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INFLUENCE OF ROTOR POSITION ON OVERSATURATED AREAS SIZE OF INDUCTION MACHINE MAGNETIC CIRCUIT

Abstract: This article contains a solution of magnetic field distribution with oversaturated areas localization and description. The rotor position is important for the maximal magnetic circuit saturated identification and oversaturated areas size influence of magnetic circuit due to the variable magnetic reluctance of path. Influence of rotor position on saturated magnetic circuit is analyzed with step on twenty angular positions per rotor slot pitch. This analysis is done for 3-phase 1.1 kW induction machine by finite element method. This the time behavior of magnetic flux density is analyzed in air gap for different load conditions of machine. The paper contains also general postprocessor results juxtaposition.

1. Introduction

Generally, the magnetic circuit of electrical machines is never whole oversaturated. Due to this effect, the magnetic field distribution is different than in case of non-oversaturated magnetic circuit. That is the air gap size is variable due to the oversaturated areas of magnetic circuit. For induction machine is usually considered an equivalent air gap size with constant size regardless of magnetic circuit saturation. The finite element method is used for localization of oversaturated areas in case of different equivalent circuit parameters due to the loads. Actually, only one value of each current is known, but for electromagnetic field calculation is necessary to known value of current for each slot. The current is obtained by returned calculation, Eq.1-3 from [1], Table II.

$$\hat{I}_S = \frac{\hat{U}_S \cdot (R'_R + jsX_R)}{\left[R'_R R_S + j(R'_R X_S + sR_S X_R) + s\left(\left(1 - \frac{X_m^2}{X_R X_S}\right) \cdot (-X_R X_S)\right)\right]} \quad (1)$$

$$\hat{I}_R = \frac{\hat{U}_S \cdot (-jsX_m) \cdot k}{\left[R'_R R_S + j(R'_R X_S + sR_S X_R) + s\left(\left(1 - \frac{X_m^2}{X_R X_S}\right) \cdot (-X_R X_S)\right)\right]} \quad (2)$$

$$k = \frac{m_S \cdot N_S \cdot \chi_S}{m_R \cdot N_R \cdot \chi_R} \quad (3)$$

where: m – no. of phases, N – no. of coil turns, χ – slot space factor.

2. Initial conditions

Briefly, it is necessary to set few conditions to the correct function of solver, as like as the definition of used magnetic circuit material, including the material definition of coil, air-gap, slot wedge, slot lining and shaft (Table 1). The next step is applying the vector parallel flux potential onto the border line of model, forms an integral part of electromagnetic field calculation.

Table 1. Material definition

Material	Properties
Sheets	Steel M54 BH Curve
Copper	μ_r=0.99999
Slot wedge and lining	μ_r=1.10000
Air-gap	μ_r=1.00000
Shaft	μ_r=150

Table 2. Stator and rotor phase currents

No.	U_S [V]	I_S [A]	φ_S [°]	I_R [A]	φ_R [°]
1	230	2.257	-54.78	78.49	180.54
2	230	2.643	-43.45	117.86	179.74
3	230	3.111	-35.82	156.21	178.99
4	230	3.842	-29.83	207.47	178.08
5	230	4.410	-22.59	254.81	176.93
6	230	5.460	-18.08	326.26	175.54

Algorithm for a distribution of the rotor and stator currents into the slots (Fig. 1) was used and it works with these parameters: stator current and phase – I_{SM}, F_{SM}; rotor current and phase – I_{RM}, F_{RM}; No. of stator coil turns – N_{TS}; No. of rotor coil turns – N_{TR}; No. of stator slots – SD; No. of rotor slots – RD; stator cross section area – S_{SD}; rotor cross section area – S_{RD}; stator current density – J_{SS}; rotor current density – J_{SR}.
The rotor current calculation:

$$I_{R01} = I_{RM} \cos\left(abs\left(\left(\frac{2\pi \cdot x}{RD} \right) - \left(\frac{F_{RM}\pi}{180} \right) \right) \right) \quad (4)$$

