Development of Pinion-Assist Type Electric Power Steering System

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As part of its development of environmentally friendly electric power steering systems, Koyo has succeeded in the development and mass-production of pinion-assist-type electric power steering systems. Such systems are equipped with a high-power motor and can be packaged under the hood, while conventional column-assist-type systems must be mounted inside the passenger compartment.

Key Words: *electric power steering, environmental friendliness, engine room*

1. Introduction

In recent years energy conservation has become a matter of concern in all industries, and the development of environmentally friendly products has become an issue of great urgency. Needless to say, the automobile industry also requires such energy-saving products. In response to these needs, Koyo in 1988 became the world's first company to succeed in the commercial manufacture of an electric power steering (EPS), and since that time it has been mass-producing column-assist-type electric power steering (C-EPS) systems, which have electric power assistance provided by a DC motor and are installed in the passenger compartment. Currently a trend exists toward application of EPS not only on subcompacts but also on light vehicles, and in response Koyo has developed a pinion-assist-type EPS (P-EPS), which has higher motor output and can be installed in the engine room. Koyo has already begun the mass-production of P-EPS for light vehicles in Europe. This system is introduced below.

2. Outline of Pinion-Assist Type Electric Power Steering System

2. 1 Target of Development

Development was focused on the three following points in order to enable installation of the system in the engine room:

1) Shortening of axial dimension
2) Usability in higher temperatures (wider range of operational ambient temperatures: –30℃ to +95℃)
3) Waterproof construction

Regarding this system, the structure is shown in **Fig. 1** and the cross-section in **Fig. 2**. This system consists of an EPS unit, comprising a torque sensor, reducer and motor, attached to a conventional rack & pinion-type manual gear. This construction enables assist characteristics to be controlled by means of the EPS unit.

