

Development of New Units for Heavy Duty Hybrid City Bus

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Summary

For the purpose of significantly improved fuel economy of heavy duty hybrid city bus, new hybrid units, motor/generator, inverter, and battery, were developed. The new hybrid bus achieved 40% fuel economy improvement as compared with conventional diesel buses. In order to achieve the above, each new hybrid unit was developed so as to improve especially power and cooling performance. This paper explains specifications and cooling design content of the developed hybrid units, especially focusing on motor/generator, and the results of fuel economy improvement of the vehicle with these new units.

Keywords: HEV (hybrid electric vehicle), bus, motor, inverter, nickel metal hydride battery

1 Introduction

In recent years, reduction of CO₂ emission is required since it causes environmental problems such as global warming. And furthermore, reduction of the fuel consumption, as well as CO₂ emission, is particularly required from the viewpoint of transportation cost reduction in commercial vehicles. Our company launched the world's first hybrid bus in 1991, and it achieved CO₂ emission reduction and fuel economy improvement as compared with conventional diesel buses. Since then, the hybrid technology has been refined in every model change.

This time, our company dramatically changes the hybrid system and the hybrid units, based on the

accumulated technologies through the many years of experience. And then, we have developed the new hybrid bus, which achieves fuel economy performance much better than the previous hybrid bus. Fig. 1 is a photograph of the new hybrid bus. The improvement of fuel economy performance is achieved by expanding the ratio of electric energy to total energy (hereinafter “electricity ratio”). New hybrid units are developed to expand the electricity ratio. Here, the hybrid units mean motor/generator (hereinafter “motor”), inverter, and battery. This paper explains specifications and cooling design content of the developed hybrid units, especially focusing on motor, and the results of fuel economy improvement of the vehicle with these new units.



Fig.1 New heavy duty hybrid city bus

2 Development goals and approach

2.1 Vehicle

The development target of the new hybrid bus was “40% fuel economy improvement as compared with conventional diesel buses”. In order to achieve this target, electricity ratio was improved. This improvement has been accomplished by new hybrid system including drivetrain layout changes, etc.. And new hybrid units are described in 2.2 and later sections.

Fig. 2 shows a configuration of developed new hybrid bus. The new hybrid bus adopts parallel hybrid system which the diesel engine and motor are positioned coaxially. The previous hybrid bus could not regenerate energy of the engine friction amount, since the clutch was positioned between the motor and transmission. The new hybrid bus, on the contrary, the clutch is positioned between the engine and motor. The new hybrid bus can regenerate energy of the engine friction amount, because of disconnection the engine from the clutch during deceleration. In addition for the same reason, the new hybrid bus can be driven only by the motor power during take-off, (hereinafter “motor run”).

The above improvements increased the electricity ratio. In order to drive the auxiliary machine such as a power steering, the engine is idling during motor run. And also, automated manual transmission (AMT) is adopted, and it makes fuel

economy performance compatible with easy operation.

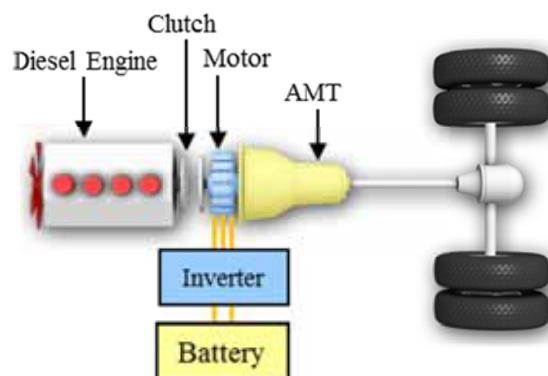


Fig.2 Configuration of new hybrid bus

2.2 Hybrid units

In order to achieve the fuel economy goals mentioned in Section 2.1, we set the target output of the hybrid system from the data of heavy duty city bus market. Fig. 3 shows a moving average power output of acceleration. From the data, to be possible to drive only by the motor power, the target outputs of the motor and inverter was set: the maximum output 90 kW and continuous output 30 kW. Taking the efficiency of the hybrid system into consideration, the target output of the battery was set 110 kW. Fig. 4 shows actual market data of city buses. From this data, maximum output 90 kW covers most of deceleration power. Therefore, it is confirmed that the target outputs are appropriate for both acceleration and deceleration. A simple upsizing of each unit, to achieve the target outputs, was disadvantageous in mountability and cost. Therefore each unit was designed being focused on performance, efficiency, and cooling performance. As a result, the new developed units realizes both mountability and output performance.

