Application of Permanent Magnet Synchronous Motor to Driving Railway Vehicles

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The development of power electronics technology in recent years has realized the inverter control of large-size induction motors. This technology is now applied to driving railway vehicles. Another noteworthy motor is the permanent magnet synchronous motor (PMSM) that has the performance required for traction motors and is more compact, lightweight, and efficient than induction motors. This report explains the construction and features of the PMSM, introduces the research and development at the Railway Technical Research Institute on its use as a direct drive traction motor and a totally-enclosed motor, and clarifies its potential in the future.

CONSTRUCTION AND FEATURES OF PMSM

Construction of PMSM. Figures 1 (a), (b), and (c) show the cross sections of typical PMSMs when the rotor is cut at a right angle to the motor shaft. Those illustrated in Figs. 1 (a) and (b) are called the surface magnet type motor since permanent magnets are fixed at the rotor surface. The motor in Fig. 1 (a), which has no saliency in the core profile, gives magnet torque but not reluctance torque in principle. Owing to the salient structure of the core, reluctance torque can be prepared by the motor given in Fig. 1 (b). The motor with magnets buried in the core in Fig. 1 (c) is called the buried magnet type motor, whose core normally has magnetic saliency to produce reluctance torque. Since the buried magnet type motor has no fragile magnets on the surface, it is simple and robust, and can be manufactured at low costs. Traction motors for railway vehicles must be durable and sturdy. To protect the main power circuit, it is desirable to use motors of the buried magnet type, in order to effectively utilize reluctance torque, and minimize the interlinkage magnetic flux generated with permanent magnets and the voltage induced at high-speed coasting.

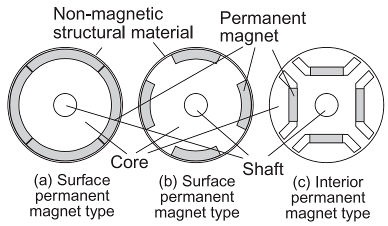

Figure 1. Cross section of the rotor of PMSM.

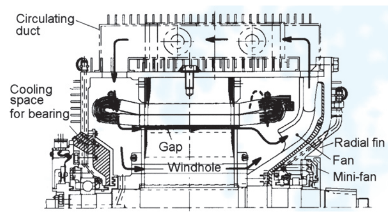

Figure 2. Cross section of the prototype totally-enclosed traction motor.

Features of PMSM. The most important feature of the PMSM is its high efficiency given with the ratio of input power after deduction of the loss to the input power. There is no field current or rotor current in the PMSM unlike in induction motors. The rotor is not subject, therefore, to loss in principle. Copper loss or generation of Joule heat due to a current flow, which is the largest loss in motors, is about half that of the induction motor. This significantly improves efficiency and subsequently reduces power consumption or power cost to make railways a more effective means of transport. Since the smaller the loss of the motor is, the smaller its constitution becomes, the PMSM features higher output than the induction motor of the same physical dimensions, or more compact and lightweight even when the output is the same.

APPLICATION OF PMSMS TO DRIVING RAILWAY VEHICLES

Use as a Direct Drive Traction Motor. To make traction motors smaller, gear units are normally employed. In a railway vehicle, the torque given by traction motors is transmitted to the wheel axle to drive the vehicle. There are a number of problems in the gear unit, however, such as transmission loss, emission of noise, and difficulty in maintenance work. Adoption of the direct drive system will solve these problems, but will make traction motors larger, increase the unsprung mass, and subject traction motors to larger shock. For these reasons, it was tough in the past to adopt the direct drive system for trucks whose size and weight are limited. Since PMSMs are more compact and lightweight than induction motors, we felt the feasibility of a direct drive system to use PMSMs and developed a traction motor of the direct drive type. See Table 1 for its features. A field test proved that noise was reduced 14 dB when prototype traction motors of the direct drive type were installed on narrow-gauge commuter EMUs. For its simple structure, the direct drive type traction motor may also be introduced for gauge-changeable EMUs and low-floor streetcars. The motor of this type should be developed further.

Use as a Totally-Enclosed Traction Motor. A ventilation cooling system is normally employed for compact and high-output traction motors for railway vehicles. However, the dust contained in the cooling air soils the inside of the traction motor, which requires regular disassembling and cleaning. The traction motors for narrow-gauge vehicles emit high noise at high-speed rotation, since a ventilating fan is connected directly to the rotor, say, self-ventilation cooling. If the traction motor is totally enclosed, little dust rushes into the inside. This will eliminate the necessity of disassembling and cleaning, and cut noise to make them quieter. However, the cooling performance of totally-enclosed motors is inferior to that of ventilation-cooling-type motors. To ensure the same performance for a totally-enclosed motor that has the same physical dimensions as those of a conventional motor, therefore, it is required that a new cooling system be introduced to reduce heat generation down to the allowable limit. To suppress temperature rises, we adopted a high-efficiency and low heat generation PMSM. In the case of a totally-enclosed motor, the whole motor structure is subject to temperature rises. This requires prevention of excessive rises in temperature at bearings. We tested a prototype PMSM equipped with a newly developed bearing cooling system and checked the effects of cooling and low noise emission (Fig. 2). The test proved that it was possible to manufacture totally-enclosed traction motors with the same output as that of conventional self-cooling motors with equivalent physical dimensions, reduce their noise 10 dB even at high-speed rotation, and attain high-efficiency and compactness of the structure.

POSTFACE

The traction motors for railway vehicles must be robust, compact, and lightweight. PMSMs, which inherently feature high efficiency, compactness, and lightweight, are ideal for railway vehicles and essential for the times when energy saving and environmental preservation are all-important social problems. We hope that the research results on PMSMs will help promote their dissemination and application to railway vehicles.

Table 1. Features of the direct drive type motor

Advantage
-Does not require the maintenance of gear unit
-Does not require the space for installation of gear unit
-No power transmission loss (high efficiency)
-Low noise
Disadvantage
-Large shock on traction motors
-Tends to be heavy and slow in rotation
-Larger unsprung mass