Abstract

The paper presents field analysis of the new structure of the line start permanent magnet synchronous motor (LSPMSM) with hybrid magnets (HM) composed of two types of magnets arranged between the cage bars (Fig.1). The rotor core was made of soft magnetic composite (SMC) material (powder) - Somaloy 500, bars of both cages were made of electrical aluminum ($\sigma_{Al} = 34$ MS/m). Hybrid magnets have been composed of two types of magnets: sintered neodymium magnet and bonded magnet (dielectromagnet). Stator of the motor has the construction of a classic squirrel-cage induction motor stator (type Sg100L-4 - 3kW). The field circuit models of considered motors have been elaborated and parameterized in Maxwell environment. To analyse the impact of hybrid magnets on the currents and torque pulsations in steady-state of the motor the construction with the hybrid magnets (HM) was compared with other variants of that structure with sintered neodymium magnets (NM) and with sinusoidal shaped sintered neodymium magnets (SNM) - Fig.2. Other functional parameters of tested motor (for example: current and starting torque, efficiency, power factor) were also considered.

1. Introduction

Magneto-electric synchronous motors have higher power factor and efficiency in comparison with conventional squirrel cage induction motors. Because of this we can observe a growing interest in such motors in drive systems for continuous duty such as pumps and fans drives in the mining industry [1, 2]. More advanced and cheaper solutions of these motors are constantly being developed. One of the new structures of Line Start Permanent Magnet Synchronous Motors (LSPMSM) with permanent hybrid magnets will be discussed in this paper. The development of new electrical machines is related with the progress in many fields of technology i.e. new magnetically and electrically active materials, insulation materials, improvement of methods of analysis, design and optimization. Thanks to the development in powder metallurgy, rotors and stators can be made of powder materials [3, 4]. This allows to form massive structural elements in a single technological process and leads to reduction of production time and costs.

Recent achievement in powder technology are the hybrid magnets. They consist of at least two materials with different magnetic properties, made in one process. Hybrid magnets can be made from blends of different materials or as magnets of a layered structure. They offer not only new material properties, but also new possibilities for the design of electrical machines [5, 6].

The paper presents new structure of the LSPMSM with hybrid magnets. To analyse the impact of such magnets on the currents and torque pulsations in steady-state of the motor the field-circuit model has been developed using Maxwell software [7, 8]. Other functional parameters of tested motor (for example: current and starting torque, efficiency, power factor) were also considered.

2. New structure of the line start synchronous motor with hybrid magnets

In this paper the new structure of line start synchronous motor with two squirrel-cages and hybrid magnets (HM) composed of two types of magnets arranged between the cage bars (Fig.1) has been examined. The calculations were made for machines with squirrel-cage induction motor stator (type Sg100L-4 - 3kW and speed of 1400 rev/min). The rotor core was made of soft magnetic composite (SMC) material (powder) - Somaloy 500, bars of
both cages were made of electrical aluminum (\(\sigma_{\text{Al}} = 34 \text{ MS/m}\)).

Hybrid magnets have been composed of:
- sintered neodymium magnet with parameters \(H_{c1}=890000 \text{A/m}, B_{r1}=1,23 \text{T}\), marked with the symbol M1,
- bonded magnet (dielectromagnet) with parameters \(H_{c2}=404970 \text{A/m}, B_{r2}=0,646 \text{T}\), marked with the symbol M2.

To analyse the impact of hybrid magnets on the currents and torque pulsations in steady-state of the motor the construction with the hybrid magnets (HM) was compared with others variants of that structure with sintered neodymium magnets (NM) and with sinusoidal shaped sintered neodymium magnets (SNM) - Fig.2. Other functional parameters of tested motor (for example : current and starting torque, efficiency, power factor) were also considered.

### 3. Selected simulation results

The field-circuit model of considered motor has been elaborated and parameterized in Maxwell 14 environment. The model enables optimization of the machine. Elaborated projects allow to perform calculation of start-up process and steady state operation of the motor.

