

2-Drive Motor Control Unit for Electric Power Steering

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ABSTRACT

The electric power steering (EPS) is increasing its number since there are many advantages compared to hydraulic power steering. The EPS saves fuel and eliminates hydraulic fluid. Also, it is more suitable to the cooperation control with the other vehicle components. The EPS is now expanding to the heavier vehicle with the advance in the power electronics. In order to meet customer's needs, such as down-sizing, lower failure rate and lower price, we have developed the new motor control unit (MCU) for the EPS. The motor and the electric control unit (ECU) were integrated for the better installation. We adopted new technologies of redundant 2-drive design for more safe EPS. "2-drive Motor Control technology" which consists of dual winding, two torque sensors and two inverter drive units. In our developed MCU, even if there is a failure in one of the drive unit, the assistance of the EPS can be maintained with the other drive unit.

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INTRODUCTION

There is growing requirement of less fuel consumption and CO₂ emission since the fuel consumption is getting higher every year. The electric power steering (EPS) is increasing its number [1] because it reduces load to the engine compared to hydraulic power steering and it can keep working without engine in HV or EV. Moreover, EPS plays an important role in the driving assistance such as active safety and automated parking. It is expected to increase its number. Originally, the fail-safe concept of the early EPS system was designed to shut down the EPS assistance by the fail-safe functions in any case if there is a failure. Because the adaption of the early EPS systems started with the small vehicles, the driver needed less effort to make a turn even if the EPS system shut down. However, as the adaptation of the EPS expands to the heavier vehicles with the advance in the power electronics, it is more preferable to maintain assistance. It is more difficult for the driver to make a turn in the heavier vehicle such as pickup trucks and SUVs without assistance of the EPS. Reducing the very low possibility of shutting down the EPS even lower may be required in the heavier vehicle.

In order to reduce the possibility of shutting down the EPS, we've developed a new motor control unit (MCU). It is 2-Drive EPS-MCU with redundant motor drive units. Since this new MCU can maintain the EPS assistance by remaining motor drive unit even if one of the motor drive units doesn't work due to the failure in the system, our 2-Drive EPS-MCU can dramatically reduce the failure rate of the

EPS. We have evaluated the conventional MCU and the new MCU according to the ISO 26262, one of the most well-known standards in the automotive industry.

CONFIGURATION OF 2-DRIVE MCU FOR EPS

1). Mechanical Structure of 2-Drive MCU

In [Figure 1](#), the mechanical structure of 2-Drive EPS-MCU is shown. One feature of the mechanical structure is having the ECU integrated into the motor housing. ECU is mainly composed of the microcontroller, the power modules for 2-Drive inverter unit, the peripheral IC for the microcontroller abnormality detection and the heat sink for spreading heat which is generated by the joule heating of the power modules. By adopting the redundant design and by integrating the motor and the ECU, a more reliable and smaller product compared to our previous product has been achieved. The volume was reduced by 30% and the weight was reduced by 20%. Specific detailed technical viewpoints to reduce the product volume are the development of direct connecting method between motor wires and Power modules, called mechanical-electric connect. It allowed us to eliminate the bus bar module which connects the motor wires and the power modules for motor drive units. The conventional motor structure is shown in [Figure 2](#).

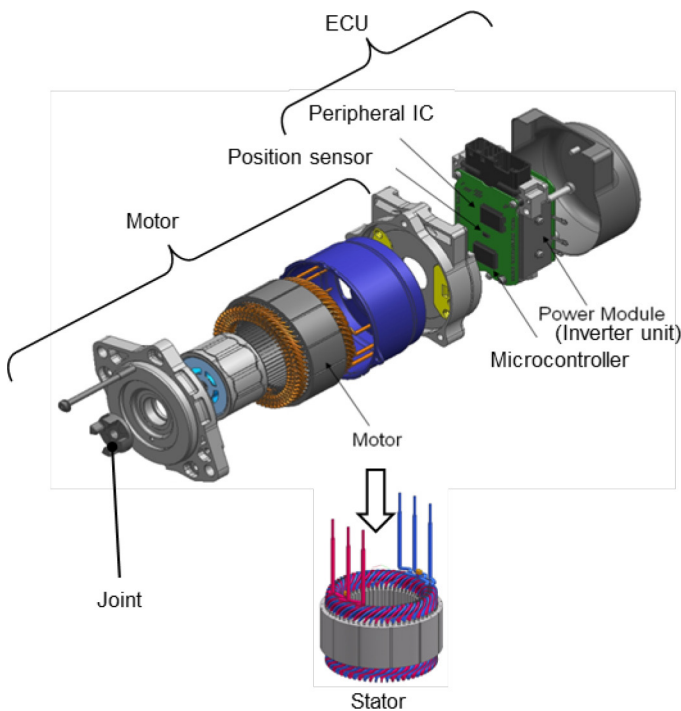


Figure 1. 2-drive MCU for EPS

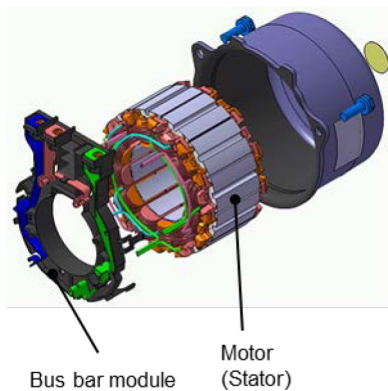


Figure 2. Conventional Motor Structure

Furthermore the 2-Drive motor drive concept could reduce the heat sink volume and the number of large size electrical parts by reduction of the maximum motor current to the half. Each power module manages the half of the required motor current. The sum of the output of the two power module configures the output of the motor.

