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Synchronous motors excited by permanent magnets in high power drives

***Abstract**. The paper presents the results of research on the use of a LSPMSM motor in the drive of the ball mill. The essence of these engines is their simple construction and operation, and the start-up is carried out by a direct connection to the supply voltage. The operational characteristics have been shown and the start-up properties of a synchronous motor excited by permanent magnets (P = 630 kW, U = 6000 V n = 187.5 rev / min) driving the mill in ZWR KGHM have been analyzed.*

***Streszczenie.** W pracy przedstawiono wyniki badań dotyczące zastosowania silników typu LSPMSM w napędzie młyna kulowego. Istotą tych silników jest ich prosta budowa i eksploatacja a uruchomienie odbywa się przez bezpośrednie przyłączenie do napięcia zasilającego. Pokazano charakterystyki eksploatacyjne oraz przeanalizowano właściwości rozruchowe silnika synchronicznego wzbudzanego magnesami trwałymi (P=630 kW, U=6000 V n=187,5 obr/min) napędzającego młyn w ZWR KGHM. (**Silniki synchroniczne wzbudzane magnesami trwałymi w napędach dużej mocy**).*

Słowa kluczowe: silnik synchroniczny, magnesy trwałe, rozruch bezpośredni, duży moment.
Keywords: synchronous motor, permanent magnets, direct start-up, big moment.

Introduction

An incessant tendency to look for energy-efficient solutions is also manifested in the field of electrical machines. According to the latest standard IEC 60034-30-1, achieving an efficiency corresponding to class IE5 will be unattainable for conventional induction machines.

An alternative are machines excited by permanent magnets, including those with the ability to launch through a direct connection to the mains, the so called Line Start Permanent Magnet Synchronous Motors.

For many years constructions of this type have been restrained to the power of several kilowatts. Better and better recognition of the characteristic phenomena in these types of machines (especially start-up and synchronization) resulted in the occurrence of the first prototypes with a power greater than 1 MW [2, 3, 4, 5, 6, 7].

New possibilities of building motors with better operating parameters have also been seen in Poland. On the initiative of prof. dr. Eng. Andrzej Demenko from the Department of Mechatronics and Electrical Machines at Poznań University of Technology, a consortium has been set up to undertake research and development on the issue: "The new generation of energy-efficient electric drives for pumps and ventilators for the mining industry." Due to the possibility of carrying out laboratory tests the teams have dealt with the issues of designing and constructing primarily low-power machines.

The Wrocław University of Technology team recognized the possibilities and needs to construct energy-efficient synchronous motors excited by large and very large power permanent magnets. The Institute of Machines, Drives and Electrical Measurements (currently the Department of Machines, Drives and Electrical Measurements) has undertaken research aimed at enhancing knowledge of the energy-efficient drive systems with electric motors of large power with new structures of magnetic circuits excited by permanent magnets, and their implementation will allow significant energy savings. The drives will be adapted to work in mines.

Using long-term contacts and cooperation with the industry operating and producing electrical machinery, it has been proposed to perform and install the prototypes of such machines in the drives of copper ore and coal mines.

The aim of the article is to present the characteristics of synchronous motors excited by high power permanent magnets: a low-speed engine of the type LSPMSM to drive the ball mill and the motor for the pump for drainage in mines.

Low-speed drive of the ball mill

In cooperation with Wrocław University of Technology, KGHM Polska Miedź SA and DFME (formerly DOLMEL), a prototype of a LSPMSM motor (SMH-1732T, 630kW), intended to drive the ball mill (Fig. 1), was designed and made. This motor has been designed to drive the ball mill, which is currently powered by a SAS engine (Fig. 2).

