Bulletin of the South Ural State University
Series "Power Engineering"
2013, vol. 13, no. 1, pp. 111–117

Specific Weight-Dimension Factors of the Electric Drives

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The Specific weight-dimension factors of the different types of electric drives and the ways to improve them are considered. To compare the specific parameters of synchronous motors with permanent magnets the minimum total losses criterion, previously proposed by Professor Vagati, was chosen. The convenience of this method is that it allows you, without resorting to complicated electromagnetic calculations to choose the optimum value of the rated speed. To compare the specific parameters of the classical asynchronous drives the electromagnetic torque expression, proposed by Professor Kopylov for classical electrical machines, was selected. The equation, which shows the relations between the electromagnetic torque and the geometric parameters of the motor, allows identifying «weak» links in the induction motor and explain its limit values. The author shows the ability of creation the torque in the field regulated reluctance machine by the higher harmonic of the current. It is shown that designing electrical machines with considering the peculiarities of the semiconductor inverter and motor cooperation it is possible to improve the specific indicators up to 30%. The paper notes that applying new approaches can increase the overload capacity of the drive, and hence its use at sites with heavy and extra-heavy operating conditions

Keywords: specific indicators, electric drive with the field regulated reluctance machine, asynchronous drives, overload capacity.

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Поступила в редакцию 27.03.2013 г.

THE ELECTRIC DRIVE WITH FIELD REGULATED RELUCTANCE MACHINE*

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The electric drive with the synchronous electrical machine of independent excitation differs by high specific parameters, adaptability to manufacture, simplicity of a design, and reliability. These properties of the electric drive allow using it in heavy conditions of operation.

The electric motor for this electric drive can be executed with two separate stator windings. Therefore, there are additional benefits connected to an opportunity of change of geometry of an iron stator stamp of the given type motor. In this report, the principle of operation of the electric drive with control system is considered. The different variants of a stator design of the electrical machine are discussed. The stator design allows improve of the mass and weight parameters of the electric machine. For the offered stator designs, the comparison of specific parameters (relationship of the nominal torque to load current) is carried out. The received results of analysis are discussed.

For calculation of the losses first of all it is necessary to determine the factors, which influence on their value, and then, to estimate a degree of influence of each of them on value of switching losses. As such factors are taken: the form of the stator core, the form of a current in phase windings, and the number of stator winding phases. The calculation of losses is executed by the method of winding functions. The experimental data are received on a breadboard model of the 20 kW drive.

Keywords: electric drive with field regulated reluctance machine; electrical losses; stator designs.

Introduction

If at designing electro-installation to pay the greater attention to new types of electrical machines, and in a complex the converter - engine to project not the converter for traditional motor with a sine wave stator voltage but try to take into account features of the join work of the electrical machine with the power supply, it is possible to achieve good results [1]. The special place in this row have synchronous reluctance machines with field regulated reluctance machine, which are characterized by extreme simplicity of a design, not containing of windings on a rotor, high efficiency, large specific and over-loaded torques. The specified advantages of these machines can be useful at designing the electric drive for electric transport with high specific parameters for the torque and power.

Literature review

The increased interest to synchronous reluctance machines is determined because of simplicity of their design and adaptability to manufacture. In the electrical machines, having traditional "smooth" stator and a distributed three-phase winding, usually aspire to increase L_d / L_q – the quotient of size of longitudinal inductance of the machine to cross inductance. It is reached or special form stamp of a rotor package or longitudinal lamination [2].

Very effective there were decisions connected with influence on stator circuits of the reluctance electrical machine. The success here was achieved by a choice of a configuration of a stator winding circuits and application of the special laws to control of stator currents distinct from sine wave. So, in [3] the multiphase synchronous reluctance motor was offered with a complete step of a winding, in which the part of stator windings creates a flux of excitation, and another part creates the rotating torque. Control currents in these two windings are independent. There was paid attention to the high specific torques of this electrical motor. In [4–10], the idea of the offered machine is developed: the mathematical description is given, the specific parameters of these machines are compared with the parameters of induction motors, some reasons are discussed at the choice of a number of phases, poles, and length of an pole arch. The new opportunities of electric drives and generators with the electrical machine having massive (executed from continuous ferromagnetic bar) are stated in [8]. This machine have small sizes of the parameter L_d / L_q (not higher 1,5 ... 2). The engineering methods of calculation and functional circuits in detail enough described in [8] also. For transport installations most urgent are mass dimension parameters, which can be achieved with the special, not round, form cross section of stator. This paper is devoted to this theme.

