Control of Direct Current Machine by the Change of Resistance in Armature Circuit

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ABSTRACT

The control of motor rotation speed by the change of resistor resistance value in armature circuit is called 'resistor control". For the regulation of resistance value R_0, included in armature winding circuit, we can use various technical solutions. The most used solution is the discrete variation of armature added resistance value by shunting its parts with contactors contacts.

Nowadays, the change of resistor resistance in armature circuit can be realized by shunting with a given porosity γ of resistor R_0 trough electronic keys. In this paper, we study the design of control system represented on figure 1.

Keywords: *Control of DC machine, change of resistance, armature circuit*

I. INTRODUCTION

DC motors consist of rotor-mounted windings (armature) and stationary windings (field poles). In all DC motors, except permanent magnet brushless motors, current must be conducted to the armature windings by passing current through carbon brushes that slide over a set of copper surfaces called a commutator, which is mounted on the rotor.[1][2]

The commutator bars are soldered to armature coils. The brush/commutator combination makes a sliding switch that energizes particular portions of the armature, based on the position of the rotor. This process creates north and south magnetic poles on the rotor that are attracted to or repelled by south and north poles on the stator, magnetic attraction and repulsion that causes the rotor to rotate.[3][4]

The dynamic behavior of DC machine is mainly determined by the type of the connection between the excitation winding and the armature winding including the commutation and compensation winding.

The greatest advantage of DC motors may be speed control. Since speed is directly proportional to armature voltage and inversely proportional to the magnetic flux produced by the poles, adjusting the armature voltage or the field current will change the rotor speed.[5]

Speed control means change of a speed to a value required for performing the specific work process. This adjustment should not be taken to include the natural change in speed which occurs due to the change in the load on the drive shaft. The electrical speed control has many economical as well as engineering advantages over mechanical speed control. There are so many methods for controlling the speed of a DC shunt motor but field rheostat control method is most reliable, economic and independent of load on the motor. This method is only applicable when we want speed which is higher than the normal speed of the motor. In this method, an increase in controlling resistance reduces the field current with a consequent reduction in flux and an increase in speed. But if we want to obtain low speed to control the low speed mechanical drive, we use armature rheostat control method. In this method, the speed at full load can be reduced to any desired value depending on the amount of resistance. But if we use both techniques in same machine then we can control motor from zero speed to maximum.[6] In field control the adjustment can be obtained by means of a small rheostat and relatively good speed regulation is obtained for all speed but with the armature control a bulky resistance is required. So if we use both methods simultaneously, cost of the machine will increase a little but we will get a large range of speed control. To neutralize the effect of power loss heat sink can be used. So by this method we can control the speed of a DC shunt motor to perform various tasks in effective and economic way.

II. EQUATIONS OF ELECTRIC DRIVE POWER CHANNEL WITH REGULATION OF RESISTANCE IN ARMATURE CIRCUIT

The system of resistor control of electromotor M rotation speed with separate excitation is composed of additive resistance R_0 in armature circuit, transistor VT, transistor control system CS VT, current captor CC_1 with shunt RS_1, speed captor BR and control installation (figure 1)

