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Winding Design for the Maximum Speed of Interior Permanent Magnet Brushless DC Motor

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In this paper we propose the winding design and lead angle control for the maximum speed of an interior permanent–magnet brushless DC motor (IPMBLDCM) for the subway locomotive. As the speed regulation ratio is larger than 2, the maximum speed of motor must be ensured by the lead–angle and the number of conductor per slot.

The motor considered is a home–made 150kW, 3–phase, 8–pole IPMBLDCM. Its rated and maximum speeds are 835r/min and 1948r/min, respectively. From zero to the base speed, it is dependent on the applied voltage, and above the base speed, on the flux weakening by the torque angle [1].

This paper describes the linkage flux and no–load speed regulation principle by lead–angle. Also the d–axis armature reaction mmf to decrease permanent magnet mmf is presented by the lead angle.

If the lead–angle of phase winding is regulated in IPMBLDCM, the linkage flux of winding can be regulated. We can see that no–load speed is increased when the lead–angle is large. When the lead–angle is 60°, no–load speed is increased twice. If the lead–angle is increased from 60° to 89°, no–load speed is increased quickly.

The d–axis armature reaction mmf is changed by the lead–angle α. The armature reaction mmf changes the amplitude and the wave form of the air–gap flux field. The speed of IPMBLDCM is higher because the flux–weakening action of average d–axis armature reaction mmf is increased with lead–angle α. But the flux–weakening effect is less because the armature reaction mmf is much smaller than permanent magnet mmf. And also we should consider the armature reaction by circle current.

When the lead–angle is controlled, the circle current flows between inverter and non–conducting winding, and it may generate the damping torque and armature reaction. As the damping torque generates, maximum speed reduces.

Initially, the number of conductor per slot was 14 but changes its value from 14 to 8 in simulation. The simulation is conducted by using Ansoft Maxwell/RMxprt software. When the lead–angle is 47° and the number of conductor per slot is 8, the rated speed is 835r/min, when the lead–angle is 89° and the number of conductor per slot is 8, maximum speed is 1 948r/min. When the numbers of conductor per slot are 10, 12 and 14, the rated and maximum speed becomes lower.

The speed, torque, output power and efficiency are tested through the lead–angle control of a home–made 150kW, 3–phase, 8–pole IPMBLDCM. The characteristics are tested as the lead–angle is changed from 0° to 89°.

As shown in the experiment results, when the number of conductor per slot is 8 and the lead–angle is 88°, IPMBLDCM can attain the rated speed of 835r/min and the maximum speed of 1 948r/min safely.

The change of the linkage flux by the lead–angle is found to increase significantly no–load speed of IPMBLDCM. At the load state, the armature reaction gives the flux–weakening action, but its effect is small. The maximum speed is controlled by the lead–angle and the number of conductor per slot.