A sensorless initial rotor position's estimation for permanent magnet synchronous machines

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Abstract. Permanent magnet synchronous motors for the effective start require information about the initial position of a rotor. In this regard, most systems use position sensors, which substantially increase entirely a cost of an electrical drive [1-3]. The aim of this article is to develop a new method, allowing determining the absolute angular position of the permanent magnet synchronous motors' rotor [4,5]. With a certain voltage pulses applied to the motor, its stator is magnetized by currents leakage in the windings. This allows using a special algorithm to calculate the absolute position of the rotor without using any motor parameters [6]. Simulation results prove the simplicity and efficiency of this method for determining an initial position of the permanent magnet synchronous motors' rotor. Thus, this method can be widely used in the electrical industry.

1. Introduction

Recently the drive with a vector control, based on a synchronous motor with permanent magnets, is increasingly used in various industries because of their advantages. There is an Urgent problem of sensorless Permanent Magnet Synchronous Machines (PMSM) control, as it allows reducing the cost of the structure and the size of the drive [7].

Many foreign scientists have been working on this issue. The most significant contribution to the study of methods for determining the initial position of the rotor is made by such scholars as Japanese T. Noguchi from Nagaoka University of Technology, Ying Yan and Jian Guo Zhu of the University of Technology, Sydney, Australia. In addition, at the company ZAO "EleSy" (Tomsk, Russia) the possibility of sensorless PMSM control applying is currently studied. Known algorithms allow operating a motor without using mechanical sensors for high and medium motor speeds, but the question remains of determining the initial position of the rotor at start-up. The main problem on this issue is to find an algorithm which would be at the same time accurate enough and simple to implement in a frequency converter.

Thus, the aim of this work is to develop an algorithm determining the initial position of the sensorless PMSM. The object of the study is a sensorless controlled driver within PMSM.

For performing PMSM modeling, which takes into account the saliency of the rotor and the stator core saturation, should be developed. The algorithm using for determining an initial position of the rotor without using of mechanical sensors should be carried out before motor starts. Thus, this algorithm has to be fast and simple to be implemented.

From the practical point of view, presented algorithm can be applied both by newly design and by modification of existing motor drives within a frequency converter.

2. Model of a Permanent Magnet Synchronous Machine

Schematic design and construction of a synchronous motor with permanent magnets are shown in Figure 1 [8].

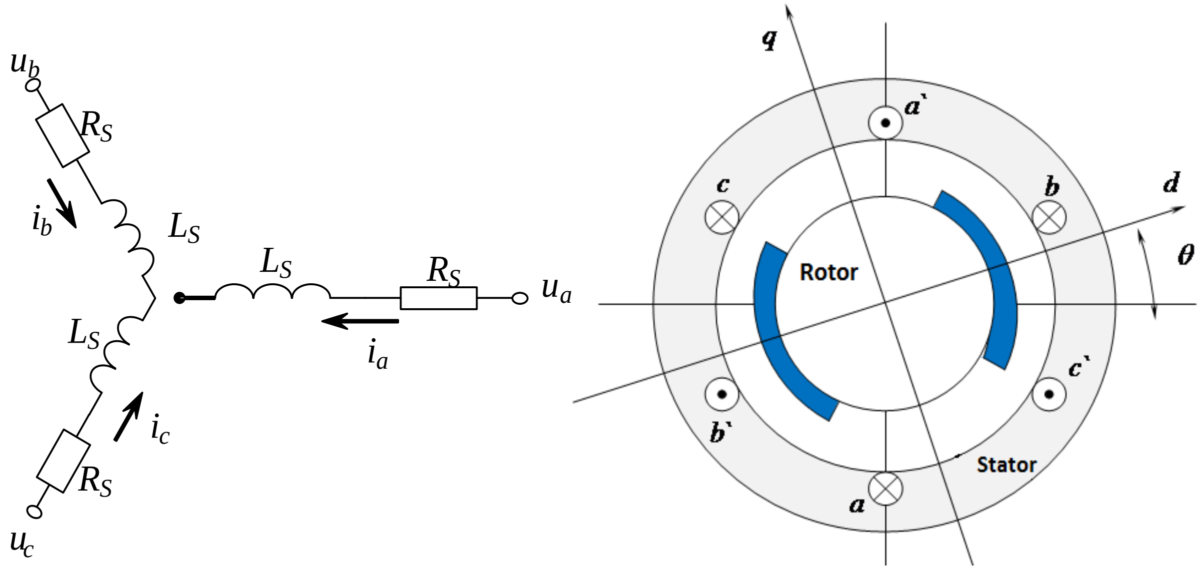


Figure 1. Schematic diagram and design of PMSM.