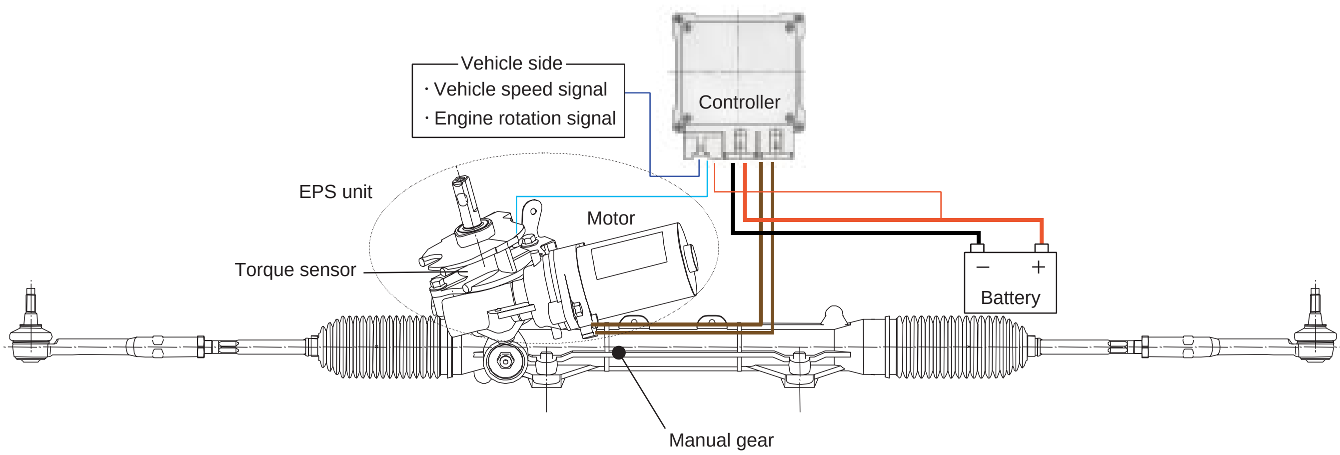

Fig. 1 Structure of P-EPS system

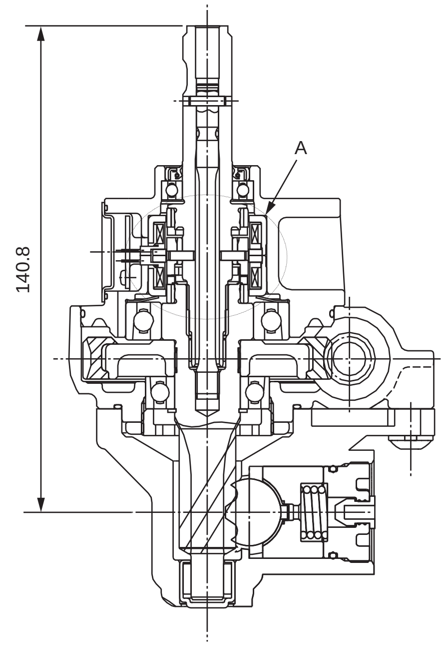

Fig. 2 Cross Section of manual gear of EPS-unit

2. 2 Small Torque Sensor

The structure of the torque sensor is shown in **Fig. 3**. The torque sensor is 7.0mm smaller axially and 3.5mm smaller diametrically than the conventional product. The following are features of its components:

1) Coil assembly: A change from the axial lead wire & connector type to the radial pin type. Application of automatic copper wire winding on the bobbin for denser winding resulted in 3.5mm diametrical reduction.
2) Distance piece: Eliminated due to 1)

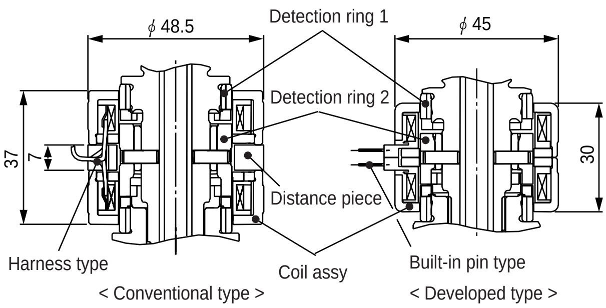

Fig. 3 Comparison of torque sensor (A) area

Figure 4 shows the results of analysis of the magnetic field between the coil assembly and detection ring[1]. In this figure, magnetic flux density (T: tesla) gets higher as the color changes from blue to red. Shown on the right side of this figure is the detection coil, where a variation of magnetic flux density in the magnetic circuit, in other words, a variation of impedance in the coil, is generated according to input torque from the steering wheel (relative torsion between detection rings), enabling an electric signal to be detected as a function of the torque. The left side shows the temperature compensation coil, the purpose of which is to compensate for impedance changes resulting from ambient temperature changes, by which the magnetic circuit's magnetic flux density is kept constant.

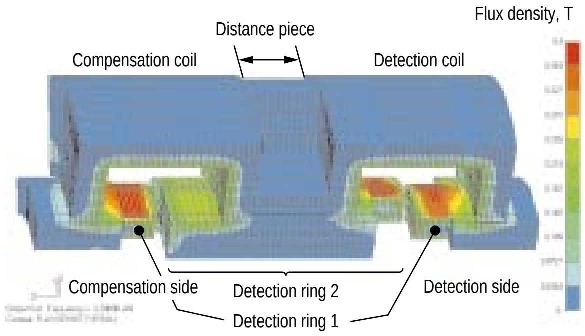

Fig. 4 Analysis of magnetic flux density for torque sensor

As the result of this analysis, it was concluded that the distance piece could be eliminated because this area is not affected by the combined magnetic fields of the detection and compensation coils.

3) Detection ring 2: Attachment position is moved 7.0mm toward detection ring 1 because of 2) above.
4) Method of securing the torque sensor control printed circuit board: Use of a tapping screw and elastic spacer in place of the conventional two tapping screws.

The objective of this method is to relieve thermal impact stress on the soldering between the coil assembly and control printed circuit board, which could be generated by the change to the pin-type coil assembly described in item 1) above. **Figure 5** shows the details of this securing method.

Through the addition of these improvements, torque sensor temperature characteristics equivalent to those of the conventional product have been obtained, as shown in **Fig. 6**.

