Development of Steering Angle Sensor for EPS Integration

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JTEKT has developed a small, lightweight and low-cost steering angle sensor (SAS) for electric power steering (EPS) integration to meet market needs. The magnetic yoke of the torque sensor mounted in the column and the main gear of the SAS have been molded as one single piece for common use, and positioned in the sensor housing. The electronic control unit (ECU) provides the electronic circuit of the SAS. These efforts have made it possible to reduce the size and the weight of the developed sensor. In addition, the number of parts has been reduced and target cost reduction has been achieved.

Key Words*: electric power steering, steering angle sensor, ESC, torque sensor*

1. Introduction

Automobiles have been aiming to become a safer, securer and more convenient means of transportation. To this end, automobile manufacturers have been developing new technologies. One typical example is the electronic stability control technology (ESC) which improves the safety of vehicles. America, Europe, Canada, and Australia, one after the other has announced that equipping new models with ESC will be compulsory from 2011 and for other models currently in production it is scheduled to be standard equipment within the next few years. In Japan, too, equipping all new models with ESC has become obligatory from 2012. In this context, demand for SASs for ESC is expected to increase. In addition, as SASs are also required for reverse parking assist systems and lane keeping assist systems, demand for SASs is likely to further increase. In order to meet such needs, JTEKT has developed SAS for electric power steering (EPS) integration which aims to be more compact and lightweight in place of conventional add-on types.

2. Purpose of Development

Conventionally, SASs were fixed as a unit (add-on type) to the steering column of vehicles, and thus it was necessary to secure space for installation.

JTEKT, taking advantage of the fact that it is an EPS manufacturer, proposed a compact, lightweight and low-cost SAS by making the SAS share the mechanical and electronic parts it requires with the EPS system, and undertook the integration of EPS and SAS with the aim to improve steering feeling by providing steering angle information to each control function of EPS.

3. Structure of Developed Product

3. 1 Basic Structure of Angle Sensor

The basic structure is such that a main gear that rotates simultaneously with the steering shaft is provided and its rotational movement is transmitted to the detection gears. Rotational angles of magnets attached to the detection gears are detected by magnetic sensors and calculated into steering wheel angles as output (**Fig. 1**). With most SASs now available on the market, the main gear, detection gears and arithmetic circuit of the SAS are unitized.

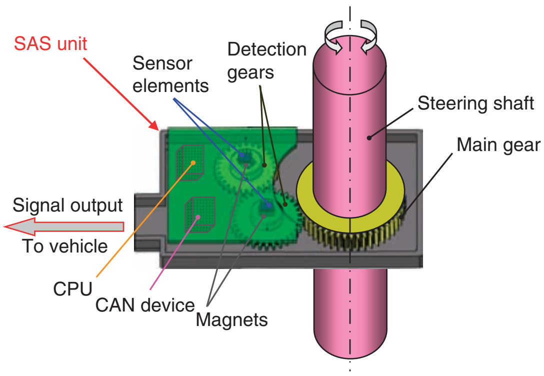

Fig. 1 Basic structure of SAS

3. 2 EPS Integration Structure and its Merits

At JTEKT, the unitized SAS is integrated into EPS and its structure is shown as follows (**Fig. 2**).

(1) The main gear of the SAS is integrally molded with the torque sensor parts of EPS.
(2) Detection gears and magnetic sensors are stored inside the torque sensor housing.
(3) ECU in EPS functions as the steering angle calculation and signal output circuit.

This integration has the following five merits:

(1) By integrating the SAS's main gear and torque sensor parts, the number of components is reduced and the retaining case of the main gear becomes unnecessary, thus material and assembly labor cost can be reduced.
(2) By using the ECU in EPS both as a steering angle calculation and signal output circuit, central processing unit (CPU) and controller area network (CAN) devices of the SAS can be removed. **Figure 3** shows resultant benefits in volume, mass and cost.

