Development of Inverter-Integrated Motor Units

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Abstract: Components for EVs (electric vehicles) and HEVs (hybrid electric vehicles) are required to be smaller in size and lighter in weight to fit into a limited vehicle space, and higher in efficiency and lower in price. This article introduces the Inverter-Integrated Motor Units that have been developed to meet these requirements.

Keywords: Inverter, motor, inverter-integrated motor unit

1. Introduction

In the past, Company M has developed and commercialized drive motors for i-MiEV, Outlander PHEV, etc. [1] [2]

In recent years, components for EVs and HEVs have been required to be smaller in size and lighter in weight to fit into a limited vehicle space, and higher in efficiency and lower in price. Company M has developed inverter-integrated motor units to satisfy these requirements.

The advantages of inverter-motor integration include reduced dead space in the vehicle and reduced weight through elimination of the three-phase high-voltage cable, cooling hose, and signal wire between the motor and inverter (Fig. 1).

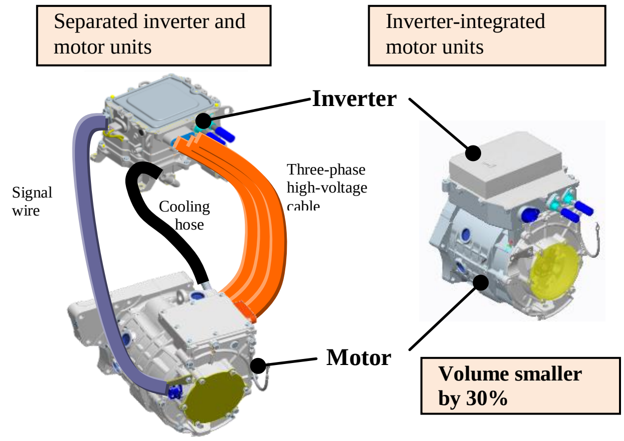


Fig. 1 Comparison of two types of units

On the other hand, it is necessary to improve vibration resistance, heat resistance, etc. of the power electronics system. This article introduces how these issues were solved in the development of inverter-integrated motor units.

2. Development of inverter-integrated motor test models

Integration of the motor and inverter enables space saving since a stay for securing an inverter in the vehicle is no longer necessary. And the reduction in the number of parts as a result of the elimination of the external harness, etc. leads to lower cost.

Integration of the motor and inverter is an effective way to satisfy the required specifications. So, we examined how the motor and inverter should be positioned in an inverter-integrated motor unit. As a result, we determined that placing the inverter section on top of the motor (Fig. 2) and placing the inverter section along the motor axis direction (Fig. 3) are the most effective solution, and evaluated these two test models.

Table 1 shows the specifications of the motor unit.

Table 1 Specifications

Specifications	
Motor	PM-Motor (Nd-Fe-B)
Max Torque	160Nm
Max Power	60kW
Rated Power	25kW
Temperature	- 40 ~ 105℃
Max Rotation Speed	12,000min^{-1}
Cooling Method	Water Cooled
DC Volt	330V (Typ)
Power Device	IGBT
Size	φ230×280
Weight	40kg

Fig. 2 Test model 1

Fig. 3 Test model 2

Each test model has its advantage and disadvantage, as shown in Table 2, Fig. 4, and Fig. 5.

Table 2 Comparison of the twotest models

	Test model 1	Test model 2
Advantage	Good maintainability	Mountable in a narrow space
Disadvantage	More dead space than test model 2	Inferior maintainability

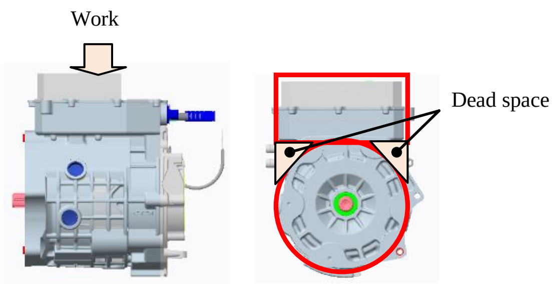


Fig. 4 Test model 1

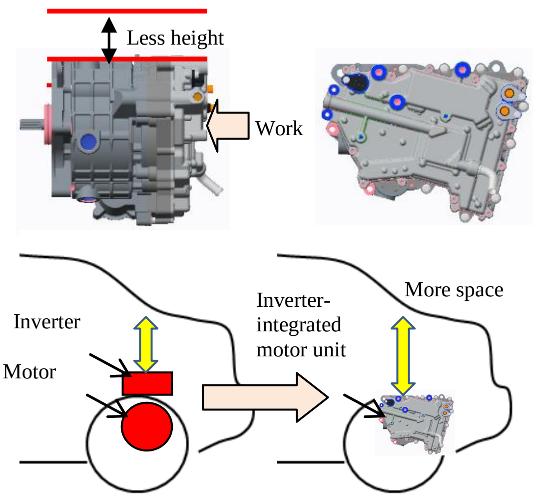


Fig. 5 Test model 2

We will develop integrated units of these two structural types to flexibly accommodate different vehicle concepts.

