International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 6, No. 3, September 2015, pp. 433~438
ISSN: 2088-8694

Influence of Sensorless Control on the Noise of Switched Reluctance Motor Drive

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Article Info

Article history:

Received Mar 22, 2015
Revised May 18, 2015
Accepted Jun 2, 2015

Keyword:

Magnetic asymmetry
Sensorless control
Switched reluctance machine
Noise

ABSTRACT

The influence of the switched reluctance motor drive sensorless control on the level of its noise is considered. Theoretically justified the increase of noise level while sensorless SRM control. The results of switched reluctance motor noise measurement with sensorless control and control using the physical position sensor are given.

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1. INTRODUCTION

As a rule, modern drive systems are built on the basis of induction electric machines. However in recent years other types of electric motors become increasingly popular. For example, a large proportion of recent publications is devoted to the study of switched reluctance electric machines (SRM) which can be called one of the most promising types of electromechanical energy converters.

For effective use of SRM it is necessary to control phase excitation current in accordance with rotor position. Typically this is done using physical rotor position sensor fixed on the machine shaft (optpelectronic sensors, Hall-effect sensors, etc). For systems intended to operate in harsh environments the position sensor may become a limiting factor. Meanwhile it is possible to determine rotor position indirectly using dependence of phase flux of the phase current and rotor position $\psi = f(i, \theta)$ [1]. Control systems based on the indirect rotor position estimation are called sensorless systems.

Currently researchers published many works on synthesis and study of sensorless control of SRM [2]. Typically, the methods of indirect rotor position estimation are classified on methods of active phase measurement and methods based on passive phase measurement. Using the methods of the first group limits the active phase current control and hence the SRM torque control. Among the methods of second group there are methods, based on sort voltage pulses (sensing pulses) application [3]. In this case it is possible to use effective algorithms of active phase control. However it is necessary to consider the impact of sensing current on energy effectiveness indexes and torque curve when the sensing current is commensurate with the active phase current. On the other hand, if the sensing current is small it is necessary to protect usefull signal from noise.

Another approach allows to allocate methods based on the use of markers and methods based on look-up tables which require not only a large amount of memory of the microprocessor control systems, but also time-consuming to determine the look-up table data. In addition, look-up tables do not take into account the differences in the characteristics of the phases which may arise as a result of the inaccuracies during SRM manufacturing process [4]. Methods based on the use of markers are generally limited to the rotation frequency or excitation current control.

SRM sensorless control enhances application of the switched reluctance drive systems in the most adverse operating conditions: high temperature, chemically aggressive environment, intense radiation exposure to the motor. In this case, of paramount importance the fact of the possibility of SRM operation without physical rotor position sensor. According to the level of reliability and durability sensorless switched reluctance drive exceeds its nearest competitors. The situation is different in the field of general industrial electric drive, when except reliability and durability other indicators are important (energy efficiency, electromagnetic torque ripple and the noise level).

2. RESEARCH METHOD

To consider the influence of sensorless control on the SRM noise level it is necessary to identify the main reasons of its occurrence. SRM noise sources are classified as follows [5, 6]:

- Noise from the stator vibration;
- Noise from radial forces acting on the rotor;
- Noise from the load and additional sources;
- Aerodynamic noise;
- Electronic noise sources (sources of noise associated with power electronic components operating in switching mode and with the characteristics of control algorithm).

In addition to the classification as a source of noise the torque ripple are considered [7].

Considering the influence of sensorless control on noise and vibration level it is necessary to specify that the greatest impact on these indicators will provide inaccurate indirect rotor position estimation. Using position sensor control system receives information about the rotor position with a relatively low latency due to the speed of CPU. In this case the error of rotor position estimation depends on the accuracy of position sensor calibration. When sensorless control is used the accuracy of look-up table, the large amount of computation required to determine the value of θ and the accuracy of measurement equipment impact on rotor position estimation accuracy. All this is the cause of a time-varying error of estimating rotor position, and as a result - changing the actual angles of opening and closing the semiconductor switches of the converter. In this case, the magnetic system is in a state of artificial asymmetry, as during dwell angle phase flux linkage take on different values. Thus, the main difference of SRM sensorless control will be the artificial phase excitation unbalance which serves as a source of additional noise and vibration [8].

It should also take into account the effect of the sensing current pulses applied to estimate the rotor position. These pulses are typically of a higher frequency than the pulses of the power supply and affect on unevenness electromagnetic torque, since the sensing current flows through the phase, relative to which the rotor is in the area of the generator operation mode. Sensing current also contributes to noise in the upper frequency range of hearing due to magnetostriction.

