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CONSIDERATIONS REGARDING IMPROVING PERFORMANCE OF THE SERVO MOTORS

BY

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Abstract. This paper highlights the possibility of improving the performance of electric servo motors by using insulating materials in class H (limit temperature 180°C). The constructive and functional particularities of the SRD 191 C servo motor, as well as its advantages over a classical servo motor, are specified. The stages of the experimental determination of electromechanical characteristics and parameters of the SRD 191 C servo motor are presented. Using the MATLAB software package, the characteristics of the SRD 191 C: $E = f(n)$, $M_0 = f(n)$, $M_u = f(I)$ and $n = f(M)$ servo motors were plotted.

Keywords: servo motor; performance; insulating materials.

1. Introduction

Special electric machines have a range of performances defined for them, as well as a number of features that can only be appreciated from the point of view of the performances of the system they belong to (Simion, 1993; Shen & Tsai, 2014); Classical electric machines operate on the basis of the

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electromechanical conversion of energy (Dobrea & Cociu, 2014), and in the case of special electrical machines the operation is based on other phenomena (magnetic hysteresis, single pole induction, form anisotropy) (Biro *et al*., 2015). The use of permanent magnets to excite servo motors has determined the disappearance of some thermal and mechanical restrictions (Basu *et al*., 2005); the absence of excitation windings, access terminals and power supplies of these windings has led to the elimination of excitation losses, resulting reduction of heating. In the operation of these servo motors, there is no danger of permanent magnets becoming out of operation due to overload. Also have some disadvantages, as the collector, the switching phenomenon and the loud noise.

Direct current servo motors performs continuous speed control within wide limits, have mechanical and linear adjustment characteristics, specific couples and high starting couples, high overload capability, lack of self-propulsion, low moment of inertia, and low electromechanical time constants (Kim, 2019). These servo motors are used in applications requiring continuous adjustment speed when the load is variable and has frequent shocks (Akar & Temiz, 2007).

The operating performance of direct current servo motors excited with low-power permanent magnets become comparable to those of relatively higher power electromagnetic excitation servomotors (Măgureanu &Vasile, 1990).

Construction of direct current servo motors excited with permanent magnets is similar constructive to the direct current classical machine, variety being a consequence of the diversity of characteristics of the magnetic materials used (Bahrin, 2006; Cojocaru-Filipiuc, 2001). The dimensions and powers of these servo motors are dictated by specific applications; the improvement of the construction-operation characteristics resulted from the use of high-performance magnetic materials for a high level of induction of the inductor, or through choosing of new technological solutions to obtain inductor, such as the cylindrical rotor, the glass shape rotor, the disc rotor, the winding rotor without a metal support, etc..

If it is compare insulation materials from class F (high temperature limit at 155°C) with insulating materials from H class (high temperature limit 180°C) it is noticed that H class materials offer a better performance of the servo motors characterized by high value of power/volume ratios. The SRD 191 C servo motor is equipped with a disc rotor which has a temperature limit of 175°C and, compared to SRD 1000 servo motors, develops a rated power with 30% higher under the same mass and gauge conditions. The SRD 1000 servo motor uses impregnated insulation with class E epoxy resins, by modifying the rotor insulation has been obtained the SRD 191 C 1300 servo motor, where the symbol has the following meanings: SRD servo motor with disc rotor, 191 outer diameter of the rotor, the C-version of the servo motor having H class insulation, and 1300 is the rated power of 1300W.

The SRD 191 C 1300 servo motor has a insulation based on glass fiber impregnated in bismaleimide rasin with H class insulation, pressed for 30 minutes at temperature 170°C. The servo motor rotor is made from stamped copper, the blades are hot-glued (due to the glass fiber impregnated with bismaleimide rasin) and then welded with the electron beam; the rotor has a high mechanical rigidity (the glass fiber impregnated with bismaleimide rasin is not sufficiently flexible) and a lower dielectric strength compare with the epoxy resin rotor. The SRD 191 C servo motor can be subjected to reversals load and has reduced mechanical and electromagnetic inertia, linearity of the characteristics, possibility of variation in wide speed limits; the servo motor meets the requirements of industrial robots and can be used in reversible drives with acceleration and braking transient modes (Celik & Gor,2019).

