Abstract

Transport electrification has attracted significant attention in recent years due to environmental issues and global warming. Hence, substantial research has been carried out on developing electrical machines, which are the core of electric powertrains.

Permanent magnet (PM) machines are the dominant solution in the market, although the cost of rare earth magnets is relatively high. Among the PM machine structures, interior permanent magnet (IPM) machines are more attractive because of their unique advantages, including robust structure, high efficiency, high power density, near-constant power for wide range of speeds, and magnet retaining structure. In addition, IPM machines can provide higher torque compared to conventional surface-mounted machines since they enjoy extra reluctance torque components.

Designing and modelling IPM machines, especially V-type IPM, are challenging due to embedded magnets in the rotor structure and saturation. One aim of this work is to develop a design procedure of V-type IPM machines based on a geometric approach taking into account electromagnetic, structural, and thermal analyses. For this purpose, an equivalent magnetic circuit technique is employed to address the nonlinear behaviour in the rotor. In addition, a simple model is developed to calculate the mechanical stress on the iron ribs taking advantage of the FEM-based design of experiment approach. Besides, a simplified thermal network is considered to estimate the temperature in the machine. The proposed design methodology can reduce the computational time compared to FEM.

The second part of this dissertation focuses on the design of novel multi-layer magnetic blocks consisting of two or more magnetic materials with diverse magnetic and mechanical properties. Several combinations of the materials are examined, and many specimens are built. The self-produced specimens are characterised experimentally by means of an advanced measurement technique. Moreover, some FEM models are proposed that can be taken into account for modelling the electrical machines equipped with multi-layer magnets. Last but not least, the feasibility and applicability of using multi-layer magnet technology for variable flux PM machine is also investigated by means of FEM simulation, and two AFPM machines equipped with multi-layer magnets are built and tested.

Key words: Multi-physic design, interior permanent magnet machines, analytical design, magnetic equivalent circuit, mechanical stress, thermal modelling, finite element analysis, magnetic materials, double-layer magnets, characterisation, axial-flux machines.