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Compared analysis of the transients and the steady states of squirrel-cage motor and LSPMSM

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In the paper the transients under starting process and the steady states of squirrel-cage motor (IM) and line start permanent magnet synchronous motor (LSPMSM) have been compared. The original stator of 3 kW induction motor type Sg 100L-4B, was used in both structures. In order to determine opportunities to increase energy parameters of LSPMSM the heating curves of both motors were compared. In LSPMSM the rotor with aluminum and copper cage was used. The basic operating parameters of the two structures which are characterized by identical stators were tested. Particular attention has been given to the transient under starting process. Efficiency, power factor and current in the stator windings obtained during measurements for both structures have been presented. The paper focuses on achieving a much higher output power for LSPMSM than an induction motor of the same size. The selected results of experimental tests were shown.

KEYWORDS: words: squirrel-cage motor, line start permanent magnet synchronous motor, starting process, heating, functional parameters

1. Introduction

Induction motors used in electric drives are increasingly being replaced by permanent magnet synchronous motors (PMSM). This is due to the lower operating costs of these motors, which are the result of increasing the efficiency and power factor parameters while reducing the overall dimensions compared to the adequate induction motors [22]. Structures with sectional magnet surface have been developed [12, 14]. In pursuit of reduce costs and production time is proposed to perform structural components of motors with powder material [16, 19, 20] in a single step of manufacturing.

The main disadvantage of PMSM is necessary to use power electronics converter systems under starting process. Significantly increases this cost of the whole drive system. In order to avoid this inconvenience in many research centers are carried out intensive work on Line Start Permanent Magnet Synchronous Motors (LSPMSM) [4, 6, 9, 11, 13]. These motors due to their advantages are used instead of squirrel-cage motors among others in mining. In order to reduce production costs of synchronous motors, very often in mass-produced are used components of induction motors (eg. stator cores, housings, bearing frames, terminal boxes, cooling systems) [11], are kept the same length of the core and the size of the shaft height. Methods for achieving growth of energy parameters are very different. With respect to induction motors can be recommended information contained in [2, 10, 17, 23]. Structures of LSPMSM are developed [6, 9, 11, 13].

It is important to pay attention to the restrictions related to heating of the winding insulation and proper mapping of thermal phenomena in the design of these machines. This problem is especially important during transient's analysis as well as operating conditions. For this reason, many research centers in Poland also deals with the analysis of thermal phenomena in AC machines [1, 3, 4, 5, 18].

In this paper, the authors present the test results related to improvement such parameters as efficiency, power factor and power output of LSPMSM with the same dimensions as the induction motor.

2. Construction of investigated motors

Three-phase squirrel cage motor type Sg 100L-4B with output power 3 kW, rated speed 1415 rpm, nominal voltage 3x400 V were tested. The stator consists of 36 semi-closed slots and is wounded with single layer 3 phase winding. The rotor cage has 28 skewed slots (Fig. 1). The machine is designed for medium and light starts-up.

The structures of designed of LSPMSM has been based on the stator of 4 pole, 3 kW IM type Sg100L-4B. The rotor cage has 28 bars placed over "U" arrangement of N42SH magnets embedded into laminated rotor core. Two rotors of considered motor were used. In one rotor is made squirrel cage with aluminum round rods, and the other with copper (Fig. 2). This construction of LSPMSM allows a comparative analysis of the energy parameters determined in the steady state and the starting parameters of both motors.

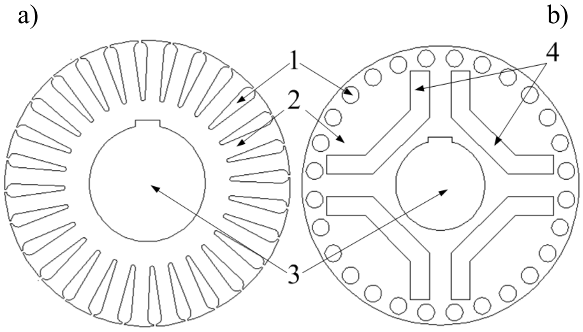

Fig. 1. Cross section of rotor a) IM, b) LSPMSM (1 - cage winding, 2 - rotor core, 3 - shaft, 4 - magnets)

