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INFLUENCE SELECTED GEOMETRICAL PARAMETERS ON ELECTROMAGNETIC AND COGGING TORQUE AND DEFORMATION OF STATOR CORE DUE TO MAXWELL FORCES IN BLDC MOTOR

ABSTRACT *This article deals with electromagnetic and cogging torque and also for stator deformation due to Maxwell forces in BLDC motor. Torque ripple is undesirable because introduces vibrations and noise. One of the main source of vibrations and noise is stator deformation due to Maxwell forces. Results were performed to establish effect change geometric parameters of BLDC machine on the electromagnetic and cogging torque and also on static deformation due to Maxwell forces using finite element program.*

Keywords: *brushless motors, BLDC motors, Maxwell forces, cogging torque*

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1. INTRODUCTION

Brushless Direct Current motors are one of the motor types rapidly gaining popularity. In generally brushless motors are used in drives in controlled values of varies rotor speed. One of the cause of the popularity of the BLDC motors is high efficiency. BLDC motors have many advantages over brushed DC motors and induction motors. A few of these are: better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges.

In addition, the ratio of torque delivered to the size of the motors is higher. The problem of the minimizing the cogging torque is especially important in electrical machines with permanent magnets (BLDC and PMSM). Usually, these drivers are characterized by relatively high torque ripple. Torque ripple reduction is essential requirement in a wide range of high-performance motion control applications. Torque ripple affects unfavorably in the work of this machines. Problem is widely developed in literature [1-6].

Torque ripple is produced by circumferential component of attractive forces between the magnet and the stator teeth. In a permanent magnet motor the torque ripple appears especially at low speeds, and is undesirable because it introduces vibrations and noise.

One of the important factors of usage of the electrical machines is level of generating vibrations and noise. One of the main sources of vibrations and noise in rotating electrical machinery due to stator deformation caused by Maxwell forces. In the phase on the prototyping the vibration behavior of the machine is calculated using magneto-mechanic models [7-8]. In structural analysis the radial Maxwell forces calculated in electromagnetic analysis are loads in structural analysis. Calculations 2D were made using finite element program which can be used in magneto-mechanical analysis.

Autors investigated effect of choosing the value of geometric parameters on the electromagnetic and ripple torque and for a size of deformation of the stator core due to Maxwell forces.

2. INFLUENCE SELECTED GEOMETRICAL PARAMETERS ON VALUE OF THE ELECTROMAGNETIC AND COGGING TORQUE

Figure 1 shows the geometry of the cross section of the device (only one six of machine is presented) and analyzed parameters of BLDC motor.

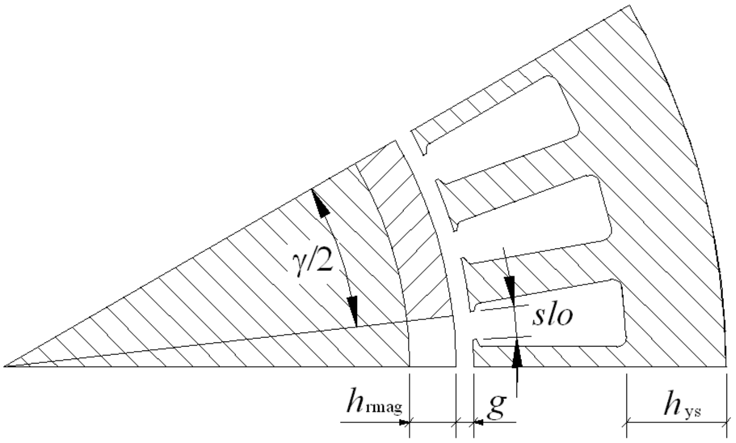

Fig. 1. Analysed geometrical parameters of BLDC motor 36/6

In the article calculations were made for different values of these geometrical parameters of the machine.

- Pole-arc width (γ [°]).
- The stator slot opening (slo [°]).
- The width of the air gap (g [mm]).
- The height of the permanent magnet (h_{rmag} [mm]).
- The height of the yoke (h_{ys} [mm]).

Rotor rotates for 10° mechanical degree, for every 0.5° position of the rotor cogging torque T_{cogg} is calculated. For estimation the electromagnetic torque T_e rotor rotates 60° degree for every 1° degree. The windings are supplied by a rectangular current waveform, thus only two phases can be simultaneously supplied. The current density is constant in the coils.

One of the main parameters which influences on value of the cogging torque T_{eav} is angle of the opening of the permanent magnet γ. Figure 2a shows relation between average electromagnetic torque T_{eav} and the angle of opening of permanent magnet γ. Decrease of the angle of the opening of permanent magnet reduces electromagnetic torque.

Figure 2b presents effect change the angle of the opening of the permanent magnet γ on maximum cogging torque $T_{\mathrm{cogg\ max}}$. It can be seen the angle of the opening of permanent magnet γ influences on the maximum cogging torque. For selected different values of the angle of the opening of the permanent magnet it can be seen there are some minima of torque ripple.

