Experimental Study of Synchronous Electronically Commutated Outer – Rotor Brushless Motor at Stalled Rotor

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***Abstract* – The paper presents experimental study of electronically commutated outer-rotor brushless synchronous motor at stalled rotor. Experimentally obtained torque-angle characteristics of outer-rotor permanent-magnet synchronous motor are analyzed and compared to the results calculated by motor two-dimensional magnetostatic field simulation using computer software based on finite element method. Comparison results demonstrate an acceptable correlation.**

***Keywords* – torque-angle characteristic, brushless synchronous motor, magnetic field simulation, permanent magnets, outer-rotor motor.**

I. Introduction

At the present time the interest in brushless synchronous motors application, especially as electronically commutated motors, is rapidly growing. It is due to the fact that these motors have a number of advantages. Such motors do not have sliding contacts and brushes that quickly wear out, even under simple operating conditions, at the same time they do not have additional losses of friction and contact voltage drop. Thus, they have high reliability, long service life, low level of noise and vibrations, wide range of speed control, and energy efficiency as well [1-3].

Depending on the requirements to motor application, the brushless synchronous motor can be designed with inner as well as outer rotor [4].

The outer-rotor design of brushless synchronous motors makes it possible to use them for direct integration into operating element of electric device without transmission gears. It can increase service life and energy performance of device in general.

Nowadays, electronically commutated outer-rotor brushless synchronous motors are widely used in electric vehicles, electric bicycles, ventilators, medical equipment, computers, consumer electronics and etc. [5, 6].

However, the operation features of electronically commutated outer-rotor brushless synchronous motors still have not been studied enough. Thus, the study of such motor characteristics is topical.

This paper presents the study results of torque-angle characteristics of synchronous electronically commutated outer-rotor brushless motor, and deals with the experimental method of obtaining the torque-angle characteristics at stalled rotor. Experimentally obtained results are compared with the results calculated by simulation of two-dimensional static magnetic field of the motor using computer software based on finite element method (FEM).

II. Design of Outer-Rotor Permanent-Magnet Synchronous Motor

The outer-rotor brushless synchronous motor that is chosen as a studied object in this paper has been designed for the application in direct driven electric hand planer.

Since the space available for the motor integration into operation element of electric planer is limited, the design of synchronous motor with outer rotor having surface-mounted high-energy permanent magnets is the most suitable for this application [7].

A cross-section of the studied outer-rotor synchronous motor with surface-mounted permanent magnets is shown in Fig. 1, and its main parameters are presented in Tab. 1.

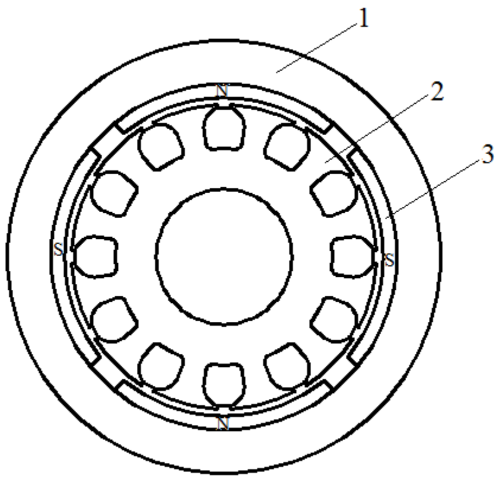

Fig. 1. The cross-section of the studied outer-rotor permanent-magnet synchronous motor: 1 – outer rotor; 2 – slotted inner stator with 3-phase winding; 3 – surface-mounted permanent magnet.

Parameters of permanent magnets have been optimized by criteria of maximum value of magnetic flux fundamental harmonic in air gap of the motor with fixed dimensions considering the restrictions of magnetic circuit saturation. For the optimization of magnet parameters analytical relations between magnetic flux fundamental harmonic and influenced parameters of permanent magnets were synthesized by the results of static magnetic field simulation. The methods of analytical relations synthesis and analyses results of permanent magnet parameters influence on magnetic circuit saturation have presented in previous studies [8, 9].

The optimized parameters of permanent magnets used for excitation of studied motor are the following:

- coercive force H_c, kA/m 740;
- residual induction B_r, T 1.2;
- thickness h_{pm}, mm 2;
- distance between permanent magnets b, mm 5.