At the servo motors operation mode is accompanied by frequent variations in speed and load (Vasile & Slaiher, 2003). In these conditions a tolerable range of operating (S1) is defined as well as the extension of the transient regime (TR) in speed-torque coordinates, Fig. 1.

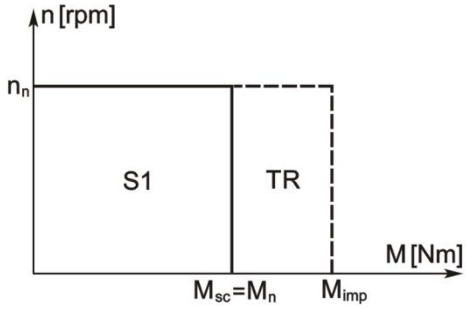

Fig. 1 − Operating range of servo motors.

2. Experimental Part

2.1. Determination of Rated Parameters

The couplings and speeds of the SRD 191 C servo motor are defined in direct current in the conditions of continuous operating (S1). The maximum impulse current, I_{imp}, refers to the permissible limit for the preservation of the mechanical, magnetic and thermal characteristics, and the prescribed value corresponds to the thermal equivalent of the allowed current over the cycle, Fig. 2.

Stabilization of permanent magnets is accomplished by running the servo motor for one hour at the speed variation after the cycle presented in Fig. 2 (the maximum pulse application rate is 9.76 s). The rated voltage U_n and the rated current I_n was determined at the rated speed n_n, the rated output P_n and the rated torque M_n:

$$M_n = \frac{60}{2\pi} \cdot \frac{P_n}{n_n} = 413.8 \times 10^{-2}\,\text{Nm} \cdot \quad (1)$$

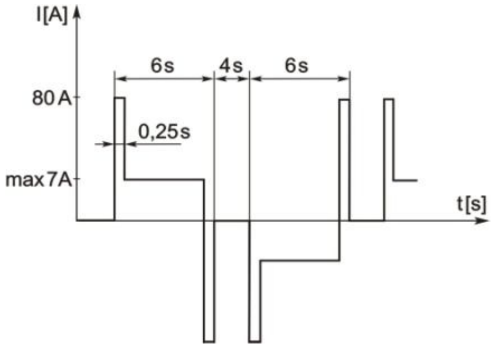

Fig. 2 − Characteristic $I = f(t)$.

The servo motor was powered from a direct curent generator and is loaded by coupling with a servo motor operating in the generator mode. For dragging the SRD 191 C servo motor, the rated current is calculated with the relation:

$$I_n = \frac{P_n}{E} + I_0 = 20.3 \text{ A}, \quad (2)$$

where: P_n is the rated power, E – electromotive voltage at rated speed (n_n = = 3,000 rpm), and I_0 is the absorbed current at idle speed at rated speed.

By varying the load resistance of the generator servo motor circuit, the rated current (calculated with the formula (2)) is fixed in the SRD 191 C servo motor circuit and also the rated speed in the group is establish by changing the supply voltage of the servo motor; for the SRD 191 C servo motor loaded at a load of 412×10^{-2} Nm and rated speed of 3000 rpm, the measured voltage resulted is 81.5 V and the absorbed current is 20.4 A.

Certification of the rated power of the servo motor is achieved by checking the maximum permissible overheat on the. The servo motor, loaded, will operate (at the calculated rated current at rated speed and rated voltage) until the temperature on the housing is stabilized. The servo motor was switched off and the temperature measurement of the rotor disk collector with a thermocouple probe (at least 5 measurements during cooling, graphically extracting the temperature when the actuator is switched off) was carried out in maximum 30 seconds. The rotor disc collector was obtained for an overheat υ_{rot} = 126°C (maximum admitted is 135°C). Measurements shall be made with measuring instruments (precision class 0.2) which determines the mean values of the measurements.

2.2. Check Current at Slow Speed

The current al the slow speed was checked by conducting a heating test until the temperature of the housing is stabilized, for the rotor current I_{sc} = 18 A;

measure the overheat of the rotor (collector) by thermocouple probe.

