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Properties and parameters of the synchronous motors with permanent magnets

Abstract: *This paper presents the results of transient torque simulations during start-up of permanent magnet synchronous motor for various initial rotor positions. The influence of input voltage on starting torque transients is also considered. Examples of applications for large electric drives are shown.*

Streszczenie*: W pracy przedstawiono wyniki symulacyjnych obliczeń momentów podczas rozruchu silnika synchronicznego wzbudzanego magnesami trwałymi dla różnych kątów początkowych położenia wirnika. Wykonano obliczenia tych momentów dla różnych wartości napięć zasilających. Pokazano przekłady zastosowań takich silników w napędach elektrycznych dużej mocy.* ***Właściwości i parametry silników synchronicznych z magnesami trwałymi.***

Keywords: electric machines, synchronous motor, permanent magnet, direct on line starting
Słowa kluczowe: maszyny elektryczne, silnik synchroniczny, magnesy trwałe, rozruch bezpośredni

1. Introduction

Due to their high efficiency and almost unity power factor, direct starting motors (LSPMSM) with permanent magnets are a very good alternative to induction motors in electric drives [1, 4]. The application of permanent magnets in the rotor results in a deterioration of the starting properties in comparison to a classic induction motor. [3, 7, 8, 10]. In the case of an induction motor start-up, the torque has a constant component dependent on rotational speed and an alternating component resulting from transition processes after starting. When the LSPMSM motor is running asynchronously, permanent magnets generate additional torque components described in [2, 5, 11]. An important operating problem for both types of machines is the value of the impact torque generated immediately after the motor is started. In the case of drives with high inertia, it is transmitted via a keyed connection to the motor shaft. This issue has been thoroughly investigated for induction motors, but has not been further discussed for LSPMSM motors.

The article aims to present the properties and operating parameters of LSPMSM motors during start-up.

2. Object under investigation

The issues related to the alternating component were analysed using the field-circuit model of a four-pole 45kW LSPMSM motor, the geometry of which is shown in Figure 1. Basic parameters of this motor are presented in Table 1.

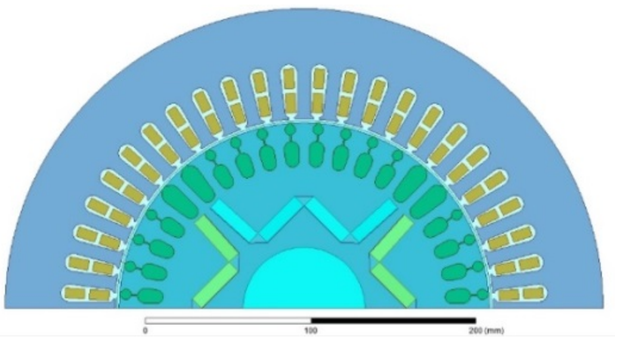

Fig. 1. Field model of the LSPMSM motor under investigation (45 kW, 1500 rpm)

3. Analysis of motor start-up characteristics

The field-circuit model of the motor was built using software Maxwell 2D (v.16.2). In the simulations, the "transient" solution was chosen, allowing for modelling of the machine's operation at voltage extortion while taking motion into account, which best reflects the phenomena under consideration. Due to the analysis of starting characteristics, the static characteristic of the starting torque and its components was calculated: asynchronous torque on cage and braking torque generated by permanent magnets. The course of this characteristic is shown in Figure 2.

Table 1. Parameters of permanent magnet synchronous LSPMSM motor

rated power (P_n)	kW	45
rated voltage (U_n)	V	400
rated current (I_n)	A	68
rotational speed (n_n)	rpm	1500
power factor ($\cos\varphi_n$)	--	0,98
rated efficiency (η_n)	%	97,0
rated torque M_n	N m	32,1
start-up current (I_r/I_n)	--	7,3
initial start-up torque (M_r/M_n)		2,25
minimum start-up torque (M_{rmin}/M_n)	--	1,35

In steady state, the generated electromagnetic torque pulses in the range from minus 4Mn to plus 8Mn, and the mean value reaches as shown in Figure 2.

3.1. Impact of the initial position on the impact torque value

In the case of asynchronous machines, the impact torque value after start-up is independent of the rotor position. This is not the case with LSPMSM machines, as the impact torque is generated both from currents flowing in the rotor cage as well as from interaction with the magnet field, which depends on the position of the rotor in relation to the voltage vector at the moment of start-up. The results of electromagnetic torque calculations in the short-circuit state (for blocked rotor) and different initial positions are shown in Figure 3a.

