High Power Density Technologies for the Driving Motors in Electric Vehicles

Takeshi Kitayama [1)] Hiroyuki Hattori [1)] Keiji Takizawa [1)]

1) Carbon Neutral drivetrain-EHV development Dept.
Carbon Neutral Development Div.
TOYOTA MOTOR CORPORATION
1, Toyota-cho, Toyota, Aichi, 471-8571 Japan
E-mail: Takeshi_kitayama_aa@mail.toyota.co.jp

ABSTRACT: In recent years, CO_2 emission regulations have been tightened, and vehicles with excellent environmental performance have become popular worldwide. The hybrid system installed in HEVs, which is a representative example of this, requires a high power density package to enable itself to be installed in any vehicle. For the driving motor in electric vehicles, which is the main unit of the system, developing high power density technologies is expected. This paper describes high-power and downsizing technologies for motors.

KEY WORDS: electric vehicle, motor, powertrain,

1. INTRODUCTION

To curb global warming, the number of countries that introduce CO_2 emission regulations is increasing year by year, and the regulatory values are also being strengthened, and it is expected that the spread of vehicles with excellent environmental performance will expand.

TOYOTA has commercialized a highly efficient THS system as one of the countermeasures to achieve global carbon neutrality, and has been improving the efficiency of the motors installed in the system for electric vehicles. In addition, to expand and accelerate the spread of electrified vehicles, we have developed and evolved high power density technologies that can be installed in any vehicle (Fig. 1).

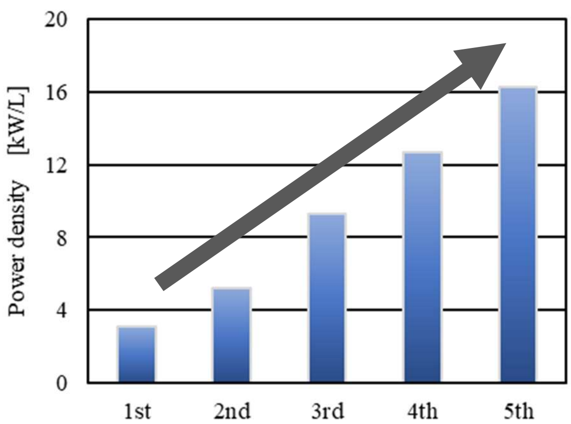

Fig.1 Power density

This paper describes the efforts to date and the latest efforts on the high power density technologies of motors.

2. HIGH POWER TECHNOLOGY

High power has been achieved by improving the occupancy ratio by adopting segment conductor windings, insulating technology for coil wires corresponding to higher voltages, and evolution of rotor magnet arrangement in pursuit of improving reluctance torque.

2.1. High voltage technology

The input voltage of the motor has been increased to 500 V in the 2nd generation and 650 V in the 3rd generation to improve the output. Since the surge voltage generated inside the motor rises, the coil layout has been improved to reduce the potential difference between adjacent coils in the same motor phase[(1)].

In the 4th generation, a segment conductor was adopted for the coil, and the insulation performance was improved by increasing the withstand voltage of the insulating coating and molding technology to ensure the distance between the coils. The latest 5th generation follows suit.

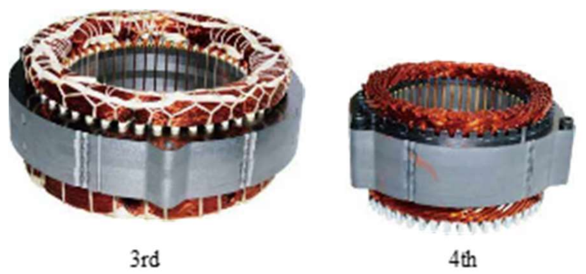

Fig.2 Coil structure

2.2. Magnetic circuit design

As for the rotor magnet arrangement, the V-shaped arrangement was adopted in the 2nd generation(Fig.3), and the two-layer ▽arrangement was evolved in the 4th generation to improve the reluctance torque(Fig.4).

