Ludwik ANTAL, Paweł ZALAS

Wrocław University of Technology, Institute of Electrical Machines, Drives and Measurements

Soft and synchronous starting of low-power SMPMSM motor

***Abstract**. This paper presents the results of simulation studies of the starting of a low-power synchronous motor supplied from an inverter and excited by permanent magnets situated on the rotor's outer surface. The computations were performed using FEM and a field-circuit model of the machine. Synchronous starting at a constant U/f ratio and linear frequency change was assumed. The effect of the moment of inertia and that of the initial rotor position on the waveforms of the principal electromechanical quantities were studied.*

***Streszczenie.** Przedstawiono wyniki symulacyjnych badań rozruchu silnika synchronicznego małej mocy zasilanego z falownika i wzbudzanego magnesami trwałymi, umieszczonymi na powierzchni zewnętrznej wirnika. Obliczenia wykonano metodą FEM za pomocą polowo-obwodowego modelu maszyny. Założono rozruch synchroniczny przy stałym stosunku U/f i liniowej zmianie częstotliwości. Zbadano wpływ momentu bezwładności i początkowego położenia wirnika na przebiegi podstawowych wielkości elektromechanicznych. **(Łagodny i synchroniczny rozruch silnika SMPMSM małej mocy)**.*

Słowa kluczowe: silnik synchroniczny, magnesy trwałe, rozruch, falownik, symulacje polowo-obwodowe.
Key words: synchronous motor, permanent magnet, starting, inverter, field-circuit simulations

Introduction

The alternating-current motor's efficiency and power factor can be increased through the permanent magnet synchronous motor (PMSM). However, permanent magnet motors are characterized by a low starting torque and their synchronization ability diminishes as the load increases. A possible solution to this problem is a line-start permanent magnet synchronous motor (LSPMSM) with a suitable starting squirrel-cage. Another solution is a similar synchronous motor without a squirrel-cage, but supplied from an inverter.

Both field-circuit computations [1, 3] and experimental studies [2] of LSPMSM starting have shown that a low-power line-start synchronous motor can reach a starting torque slightly higher than the rated torque. An induction motor with the same geometry is capable of reaching a starting torque of 2.5 M_n. This means that the main area of LSPMSM application are pump and fan drives.

The second idea of improving the starting properties of PMSM consists in synchronous starting by means of various inverter control systems [4 – 8]. Such starting is possible if an inverter with smooth supply voltage frequency adjustment is used to supply the motor. An additional advantage of this way of supplying the motor is the possibility of adjusting its rotational speed in a wide range, but this requires the use of an external cooling system.

The starting properties of a permanent magnet motor supplied from an inverter were studied using a two-dimensional field-circuit model of the motor [3]. Exploiting the symmetry of the machine, only one-fourth of the cross-section was modelled (Fig. 2). A solid rotor magnetic circuit in the form of a sleeve made of steel S235JR was adopted in the analyzed low-power surface mounted permanent magnet synchronous motor (SMPMSM) with magnets in the shape of a circular sector Fig. 1). The rotor has no starting squirrel-cage and its 90 mm long magnets are stuck on its outer surface.

Simulation studies of starting of SMPMSM motors supplied from inverter

Simulation computations of the starting of the motors loaded with a rated fan torque (13 N·m at 1500 rpm) were carried out for different moments of inertia of the drive system.

The considered systems had moment of inertia I = 3.5, 7 and 17.5·I_r (I_r – the motor rotor moment of inertia). In all the cases of starting, initial angular rotor position α_0 was changed from 0 to -90 deg at every 7.5 deg. The FEM application (Maxwell Ansoft) specific way of determining the geometric position of the rotor is shown in Fig. 2.

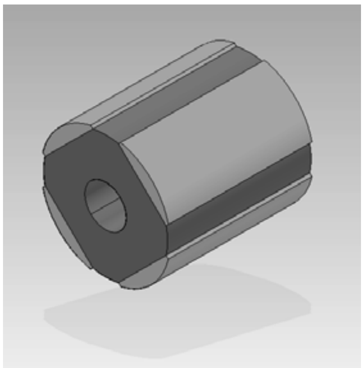


Fig. 1. Low-power SMPMSM's rotor core with mounted permanent magnets.

