

MACIEJ GWOŹDZIEWICZ, JAN ZAWILAK\*

## SIX-POLE SINGLE-PHASE LINE START PERMANENT MAGNET SYNCHRONOUS MOTOR

SZEŚCIOBIEGUNOWY JEDNOFAZOWY SILNIK  
SYNCHRONICZNY Z MAGNESAMI TRWAŁYMI  
O ROZRUCHU BEZPOŚREDNIM

### Abstract

This paper deals with the results of experimental investigation into a six-pole single-phase line start permanent magnet synchronous motor. The influence of the running capacitor capacitance on the motor running properties was investigated. The influence of the starting capacitor capacitance and its switch-off time on the motor starting properties was investigated.

*Keywords: electric machines, single-phase motor, permanent magnet, high efficiency motor*

### Streszczenie

W artykule przedstawiono wyniki badań eksperymentalnych jednofazowego silnika synchronicznego z magnesami trwałymi o liczbie biegunów  $2p = 6$ . Zbadano wpływ pojemności kondensatora pracy na właściwości eksploatacyjne silnika.

*Słowa kluczowe: maszyny elektryczne, silnik jednofazowy, magnesy trwałe, silnik wysokosprawny*

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\* Ph.D. Eng. Maciej Gwoździewicz, Prof. D.Sc. Ph.D. Eng. Jan Zawilak, Faculty of Electrical Engineering, Wrocław University of Technology.

## 1. Introduction

The norm IEC 60034 part 30 orders the electrical motor producers to produce electrical motors with minimum factor of the efficiency. The goal of this command is to minimize electrical energy consumption through the minimizing of electrical motor power losses. Nowadays, this norm ranges low-voltage electric motors with rated power  $0.75 \text{ kW} \leq P_n \leq 375 \text{ kW}$  and the number of pole pairs  $2p = 2; 4; 6$ . The new project of the norm assumes widening of the electrical motor rated power range up to  $0.12 \text{ kW} \leq P_n \leq 1000 \text{ kW}$ , the number of pole pairs up to  $2p = 2; 4; 6; 8$  and including multi-phase motors (also single-phase motors).

Polish and World producers of electric motors responded to the norm requirements by designing and producing high-efficiency three-phase motors which fulfil the norm by achieving the minimum factor of efficiency. The electrical motor producers respond did not include single-phase motors which are not yet included by the norm.

If the new norm project IEC 60034 part 30 was valid, no single-phase motor produced nowadays would fulfil the norm requirements.

In articles [1, 5, 6], the possibility of building a single-phase line start permanent magnet synchronous motor was proven. The single-phase line start permanent magnet synchronous motor would achieve much better running properties than the single-phase induction motor. Taking into account the modern electrical motor development, we can suppose that in the case of restricted new requirements of producing electrical motors, producers of single-phase motors will be forced to design and produce single-phase line start permanent magnet synchronous motors.

## 2. Construction of six-pole single-phase permanent magnet synchronous motors

In Maxwell software, two circuit-field models of single-phase line start permanent magnet synchronous motors were built. The models were based on the mass production four-pole single-phase induction motor type SEh 80-4B supplied by a voltage of  $U_n = 230 \text{ V } 50 \text{ Hz}$ . The

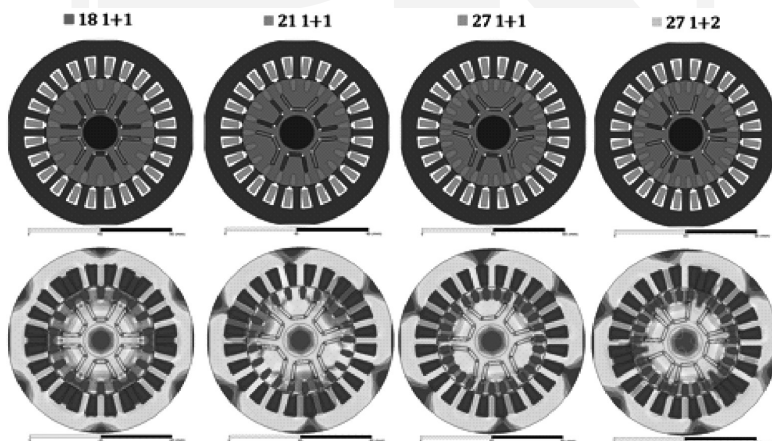


Fig. 1. Cross-sections and magnetic field distributions in built models of six-pole single-phase line start permanent magnet synchronous motor

motor winding was rewound. Cross-sections of the models and magnetic field distributions are shown in the Fig. 1. Neodymium magnet N38SH with remanence induction  $B_r = 1.24$  T and magnetic field coercivity  $H_{cb} = 990$  kA/m was chosen for the excitation. The methodology of the single-phase line start permanent magnet synchronous motor design was revealed in article [3]. Papers [2, 4, 7] were also helpful for the designer.