PMSM model, created by the blocks MATLAB Simulink, is presented in the Figure 2.

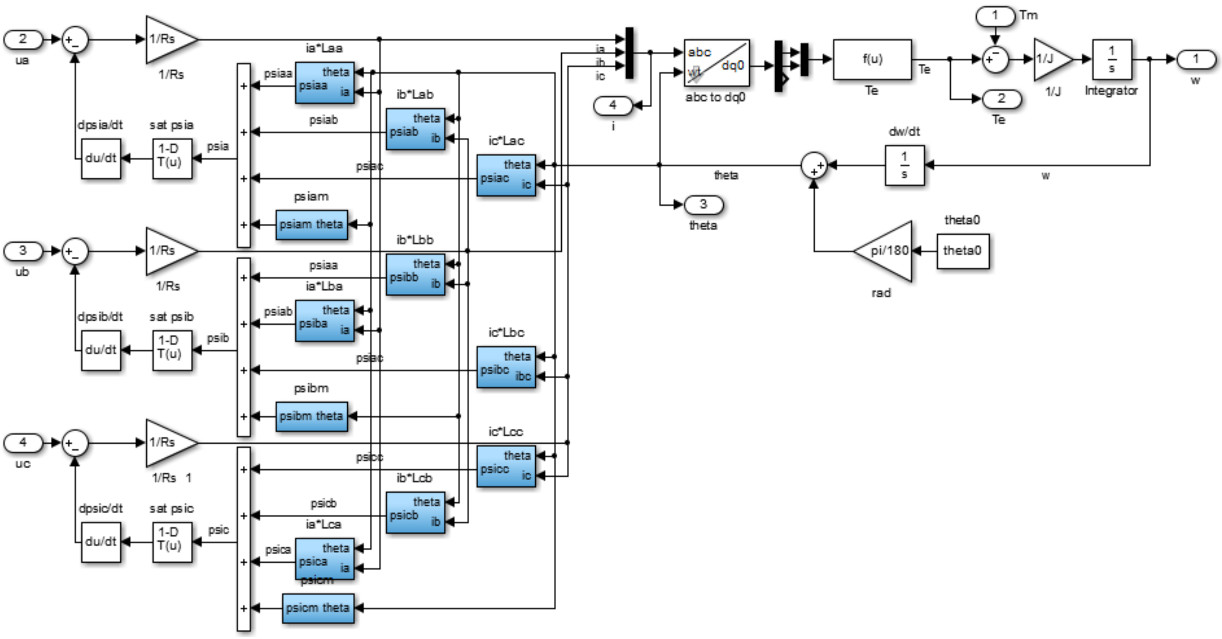


Figure 2. The contents of the PMSM.

The Next step is checking an adequacy of developed model (in comparison with the built-in Simulink model. To make it practical the scheme shown in Figure 3, was constructed in MATLAB Simulink).

