Next-generation Motor Controller Unit for Electric Power Steering

Authors: Yoshihito Asao* and Yoshihiko Kimpara**

The motor controller unit (MCU) for electric power steering (EPS) needs to be smaller and lighter to provide a superior steering feel as well as to improve fuel consumption and mountability. To meet these needs, a next-generation MCU has been developed and put into mass production by fully integrating an optimized internal structure, electromagnetic design and high-output control (Fig. 1).

Fig. 1 Next-generation motor controller unit

1. Features of Next-generation MCU - Motor

To achieve a small and light body as well as a superior steering feel, the next-generation MCU motor uses a “Poki-Poki” core, 10-pole-12-slot system, delta-connection and segment magnets.

The Poki-Poki core is Mitsubishi Electric’s original technology, where wires are first wound on a linearly extended core which is then formed into a circular shape. For the next-generation MCU motor, the conventional Poki-Poki core design has been further improved to compensate manufacturing variations of the cores and rotors and reduce cogging torque which adversely affects the steering feel.

The combination of the numbers of magnet poles and stator slots was reviewed and the conventional 8-pole/12-slot design has been modified to a 10-pole-12-slot combination. This 10-pole-12-slot system provides a high winding factor for the fundamental harmonic, which means high efficiency of magnetic flux utilization and enables the magnet volume per unit generated torque to be reduced. On the contrary, the new system provides low winding factors for the higher harmonics (5th and 7th), which reduce the torque ripple and thus improve the steering feel.

In contrast to the ring-type magnet of the current-generation product, the next-generation product employs a segment magnet (Fig. 2). In combination with the optimized electromagnetic design, the magnet volume has been reduced by about 40% from the ring-type magnet. The torque ripple and cogging torque have also been reduced by optimizing the magnet shape.

Fig. 2 Comparison of magnet shapes

2. Features of Next-generation MCU - Controller

In the next-generation MCU, a motor and a controller are integrated and arranged on the same axis to reduce the size, weight, and cost.

Figure 3 shows the internal structure of the next-generation MCU. On the heat sink, an inverter circuit is mounted to drive the motor, consisting of three compact power modules, each of which corresponds to each of three phases, and a relay module for isolating the MCU from the external power supply. These four modules in total are concentrically arranged and evenly spaced. Between these modules, large capacitors and choke coils are also concentrically arranged to achieve electromagnetic compatibility (EMC). Connection terminals for these large components are put together in the insert-molded single resin frame.

3. Features of Next-generation MCU - Control System

To achieve a superior steering feel for the next-generation MCU, we have developed a motor control system for better stabilization with an improved
damping performance and better adaptability to high rotation speed of the steering wheel.

When driving on a stone-paved or similar road surface, uncomfortable vibration is sometimes propagated to the steering wheel. The new control system successfully reduces such vibration thanks to a software damper that controls the motor based on the steering torque and the rotation speed of the motor. This system provides a superior steering feel by ignoring those vibrations in the frequency band associated with the driver’s steering actions, while effectively damping vibrations in higher frequency bands.

When the rotor rotates, the magnetic flux from the rotor changes, and then an electromotive force is generated in the stator coil by electromagnetic induction. This electromotive force is generated in such a direction that an associated electric current opposes a change in the rotor’s magnetic flux. This force is called counter-electromotive force, and the faster the steering wheel is rotated, the greater the counter-electromotive force is. When the next-generation MCU detects an increase in the rotation speed of the steering wheel, the control system reduces the counter-electromotive force by providing the motor with an electric current in the direction to oppose the rotor’s magnetic flux.

4. Features of Next-generation MCU - Packaging

Compared to the current-generation MCU with an equivalent output power, the next-generation MCU has been made 50% smaller in volume and 30% lighter, by arranging the controller and motor on the same axis, downsizing and optimally arranging the built-in parts, and rationalizing the connecting components. The new MCU significantly improves the mountability on the vehicle and reduces the fuel cost. Table 1 summarizes the key specifications of the next-generation MCU, and Fig. 4 shows a physical comparison of the current- and next-generation MCUs both having the same output power.

<table>
<thead>
<tr>
<th>Table 1 Specifications of next-generation MCU</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Item</strong></td>
</tr>
<tr>
<td>Diameter (Controller)</td>
</tr>
<tr>
<td>Diameter (Motor)</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Rated torque</td>
</tr>
</tbody>
</table>

Because of its large size, the current-generation MCU needs to be custom designed to suit the customer’s request for the vehicle layout and connector specifications. For the next-generation MCU, the connector port has been modularized (surrounded by the dashed line in Fig. 4) and only the connector can be modified as required by the customer.

We will continue to help reduce automobile fuel consumption by offering next-generation MCUs to automobile and steering manufacturers.