COMPLEX ANALYSIS OF PERGORMANCE CHARACTERISTICS OF SINGLE PHASE SHADED POLE MOTOR

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Abstract: *Development of automatic, robotic and computer science has lead to development of wide range special motors (micro motors) which have large application and are interesting for research purposes. One of them is single phase shaded pole motor having a wide application in large number of household devices. Motor performance characteristics are analyzed using method of symmetrical components. For research purposes motor mathematical model is developed enabling prediction of motor operational characteristics. Obtained results are compared with experimental ones. Motor dynamic characteristics are obtained by building the simulation model in MATLAB/SIMULINK. Adequate conclusion regarding accuracy of developed motor models is derived.*

Keywords: SINGLE PAHSE SHADED POLE MOTOR, SYMMETRICAL COMPONENTS, SIMULATION MODELS

1. Introduction

Single Phase Shaded Pole Motor (SPSPM) is well known for its simple constructions as well as for the complexity of electro-magnetic processes which occur inside the motor due to existence of three mutually coupled windings which produce elliptical electromagnetic field in motor air gap. In this paper SPSPM , AKO-16 product of company MICRON is analyzed (Fig. 1). Motor rated data are: U_n=220 V, f_n=50 Hz, I_{1n}=0.125 A, P_{1n}=18 W, n_n=2520 rpm and 2p=2.

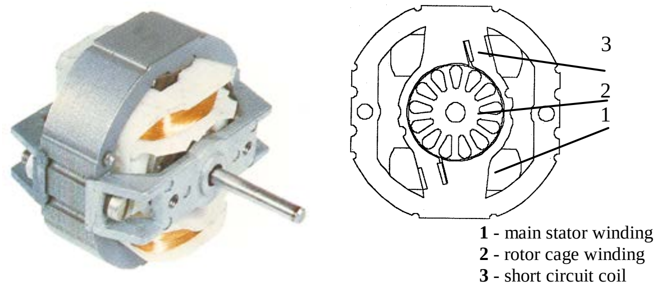

Fig. 1 *Physical layout and motor cross section*

Complex analysis of motor performance characteristics is applied by developing motor mathematical model based on symmetrical components method. Analysis is extended with experiments as well as with motor simulation model which gives inside in motor dynamical behavior at different operating regimes.

2. Motor performance characteristics based on method of symmetrical components

SPSPM is one of the most frequently used micro motors due to its simple construction and technological process for production. There are numerous advantages of this type of as motor short circuit current at main stator winding (locked rotor position) is very close to the rated current meaning that this type motor can sustain overloading or full load at locked rotor position without any overheating or motor damaging. SPSPM is very reliable during different operating regimes and overloading condition. From research purposes this type of motor is very complex as rotating electromagnetic field inside motor air gap, produces by stator windings is elliptic one meaning that there is a large inverse electromagnetic field which considerably contributes to the resulting elliptic rotating electromagnetic field and there is no standardized procedure for calculation of motor parameters and consequently motor performance characteristics. Method of symmetrical components is commonly accepted is literature as method for calculation of motor operational characteristics [1]. Mathematical model based on method of symmetrical components is developed which enables calculation of symmetrical components of currents in main stator winding i.e. direct component I_1^+ and inverse component I_1^- and consequently rotor windings I_2^+ and I_2^- [2]. Two phase unsymmetrical system of vectors of currents in main stator winding I_1 and in short circuit coil I_3 which have different amplitudes and are displaced in space for arbitrary angle α are decomposed to two symmetrical systems each containing two vectors equal in amplitude ad spatially apart for an angle of 90°. When this space angle between windings α is not equal to 90° for stator currents relation $I_3 \neq I_1$ is always valid.

Current in main stator winding is calculated from:

$$I_1 = -j\left(\frac{I_1^- e^{j\alpha}}{\sin\alpha} - \frac{I_1^+ e^{-j\alpha}}{\sin\alpha}\right)$$

(1)

Current in short circuit coil is calculated from:

$$I_3 = j\left(\frac{I_1^-}{\sin\theta} - \frac{I_1^+}{\sin\theta}\right)$$

(2)

Calculation of motor performance characteristic based on method of symmetrical components utilizes equivalent circuits for main stator winding for direct and inverse system (Fig.2).