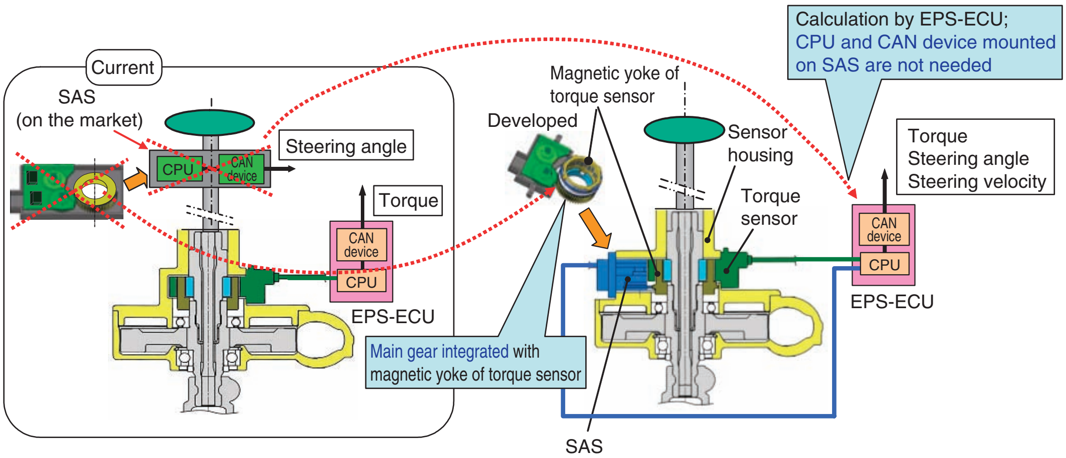

Fig. 2 Integration of EPS and SAS

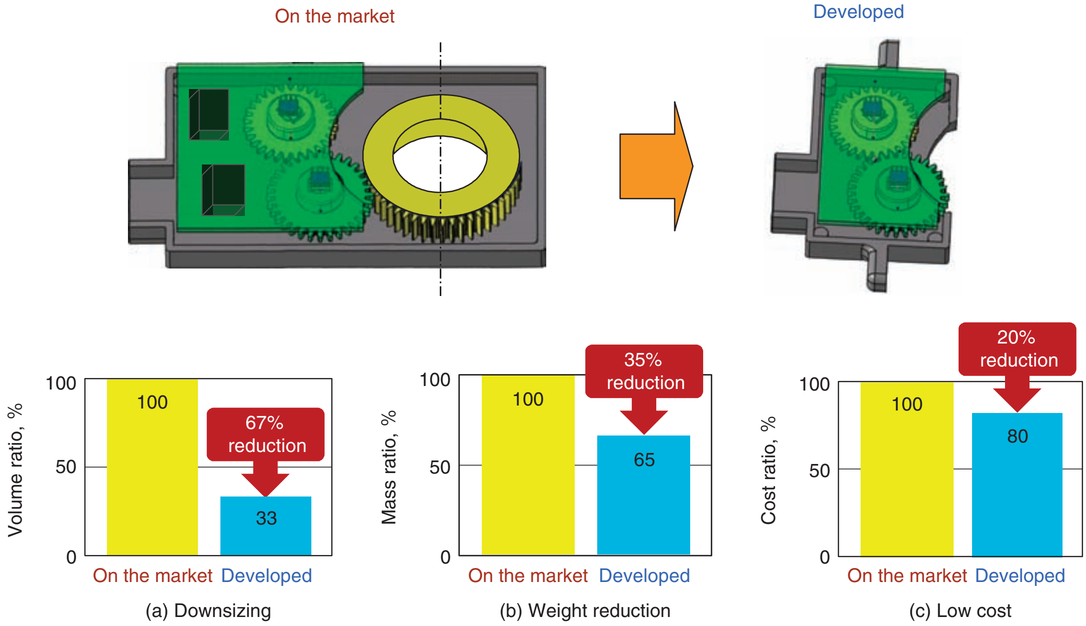

Fig. 3 Volume, mass and cost benefits

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(3) Since detection gears and magnetic sensors of the SAS are stored in the EPS housing, installation and harness connection work on assembly lines of vehicle manufacturers is no longer required.
(4) Tuning for improvement of steering feeling becomes possible by incorporating steering angle information into EPS.
(5) Motor rotation information and SAS signals work to monitor each other, which improves the safety of vehicles.

As shown in **Fig. 4**, a power assist motor is mounted in the EPS. A brushless motor has a built-in rotation angle sensor which is necessary to control the motor itself. When either the built-in rotation angle sensor or the SAS fails to function properly and sends an abnormal signal, it is possible to detect such a failure by mutual monitoring. Even with a brush motor, it is possible to detect a failure by estimating the velocity and the direction of steering angle rotation based on electric current value of the motor.

3. 3 Solution of a Problem Caused by Integration

The EPS torque sensor and the SAS both employ a magnetic system that uses magnets. As integration of the SAS into EPS means that both the sensors are positioned closer to one another, there was a problem of decrease of detection accuracy due to mutual magnetic interference.

As shown in **Fig. 5**, the magnets for the SAS influence the detection accuracy of the torque sensor due to magnetic flux leakage toward the magnetic convergence ring of the torque sensor. This magnetic influence on the torque sensor was able to be decreased by adopting a 4-pole magnet as the magnet for the SAS thereby reducing the magnetic flux leakage toward the torque sensor side. **Figure 6** shows the results of torque sensor signal output fluctuations while rotating a steering wheel, but there is no problem of magnetic flux leakage from the magnet of the SAS.