As for the motor winding technology, there are two advantages. One advantage is noise reduction and the other advantage is better motor output density. This technology enabled our products to reduce the noise and vibration. We achieved the noise lowering of 7 dBA. Regarding the increase of the motor output power, we achieved 3.5% increase of the motor output by the arrangement of the windings.

2). System block of 2-Drive MCU

At first, EPS system consists of steering wheel, mechanical components which connect steering wheel and tire, torque sensor to detect driver's steering torque which is input data for EPS-MCU, and EPS-MCU which assists the driver's steering control. Figure 3 shows

the system block diagram of 2-Drive MCU-EPS which we developed. As shown in Fig.3, our redundant concept is composed of the redundant torque sensors for detection of a driver's steering torque which is input signal for EPS-MCU, the redundant inverter units, the redundant winding wires and the redundant position sensors for detection of the motor rotation position. Each redundant function also has independent operation by each power supply. Therefore, if a malfunction happens in one of the drive line, the EPS steering assistance is able to be maintained by the remaining drive line. As for the microcontroller, in order to achieve ASIL-D based on ISO 26262, we adopted lock-step CPU architecture. The lock-step CPU architecture can detect a transient error and a permanent error, and this feature helps to enhance the EPS system reliability.

Since "2-Drive EPS-MCU" system architecture looks a bit complex and increases the number of the electrical parts, it looks like that the cost of redundant concept "2-Drive EPS-MCU" is increased, but it's not true. Because the optimization of 2-Drive motor current control allows us to reduce a number of large size electrical parts, such as an aluminum electrolytic capacitor. Also, the 2-Drive concept allows us to select smaller chip size power semiconductor devices. Since the current for the each power module is reduced, the heat generation on the power semiconductor devices by the joule heating becomes 25%. The reduction of the heat also contributes to the reduction of the size of the heat sink. Details of redundant 2-drive motor technology and 2-drive current control technologies are explained in the later chapters.

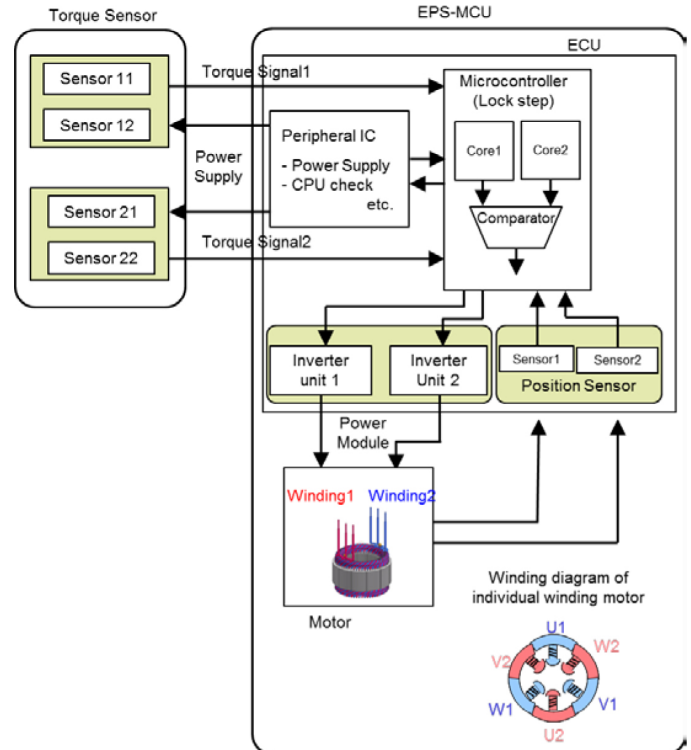


Figure 3. System Block Diagram of Developed EPS- MCU

3). Electrical Configuration of 2-Drive MCU

Figure 4 shows an electrical circuit diagram of the single motor drive as the conventional concept. There is one electrical circuit and one winding. Figure 5 shows an electrical circuit diagram of the dual motor drive as the 2-Drive EPS-MCU concept which we developed. There are two electrical circuits and two windings.

