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Electric circuit of brushless motor electric drive of technological objects of agriculture

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Abstract. In the article schemes of power circuits of a feed of synchronous reluctance machines are considered. The features of the choice of the most rational scheme by the criterion of improved weight and size parameters are shown. It is shown that the specific parameters of electric drives have values that exceed similar synchronous electric drives by approximately 20%. Improvement of specific parameters in the agriculture electric drive can be achieved not only due to the complexity of the electric machine construction, but also due to the choice of optimal schemes of power circuits. So, in agriculture electric drives with individual sources with rectangular current form, the values of overloads corresponding to electric drives with complex (compound) rotor design.

1. Introduction

Brushless electrical machines are used in many industries, and especially in agriculture, where higher demands are placed on the electric drive for reliability and overload capacity. Increase the overload capacity of the electric drive can be due to the utilization factor of the electric machine in the electromagnetic sense [1]. In this respect, the existing class of synchronous reluctance machines is characterized by increased potential. The great variety of electrical wiring diagrams requires the choice of the most rational, therefore the improvement of the mass-dimensions of an agriculture brushless electric drive due to the search for rational power schemes is an actual scientific and technical task [2].

2. Statement of the research problem

The goal is achieved by solving the following tasks:

- analysis of the requirements for power chains of synchronous reluctance machines;
- selection of rational power schemes;
- results of the study of brushless electric drives with different power circuits.

3. Analysis of requirements to power circuits obtained from the side of SRM

The idea of working principle of synchronous reluctance machine is so simple: the excitation is carried out from the side of the stator, and the electromagnetic torque is the result of the interaction of the stator current and the excitation field formed by the stator MDS and asymmetric in the magnetic ratio by the rotor [3]. According to the design, the classic reluctance machine is similar to an induction motor with



a squirrel cage rotor. Prospectivity of this class resulted in a wide variety of designs of such motors with different design differences.

Unfortunately, despite the simplicity of design and operation, a synchronous reluctance machine (SRM) designed for operation from an agriculture (three-phase sinusoidal) network has a clear drawback - low specific parameters (the capacity it can develop does not exceed 40% of the rated power of an asynchronous machine, made in the same dimensions). The energy and weight characteristics of the SRM can be significantly improved by improving the design of the rotor. It is known that the maximum value of the power factor and torque on the shaft largely depends on the ratio of the magnetic resistances along the longitudinal and transverse axes of the rotor: $T = (x_d - x_q) I_d \cdot I_q$ [4]. Consequently, while maintaining the magnetic resistance of the longitudinal axis, it is necessary to reduce the magnetic resistance of the transverse axis [5].

This can be achieved, for example, by inserting gaskets from a non-magnetic material in the rotor. Varying the number and dimensions of non-magnetic gaps, one can obtain a machine with specific parameters that are not inferior to the indices of an induction motor [6]. Thus, optimized synchronous reluctance machine occupy an intermediate position between induction motor and traditional synchronous motors. Much of the options for improving the specific capabilities of the machine remain in the classical framework, they are associated with an increase in the magnetic asymmetry of the rotor. At the same time, it remains unchanged that a network or a source with sinusoidal current powers the motor. The solutions are accompanied by the complication of the design of the machine and do not allow optimal use of the electrical machine in conjunction with the switch converter [7].

From this description it can be seen that in the induction machines, as well as in machines with permanent magnets and hysteresis machines, the main progress was achieved due to the use of expensive materials and the complication of the design of machine rotors [8]. At the same time, the control laws and electric drive systems were preserved in the traditional form. Moreover, if in the first two variants of the considered electric machines there is no way to do without the use of expensive materials in the rotor design, in the case of reluctance machines, the design of the rotor is subject not only to complication, but also to a significant rise in price [9].

In the 1990s, electrical engineering made a revolution in a regulated electric drive, decoupling the stator circuits of alternating-current electric motors (and SRM, in particular) and the network. This allowed us to rethink the capabilities of this electric drive and try to use reserves previously unavailable in the network drive. At this time, one of the possible ways to improve the characteristics of the SRM was pointed out by H. Weh [10]. He pointed out that the same windings of the stator winding can perform functions either as excitation or as an armature, depending on whether they are opposite to the interpolar gap or opposite the pole. This type of electrical machine is called the FRRM - Field regulated reluctance machine. True, we did not succeed in finding further work on the study of the processes in these electric drives [11].

Due to the fact that the FRRM is closer to a synchronous machine with an active rotor, it is useful to explain the principle of its operation. In a synchronous machine with an active rotor, excitation is produced by a winding located on the rotor or by permanent magnets. Then the magnetomotive force (MDS), created by the stator windings, interacts with the excitation field of the rotor [12]. The electromagnetic torque can be considered as a result of the interaction of the fundamental harmonic of induction in the gap created by the excitation winding and the fundamental harmonic of the armature MDS. The creation of the field of excitation in FRRM is carried out by a winding located on the stator, when its turns are opposite the interpolar gap of the rotor [13].