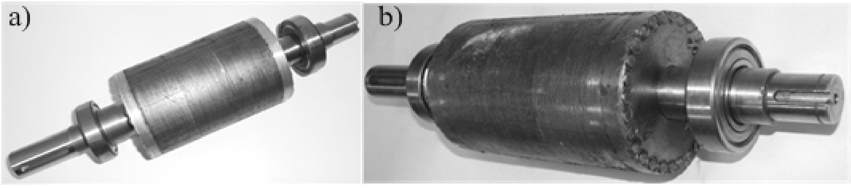

Fig. 2. LSPMSM rotor with cage a) aluminium, b) copper

The increase of power output is limited by maximum temperature rise in induction motor that could damage the insulation of the windings, and mainly high temperature resistant magnets in LSPMSM. Maximum operating temperature of neodymium magnets ranges from 80°C to 200°C [21]. This temperature depends on the components used. Neodymium magnets are sintered by powder metallurgy with chemical composition of Neodymium (Nd), Iron (Fe), Boron (B) and a binder (plastic or resin). Most sold neodymium magnets are resistant to temperatures up to 80°C or 120°C. In the built rotor are used magnets with the following parameters:

- B_r = 1,21-1,25 [T],
- H_c = min. 907 [kA/m],
- BH_{max} = 286-302 [kJ/m^3],
- maximum operating temperature 150°C.

In order to determine the possibility of exploiting the energy parameters of new LSPMSM construction, it should be noted that at increased load of the motor the temperature should not exceed the maximum operating temperature magnets.

3. Results of measurements

Developed LSPMS motor construction is a replacement for an induction motor. For this reason, rated torque of squirrel cage motor (T_N = 20 Nm) as the standard value during the researches was considered. The measurements during transients and steady state of the motor have been tested. The test stand is shown in Fig. 3.

The test stand allows to measure of currents, voltages, powers, rotational speed and torque loads on the shaft of motors. In order to avoid reading errors the electrical volumes were measured with the used of digital and analog devices. The load torque and rotational speed of the considered motors were measured by torque's head as well as by motor test bench.

Figure 4 shows the torque waveforms (Fig. 4a) and the rotational speed (Fig. 4b) on the shaft of rotor. The starting of motors at a supply voltage U = 400 V, working at no-load (no mechanical connection to the load) were tested. The obtained torque and rotational speed time characteristics for the last period of supply voltage are shown in the right corner of those figures. Based on the obtained results it can be concluded that the use copper cage instead aluminum cage in the synchronous motor resulted in a significant reduction of starting time (Fig. 4).

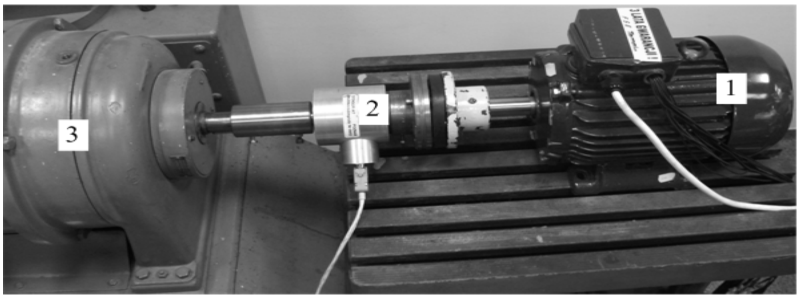

Fig. 3. Test stand for measuring squirrel cage motor and LSPMSM: motor (1), head for measuring torque and rotational speed (2), brake (3)

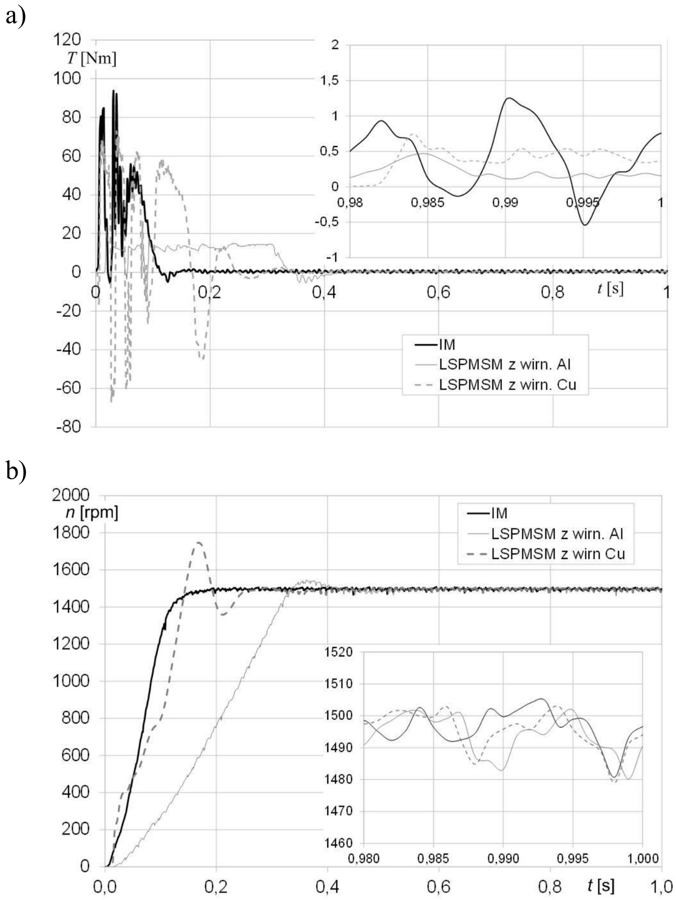

Fig. 4. Electromagnetic torque waveform (a) and rotational speed waveform (b) for $T_o = 0$ Nm