where: $x = 0 \div RD$
The stator current calculation:

$$I_{S01} = I_{SM}\cos\left(abs\left(\left(\frac{2\pi\cdot x}{SD}\right)-\left(\frac{F_{SM}\pi}{180}\right)\right)\right) \qquad (5)$$

where: $x = 0,7,13$

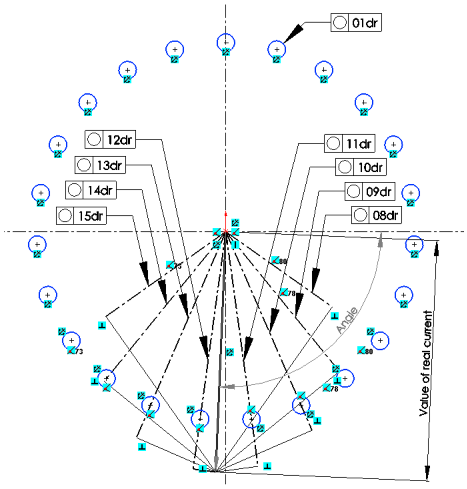

Fig. 1. Sample of the current distribution into the rotor bars

3. Oversaturated areas (due to the IM loading)

On the Fig. 3 up to Fig. 8 is shown the magnetic field distribution for different stator and rotor phase currents for rotor angular position 0°. On the Fig. 2 is shown a behavior of magnetic flux density in the center of air gap for cases No. 1 up to No. 6. If the value of magnetic flux density is over the 2.0 T (this value depends on type of magnetic circuit material), then the magnetic circuit is oversaturated and the iron losses would be increasing. The magnetic flux density values for some important part of magnetic circuit are shown in Table 3 – B_{SY} (stator yoke), B_{RY} (rotor yoke), B_{SH} (stator head teeth), B_{RH} (rotor head teeth), B_{AG} (air gap) and B_M (maximal value of magnetic circuit flux density) with comparison sizes of oversaturated areas (A_{OS}).