The simulations of motor start-up have been carried out for the load ventilator characteristic. The load torque at synchronous speed was equal 20 Nm. Motor has been designed for a rated voltage of \(U_{N} = 500 \text{V}\) and frequency \(f_{N} = 50 \text{ Hz}\).
First the influence of hybrid magnet hybridization on start-up of the motor for all variants (NM, SNM and HM) has been examined. The moment of inertia of load system was the same in all simulations. The comparison of obtained rotor speed time functions has been shown in the Fig.3. Corresponding time functions of electromagnetic torque during the motor start-up have been presented in Fig.4.

It can be noticed that the oscillations of rotor speed are smaller and the start-up time is a bit shorter for the motor variant with hybrid magnets (HM).

On the basis of the results obtained during simulation of the steady-state and the short-circuit state the functional parameters of the investigated motor variants were determined.

The calculated values of torque pulsation amplitude factor \( A\text{Tp}\% \), current in steady state \( (I_u) \), efficiency \( (\eta) \), power factor \( (\cos\phi) \), current and starting torque \( (I_r, T_r \text{ respectively}) \) have been presented in Table 1.

The torque pulsations amplitude factor \( A\text{Tp}\% \) was defined as follows,

\[
A\text{Tp}\% = \left( \frac{T_{\text{max}} - T_{\text{min}}}{2 \cdot T_N} \right) \times 100\% \tag{1}
\]

where: \( T_{\text{max}}, T_{\text{min}}, T_N \) are respectively the maximum, minimum, and rated values of electromagnetic torque.

<table>
<thead>
<tr>
<th>( A\text{Tp}% )</th>
<th>NM</th>
<th>SNM</th>
<th>HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_u ) [A]</td>
<td>4.01</td>
<td>4.27</td>
<td>5.46</td>
</tr>
<tr>
<td>( \eta ) [-]</td>
<td>0.938</td>
<td>0.934</td>
<td>0.897</td>
</tr>
<tr>
<td>( \cos\phi ) [-]</td>
<td>0.995</td>
<td>0.979</td>
<td>0.789</td>
</tr>
<tr>
<td>( T_r ) [Nm]</td>
<td>50.70</td>
<td>52.09</td>
<td>53.34</td>
</tr>
<tr>
<td>( I_r ) [A]</td>
<td>33.64</td>
<td>31.94</td>
<td>30.22</td>
</tr>
</tbody>
</table>

It can be noticed that the torque pulsations are smaller for the motor variant with hybrid magnets (HM). This is an important achievement because torque pulsations are the direct cause of noise and vibration in the machine.

On the other hand, the value of stator current in steady-state is greater for the motor with hybrid magnets. This has the direct impact on the motor efficiency and power factor which have are lower values then for motor variants with sintered neodymium magnets (NM) and with sinusoidal shaped sintered neodymium magnets (SNM). This situation can be explained by the increase of power losses in stator windings due to higher current value. Also can be noticed that motor with hybrid magnets has higher value of starting torque and simultaneously lower value of starting current.

4. Conclusions

Presented paper deals with analysis of functional parameters of the new LSPMSM structure with hybrid magnets and core made of powder materials.

Performed analysis of the line start permanent magnet synchronous motors with composite powder rotor and hybrid magnets shows that it is possible to design motor with such a magnetic circuit having good functional parameters during asynchronous as well as synchronous operation.

The obtained results have shown that hybridization of the magnets has impact on shape of the waveforms of electromagnetic torque and motor speed during the direct start-up.

Moreover, it has been proved that motor with hybrid magnets has smaller amplitude of torque pulsations which is an important achievement because torque pulsations are the direct cause of noise and vibration in the machine.

The conducted comparative analysis has shown that the elaborated new structure of LSPMSM with hybrid magnets has greater efficiency and power factor than classical asynchronous machine of the same power.

Bibliography


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