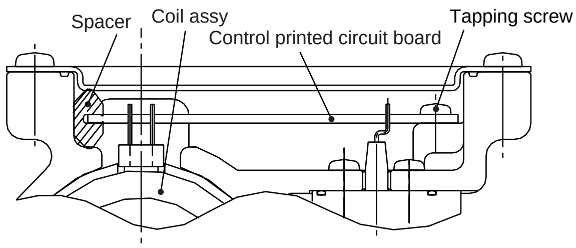

Fig. 5 PCB fixing

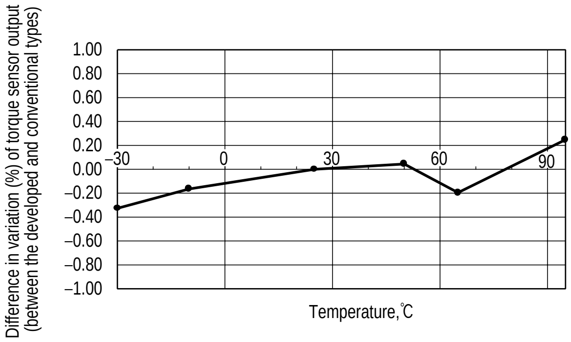

Fig. 6 Torque sensor output with temperature

2. 3 Heat-Resistant Resin Reduction Gear for High Output

A worm-type reduction gear, which is widely used in electric power steering systems and is capable of providing a high reduction gear ratio, has been adopted. A new resin material satisfying the following requirements was developed for the reduction gear:

1) Superior strength and wear resistance to be suitable for the high-output motors because of the expansion of EPS application from subcompacts to normal passenger cars.
2) Heat resistance sufficient for installation in the engine room.
3) Suitable for injection molding.

It is known that the backlash (clearance between the worm and reduction gear wheel) after reduction gear endurance testing increases inversely proportional to the resin material's relative viscosity, and therefore, taking moldability into account, the resin of upper limit relative viscosity was selected. The amount of the backlash increase after reduction gear endurance testing is equivalent to that of a conventional reduction gear.

Figure 7 shows a comparison of strength and durability between the selected material and two reinforced materials, and **Fig. 8** shows increases in backlash after reduction gear endurance testing.

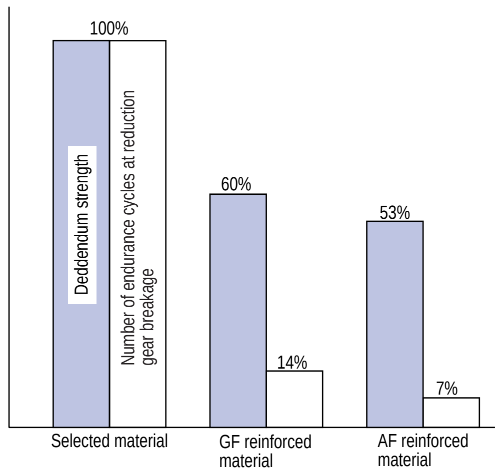

Fig. 7 Strength & durability of the material for reducer

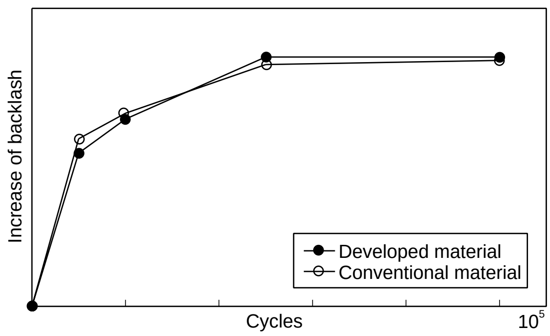

Fig. 8 Backlash increase after endurance test

2. 4 P-EPS Specifications

The following are P-EPS specifications:

Table 1 Specifications of P-EPS

Items		Specification
Theoretical rack force		7 747 N
Rack stroke		144mm
Stroke ratio		45.335mm/rev.
Rack & pinion	Module	2.3
	Number of pinion teeth	6
Reducer	Type	Worm and resin wheel
	Reduction gear ratio	15 : 1
Motor	Type	Brushed DC motor
	Rated voltage	12 V
	Rated current	65 A
	Rated torque	3.4 Nm
	Rated rotational speed	1 180 min^{-1}

2. 5 Controller for P-EPS

Controllers to be installed in the passenger compartment are currently being mass-produced for C-EPS. However, because P-EPS controllers must be installed in the severer environment of the engine room, temperature-sensitive overheating prevention control and a waterproof structure were added to the conventional controller. **Figure 9** shows the basic control block diagram.

1) Assist control

As in the case of the current controller, appropriate assist is provided on the basis of steering torque detected by the torque sensor. In addition, to ensure that an appropriate assist characteristic is obtained, matching with the vehicle on which the P-EPS is to be installed is carried out and an assist characteristic map and compensation control map suitable for the vehicle determined.

