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DEVELOPMENT OF SENSORLESS VECTOR CONTROL SYSTEM FOR PERMANENT MAGNET SYNCHRONOUS MOTOR IN MATLAB SIMULINK

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In last 20 years segment of electric drives with permanent magnet synchronous motors has increased. This type of motors has better technical characteristics compared to induction motors, but has problems in actual implementation, one of which is the requirement of rotor position data. It is possible to implement with use of sensors or without them by means of motor state observer.

The paper describes problems of sensorless vector control system for permanent magnet synchronous motors. The vector control system with state observer for permanent magnet synchronous motors is described. Synthesis of sliding mode observer for rotor speed and position is presented. The algorithm is implemented by development of model in Matlab Simulink environment with support by Texas Instruments processors support blocks. Experimental comparison of results of rotor angle state calculation and the data obtained by rotor position sensors was conducted. Research objective is a development of control algorithm, which has required precision for calculation of rotor start angle, high range of speed regulation and resistance to drift of motor parameters.

Key words: vector control, motor state observer, permanent magnet synchronous motor, sensorless control, frequency controlled electric drive

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Introduction. In last 20 years electric drive systems based on permanent magnet synchronous motors (PMSM) become widespread. In such systems presence of converter and control systems is required [1, 3, 15]. The control system governs the switching sequence of inverter switches in accordance with control law. In case of vector control it is required to obtain defined flux and electromagnetic torque. The vector control systems for PMSM require determination of rotor position. It is possible to implement by means of position sensors or by incorporation of motor state observer into control loop. The sensorless control assumes lack of position and speed sensors on the machine shaft. The use of sensorless control requires the presence of observer, which calculates rotor position and speed [5, 14, 16].

In the paper, the structure of electric drive, maintaining the preset rotation frequency, is actualized. The observer is represented by mathematical model of motor for which the input data is currents in motor power supply lines. The observer is demanded to be up to requirements, which are robustness to noses in measurement channels, provision of wide speed control range and low response to motor parameters drift [6, 11, 12].

Vector control system for PMSM. Structural diagram of model is represented in Fig.1. The speed setting block consists of rate setting device, output setting of which changes gradually, ensuring required engine acceleration rate. The speed regulation block consists of PID controller, which output variable is a torque setting. Vector control block includes observer, which calculates motor speed and transmits this signal to input of PID controller [2, 4], accordingly closing the feedback loop. Speed control loop operates with sampling rate of 100 Hz.

Torque setting signal, signals from motor phase *A* and *B* current sensors are transmitted to inputs of vector control block. Current sensors are implemented by means of current shunts. Current of phase *C* is calculated as inverted sum of two measured currents:

$$i_c = -(i_a + i_b). \quad (1)$$

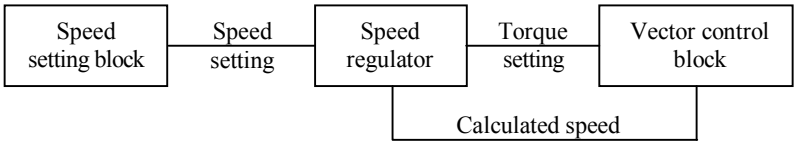


Fig.1. Diagram of algorithm general structure

The vector control system for permanent magnet synchronous motor assumes following transforms: Clarke transform – conversion from three-phase coordinate system to fixed axis α and β:

