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SINGLE-PHASE LINE START PERMANENT MAGNET SYNCHRONOUS MOTOR

Abstract: The paper deals with construction of single-phase line start permanent magnet synchronous motor. Circuit-field model based on the mass production single-phase induction motor was applied in Maxwell ver. 14 program. On the basis of obtained simulation results load characteristics: current, power factor and efficiency against load power were examined. Starting properties were also examined Obtained results of the single-phase line start permanent magnet synchronous motor properties were compared with the induction motor properties.

1. Introduction

Single-phase induction motors are widely used in domestic appliances and light-duty industrial applications where three-phase supply is not readily available. Rated power of this type of electric motors is limited by rated current of the single-phase 230 V socket which is almost always equal to 16 A. It follows that single-phase induction motor rated power does not exceed 3 kW.

In induction motors torque is developed due to slip between stator rotating magnetic field and rotor bars. It causes rotor copper loss due to flowing current through the rotor bars. Moreover, magnetizing current is needed to produce magnetic flux. It causes additional stator copper loss due to flowing current through the stator winding.

In synchronous motors magnetic flux is produced by the excitation: electromagnets or permanent magnets. It follows that the whole or most of the magnetic flux can be produced inside the machine and no or relatively small value of the reactive power [and simultaneously of the magnetizing current] is absorbed by the working motor. In case of permanent magnet excitation of a synchronous motor there is no rotor copper loss due to no slip and no DC current flowing through the excitation winding. However, typical synchronous motor has electromagnetic excitation which needs high maintenance and additional DC supply. Moreover, synchronous motors have bad starting properties.

Stators of induction motors and synchronous motors are practically the same so the simplest way to obtain high both power factor and efficiency [advantages of a synchronous motor] and inherent self-starting property, simplicity and ruggedness [advantages of an induction motor] of an AC motor is installation of permanent magnets inside the induction motor rotor saving its squirrel-cage [1, 2]. This type of motor is called Line Start Permanent Magnet Synchronous Motor.

In case of three-phase motors this operation is relatively easy because of circle rotating magnetic field. In case of single-phase motors the air gap magnetic field would be an ellipse field [because of the asymmetry of stator configuration] and can be decomposed into a positive-sequence rotating field and a negative-sequence one [6]. The negative-sequence magnetic field produces a braking torque in the motor, which makes efficiency and output torque low, and makes the mechanism character being soft [5]. This phenomenon causes a big problem during motor starting and synchronization but it can be solved by additional start-capacitor in the auxiliary winding. Start-capacitor connected in parallel with run-capacitor improves starting properties but simultaneously makes worse running properties so after starting it must be switched-off by centrifugal switch or time switch [5, 6].

2. FEM model

Two dimensional field-circuit model of the single-phase line start permanent magnet synchronous motor was applied in Maxwell ver. 14 program. The model is based on the mass production single-phase induction motor Seh 80-4B type with P_n=750 W, U_n=230 V, f_n=50 Hz, n_n=1370 rpm. Neodymium magnet N45H type with B_r=1,34 T and H_{cb}=995 kA/m was chosen for the excitation of the synchronous motor. Single-phase induction motor was changed into single-phase line start permanent magnet synchronous motor by replacement standard squirrel-cage rotor with squirrel-cage permanent magnet rotor. The

rotor slots were kept without changes. End ring width was reduced because permanent magnets were installed in the end ring area. The end sheets of the rotor core do not contain the permanent magnet slots to avoid flowing hot aluminum into them during casting of the rotor squirrel-cage. The rotor squirrel-cage is cast in the same way for single-phase induction motor and single-phase line start permanent magnet synchronous motor but in case of SPLSPMSM the end rings and the end rotor sheets are machined after casting to open slots for installation of permanent magnets.
Field part of the motor model is shown in Fig. 1 and circuit part of the motor model is shown in Fig. 2.

