the results of the study. Based on **Table 1**, we decided to employ the capacitor, which has high output density, can be charged quickly, and maintains a long battery cycle life.

Table 1 Comparison of electric power storage devices[1)]

	Capacitor	Lead battery	Li-ion battery
Energy density, Wh/kg	4~5	25~35	40~70
Output density, W/kg			
(25℃)	1 800~2 000	300~400	1 500~2 000
(−15℃)	900~1 100	200~300	300~500
Cycle life, cycles	100 000 <	500 <	1 000 <

3. 4 Charge-discharge control method

As stated previously, stationary steering maneuvers are conducted consecutively; when steering with a fixed steering angle speed, stationary steering force generally increases in response to the rise in SW steering angle, which in turn increases the necessary electric power for EPS. Therefore, as shown in **Fig. 7**, we constantly monitored EPS energy consumption, within which we established a power threshold value. If EPS energy consumption exceeds the threshold value, then power is supplied by the capacitor. If EPS energy consumption falls below the threshold value, then the capacitor is charged by the vehicle power supply. In summary, we have implemented controls to conduct charging and discharging for each steering maneuver as necessary. As a result, the effects of steering assist are able to be maintained during consecutive steering maneuvers even when using a capacitor, which has low energy density. These results are visible in **Fig. 8**. Without charge control, repeated stationary steering causes capacitor voltage to rapidly decrease. In contrast, with charge control, capacitor voltage is maintained even through 20 consecutive stationary steering maneuvers, indicating that there is no power insufficiency in the capacitor.

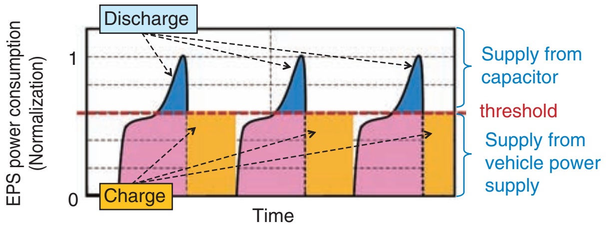


Fig. 7 Transition of electric power consumption (Charge-discharge control)[1)]

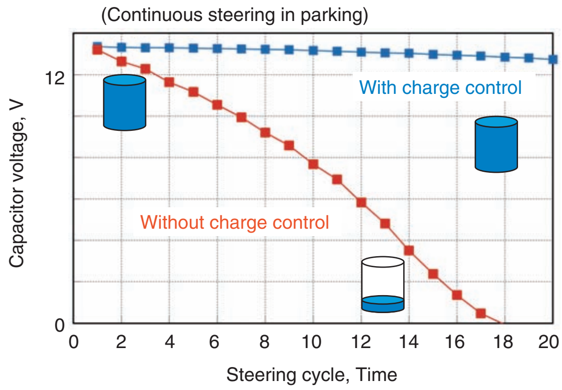


Fig. 8 Capacitor voltage transition with/without charge control[1)]

3. 5 Discharge control issues and countermeasures

The discharge control method involves supplementing EPS input voltage with voltage from the capacitor and immediately increasing voltage when the abovementioned EPS power consumption exceeds the power threshold. This poses concerns about what effect the sudden change in voltage during steering will have on steering feeling. Therefore, to confirm the influence on steering torque, we installed the developed system on an actual vehicle and conducted measurements of EPS input voltage and steering torque during stationary steering. The results of these measurements are shown in **Fig. 9**.

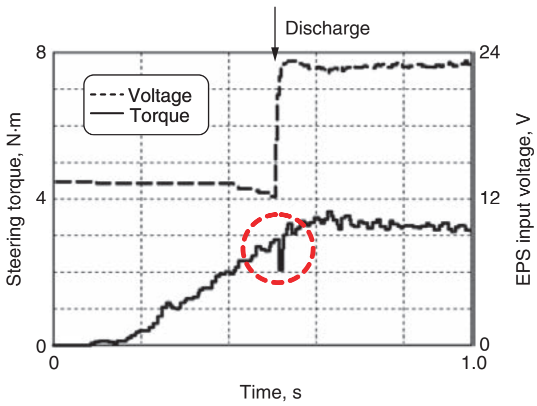


Fig. 9 Steering torque fluctuation at change of control (before countermeasure)[3)]

As shown in the figure, we have confirmed that a sudden rise in EPS input voltage causes variation in steering torque. Furthermore, this torque variation caused discomfort to the driver when performing actual steering maneuvers. As a countermeasure against this, we estimated EPS electric power according to steering angle speed as shown in **Fig. 10**, and conducted a study on control methods to enable a smooth change of discharge voltage.