TABLE I

PARAMETERS OF THE STUDIED MOTOR

Description	Value	Unit
Motor outer diameter, D_o	64	mm
Stator outer diameter, D_{so}	45	mm
Active length of the rotor, l	80	mm
Number of stator teeth, Z_s	12	
Value of air gap, δ	1	mm
Number of pole pairs, p	2	
Number of phases, m	3	
Number of conductors per slot, N_r	18	

III. METHOD OF EXPERIMENTAL DETERMINATION OF TORQUE-ANGLE CHARACTERISTICS OF OUTER-ROTOR SYNCHRONOUS MOTOR AT STALLED ROTOR

For experimental determination of torque-angle characteristics of outer-rotor synchronous motor at stalled rotor is proposed to use the stand that is shown in Fig. 2, where 1 is the studied electric motor with outer rotor, and 2 is disk with divisions in degrees fixed to the frontal surface of the outer rotor.

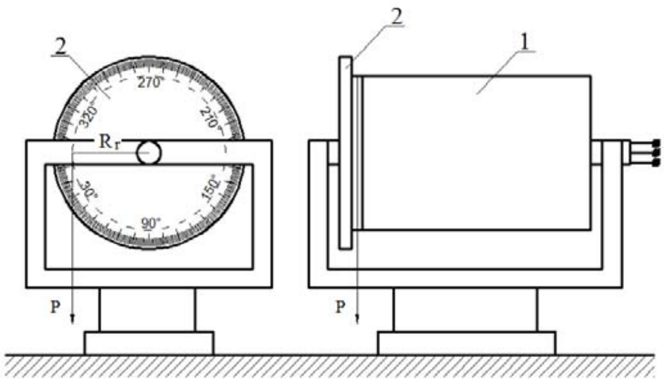

Fig. 2. Stand for experimental determination of torque-angle characteristics of outer-rotor synchronous motor.

According to the presented method of experimental determination of motor characteristics at stalled rotor a direct current is applied to the stator phase windings. Magnetomotive force created by direct current $I_=$ in the stator windings should be equal with magnetomotive force created by phase current I_1 that flows in the stator windings when the rotor rotates.

Fig. 3 presents widely used schemes of stator windings connection to the direct current supply for synchronous electronically commutated brushless motors. The value of direct current applied to the stator winding should be equal with $I_=$=1.415I_1 (scheme Fig. 3, (a)) and $I_=$=1.22I_1 (scheme Fig. 3, (b)). The value of direct current is set by resistor changing the resistance R.

Direct current $I_=$ flowing through the stator windings creates a magnetic flux that interacts with permanent magnets holds the rotor in the certain position. For the creation of static moment on the motor rotor the weight P (see Fig. 2) is suspended to the rotor. Under the impact of the torque M=PR_r (where R_r is outer radius of the rotor) the rotor rotates at a certain angle. The value of rotor rotating angle depends on the weight suspended to the rotor.

Using the proposed experimental method at stalled rotor it is possible to obtain only frontal parts of torque-angle characteristics, when the rotor has stable positions.

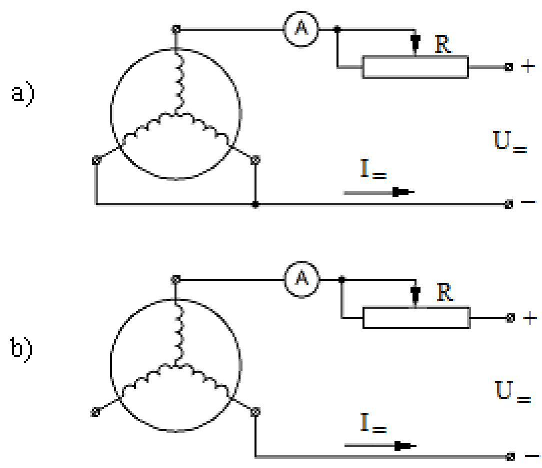

Fig. 3. Schemes of stator windings connection to the direct current supply.

