

# MATHEMATICAL MODELING A SINGLE-PHASE FLUX REVERSAL MACHINE

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**Abstract**—In this paper a new FRM construction with the increased power-to-weight ratio is described. A technique of electromagnetic calculation based on solving magnetostatic problems is developed for this construction.

**Keywords** - stator interior permanent magnet machine, flux reversal permanent magnet machine, high speed electrical machine (motor and generator), mathematical model, eddy current losses, core losses

## I. INTRODUCTION

The paper describes the procedure of modeling a single-phase flux reversal machine (FRM). The FRM comes under the heading of stator interior permanent magnet machines/SIPMM [1],[2],[3]. The chief advantage of a SIPMM is related to the absence of electrical conductors or constant magnets on the revolving rotor. This competitive advantage makes itself especially evident when this electrical machine is used for high-speed applications. These applications include those where the rotor revolving speed exceeds 20000 rpm and weight and size parameters are important.

In their technical characteristics (power density, electrical efficiency) SIPMMs are closely related to brushless synchronous motors having their magnets on the rotor and outperform them for reliability in designing high-speed electric motors and electric generators.

Fig. 1 shows a new single-phase FRM construction [4] which differs from that in [3] in that

- the neighboring magnet poles located on different teeth of the stator magnetic circuit are like ones;
- the number of the rotor teeth is half as many as the number of poles on all the teeth of the stator magnetic circuit.

The advantage of a new FRM construction as compared to that in [3] is the increase in power-to-weight ratio caused by decreasing the magnetic circuit reluctance due to enlarging the area of the stator and rotor interaction.

## II. MATHEMATICAL MODEL DESCRIPTION

In designing high-speed electric machines the necessity for taking into account the eddy losses in conducting media (magnetic circuits steel, magnets) is greatly increased; in the process, constitutive relations for these media contain time derivatives. Therefore, the most appropriate approach to FRM modeling is dynamic modeling based on solving the Cauchy boundary value problem [5], [6], [7].

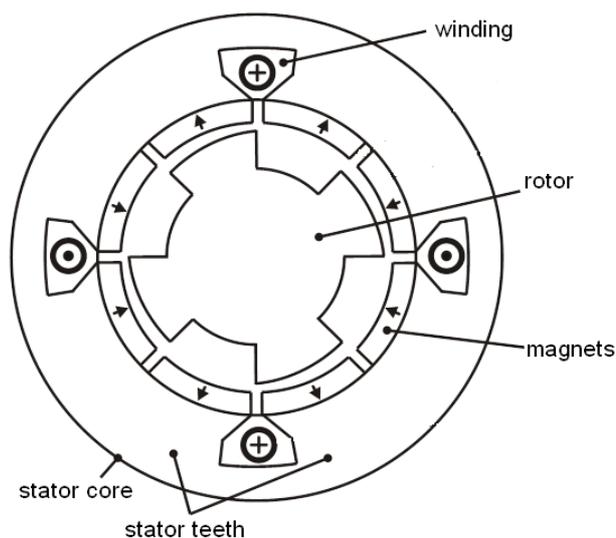


Fig. 1 New single-phase FRM cross-section.

The obvious drawback of this approach is its being resource-intensive. This necessitates developing models requiring less computation efforts. Evaluating many FRM characteristics important for designing is possible using magnetostatic calculation of the FRM with the rotor being in several positions and with different values of the current [1]. In [1], the magnetic flux and co-energy in every time moment are calculated, then, in postprocessing, current and the shaft torque dependences are calculated.

In [2] magnetostatic problems are associated with the time moments; and the method to calculate magnetic losses is demonstrated. Steel and magnet losses are not calculated in solving the magnetostatic problem, but can be calculated in postprocessing [2].

In this paper, in contrast to [1], [2]:

- a technique of electromagnetic calculation based on solving magnetostatic problems, using the finite element method, has been developed for the new FRM construction presented. Magnetostatic problems are solved with the rotor being at different angles and different winding currents. FRM's electromechanical characteristics are calculated in postprocessing;
- a new procedure for calculating losses in magnets has been proposed, that takes into account their being electrically insulated from the stator core.

### III. EXAMPLE OF FRM CALCULATION AND DESIGN

On the basis of the mathematical model developed, a new single-phase FRM was calculated and designed for electric appliances (for an angular grinding machine).

The outside diameter is 88 mm, the inside one is 17.5 mm, the gap is 0.5 mm, the remanence flux density is  $B_r=1.3$  T, the rotor and stator laminations width is  $L=30$  mm. The number of turns in the stator slit is 100. Copper factor is 0.4. Rotating speed is 25000 rpm.

Fig. 2 shows the torque dependence on the rotational angle with the current being 0,  $\pm 17$ A,  $\pm 28$ A.

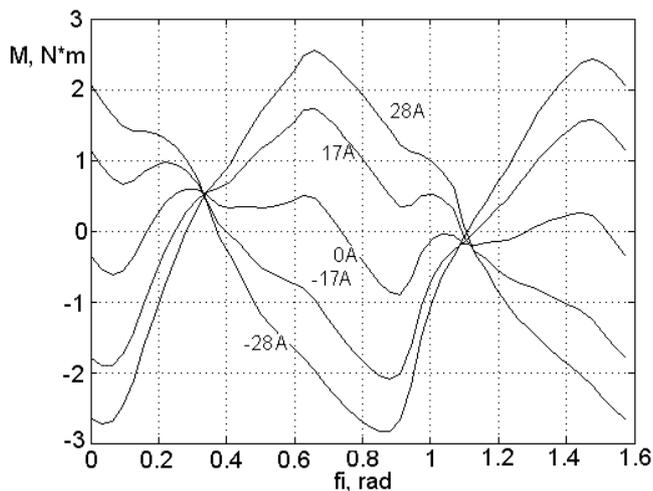


Fig.2. The plot of the torque against the rotational angle.

The control unit of the single-phase FRM is connected to the 220 V AC supply and consists of a rectifier and inverter. Constant voltage on the rectifier terminals is 310V. The inverter produces three-level voltage of 0,  $\pm 310$  V. In calculating the electromechanical characteristics of the electrical machine in the motor mode, voltage switching moments were optimized.

As a result, the calculations have led to the following data: the mechanical power is 2200 W, the maximum phase current is  $I_m=21$  A, the efficiency is 89%.

At the moment, a prototype angular grinding machine with a new single-phase FRM (Fig. 3) has been developed, and the electric motor control system is being adjusted.



Fig. 3. A prototype of the new single-phase FRM

### IV. CONCLUSION

The structure of a new single-phase FRM, where due to enlarging the area of the stator and rotor interaction the power-to-weight ratio was increased, has been presented.

The proposed procedure for calculating the eddy losses in magnets takes into account their being electrically insulated from the core.

On the basis of the mathematical model developed, a new single-phase FRM for an angular grinding machine has been calculated and designed.

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