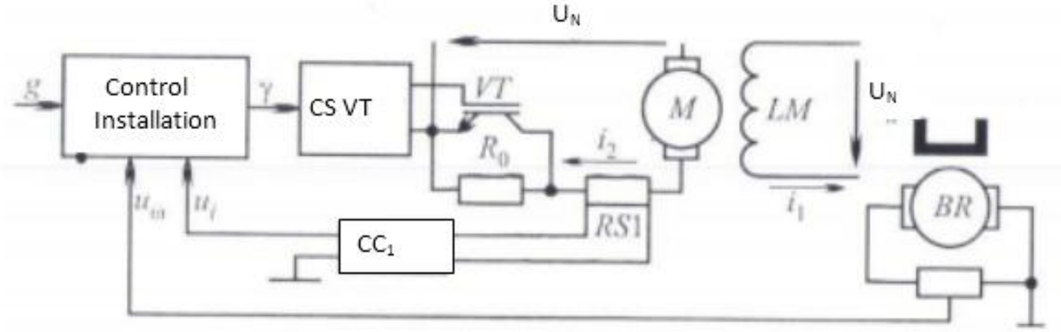

Figure 1: The circuit of resistor control of electromotor rotation speed

We shall assume that we supply in excitation winding and in armature winding direct current nominal voltage U_N. Additive resistor R_0 and transistor VT with control system CS VT constitute electrical transducer. The control of resistance value in armature circuit is done by the switch of transistor VT with porosity $\gamma \in [0,1]$.

If the working period of transistor control pulses is much more higher than the time constant of armature circuit, then we can prove that the equivalent resistance R included in armature circuit is $R = \gamma R_0$

Thus the input signal of electrical transducer is the porosity $\gamma \in [0,1]$, and the output is the equivalent resistance R. By varying R, we change armature current i_2 and the electromagnetic torque (moment) M.

To the electric drive resistor circuit in figure 1, we can match an armature equivalent circuit represented in figure 2.

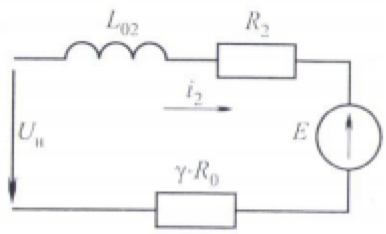

Figure 2: Armature circuit equivalent circuit

In that circuit, R_2 – active resistance of armature;
L_{02} – armature inductance;
γR_0- Additive resistance; γ є [0,1];
$E = \Psi\omega$ - armature e.m.f
$\Psi = U_N/\omega_B$ – constant expression;
ω_B – Basic armature rotation speed.

The state variables control system that describes the DC machine dynamic properties will look as follows:

$$\begin{cases} R_2^*.(T_2 p i_2^* + i_2^*) = 1 - \omega^* - \gamma R_0^*.i_2^*; \\ T_{Mech}.p\omega^* = i_2^* - I_r^* \end{cases} \quad (1)$$

We have $i_2^* = M^*$, $I_r^* = M_c^*$

The equation (1) is nonlinear because of the presence of expression$\gamma R_0^*.i_2^*$.

The equation (1) corresponds to the structural circuit shown on figure 3. That system has two input signals: pulses porosity γ and current I_r^*.

γis the control signal while $I_r^*$is the perturbation.

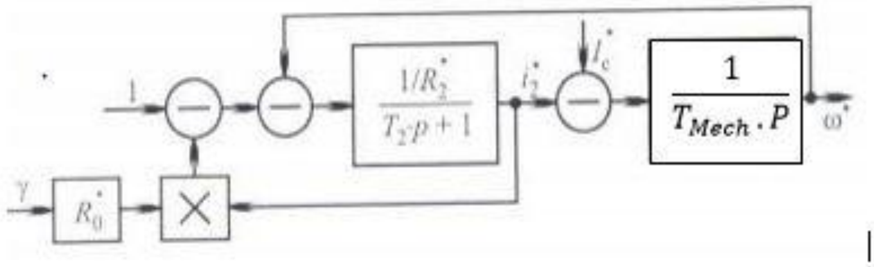

Figure 3: DC machine structural circuit with the resistance control in armature circuit

III. DESIGN OF CONTROL INSTALLATION

The resistance control system is constructed according to subordinate principle. It is composed of internal armature current loop and external speed loop. The current loop forms the control signal γ.

According to equations (1), established armature current value is

$$i_2^* = \frac{1 - \omega^*}{R_2^* + \gamma R_0^*}$$

From the last expression, when the porosity value γ increases the armature current i_2^* decreases. Let us introduce new control variable$x$, linked with γ. We consider$x = {}^1/_\gamma$.

