

Investigation of numerical model of Lenze 530 Dc drive in Matlab

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Abstract. This paper describes DC drive with thyristor voltage regulator Lenze 530 series. To investigate the transients of the drive system developed numerical model in MatLab is developed. Dual circuit structural diagram of “TCV-DC motor” system with negative feedback for the current and angular speed or current and armature voltage in model is realized. By introduction of current feedback, torque and current limit are achieved and with using of armature voltage or tacho automatic speed stabilization is obtained. At this model certain standard settings of cascade control system are made.

The basis of the internal loop consist from PI-regulator with $K_{p,c}=2$ and $K_{i,c}=100$ gains, TCV and armature transfer functions, covered by armature current feedback. Current controller is configured at technical optimum.

Second circuit can have armature voltage feedback; can be tuned at technical optimum and has a P-regulator with $K_{p,s}=36$ gain. In same way it can have a speed negative feedback with the same tunings.

A numerical model has restrictive blocks: to limit the maximum and minimum speed and maximum current. To demonstrate the obtained results virtual oscilloscopes were used. Also the electromechanical characteristics of the drive with armature voltage and current or speed and current feedbacks using XYGraph block are presented. At this paper the electromechanical characteristic of the real DC drive Lenze 530 series is presented too.

According to research results at numerical model and physical investigation equipment graphs of instantaneous values of current and electromechanical characteristics are made. Analysis of graphs confirms the adequacy of the results obtained at the numerical model and the real drive system, which enables the use of the developed numerical model for the investigation of similar DC drives.

DC drive model with thyristor voltage regulator Lenze 534 and results of investigations of electromechanical properties are presented.

Key words: Transition process, semiconductor voltage converters, feedback, PI-controls, electromechanical characteristics, model.

INTRODUCTION

Now modern regulated drives based on power electronics are widely used in industry [5, 9, 10, 15]. Technical characteristics, that are presented at datasheets for drive elements, do not give information about their work at transients. For obtaining a information about transients it is need to carry out investigations at laboratory and testing equipment, that leads to significant amount of time loss and additional costs of their creation. It is possible to simplify the study of transients using electric drive numerical model [1-4, 6-8, 11, 14-18] in MatLab, which consists of a DC motor with separate excitation and Lenze 530 Series thyristor voltage converter.

MATERIALS AND METHODS

Analysis of driving performance was based on the theory of electric drives and using computer models of the MatLab system.

AIM OF THE WORK

To provide reliable performance of DC drive with semiconductor voltage converter Lenze 530 Series at transient processes in MatLab system computer models with a significant reduction of time and reduce material costs.

RESULTS AND DISCUSSION

Thyristor voltage converters (TVC) of German company Lenze Series 530 (Fig. 1) are produced in four versions with output power range from 0.36 to 2.04 kW and are designed for use with DC motors with separate excitation in the first quadrant.

Converters work with negative armature voltage feedback (IXR-compensation) or speed tachometer voltage feedback [13].

On the front side of the device adjustment potentiometers are presented: I_{\max} – setting of maximum device current; IXR – regulation of armature voltage feedback anchor (IXR-compensation); n_{\max} , n_{\min} – saturation of maximal and minimal motor speed; T_i – adjustment of the needed transients.



Fig. 1. Appearance of Lenze 530 Series thyristor voltage converter

Electrical scheme of drive with TCV is presented at Fig. 2. When a voltage is applied to the DC controller, current appears in the excitation winding, and for power supply of the motor armature circuit, switch RFR must be enabled. In this manner enabling the drive magnetic flux is set to the nominal before start of the motor. Speed is adjusted by potentiometer $R=10\text{ kOhm}$ or external source of voltage control $U_C=0\dots10\text{V}$. Using negative speed feedback jumper between terminals 2-4 is removed and tachometer U_{BR} connected to terminals 3-4.

«Thyristor voltage converter – DC motor» dual circuit system with armature current feedback and armature voltage of tachometer voltage feedback is presented at Fig. 3 [12]. By introducing current feedback in to the drive system current and torque limitation are achieved. Using armature voltage or tachometer voltage automatic speed stabilization is obtained.

Current feedback gain $k_{C.F.}$ can be obtained as a ratio between maximal speed setpoint voltage $U_{S.S.\max}$ and maximal (starting) motor current:

$$k_{C.F.} = \frac{U_{S.S.\max}}{\lambda_I I_N}, \quad (1)$$

where: λ_I – available multiplicity of starting current; I_N – rated current of the motor.

