Development of High Power Column-Type Electric Power Steering System

Y. NAGAHASHI A. KAWAKUBO T. TSUJIMOTO K. KAGEI J. HASEGAWA S. KAKUTANI

Recently, demands have increased for column-type electric power steering that can be installed not only on small vehicles but also on medium-sized and large vehicles and features high output and quiet operation in view of the need to promote environmental protection and energy conservation on a global scale. Also, as the demand for systems increases, the need for C-EPS to possess high technical capability and performance is increasing.

This paper introduces the following elemental technologies developed and applied to C-EPS.

· Electronic control device equipped with a booster pump circuit
· Brushless motor
· Core-to-core-distance adjustment mechanism type reduction gear
· Hall IC torque sensor
· Manual gear
· Assist control

Key Words: *electric power steering, manual steering gear, torque sensor, assist control, motor*

1. Introduction

Column-type electric power steering ("C-EPS") was commercialized in 1988 for small vehicles because it reduces engine power loss and eliminates the need to consider the arrangement of the hydraulic pump and pipes in the engine compartment.

Recently, in view of the overall need for layout compatibility, environmental protection and energy conservation, the need for C-EPS that can be installed not only on small vehicles but also on medium-sized and large vehicles has increased. Moreover, high output and quiet operation are also required.

In accordance with the increasing demand for C-EPS systems, technology for system adaptation and improvement of performance of the overall system are also required.

This report introduces a newly developed high output C-EPS system with a brushless motor, a Hall IC torque sensor, and an electronic control unit ("ECU") equipped with a booster pump circuit.

2. Purpose of Development

The target of this project was to develop a C-EPS system with 12 000 N of rack axial force, a level that had been difficult to achieve by conventional EPS systems.

Figure 1 shows the output characteristics of the newly developed C-EPS.

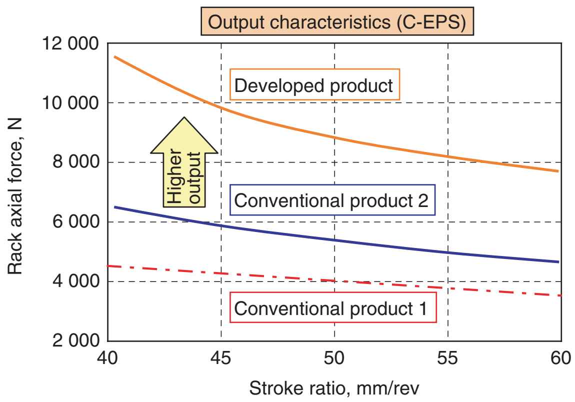

Fig. 1 Output characteristic of developed C-EPS

3. Motor and ECU

A motor with high torque and small size was achieved by using a rare-earth (neodymium) magnet (**Fig. 2**), and regarding the ECU, improvement in responsiveness was realized by adopting a booster circuit to raise the input (battery) voltage (**Fig. 3**).

Conventionally, both the motor and ECU designs were changed to achieve the required output characteristics (rotational speed × torque). However, with this newly developed technology, by adopting two booster pump circuits we could achieve one circuit in the case of mounting no element (**Fig. 4**), which enables the ECU itself to correspond to rotational speed (output characteristic). Concerning the torque (output characteristic), motors were classified to types to be serialized and different axial-length motors were manufactured in the same production line.