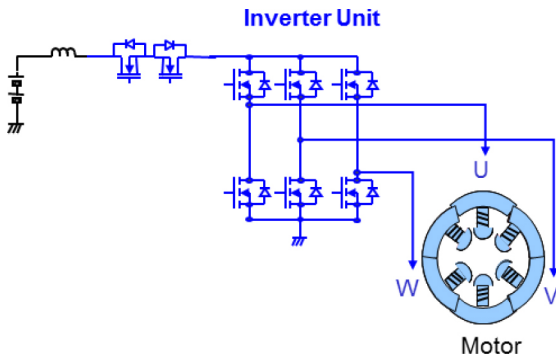


Figure 4. Single Motor Drive

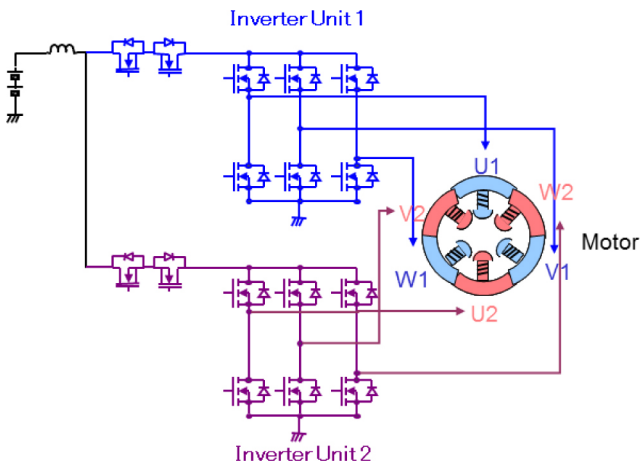


Figure 5. Dual Motor Drive

As for the specific behavior of the conventional concept, single motor drive motor control (conventional MCU for EPS) during failure occurrence, if a failure happens in any part of the electric power steering, the EPS power assistance is shut off by fail-safe functions. Since the vehicle will revert to manual steering, steering control can be maintained, but greater driver's effort would be required especially at low vehicle speeds. On the other hand, our new redundant concept, the dual motor drive, can reduce the driver's effort because the EPS assistance is maintained by the remaining drive line even if one of the drive line is stopped by a malfunction occurrence. Figure 6 shows specific operation during fault occurrence in one drive line such as Inverter unit 2. In this case, Inverter Unit 2 is shut off by fail-safe functions, but since Inverter Unit 1 is able to keep providing motor current, a driver can steer the steering wheel with greater effort, but still less than if failure occurred in a single motor drive system.

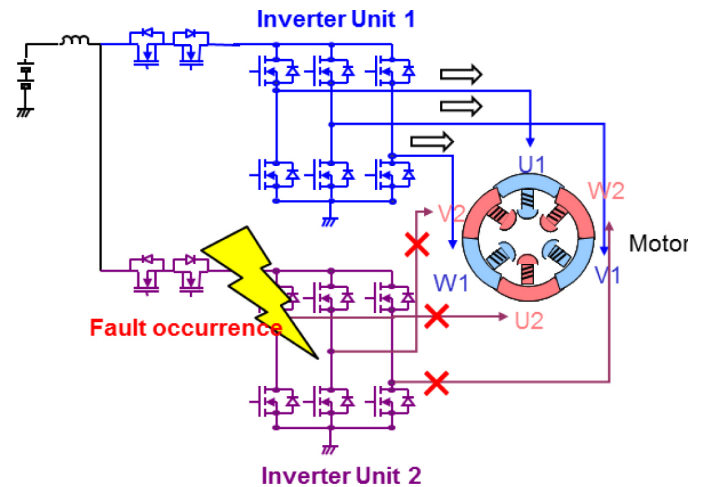


Figure 6. Operation of 2-Drive MCU during fault occurrence

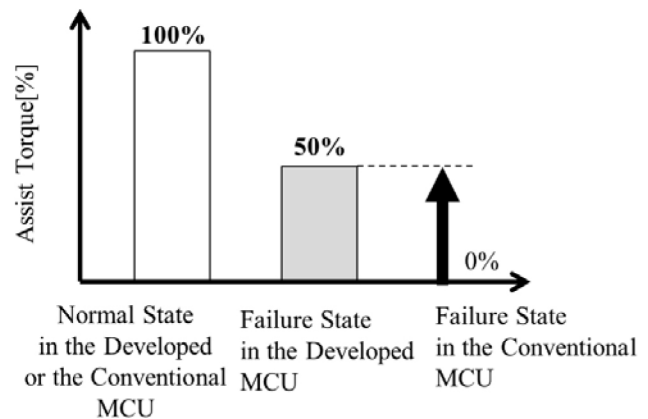


Figure 7. Assist Torque in Developed MCU and Conventional MCU

The maximum torque of the 1-drive mode, or failure state in developed system, is half of the maximum torque in 2-drive mode, or normal state. In EPS, usually large torque is required only in stopped vehicles. Therefore we think that a half of the torque is sufficient to maintain EPS assist in the moving vehicle. Comparison of the maximum torque of the normal state in the conventional and the developed MCU, the failure state in the developed MCU, and the failure state in the conventional MCU is shown in Figure 7.

MOTOR TECHNOLOGY IN 2-DRIVE MOTOR CONTROL UNIT

The motor technology of the dual winding motor is introduced in this chapter. As shown in Figure 8, two windings are arranged in the common stator. The two windings are electrically independent. The detailed layout of the windings is shown in Figure 9. Two windings are arranged in the stator with $\pi/6$ radians phase difference in the electrical angle.