EMF stabilization of TCV is achieved by supplying of negative feedback coherent signal $u_{V.F.} = e_{TCV} - i_A R_{COMP}$ to the input of adjustment speed signal. Changing of R_{COMP} , we can regulate feedback gain value. When load is increases the voltage at motor connectors is decreases due to losses at armature circuit. This increases the voltage drop across the resistance R_{COMP} , the signal from which is subtracted from the e_{TCV} and consistently applied to the input $u_{S.S.}$. The output voltage of TCV is automatically increased.

According to structural diagram of the electric drive (Fig. 3) we can write the following equations of electromechanical characteristics with negative feedback of current and armature voltage:

$$\begin{cases} k_{TCV}[u_{S.S.} - (e_{TCV} - i_A R_{COMP}) - k_{C.F.} i_A] = (T_{TCV} p + 1) e_{TCV}, \\ e_{TCV} - k_E \omega = R_A (T_{A\Sigma} p + 1) i_A, \end{cases} \quad (2)$$

and with negative feedback of current and angular speed:

$$\begin{cases} k_{TCV}(u_{S.S.} - k_{V.F.} \omega - k_{C.F.} i_A) = (T_{TCV} p + 1) e_{TCV}, \\ e_{TCV} - k_E \omega = R_A (T_{A\Sigma} p + 1) i_A. \end{cases} \quad (3)$$

After the transformation equations (2) we obtain the expressions of dynamic electromechanical and mechanical characteristics of electric drive:

$$\omega = \frac{k_{TCV} u_{S.S.}}{k_E [(T_{TCV} p + 1) + k_{TCV}]} - \frac{R_A [(T_{TCV} p + 1) + k_{TCV}] (T_{A\Sigma} p + 1) + k_{TCV} k_{C.F.} - k_{TCV} R_{COMP}}{k_E [(T_{TCV} p + 1) + k_{TCV}]} i_A, \quad (4)$$

$$\omega = \frac{k_{TCV} u_{S.S.}}{k_E [(T_{TCV} p + 1) + k_{TCV}]} - \frac{R_A [(T_{TCV} p + 1) + k_{TCV}] (T_{A\Sigma} p + 1) + k_{TCV} k_{C.F.} - k_{TCV} R_{COMP}}{k_E k_M [(T_{TCV} p + 1) + k_{TCV}]} t_L. \quad (5)$$

When $p = 0$, equation (4) and (5) are the equations of static electromechanical and mechanical characteristics:

$$\omega = \frac{k_{TCV} u_{S.S.}}{k_E (k_{TCV} + 1)} - \frac{R_A (k_{TCV} + 1) + k_{TCV} k_{C.F.} - k_{TCV} R_{COMP}}{k_E (k_{TCV} + 1)} i_A, \quad (6)$$

$$\omega = \frac{k_{TCV} u_{S.S.}}{k_E (k_{TCV} + 1)} - \frac{R_A (k_{TCV} + 1) + k_{TCV} k_{C.F.} - k_{TCV} R_{COMP}}{k_E k_M (k_{TCV} + 1)} m. \quad (7)$$

Stiffness of the mechanical characteristics in the closed system depends on the feedback gains, namely from coefficients $k_{C.F.}$ i R_{COMP} . So, at $R_A (k_{TCV} + 1) + k_{TCV} k_{C.F.} = k_{TCV} R_{COMP}$ characteristics has infinite rigidity $\beta = \infty$, and at $R_A (k_{TCV} + 1) + k_{TCV} k_{C.F.} < k_{TCV} R_{COMP}$ – has a positive rigidity $\beta > 0$.

