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Steady-state investigation of the single-phase capacitor induction motor

***Abstract**. The paper presents steady-state study of the single-phase capacitor induction motor by of 2D field-circuit model and by an actual motor laboratory testing. Developed the field-circuit model was implemented for simulation using Flux2D software package. The investigation of the motor was conducted for steady-state performance with no-load and locked-rotor tests. Computed steady-state characteristics were compared with measured ones to confirm correctness of the simulation model.*

Streszczenie.** Artykuł przedstawia badania stanu ustalonego pracy jednofazowego silnika indukcyjnego z pomocniczym uzwojeniem kondensatorowym za pomocą dwuwymiarowego modelu polowo-obwodowego oraz pomiarów laboratoryjnych rzeczywistego silnika. Model polowo-obwodowy silnika opracowano przy wykorzystaniu pakietu Flux2D. Badania silnika przeprowadzono w stanie pracy ustalonej pod obciążeniem, biegu jałowym oraz przy zahamowanym wirniku. Obliczone charakterystyki w stanie ustalonym porównano z wynikami pomiarowymi dla sprawdzenia poprawności przyjętego modelu polowo-obwodowego. **Badanie stanu ustalonego pracy jednofazowego silnika indukcyjnego z pomocniczym uzwojeniem kondensatorowym.

Keywords: small-power induction motor, single-phase, run capacitor, field-circuit modelling.
Słowa kluczowe: silniki indukcyjne małej mocy, jednofazowe, kondensator pracy, modelowanie polowo-obwodowe.

Introduction

Single-phase capacitor induction motors (SPCIMs) are commonly used as an electric drive for various appliances such as fans, blowers, pumps and compressors. The main and auxiliary stator windings have usually different number of turns, wire size and turns distribution along the periphery of the stator. This is the reason that mmfs produced by the stator winding currents is generally unbalanced. By using the capacitor connected in series with the auxiliary stator winding, the auxiliary winding current leads the main winding current by somewhat less than 90 electrical degrees. The auxiliary winding and the capacitor should be designed for better operation of the motor (e.g. at higher efficiency, power factor and lower torque pulsations) at any desired load (a specific operating point). To obtain high starting torque, the starting capacitor of appropriate value should be used, which is cut out after starting of the motor. For investigation of the capacitor induction motor in steady-state operation a two-dimensional field-circuit model of induction motor has been implemented. The 2D field-circuit model does not allow for skew effect modeling but enables taking into account non-linearity of magnetic core and induced eddy currents in the rotor bars. In the paper, the field-circuit model of the single-phase capacitor induction motor is in short described and simulation results of steady-state at load, no-load and locked-rotor performance of the tested motor together with experimental ones have been presented.

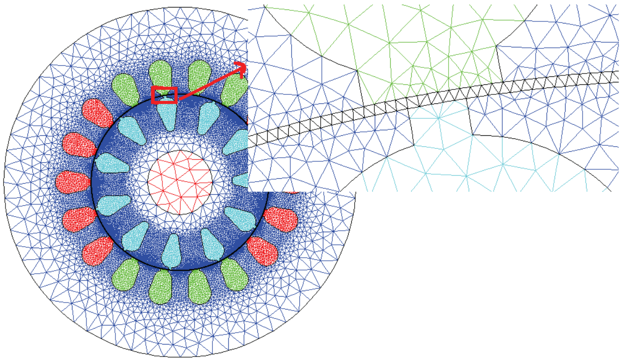


Fig. 1. Two-dimensional field model of tested motor

Field-circuit model of SPCIM

For investigation the single-phase two poles capacitor induction motor was used which discrete two-dimensional FE mesh are shown in Fig. 1.

The rotor has squirrel cage of 11 bars uniformly distributed along circumference. The ratings and structural data of the tested motor are listed in Table. 1.

