switched reluctance motor; sensorless control; start-up in a course

Maxim TCHAVYCHALOV
Rostov State University of Transport Communication
2 Rostovskogo Strelkovogo Polka Narodnogo Opolcheniya sq., Rostov-on-Don, 344038, Russia
Corresponding author. E-mail: 4_maxim_4@bk.ru

SENSORLESS START-UP OF TRACTION SWITCHED RELUCTANCE MOTORS OF THE RAILWAY ROLLING STOCK

Summary. The problem of SRM sensorless start is described. The new algorithm of traction switched reluctance motor sensorless start-up in a course is adduced. Results of physical modeling of the described method are given.

БЕЗДАТЧИКОВЫЙ ПУСК ТЯГОВЫХ ВЕНТИЛЬНО-ИНДУКТОРНЫХ ЭЛЕКТРИЧЕСКИХ МАШИН ПОДВИЖНОГО СОСТАВА ЖЕЛЕЗНЫХ ДОРОГ

Аннотация. Описана проблема бездатчикового пуска ВИД. Приведен новый алгоритм бездатчикового пуска тягового вентильно-индукторного двигателя. Даны результаты физического моделирования описанного алгоритма.

1. INTRODUCTION

Switched reluctance motors (SRM) become now more and more demanded type of the electromechanical converter of energy. To that there are many reasons among which allocate simplicity of a design, absence of sliding contact and wires on a rotor, rather small consumption of copper on stator windings and also higher reliability. Among negative sides SRM there are considerable torque ripple and the high level of the acoustic noise.

Electric train traction SRM NTI-350 (nominal power 350 kW, nominal torque 3,8 kNm) was made and examined by South Russian State Technical University (Novocherkassk Polytechnic Institute) and Novocherkassk Electric Locomotive Plant. It was found that SRM characteristics allow to use it as a traction machine on electric rolling stock [1].

It is necessary to know the rotor position information for proper SRM control. As a rule Hall effect sensors or opto-interrupters are employed to determine rotor position. All sensors increase drive’s cost and reduce its reliability [2]. That is especially undesirable for traction motors. Since 1985 work on realization of sensorless SRM control systems has been active[3].

The most of sensorless control methods use the information about phase flux linkage ψ as a function of the rotor position θ and phase current i (magnetizing characteristic) (fig. 1).

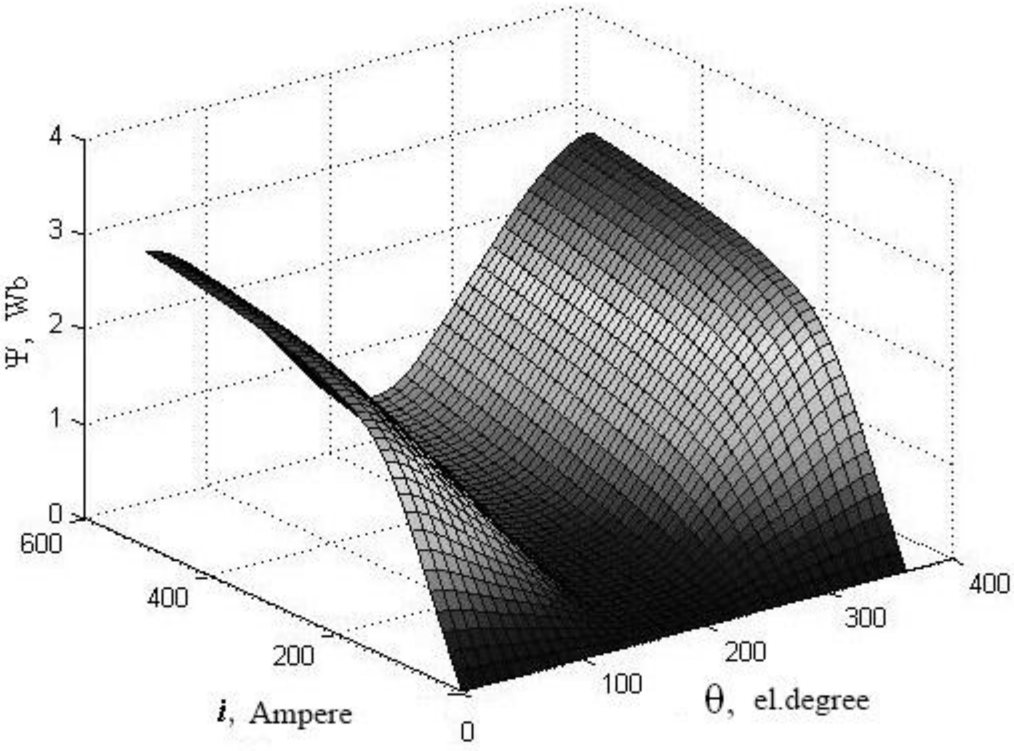

Fig. 1. Magnetizing characteristic
Рис. 1. Характеристика намагничивания

The methods of indirect rotor position estimation can be broadly classified into two classes: energized phase methods and unenergized phase (active probing) methods [4].