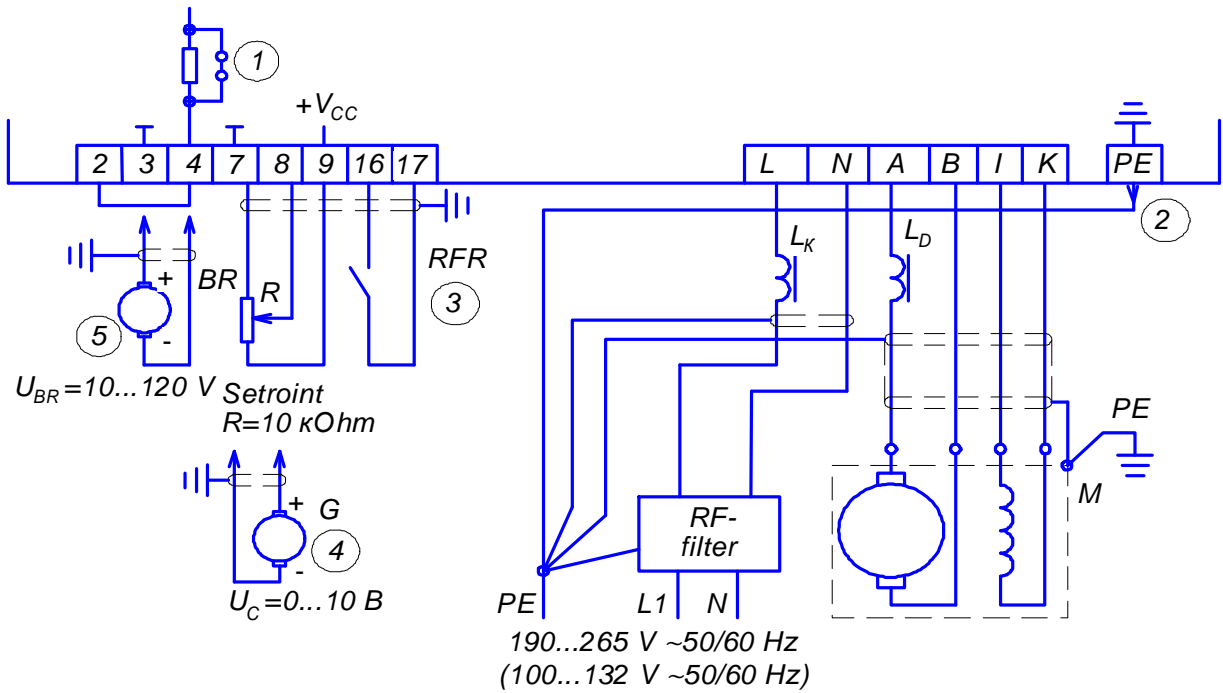


Fig. 2. The circuit diagram of DC drive with Lenze Series 530 voltage converter: 1 – jumper; 2 – fast-on connector; 3 –RFR switch for voltage connection in to the motor armature circuit; 4 – external source of control voltage; 5 – tachometer

