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Design procedures for small synchronous generators with interior permanent magnet rotors

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Abstract. This paper presents the design and analysis of a three phase synchronous generator with an interior permanent magnet rotor (NdFeB). The main point of such a rotor construction is the design of the flux barriers because of its direct connection with the saliency of the machine. The performance analysis is derived from the results of a transient 2D-finite-element method with a direct coupled electrical circuit. Furthermore an optimized rotor design results in an elementary reduction of the supplementary losses caused by the higher harmonics.

Key words

Synchronous machine, interior permanent magnet rotor, transient finite element method, coupled field analysis.

1. Introduction

Besides of all advantages of permanent magnet synchronous generator compared with classic designed one the fact of the falling price of neodymium-iron-boron magnets makes it to a cost-effective electrical generator. This paper gives an overview of the necessary design steps of such generators.
A modern permanent magnet machine is rather complex because it has to meet a variety of requirements. As a result the machine designs are different and rather complex. In order to achieve both a high efficiency and a simple controllability of the generator, various rotor designs are used.
Each design combines a lot of advantages and disadvantages in view of costs. The complexity of the rotor designs makes the computability of machine parameters by analytical method difficult. However, this conventional method results in large errors.
A coupled transient electromagnetic-mechanical finite element calculation method with directly coupled external circuits is useful, in the case of the voltage waveform, torque ripple and additional losses. The influence of higher harmonics on the design steps becomes visible by this method.

2. Design steps

A. Demagnetization stability

A fundamental design step is to guarantee the demagnetization stability of the permanent magnets at each operating point. Important is the use of magnets with a working temperature about 120 °C. The typical demagnetizing curve is linear up to a working temperature about 120°C. The demagnetizing curve of the sintered NdFeB magnet N45H is shown in Fig. 1.

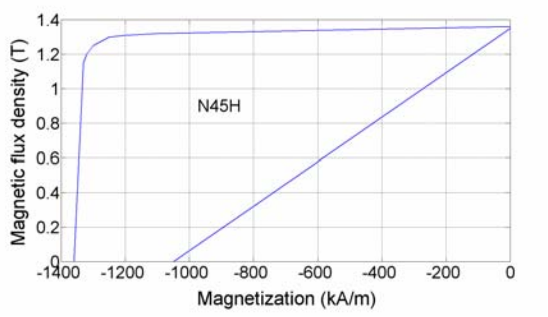

Fig. 1. The demagnetizing curve of the used magnet by its working temperature about 120°C.

B. Air gap flux density

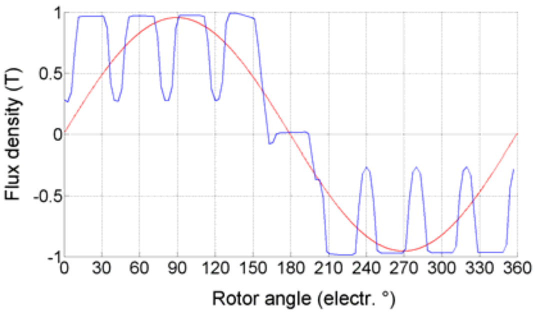

Fig. 2. Computed variation of the radial air gap flux density when the motor is unloaded.

Basis of each machine design is the air gap flux density. By using of high energy permanent magnet material, such as neodymium-iron-boron (NdFeB) the air gap flux density is around 1 Tesla. Fig. 2 shows the air gap density of the generator at no load.

C. Flux barriers design

Besides the stator winding layout, the air gap length and magnet material, the flux barriers design between the magnets is very important because magnetic and mechanical parameters will be influenced by it. In respect of the mechanical properties circular ends are useful. An optimum distance between the rotor surface and the hole of the magnets has to comply with the mechanical strength and the magnetic saturation. The sheet thickness of the laminated rotor is the smallest possible distance.
A smaller distance results in problems with the punching process of the lamina. Fig. 3 presents a principle useful rotor design.