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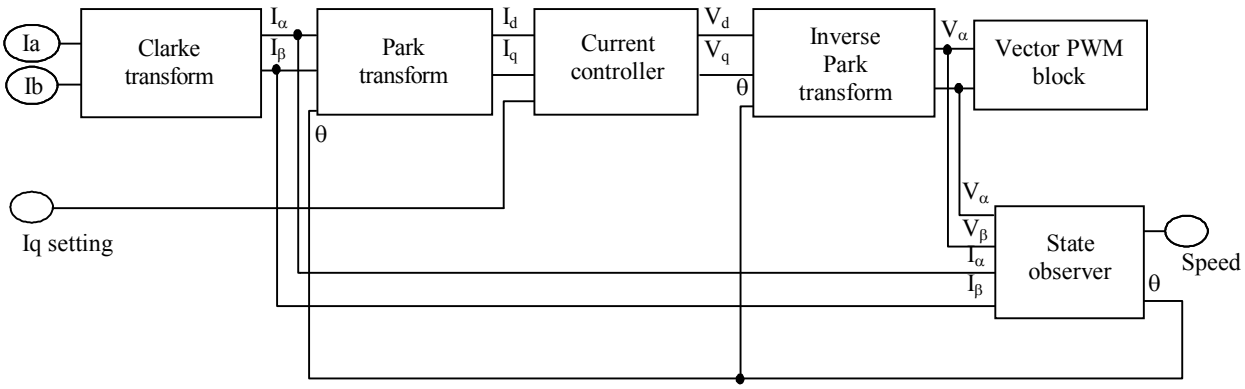


Fig.2. PMSM vector control structure

$$I_\alpha = I_a;$$
$$I_\beta = \frac{I_b - I_c}{\sqrt{3}}. \quad (2)$$

Then Park transform is used – vectors are turned to determinate angle, as we switch to rotating coordinate system, connected with rotor in axes *d* and *q*:

$$I_d = I_\alpha \sin(wt) - I_\beta \cos(wt);$$
$$I_q = I_\alpha \cos(wt) + I_\beta \sin(wt). \quad (3)$$

The vector control block is represented by control loop for motor currents in axes *d* and *q*. Control of currents is achieved by means of PI controllers, which have setting signals on the input. The current I_d must be equal to zero, as the flux of machine is created by permanent magnets. Different from zero setting values could be used in order to accelerate motor to speed, which higher then possible for respective supply voltage, by means of reducing back-EMF by field reduction [9]. Current I_q is proportional to preset tongue. Signals from current PI controllers` outputs are transmitted to input of Inverse Park transform block (Fig.2), there transition to fixed coordinate system is performed:

$$I_\alpha = I_d \sin(wt) + I_q \cos(wt);$$
$$I_\beta = -I_d \cos(wt) + I_q \sin(wt). \quad (4)$$

Voltage setting signals in axes α and β proceed to vector pulse-width modulation (PWM) block, where duration and order of inverter switches are determined [17]. The current control loop operates on PWM frequency. The measurement of currents in motor power supply lines is conducted with the same speed.

Motor state observer. It is possible to form stator current equations neglecting the inequality of rotor field:

$$\frac{d}{dt} i_s = A i_s + B(v_s - e_s). \quad (5)$$

Matrixes *A* and *B* are determined by equations:

$$A = -\frac{R}{L} I;\ B = \frac{1}{L} I;\ L = \frac{3}{2} L_m,$$

where I – unity matrix with dimensions 2×2; R and L_m – active resistance and inductance of stator phase winding.

Structure of state observer (Fig.3) consists of mathematical model of motor, relay control, filter, rotor flux angle calculator, rotor flux angle corrector [10, 13, 19-21]. At first stage the observer

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determines error between calculated and measured stator current. Calculations are proceeding in accordance with expressions:

$$\frac{d}{dt}\tilde{i}_s = A\tilde{i}_s + B\left(v_s^* - \tilde{e}_s + z\right); \tag{6}$$

$$z = k\,\mathrm{sgn}\left(\tilde{i}_s - i_s\right), \tag{7}$$

where $\tilde{i}_s$ – calculated current; v_s^* – stator voltage setting; i_s – measured current.

Controller operation purpose is to reduce error between measured and calculated currents to zero [7-9, 12]. It could be obtained by expressions written in discrete form:

$$\tilde{i}_s(n+1) = F\tilde{i}_s(n) + G\left(v_s^*(n) - \tilde{e}_s(n) + z(n)\right); \tag{8}$$

$$z(n) = k\,\mathrm{sgn}\left(\tilde{i}_s(n) - i_s(n)\right), \tag{9}$$

where $F = \exp\left(-\frac{R}{L}T_s\right)$; $G = \frac{1}{R}\left(1 - \exp\left(-\frac{R}{L}T_s\right)\right)$; T_s – period of carrier frequency.