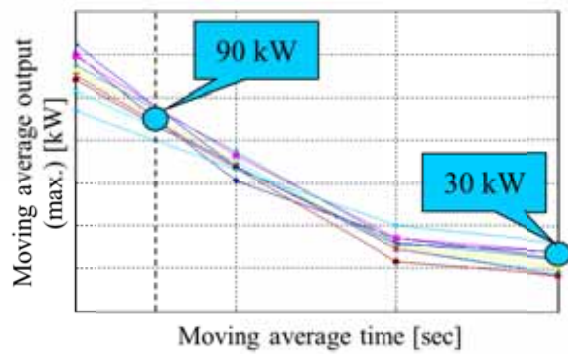


Fig.3 Average output of vehicle power during acceleration

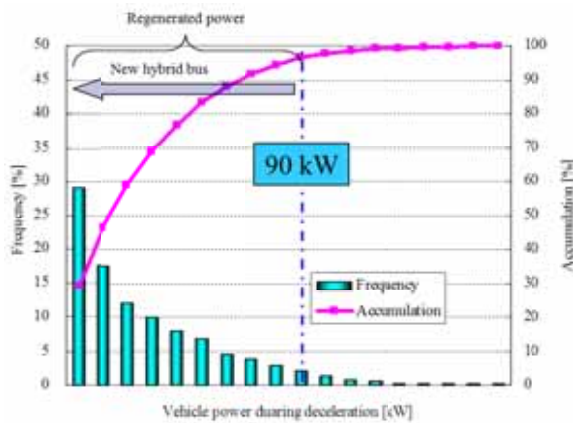


Fig.4 Distribution of vehicle power during deceleration

3 Development details

3.1 Motor

Table.1 shows the specification of the newly developed motor.

Table.1 Specification of motor

	Maximum output	90 kW
	Continuous output	30 kW
	Cooling system	oil

Motor type was selected to satisfy output performance and mountability of the vehicle required. Figure5 and figure6 show the volume and the calorific value compared the induction

motor and permanent magnet synchronous motor. To purpose of miniaturized for mounting in limited drivetrain length, and heating value reduction by high efficiency, the motor adopted the permanent magnet synchronous motor. Figure7 show the result of the comparison of the previous motor and the new motor. The new motor was improved the output, and reduced volume and weight.

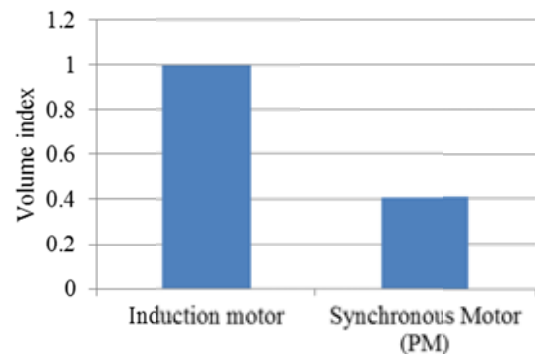


Fig.5 Motor Volume

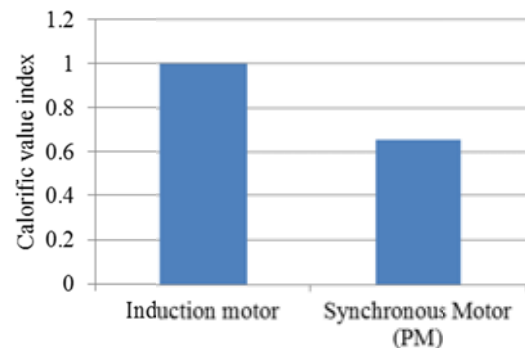


Fig.6 Motor calorific value

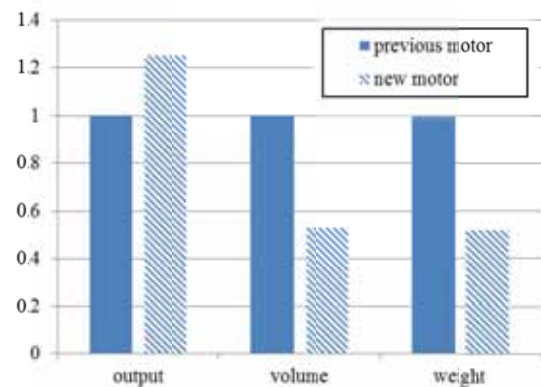


Fig.7 Motor comparison

Figure 8 shows the motor heat dissipation capacity of the air cooling system and oil cooling system in vehicle environment. In addition, Figure 9 shows the contour plot of the amount of loss to the motor output in. As shown in figure 9, since the air cooling system does not satisfy the continuous output 30 kW of vehicle required, cooling system of the motor adopts the oil cooling system.

