PARAMETERS AND CHARACTERISTICS DETERMINATION OF COMOUNDED D.C. MOTOR

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***Abstract* – The armature inductance, rotor moment inertia, mechanical losses and magnetizations characteristics for compounded d.c. motor are determined. Obtained results were used for the trolleybus electrical drive simulation.**

Keywords: *compounded d.c. motor, armature inductance, rotor moment of inertia, mechanical losses, magnetization curve.*

1. INTRODUCTION

The urban electrical transport in the main cities of Moldova Republic (MR) such as: Chisinau, Balti and Tiraspol, is assured by the only technical mean – the trolleybus with different drive control systems. For instance, Chisinau Electrical Transport Utility (RTEC) is assured with 348 trolleybuses from which 289 are ex-soviet manufactured (type ЗиУ) and only 49 are of new type, produced by Czech concern Scoda (39) and by Ukrainian concern Iujmas (20). All new trolleybus are fit out with a d.c. compounded motor controlled by a solid state converter - Chopper. The majority ЗиУ type trolleybuses are fit out with old control systems based on relays, contactors, resistors control and have small energy efficiency. Taking into consideration the route, trolleybuses electronic power systems consume with 35- 40 % less power than those with resistors control.

For Chisinau municipality is extremely actual the substitution of old trolleybuses with electronic controlled trolleybuses, through new trolleybuses import or through the cooperation with enterprises from Independent State Community, for which Moldova delivers electronic control systems or through re-equipment of the old trolleybuses with native electronic control systems. At present the RTEC used all three variants of trolleybus park modernization, the final goal being the energy save, efficiency, reliability, and drivers working conditions improvements. Thirty trolleybuses have already been modernized by RTEC in collaboration with local company INFORMBUSINESS S.R.L [1,2].

ЗиУ type trolleybuses are equipped with d.c. compounded motor in which prevails series excitation: type DK 210A-3, rated power - 110 kW, tension – 550 V, nominal current – 220 A, nominal rotation speed – 1500 Rev./min. The motor supplier doesn't present in the technique manual the necessary characteristics and parameters for the mathematical modeling and simulation. In this case it is impossible the d.c. compounded motor - Chopper system simulation.

The present work proposes to develop the d.c. compounded motor mathematical model, experimental determination of magnetization curves, mechanical losses for a wide range speed regulation, rotor moment inertia and the armature circuit inductance. The obtained results were used for dynamic regimes simulation, system's instantaneous and global efficiency determination [3].

2. D.C. COMPOUNDED MOTOR MATHEMATICAL MODEL EQUATIONS

In the specialty literature, in the majority of cases, are discussed the shunt or separately excited d.c. motors and series d.c. motors [4-7,9]. The compounded d.c. motor studies are practically missing or are represented on a superficial level. The main difference between compounded d.c. motor and those two is following: the magnetic flux is dependent on the armature current (i.e. mechanical load) and of the shunt coil current excitation. Magnetization curve of the compounded d.c. motor is not the one curve in the plan, but represents a second order surface.

In edition, we present the compounded d.c. motor mathematical model's equations:

$$\frac{di}{dt} = \frac{1}{L_i}\left[U_{\text{var}} - k\Phi\omega - iR - \frac{W_s}{W_d}\left(U - I_d R_d\right)\right]; \quad (1)$$

$$\frac{d\omega}{dt} = \frac{p}{J}\left[k\Phi i - M_m(\omega) - M_s(v)\right]; \quad (2)$$

$$\Phi = F(i, I_d), \quad (3)$$

where U, U_{var} – contact network tension and respectively Chopper's exit tension; I_d, i – the shunt current and respectively the armature current; W_d, W_s – turns number of the shunt and series coils; L_i – armature and auxiliary poles inductivity; Φ – useful magnetic flux; ω –rotation speed; $M_m(\omega)=P_{mec}/\omega$ – the torque of mechanical losses P_{mec} as rotor speed function; $M_s(v)$ - load torque as a function of trolleybus speed v; J – the total moment of inertia.