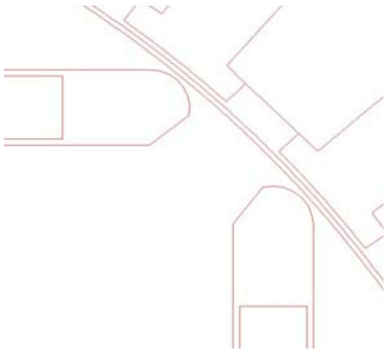

Fig. 3. Rotor design of the test generator.

3. Results

D. Synchronous reactances

The synchronous reactances of the permanent magnet motor are derived from the stored magnetic energy. For this the surface current density of the magnets are set to zero. Fig. 4 shows the field plot of the motor when the total magneto motive force (mmf) is aligned with the direct axis of the machine.

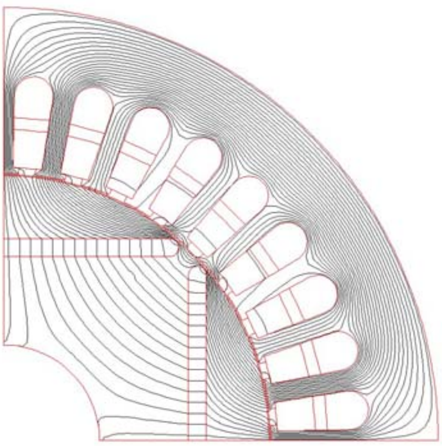

Fig. 4. Field plot of the machine when the direct axis stator currents are flown.

The q-axis reaxtance can be found when the total mmf of the stator currents is aligned with the q-axis of the machine. Fig. 5 shows this field plot.

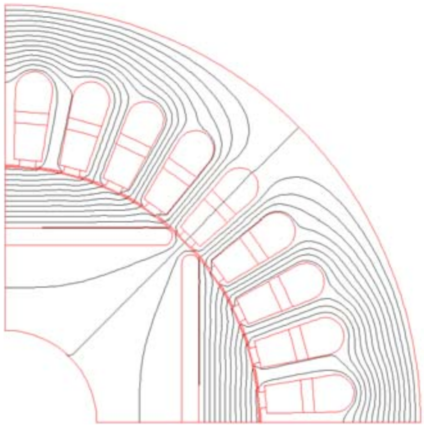

Fig. 5. Field plot of the machine when the quatrature axis stator currents are flown.

E. Losses

The rotor iron losses play an important part in connection with permanent magnet motors. Below, the magnetic flux density of the elements in the circle in Fig. 6 will be analyzed.

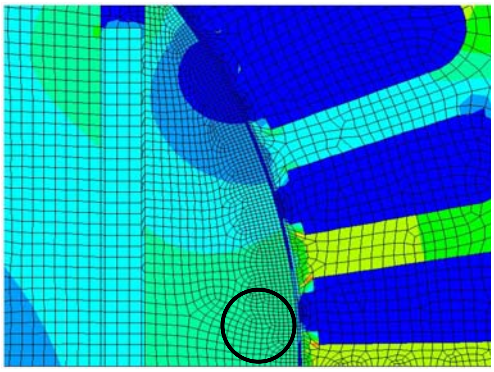

Fig.6. View of the rotor elements used by the FEM.

The main frequency of the analyzed flux density is 900Hz. The coefficient of loss at this frequency and flux density of the dynamo sheet (Power Core M330-50A) is nearly 5.5W/kg. The additional iron losses caused by the higher frequency must be taken into account when the efficiency factor of the generator will be calculated.

4. Conclusion

The design of permanent magnet machines with a small power range has to consider different aspects. First, a low cost design of the rotor.
This means an optimum between the magnetic material volume and the costs of mounting.
Moreover, several secondary effect, such as cogging torque, torque ripple, non-sinusoidal shape of no-load voltage and losses, which are worsening the operation behaviour of such permanent magnet machine, must be restricted to limiting values.