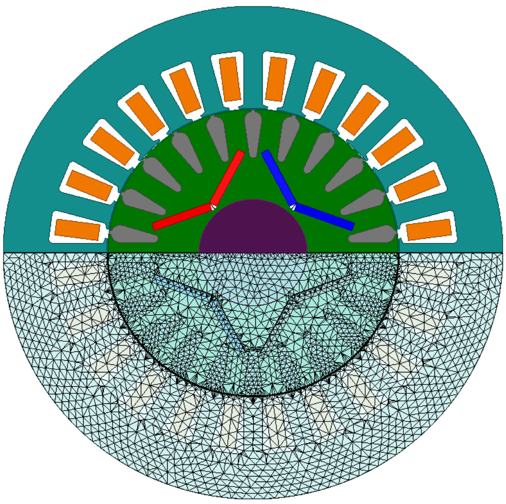

Fig. 1. Field part of the motor model

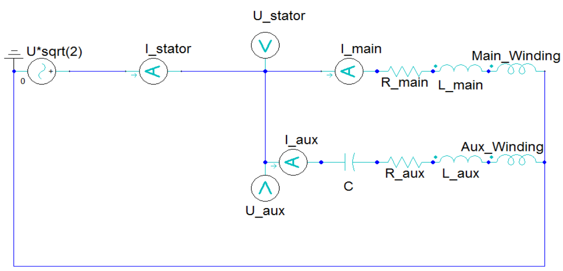

Fig. 2. Circuit part of the motor model

3. Optimal solution

LSPMSM can be recommended for drives with constant load torque and low starting torque such as pump or fan [4].
The motor to drive a pump or a fan is chosen according to the formula (1):

$$P_{motor} = k \cdot \frac{Q \cdot \Delta p}{\eta} \quad (1)$$

where:

P_{motor} – motor power in [W],
k – reserve coefficient, k=1,1–1,15,
Q – flow rate in [m^3/s],
Δp – static pressure in [Pa],
η – fan/pump efficiency.

On the basis of the equation (1) the motor to drive a fan or a pump is chosen with reserve of the power. It follows that in nominal conditions the motor works in the range of the load power (0,86–0,91) P_n.
According to the above-cited facts this paper introduces basic strategy for the design of the auxiliary winding [number of the auxiliary winding turns and capacitance of the run-capacitor] to obtain the maximum of the motor efficiency [3, 5] in the range of the load power (0,86–0,91) P_n.
The single-phase induction motor rated power P_n=750 W. SPIM is changed into SPLSPMSM by replacement standard squirrel-cage rotor with squirrel-cage permanent magnet rotor. SPLSPMSM has higher rated power [4, 5]. Electric motors are classified by their rated power with proper values. Next step in this classification for the motor with P_n=750 W is the motor with P_n=1100 W. For the investigated SPLSPMSM model the rated power was determined as the next step in the motor rated power classification so $P_{SPLSPMSMn}$=1100 W.

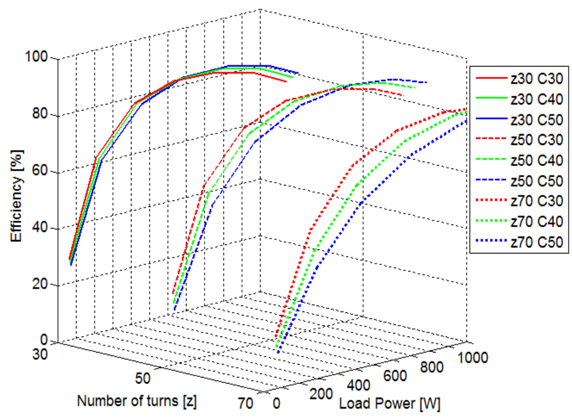

Fig. 3. Influence of changes of the auxiliary winding parameters on the motor efficiency

The initial investigation of the influence of changes of the auxiliary winding parameters (number of the turns and capacitance of the run-capacitor) on the motor efficiency curve is presented in Fig. 3. It follows that increase of the run-capacitor capacitance moves the maximum of the motor efficiency towards

higher load power and optimal solution according to the established criterion is expected to be in surroundings of the number of the auxiliary winding turns equal to 50 turns.
More accurate investigation is presented in Fig. 4. It follows that the optimal solution according to the established criterion is obtained for $N_{AUXturns}$=50 turns and C_{run}=40 µF and this solution would be compare with the base SPIM for which $N_{AUXturns}$=94 turns and C_{run}=20 µF.

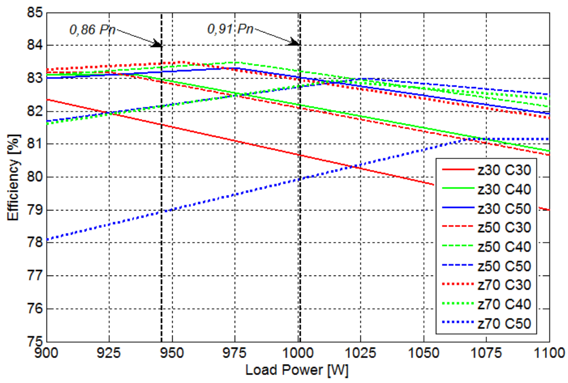

Fig. 4. The optimal solution for SPLSPMSM

4. Running properties

Comparison of the SPIM and SPLSPMSM load characteristics is presented in Fig. 5.