For considered values of the angle of the opening of the permanent magnet it can be noticed clearly three values for which cogging torque has a minimum value.

Maximum value of the electromagnetic torque is received for the same values of angle of the opening of the permanent magnet.
Figure 2c shows the torque ripple factor calculated by:

$$\tau = \frac{T_{cogg\,\max}}{T_{e\,\max}} \tag{1}$$

where:

$T_{\mathrm{cogg\,max}}$ – maximum value of cogging torque,
T_{emax} – maximum value of electromagnetic torque.

It is shown on Fig. 2c effect of changing the angle of opening of permanent magnet on the torque ripple calculated using (1), it is noticed there are some minimum visible on figure. The minima coincides with graph presented on Fig. 2b.

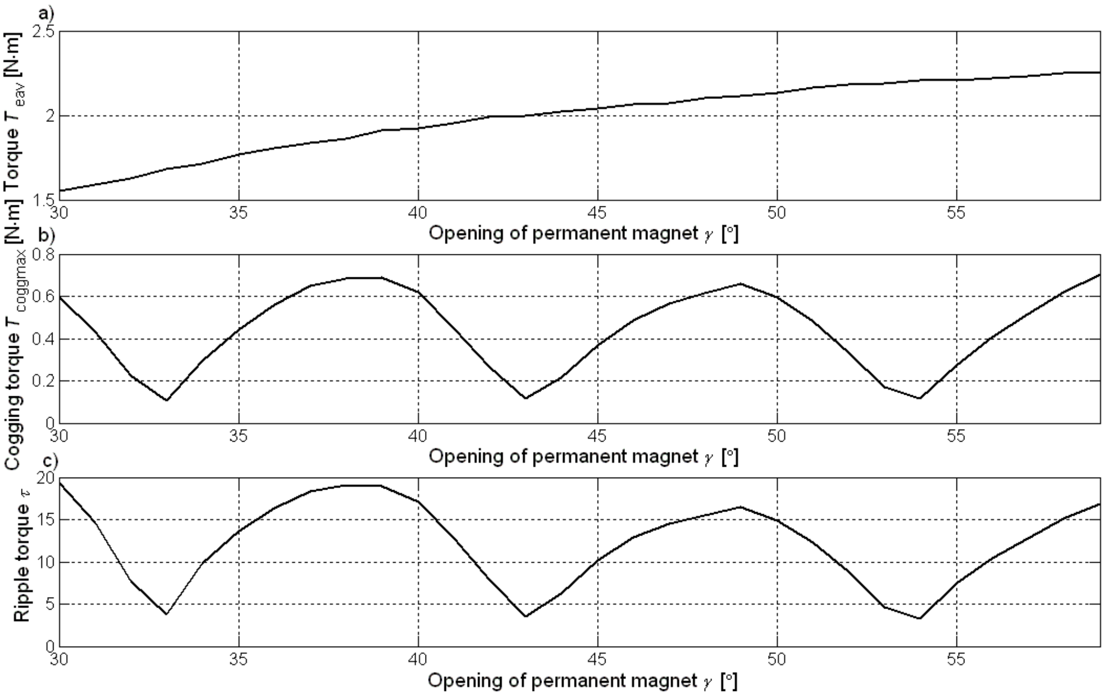

Fig. 2. Electromagnetic average value of torque T_{eav} a), maximum value of cogging torque $T_{cogg\,max}$ (b) and torque ripple (c) versus the angle openning magnet γ

The angle of stator slot opening influences also on the value of the cogging torque. Minimization of the angle of stator slot opening reduces value of cogging torque. In the ideal case the value of stator slot opening from minimization the cogging torque of view is zero, which is not possible in practice. Minimum value of the angle of stator slot opening depends on diameter of winding.

Figure 3 represents electromagnetic and cogging torque with respect to the angle of stator slot opening slo which is responsible for closing space of slot. Calculations were made assuming the angle of opening the magnets equals $\gamma = 51.5°$. Minimum value the angle of closing space of slot assumed to be equal the value of angle the stator teeth (2.4° in BLDC motor).