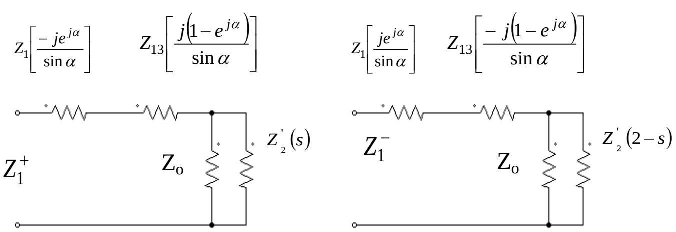

Fig. 2 *Equivalent circuit of main stator winding direct and inverse system*

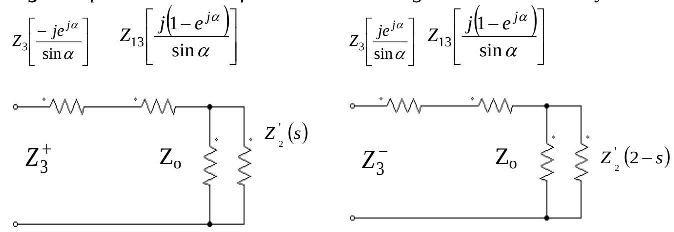

Fig.3. *Equivalent circuit of short circuit coil direct and inverse system*

Z_1^+ and Z_1^- are impedances of main stator winding and short circuit coil respectively. Z_{13} is the mutual reactance between main stator winding and short circuit coil. Impedance Z_0 is found from mutual reactance between stator and rotor winding. Z_2' is impedance of rotor winding referred to main stator winding and s is denoting motor slip.

Symmetrical components of rotor currents are found from:

$$I_2^{'+} = I_1^{+} \frac{Z_0}{Z_0 + Z_2^{'+}} \quad (3)$$

$$I_2^{'-} = I_1^{-} \frac{Z_0}{Z_0 + Z_2^{'-}} \quad (4)$$

Z_2^{+} and Z_2^{-} are rotor impedances for direct and inverse system. Consequently motor electromagnetic torque is calculated from:

$$M_{em} = M_{em}^{+} - M_{em}^{-} \quad (5)$$

where:

$$M_{em}^{+} = \frac{9{,}55}{n_s} \frac{2\left|I_2^{+}\right|^2 R_2^{'}}{s} \quad (6)$$

$$M_{em}^{-} = \frac{9{,}55}{n_s} \frac{2\left|I_2^{-}\right|^2 R_2}{2-s} \quad (7)$$

where n_s is motor synchronous speed and s is motor slip.

And resulting electromagnetic torque is calculated from:

$$M_{em} = M_{em}^{+} - M_{em}^{-} \quad (8)$$

Power factor cosφ, input power P_1, output power P_2, torque at motor shaft M_2 and efficiency factor are calculated from:

$$\cos\varphi = \frac{\mathrm{Re}\,al(I_1)}{|I_1|} \quad (9)$$

$$P_1 = U_1 |I_1| \cos\varphi \quad (10)$$

$$P_2 = \frac{P_{meh}}{1{,}15} \quad (11)$$

where P_{meh} is mechanical power on motor shaft.

$$M_2 = \frac{9{,}55 P_2}{n_s(1-s)} \quad (12)$$

$$\eta = \frac{P_2}{P_1} \quad (13)$$

Based on above mentioned methodology motor's electromechanical and operation characteristics are calculated and presented: current in main stator winding I_1, rotor current I_2, current in short circuit coil I_3, power factor cosφ, and efficiency factor η in dependence of motor slip s on Fig. 3, input power P_1 and output power P_2 as function of motor slip s on Fig. 4, and motor electromechanical characteristic of output torque M_2=f(s) and electromagnetic torque M_{em}=f(s) on Fig. 5. Motor operational characteristics power factor cosφ, efficiency η, input power P_1, motor speed n and input current I_1 in dependence of output power P_2 are presented on Fig.6.

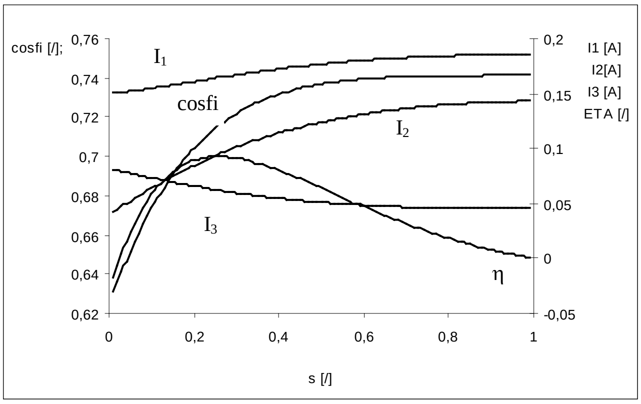

Fig. 3 *Electromechanical characteristics I_1=f(s), I_2=f(s), I_3=f(s), cosφ=f(s) and η=f(s)*