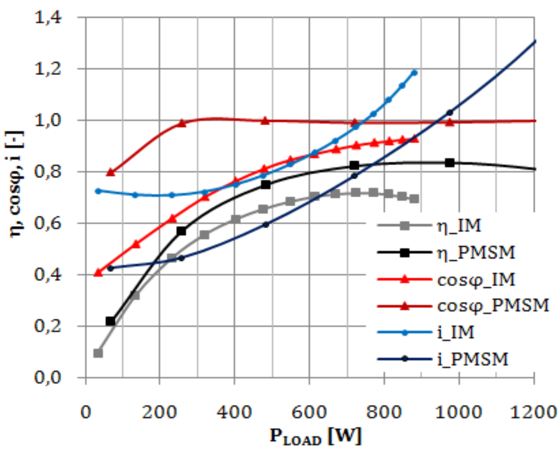

Fig. 5. SPIM and SPLSPMSM load characteristics

The obtained results of the SPIM and SPLSPMSM rated performance are shown in Tab. 1.

Tab. 1. Comparison of SPIM and SPLSPMSM

parameter	unit	SPIM	SPLSPMSM
P_n	W	750	1100
U_n	V	230	230
I_n	A	5,02	5,73
η_n	%	71,6	82,5
$\cos\varphi_n$	-	0,91	0,99
n_n	rpm	1395	1500
T_n	Nm	5,3	7,0

SPLSPMSM efficiency is much higher than SPIM efficiency because SPLSPMSM rotor copper loss is much lower than SPIM rotor copper loss what is presented in Fig. 6.

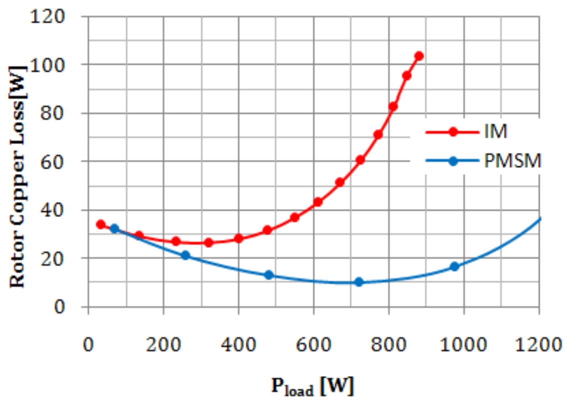

Fig. 6. SPIM and SPLSPMSM rotor copper loss

SPLSPMSM power factor is higher than SPIM power factor and besides it is leading so SPLSPMSM during its running produces reactive power.

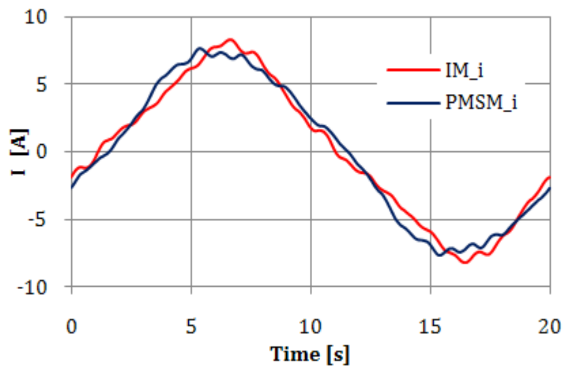

Fig. 7. SPIM and SPLSPMSM currents for rated load power

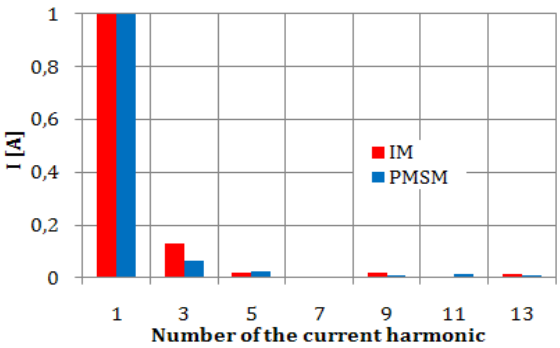

Fig. 8. SPIM and SPLSPMSM current harmonics analyses

Apart from bad starting properties LSPMSM have another significant drawback- significantly distorted current [4]. In case of SPIM and SPLSPMSM this phenomenon is different because both SPIM current and SPLSPMSM current for their rated load power are distorted. Moreover, the third current higher harmonic in SPLSPMSM is two times lower than in case of SPIM. It follows that installation of permanent magnets inside the SPIM rotor does not influence harmfully on the current distortion. The current shapes are presented in Fig. 7 and their harmonics analyses in Fig. 8.

5. Starting properties

LSPMSM are recommended for pumps or fans because of good running properties and poor starting properties [4]. Typical pump or fan load characteristic is shown in Fig. 9.