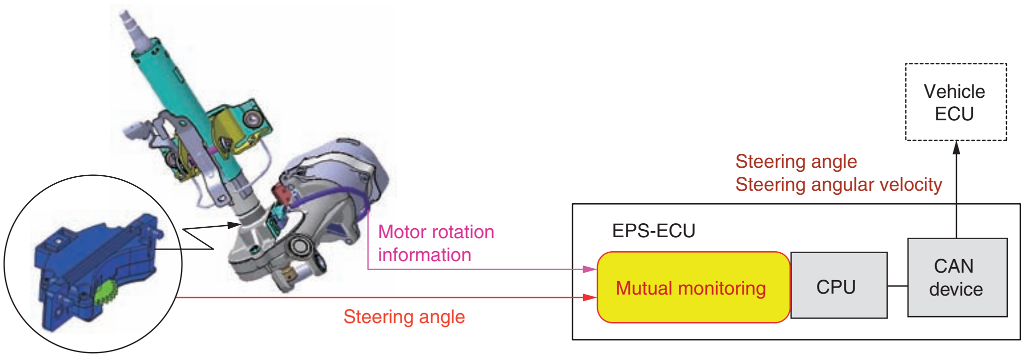

Fig. 4 Mutual monitoring of SAS signal and motor rotation information

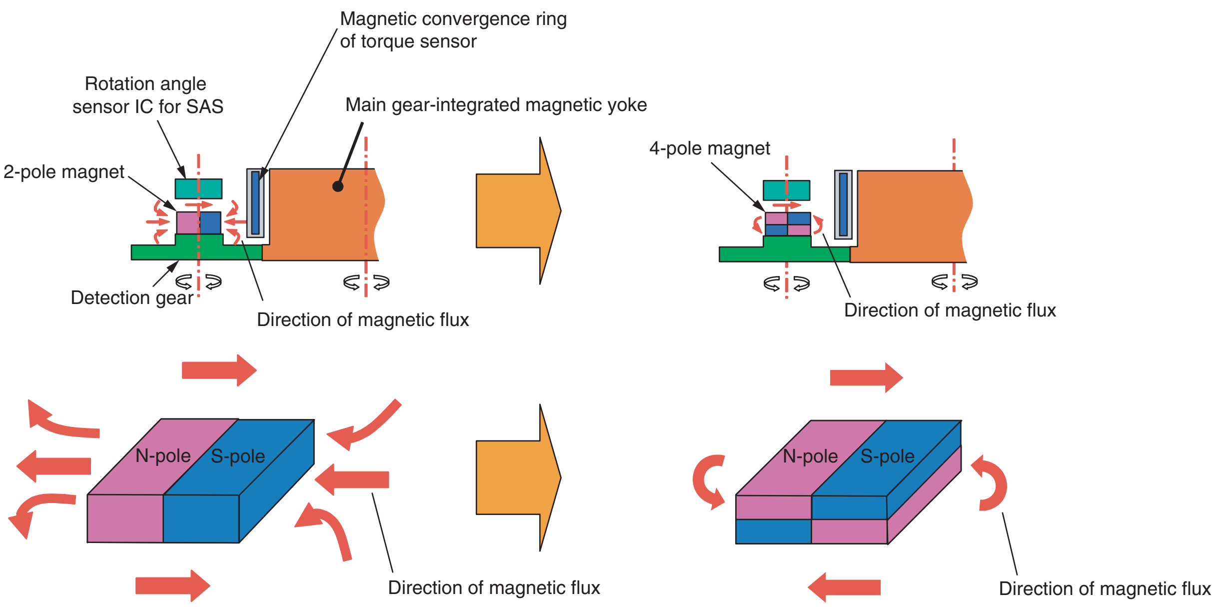

Fig. 5 Reduction of magnetic flux leakage using 4-pole magnet

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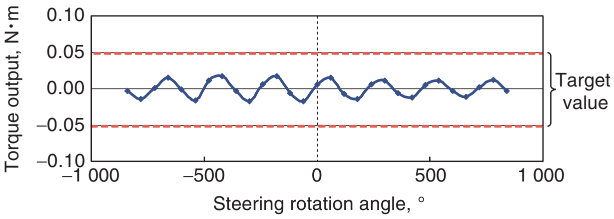

Fig. 6 Reduction of magnetic interference to torque sensor

4. Performance of SAS

4. 1 Development Target Value

Performance required for the SAS is shown in **Table 1**. These development target values have been determined based on the strictest conditions among those required by customers. Definition of hysteresis and linearity of performance is shown in **Fig. 7**.