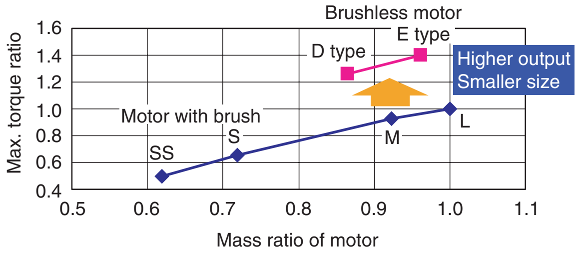

Fig. 2 Max. torque and mass of motor

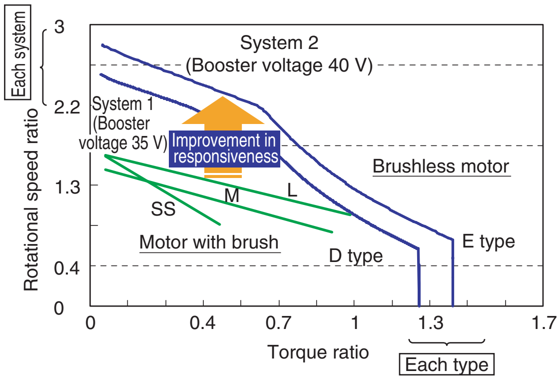

Fig. 3 Output characteristic

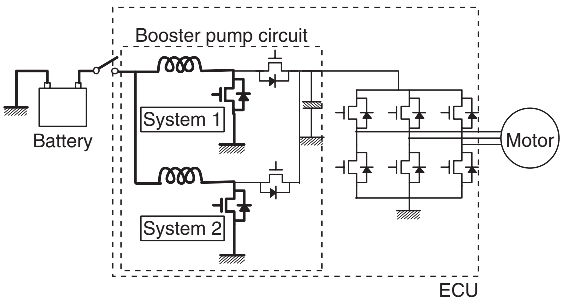

Fig. 4 ECU (booster pump) circuit

4. Column

Regarding the reduction gear structure, a new material and a worm core-to-worm wheelcore-distance adjustment mechanism were adopted in order to keep balance between friction and teeth-hitting noise and to reduce the influence of temperature change. This made it possible for the reduction gear to handle increased motor output and compatibility between steering feeling and noise. **Figure 5** shows the structure of the core-to-core-distance adjustment mechanism. In the conventional mechanism, the distance between the worm and the worm wheel was fixed. The developed one has a clearance between the end side bearing and the housing, and by use of a spring as shown in **Fig. 5**, the worm can move centering the supporting point A due to the bearing clearance and curvature at the A side supporting point. Therefore, this mechanism absorbs the change of core-to-core-distance due to resin expansion caused by temperature change and wear, and reduces the backlash at the meshing point.

Along with high output, it was difficult to achieve both required strength and reduced wear by using conventional resin material for the worm wheel. Therefore for the worm wheel of the newly developed C-EPS, we applied a new resin material with 40% increased strength and no strength reduction by moisture absorption. Furthermore, in order to reduce the influence on steering feeling (inertia feeling on the steering wheel) due to motor inertia, the reduction ratio was optimized.

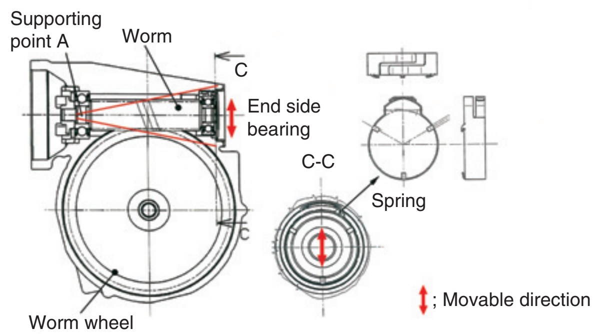

Fig. 5 Structure of reduction gear

5. Hall IC Torque Sensor

In place of the conventional torque sensor, we applied a new type torque sensor (Hall IC type) that reduces fluctuation of characteristics due to temperature change and has a complete double structure in terms of fail safe.

This new type torque sensor has a highly functional Hall IC incorporating digital processing function, nonvolatile memory, and temperature compensation function in one chip, which gives it improved torque detection accuracy, superior temperature characteristics, and the ability to maintain stable steering feeling under high-temperature environments in the engine compartment. Both the accuracy and reliability of torque detection have been improved by a 30% improvement in temperature characteristics and one-third reduction of run out fluctuation. Also, by installing two Hall IC chips to control the output difference between the two, a complete double system of defect detecting function has been achieved. This Hall IC has satisfied the New Safe Specifications in Europe to be enacted from 2010 and boasts high reliability. Moreover, its structure is simple and compact, it has fewer parts, and it is easy to install because its axial length is 10mm shorter than that of the conventional one.

Figure 6 shows the structure of newly developed Hall IC torque sensor.

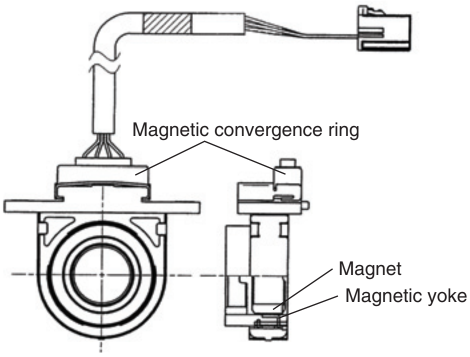

Fig. 6 Structure of Hall IC torque sensor

When the steering wheel is not operated, the yoke tooth part short-circuits the surface magnetic flux of the magnet and the magnetic flux does not transmit to the Hall IC (**Fig. 7** upper).