Further on, follows the identification methods description of magnetization curves $\Phi = F(i, I_d)$, mechanical losses P_{mec}, rotor moment inertia J_r, and L_i armature circuit inductivity (without series coil).

3. D.C. COMPOUNDED MOTOR MAGNETIZATION CURVES $\Phi = F(i, I_d)$

For this purpose was used the RTEC test bench, which consists of two identical electrical machines (Figure 1): *M* – d.c. compounded motor and *G* – the

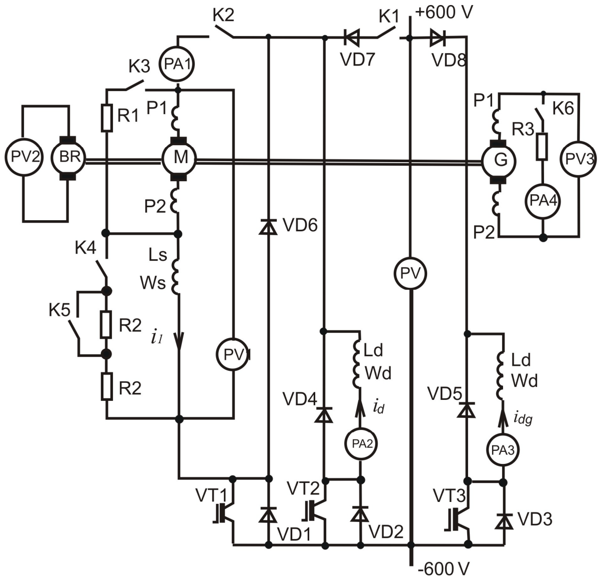

Figure 1: Test bench electrical scheme

generator which serves as load. The magnetization characteristics was determined as a $k\Phi = F(i, I_d)$ function for different armature current values $I = (0{,}25\text{-}1{,}45)I_n$ and constant values shunt excitation coil I_d. The armature current I_1 is measured with ampermeter *PA1*, tension U_1 - with voltmeter *PV1* and rotation speed n - with tachometer *BR*. With the measured data is calculated the angular speed rotation $\omega = \pi n/30$, electromotive tension $E = U_1 - I_1R$, where R represents the sum of armature, series coil and auxiliary poles resistance. The multiplication $k\Phi$ *is* equal to E/ω.

In this manner, the characteristics portion comprised between maximum and minimum value of armature current is determined. The intersection's point of the magnetization curve with ordinate axe (Figure 2) is determined from generator magnetization curve

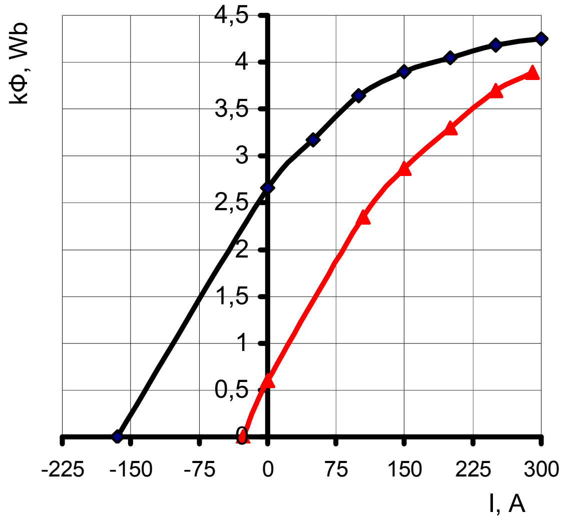

Figure 2: D.C. compounded magnetization curves

(identical with motor M) for respectively shunt current excitation. The intersection point with abscissa is determined with the formula $I = -I_d W_d / W_s$, where W_d, W_s - are respectively shunt and series coil turn number.

4. D.C. COMPOUNDED MOTOR MECHANICAL LOSSES

Mechanical losses are necessary for d.c. compounded motor efficiency determination. Because the trolleybus speed is variable we should know the mechanical losses for different rotation speed. In the methods described by specialty literature [9, 10], mechanical losses are determined from no load losses characteristics obtained to a constant rotation speed, usually rated speed.