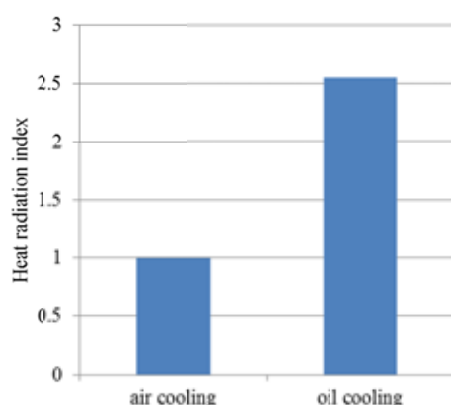


Fig.8 Motor cooling performance

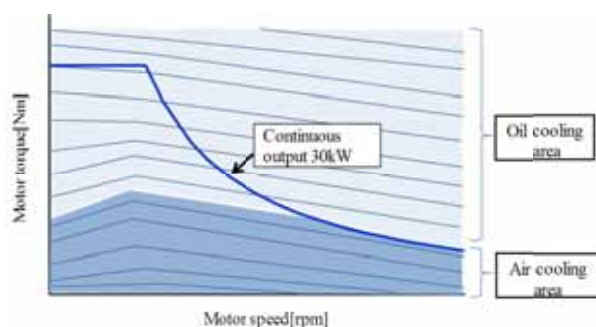


Fig.9 Motor loss map

Figure 10 shows the cooling structure of the inside of the motor. Since the electric type is unsatisfied the reliability of the power line such as lifetime and vibration, mechanical type was adopted as oil circulation pump. To decrease the number of parts and the mounting space, pump mounted coaxially on the motor output shaft without exclusive drive shaft. The structure of the oil circulation is like this: oil drops on the top of

the motor in order to cool motor and then flow to the oil pan. And then it flows to outside oil cooler of motor by oil pump.

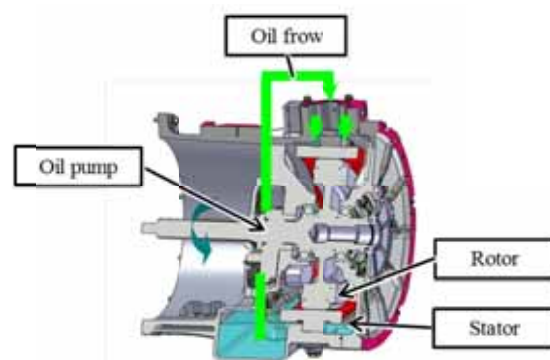


Fig.10 cooling structure of the inside of the motor

3.2 Inverter

Table.2 shows the specification of the newly developed inverter. When the inverter drives the motor, the motor output characteristic is largely dependent on the battery voltage. The inverter, from such background, in order to ensure a stable motor output in a wide battery voltage range, has been provided with the voltage booster circuit.

Fig.11 shows an internal conceptual diagram of the inverter. A water-cooling system was adopted for the inverter cooling, as a countermeasure for the heat produced by the voltage booster circuit, and in order to satisfy the continuous output 30 kW. Furthermore, IGBT, reactor, and capacitor are positioned on both sides of the heat sink so as to cooling and minimize the size of inverter and booster circuit.

Table 2 Specification of inverter

	Maximum output	90 kW
	Continuous output	30 kW
	Cooling system	water

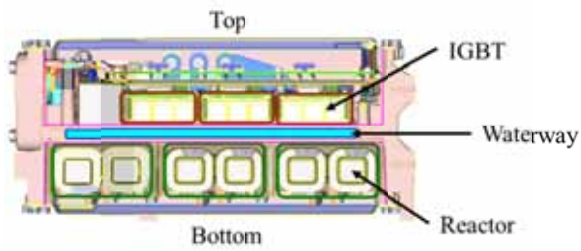


Fig.11 Placement conceptual diagram

3.3 Motor and inverter external cooling circuit

Figure.12 shows the external cooling circuit structure of the motor and the inverter.

