Ministry of Education and Science of Ukraine
Zaporizhzhya National Technical University

METHODICAL INSTRUCTIONS
for the computational and graphical assignment

of the subject
«**Theory of the electric drive**»

COMPUTATION OF THE INCLINED LIFTING MECHANISM OF THE DRIVE

for students of specialty 141
“Electrical energy, electrical
engineering and
electromechanics” for day and
extramural forms

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Methodical instructions for the computational and graphical assignment of the subject «Theory of the electric drive» COMPUTATION OF THE INCLINED LIFTING MECHANISM OF THE DRIVE for students
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CONTENT

1 THE PURPOSE OF THE WORK

The purpose is to consolidate and practically learn specific calculation and design tasks of the electric drive.

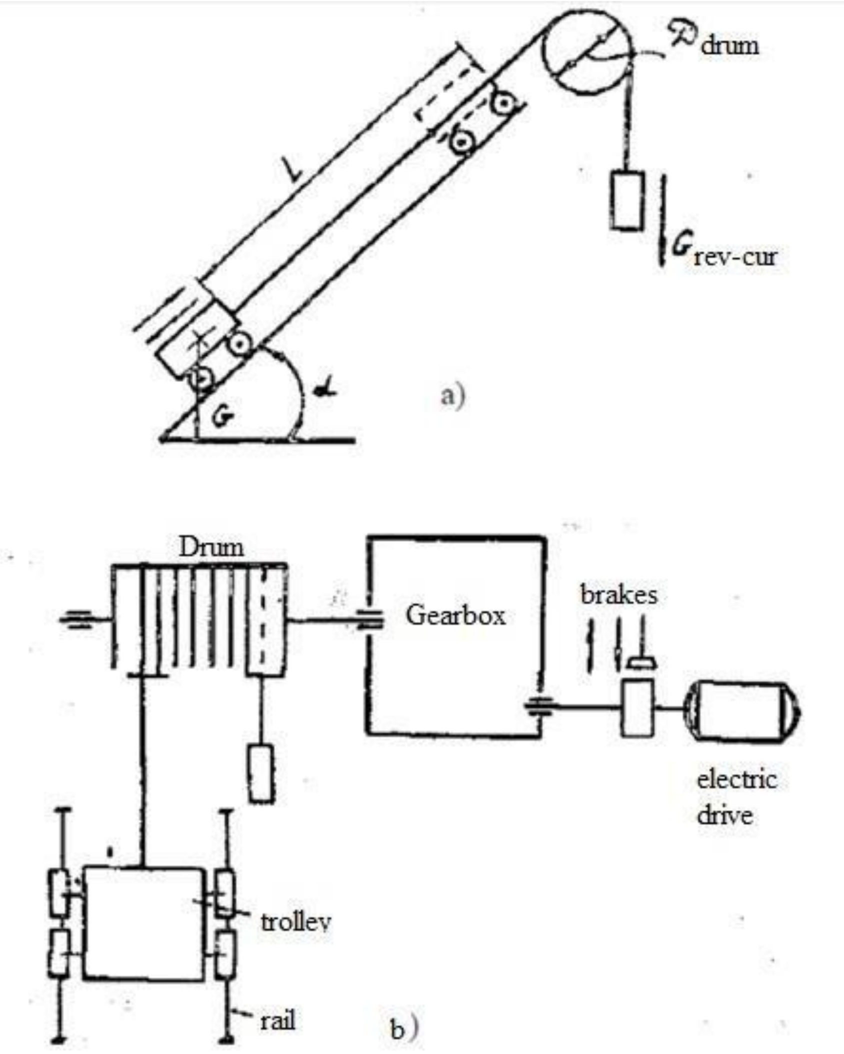
The task is to provide students with the skills in designing and studying the main parameters and control circuits of the electric drives for specified conditions.