Based on the presented results of the calculations (Fig. 3), the maximum impact torque is dependent on the relative starting position of the rotor. In the most favourable position (ca. 0 deg), the maximum torque value is approximately 6 times higher than the rated torque and this is comparable to a typical induction motor. However, in the least favourable position (ca. 270 deg), the impact torque is about 13 times the rated torque. These differences are due to the undetermined component from the rotor cage, as after the aperiodic component has disappeared, both extreme cases will become equal as shown in Figure 3b.

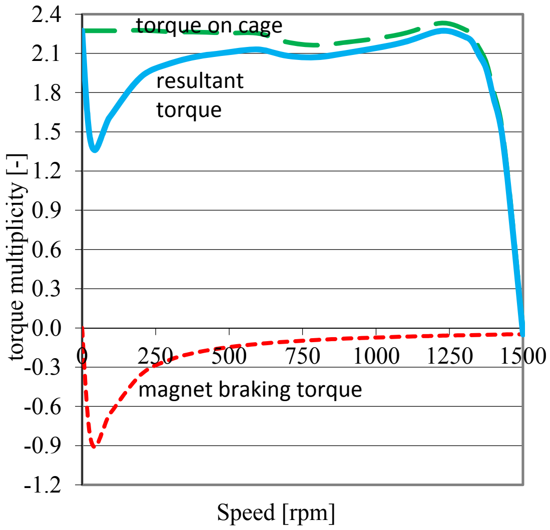

Fig.2. Total asynchronous torque and its components for the LSPMSM motor under investigation (relative to rated torque)

In practice, the power supply conditions do not have to correspond to the rated values. The value of the supply voltage may change and in the case of a network with a relatively low short circuit capacity, the voltage may drop during start-up. For this reason, the impact of supply voltage on the torque impactor during start-up has been investigated. The calculated dependency of the impact torque value on the supply voltage is shown in Figure 4.

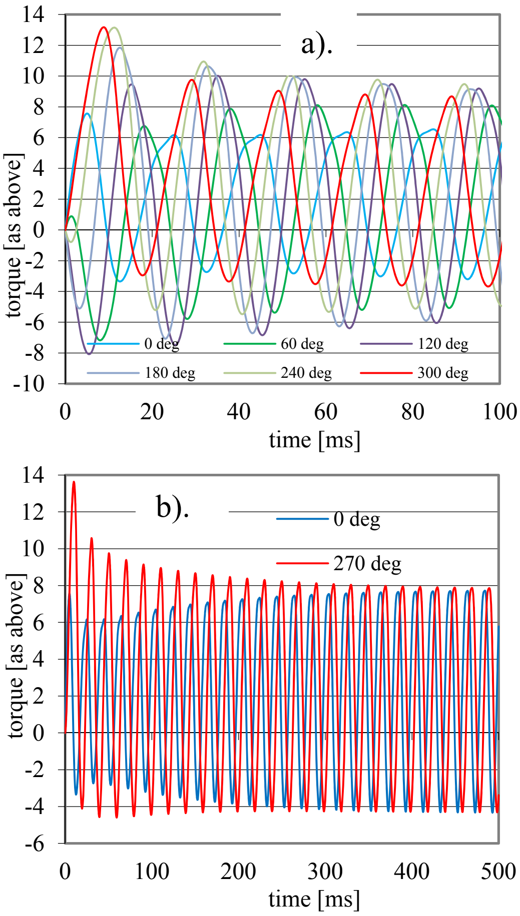

Fig.3. The course of the electromagnetic torque immediately after starting the LSPMSM motor under investigation (a) for different angles of the initial rotor position, (b) for a selected unfavourable rotor position.

3.2. Alternating torque at start-up of a synchronous motor with permanent magnets

The value of the alternating torque component depends on the rotational speed [2]. In order to show this phenomenon, calculations were made for the start-up of the motor under investigation. Figure 5 shows the course of electromagnetic torque and rotational speed at start-up with an assumed fan load and a moment of inertia about 10 times greater than the moment of inertia for the rotor.

The course of the torque demonstrates that after the transition component disappears, the alternating torque value reaches approximately 4xMn and over a wide speed range it changes only slightly. However, the frequency of these pulsations decreases significantly, which naturally results from the decreasing slippage along with the increase of the rotational speed.