Table 1. Ratings and data of the tested capacitor induction motor

Rated power	0.09 kW
Rated voltage	230 V
Rated current	0.9 A
Rated speed	2840 rev/min
Efficiency	0.55
Power factor	0.9
Frequency	50 Hz
Torque ratio	1.5
Number of stator windings	2
Running capacitor capacitance	3μF
Connection of stator windings	parallel
Number of poles: main/auxiliary winding	2/2
Winding layout: main/auxiliary winding	single layer
Rotor winding	squirrel cage
Number of slots: stator/rotor	18/11
Lamination material - generator sheet	M 600-50A
Laminated core length	32 mm

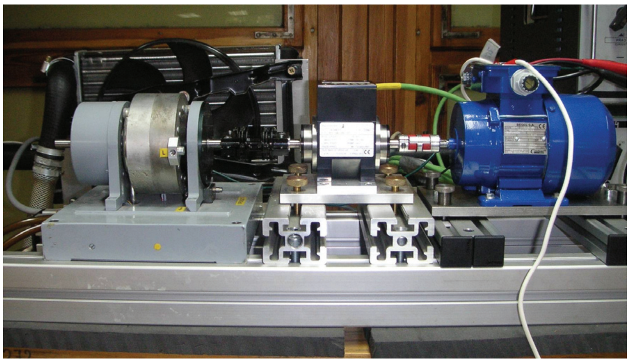


Fig. 2 View of measurement setup for single-phase induction motor

Computational simulation and measuring of the tested motor

Using of the 2D FE field-circuit model and actual motor of the single-phase capacitor induction motor was conducted for the following states of operation:

- no-load test at constant speed
- steady-state performance by varying load
- locked-rotor test at voltage frequency of 50Hz

The setup which a general view of the measurement setup is shown in Fig. 2, allows measuring the following electrical and mechanical quantities of the motor:

- voltage and intake current
- rotational speed and output torque
- voltage across capacitor

No-load test

The no-load test was conducted at rated frequency and constant speed of the running motor for voltages ranging from 120% of rated voltage down to a point where the current increases. Current, input power and power factor versus voltage characteristics were plotted in Fig. 3.

Measured and computed the no-load currents at rated voltage are almost the same but discrepancy occurs for the lower and higher voltage than rated value due to inaccuracy in modeling of magnetization curve of magnetic core of the motor. At nominal speed of the motor (n = 2840 r/min) the friction and windage torque was measured by means of a dynamometer (T_f= 0.1Nm).

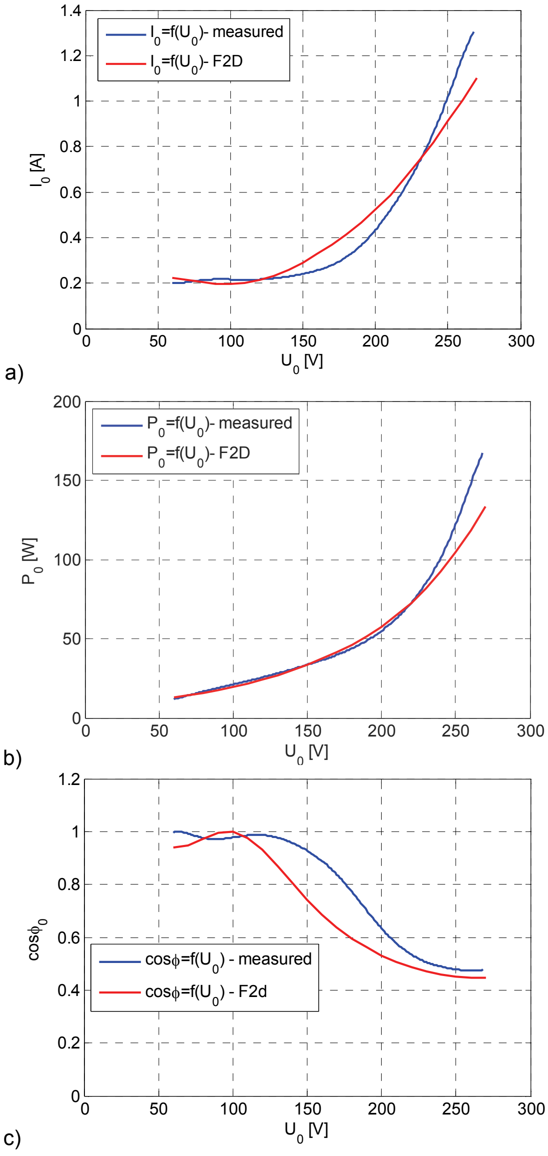


Fig. 3 Simulated and measured of current (a), input power (b) and power factor (c) versus voltage at no-load test