Based on the above provisions, it is possible to assume that the noise level of sensorless controlled switched reluctance drive will be higher than when using the physical rotor position sensor. In this case, it is possible to check the validity of this conclusion only be a physical model as a means of computer technology do not allow including all causes of SRM noise in the calculation of the data. It should be borne in mind that an adequate assessment of the impact of sensorless control on electric noise in comparison with traditional systems using rotor position sensor can be given under the following conditions:

- as an object of study should serve the same SRM fed from the same power converter;
- measurement should be performed with the same instruments in constant environmental conditions;
- SRM should not be moved between measurements, unacceptable separation of SRM structural elements and change of shaft load.

To measure the noise level SRM with tooth zone configuration 6/4 (figure 1) was utilized (SRM rated power 5kW, rated speed 1500 rpm). Experimental assembly is given on Figure 2.

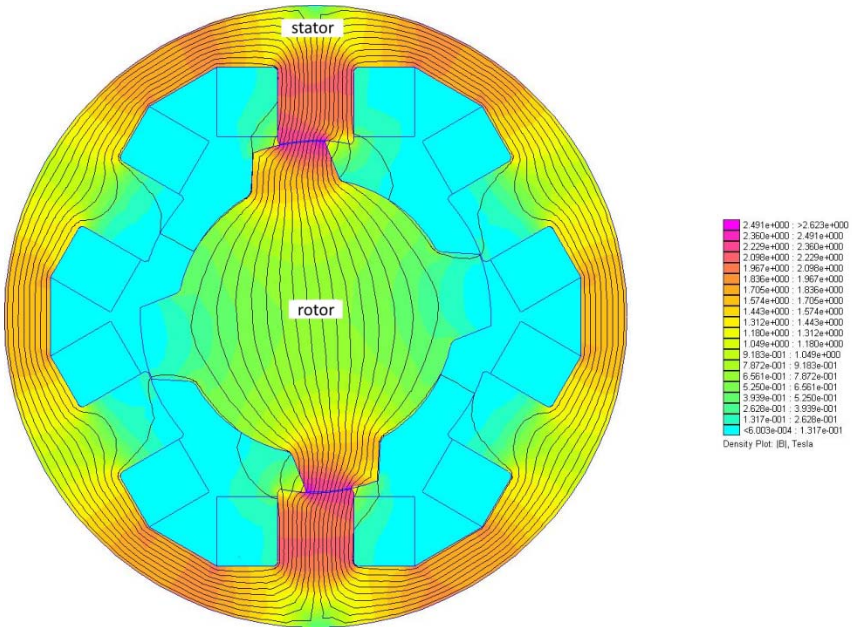