Powered the rotor with the I_{sc} = 18 A current at a slow speed of 50,...,100 rpm, the overheat value υ_{rot} = 128°C value was obtained for the rotor disk collector and for the torque value:

$$M_{sc} = K_T I_{sc} = 417.6 \times 10^{-2}\,\text{Nm}\,, \quad (3)$$

where: K_T is torque on amp and it has value $K_T = 23.2 \times 10^{-2}$ Nm/A.

2.3. Determination of electromotive voltage

The electromotive voltage, K_E, at the speed of 1,000 rpm was determined by the characteristic electromotive voltage versus speed, $E = f(n)$, Fig. 3. The servo motor was running as an empty generator at different speeds and it was measure the voltage at terminals.

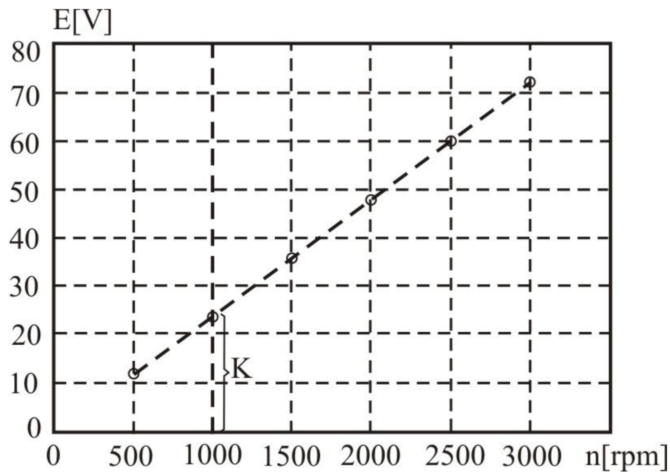

Fig. 3 − Characteristic $E=f(n)$.

2.4. Determination of Electrical Resistance at Servo Motor Terminals

The electrical resistance at the servo motor terminals, R_b [Ω], at 25°C, was determined on the cold-state by the voltmeter method, with the rotor locked. The measurements have been accomplish in nine positions corresponding to a single axis rotation and the mean value of the resistance was calculated at R_b = 0.4 Ω.

2.5. Determination of Inductance of the Rotor

The inductance of the rotor, L [μH], was determined by a measurement bridge and it was obtained values for inductance L = 42 μH at f = 800 Hz.

2.6. Determination of the Electromechanical Time Constant

The electromechanical time constant τ_m, [ms], was determined with the relation:

$$\tau_m = \frac{J}{K_E} \cdot \frac{R_b}{K_T} \times 10^2 = 9.5\,\text{ms}. \qquad (4)$$

2.7. Determination of Torque and Maximum Impulse Current

The maximum impulse torque M_{imp}, [Nm], and the maximum impulse current I_{imp}, [A], are defined as the maximum amplitudes of the useful torque or the corresponding short-time current absorbed in acceleration and braking processes so that the servo motor resists at mechanically and thermally stress, and not to be phenomena of diminishing E.M.V. as a result of the demagnetization of permanent magnets.

The servo motor was powered from a current limiting converter to I_{imp} by performing 10 accelerations and brakes over a minimum of 10 seconds with a transient process lower than that shown in Fig. 2, and each time measuring the I_{imp} value. The test was accomplish after stabilizing the permanent magnets.

Impulse torque is calculated with:

$$M_{\text{imp}} = K_T I_{\text{imp}} = 2{,}320\ \text{Ncm}. \qquad (5)$$

The servo motor has resisted at mechanically and thermally stress and there was no reduction of E.M.V.

2.8. Maximum Speed Test

The maximum speed test, n_{max}, [rpm], was performed for 2 minutes. with the servo motor, in the hot state, powered by a motor-generator group. After performing the test, the idling current was determined, I_0 [A]. The servo motor was running for 2 minutes at n_{max} = 5,000 rpm, and at n = 3,000 rpm the idling current was measured I_0 = 1.82 A.

2.9. Determination of Viscous Friction Torque

To determine the viscous friction torque, the characteristic $M_0 = f(n)$ is plotted, Fig. 4. The torque loss M_0 was determined with the relationship:

$$M_0 = M_F + nK_D 10^{-3} = \frac{60}{2\pi} \cdot \frac{p_{\text{mec}}}{n}. \qquad (6)$$

where: $p_{mec}=EI_0$, [W], are the mechanical losses of the servomotor, and M_F, [Nm], is the viscous friction torque (value of the ordinate in origin of $M_0 = f(n)$).

