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COMPARISON OF SYNCHRONOUS RELUCTANCE MOTORS WITH THE OUTER AND INNER ROTOR

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The paper presents the comparison of two synchronous reluctance motors with the inner rotor and the outer one. The aim of the research is to determine the influence of motor type on electromagnetic torque and ripple factor. The results indicate that a maximum value of electromagnetic torque and the amplitude of the first harmonic of electromagnetic torque increase for the motor with the inner rotor, and the value of ripple factor increases as well. If both motor types with equal rated power, rotation frequency and current density are compared, the results show a possibility to reduce the volume of motor with the inner rotor by 15 %.

Keywords: *electromagnetic torque, inner rotor, outer rotor, synchronous reluctance motor.*

1. INTRODUCTION

Synchronous reluctance motors (SRMs) are brushless electrical machines that have some advantages owing to their simple and reliable design and the absence of permanent magnets or windings on the rotor. High level of reliability and low production costs should be highlighted among them [1]–[4].

SRMs can be made either with the outer rotor or inner rotor, the choice of design generally depends on the specific application of a particular motor. If it is possible in principle to use both designs, it is important to evaluate the advantages of one and the other. Some results of the comparison between SRMs with the outer and inner rotors are presented in [5].

The research is conducted using the variations of SRMs with segment-shaped rotors. The main objective of the research is to perform the comparison of two SRM types: with the inner rotor and the outer one. As criteria for comparison, such parameters as the maximum value of electromagnetic torque T_{max}, the amplitude of the first harmonic of electromagnetic torque T_{1max} and the value of ripple factor k_p are used.

2. DESCRIPTION OF RESEARCH OBJECTS

The three-phase SRM with a segment-shaped outer rotor is shown in Fig.1. The motor presented in patents [6], [7] is designed with the rated power P_N = 1 kW. The number of stator slots Z = 18 and pole pair number p = 1. The optimal values calculated for the current SRM and used for the research are listed below: outer diameter D_{out} = 169 mm, active model length L = 100 mm, air gap value δ = 0.5mm and current density in stator slot j = 2.5 A/mm^2.

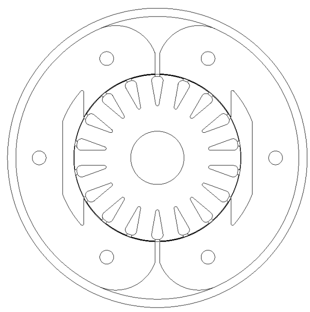
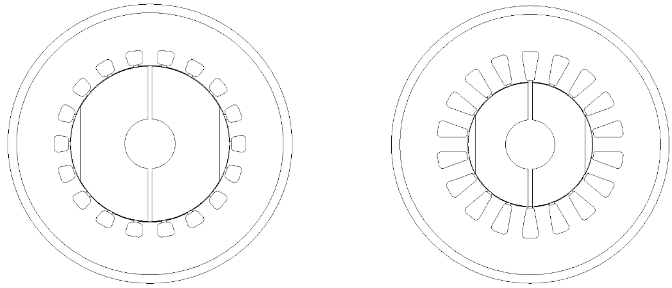


Fig. 1. Synchronous reluctance motor with a segment-shaped outer rotor.

Within the framework of the research for SRM with a segment-shaped inner rotor, the following values were presumed constant: length L, construction outer diameter D_{out}, air gap δ, pole pair number p, current density in stator slots j and a number of stator slots Z. Numerical values of these parameters are identical to values given for the motor with the outer rotor. As the main variable, the diameter D_{in} of inner rotor was chosen, which in turn led to a non-constant value of stator slot area value S_j. The value of D_{in} was changed in steps of 10 % within the range of 100 % and 70 %. As a base value, meaning 100 %, diameter of the stator of the design with the outer rotor was adopted. Therefore, models and calculations were made for 6 design variants, including a design with the outer rotor.

The following design variants are illustrated in Fig. 2: SRM with a segment-shaped inner rotor, where diameter of the inner rotor is equal to stator diameter of SRM with the outer rotor (a), and SRM with the inner rotor, where diameter of the inner rotor is equal to 80 % of stator diameter of SRM with the outer rotor (b).



a) b)

Fig. 2. SRM construction with the inner rotor a) D_{in} = 100 %, b) D_{in} = 80 %.

During the research, the value of stator slot area S_j is used as a variable dependent on the value of the inner diameter of SRM. Since the value of current density j is constant, the changes of the full current value I in stator slots are directly proportional to changes of stator slot area S_j. Results in percentage for all 6 design variants are shown in Table 1.