The motor needs two capacitors, a run-capacitor and a start-capacitor. The best running properties for both motors were obtained for run-capacitor capacitance  $C_{run} = 50$   $\mu$ F. Starting capacitor capacitance  $C_{start} = 100$   $\mu$ F is enough capacitance for the motor self-starting with a time switch-off relay which switches off the starting capacitor after motor synchronization.

The design process of the motor was divided into two steps. During the first step, the influence of the motor construction on the back EMF induced by permanent magnets in the motor main winding was investigated. The results are presented in Fig. 2. During the second

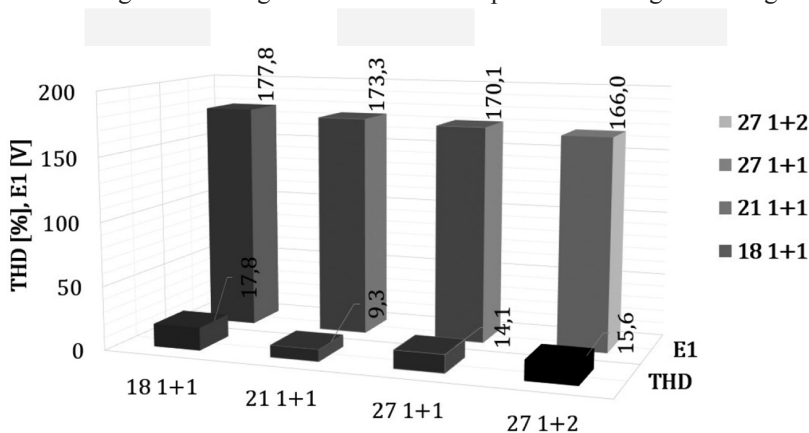


Fig. 2. Influence of the motor construction on the 1<sup>st</sup> harmonic RMS value and total harmonic distortion of the back EMF induced by permanent magnets in the motor's main winding

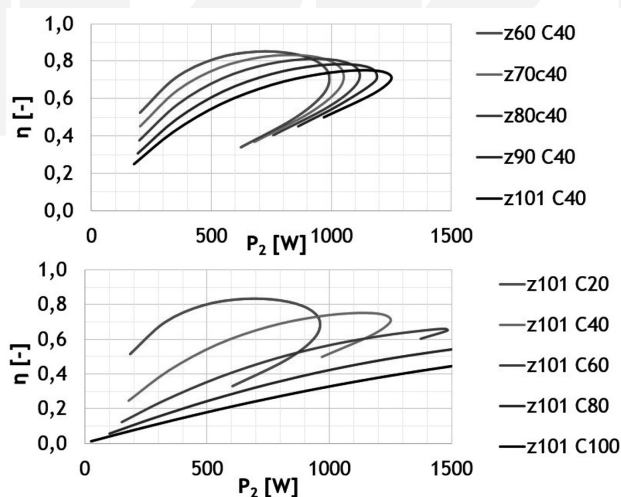


Fig. 3. Influence of the number of the auxiliary winding turns and running capacitor capacitance on the motor efficiency curve

step, the influence of the motor auxiliary winding parameters on the motor performances was investigated. The results are shown in Fig. 3.

On the basis of the obtained results, the physical model of the six-pole single-phase line start permanent magnet synchronous motor was built. The model is presented in Fig. 4. The rotor has 21 bars. The die cast squirrel cage of the rotor is made from aluminum.



Fig. 4. Rotor of the physical model of the six-pole single-phase line start permanent magnet synchronous motor

### 3. The motor performance

The influence of the running capacitor capacitance on motor performance was investigated. The results are shown in Fig. 5. An increase in the running capacitor capacitance causes an increase in the maximum load power, a decrease of the motor efficiency of the low load and an increase in the motor efficiency of the high load.

