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DYNAMIC MODEL OF TWO-PHASE PERMANENT MAGNET SYNCHRONOUS MOTOR

Summary. The paper deals with a new type of an electronically commuted two-phase salient pole permanent magnet synchronous motor for an industrial and household appliance. The motor is fed from a single voltage-source inverter with rectangular output voltage. The inverter is controlled by a microcomputer. The mathematical model of the machine was realized by means of the Matlab-Simulink program.

MODEL DYNAMICZNY 2-FAZOWEGO SILNIKA SYNCHRONICZNEGO Z MAGNESAMI TRWAŁYMI

Streszczenie. W artykule przedstawiono nowy typ 2-fazowego silnika synchronicznego z magnesami trwałymi z komutacją elektroniczną, przeznaczony do użytku przemysłowego lub w sprzęcie gospodarstwa domowego. Silnik jest zasilany z przekształtnika 1-fazowego o prostokątnym kształcie napięcia. Przekształtnik jest sterowany za pomocą mikrokomputera. Symulacje przeprowadzono przy pomocy programu Matlab-Simulink.

1. INTRODUCTION

Permanent magnet machines are used in a wide variety of industrial and household appliances for many reasons. The excitation of the machine is provided by permanent magnets, brushes and slip rings are eliminated, therefore resulting in a simple structure. Permanent magnets are current-free and have less losses, hence the efficiency and power density of permanent magnet machines are higher than those of other electric ones. The structure and unique operation mode of a permanent magnet motor give additional advantages for the control of its speed and position. The armature field and the rotor position are always synchronized, and the armature field can be precisely controlled. The speed control may be realized without a position sensor, which is of particular importance for certain applications where the use of a rotating encoder is not possible.

The application of a permanent magnet machine is limited by fixed excitation from permanent magnets. In many applications a constant power and variable speed operation in a wide range are required. This requirement can be easily satisfied for classic synchronous machine drives, by the appropriate reduction of the field current at the increased speed. In a permanent magnet machine the magnet flux is fixed. Consequently, the torque is permanently reduced. It is clear that for a variable speed permanent magnet machine, the largest allowable demagnetizing current specified by the demagnetization characteristic limits the achievable speed range.

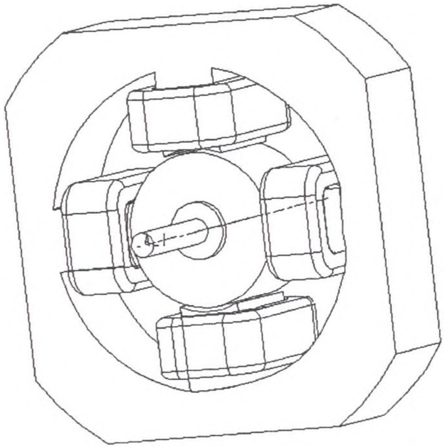

Fig. 1. Construction of the two-phase permanent magnets motor
Rys. 1. Konstrukcja dwufazowego silnika z magnesami trwałymi

2. MOTOR CONFIGURATION

Figure 1 shows the construction of a two-phase synchronous motor having permanent magnets on the rotor. The stator structure is similar to that of a two-phase salient reluctance motor. The stator is built of laminations. The rotor is a two-pole cylinder permanent magnet. Diamagnetic Ferrite with a linear demagnetization characteristic and the remanence of 0,5 T is used for constructing the magnets.

The stator windings are of particularly simple form. Two diametrically opposite stator poles have the opposite magnetic polarity. Depending on the feeding voltage, the rotor windings can be either a serial or parallel two-phase system. Normally the windings are identical.

The electromagnetic torque is mainly developed due to the interaction between the stator winding current and the rotor permanent magnet flux.

The electromagnetic torque can be calculated from two corresponding time quantities that are the phase current and the back e.m.f. or from the related spatial quantities that are the stator m.m.f. and the rotor induction.

The finite element analysis was employed for a basic design of the prototype motor of the cross-sectional geometry shown in Figure 1 and the following main specification:

Stator		**Rotor**	
Outer diameter	100 mm	Outer diameter	36 mm
Inner diameter	40 mm	Inner diameter	16 mm
Tooth width	27 mm	Magnet width	27 mm
Pole width	15 mm		
Air-gap width	1 mm		

The waveform of the induced electromotive force (e.m.f.) in the stator coil windings was numerically calculated from the waveform of the flux. The calculation results show that the waveform of the e.m.f. can be approximated by a sinusoidal function.