Oil cooler and radiator were set to be able to radiate the heat of the motor and the inverter calorific value.

To be mounted on a limited vehicle space, for the purpose of reduce mounting area and the number of parts, oil cooler and radiator was configured mounted in parallel to cool by single fan.

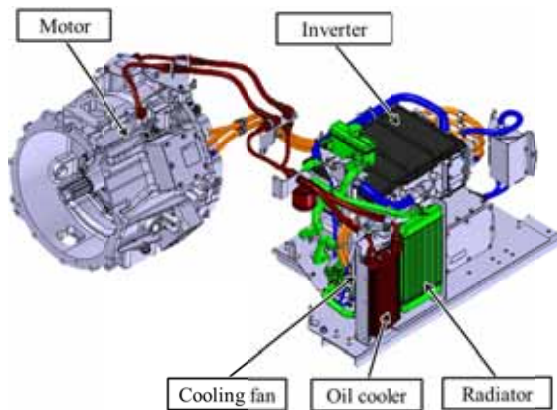
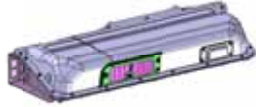


Fig.12 Motor & Inverter external cooling circuit

3.4 Nickel-metal hydride (Ni-MH) battery

Table.3 shows the specification of the newly developed battery system. The battery system is composed by parallel connection of four Ni-MH battery packs.

Table.3 Specification of nickel-metal hydride battery

	Output	120 kW
	Rated voltage	288 V
	Cooling system	air

In order to ensure the passenger capacity, the battery system was installed in the vehicle roof. To assure the output performance of the battery system, it is necessary to control air cooling and reduce variation in the temperature among the battery packs. Aerodynamic analysis was conducted, in order to develop the stable cooling, not to have influence of wind direction and running wind.

Fig.13 shows analysis result of the air pressure distribution. If the inlet is installed in vehicle front-back direction surface, the battery system can't intake air stably, since the variation in air pressure is wide by the wind direction and running wind. Therefore, the inlets were installed in the left and right surfaces that the variation in air pressure is little. The outlets was installed in the front and rear surfaces. Fig.14 shows a conceptual view of the wind flow.

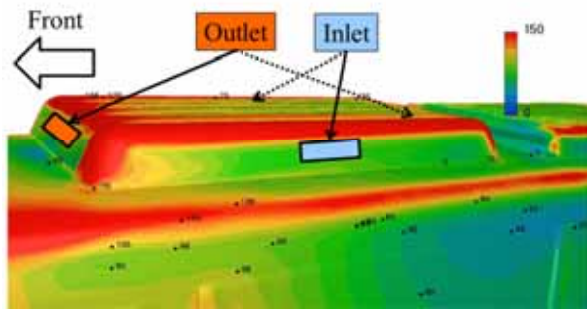


Fig.13 Aerodynamic analysis result of the pressure distribution

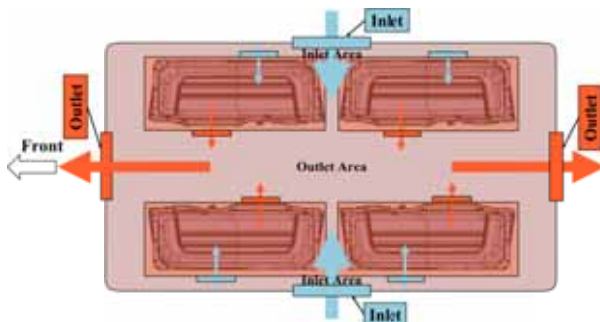


Fig.14 Conceptual diagram of the wind flow

4 Verification and result

4.1 Hybrid units

Fig.15 shows the result of a bench test that combines the motor and inverter. The maximum output has achieved to 91 kW at the actual measurement and cleared the target output 90 kW. The continuous output has achieved to 33 kW and cleared the target output 30 kW.