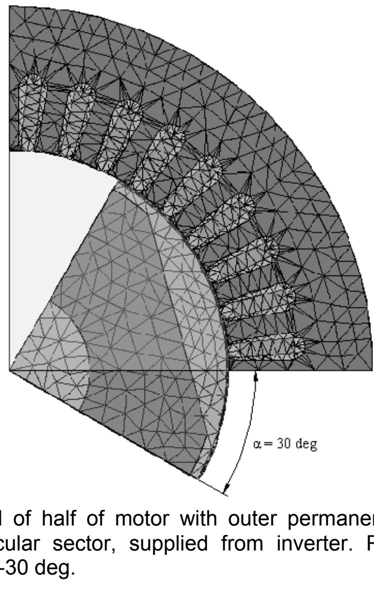


Fig. 2. Model of half of motor with outer permanent magnets in shape of circular sector, supplied from inverter. Rotor in initial position α_0 = -30 deg.

The motor was supplied from a PWM inverter and synchronously started by changing the frequency and rms value of voltage at U/f = const. Having determined that the PWM voltage signal could be replaced by a sinusoidal signal [3], two different algorithms for the voltage increase during the starting of the motor were considered. One of the algorithms (Fig. 3a) assumes that the three-phase voltage increases from prescribed initial value U_0 and frequency $f = 0$. The initial phase of the three-phase voltages is assumed to be equal to zero, which means that in the first instant of starting ($t = 0$) the instantaneous voltage of one of the phases amounts to zero while the instantaneous voltages of the other two other phases are equal to ± U_0. The other way of supplying the motor during its starting was an algorithm similar to the presented above, but with a delayed increase in voltage and frequency (Fig. 3b). In initial starting phase $t_0 = 0.2$ s small constant voltages ($f = 0$), having similar values as the instantaneous values of the three-phase voltages in the first algorithm, are supplied to the particular phases. In this initial phase of starting, the rotor is positioned by the constant field in the axis of this field. For a given initial instant and phase the axis of the constant field lies in the plane of the phase winding with zero current.

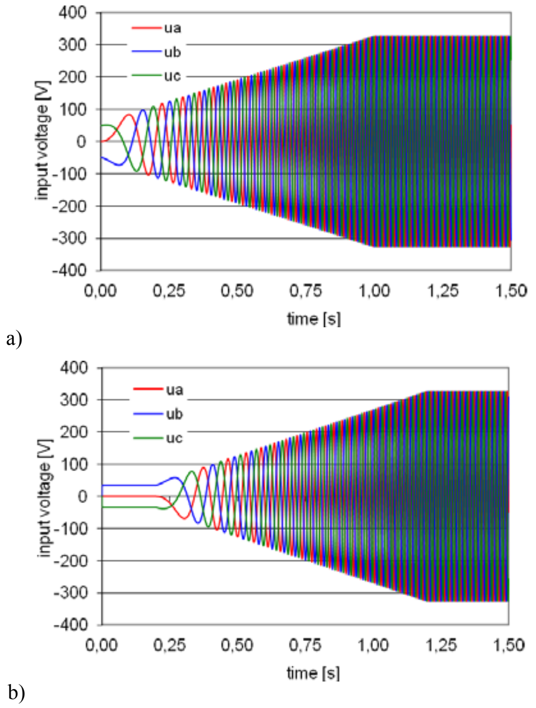


Fig. 3. Waveforms of sinusoidal voltages representing supply from inverter at delay: a) t_0 = 0, b) t_0 = 0.2 s.

Results of computations

The results of the motor starting computations for the case without constant field rotor positioning and with rotor supply according to the algorithm shown in Fig. 3a, for selected initial rotor positions and different moments of inertia are presented in Figs 4-6. The figures show the waveforms of rotational speed, torque and stator phase current.

For comparison purposes, initial rotor position α_0 = -15, -22.5, -30 deg. was chosen. The rotational speed waveforms for drive systems with a fan with three different M.I. values I = 3.5, 7, 17.5·I_r are shown in Fig. 4.