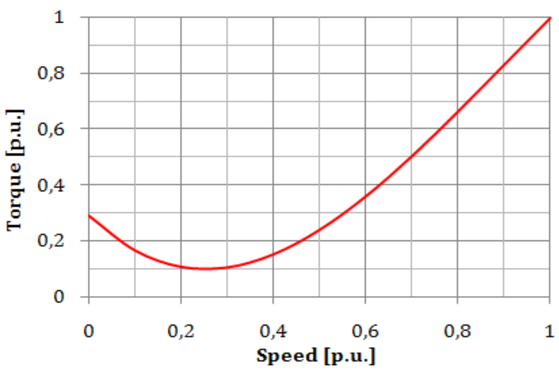

Fig. 9. Typical pump/fan load characteristic

To investigate starting properties of the SPLSPMSM pump/fan load characteristic was assumed. The rated load torque was equal to the SPLSPMSM rated torque and moment of inertia of the whole drive system was assumed to be five times greater that the SPLSPMSM moment of inertia according to the formula (2):

$$J = 5 \cdot J_{motor} = 0{,}01 kgm^2 \qquad (2)$$

For the chosen optimal solution of the SPLSPMSM two start-capacitors was applied: 100 μF and 150 μF. The results of starting simulation are presented in Fig. 10, 11 and 12.

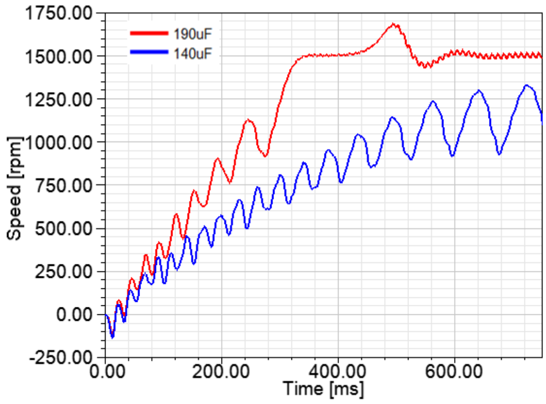

Fig. 10. SPIM and SPLSPMSM starting speeds

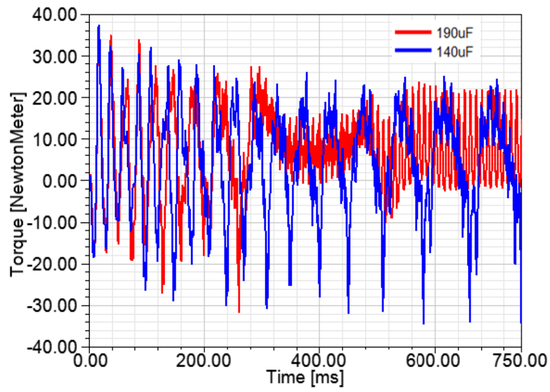

Fig. 11. SPIM and SPLSPMSM starting torques

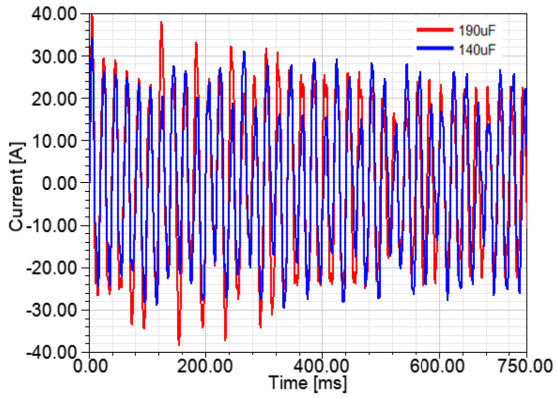

Fig. 12. SPIM and SPLSPMSM starting currents

According to the obtained starting simulation results it follows that increase of capacitance of the start-capacitor improves starting properties of SPLSPMSM and makes better ability to synchronisation. Moreover, increase of capacitance of the start-capacitor causes a little increase of the starting current.

6. Conclusions

The main advantages of single-phase line start permanent magnet synchronous motor in comparison with single-phase induction motor are:

- greater power from the same volume of the machine,
- higher efficiency,
- higher power factor,
- constant speed.

The main drawbacks of single-phase line start permanent magnet synchronous motor in comparison with single-phase induction motor are:

- start-capacitor and start-capacitor switch demand,
- more complicated construction.

Taking the SPLSPMSM very good running properties and simultaneously its average starting properties into account SPLSPMSM can be recommended for drives with constant load torque and low starting torque such as:

- pumps,
- compressors,
- blowers,
- fans.

7. Bibliography

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