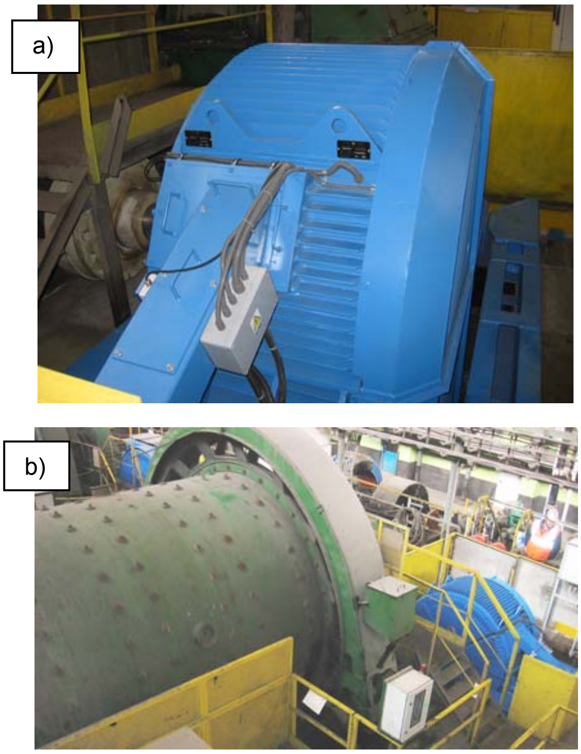

Fig. 1. View of a synchronous motor with permanent magnets with a power of 630 kW, n_n= 187.5 rev / min (a) built in the drive of a ball mill (b)

The specificity of the LSPMSM machine type means that no clear guidelines to define their parameters with specified accuracy have yetbeen developed [1]. For this reason, an analysis of the properties has been made with two complementary methods: by measuring and with a field-circuit simulation model. The motor model was constructed using Maxwell 2D software (v16). In simulations, a type of "transient" solution was chosen, allowing for modeling of the machine with a voltage enforcement while taking into account the motion, which reflects the considered phenomena in the closest way [8, 9, 10].

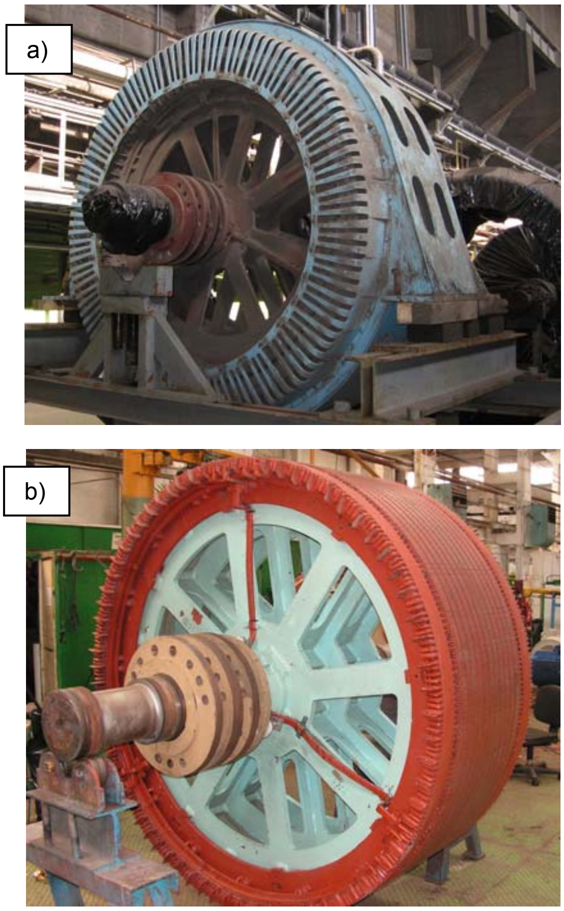

Fig. 2. View of a SAS engine with a power of 630 kW, n_n = 187.5 rev / min (a) and the rotor of the motor at the time of rewinding (b)

Analysis of the motor at zero current

The voltage waveform induced in the winding of the stator of a prototype LSPMSM motor was determined from the calculations (Fig. 3).

