Prace Naukowe Instytutu Maszyn, Napędów i Pomiarów Elektrycznych
Nr 66 Politechniki Wrocławskiej Nr 66

Studia i Materiały Nr 32 2012

permanent magnet synchronous motors, induction motors, high-efficiency motors, optimization

Wiesław JAŻDŻYŃSKI*, Martin BAJEK

A COMPARISON OF OPERATION PROPERTIES OF A HIGH-EFFICIENCY SQUIRREL-CAGE INDUCTION MOTOR AND LSPMSM

In the paper some results of design optimization calculations performed for induction motors with both the aluminum and copper cages, as well as for a line start permanent magnet synchronous motor (LSPMSM) with ratings $P_N = 0.75$ kW, $U_N = 400$ V, $f_N = 50$ Hz, $2p = 4$ are presented. Basing upon obtained optimal designs, the prototypes of the LSPMSM and an induction motor with a reduced rated power $P_N = 0.55$ kW have been manufactured. The experiments have proved that the LSPMSM has a self-starting and sufficient overloading ability, and its rated efficiency (according to standards – direct efficiency determination by means of the torque meter test) is circa 89.1%. The properties of the optimized prototype of the induction motor could not be determined due to a delay in its correct manufacturing.

1. INTRODUCTION

The paper is a continuation of a number of earlier works devoted to designing optimal constructions of high-efficiency squirrel-cage induction motors (denoted throughout the paper as IM) and Line-Start Permanent Magnet Synchronous Motor (LSPMSM – denoted also as LS in the paper) [1–4]. A majority of this work concerns an experimental verification of design optimization calculations, with the help of prototypes of both the machines manufactured by a producer of induction motors. The goal of optimization was to maximize rated efficiency of both types of the motors characterized with the data: $P_N = 0.75$ kW, $U_N = 400$ V, $2p = 4$, $f_N = 50$ Hz, frame size = 80, under a restriction, that their maximum dimensions do not exceed those of an existing motor 3SIE80-4B of the same ratings, and they meet manufacturing technology requirements imposed by the producer. For the reasons given in [4], a design of an

* AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Cracow.

optimal induction motor with P_N = 0.55 kW has been accepted at a stage of prototyping, to meet the IE3 efficiency class requirements. It was not possible to reach both the limits of the IE4 class [5] for an induction motor satisfying accepted design restrictions, and IE3 class for a P_N = 0.75 kW motor.

This work was supported in part by the polish Ministry of Science and Higher Education under Grant N N510 108538.

2. MODELS AND DESIGN OPTIMIZATION

Analytical machine models have been employed in optimization. A credibility of obtained results has been verified by means of corresponding FEM calculations. Procedures to develop proper quality synthesis programs were described earlier for both the induction motors, e.g. [3, 4], and LSPMSM [1, 2]. Cross-sections of a few analyzed FEM models are presented on Fig. 1.

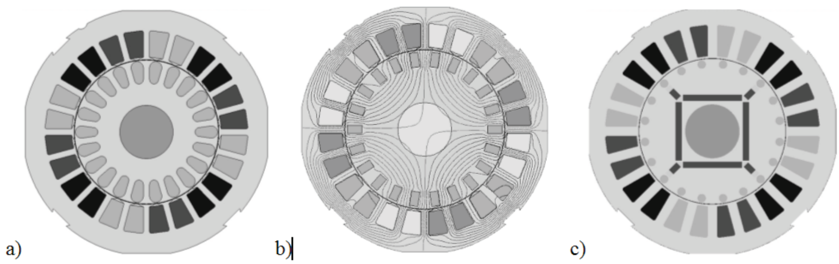

Fig. 1. Topologies of the analyzed IM (a - Al-cage, b – Cu-cage) and LSPMSM (c) used to verify the results of optimization
Rys. 1. Topologie analizowanych silników IM (a – klatka Al, b – klatka Cu) i LSPMSM (c) użyte do weryfikacji wyników optymalizacji

Constructions of the analyzed machines have been selected after a careful investigation of optimization results obtained by means of a bicriterial approach e.g. [2, 3]. The final best designs were solutions of the following scalar optimization problems:

$$\text{Problem IM (LS)} : \max \eta_N \big| \mathbf{x}_{\mathrm{IM(LS)}} \in X_{\mathrm{IM(LS)}} \qquad (1)$$

where η_N is the rated efficiency of an optimized induction motor (IM) or LSPMSM (LS), the $\mathbf{x}_{\mathrm{IM(LS)}}$ is a vector of optimization variables, in particular geometry dimensions and winding parameters, and the $X_{\mathrm{IM(LS)}}$ are corresponding feasible regions influenced by the producer requirements according to his manufacturing technology. Both the aluminum and copper cages were analyzed when searching for the best construction. In Table 1 more important results corresponding to the obtained optimal designs are presented.