3. MATHEMATICAL MODEL

The analytical description of two-phase synchronous motors with a permanent magnet rotor is simpler than that of three-phase ones, due to the fact that the stator windings of such two-phase motors are physically orthogonal and thus magnetically decoupled.

Figure 2 shows the per-phase equivalent circuit of the machine.

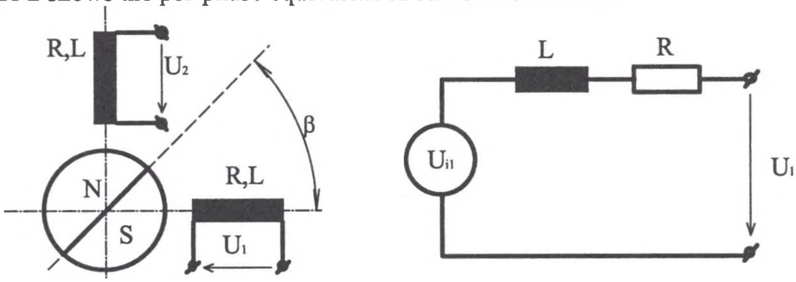

Fig. 2. Model of a two-phase synchronous motor
Rys. 2. Model dwufazowego silnika synchronicznego

Let us assume that the reluctance torque is negligible.

Assuming that the all windings are identical and the magnetic circuit is symmetrical, the instantaneous value of the electrical input power is given by:

$$p = u_1 i_1 + u_2 i_2 . \tag{1}$$

It consist of three parts:

$$p = p_j + p_m + p_e , \tag{2}$$

where:

$$p_j = R\left(i_1^2 + i_2^2\right)$$ - copper losses in the stator coils;

$$p_m = L\left(i_1 \frac{di_1}{dt} + i_2 \frac{di_2}{dt}\right)$$ - magnetic reactive power;

$$p_e = u_{i1} i_1 + u_{i2} i_2$$ - electrical output power;

where:

R- armature resistance,

L- synchronous inductance.

The product of the torque and the speed gives the electrical output power of the machine:

$$p_e = M\,\omega_m , \tag{3}$$

where:

M- instantaneous value of the torque, ω_m- speed of the machine.

In order to determine the waveform of the machine torque, it is necessary to determine the waveforms of the phase currents. Since the phases are identical they can be calculated from the voltage equations:

$$u_1 = Ri_1 + L\frac{di_1}{dt} + u_{1i} , \tag{4}$$

$$u_2 = Ri_2 + L\frac{di_2}{dt} + u_{2i}. \tag{5}$$

The electromotive forces u_2, u_{2i} induced in the stator coils can be expressed by the following equations:

$$u_{1i} = U_i \sin\theta_m, \tag{6}$$

$$u_{2i} = U_i \cos\theta_m. \tag{7}$$

The magnitudes of the electromotive forces depend linearly on the mechanical speed.

$$U_i = \frac{U_{in}}{\omega_{mn}}\omega_m, \tag{8}$$

where:

U_{in}, ω_{mn} are the rated values.

The rotor position is calculated from the mechanical speed:

$$\theta_m = \int \omega_m dt. \tag{9}$$

The machine torque is given as a sum of the torques of the both phases. The phase torque is calculated as a product of the phase current and electromotive force:

$$M = u_{1i}i_1 + u_{2i}i_2. \tag{10}$$

Finally, the mechanical speed of the machine can be calculated from the mechanical equation of the machine.

$$M - M_p = J\frac{d\omega_m}{dt}, \tag{11}$$

where:

M_p is the load torque and J is the moment of inertia.

4. SIMULATION SCHEME

Simulink working under Matlab package program has been used to work out the dynamic model of the permanent magnet machine. Equations (1÷11) have been used in simulations. It has been assumed that a two-phase rectangular voltage has fed the machine. The block structure of the simulation scheme is shown in Fig. 3.