Energized phase methods use the excitation current to detect the rotor position. In unenergized phase methods different kinds of test signals are introduced during the time when a phase is normally unenergized. As a rule, existing methods demand initial information on the machine in the lookup table form [5]. Besides, the most part of energized phase methods is applicable only for one-pulse SRM control mode.

The most part both theoretical [5-8], and practical [9, 10] material of publications about sensorless SRM control as primary assumptions has nonzero rotor speed. Meanwhile procedure of indirect definition of initial rotor position and the subsequent start-up in a course of the SRM deserves more detailed consideration.

The aim of the article is to describe the new SRM start-up algorithm, which can be used on traction machine.

2. SRM SENSORLESS START-UP

SRM phase voltage can be described by equation [2]:

$$u = i \cdot R + L_{\partial}(\theta, i) \cdot \frac{di}{dt} + i \cdot \omega \cdot \frac{dL_{\partial}(\theta, i)}{d\theta}, \tag{1}$$

where: u – phase voltage, i – phase current, R – phase resistance, $L_{\partial}(\theta,i)$ – phase inductance, θ – rotor position, t –time, ω – rotor speed.

At the initial time of start $\omega \approx 0$, equation (1) then

$$u \approx i \cdot R + L_{\partial}(\theta, i) \cdot \frac{di}{dt} \tag{2}$$

In this case the phase current will exceed nominal rate. In order to avoid operation of protective equipment and also for smoothness of start-up at low rotor speed it is necessary to limit a consumed SRM current. The problem of rotor positioning with energized phase methods in this case considerably becomes complicated. Considering the foregoing, the problem of ensuring sensorless SRM start-up not only for one-pulse mode, but also with possibility of application of pulse-width modulation without use of lookup tables can be solved on application of unenergized phase methods.

2.1. New SRM sensorless start algorithm

The algorithm of traction SRM start-up in [11] based on the simultaneous apply a short voltage impulse to all phases with the subsequent comparison of peak values of a current to i=f(θ) lookup table values. Thus, the phase in which the first power voltage impulse applied is defined. The algorithm allows defining the initial rotor position with demanded accuracy. But at nonzero initial rotor speed the data obtained as a result can become outdated by the giving beginning in an active phase of a power voltage impulse.

For sensorless start-up realization it was decided to make a change algorithm as follows:

- to analyze ratio of probing current amplitudes. Therefore, having revealed a phase with the smallest inductance value (the greatest value of a probing current) and having analyzed values of other phases, it is possible to define unequivocally first active phase;
- for definition of initial rotor position to submit a series of probing impulses at the same time to all phases. Thus it is necessary to compare values of current peak values of each phase to the previous values. Such measure will occupy an extra time at SRM start-up, but will help to avoid an error of definition to rotor position at nonzero initial speed.

Thus the algorithm consists in the following sequence of actions:

- in defined earlier active phase 1 the power voltage impulse is applied;
- in following (according to control algorithm) phase 2 probing voltage impulses are applied;
- the peak value of a current of each probing impulse of i_n is compared to amplitude of a current of the previous impulse i_{n-1}, at $i_n = i_{n-1}$ the tooth of a rotor is in aligned position with an active phase (360 el. degrees);
- i_n value registers in a control system memory;
- the phase 1 is disconnected, the power voltage impulse is applied to a phase 2, in a phase 3 probing voltage impulses are applied;
- peak values of a current of probing impulses of a phase 3 are compared to the value written down in a step. On reaching this value the active phase is switched.

So the start-up in a course and speedup of SRM in a single switching mode is carried out at the fixed values of opening and closing angles.

The considered algorithm is predesigned for heavy-duty SRM start-up and may be recommended for electric stock traction motors. Further at work positioning of a rotor can be defined by any sensorless control method.

2.2. Experimental testing of the new SRM start-up algorithm

Physical modeling of the described algorithm was made on the 3-phase 12/14 SRM in rated power of 7,5 kW and nominal frequency of rotation of 3000 min^{-1} (fig. 2). The control system is executed on the basis of the Texas TMS320F2809 microcontroller.

