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INDUCTION MACHINE PULSATING TORQUE ANALYSIS

Abstract: This article contains a pulsating torque calculation of 3-phase induction machine with power 1.1kW from electromagnetic field. Whole analysis is done by finite element method in ANSYS. The torque is calculated via a circular path integral of the Maxwell stress tensor. The Maxwell stress tensor provides a convenient way of computing forces acting on bodies by evaluating a surface integral.

1. Introduction

If it is needed to calculate mechanical torque on a body in a magnetic field it is suitable to use **TORQ2D** command. The body must be completely surrounded by air – symmetry permitted, and a closed path passing through the air elements surrounding the body must be available. A counterclockwise ordering of nodes on the **PATH** command will give the correct sign on the torque result. The calculated torque is stored in the parameter torque. A node plot showing the path is produced in interactive mode. The torque is calculated using a Maxwell stress tensor approach. Classical approach for pulsating torque analysis and calculation is mentioned in [1], [3] and [7]. Path operations are used for the calculation, and all path items are cleared upon completion.

TORQSUM invokes an ANSYS macro that summarizes the Maxwell and virtual work torque values. The element components must have had appropriate Maxwell or virtual work boundary conditions established in the preprocessor prior to solution in order to retrieve torques. These boundary conditions are used for subsequent force and torque calculations during solution. Magnetic virtual displacements are applied to nodes of elements in the components, and Maxwell surface flags are applied to air elements adjoining the element components. Incorrect force and torque calculations will occur for components sharing adjacent air elements. The torque values are stored on a per-element basis for the adjacent air layer elements surrounding the components and are retrieved and summed by the macro. Torque calculations are valid for 2-D planar analysis only. For 2-D harmonic analysis, force and torque represent time-average values.

The Maxwell stress tensor is used to determine forces on magnetic regions – element output quantity $\mathbf{F_{MX}}$.This force calculation is performed on surfaces of air material elements which have a nonzero face loading specified. For the 2-D application, this method uses extrapolated field values and results in the following numerically integrated surface integral:

$$\overline{F}_{MX} = \frac{1}{\mu_0}\int_S \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{Bmatrix} n_1 \\ n_2 \end{Bmatrix} ds \qquad (1)$$

where $T_{11} = B_x^2 - \frac{1}{2}\left|B^2\right|$

$T_{12} = B_x B_y$

$T_{21} = B_x B_y$

$T_{11} = B_y^2 - \frac{1}{2}\left|B^2\right|$

μ_0 – permeability of free space

n – number of integration points

2. Initial conditions

Also it is necessary to set a few conditions to the correct function of solver (Table 1-3).

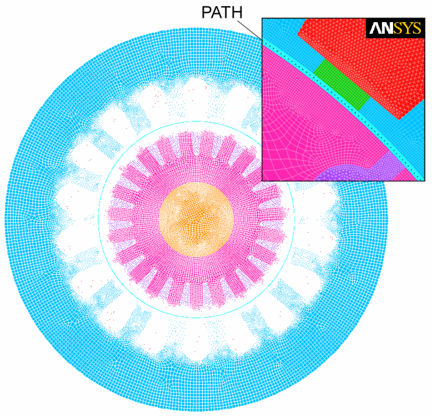

Fig. 1: MESH with counterclockwise PATH.

Table 1: Material definition

Material	Properties
Sheets	Steel M54
Copper	μ_r=0.99999
Air-gap	μ_r=1.00000
Shaft	μ_r=150

Table 2: Setting for nominal slip (s_N)

Set parameter	Value	Unit
Power	1238	W
Voltage	415.14	V
Slip	-5	%
Torque	-4,985	Nm
Stator current	$2.9837\angle -2.0912\,rad$	A
Rotor current	$246.162\angle 0.17786\,rad$	A

Table 3: Setting for nominal torque (T_N)

Set parameter	Value	Unit
Power	1030	W
Voltage	416.35	V
Slip	-3.61	%
Torque	-3,834	Nm
Stator current	$2.4730\angle -2.0447\,rad$	A
Rotor current	$179.704\angle 0.13899\,rad$	A