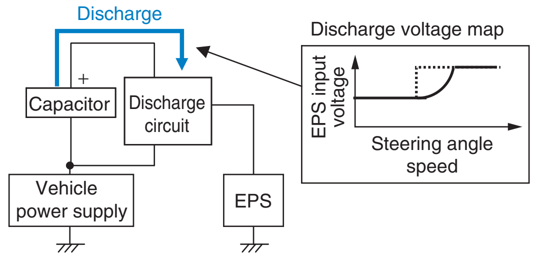


Fig. 10 Proposed countermeasure for discharge control[3)]

4. Evaluation test on actual vehicle

4. 1 Confirmation of effect of countermeasures against torque variation

We introduced, on an actual vehicle, the discharge control with countermeasures against torque variation that is described in the previous paragraph. Measurements were conducted, the results of which are shown in **Fig. 11**. This figure represents EPS input electric power measured under the same testing conditions of the actual vehicle measurement results shown in **Fig. 9**, and time sequence data of steering torque. These results confirm that the variation in steering torque visible in **Fig. 9** has been suppressed in **Fig. 11**. In addition, we have enabled smooth steering which does not cause the driver to feel discomfort when performing actual steering maneuvers.

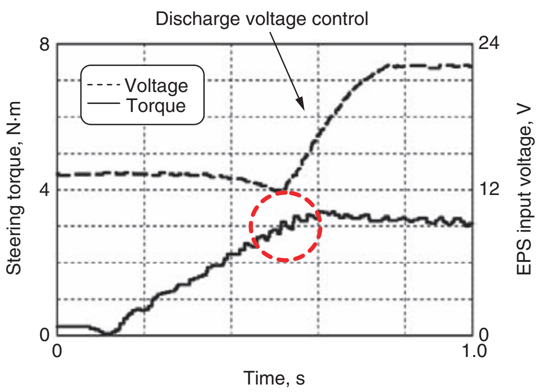


Fig. 11 Steering torque fluctuation at change of control (after countermeasure)[3)]

4. 2 Confirmation of effect of high power output

To confirm the effects of high power output, we implemented an evaluation test on assist torque responsiveness in the same method as the abovementioned **Fig. 4**. We also connected multiple capacitors in series with the aim of doubling assist torque responsiveness during steering when parking. The results of the evaluation test are shown in **Fig. 12**. In this figure, we have plotted the maximum steering torque when steering angle speed is changed. The results show that with discharge control, steering torque does not increase until a higher steering angle speed is reached, in contrast to the case without discharge control. These results confirm that the power assist provided by the capacitor improves assist torque responsiveness by twice its original amount.

In the following paragraphs, we will introduce peak shaving of electric power and the power supply backup function as examples of the practical application of the developed system.

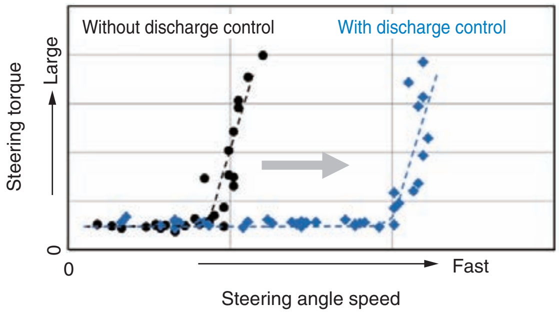


Fig. 12 Measurement results of steering angle speed against steering torque[3)]

5. Practical application

5. 1 Peak shaving of electric power

The electric power taken from the vehicle power supply increases temporarily during steering when parking, and consequently peak shaving of electric power is utilized as a means of reducing the load on the vehicle power supply, by supplying power from the capacitor. The evaluation results of peak shaving on an actual vehicle are shown in **Fig. 13**. The results shown were obtained using the same method as the actual vehicle evaluation test for high power output, and aimed to reduce peak electric power during steering when parking by 50% by connecting multiple capacitors in sequence. Within the figure, the x-axis indicates time, and the y-axis indicates the electric power supplied from the vehicle power source (solid line) and the steering angle speed (dashed line). These results confirm that, when compared with no electric power compensation (conventional system), electric power assisted by the capacitor (developed system) achieves leveling of electric power supplied from the vehicle power supply, as well as approximately 50% peak shaving of maximum electric power.