Figure 1. SRM 6/4 magnetic field

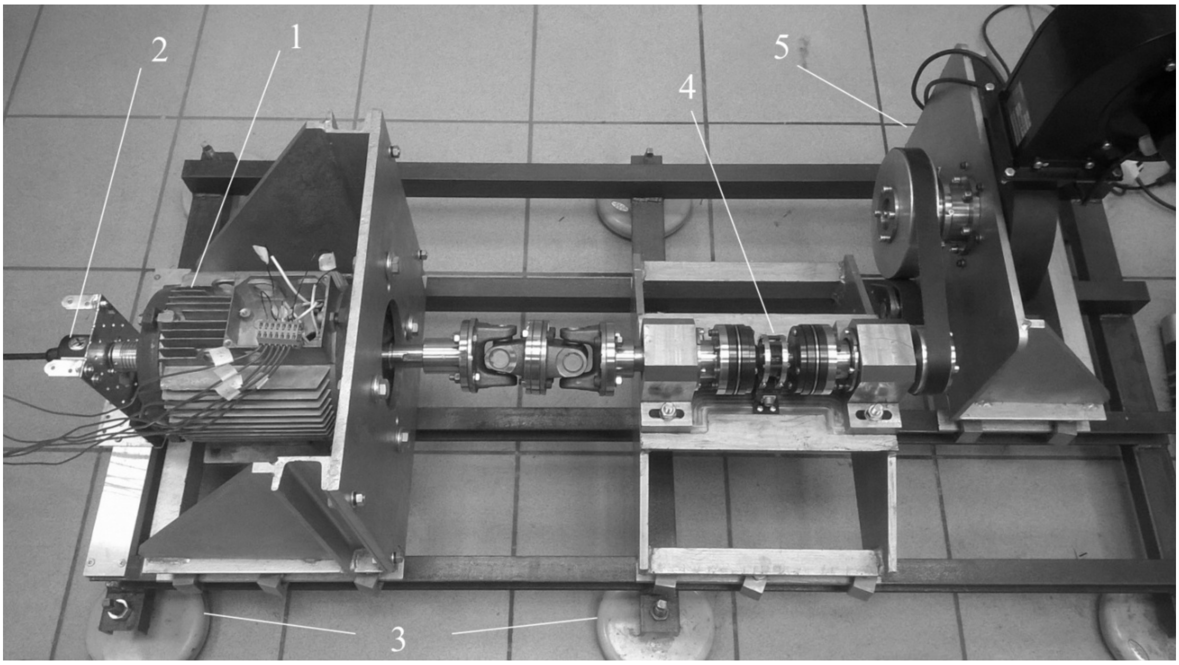

Figure 2. Experimental assembly for noise level measurement
1 – motor, 2 – encoder, 3 – resilient mounts, 4 – shaft torque sensor, 5 – controlled load

Power supply of engine was performed by half-bridge converter. Microcontroller AVR Atmega16 was used as the CPU of the control system. The rotor position at comparative tests determined using an absolute encoder or sensorless control algorithm [9], based on the use of sensing pulses and a marker. Amplitude of sensing pulse current in unaligned rotor position (180 electrical degrees) is used as a marker. Switching of phases occurs after marker, i.e. when control system registers the current amplitude of the sensing pulse, which is less than the current amplitude of the previous sensing pulse. Picture of the phase current is shown in Figure 3.

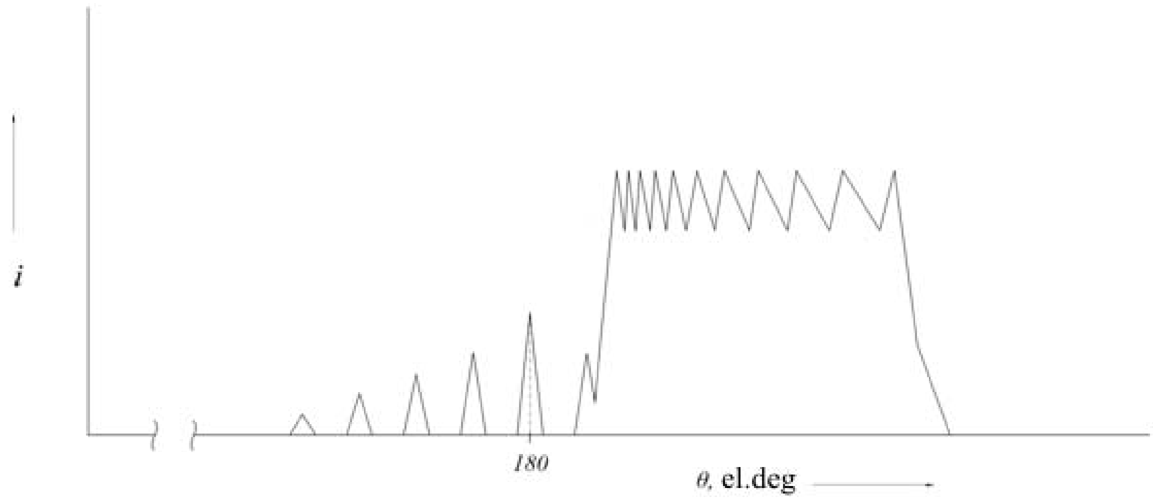

Figure 3. Sensorless controlled SRM phase current

Noise level measurements were carried out for the orientation method at five points of the measuring surface (Figure 4) for three different values of rotor speed.