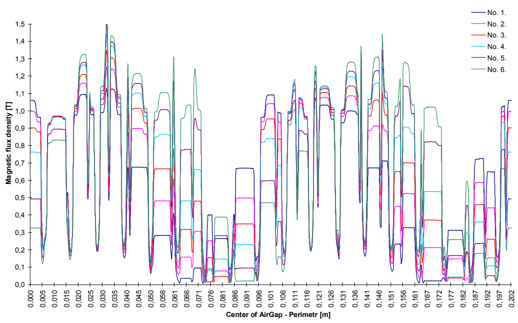

Fig. 2. Magnetic flux density in the center of AG

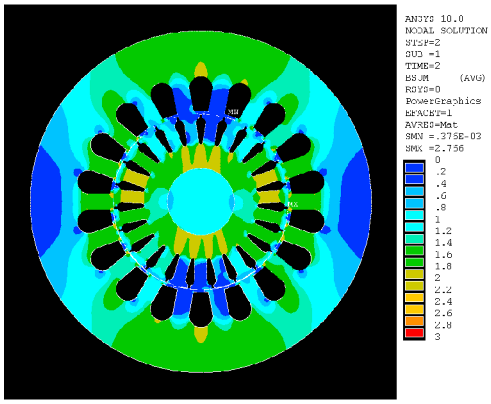

Fig. 3. Magnetic field distribution for case No.1

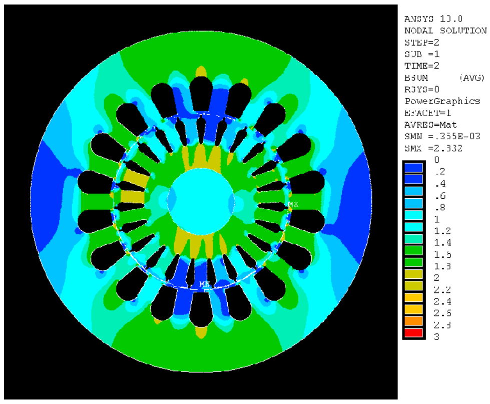

Fig. 4. Magnetic field distribution for case No.2

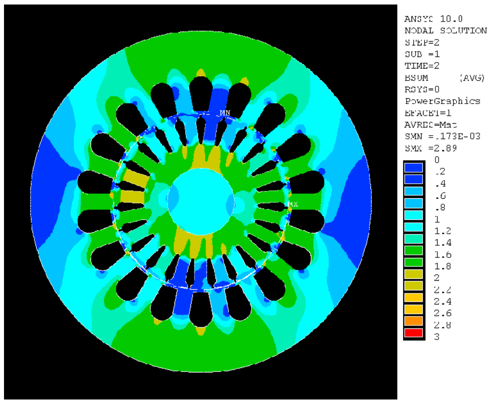

Fig. 5. Magnetic field distribution for case No.3

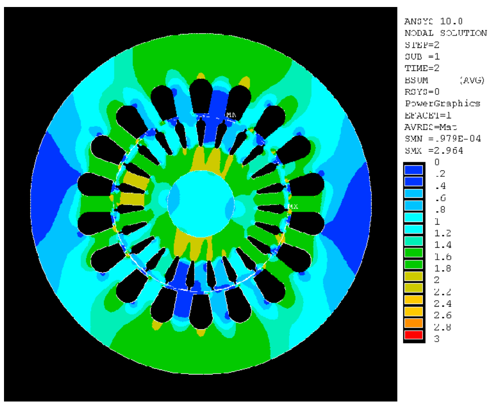

Fig. 6. Magnetic field distribution for case No.4

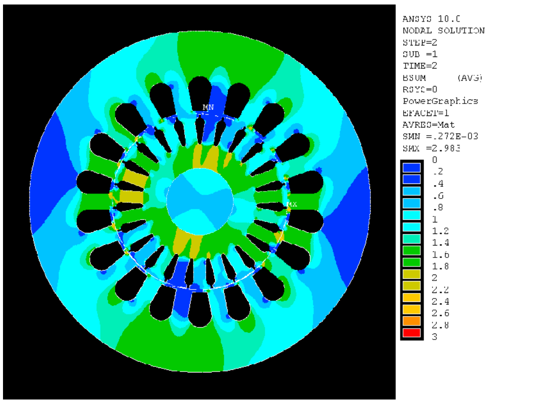

Fig. 7. Magnetic field distribution for case No.5

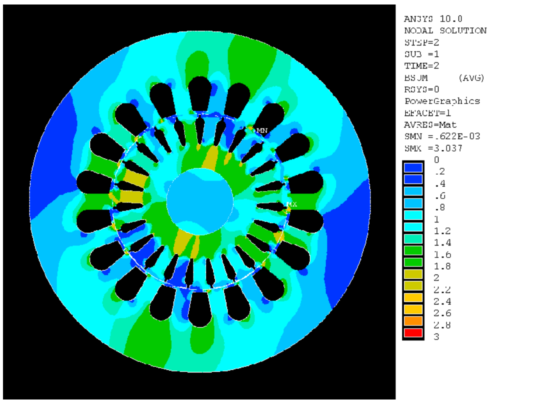

Fig. 8. Magnetic field distribution for case No.6

Table 3. Comparison table

No.	B_{SY} [T]	B_{RY} [T]	B_{SH} [T]	B_{RH} [T]	B_{AG} [T]	B_M [T]	A_{OS} [%]
1	1.04	1.58	0.80	0.62	0.55	2.51	**3.69**
2	1.09	1.61	0.84	0.65	0.57	2.64	**3.25**
3	1.12	1.63	0.87	0.68	0.60	2.70	**2.91**
4	1.17	1.66	0.91	0.72	0.62	2.79	**2.76**
5	1.20	1.67	0.93	0.75	0.64	2.84	**2.43**
6	1.25	1.71	0.96	0.78	0.66	2.89	**2.20**