Therefore with the increase of$x$, the armature current i_2^* will also increase.

The structural circuit of subordinate control system is shown on figure 3. The control system is composed of internal current loop with integral regulator. The transfer coefficient of current captor K_c^* is found from the condition $K_c^*.I_{max}^* = 1$, thus $K_c^* = 1/I_{max}^*$

p At the entrance of current loop, we install a current limit element. The maximal current value I_{max}^* should be limited to ensure given static and dynamic loads in electric drive mechanism and reliable functioning of collector-mechanism. As a rule, the armature maximal current value I_{max}^* is equal to 1,2;….;2,0.

The current limitation at a given level I_{max}^* can be achieved from the limitation of current loop input signal x_1^* by the valuex_{1max}^*. If we are given the armature current loop maximal value I_{max}^*, then

$$x_{1\,max}^* = K_c^*.I_{max}^* = 1$$

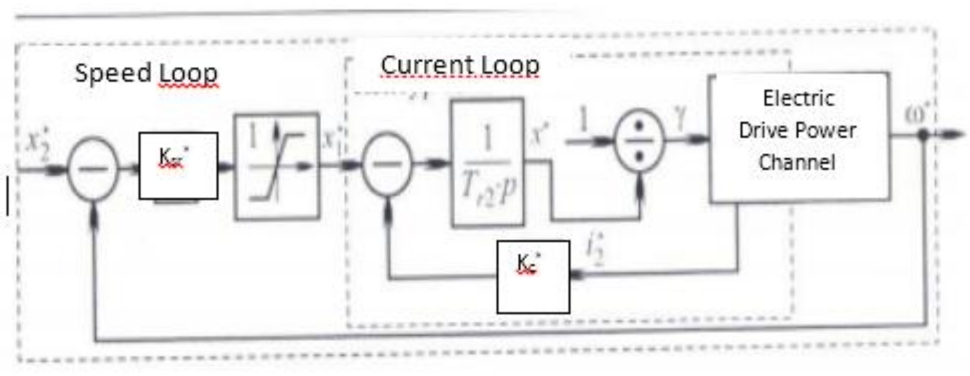

Figure 4: Structural circuit of resistance control system

IV. DEFINITION OF CURRENT AND SPEED LOOPS PARAMETERS

The parameter of integral current regulator T_{r_2} should be such that the transient processes in current control loop will have an etalon aspect. To the current loop corresponds the system of differential equations:

$$\begin{cases} T_{r_2}.px^* = x_1^* - K_c^*.i_2^*; \\ R_2^*.(T_2.pi_2^* + i_2^*) + R_0^*.\dfrac{i_2^*}{x^*} = 1 - \omega^* \end{cases}$$

That system is nonlinear on control signal x^*. For the determination of time constant for integral regulator Tr_2, we linearize those equations in neighborhood of the working point $[x(\infty)^*$, $i_2(\infty)^*]$

We observe that the mechanical time constant $T_{Mec\,h}$is sensitively higher than the armature time constant $T_2$and the speed ω^* practically does not change with current regulation, ie $\Delta\omega^* = 0$.

Considering p=0, $x^* = x(\infty)^*$, $i_2^* = i_2(\infty)^*$,
We have equations of stationary working regime:

$$\begin{cases} 0 = x_1(\infty)^* - K_c^*.i_2(\infty)^*; \\ R_2^*.i_2(\infty)^* + \dfrac{R_0^*.i_2(\infty)^*}{x(\infty)^*} = 1 - \omega^* \end{cases}$$

The solution of that system defines the stationary values of variables

$$x(\infty)^* = \frac{R_0^*.i_2(\infty)^*}{1 - \omega^* - R_2^*.i_2(\infty)^*}; i_2(\infty)^* = \frac{x_1(\infty)^*}{K_c^*}$$