In all the compared cases, an increase in the system moment of inertia results in increased speed fluctuations during both starting and synchronization after the synchronous speed is reached. But for moment of inertia $I = 7 \cdot I_r$, which is typical of low-power fan systems, the fluctuations are not significant. The comparison also shows the influence of the initial rotor position. Some of the initial positions are not conducive to synchronous starting. At high moment of inertia $I = 17.5 \cdot I_r$ such a critical position (α_0 = -22.5 deg – Fig. 4b) makes starting impossible. Similarly as in the case of rotational speed, as system inertia increases so do torque fluctuations (Fig. 5). For an initial angle of -22.5 deg they are catastrophically large, preventing the machine from starting. Similar effects are observed in the waveforms of phase currents (Fig. 6).

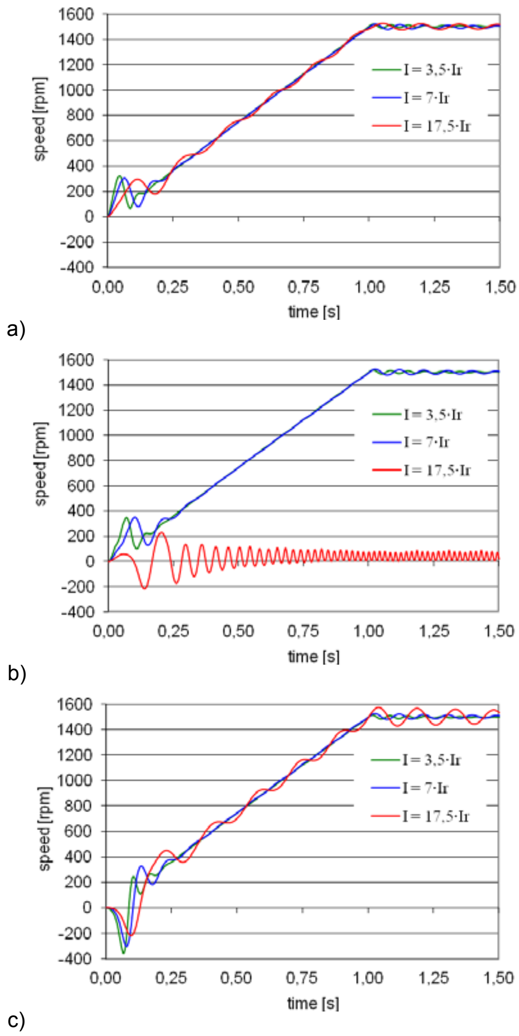
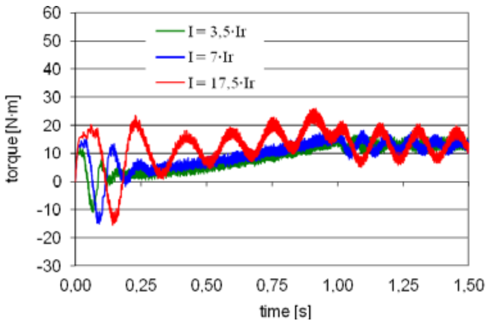


Fig. 4. Comparison of rotational speed waveforms during starting of drive systems with fan with three different M.I. values (I = 3.5, 7, 17.5·I_r) and initial rotor position α_0 : a) -15 deg; b) -22.5 deg, c) -30 deg.

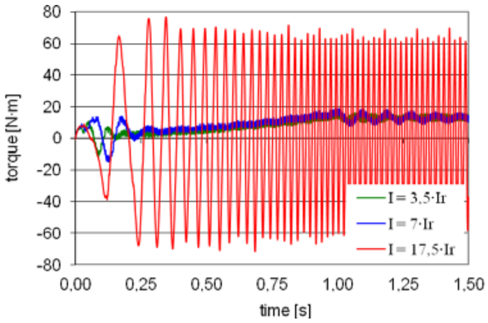
The supply algorithm with constant field rotor positioning ensures soft synchronous starting. In this case, the initial rotor position does not matter since in the meantime the constant field in the initial phase of starting manages to position the rotor most advantageously for further motion. For the adopted initial phase voltages the most advantageous position is the geometric angle of -30 deg. The rotor assumes this position in each case regardless of the initial position and the drive system's moment of inertia. An exemplary initial rotor position α_0 = -30 deg, shown in Fig. 2, was selected in order to compare the starting waveforms of the drive systems characterized by the different moments of inertia.

Rotational speed waveforms for the drive systems incorporating a fan with three different moments of inertia (I = 3.5, 7, 17.5·I_r) and initial rotor position α_0 = -30 deg are compared in Fig. 7. An increase in M.I. in all the compared cases results in larger speed fluctuations during synchronization after the synchronous speed is reached.