When steering force is applied, there occurs angular difference between the magnet connected at torsion bar and the magnetic yoke, and magnetic flux of the magnet transmits from the magnetic yoke to the magnetic convergence ring. By transmitting the magnetic flux proportional to the helix angle of the torsion bar to the Hall IC sandwiched between protrusions of the magnetic convergence ring, the steering torque can be detected (**Fig. 7** bottom).

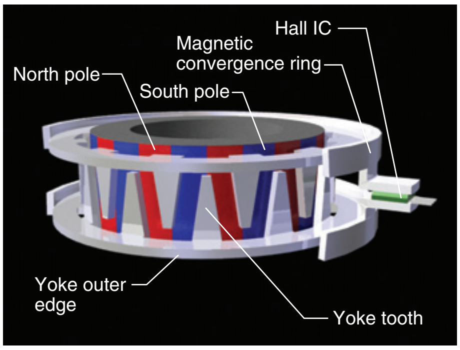

Fig. 7 Detection principle of Hall IC torque sensor

6. Manual Gear

In order to accommodate the higher output, the pinion supporting structure has been optimized, and to improve steering feeling, the gear specifications and the friction distribution of each sliding part have also been optimized.

Figure 8 shows the structure of the manual gear. In order to reduce torque, weight and cost, the combination of a ball bearing and needle roller bearing was considered best and has been adopted for the pinion supporting structure. The pinion shaft diameter has been designed larger than that of conventional ones to handle the higher output.

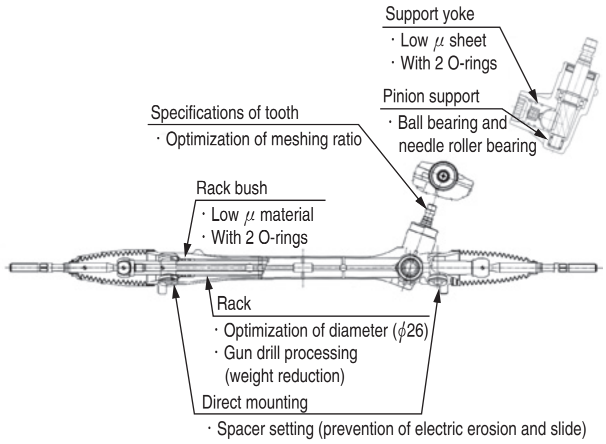

Fig. 8 Structure of manual gear

After studying the optimal specifications by using benchmarking and actual vehicles and carrying out the optimization of the gear meshing ratio, we made a series of gear tooth specifications that can be applied to other parts has been developed in order to comply with the rack axial force up to 12 000 N.

For the support yoke sheet and the rack bush, materials with low friction coefficient have been used in order to reduce sliding friction as much as possible. Accordingly, this structure can distribute frictional force by means of a coil spring load for the rack and pinion meshing area and interference of the O-ring attached to the circumference of the rack bush.

Furthermore, for noise reduction an O-ring is placed on the circumstance of the support yoke, gun drilling of the rack is performed for weight reduction, and a suspension member direct-mounting structure is adopted to improve steering feeling.

By applying a direct-mounting structure, elasticity of the bush rubber in the mounting area, which was a cause of the difference between the result of operating stability evaluation on bench test and that of actual operating stability evaluation, could be eliminated. Therefore, it has become possible to improve the steering feeling based on bench tests only by studying the internal friction distribution of the gear, and to optimize the torque distribution for the period from the start-up torque at the beginning of pinion rotation until the torque reaches its steady state in response to the pinion rotation angle (**Fig. 9**).

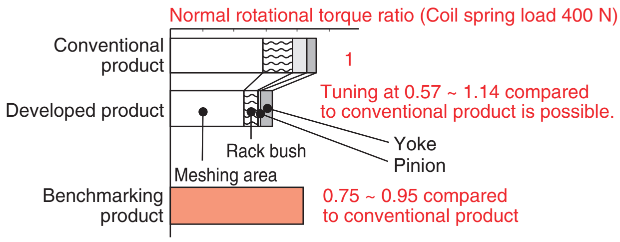

Fig. 9 Friction distribution

7. Assist Control

The EPS control algorithm for this system is JTEKT's original "J-ISM." Two features of J-ISM are shown below.