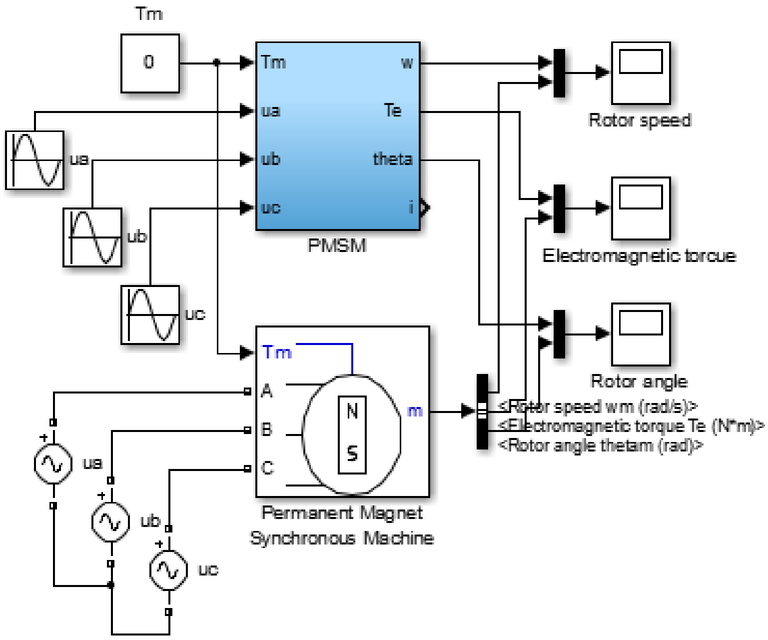


Figure 3. A comparison of the model with a built-in MATLAB Simulink.

The resulting graphics of velocity are shown in Figure 4.

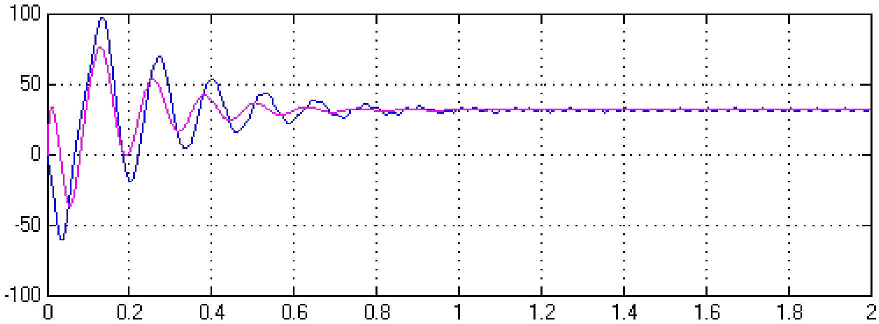


Figure 4. The waveform of rotor speed.

According to the obtained graphics it is possible to conclude that the model of a synchronous motor with permanent magnets works properly, and it can be used for further research algorithms to determine the initial position of the rotor.

3. Determining methods a rotor's initial position

Each phase of the motor is fed alternately firstly by positive and then negative voltage pulses [6]. At the same time maximum and minimum values of pulse currents depending on the angle of rotation by a certain law rotor can be measured. Thus, we have the input data for calculation: I_{Ap}, I_{Bp}, I_{Cp} – maximum values of positive pulses, I_{An}, I_{Bn}, I_{Cn} – maximum negative pulses.

First of all, we define the average current value:

- for positive pulses

$$I_{0p} = \frac{I_{Ap} + I_{Bp} + I_{Cp}}{3}, \quad (1)$$

- for negative pulses

$$I_{0n} = \frac{I_{An} + I_{Bn} + I_{Cn}}{3}. \quad (2)$$

Then, the deviation from the mean value for each phase is determined:

$$\Delta I_{Ap} = I_{Ap} - I_{0p} \quad (3)$$

$$\Delta I_{Bp} = I_{Bp} - I_{0p} \quad (4)$$

$$\Delta I_{Cp} = I_{Cp} - I_{0p} \quad (5)$$

$$\Delta I_{An} = I_{An} - I_{0n} \quad (6)$$

$$\Delta I_{Bn} = I_{Bn} - I_{0p} \quad (7)$$

$$\Delta I_{Cn} = I_{Cn} - I_{0p} \quad (8)$$

After that the sector where the north pole of the rotor is placed can be determined.

