Development of Fuel-efficient, Environmentally-friendly Hybrid Electric Vehicle Systems

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OVERVIEW: In electrically driven systems for EVs (electric vehicles), HEVs (hybrid electric vehicles), and FCEVs (fuel-cell electric vehicles), the ability to mount electric motors and inverters onboard the vehicle is critically important. To address this challenge, Hitachi Group has thus focused its R&D (research and development) efforts on reducing the size and weight of motors and inverters while maintaining a high level of output. Excellent results have been achieved: the output-to-mass ratio of the motor has been reduced by about 4.5 times while the capacity-to-volume ratio of the inverter has been increased by close to 5.2 times. With the R&D and performance challenges now out of the way, we are currently putting in place the production infrastructure to provide motors and inverters that satisfy the reliability and other exacting requirements of the vehicle manufacturers.

INTRODUCTION

VEHICLES using electric motors can be broadly classified into three categories: EVs (electric vehicles), HEVs (hybrid electric vehicles), and FCEVs (fuel-cell electric vehicles). Among these three approaches, there is consensus that the HEV has the greatest prospect for mass sales in the near-term future since it offers significantly improved fuel economy without appreciably raising vehicle cost or sacrificing vehicle performance. By combining an engine and electric motor with a control system that exploits the efficiencies of each, the HEV delivers excellent fuel economy and ample power (see Fig. 1).

Now through a combination of its traditional expertise in the development of motors and a three-phase AC (alternating current) motor control systems implemented as a power module, Hitachi Group has developed an downsized and lightweight HEV platform that is highly efficient and cost effective.

This paper will review our progress and current status of work on motors and inverters for HEV systems, and highlight several testing systems for

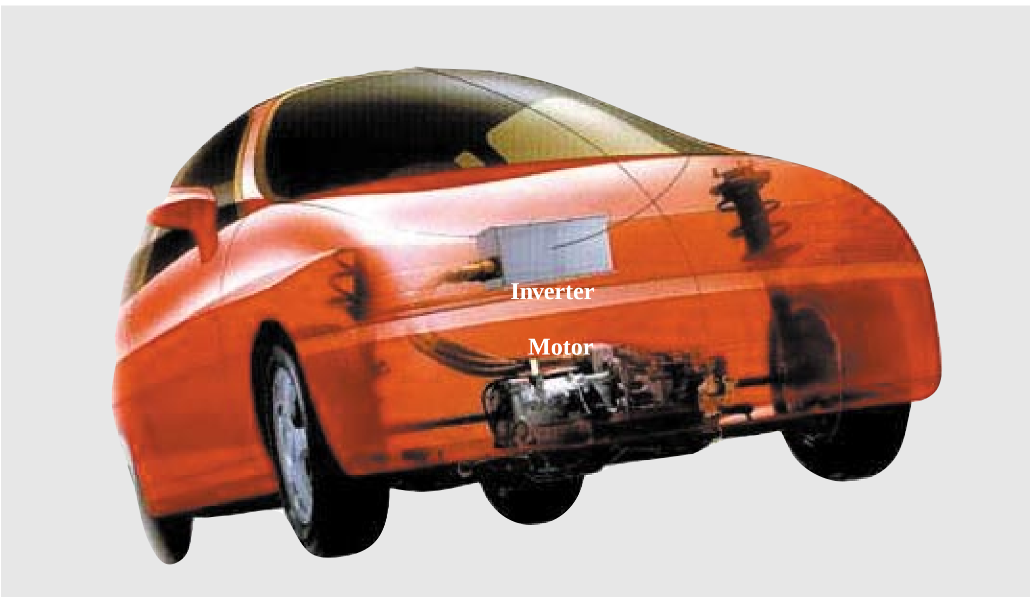


Fig. 1—Electric Vehicle in Motion.
An inverter converts power from a power source mounted in the rear of the vehicle to AC, which turns the motor and drives the vehicle. By exploiting this basic technology of EVs, HEVs provide significantly better fuel economy and increased output through synchronized control of an electric motor and gasoline engine.