Principle of electrical motor operation

In the salient pole synchronous machine, the role of a winding excitation can execute the winding placed in the stator slots, if, first, its turns are opposite of between-pole intervals of a rotor and, secondly, this winding has a complete step. So, if a current flows through windings (1-1', 2-2'), located above between rotor pole intervals, it will create flux along lengthwise magnetic axis machine. If now to pass a current through coils (3-3', 4-4', 5-5', 6-6') located above of a rotor poles, the electromagnetic moment is created.

The currents in windings of excitation (windings

* Работа выполняется при финансовой поддержке гранта Президента РФ (Соглашение № 16.120.11.6780-МК от 1 февраля 2012 г.).

1-1', 2-2'), located above between rotor pole intervals and currents windings (3-3', 4-4', 5-5', 6-6'), located above rotor poles, can be adjusted independently and to be switched in function of a rotor position. In these windings there are no necessity to pass a sine waveform current. More effective as appears is the rectangular current form, the same as in the sections of a DC motor winding. The motor works as a multi-phase machine. The different phases are shifted on π/m of electrical degrees from each other, where m is a number of phases. The electric motor for this electric drive can be executed with two separate stator windings, therefore, there are additional benefits connected with an opportunity to change the stator iron geometry stamp for the given type motor [11–13].

Mass demensional parameters of the electric drive

It is known the considered machine with the round form of a stator core package [14–19]. As the realization of this machine is possible with two separate independent windings on the stator, it is expedient to consider the electrical machine with the square form of a stator core package. The part of electro-technical steel, which is in corners of a package and which at a traditional machine design would go in elimination, can be used in magnetic circuit. Let's stop on two variants of geometry of the stator core. The first variant is characterized by simplicity of a stamp manufacturing, but use of space available in angular parts of a stator package is irrational. In the second variant the stator slots differ on height. The manufacturing of the stator core stamp of the electrical machine becomes complicated, but the spaces in the angular parts of its package are used more rationally, than in the first case. It is known the execution of the considered motor on the base of the serial induction motor [2], therefore the choice and calculation of stator iron geometry was made on the technique stated in [2]. As a prototype was taken the four pole induction motor, which detailed electro-magnetic calculation is given in [5]. The recalculation of the four pole induction motor to two pole induction motor was done under condition to preserve all dimensions of stamp [5]. The choice two pole machine is dictated by aspiration to use the motor in the electric drive with high and super-high speeds of shaft rotation (up to 3000 rev/min ... 9000 rev/min) at moderately high voltage frequency on an output of the frequency converter in the motor stator circuits.

Motor with stator core on surpasses induction motor in all parameters on 9...10 %. It is connected with the increased electromagnetic torque of the given motor in comparison with induction motor.

Motor with stator on and motor with stator on surpass motor with stator on in efficiency of use active materials on 10 % and 14 %. In use copper they concede motor, but In efficiency of use steel they win. The concede in use copper are connected with not optimum width of teeth for motor on, and for variant motor on with irrational use of space in angular parts of a stator steel package. The general losses on unit of the electromagnetic moment are lower in motor and motor, than at motor on 17 % and 26 % accordingly.

In case if the electro-technical steel remaining after punching of sheets of a package and located in the internal part from a teeth zone, could be used secondarily (for example, for manufacturing stator packages of a smaller dimension), coefficient of using steel (K_u is ratio of weight electro-technical steel used in the electrical machine to common weight of initial steel used for stamp) for an induction motor and a first motor K_u = 0,63, for second motor K_u = 0,75 and K_u = 0,69 accordingly. If an internal part of a package do not take in attention, and to take into account only electro-technical steel necessary for manufacturing of a stator package, in a case this parameter K_u = 0,27, in a second case K_u = 0,51 and in a case K_u = 0,39.