But the fluctuations are much smaller than for starting without rotor positioning (Fig. 7b).



a)



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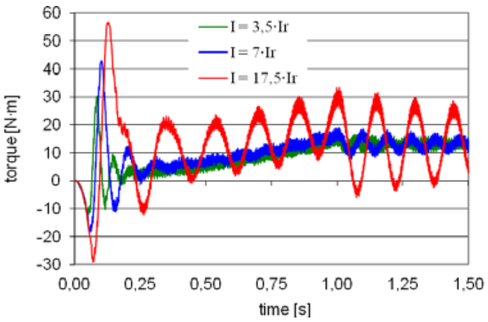
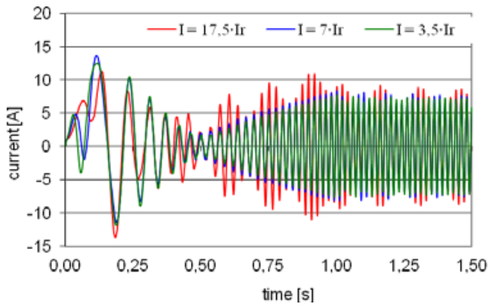
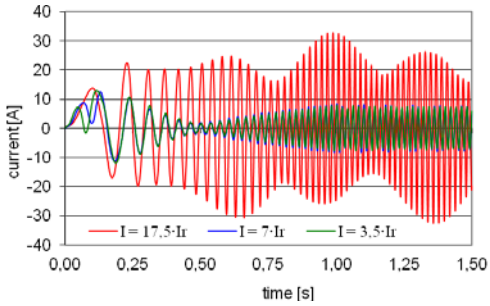


c)

Fig. 5. Torque waveforms during starting of drive systems with fan with three different moments of inertia (I = 3.5, 7, 17.5· I_r) and initial rotor position α_0 = a) -15 deg; b) -22.5 deg; c) -30 deg.



a)



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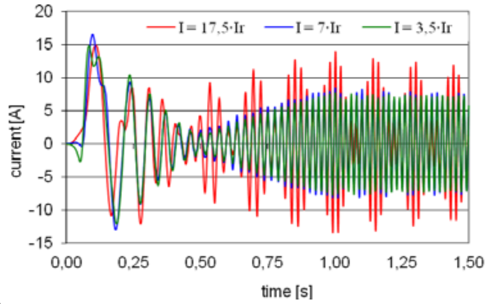
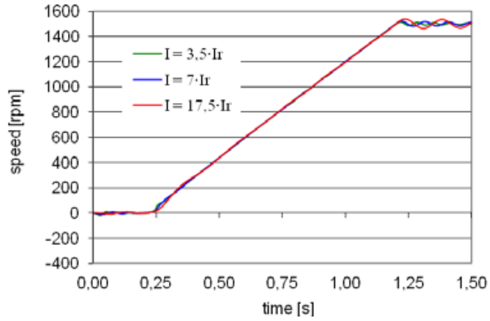
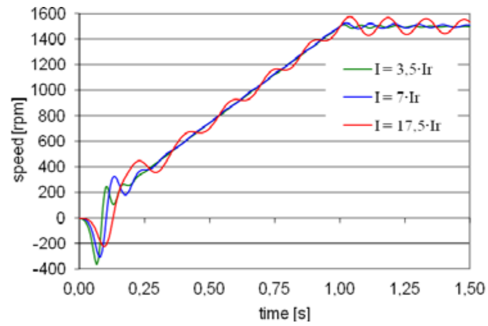


c)

Fig. 6. Stator current waveforms during starting of drive systems incorporating fan with three different moments of inertia (I = 3.5, 7, 17.5· I_r) and initial rotor position α_0 = a) -15 deg, b) -22.5 deg, c) -30 deg.