2) Overload prevention control

Heat is generated by operation of the controller and motor. The function of overload prevention control is to protect the EPS system from such heat. By limiting motor current, a major cause of heat generation, it is possible to prevent the temperature from rising above a certain level.

3) Temperature-sensitive overload prevention control

Controllers currently being mass-produced have overload prevention control, whereby current limit is set based on the correlation between the motor's maximum operational temperature and maximum-current flow time.

Because P-EPS is installed in the engine room, its sustained temperature has been set at 120℃, higher than that for C-EPS. Accordingly, because the range of operating temperatures is wide and a uniform overload protection control could degrade efficiency, a temperature-sensitive type has been used.

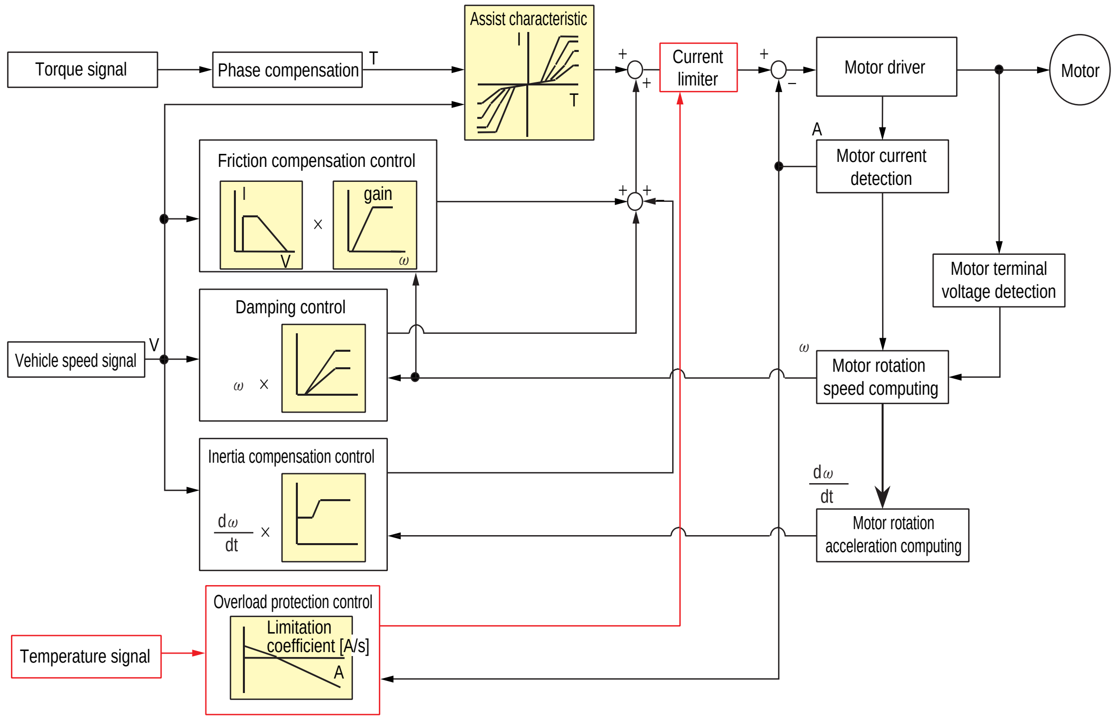

Fig. 9 Block diagram of basic control

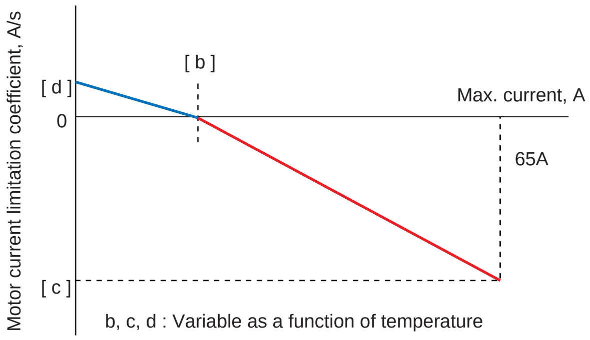

Fig. 10 Motor current control coefficient (red line) and restoration coefficient (blue line)