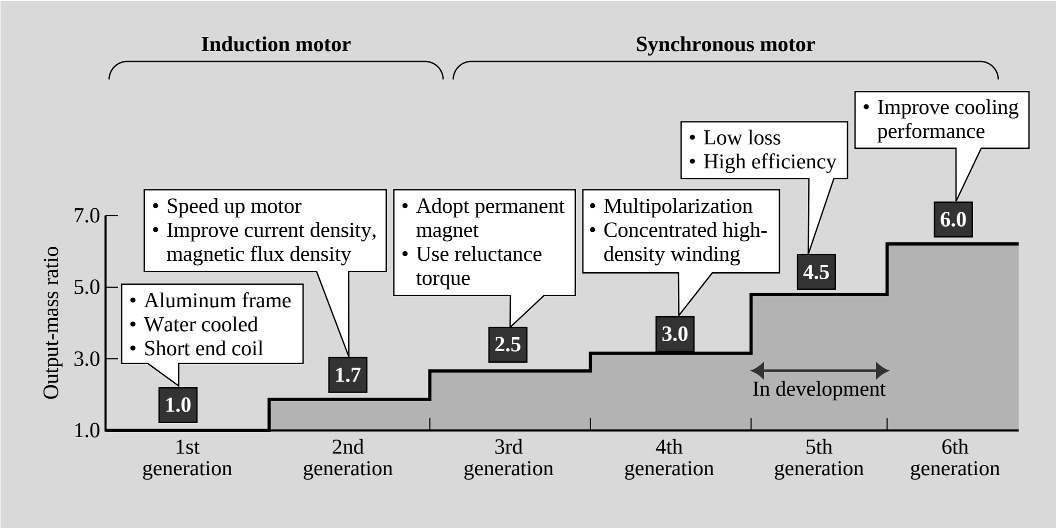
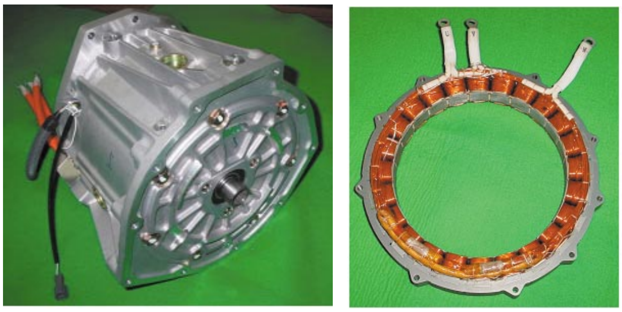


Fig. 2—Reduction of Size and Weight of Motor for HEVs.
Progress in reducing the size and weight of motors for HEVs, and technologies enabling the down-sizing are shown. We are now making headway in the development of a 6th-generation motor.



(a) **(b)**

Fig. 3—100 kW-class Motor (a) and Thin Profile Motor (b).
Prototype models of motors are under development that are smaller and lighter yet provide higher output.

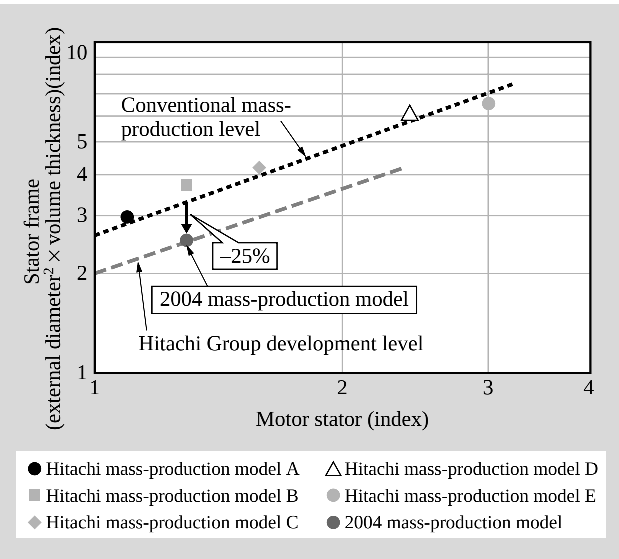


Fig. 4—HEV Motor Downsizing Level.
Motor frame has been downsized by 25% while motor torque remains unchanged.

evaluating the reliability of subsystems for HEVs.

MOTOR

The drive system for an HEV requires an electric motor to be installed together with the engine in very limited space on the vehicle, and demands a system is small, lightweight, and provides high output, efficiency, and reliability.