Table 1. Operation properties of several obtained optimal designs of induction motors
Tabela 1. Własności ruchowe wybranych optymalnych konstrukcji silników indukcyjnych

motor operation property	3SIE80-4B (initial design)	Optimal designs				
		Al – cages, drip bars		P_N = 0.75 kW, Cu – cages with bars:		
		P_N = 0.75 kW	P_N = 0.55 kW	drop-shaped	round	rectangular
I_N (Arms)	2.5268	1.7370	1.3981	1.8301	1.8134	1.7343
s_N (%)	4.4957	6.4866	4.2793	3.1994	4.9188	4.5389
η_N (%)	78.838	81.183	82.182	83.687	82.384	82.754
$\cos\varphi_N$	0.54069	0.76385	0.68778	0.70380	0.72120	0.75009
T_{max}/T_N	3.6746	2.0095	2.5808	2.7148	2.5241	2.9665
T_{lock}/T_N	3.2979	1.4829	1.8051	1.8000	1.9538	2.6127
I_{lock}/I_N	4.6556	3.9287	4.6764	5.3911	4.8137	5.7804

Using the earlier obtained results [4], the design with the die-cast aluminum cage and with rated power P_N = 0.55 kW has been used to make the prototype, as a construction with rated efficiency closest to that of the IE3 efficiency class.

The optimal design of the LSPMSM has been obtained in the paper with the help of a procedure described e.g. in [1, 2], as a result of solving (1). Following this design, the efficiency was expected to be η_N = 88.54%.

Basing upon the above optimal designs, the producer has manufactured the prototypes of the LSPMSM and induction motor.

3. EXPERIMENTS

Most experiments, apart from those requiring a variable supplying voltage, have been performed by means of a laboratory stand presented on Fig. 2.

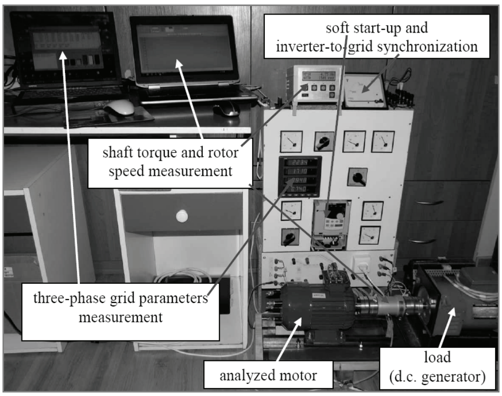

Fig. 2. Laboratory stand with a part of measurement equipment
Rys. 2. Stanowisko laboratoryjne z częścią wyposażenia pomiarowego

In both the prototypes the stator windings wire diameters were diminished (for LS – about 5%, for IM – more than 10%), and for the IM the rotor cage asymmetry (Fig. 3, model name Sh 80X-4C/AGH1) has prevented motor normal operation at a load. The motor 3SIE80-4B is a high-efficiency motor currently manufactured by the producer.

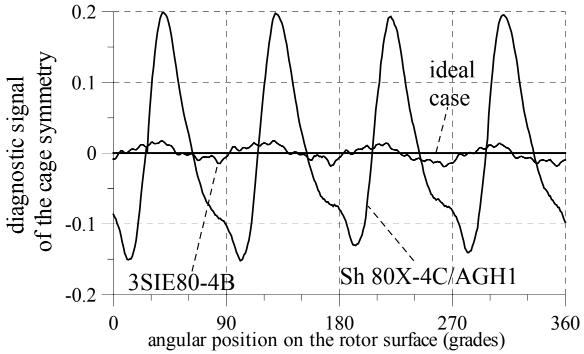

Fig. 3. IM: cage-symmetry diagnosis signal
Rys. 3. IM: sygnał diagnostyczny syme trii klatki

In the case of LSPMSM, performed experiments have confirmed the majority of optimization calculation results and in general the prototype meets the design requirements. The final results of the heating tests for P_N = 0.75 kW and P_N = 1.1 kW are presented on Fig. 4. The rotational speed of the motor during the start-up is presented on Fig. 5 for three cases: for the experiment with the prototype, for the simulation in Matlab environment, and for FEM calculations.

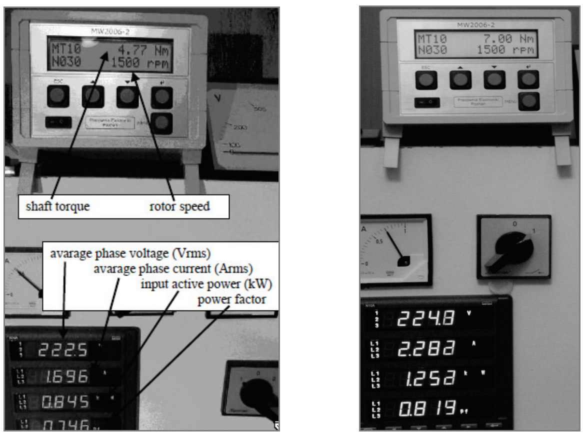

Fig. 4. LSPMSM: load data after heating test for P_N = 0.75 kW (left) and for P_N = 1.1 kW (right)
Rys. 4. LSPMSM: dane obciążenia po próbie grzania dla P_N = 0.75 kW (po lewej),
oraz P_N = 1.1 kW (po prawej)