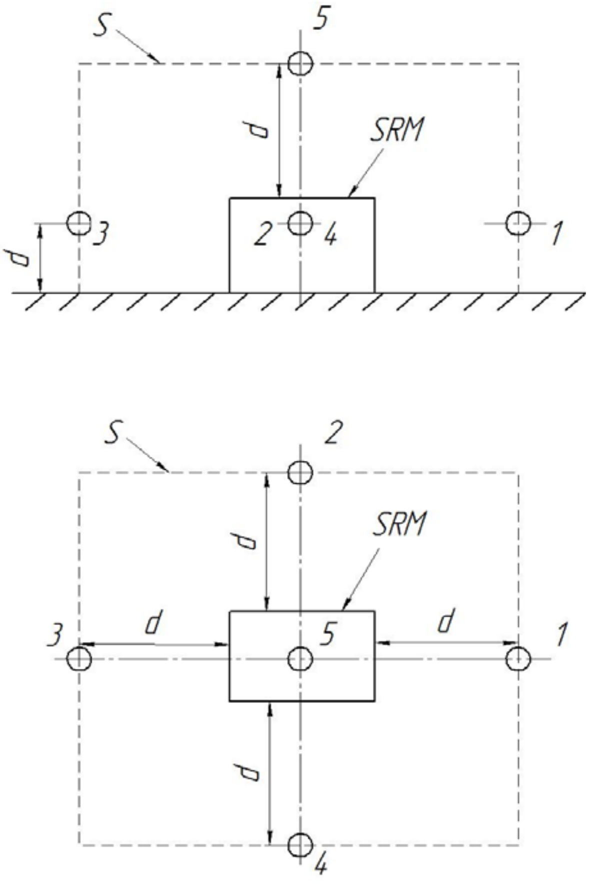

Figure 4. Location of measuring points on the measuring surface
1-5 – measurement points, S – measurement surface, d – distance from noise source (1 meter)

The computation of average noise level based on the equation

$$L = \frac{1}{n}\sum_{i=1}^{n} L_i - K \quad (1)$$

where n is a number of measurement points in which noise level measurement was, K is the premises constant, computed by equation.

$$K = 10 \cdot \lg\left[1 + 4\frac{S}{A}\left(1 - \frac{A}{S_v}\right)\right] \quad (2)$$

where S is the area of selected measuring surface, S_v is the area of limiting surfaces of the premises, A is the equivalent area of acoustic absorption.

Equivalent area of acoustic absorption is determined from equation

$$A = a_s \cdot S_v \quad (3)$$

where a_s is the average coefficient of acoustic absorption is a function of premises type.

Changing the rotor speed was made directly change the value of the supply voltage via laboratory transformer, while the value of the phase current is limited to 15 A. The noise measurements were made using a sound level meter Center 320 exhibited temporal characteristics of "Slow", the measurement of rotor speed - using a mechanical tachometer. The engine was running at idle during the measurements.

3. RESULTS AND ANALYSIS

Results of noise level measurement are given in Table 1.

Table 1 Results of SRM noise level measurement

Parameter	Serial number of measurement		
	№ 1	№ 2	№ 3
SRM shaft rotation speed (min^{-1})	*800*	*1000*	*1500*
SRM control using physical rotor position sensor			
Noise level in measuring point 1(dBA)	*57,7*	*60,1*	*64,7*
Noise level in measuring point 2 (dBA)	*57,8*	*59,4*	*65,0*
Noise level in measuring point 3 (dBA)	*57,3*	*60,4*	*65,6*
Noise level in measuring point 4 (dBA)	*57,7*	*60,7*	*64,7*
Noise level in measuring point 5 (dBA)	*57,6*	*60,9*	*64,8*
Average noise level (dBA)	**52,49**	**55,17**	**59,83**
SRM sensorless control			
Noise level in measuring point 1 (dBA)	*59,2*	*61,9*	*66,4*
Noise level in measuring point 2 (dBA)	*58,9*	*62,1*	*66,8*
Noise level in measuring point 3 (dBA)	*58,2*	*62,7*	*66,3*
Noise level in measuring point 4 (dBA)	*59,7*	*61,6*	*66,8*
Noise level in measuring point 5 (dBA)	*58,3*	*61,1*	*67,4*
Average noise level (dBA)	**53,73**	**56,75**	**61,61**

As seen from Table 1, the noise level of sensorless SRM is higher in comparison with SRM with encoder. The noise level increases with the SRM shaft speed increase. Considering that an increase in rotation frequency increases the inaccuracy of rotor position estimation, we conclude that the inaccuracy of of rotor position estimation contributes to the increase in noise

4. CONCLUSION

From these theoretical findings and results of noise measurements can be seen that sensorless control is carried out at a higher noise level of SRM. The noise increased by 1,24-1,78 dBA, we can assume that the characteristics of SRM are very sensitive to small changes in timing of the pulse voltage. Artificial magnetic asymmetry that arises as a result of error in estimating the rotor position should recognized as main reason of noise level increasing. Modern rotor position sensors can provide accurate measurements with an error not exceeding $0,25^o$-$0,125^o$. In this case, according to preliminary estimates of the authors at the sensorless control error in determining the position of the rotor is $2,5^o$-3^o. Based on this, we can conclude that for competitive advantage sensorless switched reluctance drive it is necessary to take measures to improve the accuracy of the indirect rotor position estimation. Improvement of sensorless control is possible by choosing the rational parameters of sensing pulses, increasing the accuracy of lookup tables, etc.

ACKNOWLEDGEMENTS

The work is supported by The Ministry of education and science of Russia. Agreement № 14.604.21.0040, identifier RFMEFI60414X0040.

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