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ENVIRONMENT FRIENDLY ELECTRIC MOTORS FOR DRIVING LOW-POWER FARM DEVICES AND MUNICIPAL INSTALLATIONS

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Abstract

The article presents the most important causes of energy losses in magnetic circuits of electrical machines and describes a new design of a synchronized induction motor. The basic operational parameters of two structures: induction machine with squirrel cage (IM) and newly designed machine with a rotor with permanent magnets and a copper squirrel cage (induction machine synchronized with self-starting (LSPMSM) have been identified and compared. Performance characteristics were determined for work in steady states. In both cases the stator, type Sg 100L-4B of 3 kW induction motor was used. It has been shown that the PSPMSM supplied from the public mains grid shows the efficiency approx. 5% higher than the conventional motor. The influence of the change in the supply voltage frequency on the work of both structures was tested, i.e. on the measured efficiency, power factor and the electricity from electrical grid. Studies have shown that the LSPMSM can be a replacement for an induction motor. It has been shown that the torque pulsations occurring in the new structure (cogging torque) do not increase the environmental risks.

Keywords: induction motor, Line Start Permanent Magnet Synchronous Motor – LSPMSM, efficiency, cogging torque

INTRODUCTION

Growing energy demand and the necessity of diminishing pollution originating from manufacturing processes enforced by the international conventions require seeking solutions for energy saving management of the natural resources, including energy, as well as ensuring full recycling. It necessitates looking for the technical solutions of machinery and equipment, which would guarantee their best efficiency; it applies also to all electrical equipment. Since a considerable portion of electricity at human disposal is used for all types of drives, electrical machines are a special subject of research. Asynchronous squirrel cage motors prevail among the drives. The basis advantages of these machines comprise: simple and cheap construction, relatively high efficiency of electricity conversion into mechanical energy and low overhaul costs. These machines constitute over 70% of all drives encountered in the economy. In case of drives used on agricultural farms and in municipal installations, the proportion of this type machines is even higher.

The IEC 60034-30 Standard „Rotating electrical machines – Part 30: Efficiency classes of single-speed, three-phase, cage-induction motors (IE-code)" of 2008, obligatory in the European Union, classifies the discussed machines according to their efficiency into three categories: IE1, IE2 and IE 3 (Norma IEC, 2008). In compliance with this document, the induction motors of the discussed power (from 0.75kW to 375kW) put on the market after 1 January 2015 should meet the requirement of at least IE2 level i.e. should be defined as machines with increased efficiency. The standard efficiency of these devices (level IE1) is on average 68-75%, however it may be assumed that the drives of lower power reveal poorer efficiency. It means that almost 30% of energy supplied to this machine is irretrievably lost. These are in the first place heat losses caused by the current flow (increase in the temperature of the machine and its environment) and the losses in the magnetic circuit, but also acoustic energy and vibration energy emitted to the environment (Jabłoński, 2011).

Efficiency of an electric machine may be improved in several ways:

- by a change of applied magnetic, insulating and conductive materials – each change usually causes a significant increase in the manufacturing costs and poses a potential hazard of very high costs of these materials utilization after the machine operation period is finished,
- by proper selection of manufacturing technologies, especially non-waste or low-waste technologies, particularly for treatment of details of magnetic materials, e.g. punching and annealing, laser cutting or electrical machining, etc.,
- by a change of the machine construction.

Research on developing energy saving drive for pumps and ventilators for mining industry has been conducted recently at the Institute of Electrical Engineering and Electronics at the Poznan University of Technology as the project entitled: ”New generation of energy saving electric drives for pumps and ventilators for mining industry” (POIG 01.0102-00-113/09). Irrespective of the specific requirements posed by the mining industry, the newly constructed motors may be successfully used as general purpose machines, also as drives for the devices in municipal installations.