Condition of loses account

As the initial conditions for calculation of motor losses are accepted:

– the moment of switching is selected in such a manner that was achieved maximal average integral (for the period of switching) electromagnetic torque;

– the magnetic system was not saturated;

– the value of a pole arch was accepted to an equal half from value of pole division of the machine;

– the number of stator slots is equal to forty eight;

– the calculation was carried out for three cases of the form of a current in a winding of each stator phase: trapezium form, rectangular, and sine wave form. In the first case the time of reverse a current in each phase corresponded to width phase zone of a stator. In the second case the current in everyone sinusoid developed of three steps of equal duration, thus, the amplitude of a current for an average step was accepted in 2 times above, than on extreme. This case corresponded to a feed of a three-phase stator winding from the autonomous inverter, executed on the standard power circuit. In the third case, the current form corresponded usual sinusoid. Two variants of the form of cross section of the stator core were considered: in the first (traditional) case it was a ring limited by two circles, in second – the outside diameter of section of the core represented by a square, on which corners the winding of excitation was placed [13–16].

Losses in the stator copper

The comparison of variants was done according value of a parameter q:

$$q = \frac{T_M/P_e}{\Delta T_M/\Delta P_e} \qquad (1)$$

where T_M and P_e – torque and value of power losses in stator copper at the ideal rectangular form of a current in stator phase windings and unit (nominal) amplitude; ΔT_M and ΔP_e – average value of the torque and power losses in the stator copper at other form of a current in a phase stator winding and unit amplitude.

The parameter allows estimate the efficiency of use the motor on torque at the different laws of switching.

Dependence value of parameter q from the different factors: the forms of a current in a phase winding, cross section of the stator core, and number of phases in a stator winding illustrates in Table 1. As follows from this table, the parameter q monotonously is increased in all cases in process of increase the number of the stator phases. After $m > 6$ efficiency of this increase is reduced. In all considered cases the second variant of the stator core has appeared appreciably more effectively (from 60 up to 70 %), than first. This difference was observed in all considered cases and little changed at a different m. As the best form of a current it is necessary to recognize a trapezium [17–24].

Losses in the rotor

As a criteria, which influence on values of switching losses, were considered [3]: the relation of flux amplitude of pulsations to its average value (A_F / F), and the frequency of a flux pulsations. Fig. 1 shows the dependences of relative flux pulsations from number of phases m of a stator winding for the round form of the stator core. The curve 1 (Fig. 1) concerns to the rectangular form phase current in a stator winding. In this case it is possible different variants of a feed stator windings from one (three-phase winding), two (six-phase winding) and three (nine-phase winding) autonomous inverters. The pulsations of the flux change from 5 % up to 24 %. The curve 2 (Fig. 1) concerns to the trapezium form of a phase current. The pulsations of the flux change from 1 % up to 7 %. The curve 3 (Fig. 1) concerns to the sine wave form of a current in a phase winding. The choice of this form achieve a minimum of flux pulsations, and, hence, of losses in the rotor steel. These pulsations made 0,5 ... 3 % The frequency of the flux pulsations for the round form of the core was determined by number of phase zones and calculated according the formula

$$f_F = 2m \cdot f_s \qquad (2)$$

where f_F is the frequency of the voltage source. The same dependences are shown in Fig. 2 for square stator core form. The curve 1 also concerns to the rectangular form of a current in a phase of a stator winding. The flux pulsations in this case change from 17 % up to 32 %. The curve 2 concerns to trapezoid form of a current. The flux pulsations change from 15 up to 20 %. The curve 3 concerns to the sine wave form of a phase current in the stator winding. The flux pulsations in this case change from 4 up to 10 %. For the square form of the stator core the frequency pulsations calculated under the formula:

$$F = 4 \cdot f_s.$$

Table 1

Dependence value of parameter q from the different factors

Form of the stator core	Current form	Number of phases						
		3	4	5	6	7	8	9
round	trapezium	1	2,2	3,7	6	8	9,9	12,3
	rectangular	0,1	–	–	0,4	–	–	0,7
	sinusoidal	7,3	21	31	38	45	49	53
square	trapezium	0,4	3,7	1,1	0,9	0,9	0,9	1
	rectangular	0,1	–	–	0,4	–	–	0,7
	sinusoidal	1,7	12,7	11	10	11	10,5	11