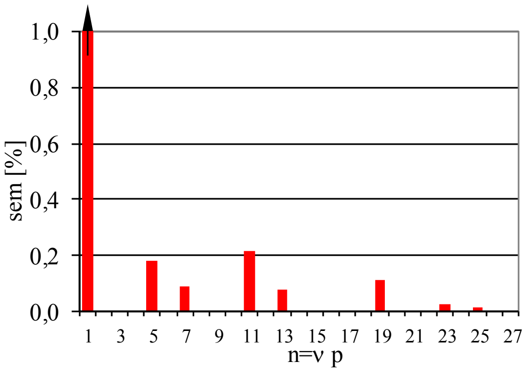

Fig. 3. Harmonic analysis of single-phase voltage (referenced to the fundamental harmonic of the rated voltage)

A harmonic analysis of the voltage shows that the greatest amplitude of the higher harmonics do not exceed 0.25%, which should be considered a very good result and rarely achieved in even high-power generators. The sinusoidal shape of the induced voltage is achieved by matching the appropriate number of grooves of the start-up cage to the number of grooves of the stator and also the proper arrangement of magnets.

The correlation of the number of rotor and stator grooves has a significant impact on the value of the cogging torque. Figure 4 shows the calculated course of the cogging torque for the two groove scales of the stator, of which the maximum value is approximately 1% of the rated torque. Such a cogging torque in this type of machinery is considered as very small.

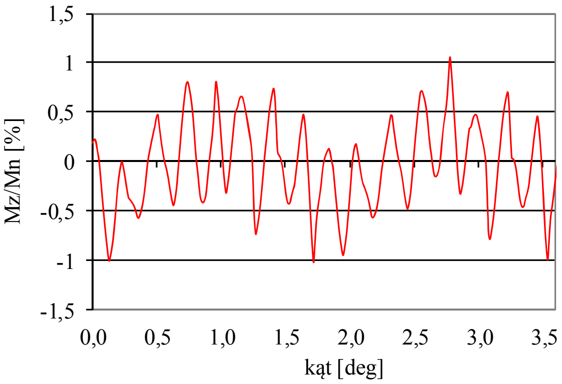

Fig. 4. The calculated course of the cogging torque (referenced to the rated torque) as a function of rotor position (angle range of two groove scales of the stator).

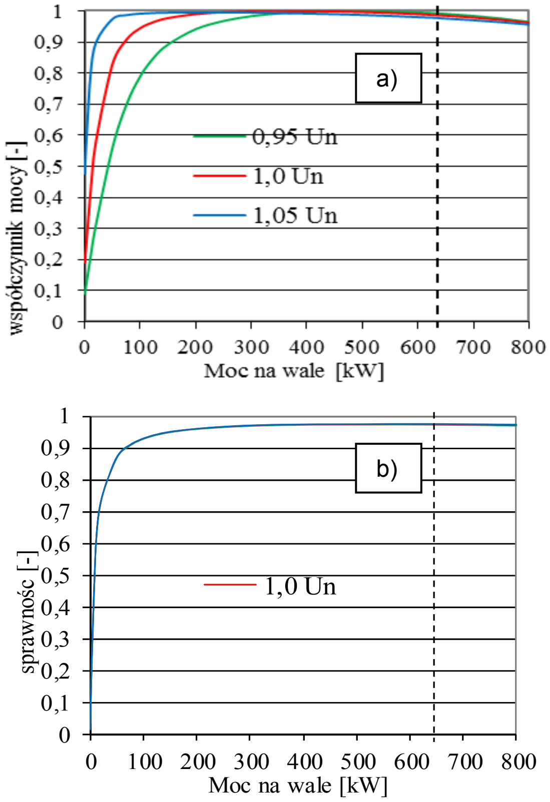

Fig. 5. Electromechanical characteristics (power factor -a, the efficiency -b) of the tested LSPMSM motor (SMH-1732T) for different values of the supply voltage

Analysis of the parameters under load

Characteristics of the load of the test LSPMSM motor were obtained by correcting the calculation results obtained by measuring the components of loss. Execution of the characteristics of the idling without the inserted permanent magnets allows for the identification of mechanical losses and basic losses in the iron core. Field-circuit simulations led to the determination of additional losses in the iron and also losses of higher harmonics in the start-up cage. The calculation results are in the form of an effective value of the armature current, and the power factor and efficiency as a function of the load on the shaft is shown in Figure 5.

The rated parameters of the motor under test are summarized in Table 1.