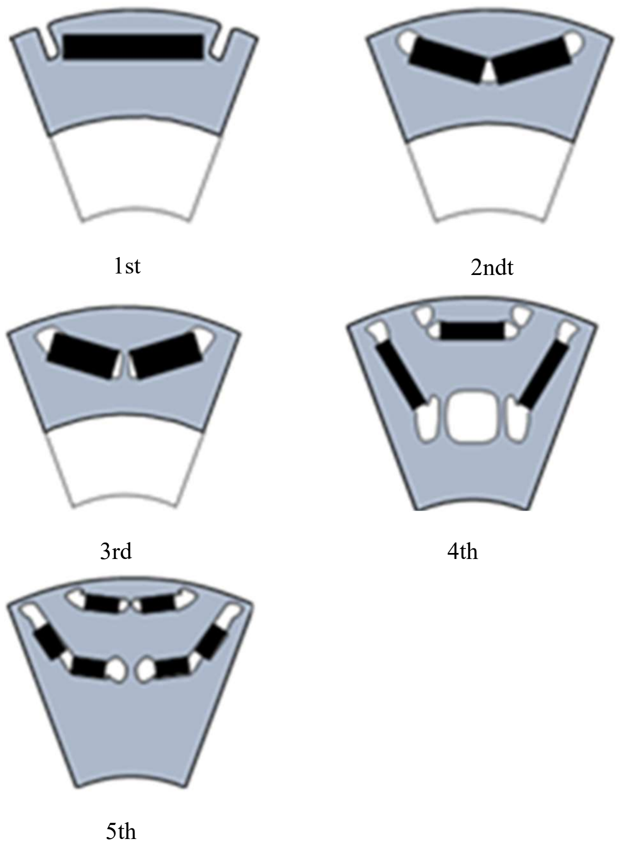

Fig.3 Magnet arrangement of the 1st ~ 5th generation

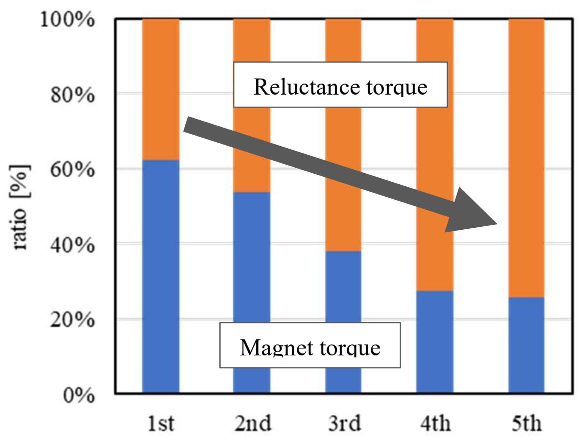

Fig.4 Torque ratio

In the 4th generation, local magnetic saturation occurred in the q-axis magnetic paths A, B, and C (Fig.5) in the rotor core. Therefore, the factors of magnetic saturation were analyzed using the frozen magnetic permeability method, and improvement was studied in the 5th generation.

The current magnetic flux density distribution (Fig.6) and the magnet magnetic flux density distribution (Fig.7) obtained by separating the magnetic flux density distribution of Fig.5 using the frozen magnetic permeability method are shown.

It was found that the current magnetic flux of parts A and B (Fig.6) and the magnet flux of parts A and B (Fig.7) flow in the same direction along the q-axis magnetic path in the rotor core. As a result, it was found that local magnetic saturation occurred.

Therefore, in the 5th generation, the bridge next to the magnet on the outer peripheral side was abolished and the current magnetic flux flow in the A part (Fig.6) was improved. In addition, by dividing the magnet and changing it to a two-layer polygonal arrangement, the flow of magnet magnetic flux in the B part (Fig.7) was improved from the direction along the q-axis magnetic path to the d-axis magnetic path direction. As a result, the current magnetic flux and the magnet magnetic flux were prevented from flowing in the same direction, the magnetic saturation of parts A and B in Fig.5 was relaxed, and the reluctance torque was improved.

In addition, it was found that local magnetic saturation occurs in the C part (Fig.6) due to the current magnetic flux flowing in a narrow place of the q-axis magnetic path. By changing to the two-layer polygonal arrangement described above, the width of the q-axis magnetic path in the C part (Fig.6) was expanded. As a result, magnetic saturation was eliminated and the reluctance torque could be further improved.

