DISK-TYPE PERMANENT MAGNET SYNCHRONOUS MOTOR

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ABSTRACT

The design of a disk-type permanent magnet synchronous motor with axially magnetized magnets and slotless windings is discussed in this paper. A simplified analytical expression for the air-gap flux density distribution is derived and applied for the construction of an experimental machine is presented here.

1 INTRODUCTION

Permanent magnet synchronous machines have been widely used in variable speed drives for over ten years. Disk-type permanent magnet synchronous machines have been found in numerous applications in power ranges from few watts to several kilowatts. A permanent magnet synchronous machine is basically an ordinary AC machine with windings distributed in the stator so that the flux created by stator current is approximately sinusoidal. Quite often also machines with windings and magnets creating trapezoidal flux distribution are incorrectly called synchronous machines. A better term to be used is a brushless DC (BLDC) machine. The operation of such machine is equal to a traditional DC machine with a mechanical commutator, with the exception that the commutation in a BLDC machine is done electronically. This paper concentrates only on permanent magnet synchronous machines (PMSMs) with sinusoidal flux distribution.

With the advent of new magnetic materials, such as NdFeB, which have energy density at very high level, the disk-type permanent magnet machines can be constructed with slotless winding. Fig.1 shows the basic layout of the machine. A simple toroidal strip-wound stator core carries a uniformly distributed slotless toroidal winding with three phases. The rotor comprises two discs carrying axially magnetized magnets.

The selection of the optimum dimensions and the shape of the permanent magnets, which leads to minimum cost and full utilization of the high-field magnets, it requires that the field distribution into the machine must be investigated. The aim of this paper is the design model of the disk-type PMSM for drive pump.

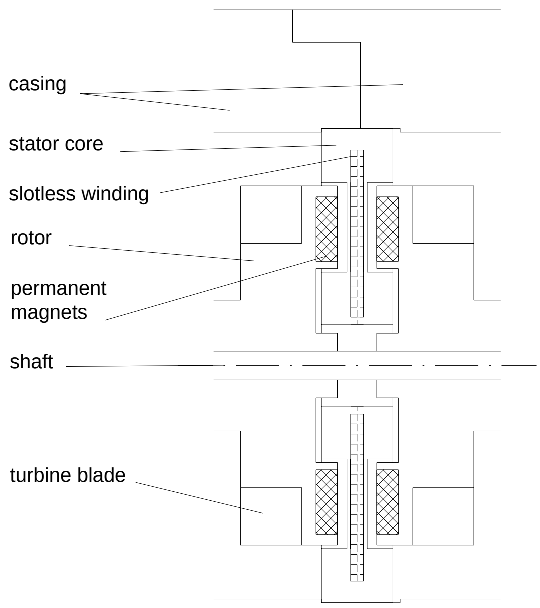

Fig. 1: *Layout of the machine*

2 MACHINE MODEL SIMPLIFICATION

Assuming that there is no saturation in the iron circuits and the magnetizing force in the magnets is uniform. Field flux and armature reaction flux can be superposed to find the resultant flux distribution in the air-gap under all load conditions. As the armature reaction flux is inversely proportional to air-gap length and proportional to pole pitch, the armature reaction for machine of this type is usually low. Consequently, the effect of armature reaction can be neglected, or the presence of the conductors in the air-gap of the machine can be ignored.

The total magnet flux can be expressed by:

$$\phi_m = \phi_\delta + \phi_l = k_\varphi \cdot \phi_\delta \tag{1}$$

where ϕ_δ is useful flux, which crosses the air-gap of the machine and ϕ_l is leakage flux, which passes between adjacent magnets without crossing the air-gap. k_φ is the flux leakage factor.

Assuming that the magnet flux density is constant at some value B_m over an active area S_m and that the air-gap flux density at the stator surface is constant at some value B_δ over an active area S_δ, the total magnet flux and air-gap flux for one pole, are given by following equations:

$$\phi_m = B_m \cdot S_m \tag{2}$$

$$\phi_\delta = B_\delta \cdot S_\delta \tag{3}$$

with using equation (1) we obtain:

$$B_\delta = \frac{B_m}{k_\varphi \cdot k_\sigma} \tag{4}$$

where $k_\sigma = S_\delta / S_m$ is defined as the fringing factor of the air-gap region.