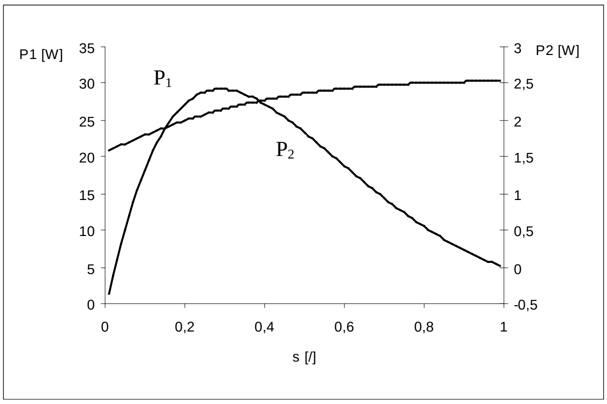

Fig.4. *Electromechanical characteristics P_1=f(s) and P_2(s)*

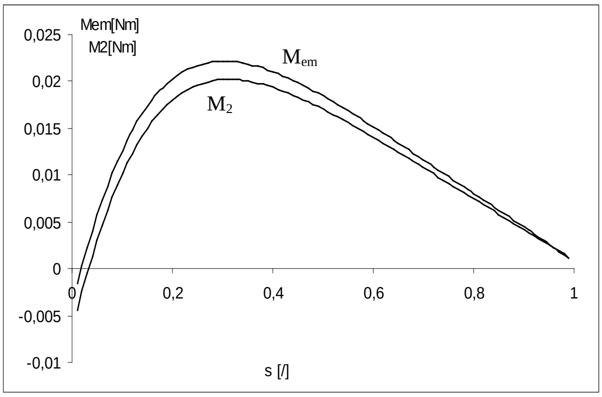

Fig.5. *Electromechanical characteristics M_{em}=f(s) and M_2=f(s)*

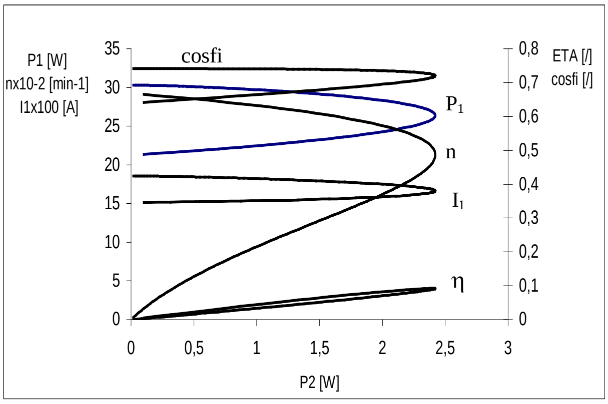

Fig.6. *Motor operational characteristics versus output power*

3. Motor experimental data

Laboratory set-up for measurements of motor operational characteristics at no-load, locked rotor and rated load was done. Experiment of no-load was performed during free rotation of motor shaft without any connected load and motor supply voltage was varied in range (0.45÷1.2)U_n. Displays of all instruments are recorded, voltage at motor stator winding U_0, no-load current I_0 and motor input power P_0. At each operating point motor speed –n is measured as well. Results from measurement at no-load operation are presented in Table 1.

Table 1: *Measurement at no-load operating regime*

n [rpm]	U_o [V]	I_o [A]	P_o [W]	$cosfi_o$ [/]
2490	125,1	0.045	3.375	0.581
2620	144,35	0.05585	4.675	0.577
2700	164,8	0.069625	6.525	0.571
2740	185	0.0845	8.8875	0.568
2790	204.2	0.101875	11.875	0.575
2780	225.5	0.11975	15.375	0.583
2720	242.5	0.144	20.15	0.577033

Experiment of locked rotor is performed when motor is in the locked position and voltage is varied until rated current is reached. Measurements of all instruments are recorded and consequently short circuit current I_k, voltage at short circuit U_k and power factor $cos\varphi_k$ are obtained. Results are presented in Table 2.

Table 2: *Measurement at locked rotor regime*

U_k [V]	I_k [A]	P_k [W]	$cosfi_k$ [/]
75.9	0.02275	1.125	0.703
109.6	0.04195	2.9375	0.688
140.1	0.06445	5.8	0.674
164.9	0.08475	9.225	0.661
186.8	0.105375	3.275	0.655
206.5	0.1244	17.6125	0.685615
235	0.15725	25.625	0.693434

Results from experiment at rated operational regime when motor is loaded with fan are presented in Table 3.