The following sections discuss the issues to be solved in the development of inverter-integrated motor units and the advantages of inverter-motor integration.

3. Issues to be solved in motor-inverter integration

3.1. Vibration resistance

In separated inverter and motor units, since the required vibration resistance differs depending on the mounting position of the units, the motor needs to have much higher vibration resistance than the inverter. In an inverter-integrated motor unit, since the inverter needs to have the same vibration resistance performance as the motor, the unit as a whole is required to have higher vibration resistance than separated inverter and motor units. Board-mounted components, in particular, need to clear heavy-load vibration conditions. So, we used CAE analysis to determine the optimal layout and fixing method of board-mounted components. Fig. 6 shows an example of optimization.

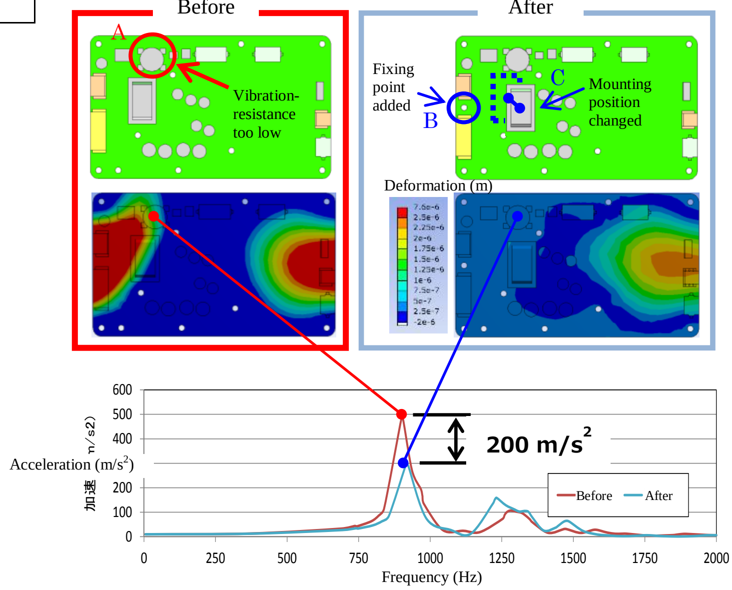


Fig. 6 Optimal layout and fixing method of board-mounted components

Although separated inverter and motor units with the conventional layout of board-mounted components satisfied the specifications for vibration-resistance of the inverter, if the vibration-resistance specifications for the motor are also used for the inverter, this will result in insufficient vibration-resistance of board-mounted components and needs for improvement (Position A). We studied the possibility of improving the layout of board-mounted components by controlling resonance acceleration using eigenvalue analysis and frequency response analysis. In our simulation, the acceleration was decreased by 200 m/s^2 after changing the positions of large-mass peripheral components and adding fixing positions (Positions B and C) to high-vibration parts of the board. A test confirmed that there was no falling of board-mounted components, and the vibration-resistance issue was solved. This way, the required vibration-resistance specifications of the motor were satisfied by repeating trials until the positions of board-mounted components and fixing positions were optimized.

3.2. Heat resistance

In the case of an in-vehicle inverter-integrated motor unit, since the vehicle structure normally does not allow as much space for components as in the case of a separate inverter, the component density will be higher inevitably. Also, since the motor and inverter share the same space, the inverter is affected by heat from the motor winding. These factors also cause a rise of internal air temperature, and the heat affects electronic components.

Therefore, in the inverter-integrated motor unit, we adopted a cooling water route for cooling the entire inverter chassis to suppress rise in internal air temperature. Fig. 7 shows the cooling water route.

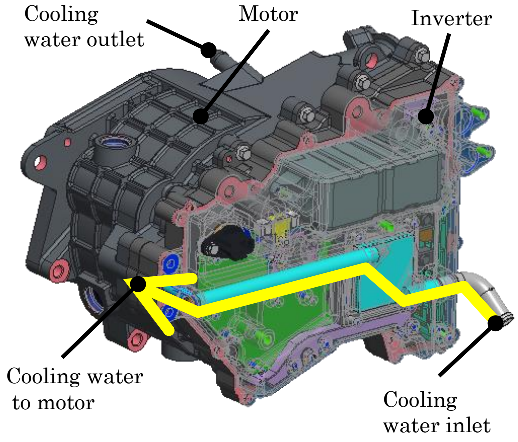


Fig. 7 Cooling water route

In the case of separated inverter and motor units, in which a three-phase high-voltage cable is used to connect the inverter to the motor, high heat from the cable is transmitted to the inverter, affecting the electronic components inside the inverter.

In the case of the inverter-integrated motor unit, on the other hand, since the inverter is connected to the motor using a bus bar with a cross-sectional area in consideration of current value, heat generation is suppressed to a lower level compared to connection using a three-phase high-voltage cable.

As a result, the temperature rise in the inverter was reduced by 42% through the use of the cooling water route (Fig. 7) and the use of a bus bar instead of a three-phase high-voltage cable.