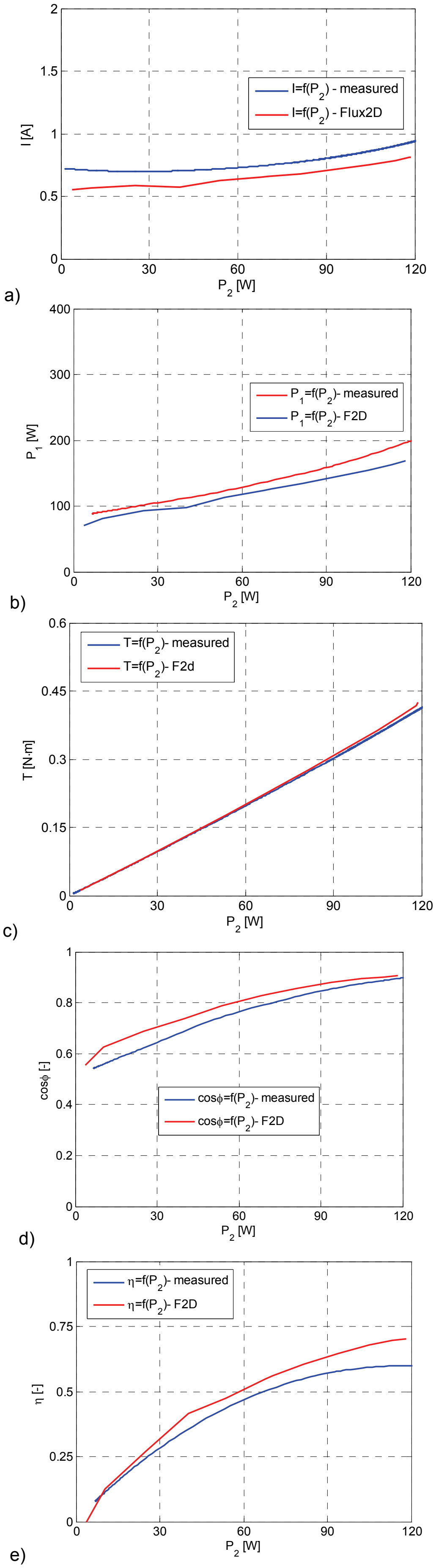


Fig.4 Current (a), input power (b), output torque (c), power factor(d) and efficiency (e) versus output power of the motor

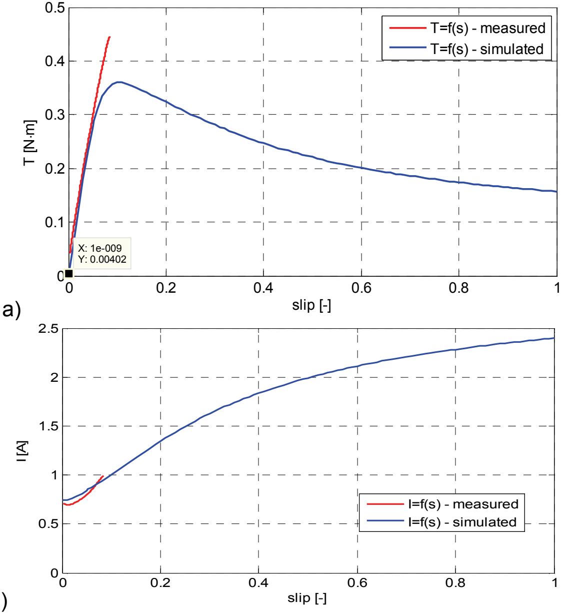
Steady-state load test

Steady-state performance of the motor was studied by varying output power of the tested motor. The motor was loaded by means of a dynamometer for output power ranging from zero to 120% of rated power. The current, input electrical power, output torque, power factor and efficiency was determined and plotted in Fig. 4. Rated values of measured and simulated quantities are listed in Tab. 2

Table 2. Computed and measured rated data of tested motor for rated output power

Rated output power of 90 W					
Rated load	T	I	P_1	cosφ	η
	[N·m]	[A]	[W]	[-]	[-]
Flux2D	0.31 (0.307)	0.71	145,50	0.86	0.63
Measurement	0.30 (0.301)	0.80	158,20	0.85	0.57

The computed torque-speed and current-speed characteristics for speeds ranging from zero to synchronous speed are plotted in Fig. 5 together with the measured ones which are limited to the stable part of motor operation.



a)

b)