In order to measure of temperature of the three coils belonging to different groups of the phase windings were used temperature sensors PT-100. Three sensors were placed in the middle of the slots length in the open area of stator slot, as indicated by the arrow - 1 in Fig. 5. The next three sensors were located between the coils winding successive phases just after the end of the stator core. Temperature sensors were connected to an eight-RTD01 SCC module National Instruments and to the computer. Windings temperature in the open area of stator slots and end turns area were recorded. After recording the temperature of the six sensor PT-100 curves of heating coils in the previously described locations to place these sensors were determined (Fig. 5). Figure 6 shows the average temperature increase of windings in the open area of the stator slot and end turn area of both motors.

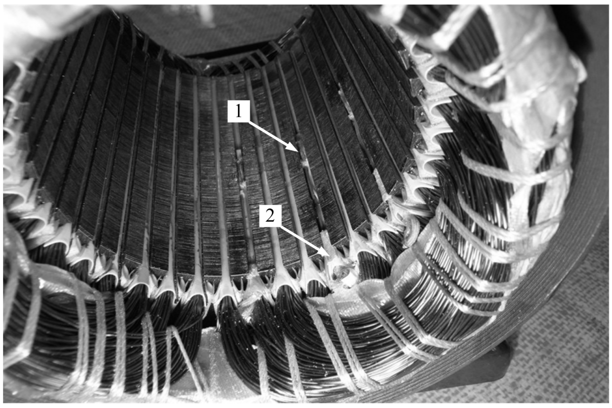

Fig. 5. Stastor with sensors PT-100 (1- in the middle of the slot length, 2 - in the end turn area)

Figure 7 presents heating curves of the LSPMS motor with copper squirrel-cage of the rotor at free air flow (without fan) and at forced air flow (with fan) that cools this machine. Temperature rise in the motor without the fan is much larger than the motor with the fan. For the heating time t = 90 minutes the temperature difference is approx. 60°C, and the heating process of the motor without the fan is still going (Fig. 7).

Based on the measurement results, it was found that for the rated load of the induction motor T = 20 Nm the temperature of LSPMSM is about 30°C lower than in IM motor. This is due to the generation of smaller power losses in the LSPMSM because there is no power loss in the rotor and losses in the stator are decreasing (less current in the stator windings). The synchronous motor rotor rotates at a speed of the magnetic field generated by the stator winding. For this reason, in steady state operation of motor, electromotive force does not induced in squirrel cage and no current will be. Therefore, there will be no loss of power in the squirrel cage winding. It will be no losses in the rotor core too, because magnetic field of the rotor does not change during LSPMSM operation. For these reasons, the synchronous motor can be loaded more power. For load torque about 20% greater than T = 20 Nm synchronous motor temperature rise is over 15°C smaller than the induction motor.