Fig. 8 shows the effect of such a design.

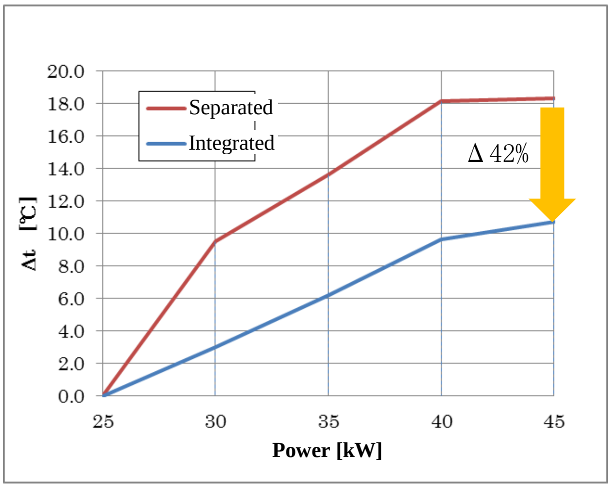


Fig. 8 Comparison of ambient temperatures of control board inside MCU

4. Effectiveness of motor-inverter integration

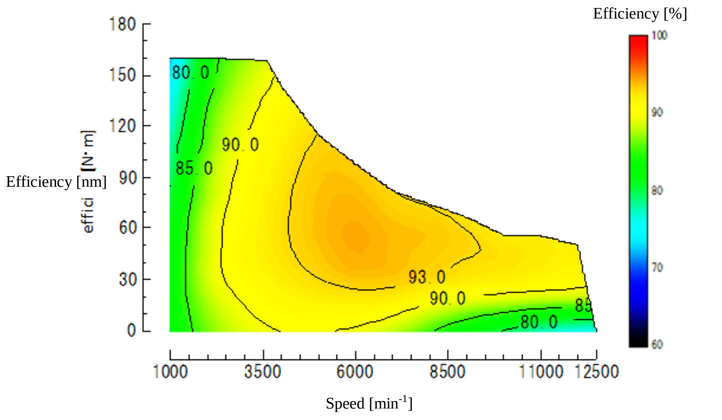
4.1. Efficiency

The system efficiency was compared between the inverter-integrated motor and the separated inverter and motor units. Fig. 9 shows the efficiency map of each unit.

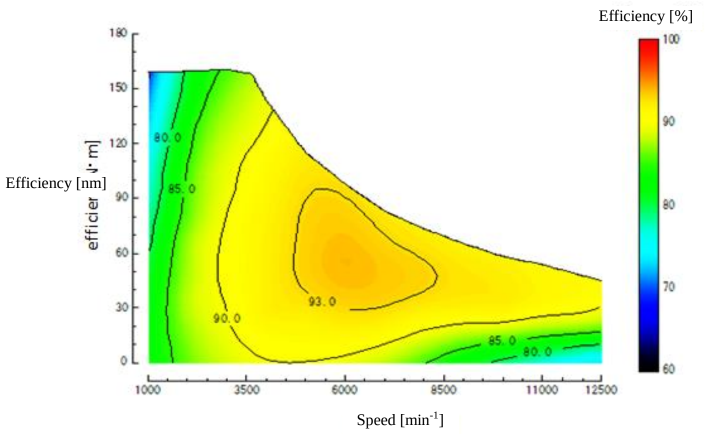
We tested the separated inverter and motor units using an approx. 1.5 meter three-phase high-voltage cable between the inverter and motor to simulate use in a vehicle.

The test result confirmed that the integrated unit was higher in efficiency than the separated units. The separated units were less efficient by as much as nearly 3%, and this is largely due to the effect of the three-phase high-voltage cable between the inverter and motor. It was confirmed that the impact of the cable was especially high in the low-rotation high-torque range where copper loss is dominant. It was also confirmed that the impact of the cable was much smaller – within approx. 1% – in the middle-to high-rotation range where iron loss is dominant.

Naturally, the longer the three-phase high-voltage cable is, the more loss will be, decreasing the overall efficiency. Therefore, the inverter-integrated motor unit, which uses a much shorter three-phase high-voltage cable, is highly effective for efficiency improvement.



a) Efficiency of an inverter-integrated motor unit



b) Efficiency of separated inverter and motor units

Fig. 9 Efficiency map

5. Conclusion

As mentioned in the introduction, components for EVs and HEVs need to be smaller in size and lighter in weight to fit into a limited vehicle space, and higher in efficiency and lower in price. Motor-inverter integration is an effective way to satisfy such requirements. The inverter-integrated motor units introduced in this article are for use with types of vehicles that require space saving mounting. In the future, we plan to improve maintainability and evaluate long-term reliability to make further improvements for future commercialization.

References

[1] Takashi Abe: Development and Commercialization of Motor and Inverter for Electric Vehicle “i-MiEV”, EVS-25

[2] Takeo Nagamori: Development of Motor System for Outlander PHEV, EVTeC 2014