4. 2 Steering Angle Detection Accuracy of SAS in Column Assembly

Steering angle detection accuracy of the SAS mounted in the column assembly is confirmed by steering wheel steering angle (angle of lower shaft side which is close to vehicle motion) and the output signal of the SAS that corresponds to the steering angle. For the steering wheel steering angle a high precision rotary encoder monitors the steering angle that is standard. Steering angle detection accuracy is calculated with signal calculation software based on the steering wheel steering angles and the signals of the SAS. **Figure 8** shows the outline of performance measurement equipment. Measurement results of the detection accuracy of the SAS are shown in **Fig. 9** as an example of overall accuracy. However, for all other performance items in **Table 1**, their target values have been also satisfied.

4. 3 Endurance Performance

Various endurance performance tests were carried out based on environmental conditions encountered when mounted on actual vehicles. Since all the target specifications were satisfied, the results were excellent (test items, conditions and results are shown in **Table 2**).

Table 1 Development target values

Item		Development target value
Operating temperature range		–40～85℃
Detection range		±800°
Performance	Resolution	±0.1°
	Hysteresis	1.5°
	Linearity	±1.5°
	Overall accuracy	4.5°

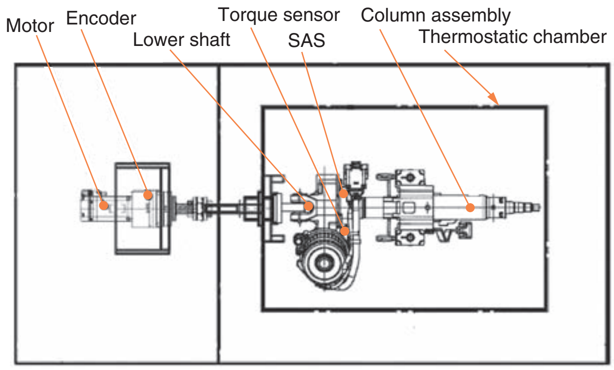

Fig. 8 Measurement equipment for SAS performance

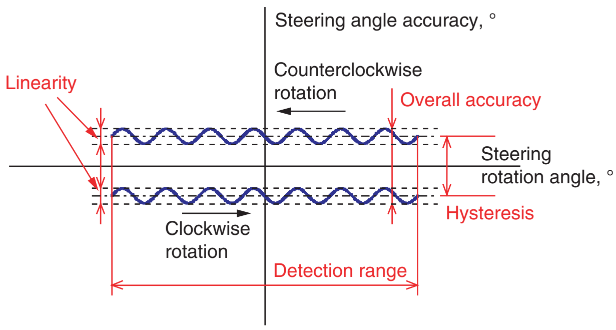

Fig. 7 Definition of accuracy

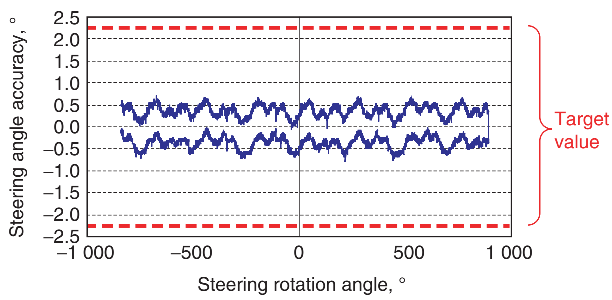

Fig. 9 Accuracy of SAS mounted on column assembly

Table 2 Endurance test results

Test item	Purpose	Test conditions	Evaluation results
Operation durability 1	Durability evaluation of resin gears ①Wear evaluation with fiber-reinforced resin ②Crack or creep deformation due to hot-cold cycle	Oscillation angle ±800° Rotation velocity 60 min^{-1} Temperature –40℃, 25℃, 80℃	○
Operation durability 2		Oscillation angle ±5°, 15 Hz Temperature –40℃, 25℃, 80℃	○
Combined cycle (Temperature, vibration)	Looseness of each part of column assembly under all temperature environments	Direction of excitation XYZ Temperature –40℃, 85℃	○
Vibration durability	Durability of column assembly under vibration	Direction of excitation XYZ Vibration acceleration 2~37 m/s^2, Logarithmic frequency sweep	○

○ : Satisfies target specifications

5. Conclusion

While this development of the SAS for EPS integration has been completed, JTEKT will continue to push ahead with making this system more compact and reducing cost for sales expansion.

Since it has become possible to improve steering feeling by controlling EPS with the help of steering angle information, JTEKT is concurrently considering adoption of the same system into not only our main product Column type EPS (C-EPS®), but also Pinion type EPS (P-EPS®), Rack type EPS (R-EPS®), Hydraulic-electric power steering system (H-EPS®) and electronically controlled variable gear ratio steering system (E-VGR®) in order to respond to the various needs of our customers.


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