From linearization results we have the system of equations in variations:

$$\begin{cases} T_{r_2}.p\Delta x^* = \Delta x_1^* - K_c^*.\Delta i_2^*; \\ R_2^*.(T_2.p\Delta i_2^* + \Delta i_2^*) + \frac{R_0^*}{x(\infty)^*}.\Delta i_2^* - \frac{R_0^*.i_2(\infty)^*}{x(\infty)^*}\Delta x^* = 0 \end{cases} \quad (2)$$

From the linearized equations system, we find the transfer function of current loop:

$$W_{cl} = \frac{\Delta i_2^*}{\Delta x_1^*} = \frac{1/K_c^*}{T_\mu^2 p^2 + d.T_\mu p + 1}$$

Where $T_\mu = d.T_2\frac{R_2^*.i_2(\infty)^*}{1-\omega^*}$;

$$d = \frac{1 - \omega^*}{1 - \omega^* - R_2^*.i_2(\infty)^*}.\sqrt{\frac{R_0^*.T_{r2}}{x_1(\infty)^*.R_2^*.T_2}} \approx \sqrt{\frac{R_0^*.T_{r2}}{x_1(\infty)^*.R_2^*.T_2}}$$

The damping factor d of transient function will have the minimal value for $x_1(\infty)^* = K_c^*.I_{max}^* = 1$:

$$d_{min} = \sqrt{\frac{R_0^*.T_{r2}}{R_2^*.T_2}}$$

If we consider $d_{min} = \sqrt{2}$, then the current regulator time constant

$T_{r2} = 2.T_2.R_2^*/R_0^*$.

The current loop time constant T_μ will considerably depend on the drive working regime. For $\omega^* = 1 - R_2^*.i_2(\infty)^*$, the time constant will have the highest value $T_\mu = \sqrt{2}.T_2$.

If we assume that the current loop has transfer function

$W_{cl} = \frac{i_2^*}{x_1^*} = \frac{1/K_c^*}{\sqrt{2}.T_2 p^2+1}$,

then the speed regulator transfer function is on technical optimum

$$W_{sr} = \frac{(\sqrt{2}.T_2 p + 1)K_c^*.T_{Mech}.P}{2T_{\mu 2}P.(T_{\mu 2}P+1)} = \frac{K_c^*.T_{Mech}}{2T_{r2}} = K_{sr}^*,$$

where $T_{\mu 2} = \sqrt{2}.T_2$.

The set of electromechanical (mechanical) characteristics of closed loop control system with speed regulator will look as shown on figure 5.

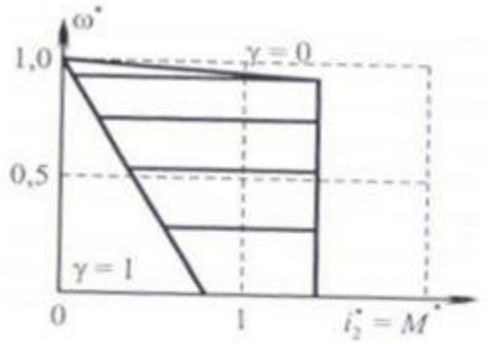

Figure 5: The set of electromechanical (mechanical) characteristics with closed loop control system

V. CONCLUSIONS

The dynamic model of Direct Current electrical drive with control by the means of armature circuit resistance change is nonlinear on control signal. For the construction of current control loop, the design of regulators is done with linearization of equations (2). It is recommended to use integral regulator in current loop. At the input of current control loop, we install an armature current limitator. The speed control loop is external compared to current control loop and it should have a proportional regulator.

The region of speed regulation by commutation of resistor in armature circuit for the electric drive is limited by the value of resistor resistance R_0 (figure 5). The domain enlargement of speed regulation by reduction of expression R_0 will lead to high commutation survoltages in the transistor and its destruction.

The enlargement of speed regulation domain can be reached by in series switching of resistors, with transistor shunts. The reduction of porosity on transistor functioning should be done in opposite manner.

A deep resistor speed regulation is not energically efficient, because of energy losses.

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