Table 3: *Measurement at rated load operating regime*

U_1 [V]	I_1 [A]	P_1 [W]	cosfi [/]
123.6	0.053125	4.15	0.627
134.8	0.06125	5.225	0.634
145.4	0.0697	6.425	0.64
154.4	0.076925	7.6125	0.642
165	0.084625	9.1	0.649
174.14	0.091375	10.35	0.653
184.6	0.099375	11.975	0.657
195.2	0.107	13.775	0.659
204.02	0.1136	15.325	0.662
213.15	0.12085	17.1	0.6645
222.9	0.128875	19.1	0.666
230.7	0.13625	20.975	0.667
243.96	0.14775	24.15	0.6675

Parameters and characteristic obtained by analytical calculations and compared with data from experiment and producer. Results of comparison are presented in Table 4.

Table 4: *Comparative analysis of results*

Experiment	Analytical calculation	Producer
I_1=0.125 A	I_1=0.1259 A	I_1=0.18 A
P_1=18 W	P_1=18.114 W	P_1=22 W
$cos\varphi$=0.6545	$cos\varphi$=0.6538	$cos\varphi$=0.555
R_1=498 Ω	R_1=493 Ω	R_1=480 Ω
I_0=0.111 A	I_0=0.1134 A	I_0=0.13 A
P_0=13.8 W	P_0=10.21 W	P_0=13.5 W
$cos\varphi_0$=0.5651	$cos\varphi_0$=0.4092	$cos\varphi_0$=0.472
I_k=0.135 A	I_k=0.181 A	I_k=0.221 A
P_k=19.87 W	P_k=29 W	P_k=31 W
$cos\varphi_k$=0.6683	$cos\varphi_K$=0.7389	$cos\varphi_K$=0.6376

In Table 1 is also presented main stator winding active resistance R_1. Results of comparison between calculated and measured current of main stator winding as well of measured and calculated input and output power are presented on Figs. 7 and 8 respectively.

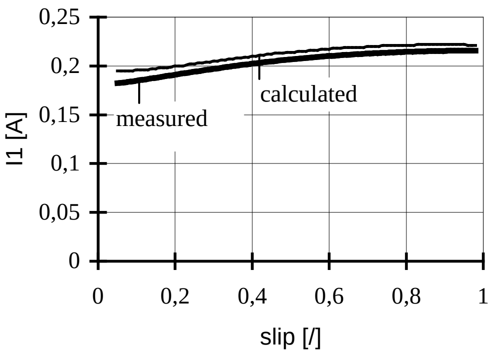

Fig. 7. *Comparison of characteristics of input current*

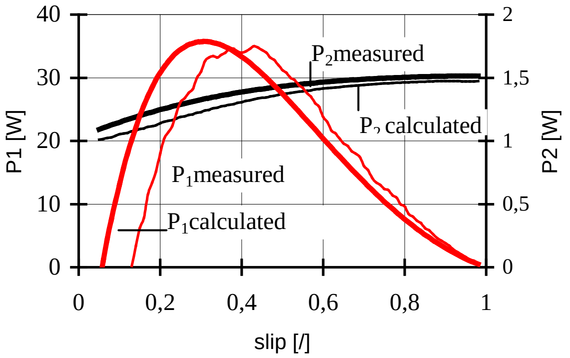

Fig.8. Comparison of characteristics of motor input and output power

3. Dynamic performance characteristics

In order to have an insight in motor dynamic behavior simulation model of the motor is built in SIMULINK [3]. Simulation model is consisted of four main parts: motor power supply (voltage sources-two phase system a,b), transformation of input variables (voltages) from two phase system into reference d,q system which is stationary, motor model where as direct output variables are obtained motor speed and torque and transformation from d,q reference system into two phase a,b system in order to be obtained motor current in main stator winding, short circuit coil as well as in rotor winding. On Fig.9, 10, 11 and 12 consequently are presented motor dynamic characteristics of current in main stator winding I_1, electromagnetic torque M_{em} motor speed n_r and flux linkage-λ_1 at rated load operating regime.

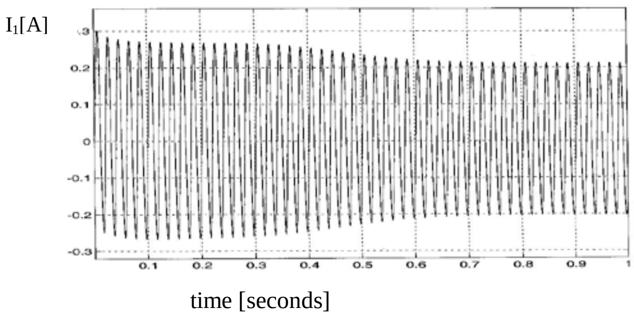

Fig.9. Transient performance characteristics of current in main stator winding at rated load