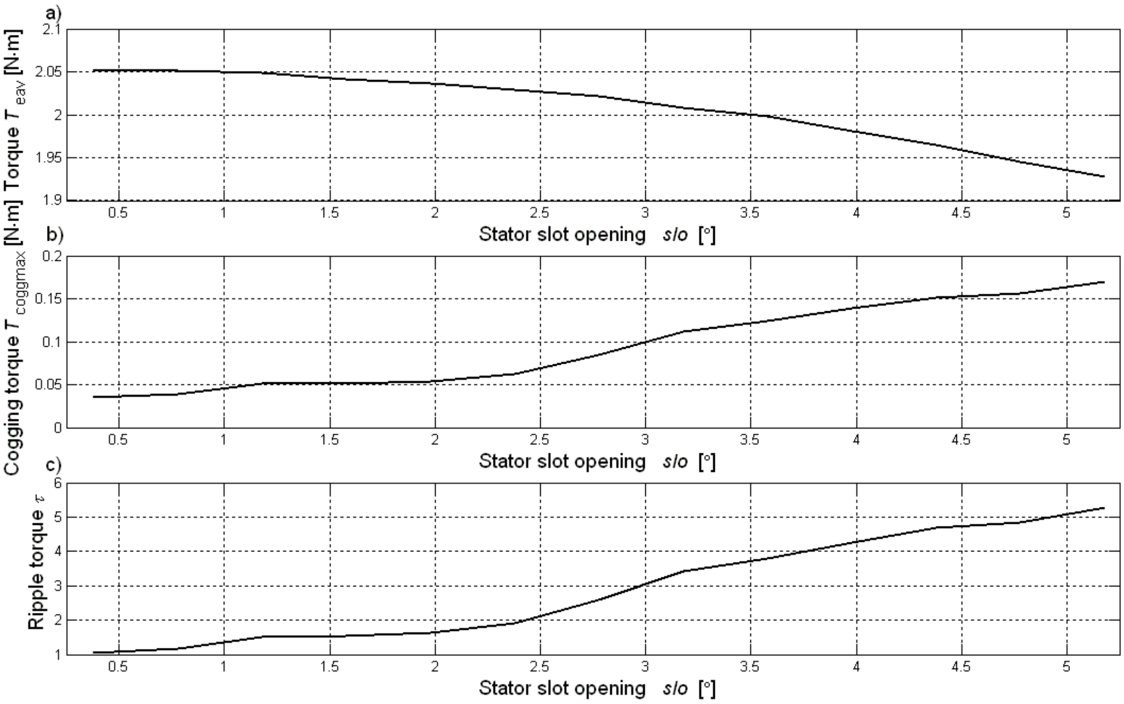

Fig. 3. Average value electromagnetic torque T_{eav} (a), maximum value of cogging torque $T_{cogg\,max}$ (b) and torque ripple τ (c) versus angle of the angle of openning space of slot *slo*

In generally, closing slots reduces cogging torque and causes small increase of electromagnetic torque.

Figure 4 shows relationships between width of the air-gap g on electromagnetic, cogging torque and torque ripple. The width of the air-gap is changing in the (0.5-4) mm every 0.5 mm. Outer of delimiter of rotor is set to be a constant, radial parameters of the stator was changed except inner diameter.

Reduction width of the air-gap causes growing up the electromagnetic torque, however very small values width of the air-gap bring in consequence grow up the of torque ripple due increase of amplitude of the cogging torque (Fig. 4b). The thickness of magnets affects the electromagnetic torque. The increase of the average electromagnetic torque is not however the linear function of thickness of magnets h_{rmag}. It can be seen on the Fig. 5a that the growth of thickness of magnets can does not give the desirable effect. The minimum of torque ripple exist for the value thickness of magnets near 2 mm in analyzed motor (Fig. 5c).