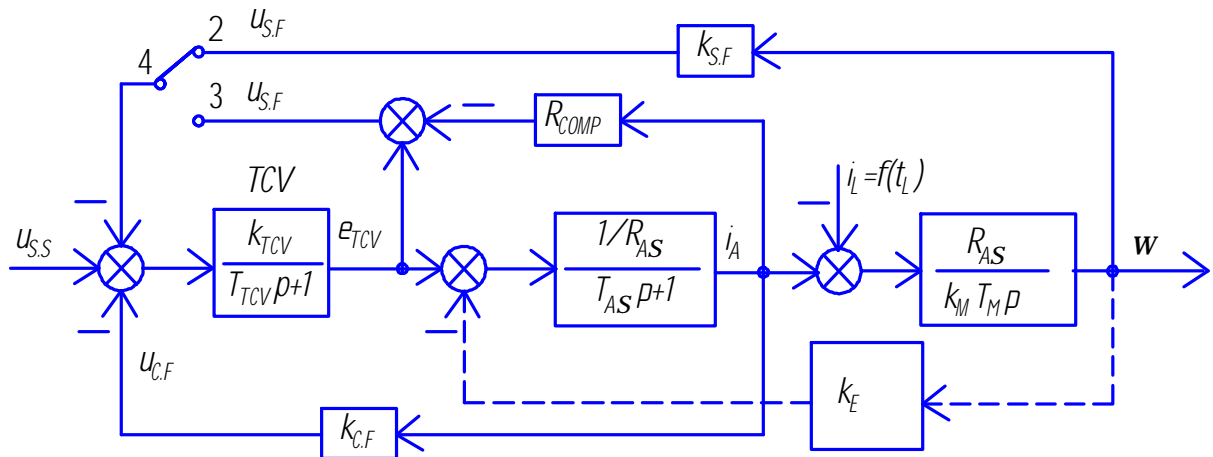


Fig. 3. Dual circuit structural diagram of “TCV-DC motor” system with negative feedback for the current and angular speed (jumper 2-4 is closed) or armature voltage (jumper 3-4 is closed): $u_{s,s}$ – speed signal setpoint; $u_{s,f}$, $u_{v,f}$ – feedback signals by speed and armature voltage; $u_{c,f}$ – current feedback signal; R_{COMP} – compensation resistance; $R_{A\Sigma}$ – total resistance of armature circuit; TCV– thyristor voltage converter; k_{TCV} – TCV gain; k_E – electrical constant of DC motor; k_M – mechanical constant of DC motor; $k_{C,F}$, $k_{S,F}$ – current and speed feedback gains, respectively; T_{TCV} , $T_{A\Sigma}$ – electromagnetic time constants of TCV and armature current; T_M – electromechanical time constant; e_{TCV} – EMF of thyristor voltage converter; i_A , i_L – instantaneous value of the circuit armature current and current, that is proportional to the load of the working machine; t_L – instantaneous value of load torque; p – Laplace operator.

Equation of static mechanical characteristic can be obtained after transforming of equations system (3).

$$\omega = \frac{k_{TCV} u_{s,s}}{k_E (1 + k_S)} - \frac{R_A + k_{TCV} k_{C,F}}{k_E k_M (1 + k_S)} t_L, \quad (8)$$

where: $k_S = \frac{k_{TCV} u_{s,f}}{k_E}$ – gain of the system.

Analysis of equation (8) shows that increasing of negative speed feedback gain $k_{S,F}$, and therefore k_S , ceteris

paribus reduces the speed of the idle speed and increase rigidity of mechanical characteristics. When $k_S = \infty$ mechanical characteristics becomes absolutely rigid.

Based on the electrical circuit of TCV, models in MatLab with negative armature voltage feedback (Fig. 4, a) and angular speed (Fig. 4, b) were created.

Simulations carried on the example of the electric DC motor with separate excitation MI32 314-02 with parameters:

$P_N = 0,78$ kW; $U_N = 110$ V; $I_N = 8,2$ A; $n_H = 2500$ rev./m.; $U_{EX} = 110$ V; $I_{EX} = 0,35$ A; $\eta_N = 0,86$; $J = 0,053$ kg·m²; $R_A = 1,8$ Ohm; $L_A = 0,021$ H; $G = 38$ kg.

Calculated values for the model:

$T_{TCV} = 0,01$ s; $T_A = L_A/R_A = 0,021/1,8 = 0,0117$ s;
 $R_N = U_N/I_N = 110/8,2 = 13,4$ Ohm; $R_A^* = R_A/R_N = 1,8/13,4 = 0,134$;
 $\omega_N = \pi n_N/30 = 3,14 \cdot 2500/30 = 262$ rad/s;
 $T_M = J R_A \omega_N^2 / P_N = 0,053 \cdot 1,8 \times 262^2 / 780 = 0,72$ s;
 $I_{S.C} = U_N/R_A = 110/1,8 = 61$ A; $k_E = (U_N - I_N R_N)/\omega_N = (110 - 8,2 \cdot 1,8)/262 = 0,36$ V·s/rad;
 $k_M = k_E = 0,36$ V·s/rad;
 $k_I = I_{S.C}/I_N = 61/8,2 = 7,4$; $k_I T_M = 7,4 \cdot 0,72 = 5,33$ s.

Following marking are used at the equations:

T_{TCV} , T_A – electromagnetic time constants of TCV and armature circle; L_A , R_A – inductance and resistance of armature winding; R_A^* – armature resistance in relative units; ω_N – nominal speed of armature rotation; T_M – electromechanical time constant; ω_0 – idling speed; $I_{S.C}$ – short-circuit current; k_E – electrical constant of DC motor; k_M – mechanical constant of DC; k_I – multiplicity of short-circuit current.

Input parameters of the model are given in relative units. To convert them from relative units to the real it is need to multiply obtained results with the corresponding baseline values U_N , I_N , R_N and ω_0 .

