Development of Custom IC for EPS Torque Sensor

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In electric power steering systems, the torque sensor plays an important role for detecting the driver’s steering operation as steering torque data and sending this information to the electronic control unit as a signal. Conventionally, printed circuit boards with general-purpose surface-mounted devices have been used to receive and amplify the torque signals detected by the pair of torque sensor coils. Recently, the energy-saving benefit of electric power steering has been receiving much attention, and the number of cars equipped with electric power steering systems has been increasing. On the other hand, requests for cost reduction and high reliability have also been increasing. This paper reports on a custom IC for electric power steering torque sensors that enable torque sensor printed circuit boards to be smaller, have fewer electronic parts, and be cheaper.

Key Words: torque sensor, electric power steering, custom IC

1. Introduction

The torque sensor is an important part within electric power steering (EPS) systems. It detects steering efforts by the driver in the form of steering torque and transmits this data to the control unit. Conventionally, printed circuit boards (PCBs) mounted with general-purpose electronic components have been used to receive and amplify torque signals detected by a pair of coils in the torque sensor. The energy-saving benefit of EPS is receiving much attention, and in recent years more and more automobiles are being equipped with EPS. At the same time, demands for cost reduction and high reliability have also been increasing. This paper contains a description of a custom IC for EPS torque sensors developed by Koyo that enables the manufacture of low-cost, compact torque sensor PCBs with fewer parts to satisfy these demands.

2. Noncontact Torque Sensor Function

Figure 1 shows the torque detection mechanism of the noncontact torque sensor. This mechanism consists of detection rings (1) and (2) mounted on the input shaft, a separate detection ring (1) mounted on the output shaft, and detecting and compensating coils. Torque is detected by the detecting coil, and the effects of detecting coil temperature and external noise are cancelled by the compensating coil. The detecting coil and compensating coil make up a bridge circuit as shown in Fig. 2. Only the changes in the impedance of the detecting and compensating coils are taken as voltage signals. The coil is excited by high frequency sine wave. The high-frequency portion is removed by the detection circuit, and only the torque signal is amplified. The detection circuit has the same circuit configuration for main output and sub-output, making it a redundant system.

As for the torque detection mechanism, the torsion bar is twisted by steering wheel torque as shown in Fig. 3, and the change of magnetic reluctance produced by changing the opposing areas of the detecting coils is converted into a change in coil impedance as the means of detecting torque.

![Fig. 1 Detection mechanism of noncontact torque sensor](image1)

![Fig. 2 Circuit block diagram](image2)

![Fig. 3 Torque detection mechanism](image3)
3. Development

3.1 Aim of Development
The targets given in Table 1 were established when developing the custom IC. The first target was expansion of the temperature range. The operating temperature range specification of general-purpose ICs used in conventional torque sensor PCBs was narrow, at \(-30\,^{\circ}\text{C} \sim 80\,^{\circ}\text{C}\), so these PCBs could not be mounted in the engine room. Therefore, we developed our custom IC with the aim of its being mountable in the engine room by designing it to have low chip and package thermal resistance. As a result, a torque sensor with an operating temperature range of up to 120\,^{\circ}\text{C} was developed that can be applied to P-EPS, in which case the torque sensor is mounted in the engine room.

The second and third targets were to reduce the number of external parts by including as many semiconductor and resistor parts as possible in the single custom IC. Costs can be reduced if the number of parts is reduced.

Also, improved quality and a reduced failure ratio can be expected if the number of soldering places is decreased because the number of soldering defects will be reduced.

The fourth target was to reduce the PCB area by changing to one chip. A prototype PCB was prepared, and a 20\% reduction was realized.

Table 1 Objectives for developing custom IC

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<th>No.</th>
<th>Aim</th>
<th>Reason</th>
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| 1   | Expansion of working temperature range | Mounting in engine room | \(\cdot\) Performance guaranteed temperature \(-40\,^{\circ}\text{C} \sim 105\,^{\circ}\text{C}\)
|     |                               |                         | \(\cdot\) Operating guaranteed temperature \(-40\,^{\circ}\text{C} \sim 120\,^{\circ}\text{C}\)
|     |                               |                         | \(\cdot\) Storage guaranteed temperature \(-40\,^{\circ}\text{C} \sim 150\,^{\circ}\text{C}\) |
| 2   | Quality enhancement           | Reduction of failure rate | \(\cdot\) Reduction of number of components
|     |                               |                         | \(\cdot\) Reduction of number of places to be soldered |
| 3   | Cost reduction                | —                       | \(\cdot\) Reduction of number of components
|     |                               |                         | \(\cdot\) Reduction of number of steps in component mounting process |
| 4   | Downsizing                   | Improvement of mountability | \(\cdot\) Reducing board size (20\% reduction) |