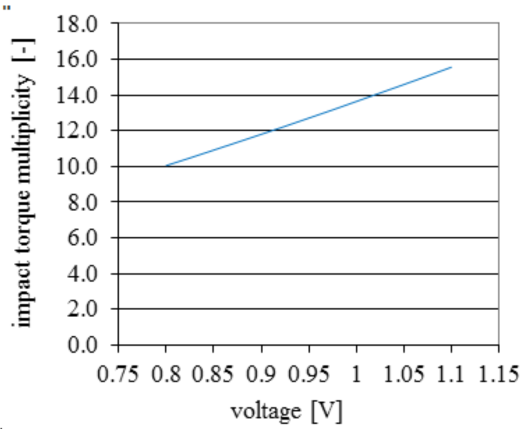

Fig.4. Dependence of impact torque multiplicity on the value of supply voltage for a synchronous motor with permanent magnets

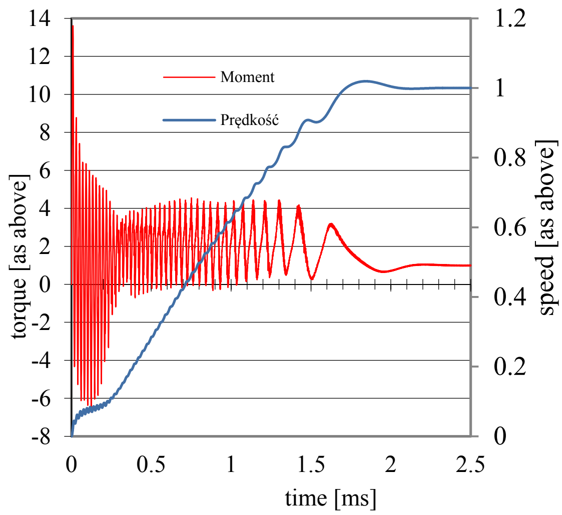

Fig.5. Time courses of the electromagnetic torque and starting rotational speed of the synchronous motor with permanent magnets

4. LSPMSM applications for high power electric drives

Using the results of the calculations and experience gained in designing permanent magnets synchronous motor, it was proposed to apply them in high-power drives. These motors are supplied with rated voltage U=6000 V.

4.1. Main drainage pump drive in a mine

Figure 6 demonstrates a picture of the pump drive of the main drainage system in an underground mine, and Table 2 presents the basic parameters of the LSPMSM motor.

Table 2. Parameters of the permanent magnet synchronous motor used for driving a pump

rated power	kW	1 600
rated current	A	158
rotational speed	rpm	1 500
rated torque	kN·m	10,2
power factor	---	0,99
efficiency	%	98,7
start-up current	I_r/I_n	6,5
initial start-up torque	M_r/M_n	2,6
minimum start-up torque	M_{rmin}/M_n	1,7
fixed increase in stator winding temperature	°C	70

Fig. 6. View of the main drainage pump drive in an underground mine

High independence of power factor (passive energy supplied from permanent magnets) and efficiency should be emphasized in case of large load changes. (Fig. 7).

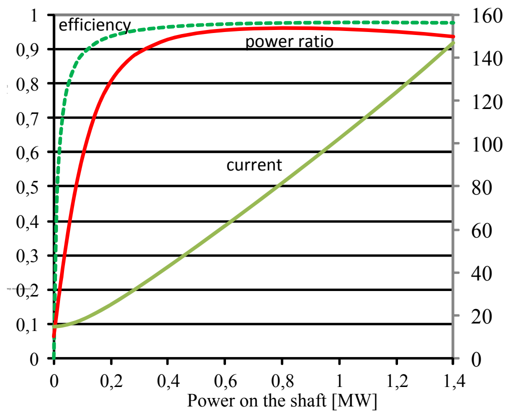

Fig. 7. Dependence of the stator current, efficiency and power factor on the motor load

Fig. 8. View of the main fan drive in an underground mine

4.2. Main fan drive for an underground mine air conditioning

Figure 8 shows a picture of the main fan drive with LSPMSM motor in an underground mine station.

4.3. Ball mill drive

Figure 9 shows a picture of the ball mill drive, and Table 3 shows basic parameters of the LSPMSM motor. A large number of poles (small rotational speed) of this motor is worth noticing.

Table 3. Parameters of permanent magnet synchronous motor driving a ball mill

rated power	kW	630
rated current	A	63
rated rotational speed	**rpm**	**187,5**
power factor	$\cos\varphi_n$	0,99
efficiency	η_n	97,1
rated torque M_n	kN·m	32,1
start-up current	I_r/I_n	7,3
initial start-up torque	M_r/M_n	2,0
minimum start-up torque	M_{rmin}/M_n	0,95
fixed increase in winding temperature	°C	70

5. Conclusions

Based on the calculations and experimental studies, it can be concluded that the value of alternating torque in asynchronous operation of the LSPMSM motor is an important operational issue. The impact torque in this type of motors is much higher than in induction motors, which should be taken into account when designing the mechanical design of the drive. This torque depends on the time of applying voltage.

The results of the calculations are shown for a motor model with a rated power of 45 kW (Table 1), but calculations made for other machines, different powers and the number of pole pairs show that the nature of the phenomena is very similar.

The designed and manufactured direct starting synchronous motors with high-power permanent magnets have been implemented in various types of drives and operating for several years without failure.

Fig. 9. View of the ball mill drive

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