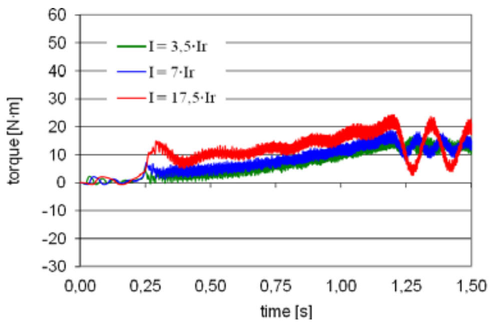
a)



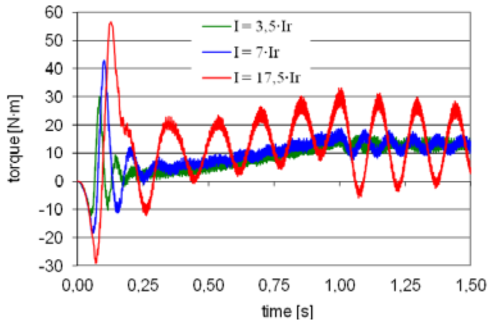
b)

Fig. 7. Rotational speed waveforms during starting of drive systems incorporating fan with three different moments of inertia (I = 3.5, 7, 17.5· I_r) and initial rotor position α_0 = -30 deg; a) – with rotor positioning, b) – without rotor positioning.

A comparison of the torque and current waveforms for the different moments of inertia after the rotor has been positioned leads to the reduction of the quantities and their fluctuations during synchronization (Figs 8a and 9a).

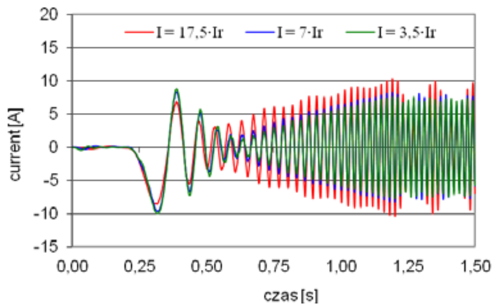


a)

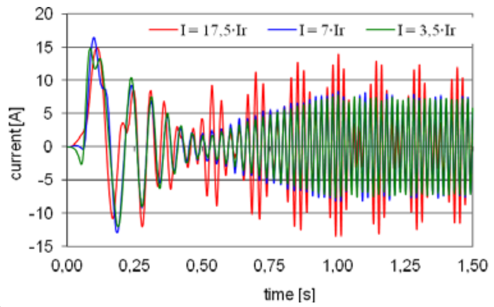


b)

Fig. 8. Torque waveforms during starting of drive systems incorporating fan with three different moments of inertia (I = 3.5, 7, 17.5·I_r) and initial rotor position α_0 = -30 deg; a) – with rotor positioning, b) – without rotor positioning.



a)



b)

Fig. 9. Stator current waveforms during starting of drive systems incorporating fan with three different moments of inertia (I = 3.5, 7, 17.5· I_r) and initial rotor position α_0 = -30 deg, a) – with rotor positioning, b) – without rotor positioning.

A comparison of the waveforms with the ones for the algorithm without rotor positioning (Figs 8b and 9b) shows that both during starting and synchronization the torque and current values are much higher in the latter case, which represents the benefits resulting from the initial positioning of the rotor relative to the initial direction of the stator field.

Conclusion

The starting waveforms computed for the SMPMSM motors without a starting squirrel-cage show that soft and synchronous starting of the drive systems with a fan characteristic at a constant U/f ratio is possible. But its quality and efficiency depend on the system inertia and the initial position of the rotor with magnets relative to the stator winding field axis in the first instant after power up.

An accidental rotor position and an accidental initial phase of the three-phase voltages may result in high currents and torques in the first starting instants and in fluctuations of these quantities and the rotational speed in the subsequent course of starting. These effects intensify as the moment of inertia of the drive system increases.

Much better starting conditions can be obtained by carrying out a special supply algorithm making it possible in the first instant of starting to move the rotor to a position in which its magnetic axis coincides with the magnetic axis of the three-phase stator winding. The use of the supply algorithm with the initial positioning of the rotor by the constant field leads to soft synchronous starting. The initial position of the rotor is irrelevant in this case since the constant field in the first phase of starting manages to position the rotor most advantageously for further starting.

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***Authors**: Prof. Ludwik Antal, PhD, E., Wrocław University of Technology, Institute of Electrical Machines, Drives and Measurements, Smoluchowskiego 19, 50-372 Wrocław, E-mail: ludwik.antal@pwr.wroc.pl; Paweł Zalas, PhD, E., Wrocław University of Technology, Institute of Electrical Machines, Drives and Measurements, Smoluchowskiego 19, 50-372 Wrocław, E-mail:pawel.zalas@pwr.wroc.pl.*