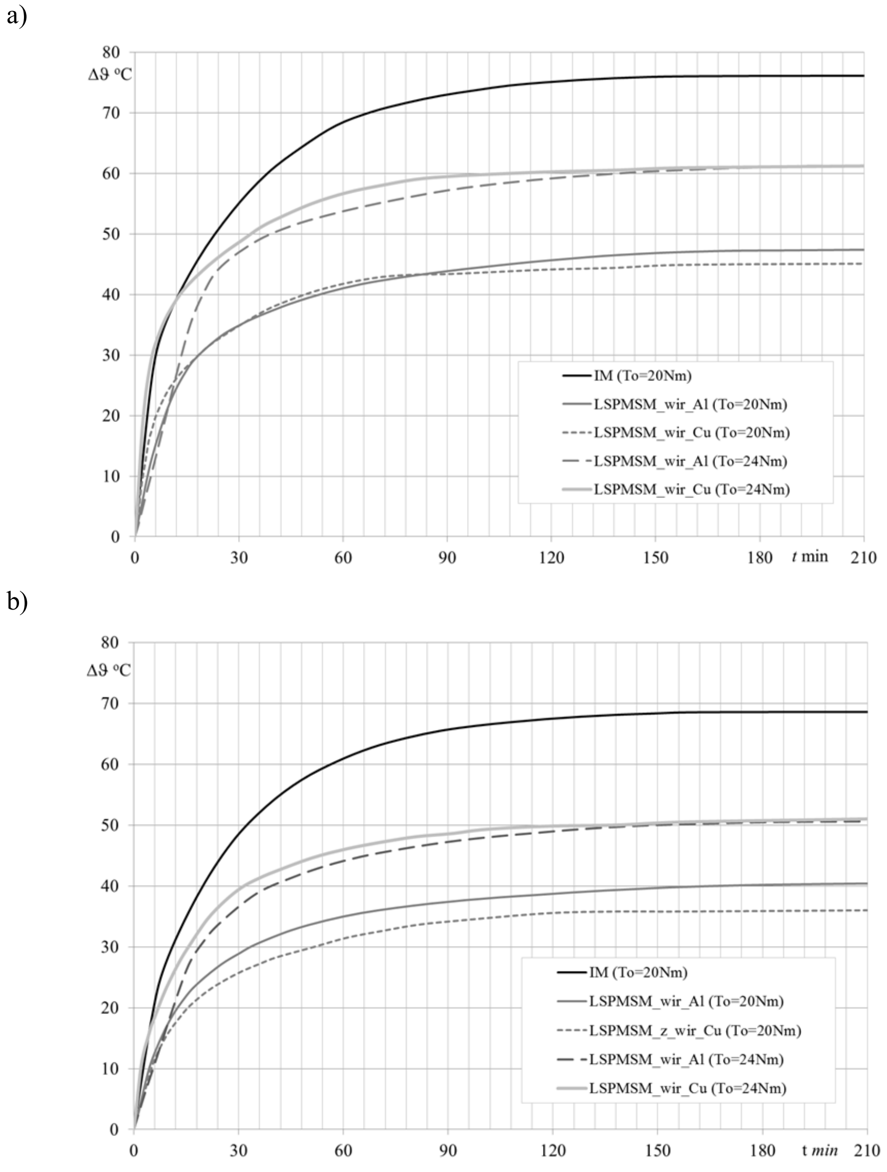

Fig. 6. Heating curves for T_o=20 Nm (motors IM i LSPMSM) and for T_o=24 Nm (motor LSPMSM) in end turn area (a) and in the middle of the slot length (b)

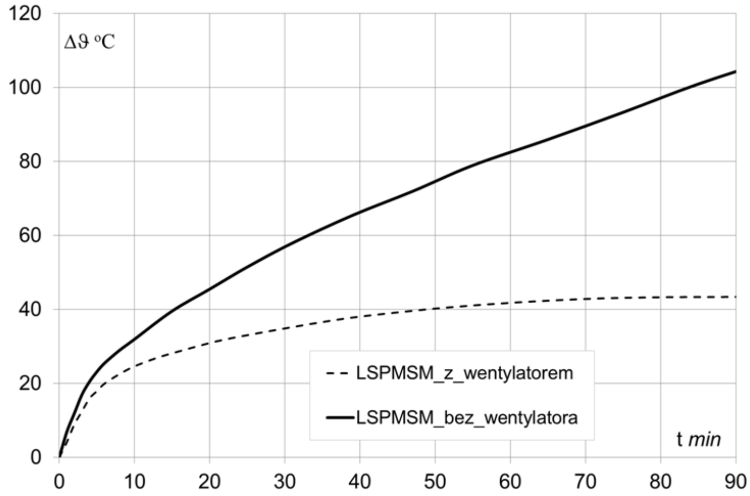

Fig. 7. Heating curves of motor LSPMSM with the fan and without the fan in end turn area, for T_o=20 Nm,

In order to compare the energy parameters of both motors, Table 1 presents values of efficiency, power factor, the current in the stator windings as well as the output power.

Table 1. Functional parameters in steady state operation of considered motors

Motor parameters	Squirrel-cage T = 20Nm	LSPMSM	
		T = 20Nm	T = 24Nm
η [%]	0,81	0,86	0,88
cosφ [-]	0,81	0,93	0,94
I [A]	7,2	6,0	7,1
P_u [kW]	3,0	3,1	3,8

On the basis of the obtained functional parameters of considered motors (Tab. 1) we can see that when the load torque of LSPMSM is greater by 20% than his nominal torque then the temperature increase of LSPMS motor is lower about 15°C than in induction motor. This is due to also the increase in load torque and the increase in speed to 1500 rpm. Therefore, the flow rate of pumps and fans driven by LSPMS motors is also increased proportionally.