Filtration of feed-back EMF [18, 22] is carried out in accordance with

$$\frac{d}{dt}\tilde{e}_s = -\omega_0\tilde{e}_s + \omega_0 z, \tag{10}$$

where $\omega_0 = 2\pi f_0$; f_0 – filter boundary frequency.

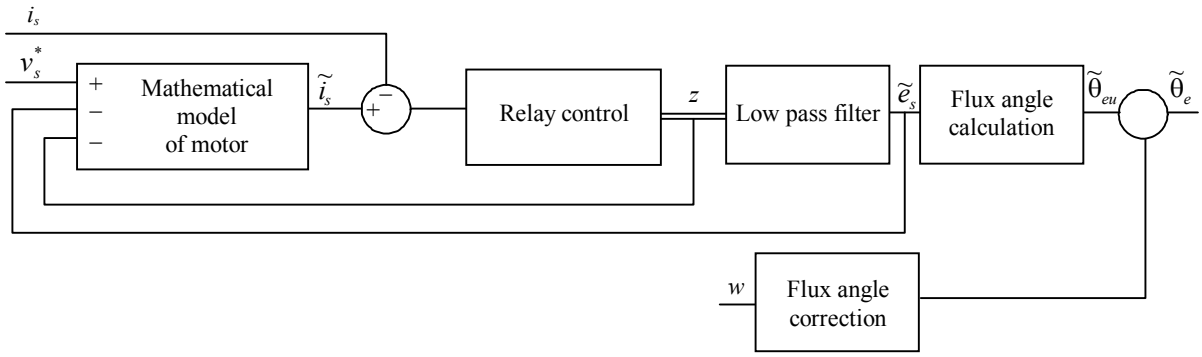


Fig.3. Structure of state observer operating in sliding mode

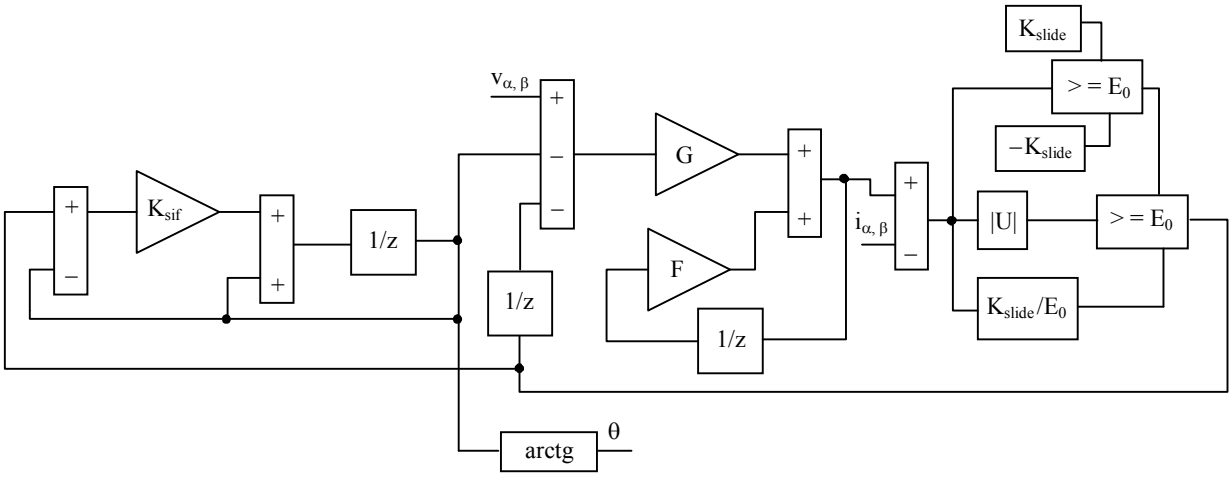


Fig.4. Structure of state observer complied in accordance with equations (8)-(13)