3. Oversaturated areas (due to the rotor position)

Note: $\hat{I}_S = 3.111A\angle -35.82°; \hat{I}_R = 156.21A\angle 178.99°$

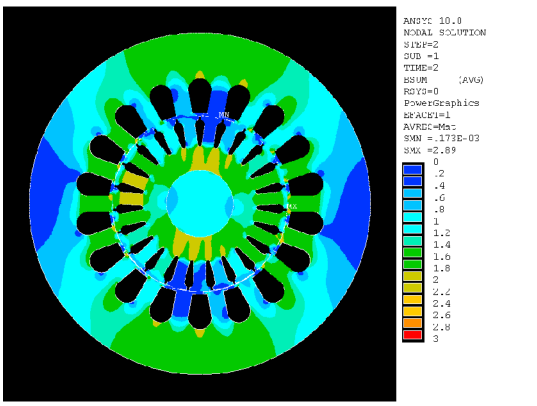

Fig. 9. Behavior of flux density for 0°

The maximal value of flux density: 2.89 T
Flux density value in the center air gap: 0.60 T
Oversaturated areas size: 2.911%

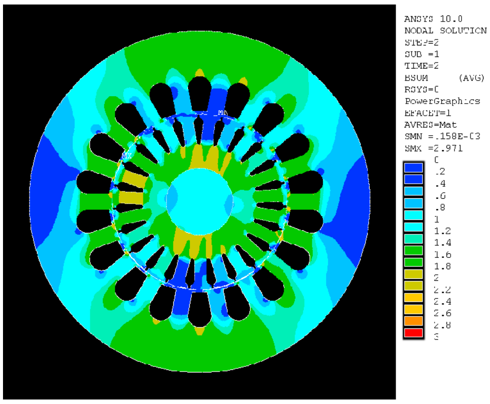

Fig. 10. Behavior of flux density for 0.7826°

The maximal value of flux density: 2.971 T
Flux density value in the center air gap: 0.58 T
Oversaturated areas size: 2.876%

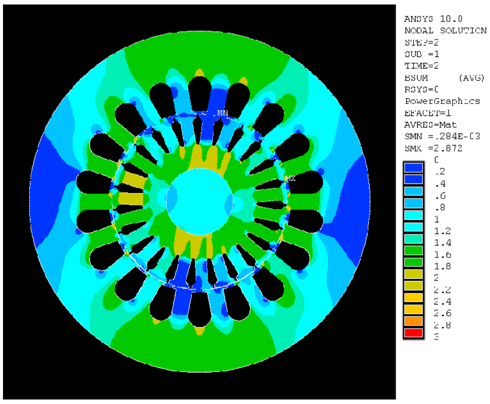

Fig. 11. Behavior of flux density for 1.5652°

The maximal value of flux density: 2.872 T
Flux density value in the center air gap: 0.59 T
Oversaturated areas size: 2.902%

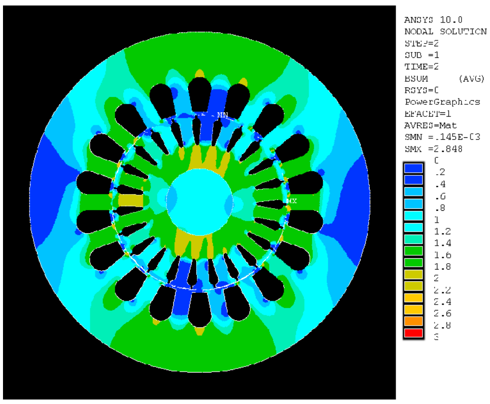

Fig. 12. Behavior of flux density for 2.3478°

The maximal value of flux density: 2.848 T
Flux density value in the center air gap: 0.59 T
Oversaturated areas size: 2.895%