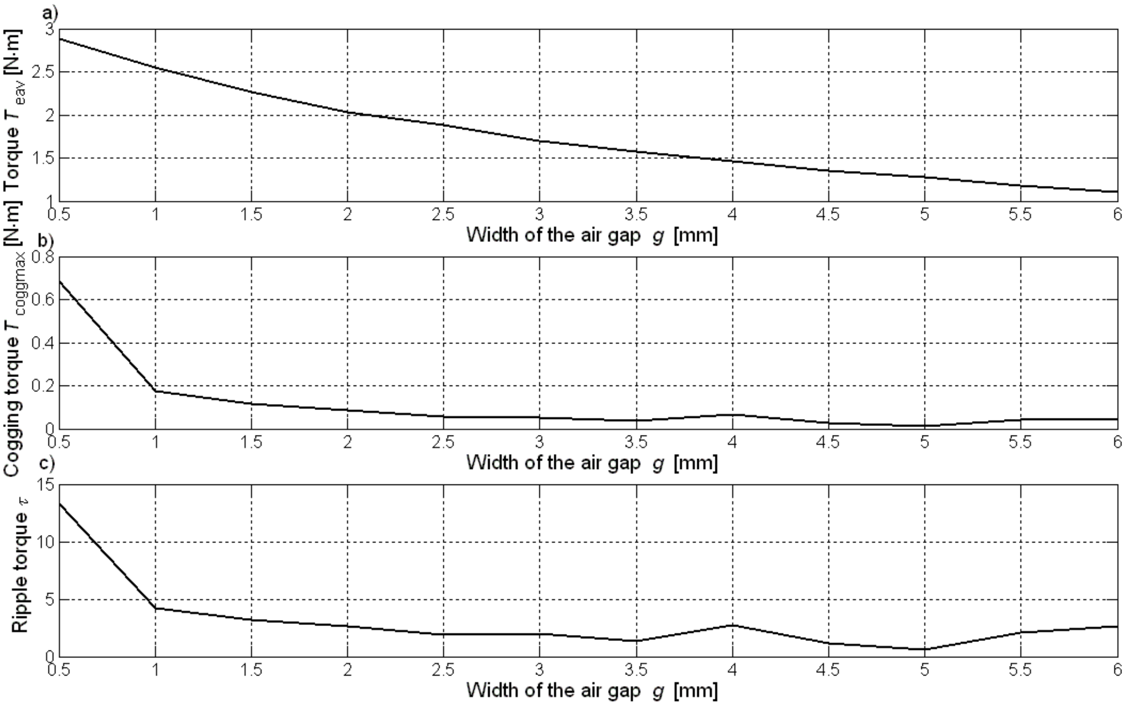

Fig. 4. Average value electromagnetic torque T_{eav} (a), maximum value of cogging torque $T_{cogg\ max}$ (b) and torque ripple τ (c) versus the width of the air-gap g

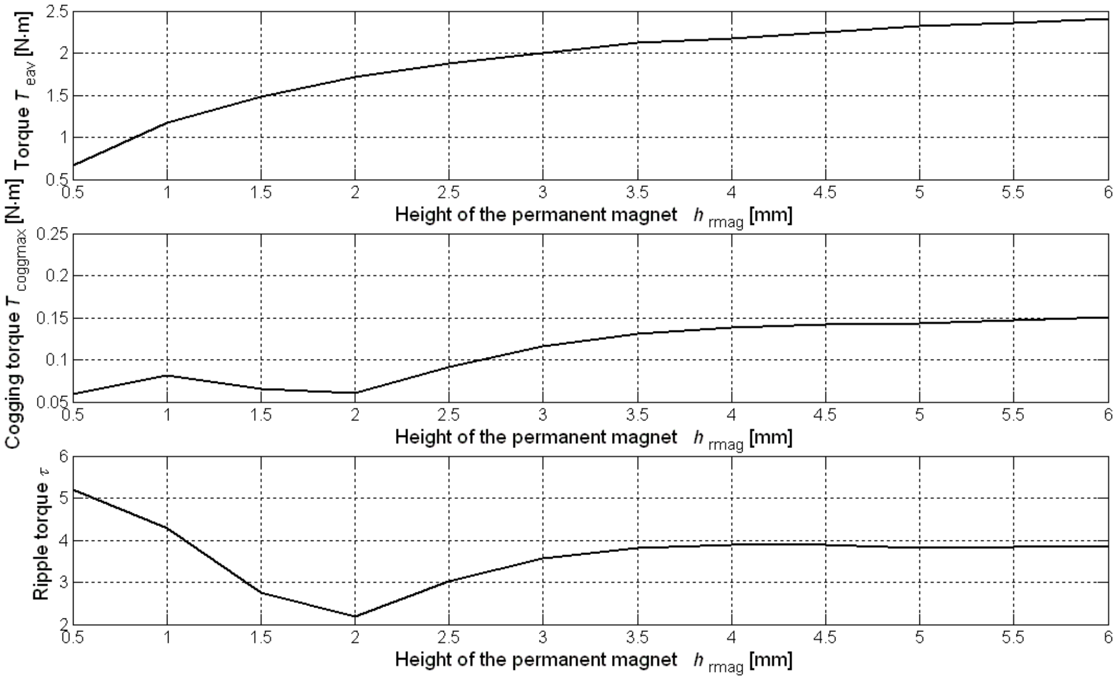

Fig. 5. Average electromagnetic torque T_{eav} (a), maximum value of cogging torque $T_{cogg\ max}$ (b) and torque ripple τ (c) versus height of the permanent magnet h_{rmag}

Enlargement the thickness of yoke does not affect on value of the electromagnetic or cogging torque. The reducing of the thickness of yoke bring in consequence decrease electromagnetic torque as result of strong saturation the magnetic circuit.

3. STATIC ANALYSIS OF DEFORMATION OF STATOR CORE OF BLDC MOTOR

For estimation deformation the stator due to Maxwell rotor rotates for 60° mechanical degree for every 1° degree calculations was made. For selected geometrical parameters such as detailed in part 2 structural analysis was done. Results of calculation of displacement of selected node is shown on Fig. 6. Details of magnetic and mechanic model of BLDC stator and equations governed the magneto-mechanical problem was presented in earlier articles [7].