The currents I_B of the excitation windings located above the pole spacing of the rotor and currents I_A in the armature windings [14]. They located above the poles of the rotor can be adjusted independently. In order for this independence to be realized, the stator windings are carried out with a full step. Then each of the sections performs functions either rigidly anchored or rigidly excited. Unlike a synchronous machine with an active rotor, there is no need to pass a sinusoidal current through the stator windings [15]. As an example, figure 1 shows a section of a six-phase FRRM, as well as a rectangular shape of

the phase winding current, on which the parts on which the phase participates in creating the armature response field or excitation field are clearly visible [16].

Later, the idea of this electric drive received the greatest coverage and justification in the works of T. Lipo and his colleagues [17]. In their publications, the authors come to the conclusion that with the same copper masses, electrical losses and maximum induction in the gap, the motor has a 68% greater force than an asynchronous machine. Such experimental data have been confirmed in further studies and publications [18]. This is achieved due to the fact that this type of electric motor has several obvious and important advantages:

- simplicity of design (simple rotor design, single-layer stator winding with full step);
- ability to develop high overload capacity;
- low losses (contactlessness, absence of winding on the rotor).

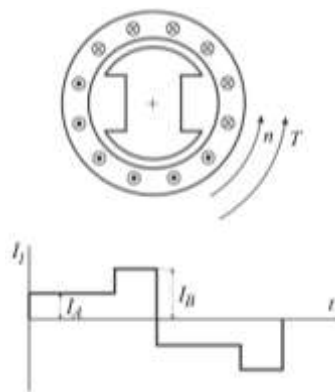


Figure 1. Operation of FRRM.

Further research on this type of electric drive was continued by domestic authors [19, 20]. They systematized the information of the FRRM, proposed algorithms for optimizing the shape of the linear density of the surface current. Structural, functional and principal schemes of electric drive control systems with FRRM were developed, providing the considered electric drive with the adjusting properties of the reversed DC machine.

In the above works, there is little coverage of the construction of control systems for electric drives of this class, taking into account the finite speed of the elements, as well as the choice of the design elements and the laws governing the electric drive. Nevertheless, in the above publications, the authors cite three variants of functional schemes that are convenient for the management of the FRRM. This is a circuit with individual phase power supplies, a circuit with a multiphase inverter and a circuit with two three-phase inverters [21].

The very idea of the work of the FRRM is due to its appearance in the wide development of semiconductor technology [22, 23]. The design of electric drives based on FRRM with high dynamic, adjusting and mass-dimensional indicators implies the availability of high-quality power supplies. An important aspect in this case is the type of semiconductor switches. Schemes based on thyristors are widely known and are serial, however, due to the pulsating shape of the current at the output of such converters, it is necessary to introduce additional equipment or additional feedbacks that can harm other performance indicators of the system (primarily speed). Consequently, the most promising in this respect are transducers based on PWM controlled transistors [24, 25].

4. Synthesis of power circuit schemes

Consider the merits and demerits of each of the schemes. The circuit with a multiphase inverter (see figure 2) is most convenient for an FRRM with an odd number of phases. This circuit does not require a large number of switches, at the same time, it is not a serial one, therefore, it is necessary to develop a

switch control law and to coordinate the operation of the inverter racks. Also, this scheme gives a very low coefficient of use of the switches, since each switch alone works little time [26].

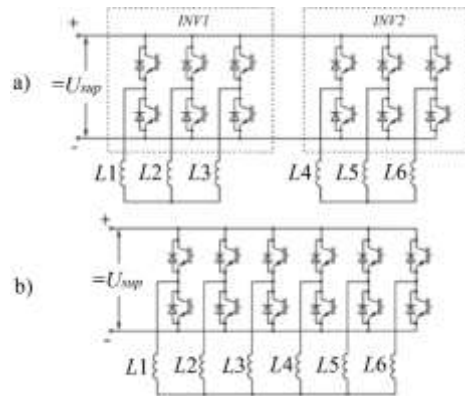


Figure 2. Functional diagrams of the power part of electric drives with FRRM: a - with two three-phase inverters, b - with a multiphase inverter.

Taking into account the possibilities of serial three-phase voltage inverters (IN), it is advisable to consider the electric drive variant, in which the stator windings are assembled into two three-phase stars shifted by 30 electric degrees relative to each other (see figure 2). The circuit requires two three-phase inverters. In electric drives of small and medium power it is more advantageous than the scheme with a smaller number of keys. In electric drives of high power, it is the most natural, because it does not require parallel connection of keys at high currents. However, this variant of the circuit, like the previous one, does not always allow us to obtain a qualitative form of the current in the windings [27].