IV. STUDY OF TORQUE-ANGLE CHARACTERISTICS OBTAINED EXPERIMENTALLY AND BY MAGNETIC FIELD SIMULATION

It is possible to obtain the complete torque-angle characteristic of the studied motor by means of simulation of static magnetic field of motor model using computer software QuickField. Computer software QuickField based on the FEM allows the calculating of magnetic parameters with high accuracy considering material saturation [10].

The electromagnetic torque, using computer software QuickFiled, can be calculated by means of Maxwell's stress tensor or as the derivative of the magnetic energy with the rotor position [11].

In this paper, solving the problem of two-dimensional magnetic field, the electromagnetic torque is calculated by integrating Maxwell's stress tensor along a line in the middle of the air gap of the motor, and then multiplying the result by the active length of the rotor.

Example of magnetic field picture of the studied motor obtained using software QuickField is given in Fig. 4.

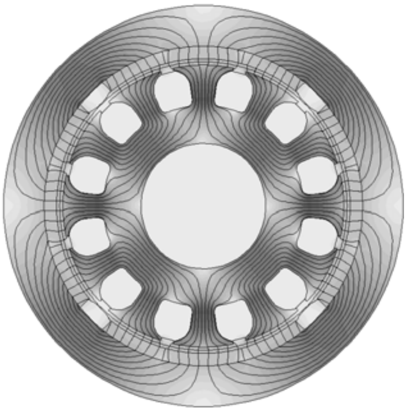

Fig. 4. Magnetic field picture of the studied outer-rotor permanent-magnet synchronous motor.

Fig. 5 shows torque-angle characteristics obtained experimentally and by integrating Maxwell's stress tensor under no-load operating conditions of the motor. Comparison results demonstrate an acceptable correlation.

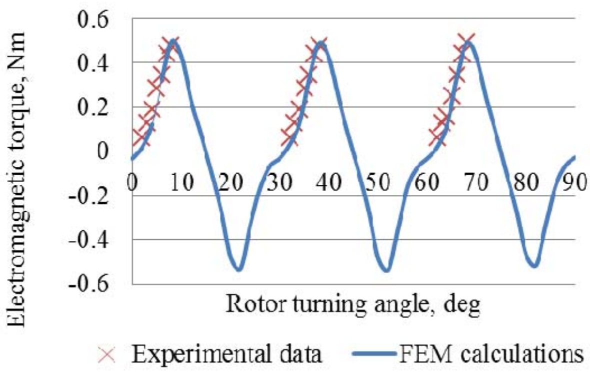

Fig. 5. Torque-angle characteristics of the studied motor under no-load operating condition.

Torque-angle characteristics of the studied motor obtained experimentally and by the results of magnetic field simulation at I_1= 3.5 A are shown in Fig. 6 (scheme (a) in Fig. 3) and Fig. 7 (scheme (b) in Fig. 3).

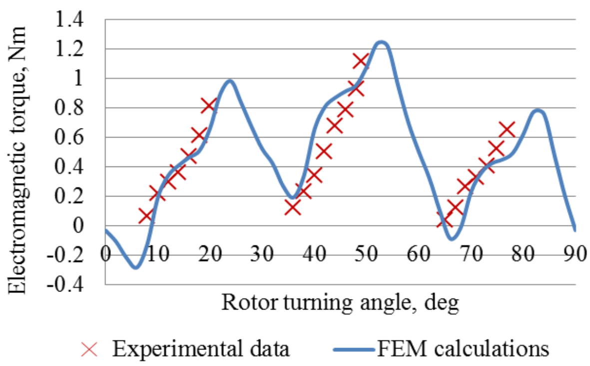

Fig. 6. Torque-angle characteristics of the studied motor under load operating condition at I_1= 3.5 A (scheme Fig. 3 (a)).

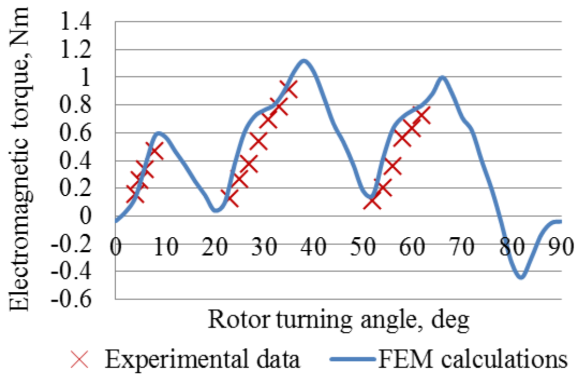

Fig. 7. Torque-angle characteristics of the studied motor under load operating condition at I_1= 3.5 A (scheme Fig. 3 (b)).