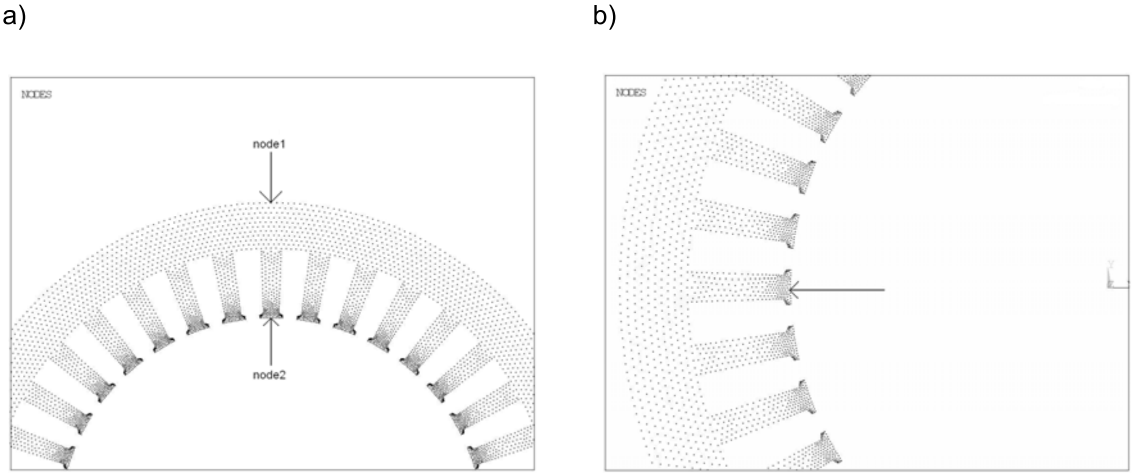

Fig. 6. Position of selected point 1/node1 (a) and point 2 (b)

On figure 7 is shown relation between the value of radial displacement of selected node and the angle of opening magnets γ. Displacement of chosen points is shown for selected angles of the opening magnets presented on figure 2a and 2b. The growth of the angle of opening of magnets increase deformation due to Maxwell forces.

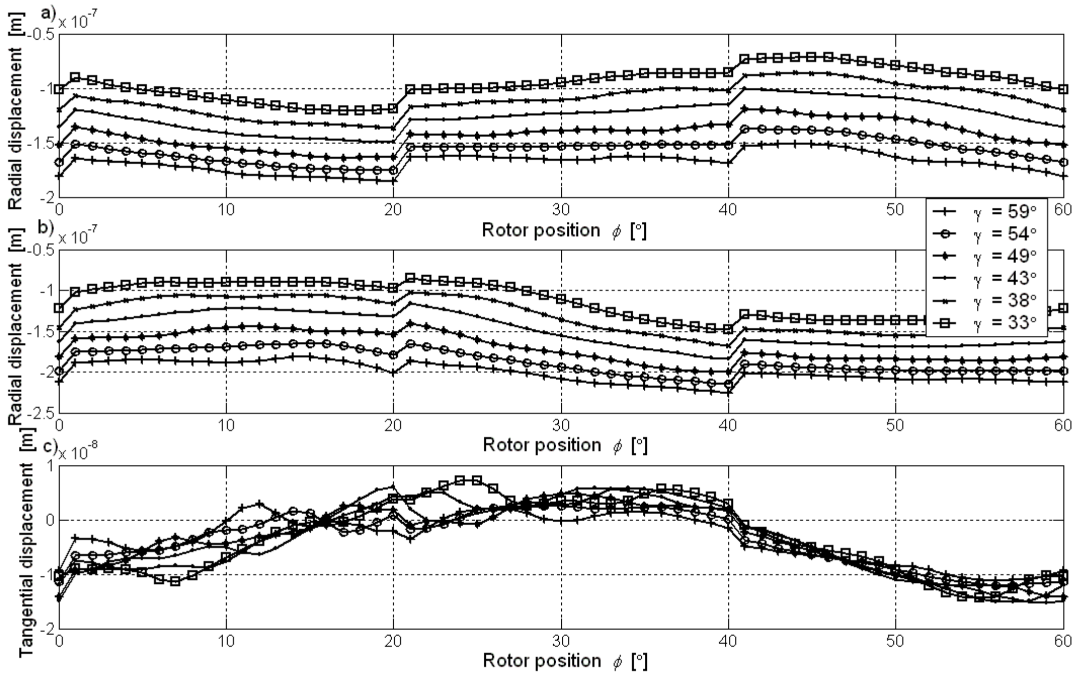

Fig. 7. Radial displacement point1 (a), point 2 (b) and tangential displacement point 2 (c) of stator core versus angle of rotor magnets γ with respect to rotor positions ϕ

The reduction the stator slot opening angle *slo* increase the radial displacement, but it also considerable for enlargement the tangential displacement (the Fig. 8).