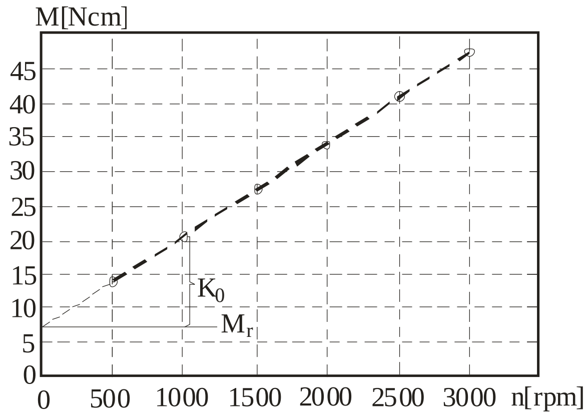

Fig. 4 − Characteristic $M_0 = f(n)$.

2.10. Determination of Torque Loss

The torque loss constant, K_D, was determined from the variation of the mechanical torque corresponding to the speed variation from 0 to 1,000 rpm on the characteristic $M_0 = f(n)$; the $K_D = 13.4 \cdot 10^{-2}$ Nm was obtained.

2.11. Determining the Torque on the amp

The servomotor was powered with the voltage $U = U_n$ = const. and by variation of the load the characteristic torque-current was plotted, $M_u = f(I)$, Fig. 5. The voltage was set at U = 81.5 V = const.

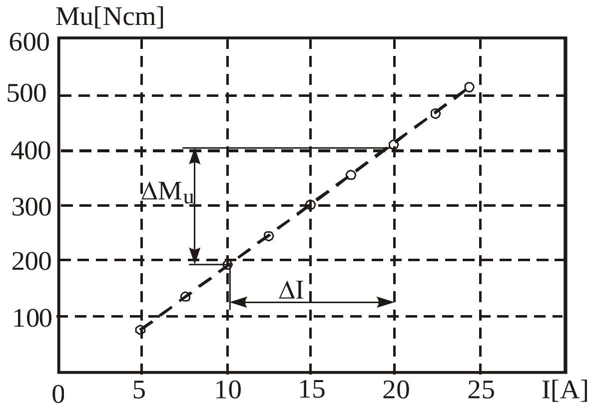

Fig. 5 − Characteristic $M_u=f(n)$.

The torque on the ampere is determined by the torque variation on the $M_u = f(I)$ characteristic corresponding to a 1 A variation of the current:

$$K_T = \frac{\Delta M_u}{\Delta I} = \frac{230}{10} = 23 \times 10^{-2} \frac{\text{Nm}}{\text{A}}. \quad (7)$$

2.12. Determination of Load Speed Decrease

The servo motor with the voltage $U = U_n$ = const. was powered, and by load variation the speed-torque characteristic was plotted, $n = f(M)$, Fig. 6, at the voltage U = 81.5 V = const.

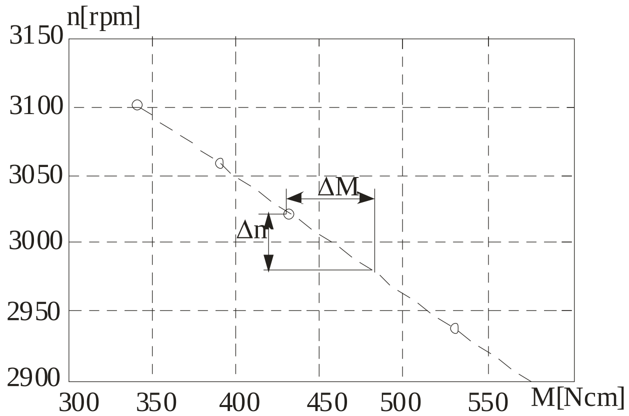

Fig. 6 − Characteristic $n = f(M)$.

The load speed decrease K_N, was determined as the variation of the speed (on the characteristic $n = f(M)$) corresponding to a torque variation of 1×10^2 Nm:

$$K_N = \frac{\Delta n}{\Delta M} = 1 \times 10^2 \frac{\text{rpm}}{\text{Nm}}. \quad (8)$$

2.13. Determination of Idle Current

The idle current, I_0, [A], defined at rated speed, is determined by performing the idling test of the servo motor resulting the value I_0 = 1.98 A.