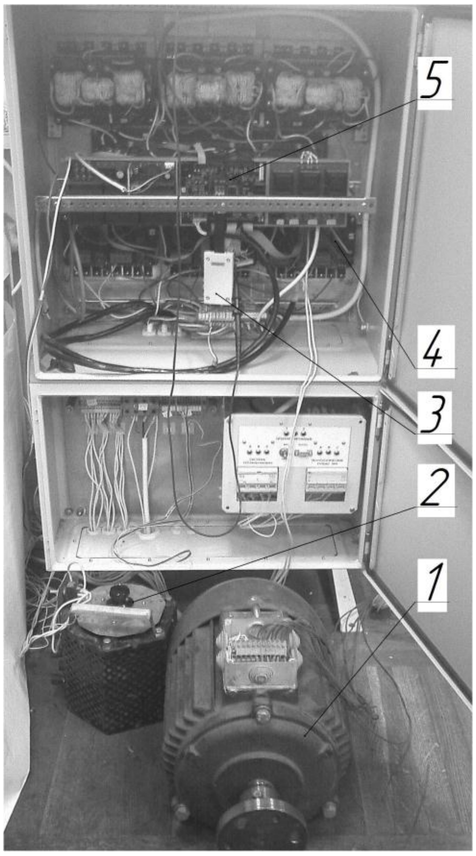

Fig. 2. Measured SRM rotor speed at sensorless start
Рис. 2. Измеренная скорость ротора ВИМ при бездатчиковом пуске

Below (fig. 3 and 4) are given the speedup characteristic SRM when using indirect positioning in an idling mode.

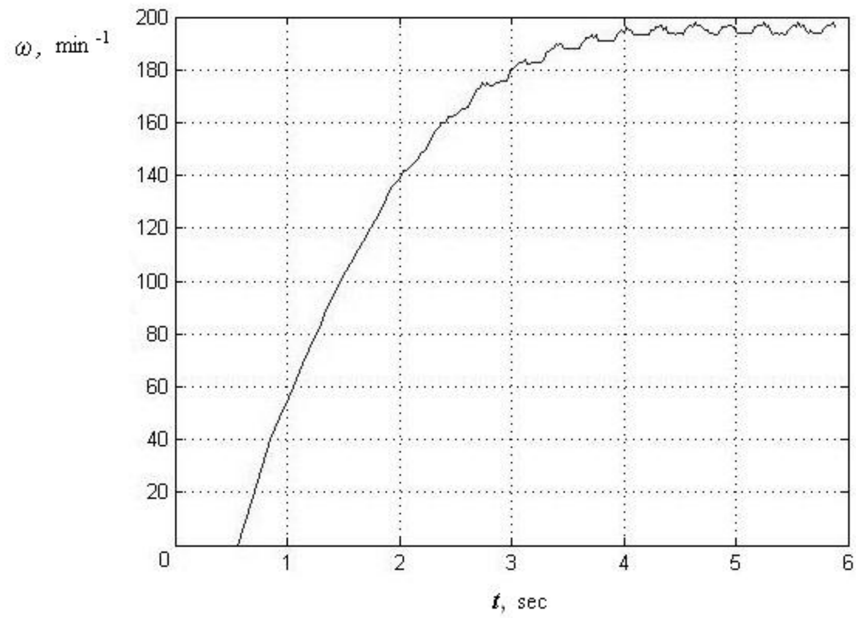

Fig. 3. Measured SRM rotor speed at sensorless start
Рис. 3. Измеренная скорость ротора ВИМ при бездатчиковом пуске