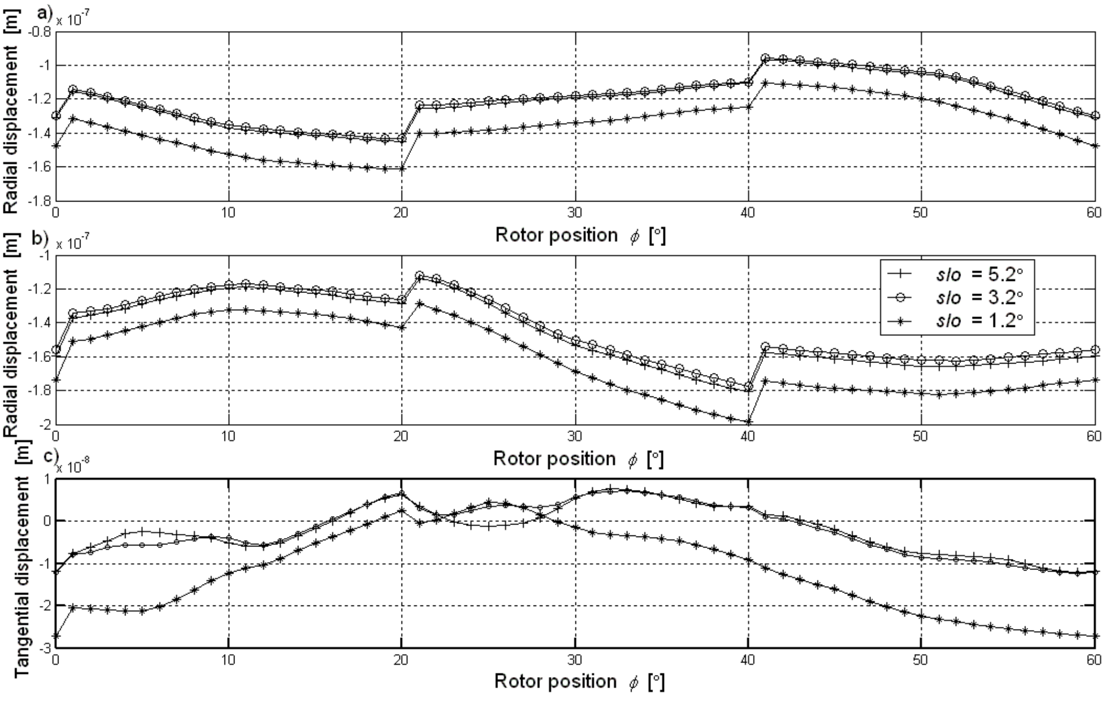

Fig. 8. Radial displacement point1 (a), point 2 (b) and tangential point 2 (c) of stator core for different the stator slot opening angle *slo* with respect to rotor positions ϕ

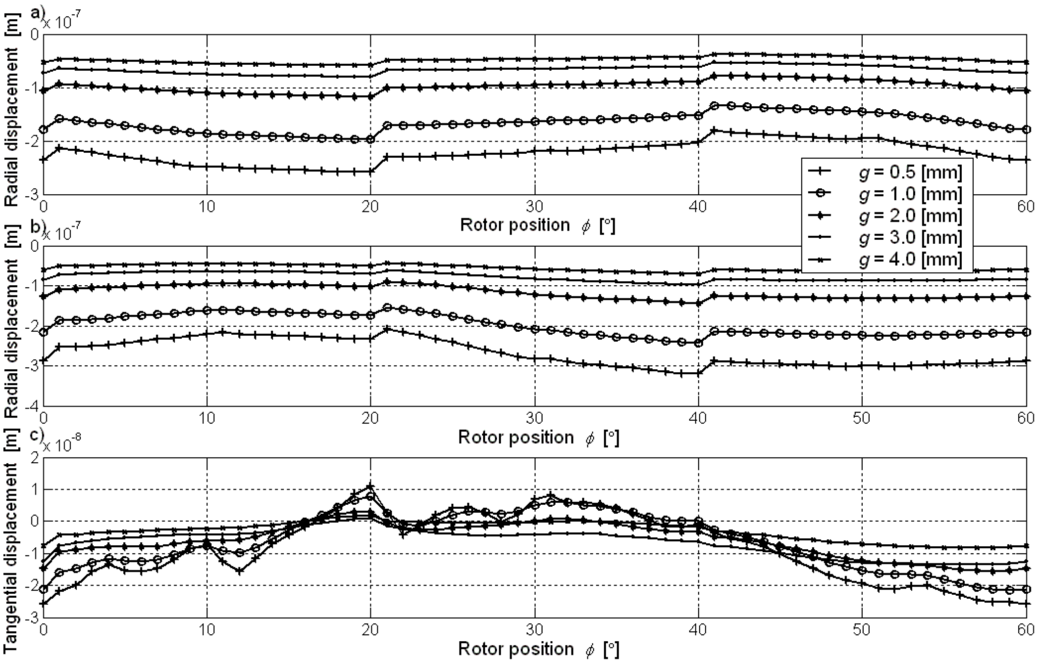

Fig. 9. Radial static displacement point1 (a), point 2 (b) and tangential displacement point 2 (c) of stator for different values of the width of air-gap *g* with respect to rotor positions ϕ

Reduction of the width of air-gap decrease of radial displacement of stator teeth's. A little bit value of the width of the air-gap also results a reduction the tangential displacement of stator teeth's (Fig. 9c).