INEVITABLE ENERGY LOSSES IN AN ELECTRIC MACHINE

In an asynchronous squirrel cage motor, like in any other electromagnetic or electromechanical energy converter, a conversion of supplied electric energy into mechanical energy takes place during its work, associated with a displacement or rotation. The energy of magnetic field mediates in the conversion of the above mentioned energy forms. A transitional “ordering” of the magnetic circuit structure material happens in the machine, i.e. from a magnetically neutral body it changes into a body with visibly arranged structure – it becomes a magnet. This conversion is associated with a change of energy state of each part of the circuit. If additionally induction – magnetic field – changes in time, the magnetization will be also a variable process. The changes are best described by the value of magnetic induction and more precisely characterization of magnetizing with hysteresis loop. The characteristics and shape of the hysteresis loop depend on the kind of material, forced values, frequency of re-magnetization, but also on the shape of magnetic circuit. The course of induction changes is represented by the hysteresis loop (Dąbrowski, 1981). Re-magnetization of soft ferromagnetic material, i.e. the one which does not have “the magnetizing state memory” requires a supply (forcing) of some external energy. The energy is crucial to cover the losses connected with the re-magnetization of the circuit. The value of this energy is evidenced by the area covered by the above mentioned hysteresis loop. Therefore, the trend towards seeking magnetic materials, whose hysteresis loops would have the smallest areas, in the comparable conditions, is obvious.

Energy losses connected with re-magnetization of the motor magnetic circuit are active. They may be divided into two components:

- the losses proportional to the frequency of re-magnetization, called “hysteresis” losses,
- the losses proportional to the square frequency of re-magnetization, called “eddy-current” losses.

Both components complexly depend on the induction, frequency, kind of material, applied machining and thermal treatment but also on the mass of magnetic circuit. In engineering practice these components are usually described by empirical dependencies (Dąbrowski, 1981, Jabłoński, 2011, Wilczyński, 2003).

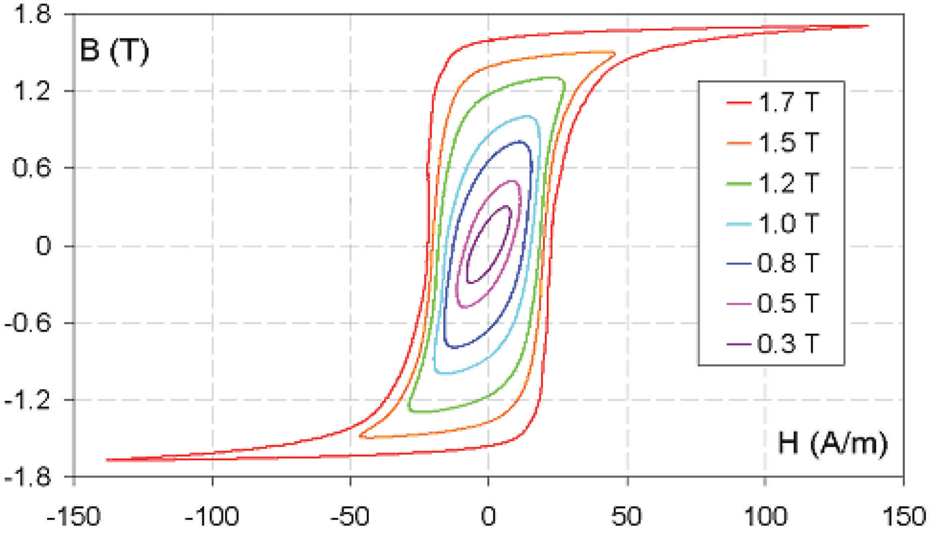

Figure 1. Hysteresis loops of soft ferromagnetic material

Eddy-current Losses originate in each massive electric current conductor placed in the time variable magnetic field. Because soft ferromagnetic materials are electricity conductors, this kind of losses will also occur in them.

In the asynchronous squirrel cage motor the inevitable losses resulting from the circuit re-magnetization occur both in the stator and rotor. Since the rotor mass constitutes ca. 40-48% of the whole machine mass, reduction of the total losses may be achieved by diminishing the losses in the rotor. It is possible by the rotor entering the synchronous working state. The rotor of the asynchronous motor rotates always with the speed slightly lower than the magnetic field rotating speed. It causes the self-induction of electromotive forces in the conductive parts of the rotor and thus current flow and generating losses. The rotor entering synchronous working state eliminates the above mentioned phenomenon. At this state of the rotor practically no losses occur (no core re-magnetization or current induction). To achieve this state in the designed constructions, properly distributed permanent magnets were placed. The motor developed in this way, in literature called Permanent Magnet Synchronous Motor (PMSM) at the start shows the features of asynchronous motor but synchronous motor characteristics during normal work.

Inevitable losses comprise also so called active losses resulting from current flow through the wiring, mechanical losses connected with the friction phenomenon, but also partly the losses originating during the machine ventilation. The aim of presented research was seeking solutions allowing minimizing the losses occurring in the rotor magnetic circuit.