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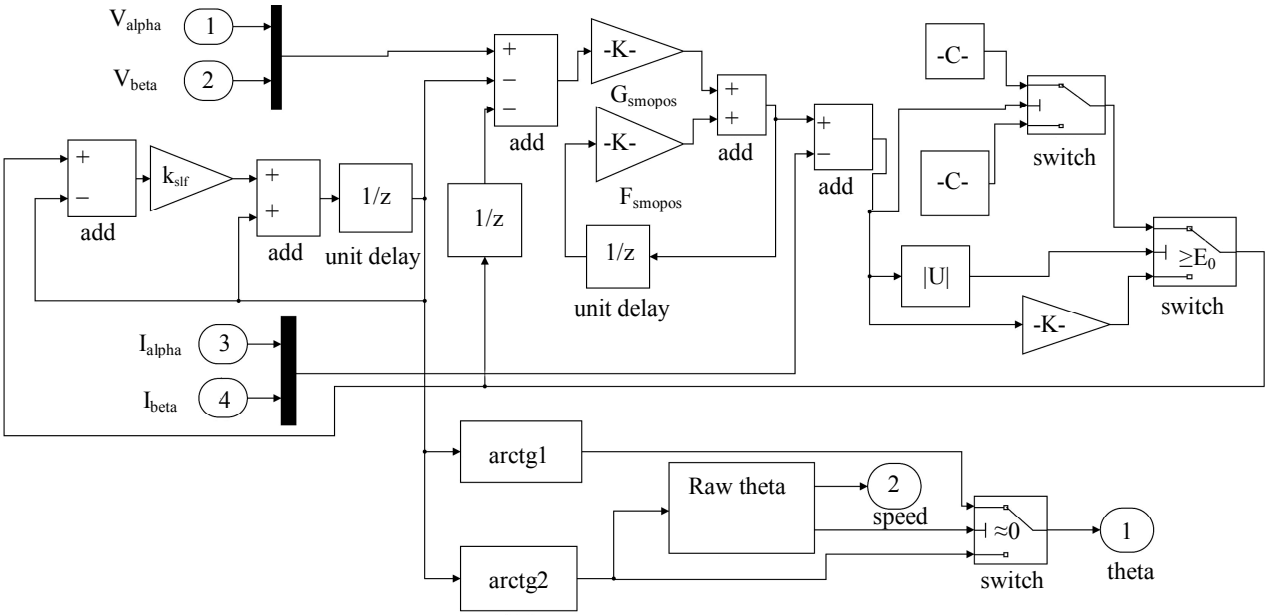