Table 1. The parameters of the motor type SMH-1732T

rated power	kW	630
rated rotation speed	rev / min	187.5
rated torque M_n	kN·m	32.1
voltage (U_n)	V	6000
current (I_n)	A	63
power factor	$\cos\varphi_n$	0.99
efficiency	η_n	97.1
fixed increase in the winding temperature	°C	70
inrush current	I_r/I_n	7.3
starting torque	M_r/M_n	2.0
minimal starting torque	M_{rmin}/M_n	0.95

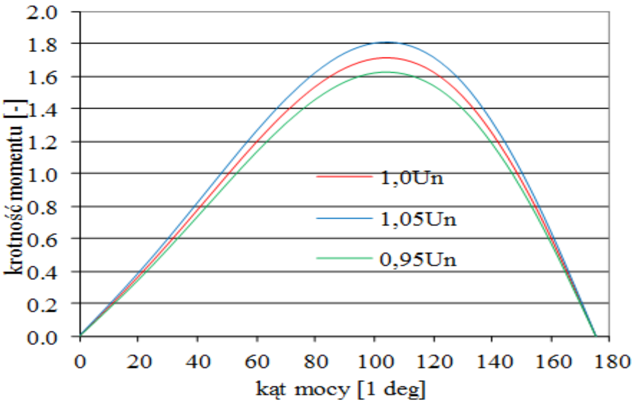

Fig. 6. The angular characteristics of M = f (ϑ) (with respect to the rated torque)

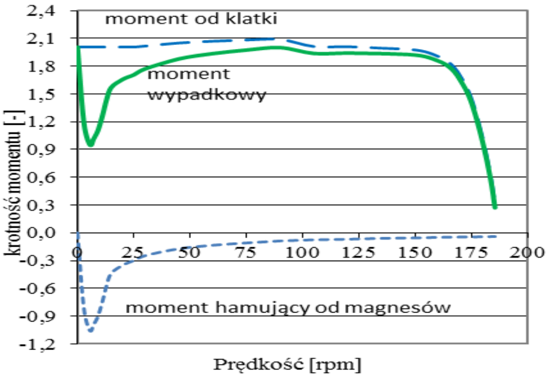

Fig. 7. Total asynchronous moment and its components on the test LSPMSM motor (referenced to the rated torque

Figure 6 shows the angular characteristics of the test LSPMSM motor, which indicates that the rated load is achieved at an angle of 50 deg. The static overload capacity of the torque is 1.7.

Thanks to the performed measuring of short-circuit characteristics, the model elements that are crucial from the point of view of the start-up properties were adjusted, and then the static mechanical characteristics were determined (Fig. 7).

Starting the motor in the workplace

The most important test for the prototype motor were run tests at the workplace. The voltage and current when starting the motor with the mill was coupled and loaded with balls. The course of the basic physical quantities during start-up are shown in Figure 8.

The measurements show that the start-up time is approximately 2 seconds. A voltage drop of approximately 7% of the rated voltage occurs at the first moment of the start-up. Along with a diminishing current taken in by the motor during start-up, the voltage restores to the level from before the time of switching. The power consumed after start-up stabilizes at a level of approximately 500 kW, which means that even a fully loaded mill charges the motor to 80% of the rated power. Much more power during start-up is converted to heat in the start-up cage.

The estimated temperature increase of the start-up cage during the full start-up is about 40 degrees C. This means that even for a warmed-up motor it is still possible to perform about 4 consecutive start-ups, which due to the nature of the mill drive is unlikely to occur.