No load losses are equal to sum of the mechanical and iron losses. Through their separation are determined mechanical losses. The described method in [8, 10] can't be used directly for experimental determination of d.c. compounded motor mechanical losses because the last one operates on different rotation speed. Further on, is described the method used on this purpose where are taken into consideration not only motor's characteristics, but also the available test bench possibilities:

- The generator *G* operates in the no load regime (the *K6* contact is open, the *VT3* transistor is closed);
- The tension is varied on the motor *M* armature and measured: armature motor tension U_1, current I_1 and rotation speed n.

With the measured data is calculated the motor mechanical losses:

1. The absorbed power from the supplying source: $P_1 = U_1 \cdot I_1$.

2. Electrical losses in motor armature circuit: $P_{Cu} = I^2{}_1 \cdot R$, where R is the armature circuit total resistance.
3. The difference $P_1 - P_{Cu}$ is equal to sum of mechanical losses P_{MM} in the motor and mechanical losses P_{MG} in the generator and motor losses in iron P_{FeM} : $P_1 - P_{Cu} = P_{MM} + P_{MG} + P_{FeM}$. Motor iron losses are proportional with magnetic flux square, which during the measurements doesn't exceed 20 % from the nominal one. Iron losses will be 25 times smaller than the nominal one and they can be neglected. Both electrical machines (motor and generator) are identical, having the same mechanical losses $P_{MM} = P_{MG}$ and from p. 3 follows:

$$P_{MM} = (P_1 - P_{Cu})/2 \qquad (5)$$

4. Graphically is performed curve $P_{MM} = F(\omega)$ presented in Figure 3, where for rated speed equal to 1500 Rev/min (157 s^{-1}) are determined the motor mechanical losses equal to 962 W. If we extrapolate $P_{MM}= F(\omega)$ till the speed equal to zero, it comes out that it will intersect the coordinate origin. This result indicates that the iron losses are very small and the supposition made above is motivated.

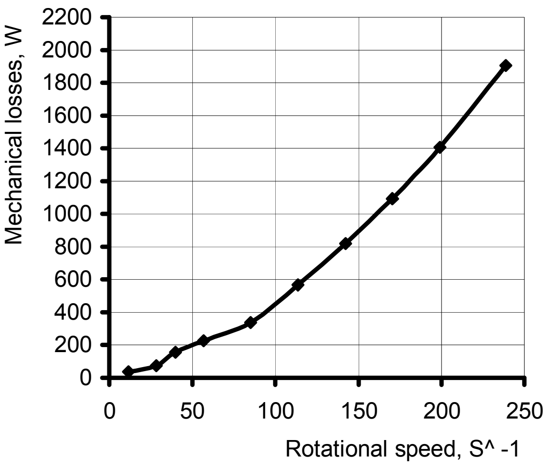

Figure 3: Mechanical losses

5. MOTOR MOMENT OF INERTIA

In order to determine experimentally motor moment of inertia was used the auto brake method [8, 10]. In this case the motor operates in the no load regime and is accelerated till the rotation speed grows with 15 % - 20 % than the rated one. In our case, it constitutes 1800 Rev/min or 188,5 s^{-1}. Than, the motor is disconnected from the network and record $\omega(t)$ curve, named the auto brake diagram. The motor moment of inertia is determined by the expression

$$J_M = \frac{P_{MM}}{\omega \dfrac{d\omega}{dt}}, \qquad (6)$$

where P_{MM} - are mechanical losses in one of the diagram points $\omega(t)$ and is determined from $P_{MM} = F(\omega)$ characteristics in figure 3; $d\omega/dt$ – the derivation in the same point. For DK 210A-3 motor was obtained $J_M = 1{,}7$ kg·m^2.