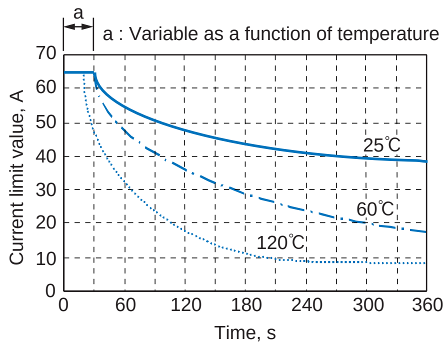

Fig. 11 Current limit pattern per temp. (max. current)

This function enables the environmental temperature of the P-EPS system to be perceived by a thermistor positioned on the torque sensor so that the controller can perform overload protection control in conformity with the environmental temperature (operational temperature) of the P-EPS system.

Basically, the temperature signal shown in the basic control block is read into the overload control block and the following control performed.

(1) The parameter value ([a][b][c] or [d]) is selected according to the environmental temperature of the EPS system. See **Figs. 10** and **11**.

(2) When the current value detected by the motor current detection block is higher than [b], the motor current limit value is progressively decreased at a rate of [c] from its initial value by the electric current limiter.

<Example of control> Case : 65A system. Normal temperature = 25℃. Continuous flow of maximum current (65A) for 40 seconds. ([a] = 30s, [b] = 18.5A, [c] = – 0.177A, [d] = 0.0508A/s)

Initial value : 65 – [a] × [c] = 70.31A

Maximum admissible current value:

70.31 + ([c] × 40) = 63.23A

Accordingly, for the purpose of overload prevention, the maximum current is limited to 63.23A, even at the maximum steering torque.

(3) When the current value detected by the motor current detection block is smaller than [b], it restores the motor current limit value at a rate of [d]. **Figure 12** shows the pattern of electric current restoration by temperature.

<Example of return> In the case that a current of 0A is held for 30 seconds after completion of (2):

Maximum admissible current value:

63.23 + ([d] × 30) = 64.75A

Accordingly, the motor current limited by the overload protection control is restored to 64.75A.

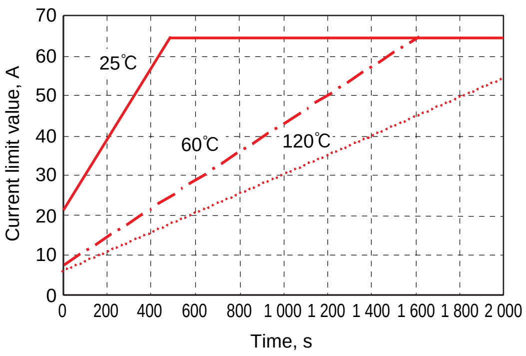

Fig. 12 Current restoration pattern per temp. (at zero current)

2. 6 Waterproof Structure

Figures 13 and **14** show the waterproof structure of this system. The motor is class JIS D1 (functional test for parts susceptible to temporary water immersion), and the EPS controller is class JIS S2 (functional test for parts susceptible to direct rain or water splashes).

