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Summary of the Doctoral Dissertation

'Analysis of the Impact of Selected Changes in the Magnetic Circuit on the Parameters of a Commutator Motor with Permanent Magnets'

This dissertation addresses the issue of the impact of changes in the magnetic circuit on the parameters of a commutator motor with permanent magnets. When designing electric machines with magnetoelectric excitation, it is particularly important to shape the magnetic circuit in a way that reduces the cogging torque. This is a negative phenomenon resulting from the interaction between the magnetic field generated by the permanent magnets and the stator with variable reluctance. The cogging torque causes additional vibrations and noise. The ripple in the electromagnetic torque (which is influenced by the cogging torque from the magnets) affects the positioning accuracy and smooth operation of drives that use magnetoelectric machines—this is because it depends on various vibrations caused both mechanically and electromagnetically throughout the drive system.

A literature review indicates that in recent years, many studies have focused on the impact of structural parameters of machines with magnets on their properties, with an emphasis on minimizing cogging torque. It is worth noting that most research has focused on brushless machines, both DC and AC. However, commutator motors have largely been overlooked in studies of cogging torque minimization methods. According to the author, this is because most commutator machines use inexpensive ferrite magnets in their excitation circuits. These magnets have a low energy density—not exceeding 40 kJ/m^3—resulting in a low level of flux density in the air gap and thus a low value of cogging torque. Due to cost considerations, the use of high-energy magnets with rare-earth metal additives (with energy densities of up to 400 kJ/m^3) is not common. A particular challenge is the shape of the magnets—ferrite magnets are produced in the form of ring segments. Obtaining sintered magnets (e.g., neodymium) in such a shape significantly increases costs, as the magnet must be cut from a larger rectangular block.

An intermediate solution could be the use of appropriately placed rectangular neodymium magnets in the excitation circuit. The author believes this could positively impact the machine's parameters, including increasing the electromagnetic torque and reducing the machine's size. However, a potential drawback of this solution could be an increase in the level of torque ripple related to the cogging torque. The aim of this study is to analyze the possibilities and benefits

of replacing ferrite magnets in a classical commutator machine design with rectangular neodymium magnets and to evaluate the impact of selected changes in the magnetic circuit on the machine's parameters.

To achieve this goal, the study includes an analysis of the current state of knowledge in the following areas: methods for minimizing cogging torque in magnetoelectric machines, the potential use of field and field-circuit methods for electromagnetic field calculations in the studied machines, and methods and tools for determining cogging torque in electric machines. Based on this analysis, a research plan for simulations and laboratory experiments was developed. The practical experiments were made possible by the creation of test setups, including a particularly automated measurement setup for determining cogging torque.

The study developed a series of field and field-circuit models for both a machine with a classical design (excited by ferrite magnets in the form of ring segments) and a new machine design with rectangular neodymium magnets. Additionally, a comparative analysis of models was conducted in various finite element method (FEM) programs for different levels of computational complexity for the classical machine. For the new machine with rectangular magnets, an analysis was conducted to determine the impact of selected magnetic circuit parameters on its electromechanical properties. The research focused on parameters such as the ratio of the number of slots to the number of pole pairs (integer and fractional), air gap thickness, and magnet placement (pole shoe design). The simulation results were verified through measurements on built prototypes.

Based on the conducted simulations, it was found that the studied modifications significantly affect the machine's parameters—particularly the cogging torque. The research demonstrated that it is possible to select magnetic circuit parameters that allow for replacing traditional ferrite magnets in the form of ring segments with rectangular neodymium magnets, resulting in a reduction in machine size while simultaneously increasing the electromagnetic torque without increasing the level of torque ripple. The studies also showed that achieving some design criteria might require compromises that worsen the performance in other areas. For the studied machines under nominal load, the efficiency decreased—depending on the magnetic circuit parameters—by several to over ten percent. The analysis suggests that replacing ferrite magnets with rectangular rare-earth magnets is an interesting alternative worth further investigation. According to the author, future research could focus on developing more precise three-dimensional models, particularly aimed at analyzing power losses. It would also be valuable to consider the influence of end windings, eddy currents, and temperature effects on the properties of the applied materials in future models.

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