6. EXPERIMENTAL DETERMINATION OF ARMATURE AND AUXILIARY POLES INDUCTENCE

The method is based on current armature recording in the process of a short circuit in a blocked rotor (speed is equal to zero). The test bench scheme is modified: in the armature circuit is intercalated a current transducer *LEM,* which exit is connected to oscilloscope; the resistance *R1* is disconnected from the brake circuit and is connected consecutively with the armature (between *K1* and *K2* contacts); series excitation coil is disconnected. The motor's rotor is blocked mechanically and the following are effectuated:

1. At the armature terminal is applied a 100 V tension.

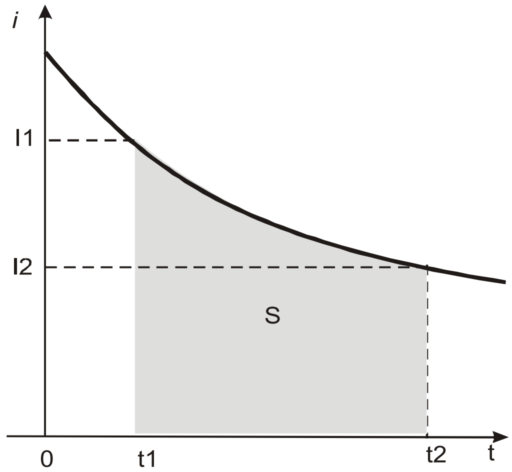

Figure 4: Concerning the armature & auxiliary poles inductance determination

2. *K3* contact is closed and armature circuit current *i(t)* diagram is recorded.
3. Assuming that armature circuit inductance is constant, the average value can be calculated directly from the diagram presented in Figures 4, and 5 taking the integral on the t_1-t_2 interval and which is equal to surface *S.*

$$L_i = \frac{R\int_{t_1}^{t_2} idt}{I_1 - I_2} . \qquad (5)$$

The average value of armature inductence is equal to 2,6 mH.

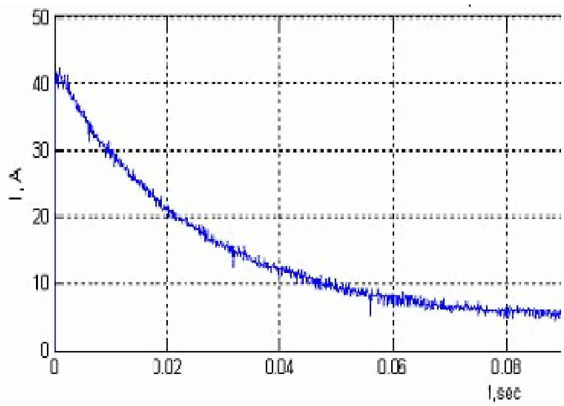

Figure 5: The current armature oscillogramm

5. CONCLUSIONS

For dynamic regimes stimulation, efficiency determination of electrical drive systems d.c. compounded motor – Chopper, for command strategies identification, etc., are necessary motor characteristics and parameters: magnetization curves, mechanical losses, motor moment of inertia, armature and auxiliary poles inductance.

In order to obtain entirely magnetization characteristics, it was preceded like this:

- Intersection coordinate point with ordinate axe was determined from magnetization characteristic of auxiliary machine, identical with motor which is imposing to function as a generator with separately excitation. For respectively excitation current in derivation value is determined $k\Phi_0$ flux.
- Intersection coordinate point with abscise axe cannot be determined in an experimental way because the rotation speed, theoretically, tends to infinite. In such a case it is determined through calculations: $I = - I_d W_d / W_s$, $k\Phi = 0$.

For the trolleybus electrical drive is important to know motor mechanical losses for the whole speed scale variation. For a trolleybus drive motor, which functions are on a large speed scale, traditional methods are not acceptable. The proposed method consists in power measurement absorbed from network by the motor-generator unit, which functions are at different rotation speed. The motor functions with a magnetization flux smaller than the nominal one and the iron losses are ten times smaller than the nominal ones, so, they can be neglected. If from the power absorbed from the network are excluded armature coil losses we obtain the mechanical losses sum for both electrical machines.

For motor moment of inertia determination, armature and auxiliary poles inductance are utilized traditional methods adapted to technical possibilities of the test bench: auto brake method for motor moment of inertia determination and respectively - from the dynamic electromagnetic diagram processes in the blocked rotor circuit.

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