2.14. Determination of Idle Current

Determination of insulation resistance of windings to the servo motor housing was accomplish by measurement with 500 V megohmeter, for two distinct cases:

– for cold-dry state (before running under normal environmental conditions) 70 MΩ was obtained;

– for the hot-dry state (the servo motor running and reaches the operating temperature), 10 MΩ were obtained.

2.15. Dielectric Strength of the Insulation Against the Servo Motor Housnig

This was accomplish by applying a sinusoidal alternative voltage between 500 + $2U_n$ = 665 V and 50 Hz frequency for 1 minute between the rotor winding terminals and the servo motor body. The insulation of the servo motor tested has not been bypassed or broken.

In Table 1 are presented standard electromechanical parameters of the 190 SRD servomotor and for the SRD 191 C servomotor, the standard parameters and the experimental results (Bahrin, 2006).

Table 1
Electromechanical Parameters of the 190 SRD Servomotor and for the SRD 191 C

Parameters	Symbol	UM	190 SRD	SRD 191 C	
				Standard	Experimental
Rated power	P_n	W	1,000	1,300	1,300
Rated torque	M_n	Nm	320×10^{-2}	413×10^{-2}	413.8
Rated speed	n_n	rpm	3,000	3,000	3,000
Rated voltage	U_n	V	82	82	81.5
Rated current	I_n	A	15	20	20.4
Maximum current at low speed	I_{sc}	A	16.5	18	18
E.M.V. at 1000 rpm	K_E	V	25	24.3	23.9
Terminal resistance at 20°C	R_b	Ω	0.45	0.45	0.4
Self inductance of rotor	L	μH	100	100	42
The inertia moment of rotor	J	Kg.m^2	12×10^{-4}	12×10^{-4}	11.98
Mechanical time constant	τ_m	ms	11	12.5	9.5
Maximum impulse torque	M_{imp}	Nm	$2,440\times10^{-2}$	$2,670\times10^{-2}$	2,320
Maximum impulse current	I_{imp}	A	100	100	100
Maximum speed	$n_{\max}$	rpm	5,000	5,000	5,000
Viscous friction torque at 1000 rpm	M_F	Nm	15×10^{-2}	15×10^{-2}	7
The constant of the losses couple in idle	K_D	Nm	15×10^{-2}	15.3×10^{-2}	13.4
Torque per amp	K_T	Nm/A	24.2×10^{-2}	23.2×10^{-2}	23
Load speed decrease for constant voltage	K_N	rpm/Nm	0.88×10^{2}	1×10^{2}	1
Idle current	I_0	A	2	2.5	1.98

3. Conclusions

This paper present the possibility of improving the performance of electric servo motors by using a different class of insulation material. The experimental results present that:

– using of Class H insulating materials has led to improvements in 190 SRD servo motor performance;

– high match between the standard parameters and those determined experimentally for the SRD 191 C servo motor.

The $M = f(I)$ and $n = f(I)$ characteristics of permanent magnet exciting servo motors are linear, which is a great advantage (because the elevation of these features involves the determination of only two points).

The characteristics $M = f(n)$, $M_u = f(I)$ and $n = f(M)$ of the SRD 191 C servo motor were determined with the MATLAB software.

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CONSIDERAȚII PRIVIND AMELIORAREA PERFORMANȚELOR SERVOMOTORELOR ELECTRICE

(Rezumat)

În această lucrare se evidențiază posibilitatea ameliorării performanțelor servomotoarelor electrice prin utilizarea materialelor izolante din clasa H (temperatura limită 180°C).

Sunt precizate particularitățile constructive şi funcționale ale servomotorului SRD 191 C, precum şi avantajele acestuia față de un servomotor în construcție clasică.

Sunt prezentate etapele determinării experimentale ale caracteristicilor şi parametrilor electromecanici ai servomotorului SRD 191 C.

Cu datele obținute s-au trasat, utilizând pachetul de programe MATLAB, caracteristicile servomotorului SRD 191 C: $E = f(n)$, $M_0 = f(n)$, $M_u = f(I)$ şi $n = f(M)$.