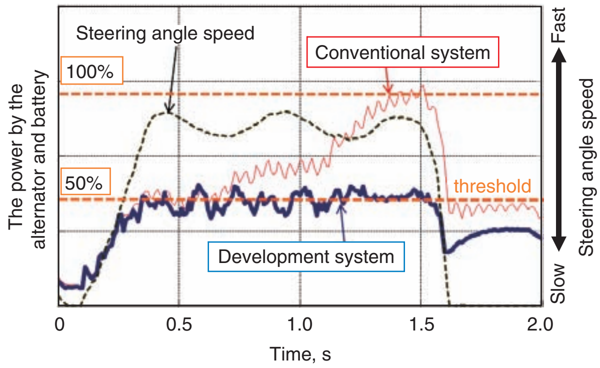


Fig. 13 Measurement results of power consumption[1)]

5. 2 Power supply backup

The purpose of the power supply backup function is, in the event of a failure of the vehicle power supply system, to ensure a smooth transition to the auxiliary power supply in order to temporarily maintain EPS function, so that steering torque variation will not occur if the power supplied to EPS is temporarily cut off. The method for evaluating this function involved deliberately cutting off the input electric power of the EPS while keeping the SW turned during circular driving. The results of this evaluation are shown in **Fig. 14**.

In the conventional system shown in the figure to the left, the EPS function ceases when electric power from the vehicle power supply is cut off (①), causing loss of assist torque and increase in the steering torque burden on the driver (②).

In contrast, as seen in the figure on the right, the installation of an auxiliary power supply system mitigates the effect on the driver by switching the power supply to the capacitor the moment electrical power is cut off, which maintains electric power supply to EPS, thus preserving EPS function and suppressing sudden variation in steering torque (④).

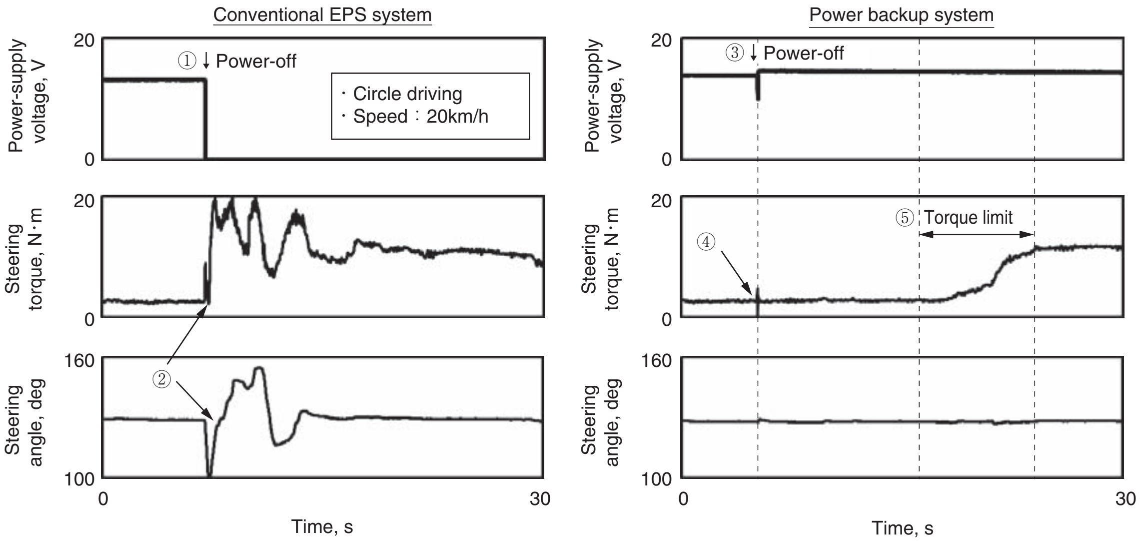


Fig. 14 Power-off test results

6. Conclusion

We have developed a prototype charge-discharge ECU installed with a capacitor as an auxiliary power supply, and conducted evaluations on the high output function of this developed ECU. Through the results of the evaluation, we have confirmed an improvement in steering assist responsiveness during rapid steering action without increasing the electric power taken from the 12 V vehicle power supply, which has been achieved by temporarily supplying power from the capacitor. As a result, we believe this system may serve as a proposal for countermeasures against insufficient electric power, which is an issue in the installation of EPS on large size vehicles. We plan to improve the functions of the developed system in order to expand the applicable range of EPS to include large size vehicles.

In addition, we introduced electric power peak shaving, which reduces maximum electric power during steering when parking, as well as a power supply backup function, which prevents sudden change in steering torque when the power supply is cut off. We plan to continue studies on both of these functions in order to optimize the entire system we have developed.

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