Fig.5. Model of state observer in Matlab Simulink

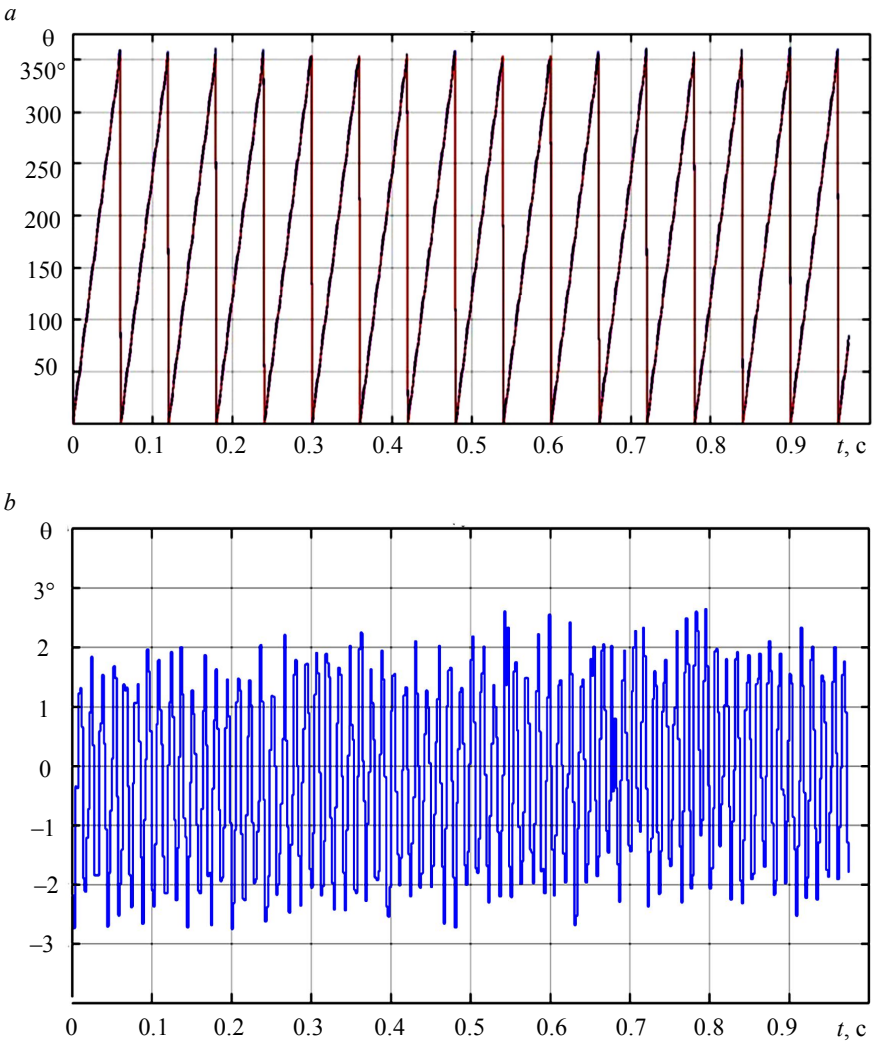


Fig.6. Results of experiments with introduced observer:
a – measured (red line) and calculated (blue line) angles; *b* – angle calculation error

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From expression (6) derives

$$\tilde{e}_s(n+1) = \tilde{e}_s(n) + 2\pi f_0\left(z(n) - \tilde{e}_s(n)\right), \tag{11}$$

rotor flux angle value is determined from equation

$$e_s = \frac{3}{2} k_e \omega \begin{pmatrix} -\sin\theta \\ \cos\theta \end{pmatrix}. \tag{12}$$

Thus, rotor flux angle value is determined as angle between vectors of calculated back-EMF in axes α and β:

$$\tilde{\theta}_{eu} = \text{arctg}\left(-\tilde{e}_{s\alpha}, \tilde{e}_{s\beta}\right). \tag{13}$$

The sliding observer system for permanent magnet synchronous motor state, represented in Fig.4, was implemented in Matlab Simulink environment (Fig.5).

Results. The model was tuned using nameplate data of motor, calculation step of rotor position angle corresponds with PWM carrier frequency of 20 kHz. In the course of research comparison of rotor position angle calculated by the observer and obtained with use of Hall sensors was conducted. The results of comparison are presented in Fig.6. Shown regime corresponds with rotation frequency 1000 rpm.

Conclusion. The implementation of sensorless control system for permanent magnet synchronous motors, including the observer operating in sliding mode, is presented in the paper. Two current sensors, placed in motor power supply lines, and setting voltage knowledge were required in order to use the observer. Also, motor stator parameters, inductance and active resistance, must be known. Presented observer shows good results in calculation of rotor flux angle and rotation frequency in wide range of speed and could be implemented in control scheme with function of demagnetization for operation at high velocity. The structure of observer allows avoiding calculation error increase in case then motor parameters drift (for example, as a result of heating). Obtained control system can be implemented as a replacement to rotor position determination methods, such as measurement of back-EMF in free phase [16], and, also, with the use of test signals.

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