In present model (Fig. 4, a) block "Transfer Fcn" models link of armature motor with $T_A = 0.02$ s and gain of $1/R_A^*$, and block "Transfer Fcn1" models link of voltage thyristor converter with $T_{TCV} = 0,01$ s. Block "Integrator" and block "Gain" with coefficient $K = 1/k_I T_M$ implement the equation of drive motion. The load current is formed by blocks "Step1", "Gain2" with coefficient $K_2 = 0,7$ and "Integrator1" as the integral from continuous signal.

To achieve high accuracy of speed control was necessary to simultaneously control armature current (torque). For this purpose subordinate control system with certain standard settings is used.

The basis of the first circuit is a PI controller, TCV and armature winding of motor, covered by negative feedback of armature current. Usually the current controller is adjusted at technical optimum. However, according to the theory of automatic control [12] it is required that the transfer function of controller had the form:

$$W_{C.R}(p) = \frac{T_A p + 1}{T_{TCV} p} \quad (9)$$

According to (9) the gains of current regulator are next:

- integral gain coefficient:
 $k_{I.C} = 1/T_{TCV} = 1/0,01 = 100$,
- proportional gain coefficient:
 $k_{P.C} = T_A/T_{TCV} = 0,02/0,01 = 2$.

The external circuit with armature voltage negative feedback is adjusted at technical optimum and contains a proportional regulator too. Coefficients are taken from transfer function of controller [12, 15]:

$$W_{I.R}(p) = \frac{T_M}{2T_{TCV}} \quad (10)$$

According to (10) speed regulator gain is:

$$k_{S.R} = 0,72/(2 \cdot 0,01) = 36.$$

By means of T_i potentiometer adjustment, which mounted at the front panel of TCV (presented at Fig. 1), gain of proportional speed regulation can be changed, that allows changing time of transients.

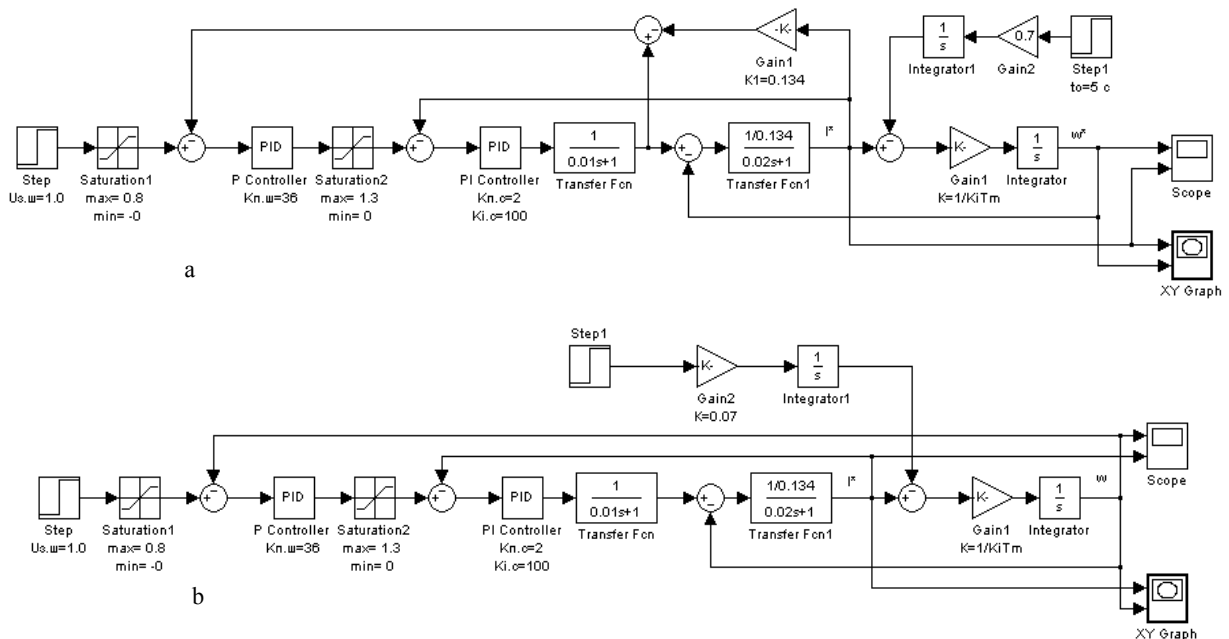


Fig. 4. Numerical model of DC drive with negative armature current and voltage (a) and angular speed (b) feedbacks