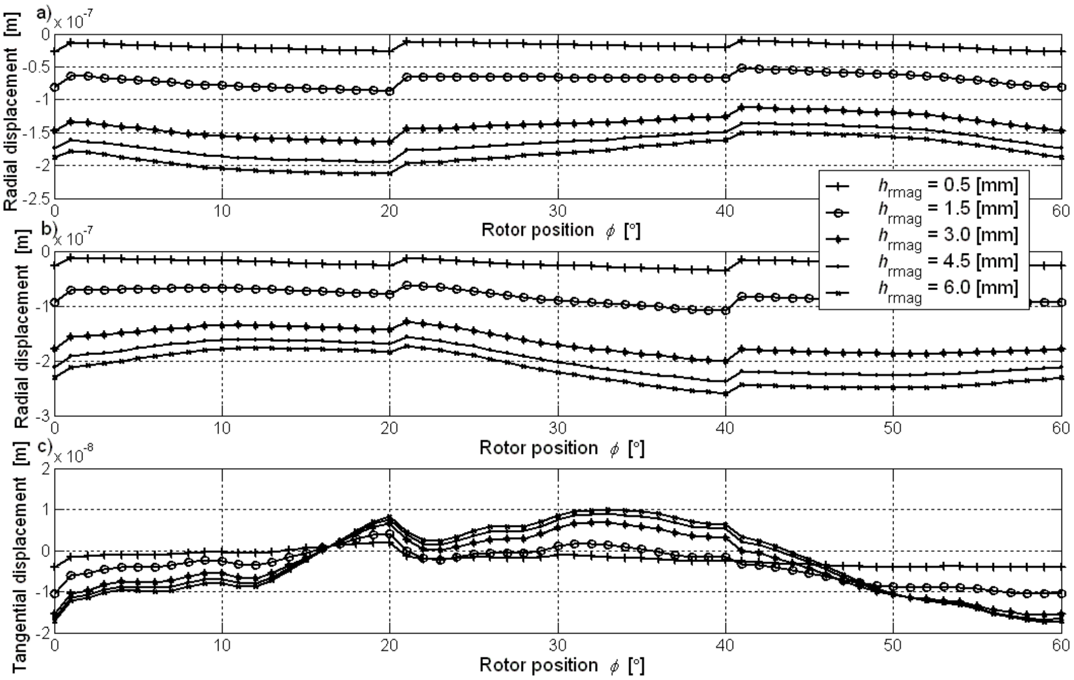

Fig. 10. Static radial displacement of selected point 1 (a), point 2 (b) oraz tangential displacement (c) for different values of permanent magnet height h_{rmag} with respect to rotor positions ϕ

Reduction of the height of permanent magnet (h_{rmag} [mm]) results increase the electromagnetic torque and tangential displacement of the stator teeth's. Similarly in the case of the small values the width of air-gap the increase of the height of the permanent magnet (h_{rmag} [mm]) increase radial displacement and changes nature of tangential deformation of stator core (Fig. 10).

