Electromagnetic Design of Hybrid Synchronous Motor
Elena Suvorkova, Istvan Vajda, Yuriy Dementiev
1Budapest University of Technology and Economics (Hungary)
2National Research Tomsk Polytechnic University (Russia)
Vajda.istvan@vet.bme.hu, suvorkova_elena@mail.ru, dementiev@mail2000.ru

Abstract—This paper introduces the conceptual design and finite-element method analysis of a hybrid synchronous motor. Careful flux-barrier and permanent-magnet sizing, high magnetic saturation, and current density are the main requirements for maximum torque production with constraint volume.

I. INTRODUCTION
Quite recently, rather complete studies [2]–[14] and comparisons between induction [14], permanent-magnet (PM) synchronous [11], reluctance synchronous, switched reluctance [9], [10], PM-assisted reluctance synchronous, and PM transverse flux machines [13] have led to the conclusion that the induction motor (IM) has two strong competitors in terms of losses and motor weight: the PM-assisted reluctance synchronous (PM-RSM) [6], [3] and the PM transverse flux machines [2] at lower total equipment costs and total system losses.

References [9]–[11] do present results that suggest the PM-RSM is a better solution than the IM, but without a realistic approach to PM-RSM modeling and conceptual design with finite-element method (FEM) analysis.

The main goals of this paper are to settle on a practical topology, develop conceptual design for heavy saturation, FEM thorough analysis and verification, mainly in terms of torque versus, currents.

II. TYPICAL SPECIFICATIONS
Hybrid synchronous motor (HSM) combines positive properties of reluctance motors and synchronous permanent-magnet motors [6-7]. The main part of HSM’s power is developed by reluctance machine as the cheapest and simple in design, and energy of constant magnets poles is used for increasing power and improving operational characteristics [1].

Taking into account the hybrid synchronous motors specific operation conditions these machines should meet the following requirements:
1. The possibility to start at full load;
2. Stable operation with periodic load during frequency adjustment range (up to 18000 revolutions per minute).

In Fig. 1, the design configuration for main parts of the hybrid synchronous motor are presented [5, 7]. The stator laminations were chosen from a suitable existing asynchronous motor in order to lower the costs of the prototype.

Fig. 1. Rotor sheet construction of reluctance motor and synchronous permanent-magnet motor: (a) permanent-magnet motor rotor sheet, (b) reluctance synchronous motor sheet.

The rotor topology and the polarization of the magnets are presented in Fig.1.b The rotor design (the PM dimensions) was made with FEM assistance. Also, attempts have been made to reduce the PM flux density harmonics in the air gap by increasing the PM radial dimension of flux barriers toward the shaft.

Table 1 indicates basic parameters of hybrid synchronous machine.

TABLE I
HYBRID SYNCHRONOUS MOTOR MAIN PARAMETERS [1]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>220/380</td>
</tr>
<tr>
<td>Supply Frequency</td>
<td>50Hz</td>
</tr>
<tr>
<td>Number of Phases</td>
<td>3</td>
</tr>
<tr>
<td>Pole Pair Number</td>
<td>4</td>
</tr>
<tr>
<td>Base Speed</td>
<td>1500 RPM</td>
</tr>
<tr>
<td>Nominal Power</td>
<td>2.5 kW</td>
</tr>
<tr>
<td>Efficiency</td>
<td>82%</td>
</tr>
<tr>
<td>Power Factor</td>
<td>0.795</td>
</tr>
<tr>
<td>Airgap</td>
<td>0.25 MM</td>
</tr>
</tbody>
</table>

Usage of rare earth magnets caused by its high energy density and satisfying physico-mechanical properties. In synchronous permanent-magnet motor part we use Sm-Co magnets.

Main properties of KC37A type magnets are:
1. \( B_r = 0.82 \) T - remanent flux density;
2. \( H_c = 5.6 \times 10^5 \) A/m– coercive force;
3. \( \rho_d = 1.3 \times 10^{-6} \) H/m – resetting ratio.
III. PRACTICAL CONFIGURATION AND CONCEPTUAL DESIGN ASPECTS

In Fig. 6, with FEM support, the torque values for different rotor positions are shown. The maximum torque (43 Nm) is obtained at 171 mechanical degrees. This means 342 electrical degrees (2p=4).

![Fig. 6. FEM torque versus rotor position (maximum current).](image_url)

In Fig. 7, the PM flux lines are shown. Figs. 8 and 9 present the PM air-gap flux and flux density. The PM flux density in the air gap is approximately 1 T and its distribution is remarkably uniform.

![Fig. 7. Magnetic induction field distribution of synchronous permanent-magnet motor.](image_url)

![Fig. 8. Flux distribution in synchronous permanent-magnet motor.](image_url)

![Fig. 9. Air-gap flux density distribution of synchronous permanent-magnet motor.](image_url)

In Fig. 10, the magnetic induction field distribution of synchronous reluctance motor is shown.

![Fig. 10. Magnetic induction field distribution of synchronous reluctance motor.](image_url)

The phase current was maximum in phase A and 50% of it in phases B and C and the rotor was placed in various positions and then the flux linkage in all coils of phases A, B, and C has been calculated through FEM.

Taking into account the motor behavior with saturation we can calculate flux density extension proportional to phase current increase which is shown TABLE II.

<table>
<thead>
<tr>
<th>J_A =1200000 A/m²</th>
<th>J_B =600000 A/m²</th>
<th>J_C =600000 A/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>J_A =2400000 A/m²</td>
<td>J_B =1200000 A/m²</td>
<td>J_C =1200000 A/m²</td>
</tr>
<tr>
<td>J_A =4800000 A/m²</td>
<td>J_B =2400000 A/m²</td>
<td>J_C =2400000 A/m²</td>
</tr>
</tbody>
</table>

| M= -10.812 N·m | M= -39.227 N·m | M= -82.004 N·m |

Stator flux density excluding rotor is shown along the contour, in Fig. 11.
IV. CONCLUSION

This paper has presented main design features of hybrid synchronous motor and here was researched magnetic field influence on hybrid synchronous motor parameters.

It may be concluded that the PM-assisted reluctance synchronous motor gives good performance with good values for torque density.

REFERENCES