On the basis of measurements of electrical and mechanical parameters of tested motors were determined efficiency (Fig. 8a), power factor (Fig. 8b), and current in stator winding (Fig. 8c) as a function of the load torque. The obtained characteristics are confirmed by improved functional parameters of the new LSPMSM (increase efficiency and power factor, and reducing the current in the stator windings at the same load) relative to the induction motor of the same stator.

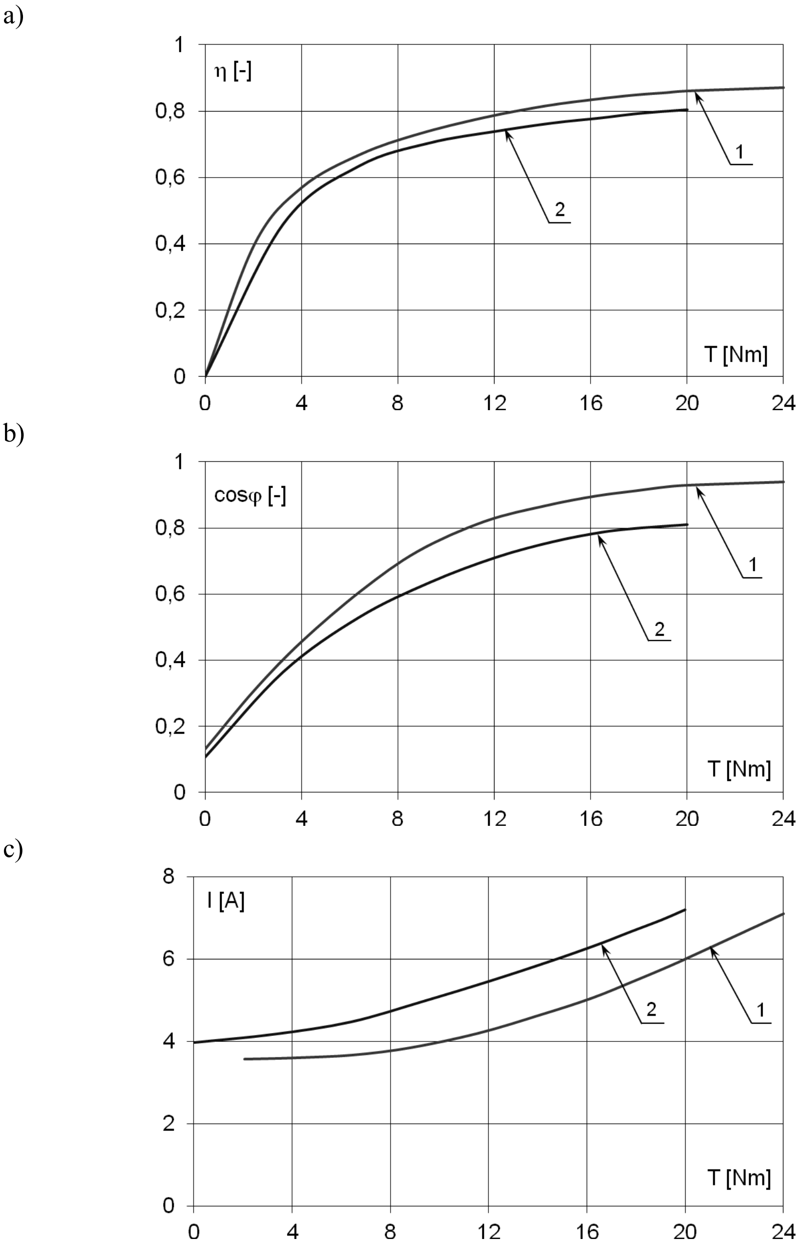

Fig. 8. Efficiency (a), power factor (b), current in the stator windings (c) as a function of the load torque of LSPMSM (1) and inductor motor (2)

4. Conclusions

Elaborated LSPMS motor is characterized by better parameters than the squirrel-cage motor of the same size. The power factor and efficiency of permanent magnet motor are significantly higher than the values obtained for the induction motor. RMS current of LSPMSM in steady state with the same load on both machines is approx. 20% less than in classical asynchronous motor. Results of measurements are proved that permanent magnet synchronous motors can be successfully applied in energy-intensive industry to drive fans and pumps. It is therefore appropriate to implement this type of machinery for the production and operation.

Looking from the performance point of view, on the basis of obtained results it can be seen that using a simple replacement of the squirrel-cage rotor of asynchronous machine on the rotor of a suitably shaped magnetic circuit can be obtained LSPMSM, which can achieve proper synchronization. Moreover, it has been found that functional parameters of new construction machines are better than the squirrel-cage motor parameters.

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