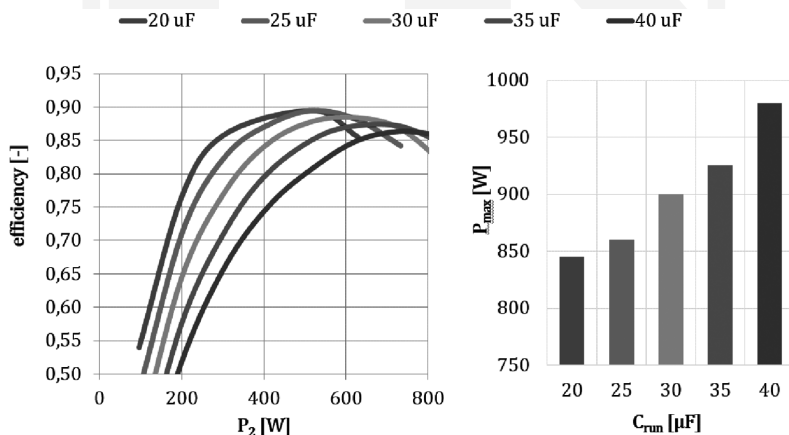


Fig. 5. Influence of the running capacitor capacitance on motor performance

The starting process of the motor is presented in Fig. 6. The starting capacitor ( $C_{\text{start}} = 110 \mu\text{F}$ ) was switched off by the time relay after 0.5 s. The starting capacitor was switched off after synchronization.

The motor performance is shown in Table 1. A comparison of the built motor physical model with a single phase induction motor manufactured by the electric motor producers is presented in Table 2. Single-phase line start permanent magnet synchronous motor efficiency is extremely high in comparison with single-phase induction motor efficiencies.

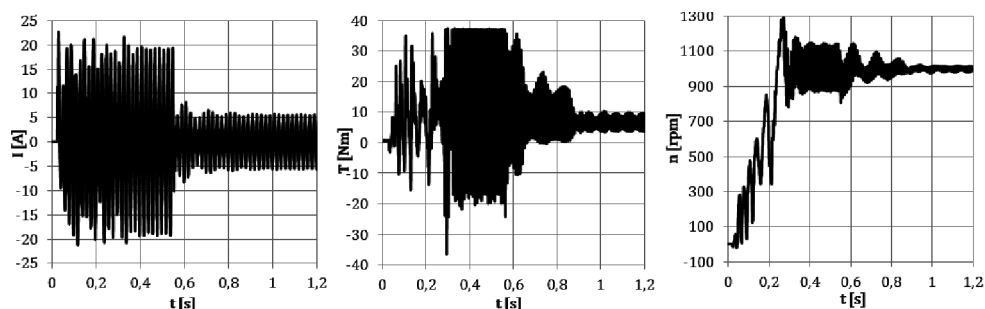


Fig. 6. Starting process of the six-pole single-phase line start permanent magnet synchronous motor

Table 1

#### Six-pole single phase line start permanent magnet synchronous motor performance

Parameter	Unit	Value
$U_n$	V	230
$P_n$	W	<b>650</b>
$n_n$	rev/min	<b>1000</b>
$I_n$	A	3.49
$\eta_n$	%	<b>87.1</b>
$\cos\phi_n$	-	0.93
$T_{\text{max}}/T_n$	-	1.3
$\Delta T_{\text{winding}}$	°C	30
$\Delta T_{\text{rotor}}$	°C	26
$C_{\text{run}}$	$\mu\text{F}$	25
$C_{\text{start}}$	$\mu\text{F}$	110
$m$	kg	9.9

**Comparison of six-pole single phase PMSM with six-pole single phase induction motors produced by the world electric motor manufacturers**

Motor	$P_n$ [W]	$n_n$ [rpm]	$\eta$ [%]	$m$ [kg]
Single-phase PMSM	650	1000	87.1	10.5
Producer A	735	1140	65	28
Producer A	650	900	67.5	11.5

#### 4. Conclusions

The six-pole single phase line start permanent magnet synchronous motor has very high efficiency. It is the main advantage of the motor. The main drawback is the starting capacitor which is needed for self-starting. The time relay which switches off the starting capacitor should work after the motor synchronization. The construction of the six-pole single phase motor presented in the article is both energy-saving and material-saving. The built motor has an IE4 efficiency class – the highest class nowadays.

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