The demagnetization characteristic of the magnet is a straight line as described by:

$$B_m = B_r + \mu_0 \mu_r H_m \tag{5}$$

Substitution of equation (5) in equation (4) gives:

$$B_\delta = \frac{B_r + \mu_0 \mu_r H_m}{k_\varphi \cdot k_\sigma} \tag{6}$$

Considering Ampere's law around the air-gap region:

$$2H_m l_m + 2H_\delta l_\delta = 0 \tag{7}$$

Hence from equations (6) and (7) after adjustment to obtain that the air-gap flux density B_δ is:

$$B_\delta = \frac{B_r}{k_\varphi \cdot k_\sigma + \mu_r \dfrac{l_\delta}{l_m}} \tag{8}$$

For the idealized conditions, when flux leakage or fringing are neglected, both k_φ and k_σ are unity and a simplified expression for the air-gap flux density B_δ is given by:

$$B_\delta = \frac{B_r}{1 + \mu_r \dfrac{l_\delta}{l_m}} \tag{9}$$

As the air-gap length increases, the value of maximum air-gap flux density falls off proportionally due to the increased leakage.

3 MACHINE DESIGN IMPROVEMENT

The simplified analytical expression for the air-gap flux density as described in equation (9) can be applied for the preliminary design only. However, flux leakages and fringing always exist in the axial-field permanent magnet machine. The values of leakage factor and fringing factor will depend on the physical arrangement of the magnetic circuit and are dependent on the machine dimensions, pole number, air-gap length and distance of the magnet pieces. From equation (1), it is found that the leakage factor is only related to the leakage flux if the total magnet flux is constant, and will always be greater then unity. Generally speaking, the effective area of the constant air-gap flux density region at the stator surface which defining the fringing factor may be larger or less than the effective area of the magnet pole. Thus the fringing factor may be greater or less than unity depending on the particular geometry of the air-gap region of a particular design.

In order to calculate accurately the air-gap flux density, it is necessary to consider the effect of leakage and fringing flux. Rather than to derive analytical expressions for the leakage and fringing factors, which are very difficult as the ratio between pole pitch and length of air-gap varies with radius in the disk-type machine. 3D finite element analysis method will be used to investigate the air-gap region and to find these factors. There are not experimentally measured results yet, but prototype is nearly finished.

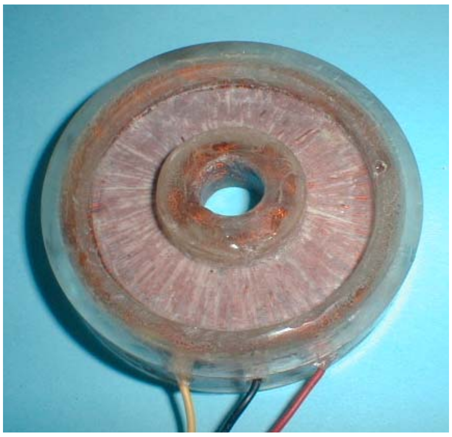

Fig. 2: *The slotless winding*

Fig. 3: *The rotor with permanent magnets*

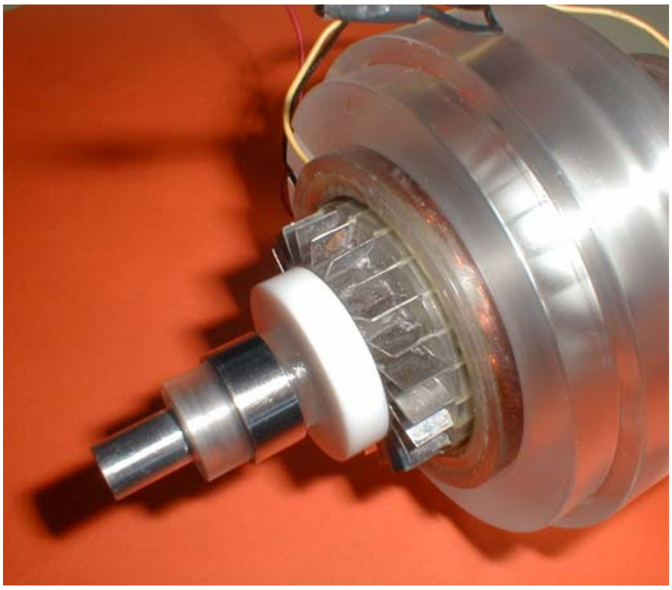

Fig. 4: *The machine prototype*

4 CONCLUSION

The functional prototype of disk-type permanent magnet synchronous motor has been made. The complete pump with the disk-type PMSM has been purveyed on the Faculty of Mechanical Engineering, where the required measurement will be performed. The model parameters in the program ANSYS will be compared with measurement results. The selection of the optimum dimensions and the final shapes of the machine, which leads to minimum cost, will be performed by means of this model. The effect of the main parameters upon the air-gap flux density distribution will be analyzed. A simplified analytical expression for the air-gap flux density distribution has been derived for the design of disk-type permanent magnet synchronous machine.

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