2 THE TASKS OF THE WORK

The object of calculation is electric drive of lifting machine, made on the basis of DC motor and asynchronous motor. Output data for calculation are given in Appendix A, where the number of variants, composition, terms are indicated, as well as basic parameters of the drive and its type according to the current. The technical data for DC motors are given in Appendix B. In order to simplify the calculations the data are given for respective single-motor electric drives for load-lifting mechanisms. While realizing the research the following problems are considered and solved: preliminary selection of the motor; calculations and building up of velocity diagrams; determination of the equivalent motor power as per equivalent torque; motor test its overload capacity; calculation of the natural mechanical characteristics in nominative and relative units; calculation of the artificial rheostat characteristics for regulating the angular velocity for set conditions in nominative and relative units; calculation of the braking modes characteristics; calculation of the starting diagram; calculation of transient processes when starting; drive control circuit diagrams; drive control circuits design (starting, braking, speed regulation, etc.).

The above list of problems can be modified, some sections may be shortened, widened or replaced by others.

The mechanism (Figure 2.1) of the calculated open drive system is the inclined lift with a counterweight, that is working in the main modes: lifting and lowering with respect to loaded and empty trolley.



a) kinematic lifting diagram
b) design of the kinematic lifting diagram

Figure 2.1 - Kinematic diagram of the inclined lifting mechanism of the drive

3 METHODICAL GUIDES

3.1 Electric drive computation for the load-lifting mechanism.
All calculations are to be realised according to the international system of units (SI). The sequence of calculations is as follows.

3.1.1. The value of static power (17–19), according to the nominal motor load is determined by the formula (3.1)

$$Ps = 1.3 \cdot \frac{Q_0 \cdot g \cdot V}{\eta} \cdot 10^{-3}, \qquad (3.1)$$

P_s - motor static power, kW;
V - load lifting speed (Appendix A), м/s; g - acceleration of gravity, 9,81 м/s^2;
η - efficiency of the load-lifting mechanism.

The efficiency of the load-lifting mechanism takes into account a gearbox and a drum efficiency and may be roughly taken as 0.85 to 0.9.

3.1.2 According to initial data (Appendix A) and calculated power P_s, drive motor may be chosen in Appendix B.

3.1.3 Finding the static load torque M_s, N·m :

$$Ms = \frac{Ps}{\omega_n} \cdot 10^3, \qquad (3.2)$$

where ω_n - nominal angular velocity of the chosen motor, rad / s; P_s - motor static power as per the nominal load, kW;

$$\omega_n = \frac{2 \cdot \pi \cdot n}{60}, \qquad (3.3)$$

where n - rotational speed of the selected motor, rpm.

3.1.4 For set values of linear lifting velocity V, acceleration and lifting height H, determine duration of work and distance covered on separate sections: acceleration, constant motion and breaking of the drive.

$$t_1 = t_2 = \frac{V}{a}, \qquad h_1 = h_1 = \frac{a \cdot (t_1)^2}{2}, \qquad (3.4)$$

$$h_c = H - (h_1 + h_2), \qquad t_c = \frac{h_c}{V}, \qquad (3.5)$$

where t_1, t_2, h_1, h_2 - are time [s] and distance [H] of accelerating and braking;

a - tolerated acceleration (slowing) м/s^2; (to simplify we take tolerated acceleration when drive starting numerically equal to tolerated slow down when drive breaking);

h_c, t_c- distance and time for continuous motion.

$$T_c = t_1 + t_2 + t_0 + t_c, \qquad (3.6)$$

where T_c is cycle time;

t_0 - delay in time between liftings, s.

3.1.5 Build up the velocity diagram V(t) as per data from paragraph 3.1.4 .

3.1.6 Determination of the drive real energizing time ET_r.

$$ET_r = \frac{t_1 + t_2 + t_c}{T_c} \cdot 100 . \qquad (3.7)$$

3.1.7 Finding out of the reduced moment of inertia I_{red} (кg/m^2)

$$I_{red} = I_m + I_g + \frac{I_\delta}{ig^2} + 2 \cdot Q_0 \cdot \frac{V^2}{\omega_h^{\ 2}} \ , \qquad (3.8)$$

where I_m - inertia moment of the motor moving parts , kg/m^2;

I_g - gear inertia moment, kg/m^2; I_δ - drum inertia moment, kg/m^2; i_g -gear ratio.

