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Concept for Magnet Intra Logistics and Assembly Supporting the Improvement of Running Characteristics of Permanent Magnet Synchronous Motors

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Abstract

Current scientific studies prove the dependency of the running characteristics of permanent magnet synchronous motors on variations of the physical properties of permanent magnets and manufacturing errors. Currently, this fact is not considered in most process chains for magnet and rotor assembly. Thus, insufficient rotor quality can only be detected during the end-of-line test, causing rejects of whole motors. As a solution for these drawbacks, a computerized magnet intra-logistics storage and assembly concept is presented, using sophisticated magnet measurement technologies. This concept allows for the traceability of single magnets and enables to compensate variations of the magnetic properties by selective magnet assembly.

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1. Introduction

As the market share of PMSM among electric drives is growing constantly, quality assurance gains in importance. Special purposes require high standards in running characteristics, power density and energy efficiency. With efforts on automation the production rates are being increased. As the methods for fully automated magnet assembly have been widely investigated at the Institute for Factory Automation and Production Systems of the Friedrich-Alexander-University of Erlangen-Nuremberg in various demonstrators for magnet assembly and different magnet gripper concepts the accuracy of this process can be ensured. [1][2]

While stators are being tested regarding insulation and resistance before rotor and stator assembly magnets rotors are mostly assembled without magnetic testing [5]. Thus errors on magnetization can only be detected during the end-of-line test by measuring high cogging torque, noise and low back electromotive force. This leads to rejects due to insufficient quality or a wide tolerance band within these parameters and a more conservative motor design.

As the reject costs can be reduced by quality control in an early stage of production and the avoidance of errors within the assembly processes, an automation solution for the whole process chain is required. The idea presented in this paper provides for a 100 % check of magnets in conjunction with an automated logistics and storage solution for magnetized permanent magnets and fully automated magnet assembly systems. Thus each magnet can be classified according to the angular deviation of the magnetic moment vector from the ideal direction and the value of the remanent polarization. The measuring data is stored in a database and linked with the position of the magnet in the physical magnet storage. A request on magnets for the assembly of one rotor will initiate the calculation process among all available magnets in the

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storage for determining the best assembly sequence. With this information a sequenced magnet stack will be created to be delivered to the automated magnet assembly system. The aims of the concept are reduction of rejects among single magnets and rotors as well as improvement of the quality especially of high end drives by minimizing the tolerance band. This paper deals with the challenging aspects of rotor assembly and magnet measurement as well as with solutions and the synthesis of different solutions to a new approach in magnet assembly. Finally further advantages of the presented concept are described, which allow for the traceability of single magnets among rotors and the process monitoring by using data mining methods.

2. Influences on running characteristics

Manufacturing imperfections within the sintering process and the subsequent shaping process of anisotropic permanent magnets lead to deviations in shape, density, remanent polarization and deviations of the magnetic moment vector. These imperfections are caused by the inhomogeneous magnetic field during pressing of magnet blocks within the mould. They differ depending on the exact pressing method. The material density of axial field die pressed magnets is more inhomogeneous than of transverse field die pressed magnets. Cutting single magnets out of the pressed and sintered magnet block causes different magnetic characteristics within one batch depending on the location within the block. [3]

A rough study among the tolerances of magnetic characteristics has been done at the FAPS institute before [11].

Various papers describe the undesired influences of these manufacturing imperfections on the running characteristics of permanent magnet synchronous motors. The geometrical deviations of single magnets and their influence on the cogging torque components have been examined in [9]. Here magnet misplacement, thickness and width of the magnets are mentioned to cause a significant effect on the cogging torque of PMSM. However, the dependencies of the magnetic moment on the dimensions of the magnet were not considered in the mentioned paper and remain uninvestigated in this approach. The influence of deviations in the flux density on the EMF is examined in [4] and on the cogging torque in [5]. Both show a significant influence on noise, harmonics and torque ripple. All these effects were investigated further in a DOE [6] using statistical methods for analyzing both cogging and BEMF.

To face these inadequacies in the past an approach was already presented. To measure the magnetization deviation of entire rotor stacks with integrated permanent magnets, a fixture has been developed. In this case lamination stacks are assembled with magnets and thereafter magnetized. Since the single magnets are not being measured, uncertainties remain until the magnetization process. To compensate the undesired effects described above, the measured stacks are being clustered and assembled together in an optimized sequence. [7][8]

This approach is limited to a certain design such as integrated permanent magnets and rotor stacks. Especially when having a wide variant diversity, it is not suitable. Therefore the presented concept has been developed.

3. Measurement of magnetic characteristics

The standard method to determine the magnetic dipole moment of permanent magnets is the measurement with a Helmholtz coil in combination with a fluxmeter. The approach and measurement details are described in the IEC 60404 standard. During measurement, the specimen has to be moved into a Helmholtz coil. The variation of the magnetic flux induces a time-dependent voltage in the coil. From the integral of the voltage over the time and the coil factor k, the component of the magnetic dipole moment of the magnet along the coil axis can be determined. To identify the error angle of the magnetization, the magnet has to be measured in all three spatial axes.

The described procedure is not well suited for fully automated highly clocked inline measurement processes. One reason is the problem of the magnet feeding. It has to be moved into the coil with a linear movement. In order to measure the error angle, a three-dimensional Helmholtz coil and a three-channel fluxmeter have to be used. The feeding of the specimen into a three-dimensional Helmholtz coil is even more difficult, since all three spatial axes are equipped with coils. Further, Helmholtz coil systems are sensitive to electric disturbing fields.

An alternative measuring technique which allows for a highly clocked 100% inline measurement of permanent magnets is the so called **“Magnetic Monitoring”**.

Within the magnetic monitoring technique, the magnetic stray field of the specimen is measured in the far field with magnetic field-sensitive sensors (e.g. Hall effect sensor, AMR-sensor, etc.). With an algorithm the magnetic moment and the error angle of the magnetization are determined in a quasi-static way. Besides the determination of the magnitude and orientation of the magnetic dipole moment, the magnet is also localized in 3D space. This information can be used to give the current position of the test item to a positioning system for handling processes.

The advantage of the magnetic monitoring is the quasi-static principle. It is not necessary to move the sample for the measurement. Furthermore, it is insensitive to electric disturbing fields. Measuring rates up to kHz range can be realized.

However, the biggest advantage is its accessibility. While even a single Helmholtz coil has a rather large extent in all spatial directions, it is not necessary to place magnetic field sensors around the whole sample within the magnetic monitoring technique. Therefore, integration into fully automated systems is possible without any difficulty.

3.1. Theoretical background “Magnetic Monitoring”

Within the magnetic monitoring technique, an array of magnetic field-sensitive sensors is used to track small dipolar permanent magnets. At the same time the characteristics of the specimen itself can be measured. For the localization algorithm, the position and orientation of the magnetic dipole constitute five independent parameters. If the magnitude of the magnetic dipole moment of the specimen is not known or is subject to variation during the measurement, this quantity constitutes a sixth parameter which must be determined. Mathematically, it would be sufficient to use six magnetic field sensors in order to determine the six unknown parameters. In