Correlation of experimentally obtained and calculated results by FEM under load operating condition is also acceptable. However, obtained torque-angle characteristics of the studied motor have significant ripples, which amplitude period coincides with stator tooth pitch.

Figure 8 and figure 9 present torque-angle characteristics at different values of current obtained by FEM for stator phase windings connection scheme (a) and scheme (b) respectively (see Fig. 3).

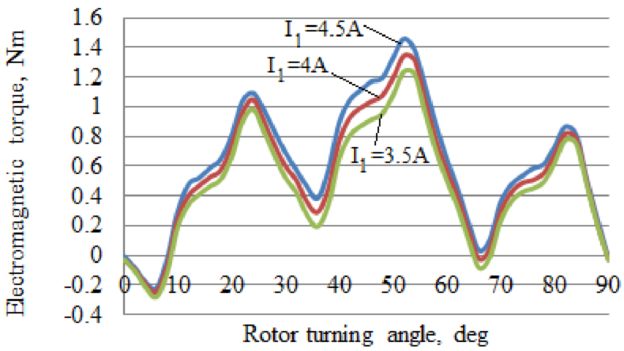

Fig. 8. Torque-angle characteristics at different values of current obtained by FEM (scheme Fig. 3 (a)).

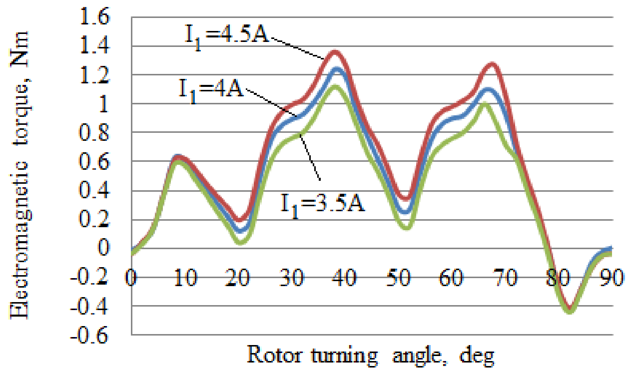

Fig. 9. Torque-angle characteristics for different values of current obtained by FEM (scheme in Fig. 3 (b)).

Obtained torque-angle characteristics show that the period of torque ripples amplitude for different level of motor saturation is maintained the same. This means that higher order stator slot harmonics have significant effect on the electromagnetic torque of the studied motor.

Torque ripples cause the noise and vibrations during the motor operation. Therefore, it is necessary to reduce the values of the higher order harmonics for torque ripples minimization. In practice the easiest way of torque ripples minimization is stator slots or permanent magnets beveling.

V. Conclusions

Based on the results obtained in the paper, the following conclusions can be drawn:

1. The proposed method of the experimental study of the outer-rotor synchronous motor with permanent magnets at stalled rotor allows to obtain torque-angle characteristics easily and conveniently.
2. The comparison of the experimentally obtained results and the results obtained by magnetic field simulation shows acceptable correlation.
3. The analysis of the obtained torque-angle characteristics shows that higher order stator slot harmonics have significant effect on electromagnetic torque of the studied motor.

Acknowledgement

EIROPAS SOCIĀLAIS FONDS EIROPAS SAVIENĪBA

IEGULDĪJUMS TAVĀ NĀKOTNĒ

This work has been supported by the European Social Fund within the project "Support for the implementation of doctoral studies at Riga Technical University" No. 2009/0144/1DP/1.1.2.1.2/09/IPIA/VIAA/005

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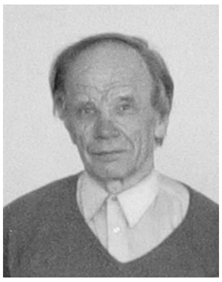

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Ludmila Lavrinoviča, Jānis Dirba, Uldis Brakanskis, Nikolajs Lavrinovičs. Sinhronā ventiļdzinēja ar ārējo rotoru eksperimentālā izpēte pie nobremzētā rotora