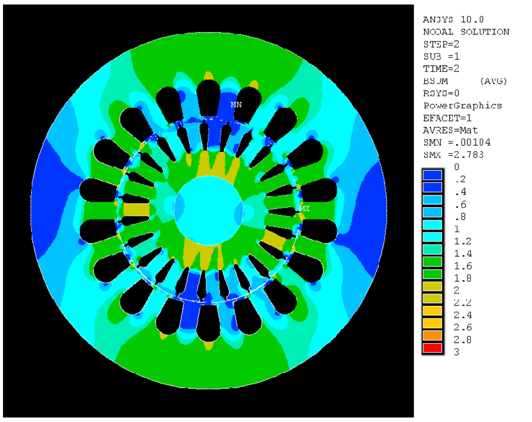

Fig. 13. Behavior of flux density for 3.1304°

The maximal value of flux density: 2.783
Flux density value in the center air gap: 0.58 T
Oversaturated areas size: 2.700%

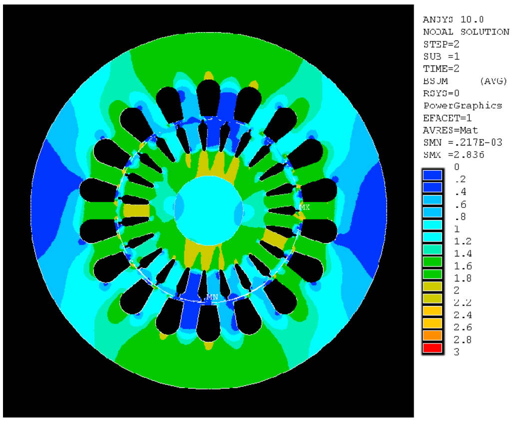

Fig. 14. Behavior of flux density for 3.9130°

The maximal value of flux density: 2.836 T
Flux density value in the center air gap: 0.59 T
Oversaturated areas size: 2.905%

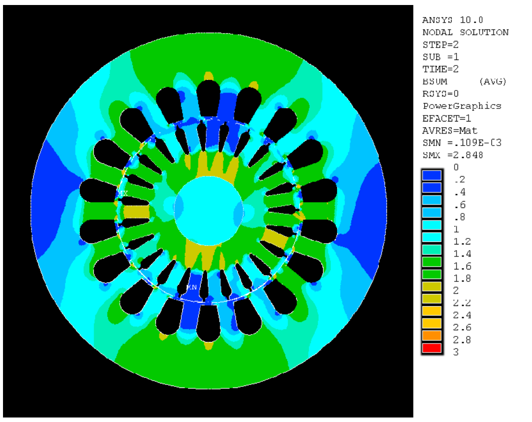

Fig. 15. Behavior of flux density for 4.6956°

The maximal value of flux density: 2.848 T
Flux density value in the center air gap: 0.59 T
Oversaturated areas size: 2.901%

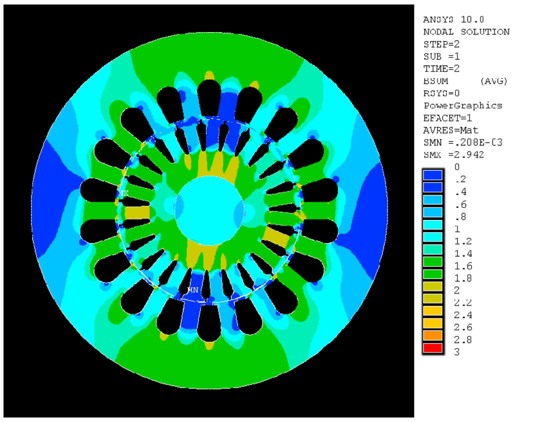

Fig. 16. Behavior of flux density for 5.4782°

The maximal value of flux density: 2.942 T
Flux density value in the center air gap: 0.60 T
Oversaturated areas size: 2.917%