DESCRIPTION OF A MODEL ENERGY SAVING MOTOR CONSTRUCTION

Detailed description of the construction was presented in a report available on www.ngn.put.poznan.pl. During design work it was assumed that the model should be an equivalent of serially produced induction motors. The model was constructed as a replacement of the Sg 100L-4B three phase motor with power 3.0 kW, rated speed 1425 rpm at the rated voltage 3x400 VAC at star connection. The motor was an explosion proof construction (EEx), i.e. its housing was made of cast iron (Barański, Idziak et al. 2013, Barański, Szeląg et al. 2013).

The constructed model used a ready-made stator and only the rotor was changed. Beside the squirrel cage made of aluminium rods, also permanent magnets were placed, distributed as shown in Figure 3. Figures 2 and 3 respectively show the views of rotor blades of traditional asynchronous motor and PMSM motor and ready rotors.

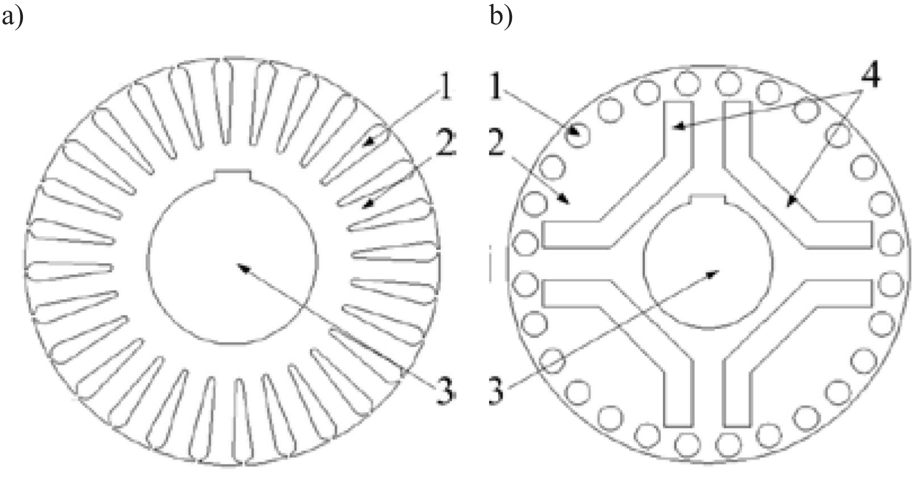

Figure 2. The cross section of a rotor a) induction motor, b) synchronous motor 1 – squirrel cage winding, 2 – the rotor core, 3 – the shaft, 4 – permanent magnets)

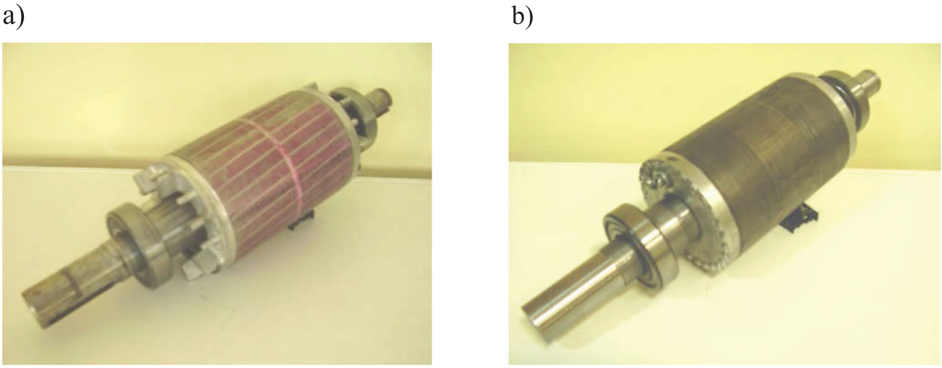

Figure 3. Back in a compete rotor: a) induction motor; b) aluminium cage PMSM

OPERATIONAL PARAMETERS OF THE MODELS, RESEARCH RESULTS

Leaving the cage in the rotor of the model motor ensured a possibility of the motor self-starting without the necessity of additional starting devices application (a drawback of synchronous motors). In this way an asynchronous synchronized motor was constructed, in literature called Line Start Permanent Magnet Synchronous Motor (LSPMSM). Investigations on motors of this type has been conducted in many research centers (Barański et al., 2013, Fie et al, 2009, Idziak et al., 2013, May et al., 2004, Miller et al., 2004, Zawilak, 2007).

