SIMULATION AND MEASUREMENT OF TWO-PHASES SYNCHRONOUS MOTOR WITH PERMANENT MAGNETS

Abstract: This paper describes the simulation and measurement of two-phase synchronous motor prototype with permanent magnets. Based on geometric dimensions, a 3D solid model was created in ANSYS/Maxwell program. The electromagnetic design was calculated in ANSYS/RFxprt program. The cross section with graphically presented magnetic field, in particular a part of electromagnetic circuits, was shown. The 3D magnetic simulation, simulated and measured characteristics of the motor and analysis of the two-phase synchronous motor with permanent magnets presents an integral part of the article, too.

Keywords: two-phase synchronous motor, permanent magnet, ANSYS/Maxwell program

1. Introduction

Synchronous motors operate at a constant speed in absolute synchronism with the line frequency or, respectively, can be supplied also from a frequency converter. Synchronous motors are, according to their rotors design, construction, materials and operation, classified into the below listed four basic groups [1]:

- electromagnetically-excited motors,
- PM motors,
- reluctance motors,
- hysteresis motors.

In electromagnetically excited and PM motors the cage winding is frequently mounted on salient-pole rotors to provide asynchronous starting and to damp oscillations under transient conditions, so-called damper.

Recent developments in rare-earth PM materials and power electronics have opened new prospects in designing, construction and application of PM synchronous motors. Servo drives with PM motors fed from static inverters are finding applications on an increasing scale. PM servo motors with continuous output power of up to 15 kW at 1500 rpm are common. Rare-earth PMs have also been recently used in large power synchronous motors rated at more than 1 MW.

PM synchronous motors are usually built with one of the following rotor configurations:

- surface-magnet rotor;
- inset-magnet rotor;
- rotor with symmetrically distributed buried magnets;
- rotor with asymmetrically distributed buried magnets.

2. Model of the motor in Ansys/Maxwel

The 3-D solid model of the electromagnetic circuit of two-phase synchronous motor with permanent magnets has been created in the Ansys/Maxwell program. Based on geometric dimensions, the 3D model of motor is presented in Figure 1.
Figure 2 presents 3-D model of the rotor with permanent magnets.

The rotor has two-poles created with six NdFeB permanent magnets. Table 1 lists characteristic parameters of the synchronous motor.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Rated power</td>
<td>200 W</td>
</tr>
<tr>
<td>Rated torque</td>
<td>0.55 N.m</td>
</tr>
<tr>
<td>Number of poles</td>
<td>2</td>
</tr>
<tr>
<td>Synchronous speed</td>
<td>3000 rpm</td>
</tr>
</tbody>
</table>

The supply voltage for this two-phase motor must be shifted for a single phase motor phase by 90 degrees. Therefore, two-phase synchronous motor must be supplied by a special transformer (in Scott-connection) or special two-phase variable frequency converter.

3. Computer simulation

Synchronous motor was simulated in the Ansys/Maxwell program. The motor is supplied with two-phase symmetrical voltage and the phase shifted by 90 degrees.

3.1. Simulation of electromagnetic field

Simulation of the electromagnetic field of synchronous motor with PM is shown in Fig. 3.

3.2. Simulation of induced voltage

The no-load RMS voltage induced in one phase of the stator winding (EMF) by the magnetic excitation flux $\Phi_f$ of the rotor is

$$ E_f = \pi \sqrt{2} f N_f k_w \phi_f $$

where $N_f$ is the number of the stator turns per phase, $k_w$ is the stator winding coefficient and $\Phi_f$ is the fundamental harmonic of the excitation magnetic flux density without armature reaction.

Simulation of induced voltage is shown in Fig. 5.

4. Measurement of two-phase motor prototype

Simulation results of two-phase synchronous motor were attained through comparison of measurements on a real two-phase synchronous motor. For practical measurements the physical
model of the two-phase synchronous motor was used, which is shown in Fig. 6.

Fig. 6. The prototype of two-phase synchronous motor

The photographs of the motor without bearing plate and of the rotor are shown in figures 7 and 8.

Fig. 7. The synchronous motor without bearing plate

Fig. 8. The rotor of two-phase synchronous motor

During the laboratory tests, the two-phase synchronous motor is supplied by a special transformer with two-phase power line at maximum RMS current of 0.8 A. The output voltage is continuously adjustable.

4.1. Measurement of generator operation

The machine was tested as a stand-alone generator. The waveforms were recorded with an oscilloscope showing the voltage induced in individual phases. Figure 9 shows the waveforms of induced voltages in the first and second phase of the generator for the speed of 3000 rpm.

Fig. 9. The measured induced voltages

Figure 10 shows the plot of efficiency and the total power supplied to the low-voltage network versus mechanical torque for generator speed of 3000 rpm. The measured quantities are indicated by crosses.

Fig. 10. Measured generator quantities for 3000 rpm

4.2. Motor load tests

The synchronous motor was operated at constant speed (3000 rpm) and was loaded by a torque. At constant mechanical speed, the mechanical output power is equivalent to mechanical
torque on the shaft. Figure 11 shows waveforms of supply voltages in the first phase (in blue), second phase (in red) and the waveform of current in neutral wire (in purple), respectively. The motor is loaded with constant torque of 0.45 Nm.

Fig. 11. Measured waveforms of supply voltages and the current

Figure 12 shows the plot of efficiency and the mechanical power supplied to the low-voltage network versus mechanical torque for motor speed of 3000 rpm. The measured quantities are indicated by crosses.

Fig. 12. Measured motor quantities for 3000 rpm

Figure 13 shows waveforms of torques for the motor and generator versus current in one phase of the synchronous machine (for speed of 3000 rpm).

Fig. 13. Measured torques for motor and generator

5. Conclusion

The present paper shows initial results of the simulation and measurement of two-phase synchronous machine prototype with permanent magnets. When the synchronous machine operates as a generator efficiency is higher than 90%. The synchronous motor has an efficiency of around 60% (depending on the load). The maximum measured load angle of a synchronous motor is 28 degrees.

Stator windings of the two-phase synchronous machine are orthogonal with a 90-electrical-degree phase-shift. In practical measurements, the two-phase synchronous machine is supplied by a special transformer in Scott-connection. Two-phase output voltage is phase shifted by 90 degrees. Figure 11 shows the waveform of current in the neutral wire (in purple), which contains higher harmonics though. Therefore, it is anticipated to perform future measurements of synchronous machine supplied with special two-phase variable frequency converter.

6. Acknowledgment

The financial support of the Slovak Research and Development Agency under the contract No. APVV-0138-10 is acknowledged.

7. Bibliography

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