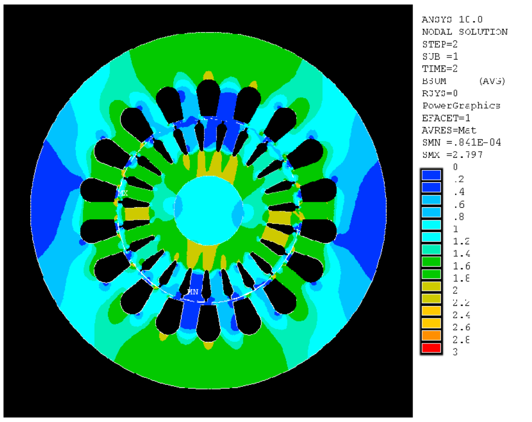

Fig. 17. Behavior of flux density for 6.2608°

The maximal value of flux density: 2.797 T
Flux density value in the center air gap: 0.61 T
Oversaturated areas size: 2.924%

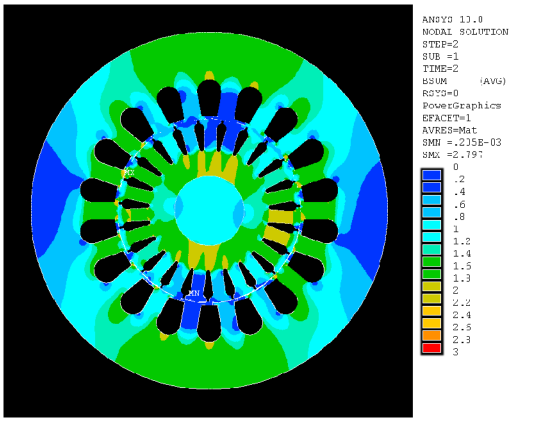

Fig. 18. Behavior of flux density for 7.0434°

The maximal value of flux density: 2.797 T
Flux density value in the center air gap: 0.63 T
Oversaturated areas size: 3.128%

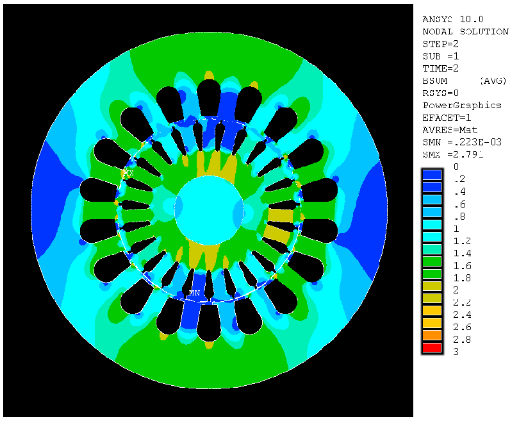

Fig. 19. Behavior of flux density for 7.8260°

The maximal value of flux density: 2.791 T
Flux density value in the center air gap: 0.60 T
Oversaturated areas size: 2,.913%

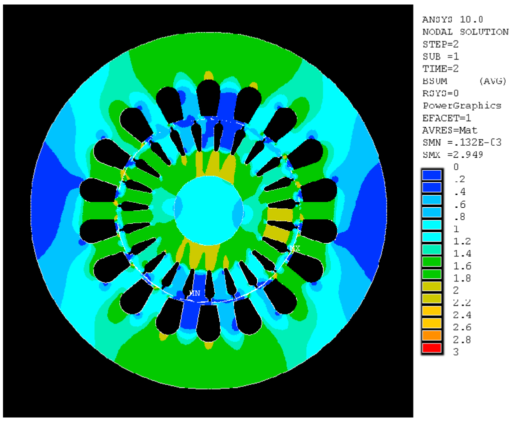

Fig. 20. Behavior of flux density for 8.6086°

The maximal value of flux density: 2.949 T
Flux density value in the center air gap: 0.59 T
Oversaturated areas size: 2.868%