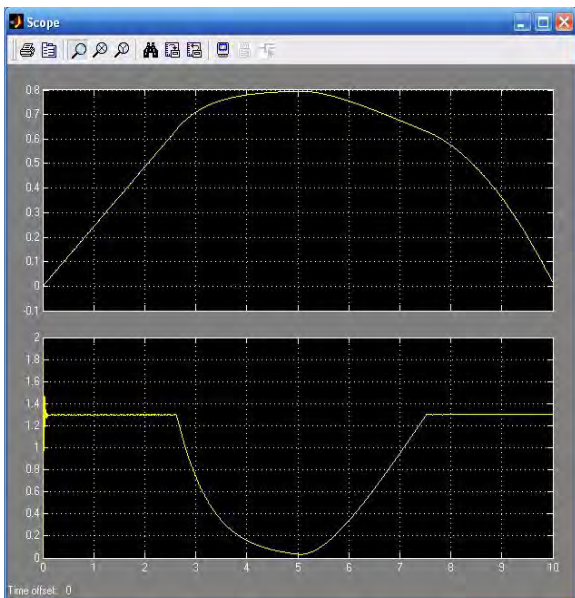
Control of the model is adjusted by “Step” block, which specify the output voltage of TCVC. Model has two limiting blocks “Saturation”. “Saturation1” is used for limiting of maximal n_{max} and minimal n_{min} angular speed, “Saturation2” – for limiting of maximal armature current I_{max} .

To visualize the electromechanical (mechanical) characteristics “XYGraph” is used, and at the oscilloscope “Scope” trends of angular speed and armature current are observed.

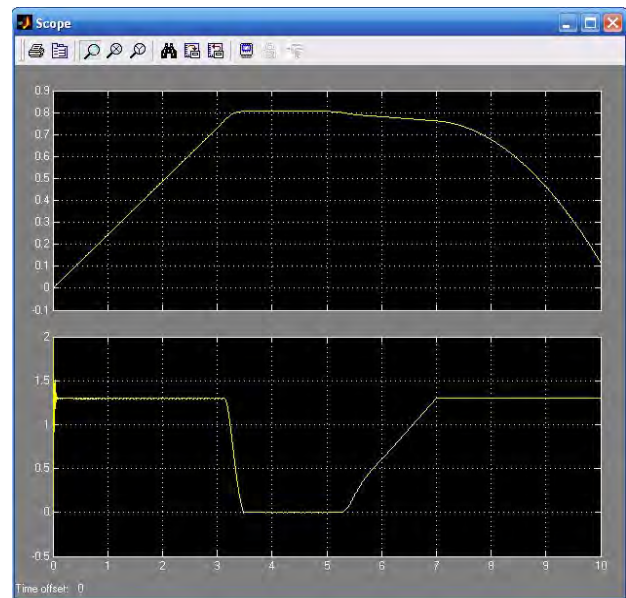
The simulation results of the electric drive work are shown at Fig. 5 and 6.

The process of the motor work modelled as follows. Motor starts with no-load (Fig. 5), and after 5 s, the load starts to increase. According to adjusted value of speed the limits are set: for the speed up to $0,8\omega_0$, and for the current up to $-1,3I_N$. Numerical model accurately tracks

established limits, as shown at Fig. 6. At start when the difference between adjusted and actual speed value is large enough, speed controller switches to "saturation" mode. Herewith current setpoint is constant and we have only armature current control loop. Due to PI-regulator the value of armature current remains constant and angular speed increases linearly (Fig. 6). When P-regulator of angular speed (armature voltage) comes out from «saturation», control system becomes dual-loop with internal current regulation loop and external voltage regulation loop. This increases the rigidity of characteristics, but they become not absolutely rigid because of using of P-regulator. Starting current drops and the system stabilizes the angular speed at adjusted level. When the motor load becomes greater than the critical torque, the motor speed is reduced and the system again switches to stabilize the current.

