Maciej Gwoździewicz
Wroclaw University of Science and Technology, Wrocław

2.5D IM MODEL WITH SKEWED ROTOR

MODEL 2,5D SILNIKA INDUKCYJNEGO ZE SKOSEM W WIRNIKU

Abstract: The papers deals with 2.5D induction motor model with skewed rotor. The model is based on two different IM with the same magnetic core: 55kW *2p*=6 and 45kW *2p*=8. Influence of the number of rotor slots and the number of slices on the torque ripple and magnetic field distribution in the air gap was considered.

Streszczenie: Artykuł przedstawia model 2,5D silnika indukcyjnego ze skosem w wirniku. Model silnika bazuje na silniku 6-biegunowym 55kW oraz 8-biegunowym 45kW o tym samym magnetowodzie. Zbadano wpływ liczby żłobków wirnika oraz liczby części modelu 2,5D silnika na tętnienia momentu oraz rozkład indukcji magnetycznej w szczelinie powietrznej.

Keywords: *2.5D model, induction motor, torque ripple, total harmonic distortion*
Słowa kluczowe: *model 2,5D, silnik indukcyjny, tętnienia momentu, współczynnik zawartości harmonicznych*

1. Introduction

Induction motors with aluminium cast rotors are manufactured almost always with skew. It limits noise and torque ripple of the motor [1–4]. In case of induction machines with copper bars in the rotor they are rarely produced with skew because of more difficult construction and higher clearance. FEM calculation of 2D model of induction machine with non-skewed rotor is accurate enough and quite fast taking into consideration modern computers with fast multi-core processors. 3D model calculation of electric machine by FEM is extremely accurate but needs too much time. Alternative solution for induction motors with skewed rotors is 2.5D model computed by FEM. Example of 2.5D model of motor is presented in Fig. 1. The time needed to model computation is *n*-time higher in comparison with 2D model, where *n* is the number of the model slices. During research presented in the paper maximum number of the 2.5D model slices was 7. Ansys Maxwell 17.2 was used for computation. From 17th version of Ansys Maxwell software enables easy calculation of 2.5D electric machine models.

2. Induction motors construction

Two different induction motors with the same magnetic core were considered: 55kW *2p*=6 and 45kW *2p*=8. The motors have skewed squirrel cage made by cast aluminium. Basic parameters and dimensions of both machines are shown in Tab. 1. Field part of the model is presented in Fig. 2. Shape and dimensions of the rotor slots are shown in Fig. 3. Widths *rBs1*, *rBs2* and *bdr* depends on the number of rotor slots to obtain constant value of the magnetic field density in rotor teeth equal to 1.65 T.

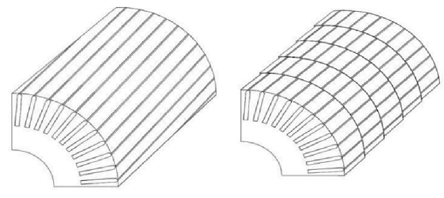

Fig. 1. Example of multi-slice 2.5 IM model [5]

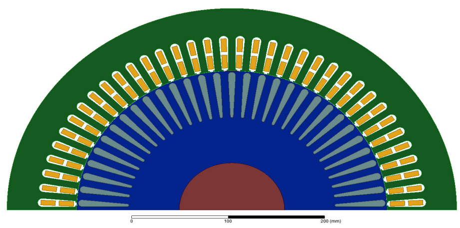

Fig. 2. Field part of the 2.5D motor model

Tab. 1. Basic parameters and dimensions of considered motors

P_n [kW]	55	45
$2p$ [-]	6	8
U_n [V]	400	
Q_s [-]	72	
Q_r [-]	54-62	
D_{se} [mm]	470	
D_s [mm]	325	
D_{shaft} [mm]	110	
δ [mm]	0.8	
L [mm]	200	230

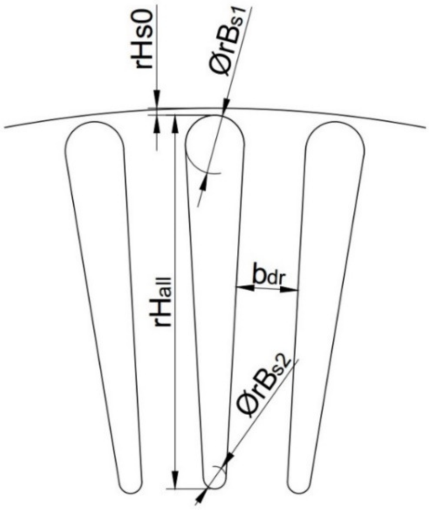

Fig. 3. Shape and dimensions of rotor slots; rHs0=1.0 mm, *rHall*= 52.9 mm

The following numbers of rotor slots for further investigation were considered: 54, 56, 58, 60 and 62.