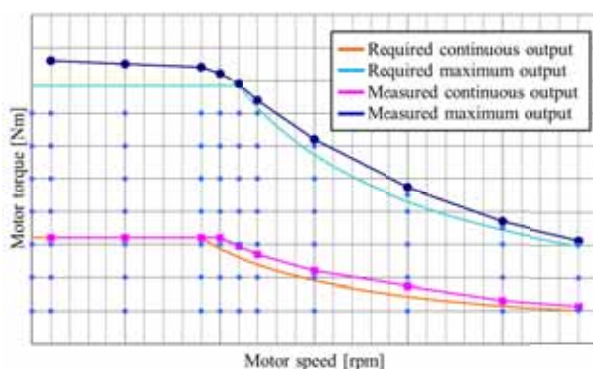


Fig.15 Result of motor and inverter bench test

4.2 Vehicle

Fig. 16 shows a vehicle evaluation result of the output and cooling performance of each unit. From the result, the temperatures of each unit were confirmed that the temperatures were under the protection temperatures. And furthermore, required vehicle output was confirmed.

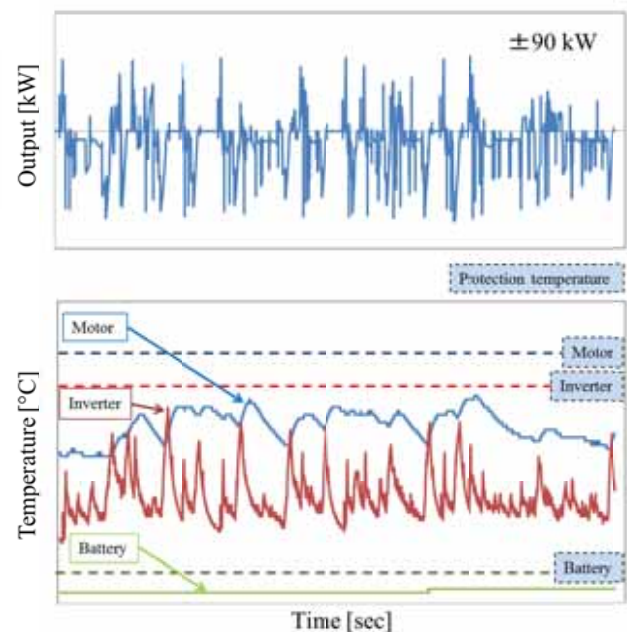


Fig.16 Result of vehicle cooling performance and output test

Fig.17 shows the fuel economy improvement result of the internal evaluation that simulates the operation of the heavy duty city bus market. Fig.18 shows the demonstration test results that were conducted in actual user operations. As a result, the new hybrid bus equipped with the newly developed unit achieved development goal of 40% fuel economy improvement as compared with conventional diesel buses.

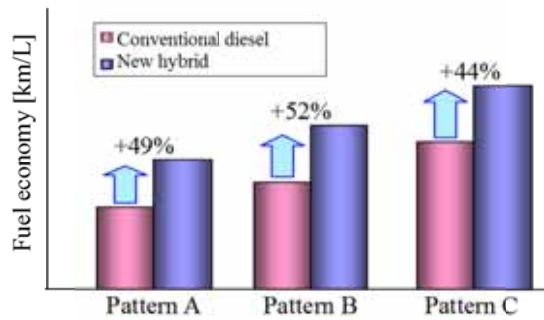


Fig.17 Results of fuel economy improvement by the pattern

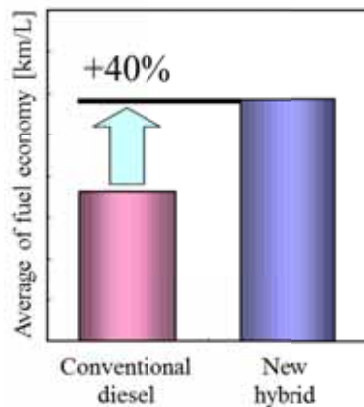


Fig.18 Result of the monitoring survey

Authors



Shotaro Hamai is a hybrid units engineer, Hino Motor, Ltd. Mainly has desined motor/generator since April, 2010. He acquired a bachelor of a Electrical Engineering at Aoyama Gakuin University in Japan in March, 2010.

5 Conclusion

Our company, in order to achieve the fuel economy improvement of heavy duty hybrid city bus, developed the new hybrid units that ensure the output performance and cooling performance. The new hybrid bus equipped with the developed units was confirmed to improve 40% fuel economy as compared with previous diesel buses. Our company accumulates technology obtained in this development, and continues to develop commercial hybrid vehicles aimed at further performance improvement.

References

- [1] Satoshi Uemura, et al: Development of New Hybrid City-Buses, JSAE Proceedings, No.14-15A, pp.318-321 (2015)