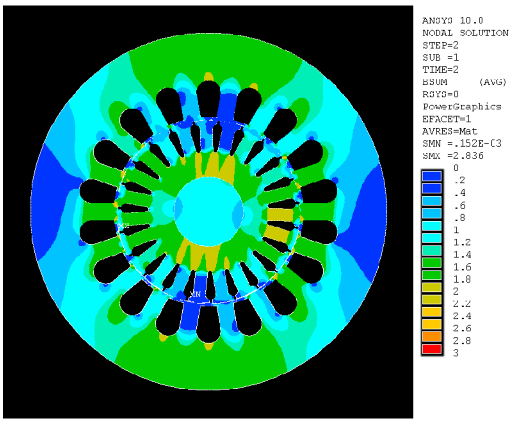

Fig. 21. Behavior of flux density for 9.3912°

The maximal value of flux density: 2.836 T
Flux density value in the center air gap: 0.59 T
Oversaturated areas size: 2.896%

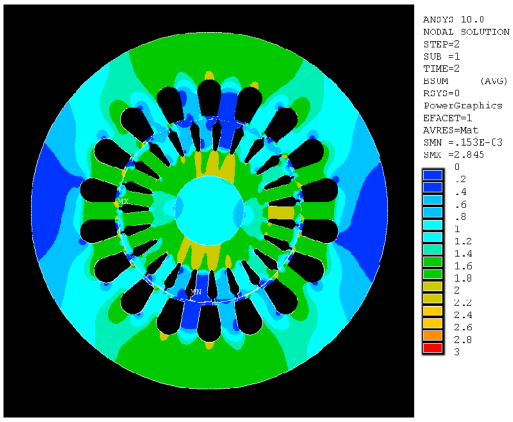

Fig. 22. Behavior of flux density for 10.1738°

The maximal value of flux density: 2.845 T
Flux density value in the center air gap: 0.59 T
Oversaturated areas size: 2.900%

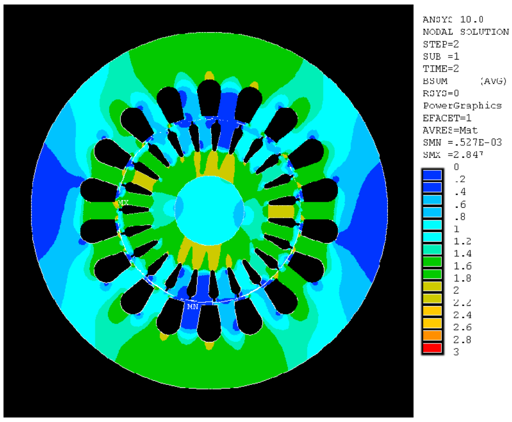

Fig. 23. Behavior of flux density for 10.9564°

The maximal value of flux density: 2.847 T
Flux density value in the center air gap: 0.57 T
Oversaturated areas size: 2.690%

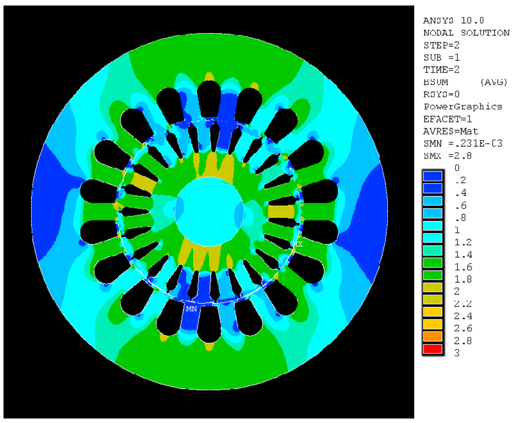

Fig. 24. Behavior of flux density for 11.7390°

The maximal value of flux density: 2.800 T
Flux density value in the center air gap: 0.60 T
Oversaturated areas size: 2.897%