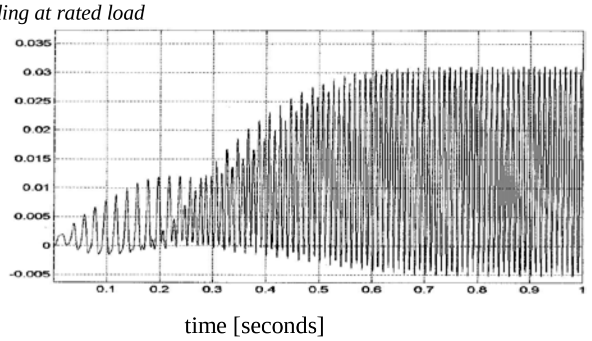

Fig.10. Transient performance characteristics of electromagnetic torque at rated load

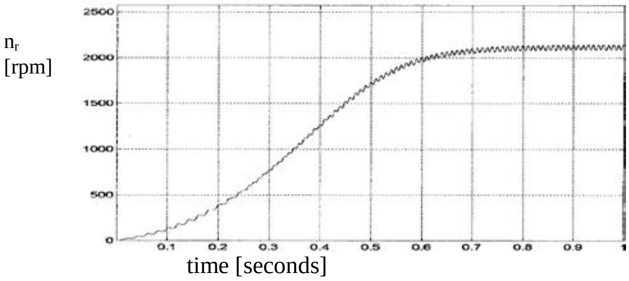

Fig.11. Transient performance characteristics of speed at rated load

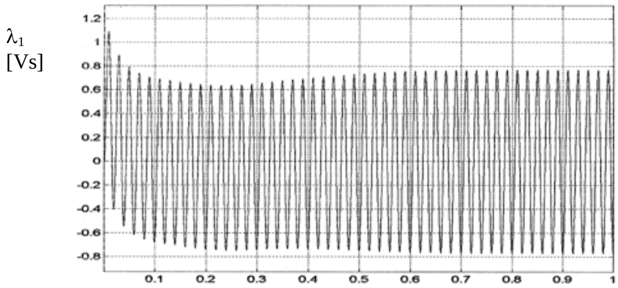

Fig.11. Transient performance characteristics of flux linkage at rated load

Comparison between results from simulation and calculation are presented in Table 5.

Table 5: Comparison between simulated and calculated values

	Rated load operating regime		
Param.	Simul.	Calcul.	Producer
n_r [rpm]	2857	2856	2523
Mem[Nm]	0.0198	0.018075	/
I_1 [A]	0.1259	0.134	0.18

In Table 6 is presented comparison between obtained values of electromagnetic torque from simulation and calculation and on the base of obtained values motor electromechanical characteristics in Fig. 12 are plotted.

Table 6: Comparison between simulated and calculated values

	Calculation	Simulation
slip [/]	M_{em} [Nm]	M_{em} [Nm]
0.047	0.005211	0.004
0.09	0.01145	0.011409
0.31	0.022166	0.02023
0.56	0.016509	0.01639
0.81	0.007681	0.0088
0.98	0.001568	0.002

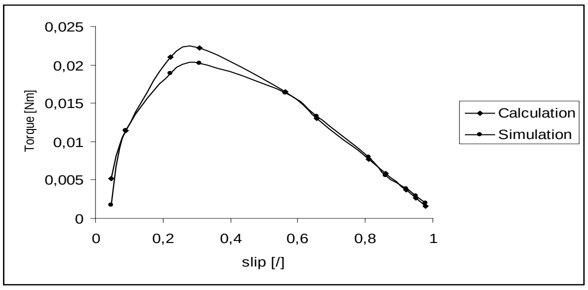

Fig.12. *Comparative characteristics of electromagnetic torque from calculation and simulation*

4. Conclusion

Methodology for analytical calculation of operational characteristics of SPSPM is developed based on method of symmetrical components. Experiments are performed regarding motor characteristic operating regimes: no-load, rated load and locked rotor. Obtained results of analytical calculation are compared with values from experiment and producer data confirming the accuracy of proposed methodology for calculation of motor parameters and performance characteristics. Motor dynamic performance characteristics are evaluated with simulation model built in Simulink at different operating regimes. Obtained values from motor transient characteristics of current in main start winding, electromagnetic torque and speed after dynamic process of motor acceleration is terminated are compared values obtained from calculation and producer showing reasonable agreement and proving the accuracy of developed simulation model. Mean value of motor electromagnetic torque from transient performance characteristic for different slips, meaning different operating regimes is compared with values from analytical model and agreement of results is satisfactory.

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