3. Influence of the number of 2.5D model slices on motor parameters

Influence of the number of 2.5D model slices on fully loaded motor parameters were investigated. 45kW $2p$=6 IM model with Q_r=56 and skewed squirrel cage was taken into account. In case of 0 slices there was 2D model. Results are presented in Tab. 2. Torque ripple T_{pkavg} was calculated according to the equation (1):

$$T_{pkavg} = \frac{T_{max} - T_{min}}{\frac{1}{T_{ss}}\int_0^{T_{ss}} T dt}, \quad (1)$$

where:
T_{max} – maximum torque value in steady state,
T_{min} – minimum torque value in steady state,
T_{ss} – time interval of steady state,
T – electromagnetic motor torque,
t – time.

Tab. 2. Influence of the number of 2.5D model slices on fully loaded motor parameters

No. of slices	T_{pkavg} [-]	dP_{Fe} [W]	T_r [Nm]	I_r [A]
0	0.1517	0.4965	649	476
3	0.0348	0.5063	672	479
5	0.0293	0.5063	686	479
7	0.0248	0.5060	686	479

According to the results shown in Tab. 2 there is quite big difference between 2D model and 2.5D model with 3 slices. Difference between the numbers of 2.5D model slices is much smaller. For further investigation 2.5D IM models with 3 slices were taken into account because of acceptable difference in comparison with results of 2.5D models with higher number of slices and time of computation proportional to the number of 2.5D model slices.

Next step was investigation of influence of the number of rotor slots on 45kW $2p$=8 2.5D and 2D IM model parameters. Results are presented in Tab. 3 and Tab. 4.

Tab. 3. Influence of the number of rotor slots on fully loaded 45kW 2p=8 2.5D IM model parameters

Q_r [-]	T_{pkavg} [-]	dP_{Cu2} [W]	dP_{Fe} [W]
54	0.0245	677.9	511.9
56	0.0348	671.3	506.3
58	0.0239	671.8	500.4
60	0.0278	672.5	494.7
62	0.0284	674.1	487.3

Tab. 4. Influence of the number of rotor slots on fully loaded 45kW 2p=8 2D IM model parameters

Q_r [-]	T_{pkavg} [-]	dP_{Cu2} [W]	dP_{Fe} [W]
54	0.0490	677.5	511.2
56	0.1517	693.3	496.5
58	0.0355	671.4	500.0
60	0.0380	672.1	492.2
62	0.0320	673.4	487.0

Obtained results show that for Q_r=56 except extremely high torque ripple in 2D model there are quite big differences between power loss in squirrel cage [dP_{Cu2}] and power loss in magnetic core [dP_{Fe}]. Due to that determination of efficiency of IM with skewed rotor by FEM 2D model can be inaccurate and give mistaken scores.

4. 2.5D 2p=6 and 2p=8 IMs models with the same magnetic core

Influence of the number of rotor slots in 55kW $2p$=6 and 45kW $2p$=8 with the same magnetic core was investigated. Torque ripple T_{pkavg} and *THD* coefficient of magnetic flux distribution in air gap were determined. Obtained results are presented in Fig. 4 and Fig. 5.