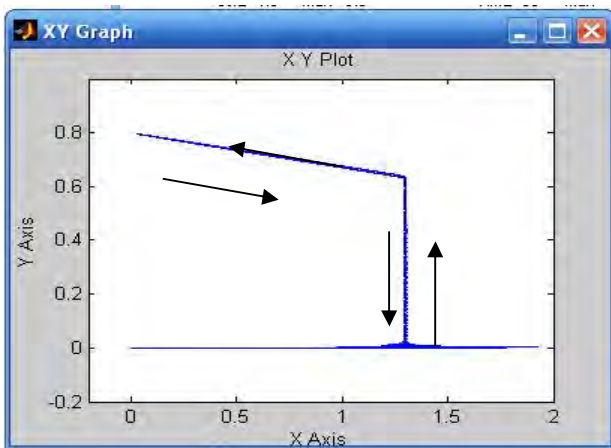


a

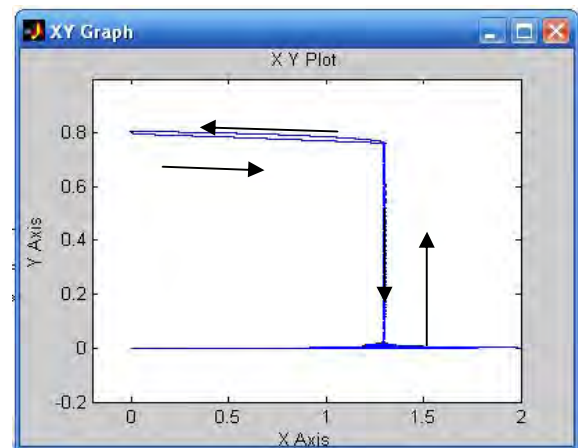


b

Fig. 5. Angular speed (top) and armature current (bottom) transients. a – $R_{COMP}= 0,034$ p.u.; b – $R_{COMP}= 0,134$ p.u.



a



b

Fig. 6. Electromechanical characteristic of the drive: a – $R_{COMP}= 0,034$ p.u.; b – $R_{COMP}= 0,134$ p.u.

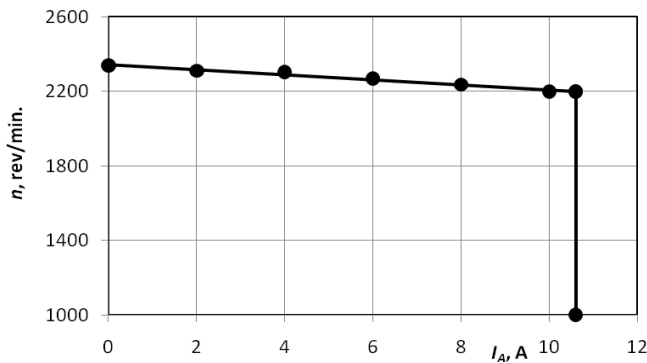


Fig. 7. Electromechanical characteristics, obtained at laboratory equipment ($R_{COMP}=0,134$ p.u.)

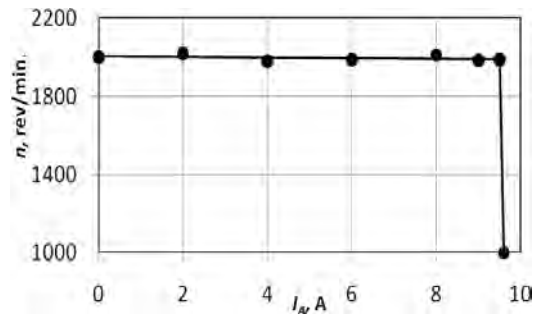
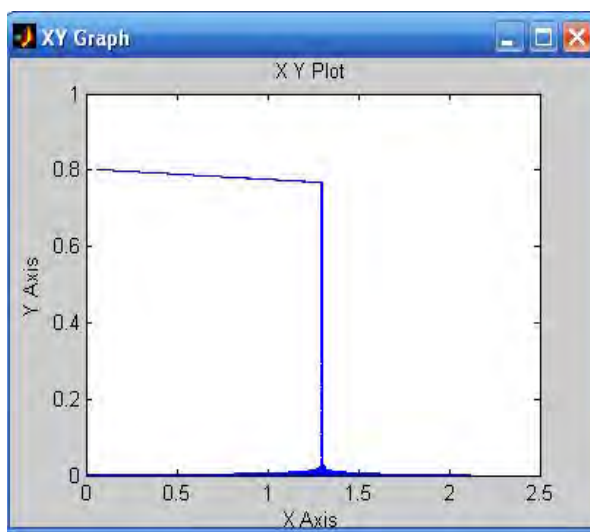
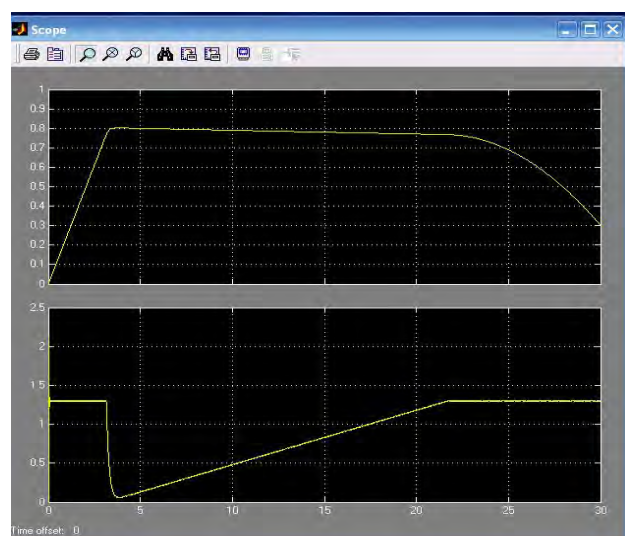