Initial research demonstrated that, due to starting parameters a copper cage would be more convenient to use. The results of comparative research on selected operating parameters of the motor with a squirrel cage rotor (induction motor – IM) and the motor with permanent magnets and copper cage were presented below.

The research also considered the fact, that modern drives very often require the rotation speed regulation. Therefore presented characteristics include the work of the motor powered by voltage of different frequency. During the tests the motors were loaded with the torque of 75% of the rated torque (Barański et al., 2013, Idziak et al., 2013).

Figure 5 presents the compilation of the tested machines efficiency depending on the frequency of supply voltage. The machines were powered from the variable ferquency converter, i.e. with mainatined voltage value to frequncy ratio.

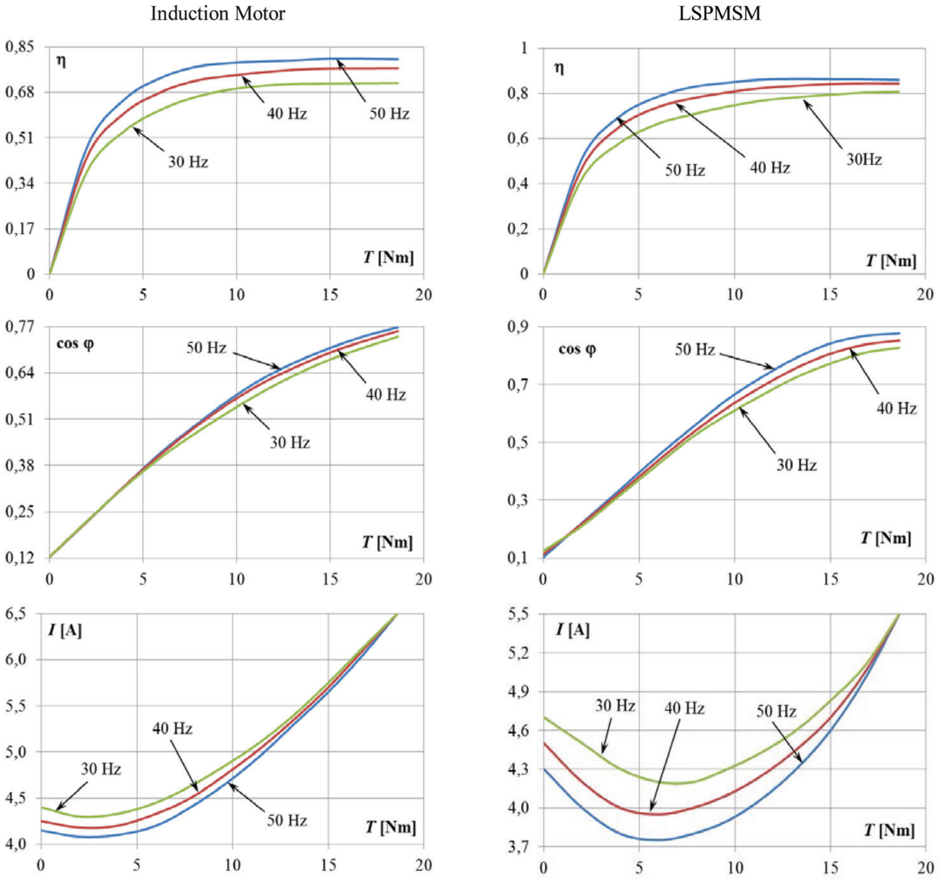

Figure 4. Comparison of selected operating characteristics of the induction motor and the PSPMSM

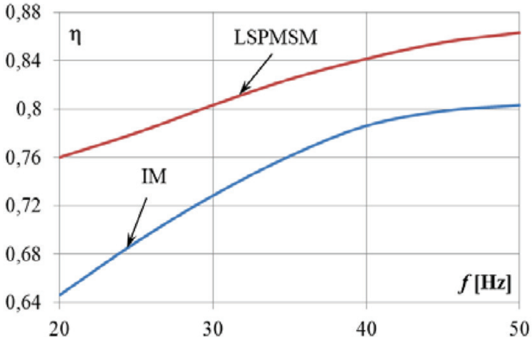

Figure 5. The influence of the frequency on the motors efficiency

VIBRATION TESTS OF LSPMSM MOTOR

The fault of PMSM motor frequently mentioned in literature and by their users are torque pulsations. The phenomen results from the machine construction.The grooves in the stator and magnets placed in the rotor are put dicreetly, which causes that the rotor assumes some pre-defined positins in relation to the stator. Variable magnetic conductivity of the aperture between the stator and the rotor causes creation of cogging torque (May et al., 2004, Miller et al. 2004).