3. Analysis results

CASE: NOMINAL TORQUE

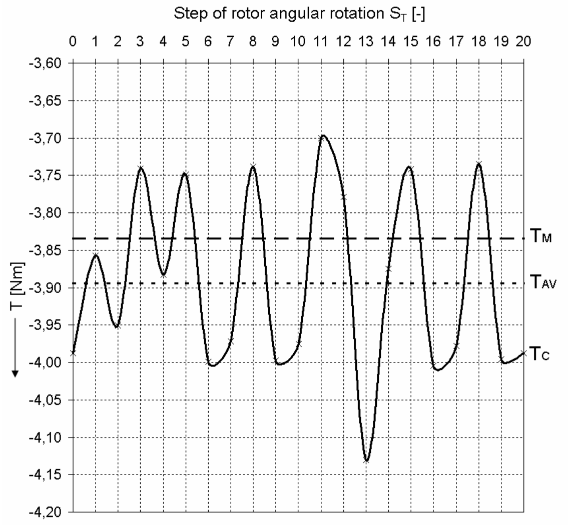

Fig. 2: Pulsating torque behavior per one rotor rotation (1step/18degree).

where: T_M – measured torque
T_C – torque calculated by Maxwell stress tensor
T_{AV} – average value of torque T_C

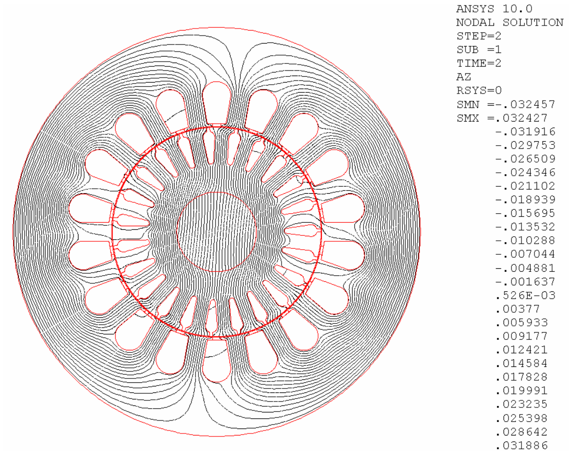

Fig. 3: Magnetic field distribution – Flux lines (maximal value of pulsating torque).

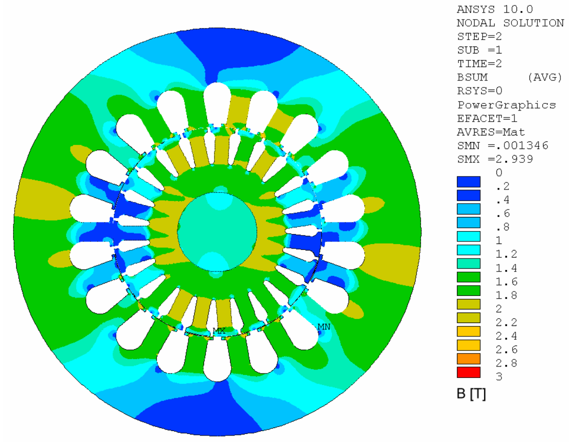

*Fig. 4: Magnetic field distribution – Flux density **B** (maximal value of pulsating torque).*

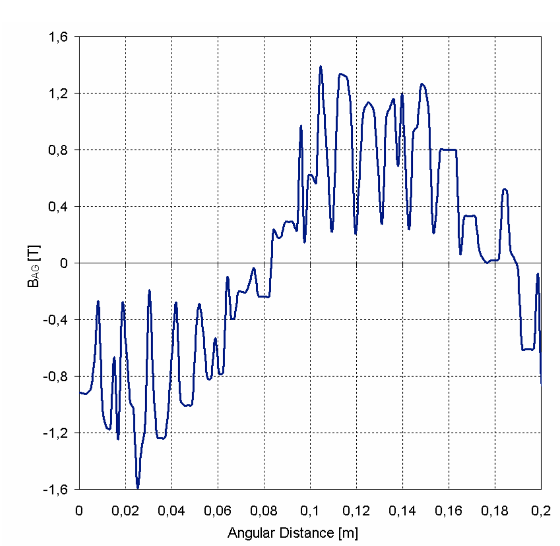

*Fig. 5: Magnetic field distribution – **B** in the center of the air-gap (maximal value of pulsating torque).*

CASE: NOMINAL SLIP

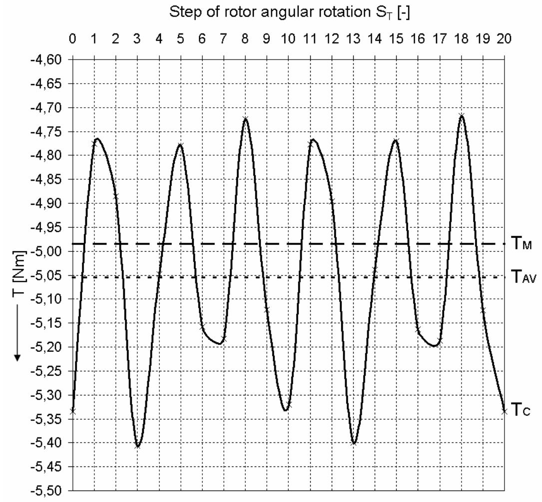

Fig. 6: Pulsating torque behavior per one rotor rotation (1step/18degree).