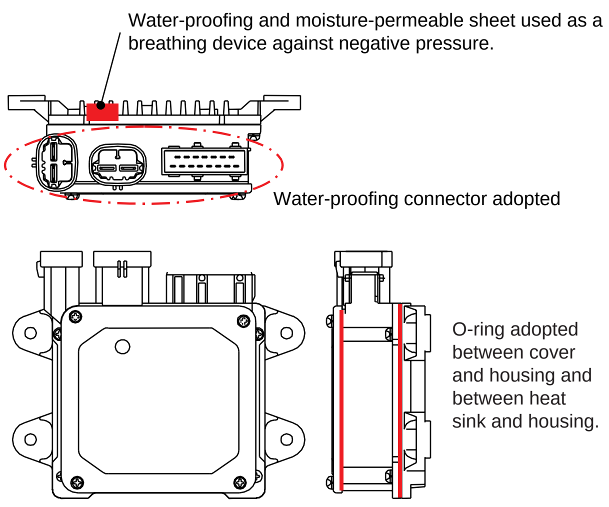

Fig. 13 Water-proof structure of ECU

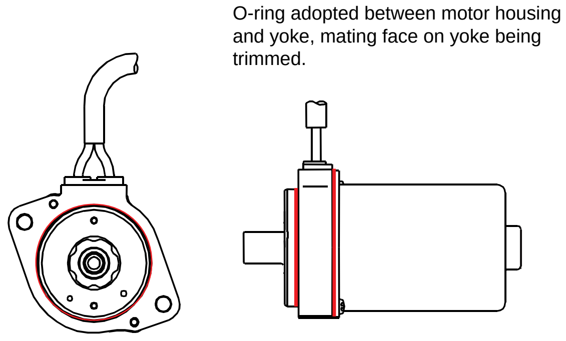

Fig. 14 Water-proof structure of motor

3. System Performance[2)]

1) Reverse input sliding load characteristic

Enlargement of the reduction gear ratio is generally one method of improving the system's assist force. However, this causes increased inertia and torque loss-unavoidable in the case of brushed motors-to increase on the steering wheel shaft, which leads to the problem of insufficient steering wheel return, a disadvantage of EPS systems. To resolve this problem, we set the reduction gear reduction ratio as high as possible after considering customer requirements in areas such as steering gear packaging space, steering responsiveness, steering feeling, and rack force. In addition, as shown in **Fig. 15**, a 10% reduction in steering gear assembly reverse sliding load (friction of the steering gear itself when load is applied through the rack shaft) in relation to the conventional product was achieved, control to return the steering wheel to neutral position electrically through the use of an angle sensor, etc. became unnecessary, and a steering feeling with both naturalness and good center-feeling was obtained. We are working to reduce this reverse sliding load by reducing the frictional resistance of all parts within the EPS unit and rack & pinion area. Regarding the EPS unit, we are studying oil seal rotational torque and rotational torque after preload adjustment of the bearings supporting the reduction gear, while regarding the rack & pinion area, we are study support yoke sheet material selection, rack bush materials, bearing support construction, and coil spring set load.

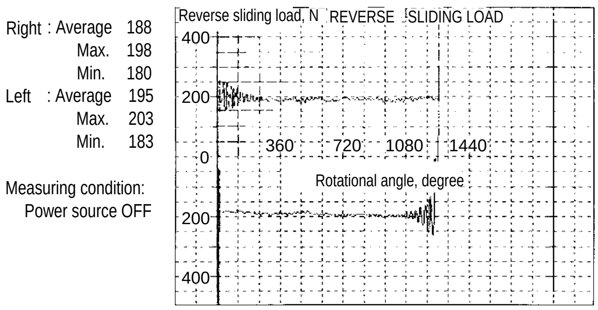

Fig. 15 Reverse sliding load of steering gear

2) Assist characteristic

Figure 16 shows representative assist characteristics for this P-EPS system.

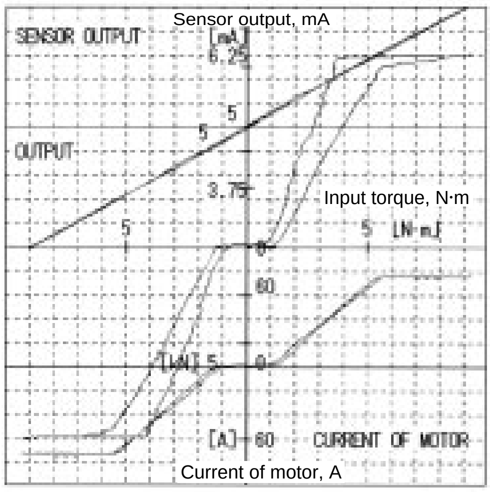

Fig. 16 Assist performence of steering gear

4. Conclusion

Mass-production for export of this P-EPS system containing a worm-gear-type reduction gear has now begun in full. Regarding the development of this system, the R&D Center in Japan was responsible for the EPS unit, and the European Technical Center was responsible for the reduction gear, marking the first case in which Japan and Europe jointly developed an entire EPS system. Initially, communication problems stemming from differences in language, culture and design concepts existed, and the team had to tackle such problems as identifying the friction of various parts in order to reduce reverse sliding load. However, through such IT means as TV conferences, joint design reviews and various forms of data exchange, the two sides were able to achieve mutual understanding and succeed in this global development project.

Regarding the future direction of P-EPS development, we will endeavor to reduce costs through the increase of local content, improve the freedom of tuning so that it can be optimally matched to the vehicle, and expand application to larger vehicles. In addition, we will work on a global basis to develop systems suitable for high-voltage vehicle systems, toward which the automotive industry is currently moving.

References

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