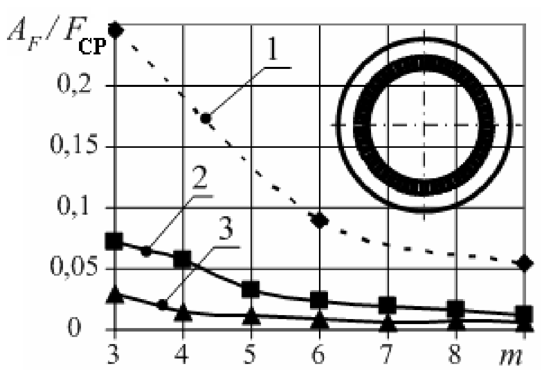

Fig. 1. Relative flux pulsations in the round form of the stator core

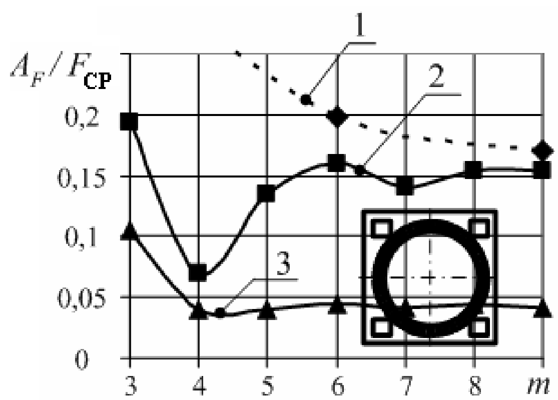

Fig. 2. Relative flux pulsations in the square form of the stator core

Conclusion

1. Considered motor with the traditional form of a stator package stamp (Fig. 1) has the best parameters than induction motor in values of specific losses in copper and in use of electro- technical steel.

2. The further improvement can be achieved if to apply a stator package of the square form (Fig. 2a and 2b).

3. The trapezium current wave form is optimal for receiving maximum motor torque while minimum losses in the motor copper. It is irrespective of the form of the stator core.

4. In motor with round and square form of the stator core, the sine wave form currents reduce switching losses.

5. Rotor losses sharply decrease because of the superficial effect, if a frequency of stator voltage increases up to 100, 200 Hz.

6. In motor with the square form of the stator core, frequency of pulsations for three-phase variant in 1.5 times less than at the round form of the stator core at the same voltage frequency and does not depend from number phases of the stator winding.

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УДК 62-83::621.313.3

ЭЛЕКТРОПРИВОД С СИНХРОННОЙ РЕАКТИВНОЙ МАШИНОЙ НЕЗАВИСИМОГО ВОЗБУЖДЕНИЯ

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Электропривод с синхронной реактивной машиной независимого возбуждения отличается улучшенными удельными показателями, технологичностью в изготовлении, простотой в проектировании и надежностью, поэтому он может быть использован в тяжелых условиях эксплуатации. Показано, что если статор электрической машины выполнить с прямоугольным сечением, то можно увеличить коэффициент использования машины по «железу». Сопоставление разных конструкций электрической машины и законов управления выполнялось по критерию минимума потерь в статоре и роторе. Обращается внимание на то, что при трапецеидальной форме тока удается снизить потери. Этот эффект наиболее заметен в случае, если пакет статора будет иметь прямоугольное сечение. В этом случае частота пульсаций электромагнитного момента при трехфазном питании в 1,5 раза меньше, чем при круглой форме сердечника статора. Увеличение фазности электрической машины заметного эффекта не дает.

Ключевые слова: электропривод с синхронной реактивной машиной независимого возбуждения, электрические потери, проектирование статора электрической машины.

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Поступила в редакцию 11.02.2013 г.