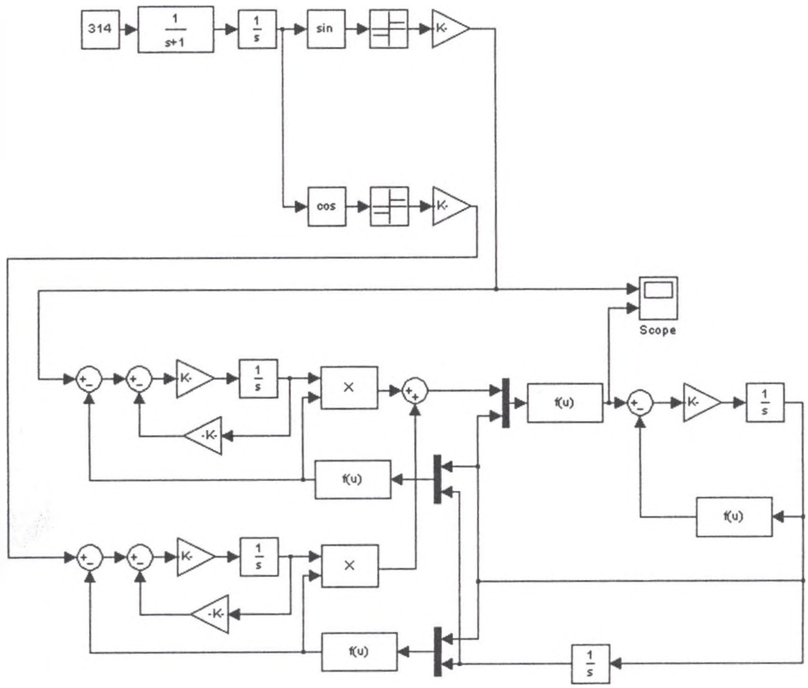

Fig. 3.Block structure of simulation scheme
Rys. 3. Schemat blokowy struktury modelu symulacyjnego

5. SOME SIMULATION RESULTS

In Figures 4 and 5 two of the performed simulations are shown. The both figures represent the starting of the machine. Figure 4 shows the torque and rotor speed at run-up. The phase current and torque of the machine are presented in Figure 6.

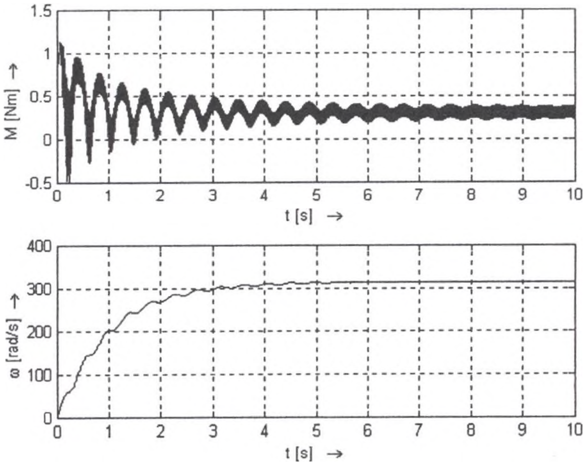

Fig. 4. The run-up of the machine
Rys. 4. Rozruch silnika

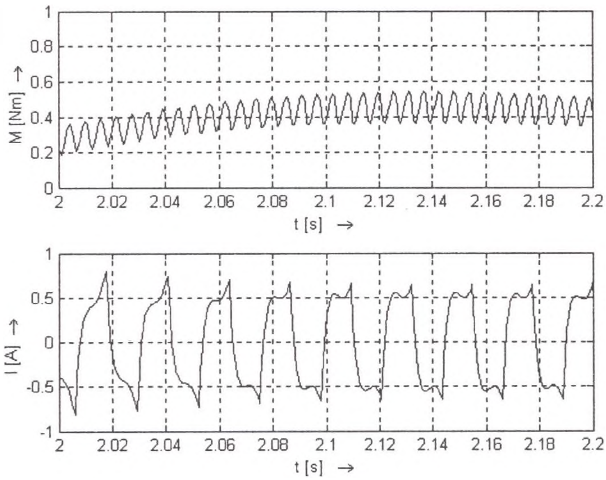

Fig. 5. The torque and the phase current
Rys. 5. Moment elektromagnetyczny i prąd fazowy

6. CONCLUSION

The paper describes the developement of a dynamic model of a special two-phase permanent magnet synchronous motor. The constructed model allows studying the behaviour of the machine in different dynamic states. The electromagnetic torque ripple is caused by a rectangular feeding voltage. It can be minimized by reduction in the pulse width of the feeding voltage. The experimental works are in progress.

All the simulation results are in accordance with the results calculated in [5].

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