Variable magnetic field technology and permanent magnet characteristic by the request of electric traction motors

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A traction electric motor of HV, PHV and EV is required high efficiency to reduce fuel consumption. While, to secure passengers space, the motor is also demanded downsizing. Since the motor is in the industrial products, low-cost is also required without doubt. The motor requests a several characteristic of a permanent magnet for fulfilling above 3 demands. In order to downsize the motor, firstly, we need a high magnetic flux density magnet (a strong magnet) and a magnet which is hard to demagnetize. The motor is often put in a small space for which it is easy to be filled with heat, for example, an engine compartment. The motor which uses a strong magnet can produce large torque, even though the motor is put in a small space. The motor is often cooled using by a transmission fluid to prevent temperature rise. Even if the motor is chilled using the fluid, the temperature is more than 100℃. Therefore, the magnet which is hard to demagnetize in high temperature is desired in the motor. Almost traction motors use a Nd-Fe-B sintered permanent magnet in order to fulfil the demand of minimization and demagnetization. It is, however, a problem that the Nd-Fe-B magnet has high cost price. Reducing the cost of the Nd-Fe-B magnet is a 2nd request of the motor. In order to realize high efficiency which is a 3rd demand for the motor, we request high electrical resistance magnet and variable magnetic field magnet. Cyclical change of magnetic resistance caused by stator tooth make a magnetic flux change in a magnet placed in the motor. An eddy current occurred by the magnetic flux change makes loss in a magnet. High electrical resistance of a magnet avoids eddy current and reduces the loss. Reduction of the loss achieves increasing motor efficiency. Maximum torque of the motor determines a magnet force in many situations. However, the magnet force is often too strong to achieve high efficiency in high rotational speed and small load area. The efficiency in this area has great influence on fuel consumption of a vehicle. Therefore, variable magnetic field magnet is desired to improve efficiency. The strength of a Nd-Fe-B magnet is also fixed like other permanent magnets. The motor used in vehicle replaces a part of magnet torque with reluctance torque to carry out variable magnetic field. Reluctance torque is not, however, large enough to replace all magnet torque. So, last 10 years several studies which achieve variable magnetic field using not only reluctance torque but also new mechanisms have been done actively. As one kind of studies which achieve variable magnetic field, there is a motor which controls permanent magnetic force[1]. The advantage of this motor is that the structure is almost same with an ordinary IPM motor. The disadvantage is vibration occurred by pulse current which is used for controlling magnet force. Changing magnetic resistance method using mechanical way[2] is one of a variable magnetic field study. The advantage of this method is that the magnetic field can be accurately measured using a mechanical air-gap. The motor needs, however, a mechanical actuator. This actuator is a weak point. Other method controlling magnetic force has an electromagnet in addition to a permanent magnet. This method has ability changing magnetic force quickly because of an electromagnet. An electromagnet needs space bigger than a permanent magnet. Therefore, it is a problem to increase the size of the motor. There is a study solving this problem in order to achieve downsizing with high efficiency[3]. The proposed motor in Fig. 1 constitutes a 3-DOF magnetic circuit with dust core. The circuit has one radial air-gap and two axial air-gaps to increase torque density. This motor settles an excited field coil of an electromagnet in the gap of a radial and an axial air-gap not to increase the size. Therefore, this motor can achieve variable magnetic field with downsizing. As mentioned as above, traction motor demands various performances to a magnet. A magnet that satisfies all performance has not yet been developed. Development of a higher-performance magnet will improve characteristic of the motor and realize restraint of the global warming.

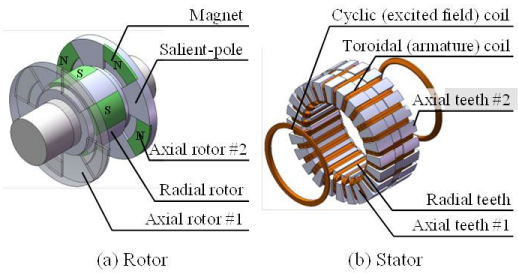

Fig. 1　3 air-gaps motor with excited field coils.

References

1) K. Sakai et al., *IEEJ Transactions on Industry applications*, **Vol.131**, **No.1**, pp.53-60 (2011) (in Japanese).
2) H. Nakai et al., *JIASC2007*, **No.3-64**, pp.337-342 (2007) (in Japanese).
3) M. Namba et al., *IEEJ Transactions on Industry applications*, **Vol.135**, **No.11**, pp.1085-1090 (2015) (in Japanese).