The cogging torque occurs also in the presented construction. Torque pulsations lead to formation of variable electrodynamic forces between the stator and the rotor, visible among others as increased level of vibrations emitted to the environment. Because one of the basic causes of machine vibrations is their imbalance, the rotor imbalance was corrected before the measurements. The standard imbalance of IM motor 2e-5 Nm was reduced to 0.5e-5 Nm, whereas the model motor imbalance was reduced to 0.6e-5 Nm.

Vibration tests were conducted for several cases:

- for idle running machine (no mechanical connected with loading).
- for machine coupled with eddy current brake with the moment of inertia equalling 150% of squirrel cage rotor moment of inertia and load torque 0.0 Nm,
- for the machine loaded with rated torque, i.e. 20Nm.

Dynamic changes of the stator shape during the motor work were determined during the testing by means of Operational Deflection Shape (ODS) analysis. The method allows noticing the changes of the examined construction and determining the places undergoing particularly serious deformations.

In both discussed cases the greatest shape deformations (mechanical stress of the housing) occur at machine idle running. Increase in the moment of rotor inertia decreases them considerably. Modified motor at the loading state practically does not change the level of vibrations as compared with idle running. It occurs differently than in the squirrel cage motor. The reason is most probably the cogging torque. In the tested model, the cogging torque was 0.54Nm, which constitutes ca. 2.7% of the induction machine rated torque. Additional tests (heating) revealed that, due to thermal reasons the modified motor, because of the lack of losses in the rotor, may be permanently loaded with 20% bigger torque, i.e. the torque of 24Nm. It will not lead to exceeding of the admissible temperature. The increase in loading torque to the value of 24Nm did not cause increased vibrations.

OBSERVATIONS

The research demonstrated evident premises for implementing the production of line start permanent magnet asynchronous motor. The cogging torque, inevitable in a construction of this type, does not cause any significant negative results. Observed deformations of the motor construction do not evidence any increased mechanical stress in its structure. A higher level of vibrations amplitude within low frequencies range slightly exceeds the level admissible for the machine of this size (Norma PN-EN, 2007). The tests demonstrated that machines of this type definitely should not work without loading. Application of permanent magnets in the rotor increases significantly the machine torque (in the tested solution by 20%) at practically unchanged vibrations level.

Assuming as the reference the torque developed by induction motor, the exchange of the rotor will result in an improvement of power factor and machine efficiency. These parameters are growing with increased frequency of supply voltage frequency. Also current drawn by the synchronous motor, at steady state, at torque loading over 50% of the value assumed as the reference value, is ca. 10-20% lower than in the cage induction motor.

Increase in the torque and associated decrease in the wiring temperature during work with the loading so far regarded as rated makes possible diminishing the diameter of the machine external ventilator and another reduction of losses. Because the ventilation noise is inextricably tied with the linear velocity of the air current leaving the ventilator blades, diminishing the latter diameter results in lowering the level of emitted noise, which may even reach 3-5db (Jabłoński 2011).

The change of the rotor construction in newly constructed model led to the improvement of its efficiency by 5% at the loading of 75% of the reference loading, which denotes a decrease in operating costs. Over 8-month exploitation of the constructed motor with the power of 1400kW put into operation, revealed the benefits compensating the costs of construction and assembling of a new drive. The motor was developed by the team headed by Professor J. Zawilak from Wrocław University of Technology, who participated in the activities at the beginning of the research programme. The motor was installed in one of the mines in Poland (Gwoździkiewicz, Zawilak 2011).

The fault of presented construction is limited number of starts per time unit. These machines should be installed in places where work is conducted without break (pumping, ventilation or heating systems).

The costs of exploited LSPMSM type machines disposal mentioned at the beginning of the paper do not exceed the costs of traditional machines disposal. Small supplements, such as permanent magnets do not enforce the changes in the technology of ferromagnetic material recovery.

The latter feature becomes particularly important in the face of the obligatory life cycle assessment of energy and environmental impact of products, i.e. from the resources acquisition until the moment of the post-consumer management processes completion, to be introduced in the European Union member states (Górzynski, 2007, Norma ISO 2000). It is expected that electric motors will be covered by the procedure.

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