The paper [28] gives a detailed comparison of different inverters from the point of view of the harmonic composition of the current. It is shown that as the number of phases increases, the harmonic composition improves, the influence of higher harmonics decreases [29]. It is also worth noting that in circuits with multiphase inverters the effect of higher harmonics is less than in circuits with a traditional three-phase (or several three-phase) inverter. This is explained by the different effects of the 5 and 7 harmonics, which is more clearly expressed in three-phase inverters.

The simplest in terms of implementation and configuration is a circuit with individual current sources (ICS) per phase (see figure 3). Such systems can be performed with symmetrical or unbalanced switch control [30]. This scheme most fully uses the motor in size and allows you to achieve the greatest values of torque, compared with other schemes [31, 32].

The great advantage of this scheme is the blockness and independence of the elements of the construction from each other, which allows to achieve significant reliability of operation and easy interchangeability of the elements. In addition, this power circuit allows you to get the most qualitative rectangular current in the motor windings without degenerating the latter into a trapezoid. In addition to the advantages of the circuit, there is a large total number of keys $4m$ (where m is the number of phases of the FRRM) and the lack of fully prepared serial solutions of the electric drive as a whole. From the latter follows the higher price of the scheme with ICS in comparison with other types of schemes.

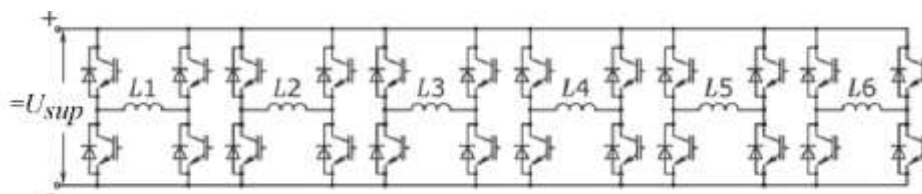


Figure 3. Functional diagram of the power section of the electric drive with individual power sources of phases.

In addition to circuit solutions of switch converters, there are also solutions in the literature for the design of the direct electric motor. These solutions concern the geometry of the stator [33] and the rotor

[34]. The rotor of FRRM can be made monolithic, which allows achieving high mechanical stiffness of the rotor. This makes it possible to obtain high reliability of operation at large overloads, and also significantly reduce the costs of manufacturing the rotor. In addition, the monolithic nature of the rotor contributes to the creation of gearless electric drives in which the rotor of the motor is directly connected to the working member [35].

Given the reluctance nature of the torque developed by the motor, the decisions regarding the rotor modernization, applied to traditional SRS, are equally applicable to the FRRM. The use of a rotor with non-magnetic gaskets makes it possible to obtain the highest specific parameters and power characteristics of an electric drive [36, 37].

However, despite the existing options for power schemes and ideas for improving the mass-dimensional parameters of the FRRM, it is necessary to develop a management system and formulate control laws, taking into account the study of static and dynamic modes of operation of the electric drive with the FRRM. The control system should not only ensure the necessary flow of processes in the electric drive, but also most favorably develop the advantages of the electric motor, listed above. For this, it is necessary to pay attention to those features of the functioning of the power section of the electric drive, which must be taken into account when developing the control system of the electric drive. Here it is necessary to distinguish two groups of such features [38, 39].

5. Results of electric drive studies in various power supply schemes

For this, a series of experiments was carried out (see Table 1). The specific parameters of electric drives in an electric machine with different types of rotors were compared (with a conventional rotor and with magneto-conductive inserts) and with different phase current forms, with the relative value of currents being assumed to be 1; 1.1; 1.2; 2 of the nominal value.

As can be seen from Table. 1 the change in the law of control of phase currents from sinusoidal to rectangular allows improving the specific parameters of the electric drive without complicating the design of the rotor. In the case of rectangular currents in a machine with a complicated rotor design (with inserts), the magnitude of the electromagnetic torque increases only by 5%.

Table 1. Comparison of specific indicators of electric drives with synchronous reluctance machines.

<i>I</i>	<i>T</i>			
	With rectangular shape of phase current		With sinusoidal	
	Usual	With inserts	Usual	With inserts
1	1.0	1.05	0.8	1.2
<i>1.1</i>	1.1	1.1	0.9	1.3
<i>1.2</i>	1.3	1.3	1.0	1.5

6. Conclusion

Brushless agriculture electric drives based on synchronous reluctance machines have high potential capabilities. Specific characteristics of electric drives have values that exceed similar synchronous electric drives by approximately 20%. Improvement of specific parameters in the electric drive can be achieved not only due to the complexity of the construction of the electric machine, but also due to the choice of optimal schemes of power circuits. Thus, in electric drives with individual sources with rectangular current form, the values of overloads corresponding to electric drives with a complex (compound) rotor design are achieved.

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