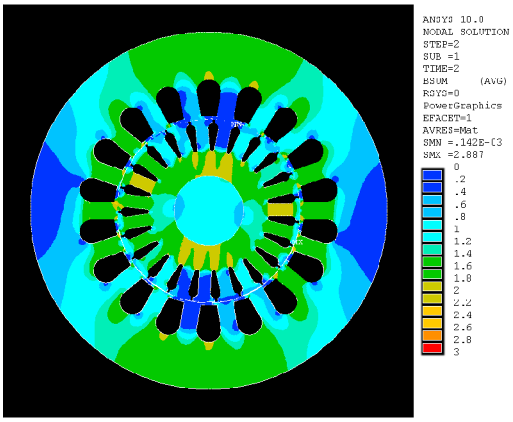

Fig. 25. Behavior of flux density for 12.5216°

The maximal value of flux density: 2.887 T
Flux density value in the center air gap: 0.60 T
Oversaturated areas size: 2.915%

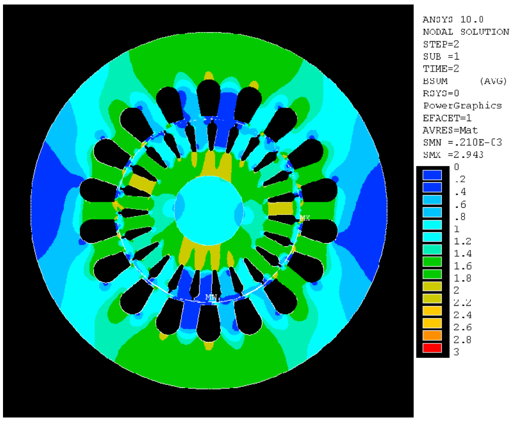

Fig. 26. Behavior of flux density for 13.3042°

The maximal value of flux density: 2.943 T
Flux density value in the center air gap: 0.61 T
Oversaturated areas size: 2.924%

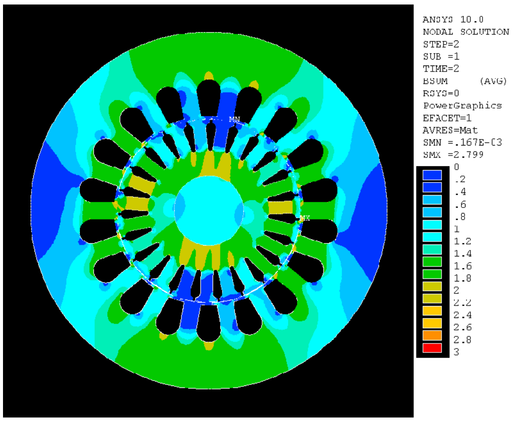

Fig. 27. Behavior of flux density for 14.0868°

The maximal value of flux density: 2.799 T
Flux density value in the center air gap: 0.61 T
Oversaturated areas size: 2.921%

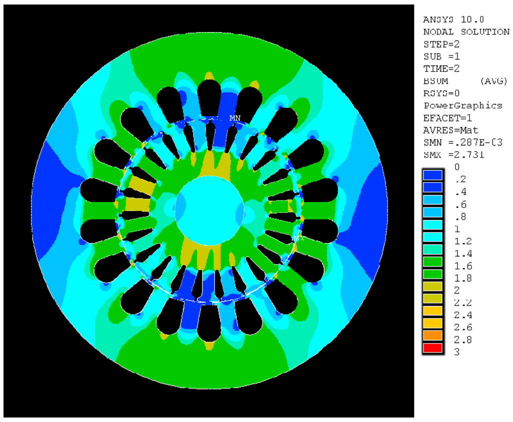

Fig. 28. Behavior of flux density for 14.8694°

The maximal value of flux density: 2.731 T
Flux density value in the center air gap: 0.62 T
Oversaturated areas size: 3.000%

4. Bibliography

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