Table 1

Values of Stator Slot Area as a Function of Rotor Diameter

	Outer rotor construction	Inner rotor construction				
D_{in}, %	100	100	90	80	75	70
S_j, %	100	108.02	156.07	194.88	209.52	221.24

3. MAGNETIC FIELD SIMULATIONS AND RESULT ANALYSIS

In order to estimate values that are necessary for comparison of design variants of SRM, calculations based on finite elements method are used. These calculations are performed through magnetostatic field simulations in software *QuickField*, which is a two-dimensional finite element analysis system from *Tera Analysis* [8]. Electromagnetic torque is calculated by using Maxwell stress tensor [9]. In this case, the electromagnetic torque is described with surface integral (1) over the closed surface S in the middle of the motor air gap.

$$T_{em} = \oint_S \left(\bar{r} \times \left[\frac{1}{2\mu_0} \left(B_n^2 - B_t^2 \right) \times \bar{n} - \frac{1}{\mu_0} B_n B_t \bar{t} \right] \right) dS \,, \tag{1}$$

where T_{em} is the electromagnetic torque;

μ_0 is permeability constant (μ_0=4π×10^{-7},H/m);

$\bar{n}$ is the normal vector of the point on the closed surface S;

$\bar{r}$ is the radius vector of the point on the closed surface S;

$\bar{t}$ is the tangent vector of the point on the closed surface S;

B_n is the normal component of the magnetic flux density;

B_t is the tangential component of the magnetic flux density.

The values of electromagnetic torque are calculated when rotor rotation is performed in steps of 2 el. deg. The values of electromagnetic torque as a function of rotor rotation angle ε for SRM with the outer rotor and for SRM with the inner rotor at D_{in}=100 % and D_{in}=75 % are shown in Fig. 3 and Fig. 4.

Based on the results of simulations, the values of the proposed criteria for comparison are obtained:

1. T_{max} – the maximum value of electromagnetic torque curve;
2. T_{1max} – the amplitude of the first harmonic of electromagnetic torque curve;
3. k_p – the ripple factor.

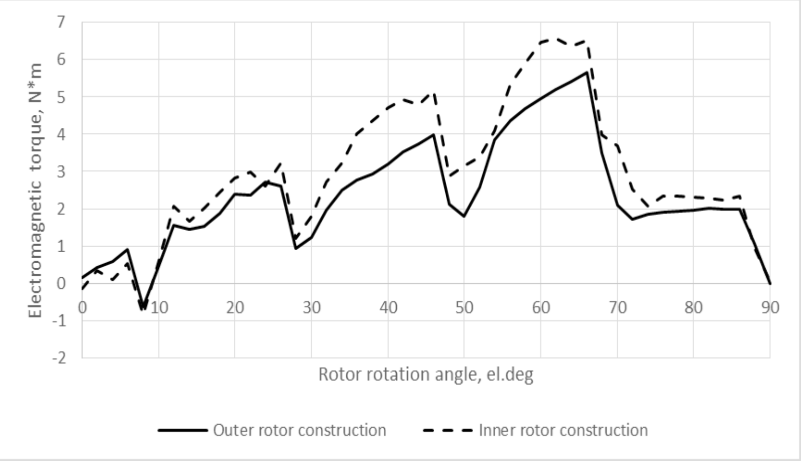


Fig. 3. Electromagnetic torque curves for SRM constructions at D_{in} = 100 %.

For calculation of ripple factor k_p formula from [10] is used

$$k_p = \frac{\sum_{i=1}^{n} |\Delta a|}{n \cdot T_{\max 1}}, \tag{2}$$

where n is the number of evenly selected points on the half interval of the electromagnetic torque sinusoidal curve;

Δa is the difference between values of the electromagnetic torque T_{em} and the first harmonic of electromagnetic torque T_{em1} in relevant points;

$T_{\max 1}$ is the maximum of the first harmonic of electromagnetic torque.

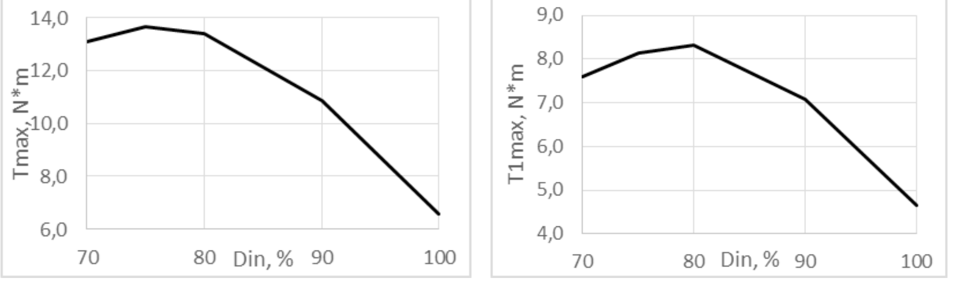
Fig. 4. Electromagnetic torque curves for different constructions of SRM rotor.