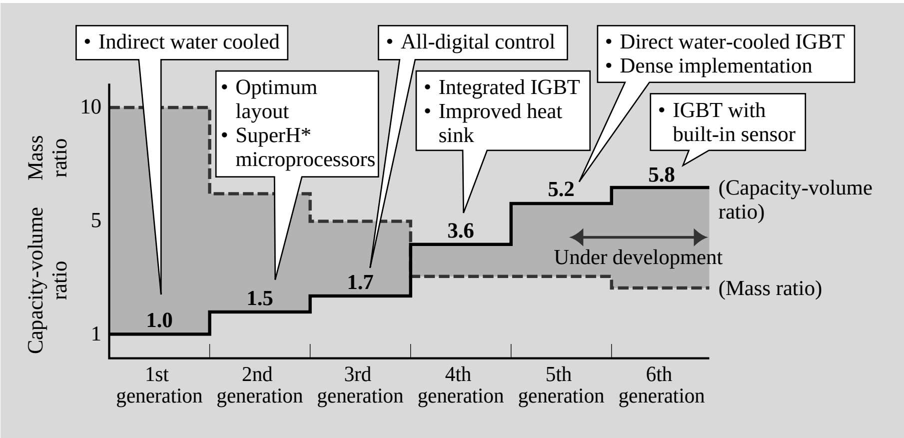
Motor Downsizing Trend

Hitachi Group selected the permanent magnet synchronous motor as best suited for meeting all requirements — small and lightweight but efficient and delivering high output — and has been pursuing R&D (research and development) on a motor with a high output-to-mass ratio. Fig. 2 traces our progress in reducing the size and weight of the HEV motor. Starting from a base output-mass ratio of 1.0 for Hitachi Group's 1st-generation induction motor system, we have now completed work on a 5th-generation motor, a permanent magnet synchronous motor system with an output-mass ratio of 4.5, and have a 6th-generation motor under development.

It is also critically important that HEVs provide a high standard of driving performance, and we have now constructed a full-scale working prototype of a motor with a maximum output exceeding 100 kW [see Fig. 3 (a)]. In addition, the motor must be implemented as a low-profile module in order to fit within the limited space available on board the vehicle, and this development is also completed and now being tested and evaluated [see Fig. 3 (b)].

Fig. 5—Motor Winding Production Line for HEVs.
Production capacity is 5,000 units per month.

Fig. 6—Motor Assembly Line for HEVs.
Production capacity is 5,000 units per month.



* SuperH is a trademark of Renesas Technology Corp.

Fig. 7—Inverter Trend.
Inverters are becoming progressively smaller and lighter, and the technologies enabling this development are shown.

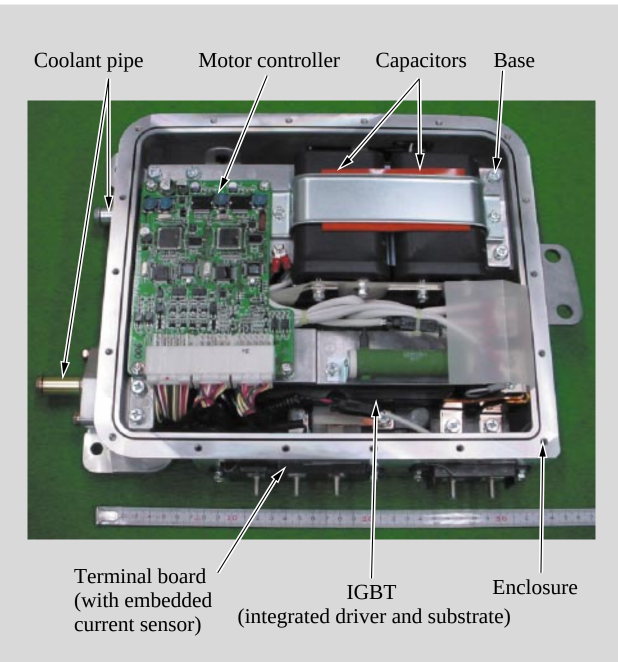


Fig. 8—Inside 5th-generation Inverter.
Size and weight reduction can be achieved using direct water-cooled IGBT twin inverter.

Current Status of Motor Miniaturization

Fig. 4 shows motor torque as a function of stator frame size that serves as a good index of technology level in downsizing the motor while increasing torque. For example, we have now succeeded in reducing the size of stator frames for HEVs by 25% compared to the size used in conventional mass-produced vehicles. This downsized, high-torque motor will go into mass production in 2004, and a production line with monthly capacity of 5,000 vehicles is already set up and ready to go (see Figs. 5 and 6).

INVERTER

Inverter Downsizing Trend

Inverters for HEVs must be downsized to fit in the limited space available on the vehicle, must provide greater output capacity to maintain driving performance, and must be reduced in cost.