Fig. 8. Electromechanical characteristics, obtained at laboratory equipment



a



b

Fig. 9. Results of drive research at the Matlab model:

a – electromechanical characteristic; b – angular speed (top) and armature current (bottom) transients

There is the following explaining of the obtained electromechanical characteristics (Fig. 6). When starting the motor there is a slight wobble of starting current, then it is held at the maximum allowable level, while the motor speed increases. When the current becomes less than the maximum, angular speed increases linearly up to maximum $0,8\omega_0$. When the load increases, the reverse process occurs. At Fig. 6, b it is good to see the impact of dynamic moment when over clocking motor (upper curve of electromechanical characteristics).

Simulations performed for two values of feedback gain of armature voltage, determined by resistance R_{COMP} (compensation coefficient). As shown in Fig. 6 rigidity of electromechanical characteristics increases with increasing feedback gains, confirming the theoretical calculations previously presented. Coefficient of compensation in electric drive Lenze Series 530 is adjusted by "I×R" potentiometer.

In Fig. 7 shows electromechanical characteristics which obtained at laboratory equipment. Analysis of

graphs confirms the adequacy of the results obtained on the model and at the real drive.

At Fig. 6, b shows the graphs obtained in the model, which contains the loop with only angular speed feedback. Loop also includes proportional to P-controller with gain $k_{S,R} = 36$. The current control loop is adjusted at technical optimum, angular speed control loop is adjusted at symmetrical optimum with the selected regulators.

In Fig. 8 shows electromechanical characteristics which obtained at laboratory equipment. Analysis of graphs confirms the adequacy of the results obtained on the model and at the real drive.

The process is similar to the previous simulation. The simulation results of the electric drive are shown at Fig. 9. According to adjusted value of speed the limits are set: for the speed up to $0,8\omega_0$, and for the current up to $1,3I_N$. Numerical model accurately tracks established limits, as we can see from electromechanical characteristics (Fig. 9, a).

CONCLUSIONS

1. Simple investigation of the characteristics of the industrial DC drives with TCv is possible using numerical models. Easiest programming tool for this purpose is MATLAB, that gives a possibility to build models in structural form. The numerical model in MatLab with TCv Lenze series 530, which provides limits of the maximal and minimal speed, limit of armature current, stabilization of adjusted speed, regulation of transient time gives a possibility to research a characteristic of the "TCv-DC motor" system without using a physical equipment.

2. There are two modes of work of DC drive, which can be easily defined from the models. At the mode of saturation of the speed controller, drive system forms absolutely sort electromechanical characteristic, that gives a possibility to limit a armature current and, consequently, the torque of motor. At the second mode both feedbacks, namely current feedback and voltage (speed) feedback are work properly, so rigidity of electromechanical characteristics becomes bigger. Same way using numerical model it is easy to obtain the transients of speed and armature current.

3. This is especially important when analyzing the speed, because of armature current and voltage can be measured by expensive oscilloscope, while measuring of speed can be done only at the case of mechanically installing the speed sensor on the motor shaft.

4. A comparison of the transients and characteristics, obtained from numerical model and real drive system, confirmed the adequacy of simulated transients with real behaviour of electric drive.

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