A summary of the obtained values are given in Table 2 and shown in Fig. 5.

Table 2

Summary of the Results

	Outer rotor construction	Inner rotor construction				
D_{in}, %	100	100	90	80	75	70
$T_{max,}$ N*m	5.65	6.57	10.84	13.38	13.66	13.11
$T_{1max,}$ N*m	3.61	4.64	7.08	8.32	8.15	7.59
k_p	0.23	0.20	0.24	0.26	0.29	0.32



a) b)

Fig. 5. Result curves for T_{max} (a) and T_{1max} (b).

The results shown in Table 2 indicate that at a constant value of outer diameter D_{out}, the design of SRM with the inner rotor allows achieving a comparatively higher value of electromagnetic torque than the design of SRM with the outer rotor. The largest values of T_{max} and T_{1max} were obtained for design variants with the inner rotor at D_{in} = 75 % and D_{in} = 80 %, respectively. SRM with the inner rotor is able to produce T_{max} increased by 141.64 % for the design variant with D_{in} = 75 %, and T_{1max} increased by 130.35 % for variant with D_{in} = 80 % if compared to values obtained for SRM with the outer rotor. This result is achieved with a similar increase of full current value I in stator slot by 109.52 % and 94.88 % for constructions with D_{in}=75 % and D_{in} = 80 % respectively, and the increase of ripple factor values k_p by 28.19 % and 15.01 % for these constructions.

In some cases it may be reasonable to compare SRM with the outer rotor and SRM with the inner rotor by using the value of the outer diameter D_{out} as a variable. For that purpose it is necessary to calculate the value of outer diameter D_{out} for SRM with the inner rotor, which produces the same rated power P_N = 1 kW as SRM with the outer rotor, taking the value of current density j as constant. Electromagnetic torque curves presented in Fig. 6 belong to SRM with the outer rotor and SRM with the inner rotor with a comparatively smaller outer diameter. Value of D_{out} is only 92 % that allows producing this SRM with the inner rotor with volume equal to 85 % of SRM with the outer rotor. It shows the possibility to reduce the volume of SRM by 15 % while remaining its power constant, if inner rotor construction is used instead of outer rotor construction.

Fig. 6. Electromagnetic torque curves for outer rotor construction and inner rotor construction at V = 85 %.

4. CONCLUSIONS

Based on the results obtained within the framework of the research conducted, the following conclusions can be drawn:

1. If the values of outer diameter D_{out} and current density j are constant, the design of SRM with the inner rotor may produce approximately 130 % higher electromagnetic torque in comparison with construction of SRM with the outer rotor.
2. Increase of full current value I in stator slot by approximately 95 % can be achieved due to changes in the stator slot area for all calculations with constant current density j.
3. The values of ripple factor for SRM with the inner rotor are increased by approximately 25 % in comparison with SRM with the outer rotor.
4. It may be possible to produce SRM with the inner rotor with reduced volume by 15 % in comparison with SRM with the outer rotor, while maintaining similar values of electromagnetic torque, rotation frequency and rated power.

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SINHRONO REAKTĪVO DZINĒJU AR ĀRĒJO UN IEKŠĒJO ROTORU SALĪDZINĀJUMS

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K o p s a v i l k u m s

Veikts salīdzinājums sinhronajiem reaktīvajiem dzinējiem ar ārējo un iekšējo rotoru. Izpētīta konstrukcijas tipa (dzinēji ar vienādu tilpumu un dzinēji ar vienādu jaudu) ietekme uz elektromagnētisko griezes momentu un pulsācijas koeficientu. Parādīts, ka konstrukcija ar iekšējo rotoru, salīdzinot ar konstrukciju ar ārējo rotoru, ļauj palielināt elektromagnētisko momentu, tomēr pieaug arī momenta pulsācijas.

Ja jauda, rotācijas frekvence un strāvas blīvums ir nemainīgi, konstrukcija ar iekšējo rotoru ļauj samazināt dzinēja kopējo tilpumu aptuveni par 15%, salīdzinot ar dzinēju ar ārējo rotoru.

10.03.2017.