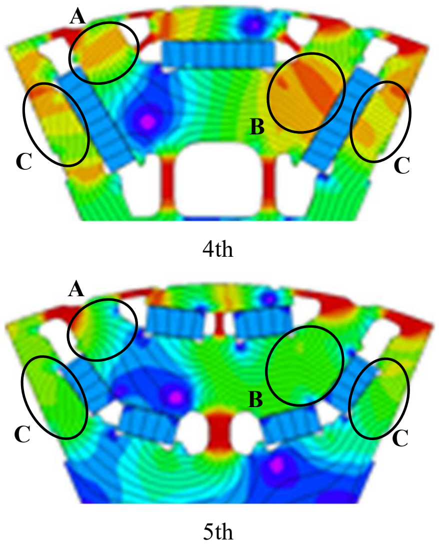

Fig.5 Magnetic flux density distribution

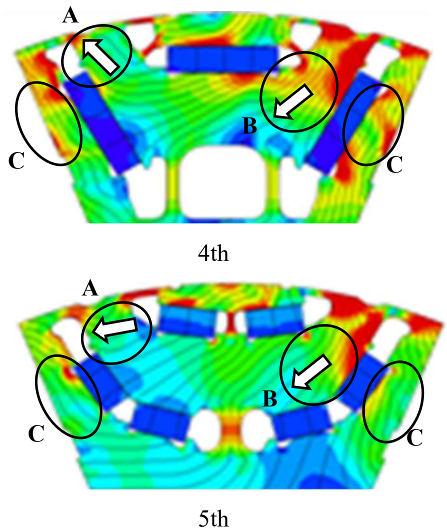

Fig.6 Current magnetic flux density distribution

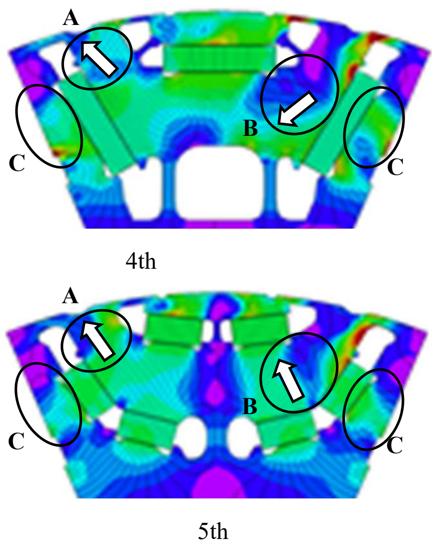

Fig.7 Magnet flux density distribution

In addition, to suppress the invalid magnetic flux which short-circuits in the rotor core, the narrowing of the core bridge width was studied. Improving the strength of the electromagnetic steel sheet of the core by atomizing the crystal grain size, makes it possible to reduce the bridge width, therefore the effective magnetic flux was increased to improve torque.

On the other hand, since the electromagnetic steel sheet for the stator core also uses the same material as the rotor core, if the crystal grain is small, iron loss increases. To avoid that, the electromagnetic steel sheet of the stator core was annealed after press stacking to grow crystal grains.

3. DOWNSIZING TECHNOLOGY

Downsizing has been realized by increasing the rotation speed of the motor and reducing the coil end size.

3.1. High rotation technology

By increasing the maximum rotation speed of the motor to 6,200 rpm in the 2nd generation, 13,000 rpm in the 3rd generation, and 17,000 rpm in the 4th and 5th generations, the maximum torque of the motor has been reduced and downsizing has been realized (Fig.8).Although losses will worsen, we have taken measures by adopting loss reduction technologies such as thinning of electromagnetic steel sheets.

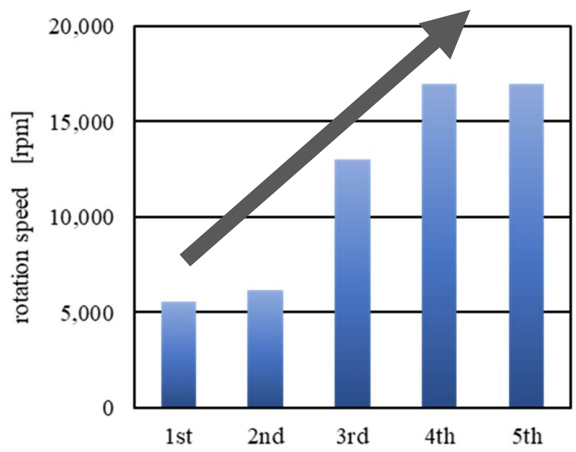

Fig.8 Maximum rotation speed

3.2. Coil end downsizing technology

In the 4th generation, a distributed winding using a segment conductor was used for the coil, and the interphase insulation paper was abolished to reduce the coil end size. Securing insulation between coils without interphase insulation paper was achieved by reducing the dielectric constant of the coil wire coating.

The coil structure of the 5th generation follows the 4th generation, but by changing from full-pitch winding to fractional pitch winding and shortening the peeling length of the coil weld, further reducing the coil end size.

4. CONCLUSION

In the THS system, we have developed technology to high power and downsizing of motors and work on increasing their density.

The high power has been realized by the insulation technology of coil wires corresponding to high voltages and the improvement of reluctance torque by the evolution of rotor magnet arrangement. Downsizing has been realized by increasing the rotational speed of the motor and downsizing the coil end.

In the future, it is expected that the spread and expansion of automobiles with excellent environmental performance will further advance, so we will promote further efforts to high power density.

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