3.2 Development Result

Figure 4 shows the custom IC circuit block diagram. A sine wave for coil excitation is created by the oscillator circuit. This, along with the sine wave reversing the 180\(^{\circ}\) phase by the amplitude reversal current amplification circuit, drives the detecting and compensating coils. Because impedance of the detecting coil is changed by input torque, its change is detected as a voltage change by the bridge circuit. Voltage is amplified by the differential amplifier circuit, and only the input torque signal is extracted by the synchronous detecting circuit. The development content is described in the following section.

Fig. 4 Custom IC circuit block diagram
1) Redundant Dual System Inside Chip

The torque sensor circuit comprises a redundant system using circuits identical to the sub-circuit and main circuit subsequent to the bridge circuit, enabling detection of circuit failure. If a custom IC is used, the main and sub-circuits are made into one package, reducing the benefit of the redundant system. The power source pin and ground pin are therefore provided independently each other. By separating main and sub, the inside of the chip is made into a redundant system, and the element layout enhances the redundant system effect up to the same level as discreet configuration while still being one package (see Fig. 5).

![Fig. 5 Custom IC chip configuration](image)

2) Oscillator Circuit

The oscillator circuit is a 2-phase oscillator that has been used in mass-production products. The question of whether the resistor used in the oscillator circuit should be built into the custom IC was studied. Diffused resistors are generally used in ICs. The absolute precision of these resistors is plus or minus a few dozen percent, and the temperature coefficient is also several thousands ppm/°C. Performance is therefore inferior to that of discreet components. The possibility of creating oscillator circuits by using these resistors was considered, and it was concluded that because precision is low in the case of diffused resistors, oscillation stoppage could occur. Through the use of metal-film resistors able to secure the same precision as discreet components, therefore, components other than capacitors could be built into the custom ICs.

Because an ideal diode circuit using an OP amp was used as an amplitude-limiting circuit, coil excitation voltage was stabilized as shown in Fig. 6, and temperature drift and dispersion could be minimized.

![Fig. 6 Coil excitation voltage temperature characteristics](image)

3) Lower Distortion of Coil Excitation

If the detecting and compensating coils are driven by the OP amp alone, because the electric-current drive capacity of the output stage transistor is insufficient, the coil cannot be excited by sine waves, crossover distortion such as that shown in Fig. 7 is produced, and output is sent to the sensor output as distortion.

In the case of the custom IC, by devising an output stage circuit for the built-in OP amp, we were able to eliminate crossover distortion, as shown in Fig. 8.

![Fig. 7 Coil excitation waveform](image)

4) High-Precision Standard Voltage Source

Standard voltage circuits having superior absolute precision and temperature characteristics were built-in independently for the main and sub circuits. A band gap voltage source circuit was used for each standard voltage circuit. Band gap voltage source circuits are made by combining a VBE* dependent voltage source (negative temperature coefficient) and VT** dependent voltage source (positive temperature coefficient). Therefore the temperature coefficient for the output voltage is approximately zero.

*VBE: Voltage between base and emitter of transistor
**VT: Thermal voltage

Figure 9 shows measurement results and simulation results for temperature characteristics of the regulator built into the custom IC. The temperature characteristics curves match well, and temperature characteristics were able to be minimized.

![Fig. 9 Regulator voltage temperature characteristics](image)
5) IC Built-in Resistor
IC built-in resistors are characterized by low absolute precision and high relative precision. Accordingly, we used diffused resistors for voltage dividing circuits and OP amp return circuits, for which performance depends on relative precision of the resistor, and metal-film resistors for the regulator circuits and oscillator circuits, which require both high absolute precision and high relative precision.

4. Temperature Characteristics of Torque Sensor PCBs
Figure 10 shows the results of measured temperature characteristics of a prototype torque sensor PCB mounted with the custom IC. As 20% temperature drift relative to the required standard is provided with little dispersion, the device can be mounted in the engine room.

Fig. 10 Temperature characteristics of board mounted with custom IC

5. Conclusion
Development of the custom IC has enabled the number of components mounted on the torque sensor PCB to be reduced and costs to be lowered. There being fewer components enables the board area to be smaller and minimizes the dispersion of temperature characteristics. It is believed that EPS systems will frequently be mounted in the engine room in the future. This will increase the need for custom ICs and lead to the enhancement of EPS performance.

References