Magnetic material and magnetic measurement of the traction electric motor for high efficiency and miniaturization

H. Nakai[1]　[1] Toyota Central R&D Labs., Inc., Nagakute, Aichi 480-1192, Japan

Compared to other types of electric motors used in vehicles, traction electric motors, which are used in hybrid vehicles (HVs), plug-in hybrid vehicles (PHVs), and electric vehicles (EVs), have a long operation time and a large output. In order to drive a vehicle, a motor must have a wide operation area. Motors are most frequently used under light- to medium-load conditions, and are driven by an inverter. Based on the above characteristics, traction electrical motors must be highly efficient and compact. In order for motors to satisfy these demands, high performance is also expected for magnetic materials.

Miniaturization of motors can provide an increase in the output power with the same volume, or in other words an increase in the output density. Increasing the rotation speed and torque are effective means for increasing the output density. It is desirable for the rotor to be constructed of a high-strength core material in order to increase the rotation speed. High torque density can be achieved by improving the saturation magnetic flux density and the space factor in the core material. In order to realize a high-efficiency motor, it is necessary to lower the iron and copper losses. Iron loss is caused by magnetic flux fluctuations. Therefore, reducing unnecessary magnetic flux, which does not contribute to the torque, and selecting an appropriate core material according to the flux fluctuation, are effective strategies for improving the efficiency.

Magnetic flux in the motor exhibits various behavior. Alternating flux is dominant in the stator teeth and the stator back yoke, while rotating flux is dominant in the tips of the stator teeth and in the joint of the stator teeth and back yoke. On a rotor, a DC flux is generated by a permanent magnet and a fundamental waveform of stator currents. At the area near the air gap, the magnetic flux fluctuates due to a change in the magnetic resistance. Moreover, an inverter superimposes high-frequency magnetic flux having a switching frequency on the above-mentioned magnetic fluxes. On the other hand, various mechanical situations occur in the motor. For example, for the case in which the stator is fixed by shrink fitting, a large stress is applied to the stator back yoke. In addition, when the coil end is compressed in order to miniaturize the height of the coil end, the stator core is subjected to stress in the direction of the rotation axis. As described above, the manner in which the magnetic flux flows and the manner in which the stress is applied are different for each portion. In motor design, it is important to know in detail the types of phenomena that occur for each portion. Understanding each phenomenon makes it possible to choose the appropriate materials in a suitable shape. Magnetic measurement is important in order to determine the characteristics of the materials. The next paragraph describes two important measurement examples.

First, we show the apparatus for measuring the rotational magnetic flux[1)]. In this apparatus, the number of teeth of the excitation yoke is increased from four (in the conventional apparatus) to eight. The eight teeth are divided into two groups, a main-pole and a sub-pole, and different currents flow in the exciting coil on the main-pole and the exciting coil on the sub-pole. This makes generating a rotating magnetic field in the measurement part in the center of the specimen easy at high magnetic flux density. By setting the ratio of the magnetomotive force distribution of the sub-pole to the main pole to 30:70, this apparatus made it possible to measure the iron loss under the condition that there is a rotating magnetic flux up to 1.9 T, as shown in Fig. 1. Figure 2 shows the thin needle probes on a steel sheet used to measure a magnetic property under out-of-plane stress[2)]. Measurement is performed while pressurizing the measurement part from the normal direction of the plate. Therefore, the wire diameter of conventional search coils is too thick to generate uniform pressure. Therefore, thin-film probes were fabricated on the surface of the sheet by sputtering, and the magnetic flux was measured using the principle of the probe method. Since the probe formed by sputtering is as thin as 20 μm, it is possible to perform measurement while applying pressure. The measurement results revealed that the iron loss increased or decreased depending on the direction of the magnetic flux by pressurization.

By measuring the magnetic characteristics, we can design an electric motor that considers these properties in detail, allowing the design of highly efficient and high power density motors.

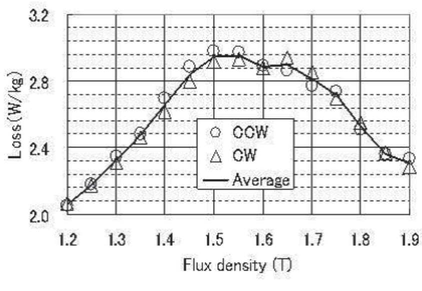

Fig. 1 Measurement results for the rotational flux.[1)]

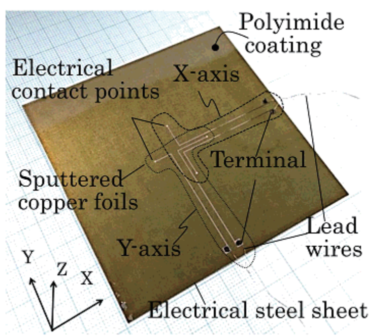

Fig. 2 Thin needle probe on a steel sheet.[2)]

References

1) Y. Maeda et al., *IEEJ Transactions on fundamentals and materials*, **Vol.131, No.6**, pp.460-465 (2011).
2) Y. Maeda et al., *AIP Advances*, **Vol. 7, issue 5**, dot: 10.1063/1.4977760 (2017).