Fig. 5 Torque-speed (a) and current-speed (b) characteristics of the motor

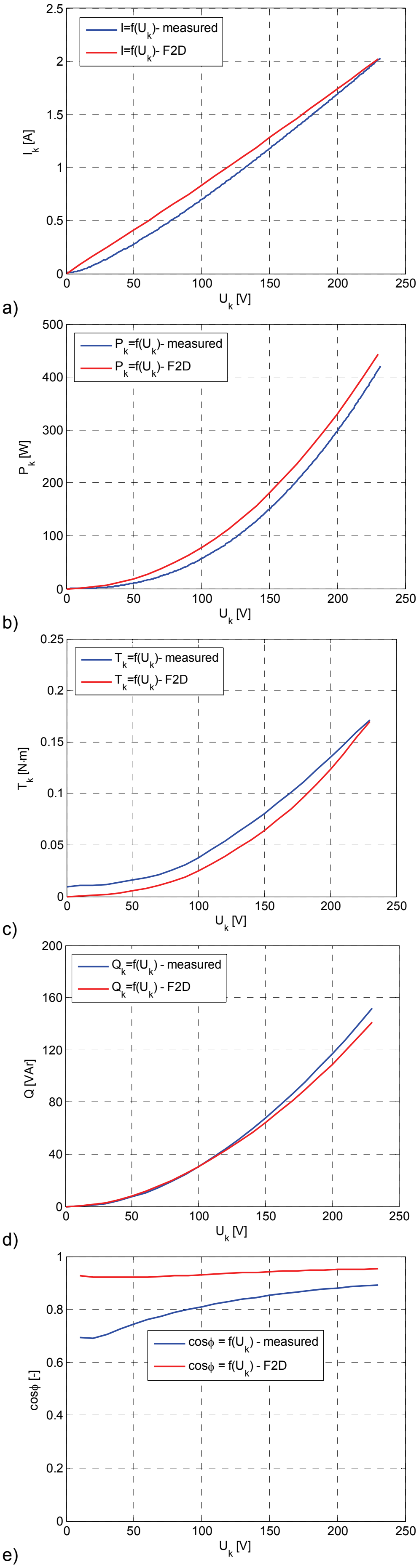
As it is seen, there is satisfactory agreement between the computed and measured curves as regards operation of the motor for the slip ranging form no-load to rated-load slip (Tab. 3).

Table 3. Measured and computed data of tested motor for steady-state

Steady-state operation	Current [A]		Torque [Nm]	
	Measured	Flux 2D	Measured	Flux 2D
No-load slip	0,71	0,74	0,04	0,02
Rated load slip	0,80	0,85	0,301	0,307

Locked-rotor test

The locked-rotor test of the motor was performed at rated frequency of 50Hz and voltage ranging from zero up to rated value which is possible for small power electric motors of low value of locked-rotor current. Since the motor torque depends on position of the rotor with respect to the stator a preliminary test was carried out to determine the angular position of the rotor at which the minimum torque is developed. The computed and measured currents, input powers, torques, and power factors of the motor were shown in Fig. 6.



a)

b)

c)

d)

e)

Fig. 6 Current (a), active power (b), torque (c), reactive power (d) and power factor (e) of the motor at locked-rotor test

Nominal values of measured and simulated quantities at locked-rotor test are listed in Tab. 4. Total motor current and output torque (Fig. 6a,c) shows good agreement for nominal voltage, but for lower voltage (less than 50V) simulated current and torque differ from the measured ones of about several percent. The measured torque at zero voltage differs from zero value because of torque transducer error of 0.01 Nm. Calculated active power (Fig. 6b) is 5% greater than measured one in whole range of voltage at locked-rotor test but reactive power curves show discrepancy above voltage of 110 V which finally reach 7%. All above differences can be minimized by more accurate determination of fixed values of resistance and inductance of end-winding of the stator windings and rotor cage.

Table 4. Computed and measured locked-rotor data of tested motor for locked-rotor

Locked-rotor test	Current [A]	Torque [N·m]	Active power [W]	Reactive power [VAr]	Power factor [-]
Flux 2D	2.02	0.17	442.6	141,4	0.95
Measurement	2.012	0.17	421.5	151,5	0.89

Conclusions

The implemented 2D field-circuit model of the single-phase capacitor induction motor was experimentally verified from point of view its usefulness for simulation and study of performance characteristics of the single-phase capacitor induction motor at steady state operation. The obtained curves for no-load, load and locked–rotor operation were compared with measured ones which confirmed correctness of the simulation model. Some discrepancies which occurred between simulation and measuring results in torque and current are caused by inaccuracy in modelling of magnetization characteristic of the magnetic core of the motor and by non-sinusoidal shape of the supply voltage in laboratory during conducting the tests (4% of THD).

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