**Table. Cases for (θ`) defining** The Sector is defined by the angle shift $\theta$` and determined by the maximum value of current deviation from the mean value.

p.p	Maximum value (A)	Sector θ`(rad)
1.	ΔI_{Ap}	0
2.	ΔI_{Bp}	$\frac{2\cdot\pi}{3}$
3.	ΔI_{Cp}	$\frac{4\cdot\pi}{3}$
4.	ΔI_{An}	π
5.	ΔI_{Bn}	$\frac{5\cdot\pi}{3}$
6.	ΔI_{Cn}	$\frac{\pi}{3}$

Then, the angle within a sector is determined by two remaining values with a help of the following equation:

$$\theta = \frac{\cos\left(\frac{2\cdot\pi}{3}\right)}{\sin\left(\frac{2\cdot\pi}{3}\right)} \cdot \frac{\Delta I_1 - \Delta I_2}{\Delta I_1 + \Delta I_2} \text{ radian.}, \quad (9)$$

where $\Delta I_1, \Delta I_2$ the currents in other two phases.

The angle of rotor's rotation is defined by the sum of the angle that characterizes the sector, where the north pole of the rotor is situated, and the angle calculated by the formula [9]:

$$\theta_r = \theta\text{`} + \theta \text{ [rad]}, \quad (10)$$

Model, constructed in MATLAB Simulink to analysis the developed algorithm, is shown in Figure 5.

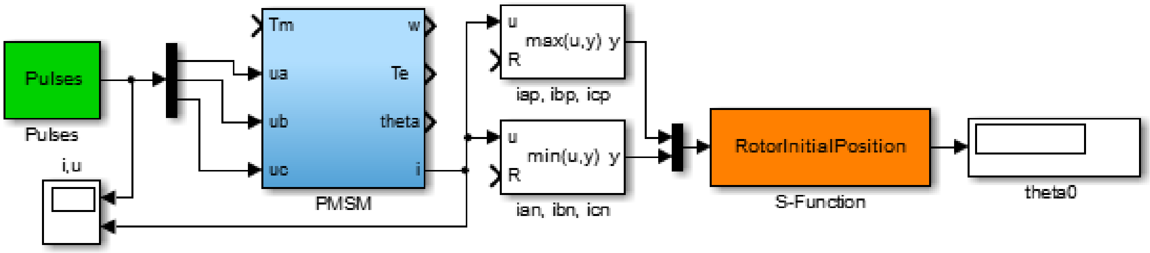


Figure 5. Model in MATLAB Simulink.

The inputs of the block PMSM are supplied by voltage pulses with the form and duration, as shown in Figure 6.

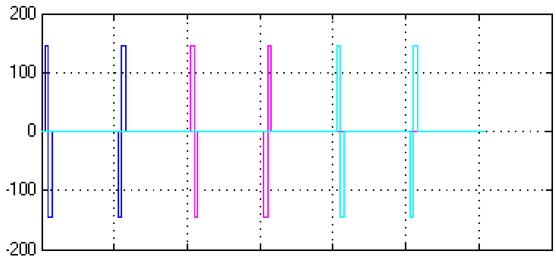
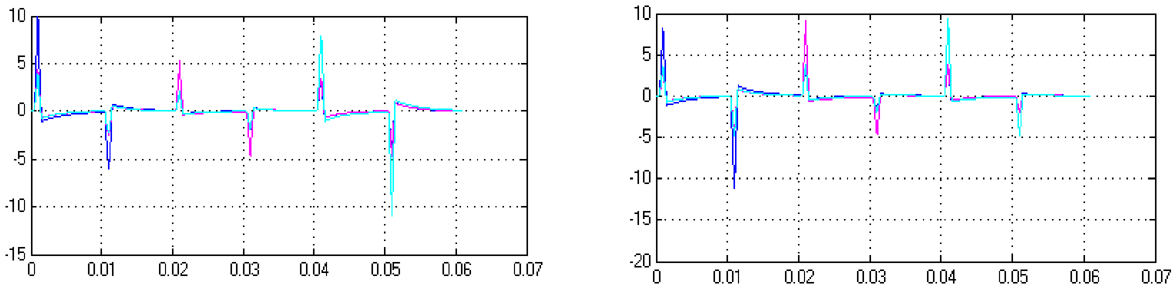


Figure 6. The voltage pulses at the input of the motor.

Oscillograms of the currents depend on the position of the rotor. The angles of rotor's rotation 45 and 180 degrees [10] are shown in Figure 7.