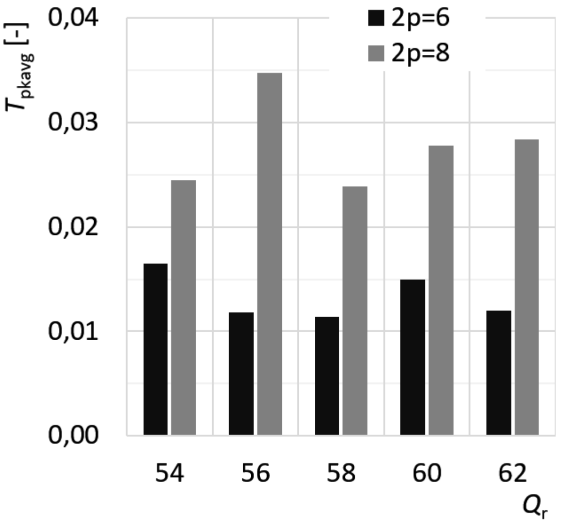

Fig. 4. Influence of the number of rotor slots in fully loaded 55kW 2p=6 and 45kW 2p=8 on torque ripple

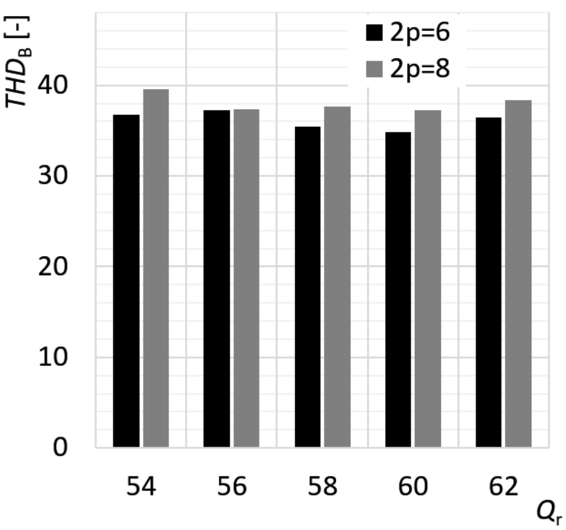

Fig. 5. Influence of the number of rotor slots in fully loaded 55kW 2p=6 and 45kW 2p=8 on THD coefficient of magnetic flux distribution in air gap

The best choice of the number of rotor slots Q_r in $2p$=6 and $2p$=8 IMs with the number of stator slots Q_s=72 is Q_r=58. For this construction of IMs with the same magnetic core torque ripple obtains the lowest value. In case of *THD* coefficient of magnetic flux distribution in air gap the lowest value occurs for Q_r=60. In comparison with Q_r=58 there is same difference but this difference is much lower than difference between torque ripples for these two numbers of rotor slots.

5. Conclusions

2D IM model with skewed rotor is not accurate enough. To obtain acceptable results 2.5D model must be applied. There are some difference between 2.5D models with various number of slices but 3 slices seems enough for proper scores.

Furthermore, for $2p$=6 and $2p$=8 IMs with the same magnetic core, the number of stator slots Q_s=72 and skewed rotor the optimal number of rotor slots Q_r=58 taking into account torque ripple and *THD* coefficient of magnetic flux distribution in air gap.

6. Literature

[1]. M. Korkosz, J. A. Młot, "TORQUE RIPPLE ANALYSIS IN BRUSHLESS DC MOTOR WITH SKEWED MAGNETS", *Maszyny Elektryczne - Zeszyty Problemowe*, nr 88/2010

[2]. K. Ludwinek, R. Nadolski, J. Staszak, "COMPARISON OF HIGHER HARMONIC CONTENTS IN SALIENT POLE SYNCHRONOUS GENERATOR WITH RADIAL INCISIONS ON THE SOLID POLE SURFACE", *Maszyny Elektryczne - Zeszyty Problemowe*, nr 4/2015

[3]. M. Gwozdziewicz, M. Mikolajczak, "APPLICATION OF STATOR SKEW IN SINGLE-PHASE PERMANENT MAGNET SYNCHRONOUS MOTOR", *Maszyny Elektryczne - Zeszyty Problemowe*, nr 3/2016

[4]. K. J. Binns; G. Rowlands-Rees, "Simple rules for the elimination of cogging torque in squirrel-cage induction motors", Proceedings of the Institution of Electrical Engineers (Volume: 121, Issue: 1, January 1974)

[5]. www.ansys.com

Authors

PhD Maciej Gwozdziewicz – assistant professor in Electrical Engineering Faculty at Wroclaw University of Science and Technology
e-mail: maciej.gwozdziewicz@pwr.edu.pl

Calculations have been carried out using resources provided by Wroclaw Centre for Networking and Supercomputing (http://wcss.pl), grant No. 400.