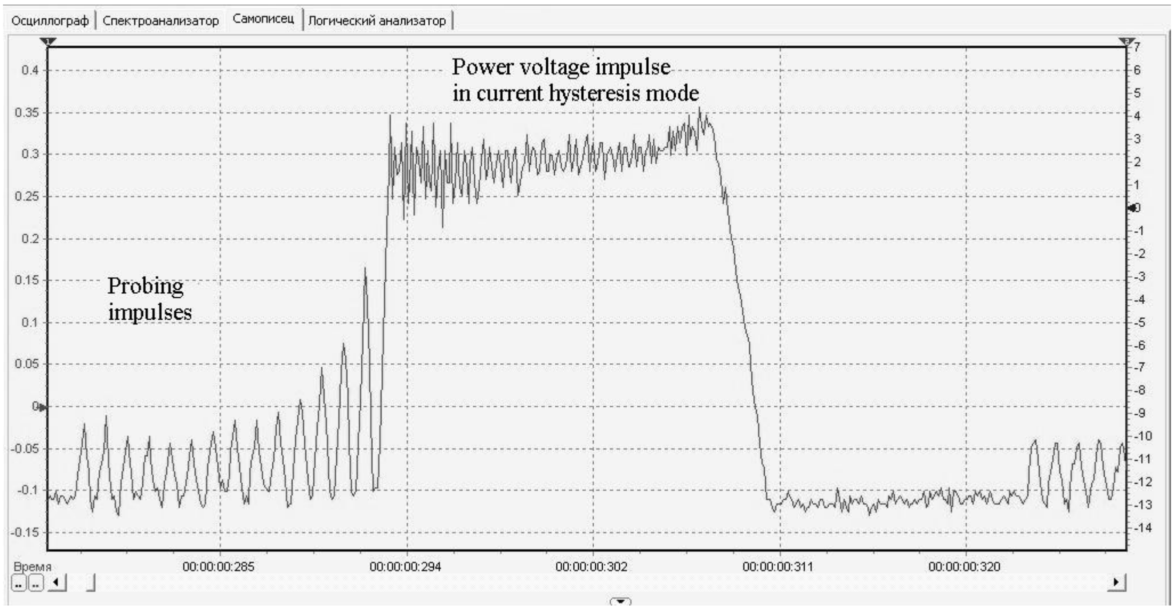

Fig. 4. SRM phase current oscillogram (horizontal 1 segment – 9 millisecond, vertical 1 segment – 0,375 Ampere)

Рис. 4. Осциллограмма фазного тока ВИМ (1 деление по горизонтали – 9 мс, 1 деление по вертикали – 0,375 А)

The measuring of rotary speed was made by rotor position sensor. As can be seen about 0,5 sec is taken for initial rotary speed estimation. The course of ω pulsing after 3 sec is generating torque (because phase is turned off after aligned rotor position) and one-pulse current hysteresis commutation mode.

As a result of physical modeling it was revealed that when using the offered algorithm, SRM is surely accelerated in the necessary direction of rotation. Besides, at the expense of regulation of the starting moment by a choice of parameters of that restriction it is possible to lower shock loadings in the working mechanism of a drive.

3. DISCUSSION

Currently, there are several ways to determine the starting position of the rotor and the subsequent SRM start-up: stepper mode, pull the rotor to the same phase for fixing the aligned position of stator and rotor flux determination, etc.

Stepper mode start-up is to manage the SRM without position feedback of the rotor. For each phase of the machine are applied voltage pulses of fixed frequency in accordance with the selected direction of rotation. Pulse frequency is linearly increased to increase the rotation speed of the rotor. The SRM stepper mode start-up procedure with subsequent determination of the rotor position on the current gradient method is given in [12]. According to the authors, this method neither optimal nor effective but provides a reliable start of the machine under load.

The procedure for determining the starting position of the rotor attraction to one phase is a current supplying phase winding machine. The rotor stops in aligned position relative to the stator teeth of the active phase [13]. However, in this case, can take place as a range excited phase in the unaligned position. At the same time the solenoid would not be sufficient to start the motion of the rotor. Furthermore, arbitrary phase excitation is possible that movement of the rotor in the opposite direction given, which is unacceptable in some devices.

It is also possible to determine the starting position of the rotor is fed to the phase of short voltage pulse duration *t*, and with the known values of the current and the resistance phase to determine the flux linkage of the formula

$$\psi = \int_0^t (u - ir)dt. \quad (3)$$

Further, under certain values of current and flux linkage of the lookup table to determine rotor position. Since the function ψ (θ) is symmetric with respect to align and unaligned positions it is necessary to determine the flux linkage of at least two phases to avoid errors. In this case, the angular position of the rotor can be uniquely determined. However, if a nonzero initial rotary speed a method for determining the starting position is unacceptable.

In [11] is described the SRM start-up method based on the simultaneous application to all phases of a short voltage pulse and then comparing the amplitude of current values with a pre-recorded in the control system microcontroller memory dependence i = f (θ). Thus defines the phase in which is first applied power voltage pulse. The algorithm allows the required accuracy to determine the initial rotor position. However the author considers the use of lookup tables undesirable. Furthermore in case of nonzero initial rotary speed resulting data may become obsolete in the beginning of the active phase supply power voltage pulse.

Described in article algorithm does not require the initial setting information in the form of a lookup table and can be modified to other SRM tooth zone configurations. Of the shortcomings can be identified the need to determine the absolute reference. The author plans to improve the algorithm and eliminates the need to define and store the reference value.

4. CONCLUSION

Given the increasing popularity of SRM more promising are sensorless control system, allowing not only to reduce the cost of the drive, but also improve the performance of its reliability. With limited opportunities for individual methods of indirect rotor position important to solve the problem of sensorless SRM start-up. It is especially important for traction motors. The article describes the new SRM sensorless start-up method which may be used for traction motors. Moreover, the provisions of this algorithm can be the basis of a new sensorless control method.

5. ACKNOWLEDGEMENT

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