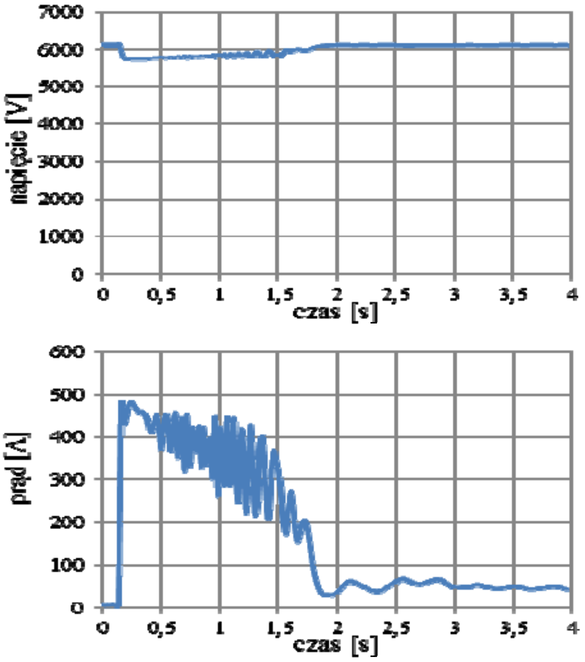

Fig. 8. Waveforms of power supply voltage and the stator current when starting the motor coupled with the loaded ball mill

Fig. 9. The existing drive of the main mine drainage using the asynchronous motor type SBUd 154d

Drive of the main drainage pump

The paper presents a model of a prototype of a synchronous motor excited by a permanent magnet with a direct start-up built into the drive of the modernized main mine drainage pump. In the project it was determined that the motor has a rated power of 1600 kW at a speed of 1500 rev / min. [12].

Figure 9 shows photographs of the existing one, and figure 10 shows the new pump drive of the main mine drainage using a synchronous motor excited by permanent magnets.

Table 2 lists the most important rated parameters of the test synchronous motor with the parameters of the permanent magnets driving the pump.

Fig. 10. The prototype synchronous motor with permanent magnets mounted on the workstation driving the main mine drainage pump

Table 2. Rated parameters of the test synchronous motor with the parameters of the permanent magnets driving the pump

rated power	kW	1 600
rotation speed	rev / min	1 500
rated torque	kN·m	10.2
rated voltage	V	6 000
rated current	A	158
power factor	---	0.99
efficiency	%	98.7
the determined temperature rise of the stator winding	°C	70
inrush current	I_r/I_n	6.5
starting torque	M_r/M_n	2.6
minimal starting torque	M_{rmin}/M_n	1.7

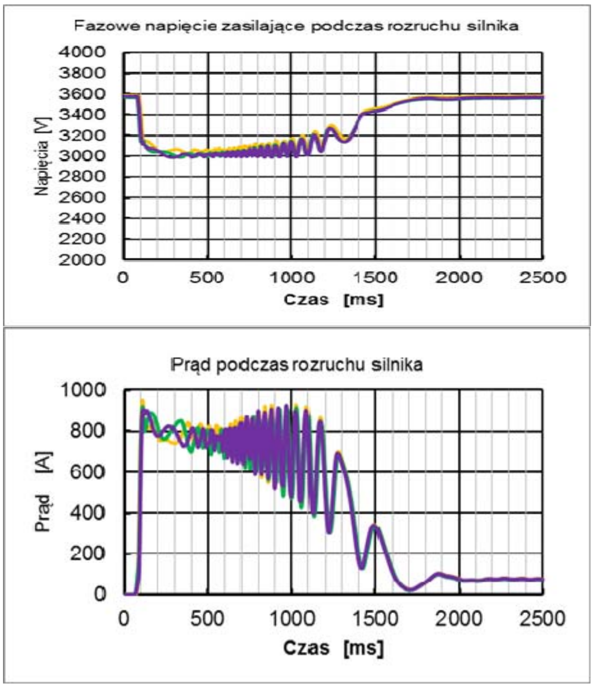

Fig. 11. The course of the stator voltage and current during start-up of the test motor

Figure 11 shows a graph of the supply voltage and current absorbed by a synchronous motor with the pump during start-up.

Summary

On the basis of the performed calculations, and especially after performing the operation tests of the prototype synchronous motor excited by permanent magnets driving the ball mill, it was found that they can be applied in electric drives that have the most difficult technical requirements related to the starting torque and moment of inertia.

The use of such motors instead of induction motors can reduce energy loss in the motor by increasing efficiency, and in the supply system by increasing the power factor and reducing the current consumed. The operating costs decrease significantly and the investment may return in a short time.

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