where: T_M – measured torque

T_C – torque calculated by Maxwell stress tensor

T_{AV} – average value of torque T_C

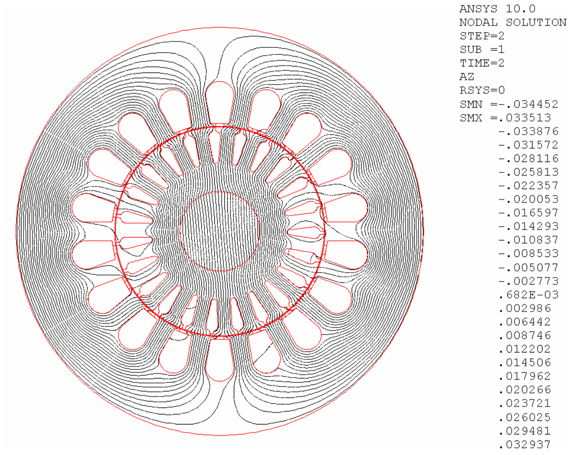

Fig. 7: Magnetic field distribution – Flux lines (maximal value of pulsating torque).

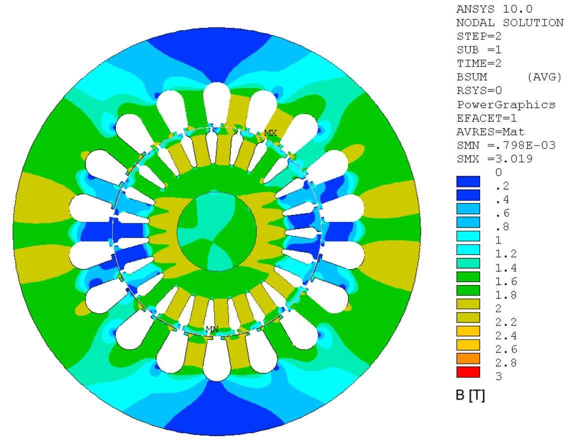

*Fig. 8: Magnetic field distribution – Flux density **B** (maximal value of pulsating torque).*

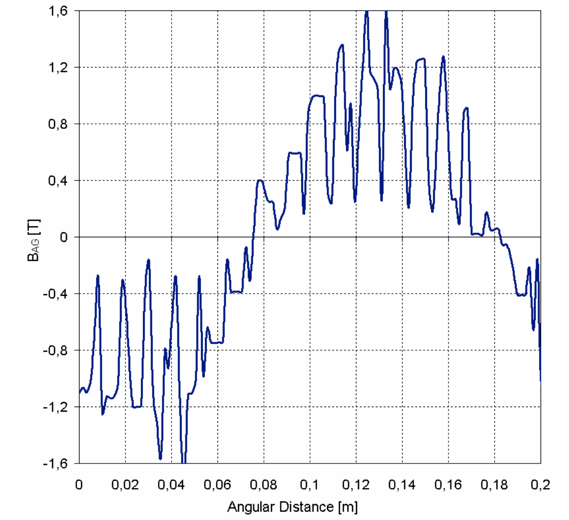

*Fig. 9: Magnetic field distribution – **B** in the center of the air-gap (maximal value of pulsating torque).*

4. Conclusion

The torque measurement and calculation was done for 3-phase induction machine with power 1.1kW working as a generator for nominal slip s_N and nominal torque T_N. Error of resultant torque, it means error between measured value and average value of torque calculation by Maxwell stress tensor is less than 1.6%.

This procedure could be used for a new design of induction generators, because it is built on non-linear equivalent circuit parameters [6].

The magnetic flux density average values for some important part of magnetic circuit:

	B_{SY} [T]	B_{RY} [T]	B_{SH} [T]	B_{RH} [T]	B_{AG} [T]
T_N	1.18	1.72	1.19	0.86	0.65
s_N	1.22	1.75	1.27	0.95	0.69

where, B_{SY} is magnetic density in stator yoke, B_{RY} is magnetic density in rotor yoke, B_{SH} is magnetic density in stator head, B_{RH} is magnetic density in rotor head, B_{AG} is magnetic density in air gap.

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Acknowledgment

This work has been prepared under the projects:
MSM0021630516: *Sources, Accumulation and Optimization of the Energy Exploitation in the Conditions of Sustainable Development*;
GA ČR 102/09/1875: *Analysis and Modelling of Low Voltage Electric Machines Parameters*.

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