7. 1 Structure of Phase Compensation

Phase compensation is a system to stabilize self-excited vibration caused by inertia, spring and assist of EPS system.

As shown in **Fig. 10**, with conventional control a uniform phase compensation was maintained matching the high torque region regardless of basic assist characteristics, but with J-ISM as shown in **Fig. 11**, a control logic which orders the required phase compensation depending on basic assist characteristics is adopted.

With this control logic, it has become possible to reduce the quantity of phase compensation in the low torque regions, resulting in improvement of the control of steering feeling around neutral regions of actual vehicles.

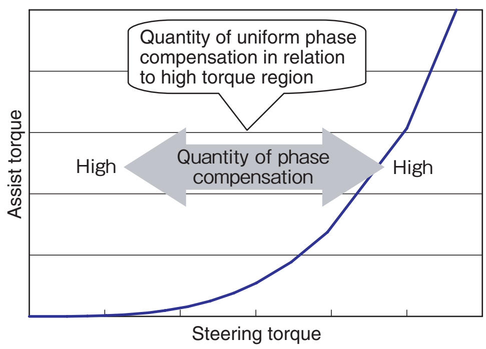

Fig. 10 Phase compensation in relation to basic assist (conventional)

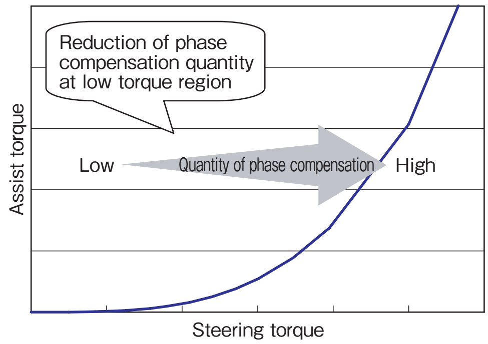

Fig. 11 Phase compensation in relation to basic assist (J-ISM)

7. 2 Disturbance Suppression Effect

Along the development of high-output EPS, a brushless motor has been adopted and its low inertia improves steering feeling. On the other hand, sensitivity to such inverse inputs as flutter and brake vibration has become higher.

J-ISM has adopted a suppression system that can detect inverse input vibration as torque differentiation value, and by providing assist in the direction of canceling the vibration, the vibration is not transmitted to the steering wheel.

Figure 12 shows the result of circumferential acceleration of the steering wheel when sweep vibration is applied from the tie rod. As can be seen in **Fig. 12**, circumferential acceleration of the steering wheel is dramatically reduced over the frequency band range of flutter and brake vibration.

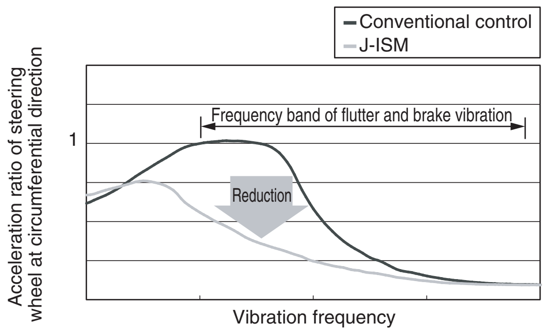

Fig. 12 Example of suppressing effect for disturbance

8. Conclusion

C-EPS was firstly developed for small vehicles for the advantages of ease of installation and energy conservation. Recently, demands for C-EPS for large vehicles have been increasing.

This time JTEKT worked to develop for the first time a brushless C-EPS system and made improvements on such characteristics as quietness of operation and has brought this system to mass-production. JTEKT will continue striving to improve mechanical strength and efficiency to achieve C-EPS with even higher output.

References

1) T. SUGIURA: JTEKT Engineering Journal, 1001E (2006) 65.



Y. NAGAHASHI* A. KAWAKUBO** T. TSUJIMOTO***



K. KAGEI*** J. HASEGAWA**** S. KAKUTANI*

* *System Engineering Department 1, Steering System Operations Headquarters*

** *NV Engineering Department, Steering System Operations Headquarters*

*** *Electronics Engineering Department, Steering System Operations Headquarters*

**** *System Development Department, Steering System Operations Headquarters*