Šajā rakstā veikts sinhronā ventiļdzinēja ar ārējo rotoru leņķa raksturlīkņu pētījums, kā arī aplūkotas raksturlīkņu eksperimentālās noteikšanas metodes. Kā pētījuma objekts šajā rakstā tiek izvēlēts sinhronais ventiļdzinējs ar ārējo rotoru un ierosmi no augstenerģētiskajiem pastāvīgajiem magnētiem (NdFeB), kas paredzēts pielietošanai rokas elektriskās ēveles tiešai piedziņai. Apskatīta pētāmā dzinēja leņķa raksturlīkņu eksperimentālās noteikšanas metode pie nobremzētā rotora. Saskaņā ar šo metodi, statora tinumus pieslēdz līdzstrāvas avotam. Magnētodzinējspēkam, kuru rada līdzstrāva pie nobremzētā rotora, jābūt vienādam ar magnētodzinējspēku, kuru rada fāzes strāva statora tinumos pie rotējošā rotora. Lai radītu elektromagnētisko momentu uz pētāmā dzinēja rotora pie tā ir piekārts svars. Piekārtā svara spēka iedarbības rezultātā rotors pagriežas par noteiktu leņķi un noturas šajā stāvoklī pastāvīgo magnētu un statora tinumos plūstošās strāvas mijiedarbības rezultātā. Leņķa lielums ir atkarīgs no svara lieluma pie nemainīgas strāvas vērtības statora tinumos. Metode ļauj noteikt tikai leņķa raksturlīknes frontālās daļas, t.i., tad kad rotoram ir stabilais stāvoklis. Tāpēc pētāmā dzinēja pilnas elektromagnētiskā momenta leņķa raksturlīknes iegūšanai pie dažādiem rotora stāvokļiem pielietota magnētiskā lauka modelēšanās metode, izmantojot datorprogrammu kompleksu QuickField. Datorprogrammu komplekss QuickField, kura pamatā ir galīgo elementu metode, ļauj noteikt magnētiskos parametrus, ievērojot materiāla piesātinājumu, kas ir svarīgs precīzos aprēķinos. Eksperimentāli iegūto rezultātu pie nobremzētā rotora un rezultātu iegūto ar magnētisko lauku modelēšanas palīdzību salīdzināšana parādīja pieļaujamu konverģenci.

Людмила Лавринович, Янис Дирба, Улдис Бракanскис, Николай Лавринович. Экспериментальное исследование синхронного вентильного двигателя с внешним ротором при заторможенном роторе

В данной статье представлено исследование угловых характеристик синхронного вентильного двигателя с внешним ротором, а также приведены возможные методы экспериментального их определения. На примере синхронного вентильного двигателя с внешним ротором и с возбуждением от высокоэнергетичных постоянных магнитов (NdFeB), предназначенного для прямого привода ручного электрического рубанка, рассматривается метод экспериментального определения угловых характеристик при заторможенном роторе. Согласно методу, по обмоткам статора пропускается постоянный ток. Магнитодвижущая сила, создаваемая постоянным током при заторможенном роторе, должна быть равной магнитодвижущей силе, которую создаёт фазный ток в обмотках статора при вращающемся роторе. Для создания электромагнитного момента на роторе исследуемого двигателя к ротору подвешивается груз. Под воздействием силы подвешенного груза ротор проворачивается на определённый угол и удерживается в этом положении силами взаимодействия постоянных магнитов и протекающего тока в обмотках статора. Величина угла поворота ротора зависит от веса груза при неизменном токе в обмотке. Данный метод позволяет определить только фронтовые части угловых характеристик, т.е. при устойчивых положениях ротора. Поэтому для получения полной картины угловых характеристик исследуемого двигателя в данной статье применяется метод определения электромагнитного момента при разных положениях ротора путём моделирования магнитного поля, используя программный комплекс QuickField. Программный комплекс QuickField, основанный на методе конечных элементов, позволяет определить магнитные параметры с учётом насыщения материала, что является важным для точных расчётов. Сравнение результатов полученных экспериментально при заторможенном роторе и при моделировании магнитного поля показали приемлемую сходимость.