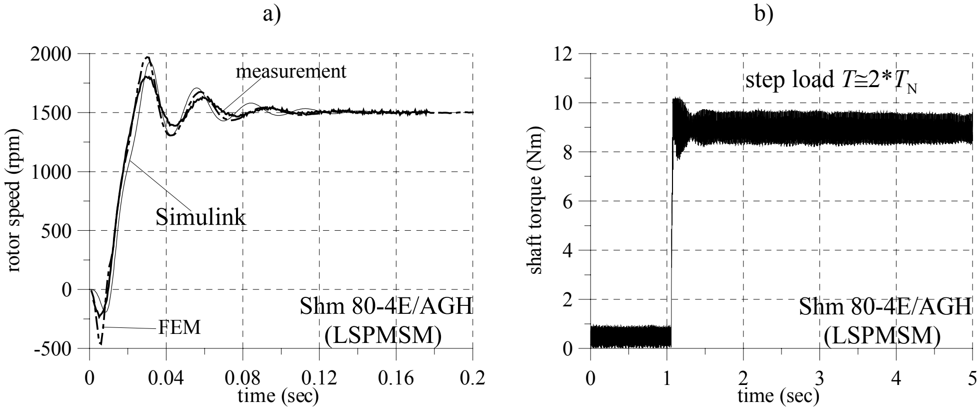

Fig. 5. LSPMSM: rotor speed during the start-up (a) and step over-load (b)
Rys. 5. LSPMSM: rozruch silnika (a) oraz jego skokowe przeciążenie (b)

Rated efficiency of the LSPMSM arises from the data on Fig. 4. It was determined according to [6] employing direct efficiency determination method by means of the torque-meter test. A correction of these data was necessary to compensate an influence of a discrepancy of the supplying voltage (U = 222.5 V instead of the rated one), and the stator windings wire diameter d_{el} (circa 5% less than in the design). Obtained values are η^*_N = 89.1% at P_{N} = 0.75 kW, and η^*_N = 88.3% at P_{N} = 1.1 kW. It corresponds to the most rigorous, although informal standards introduced by some enterprises (they are called in literature e.g. SuPremE or ECOiPM). The 3SIE80-4B motor mass was circa 12.3kg, whilst the LSPMSM (model name Shm 80-4E/AGH) – circa 9.6kg.

The following conclusions can be drawn:

1. Presented results for the LSPMSM prove that proper optimization calculations based on the analytical models of the motors, and verification with the help of corresponding FEM models allow to obtain motors with desired, very good properties, without ~~a~~ prototyping stage.
2. The investigated prototype of the LSPMSM of the frame size 80 reaches the rated efficiency η^*_N = 89.1% at P_{N} = 0.75 kW by the weight circa 9.6 kG, but it can work continuously overloaded at P_{N} = 1.1 kW and still shows high efficiency η^*_N = 88.3%. The high-efficiency squirrel-cage induction motor 3SIE80-4B of the same frame size and ratings, see Table 1, which is currently manufactured by the producer, has the measured rated efficiency below 80% and its weight is circa 12.3 kG.
3. The LSPMSM prototype described in the paper satisfies requirements imposed in its design at least for the rated efficiency, start-up conditions and over-load ability, despite the manufacturing discrepancies.

REFERENCES

[1] BAJEK M., JAŻDŻYŃSKI W., *Optimization of construction of a Line Start Permanent Magnet Synchronous Motor with the use of a magnetically linear analytical model*, Electrical Review, 2010, Vol. 86, No. 7, 330–337.
[2] BAJEK M., JAŻDŻYŃSKI W., *Modeling and Bi-Criterial Optimization of a Line Start Permanent Magnet Synchronous Machine to Find an IE4 Class High-Efficiency Motor*, Proceedings of the International Conference on Electrical Machines ICEM 2010, Rome, Italy, September 6–8, 2010, paper RF-002232, 1–6.
[3] JAŻDŻYŃSKI W., *Multicriterial optimisation of squirrel-cage induction motor design*, Proc. IEE, Pt.B, 1989, 136, 299–307.
[4] JAŻDŻYŃSKI W., *Modeling and optimization of an IE4-class high-efficiency induction motor prototype*, Maszyny elektryczne. Zeszyty Problemowe BOBRME KOMEL, Katowice 2011, No. 93, 37–42.
[5] IEC/TS 60034-31 Ed.1.0 2010-04: *Rotating electrical machines* – Part 31: *Selection of energy-efficient motors including variable-speed applications* – Application guide.
[6] *Rotating electrical machines* – Part 2 – 1: *Standard methods for determining losses and efficiency from test (excluding machines for traction vehicles)*, IEC Standard 60034 – 2 – 1. Edition 1.0, 2007 – 09.