Hitachi Group adopted PWM (pulse width modulation) controlled inverters using IGBTs (insulated gate bipolar transistors) for switching

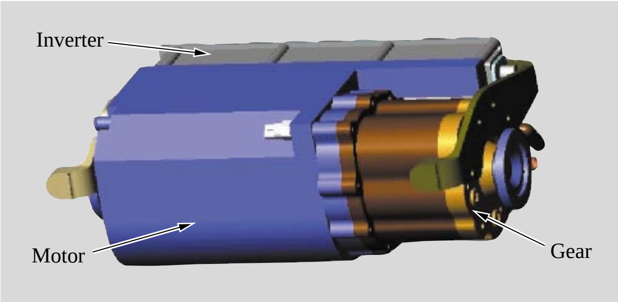


Fig. 9—Integrated Electrical-mechanical Unit for HEV Drive.
The system as a whole can be significantly reduced in size and cost by integrating the motor, inverter, and gear.

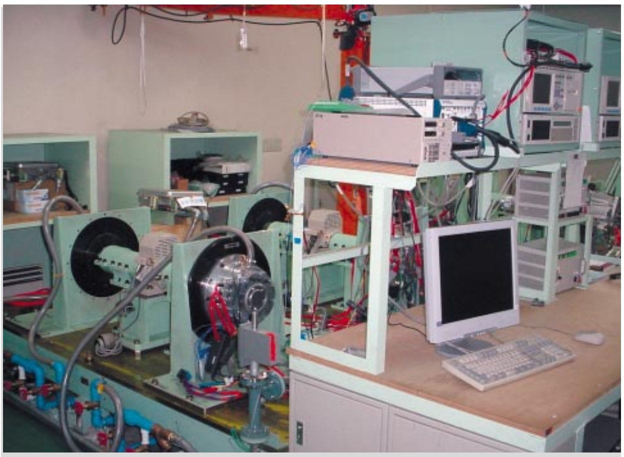


Fig. 10—Testing and Evaluation Equipment.
All kinds of tests are performed to assess the reliability of the motor.

elements. Fig. 7 shows our progress in downsizing the inverter. At this point we have finished the 5th-generation inverter and have commenced work on the 6th-generation unit. One can see in the figure that the output per volume capacity of the 5th-generation inverter is about 5.2 times greater than the 1st-generation device. This is possible thanks to a very dense implementation based on a novel direct water-cooled IGBT developed by Hitachi (see Fig. 8). The additional heat generated by the dense implementation is removed by a strategically placed intermediate plate with excellent thermal conducting properties, so the heat is effectively dissipated to the water-cooled side of inverter.

Integration of Motor, Inverter, and Gear

Hitachi Group developed an integrated electrical-mechanical unit for HEV drives that combines the motor, inverter, and gear, and is ready to accept orders (see Fig. 9). Adopting this integrated approach, the volume of the system as a whole can be implemented much more efficiently, the cooling system is simplified, and component costs are reduced.

RELIABILITY EVALUATION EQUIPMENT

Performance Testing Equipment

In order to reproduce the environmental conditions of a vehicle, the performance testing equipment automatically measures motor output, efficiency, and other variables while varying the battery voltage, coolant temperature, and ambient temperature. Using the vehicle communication system CAN (controller area network) that has emerged in recent years, physical data such as motor torque and rotation as well as control data handled by the controller can be simultaneously displayed on a monitor (see Fig. 10).

Endurance Testing Equipment

Endurance testing equipment has been brought in so we can evaluate operability while freely varying

(a) Vibration resistance evaluation equipment

(b) Large-scale thermal collision testing system

Fig. 11—Endurance Testing Equipment.
Equipment and evaluation conditions for evaluating vibration and thermal collision reliability.

vibration conditions applied to the inverter and motor. In the past we were only able to conduct evaluations in a non-current-carrying state, but this equipment permits much more advanced reliability assessment testing [see Fig. 11 (a)].

We have also acquired a large-scale thermal collision testing system. Because of the large mass of the products being tested, it has always been very difficult to apply the rapid temperature changes that are called for; but now with the availability of this equipment, we can perform much more rigorous testing contributing to a better grasp of acceleration and actual values [see Fig. 11 (b)].

With these more sophisticated reliability testing systems available on site, we are able to satisfy the demands of vehicle manufacturers for a full range of evaluations and endurance condition testing.

CONCLUSIONS

In this article we reviewed recent trends, development processes, and the current level of success in downsizing and increasing the output of motors and inverters used to configure electric drive systems primarily for HEVs. We also highlighted some of the equipment and systems that Hitachi Group has put in place to test and evaluate the reliability of the motors and inverters for HEVs.

There is general consensus that in the near-term future the market for HEVs will grow very rapidly. Hitachi Group will continue its R&D efforts tailored to the needs of vehicle manufacturers and consumers, while strengthening its commitment of best solutions, environmental conservation, and reduced reliance on fossil fuels.

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