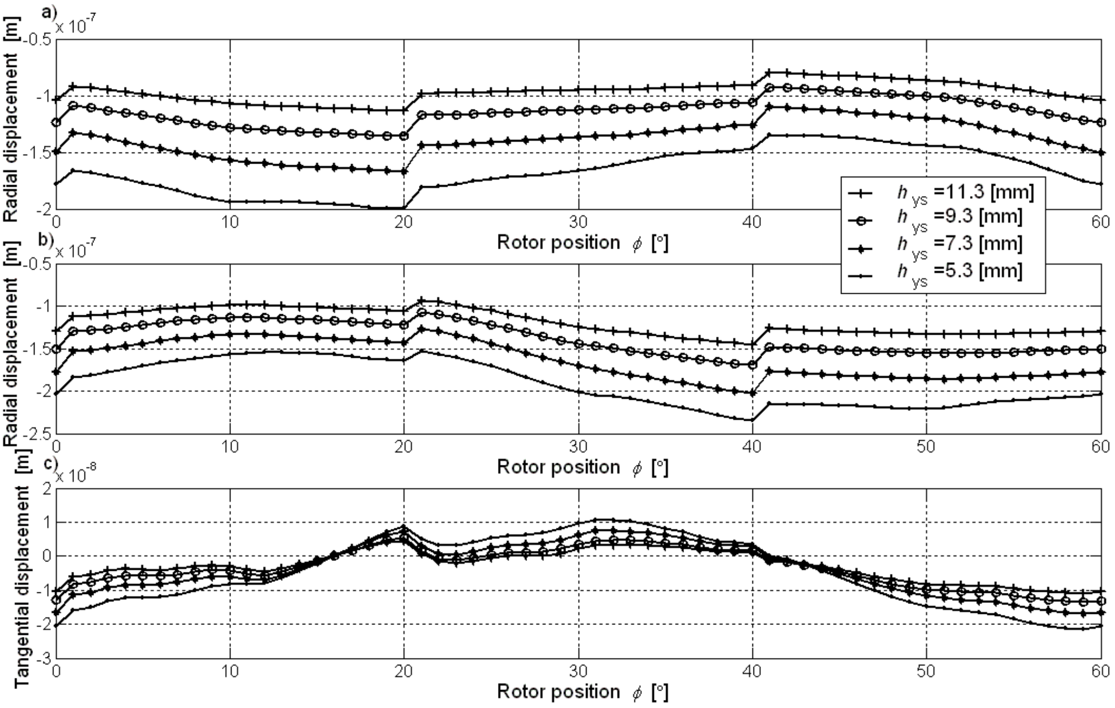

Fig. 11. Radial displacement of selected points point 1 (a), point 2 (b) tangential point 2 (c) of stator core for different values of the height of the yoke h_{ys} with respect to rotor positions ϕ

The height of the yoke h_{ys} has a big influence for values of the deformation. Relatively big values of this parameter causes increase of the stiffness of the stator and in consequence decrease of radial deformation (Fig. 11a,b) and tangential one (Fig. 11c).

4. CONCLUSION

Calculations were performed to establish the effect of change selected geometric parameters of machine on the electromagnetic and cogging torque and also for deformation the stator core. The calculations show that the angle of the opening magnet influences on the value of the electromagnetic and cogging torque. Other geometrical parameters as width of the air-gap and height of the magnets have essential influence on values electromagnetic torque but it involves also higher deformation of the stator core due to Maxwell forces. In such considerations in aim minimizing the deformation from Maxwell forces it is worth to consider increase the height of the stator yoke to minimize the deformation.

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WPŁYW WYMIARÓW GEOMETRYCZNYCH SILNIKA NA WARTOŚĆ MOMENTU ZACZEPOWEGO ORAZ DEFORMACJE STOJANA SILNIKA BLDC

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STRESZCZENIE *W artykule poruszono problem wpływu wybranych wymiarów geometrycznych maszyny na wytwarzaną wartość momentu elektromagnetycznego oraz ograniczania zjawiska pasożytniczego w tej maszynie jakim jest moment zaczepowy. Moment zaczepowy jest jednym ze źródeł drgań maszyny pochodzenia magnetycznego. Dla wybranych przypadków przeprowadzono statyczną analizę przemieszczeń wybranych punktów stojana maszyny z zastosowaniem metody numerycznej.*

Zainteresowanie maszynami elektrycznymi z komutacją elektroniczna utrzymuje się na wysokim poziomie już od kilku lat. Ogólnie maszyny bezszczotkowe z komutacją elektroniczną są przeznaczone do napędów o regulowanej prędkości obrotowej. Jedną z przyczyn takiego stanu rzeczy jest wysoka sprawność maszyn bezszczotkowych. Dotyczy to szczególnie maszyn w których są wykorzystane wysokoenergetyczne magnesy trwałe (BLDC i PMSM). W maszynach w których jako wzbudzenie wykorzystuje się magnesy trwałe powstaje problem momentu zaczepowego.

Problem ten jest szeroko opisany w literaturze [1-6]. Moment zaczepowy wpływa bardzo niekorzystnie na pracę maszyny. Jest jednym ze źródeł pulsacji momentu elektromagnetycznego oraz dodatkowym źródłem drgań oraz hałasu pochodzenia magnetycznego.

W chwili obecnej szczególna uwagę zwraca się na poziom generowanego hałasu poprzez maszyny elektryczne już w trakcie ich projektowania. Wymaga to odmiennego niż dotychczas podejścia do zagadnienia procesu projektowania. Dotychczasowy proces projektowania maszyny musi zostać uzupełniony o zaawansowaną analizę strukturalną maszyny. Jako dane wejściowe do analizy strukturalnej wykorzystuje się wyniki z analizy elektromagnetycznej [7-8]. Obliczenia wykonuje się z wykorzystaniem metod numerycznych (FEM).

Odpowiedni dobór wymiarów geometrycznych ma dość istotny wpływ na wartość wytwarzanego momentu elektromagnetycznego oraz wartość momentu zaczepowego. W artykule dokonano analizy wpływu zmiany wybrany wybranych wymiarów geometrycznych na wartość średnią wytwarzanego momentu elektromagnetycznego, kształt momentu zaczepowego silnika BLDC. Dodatkowo przeprowadzono analizę deformacji stojana wywołanej siłami (Maxwella) naciągu magnetycznego poprzez obserwację przemieszczania się wybranych punktów stojana.