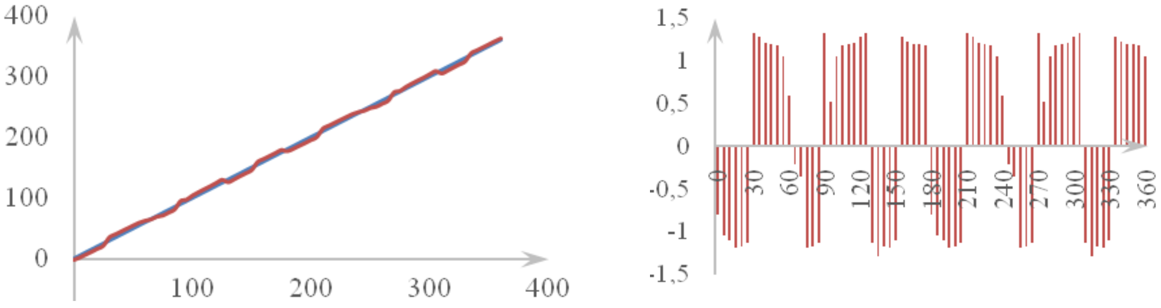


(a) (b)

Figure 7. The oscillograms of current for rotation angles: a) 45 degrees; b) 180 degrees.

After all minimum and maximum values of the currents, measured in the windings of the motor, have been transmitted to the input of "Rotor Initial Position", the calculation of rotor position starts.

For different values of angle of rotor's rotation the experiments were carried out. According to that we constructed the real and calculated position of the rotor. Moreover an angle's error determining histogram was received and data are reflected in Figure 7 [11].



(a) (b)

Figure 8. The actual and calculated position of the rotor, degrees (a) and the determining error (b).

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4. Conclusion

This work presents a technique to calculate the absolute position of the initial rotor angle of synchronous machines with permanent magnets. It is possible to measure by applying voltage pulses that partially drive the stator iron into saturation of the rotor's absolute position for a given pole pair. The scheme is computationally simple and does not need the information of any motor parameters.
Total error of measurement is less than 5%. So, this is a valid value, and the proposed algorithm that can be used in industry [12].

Implementing this technique to sensorless control algorithms while a motor turns around will allow a totally sensorless control scheme operating the motor reliably from zero speed up to full speed. Research to implement sensorless technology on a process of application is currently being processed.

References

[1] Vogelsberger M, Grubic S, Habetler T and Wolbank T 2010 *IEEE Trans. Ind. Electronics* **57** 365-374
[2] Raca D, Garcia P, Reigosa D, Briz B and Lorenz R 2010 *IEEE Trans. Ind. Applications* **46** 167-178
[3] Hammel W and Kennel R 2010 *Symposium on Sensor less Control for Electrical Drives* p 56-63
[4] Paulus D, Landsmann P and Kennel R 2011 *Symposium on Sensorless Control for Electrical Drives* 41-46
[5] HuaY, Sumner M, Asher G, Gao Q and Saleh K 2011 *IET Electric Power Applications* **5(4)** 359-370
[6] Wang Yi, Guo N, Zhu J, Duan N, Wang S, Guo Y, Xu W and Li W 2010 *IEEE Transactions On Magnetics* **46(6)** 2016-2019
[7] Bolognani S, Calligaro S, Petrella R and Sterpellone M 2011 *Symposium on Sensor less Control for Electrical Drives* 64-73
[8] Leidhold R 2011 *IEEE Trans. Ind. Electronics* **58(12)** 5371-537
[9] Schmidt P, Gasperi M, Ray G and Wijenayake A 1997 *Proc. IEEE-IAS Annu. Meeting* 463-549
[10] Haque M, Zhong L and Rahman M 2002 *Proc. IEEE Power Electron. Spec. Conf.* **1** 276-281
[11] Parasiliti F, Petrella R and Tursini M 2000 *In: IAS 2000 Annual Meeting and World Conference on Industrial applications of Electrical Energy* p 8-12
[12] Jang J, Sul S, Ha J, Ide K and Sawamura M 2003 IEEE Transactions on Industry Applications 1031-1039