For the AC motor (Appendix 2)

$$I_{dr} = \frac{GD^2}{4}, \qquad (3.9)$$

where GD – flywheel moment, kg/m^2.

When gear and drum data are not available, it is possible to take

$$I_g + \frac{I_\delta}{ig^2} = (0.25 - 0.30) \cdot I_{dr}. \qquad (3.10)$$

3.1.8 Dynamic moments for acceleration and braking respectively $M_{dyn\ a}$, $M_{dyn\ b}$(N·м)

$$M_{dyn\ b} = -I_{red} \cdot \frac{\omega_n}{t_2}, \qquad (3.11)$$

$$M_{dyn\ a} = I_{red} \cdot \frac{\omega_n}{t_1}. \qquad (3.12)$$

3.1.9 The average starting torque ($M_l = M_{av\ st}$) and the average breaking torque (Mav br) can be found by the formulas

$$M_l = M_{avst} = M_s + M_{dyn\ a}, \qquad (3.13)$$

$$M_{avbr} = M_s - M_{dyn\ b}. \qquad (3.1$$

4)

3.1.10 According to p. 3.1.3-3.1.9 the load diagram is built up. Example of the diagram is presented in the Figure 3.

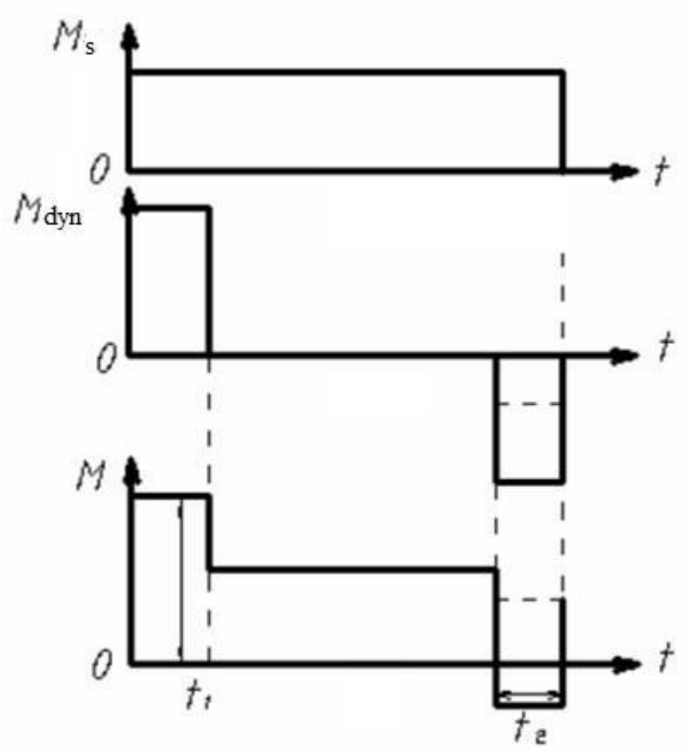


Figure 3.1 - The load diagram

3.1.11 The value of the equivalent motor torque M_e is determined by the following formulas:

$$M_{e1}=\sqrt{\frac{1}{(t_1+t_2)\cdot\beta+t_c+0.5\cdot t_0}\cdot\sum_{i=1}^{n}M^2\cdot t_i}\ , \tag{3.15}$$

$$M_{e2}=\sqrt{\frac{1}{T_c}\cdot\sum_{i=1}^{n}M_i^2\cdot t_i}\ , \tag{3.16}$$

where M_i, t_i - moment (N• m) and duration (s) respectively to the loading diagram areas;

β - factor that consider frequency of the drive energizing N_S

$$N_S = \frac{3600}{T_c}. \qquad (3.17)$$

At N_s to 100, factor β is approximately 1,1; at N_s more than 100, factor β is reduced from 0,8 to 0,6 (N_s, more than 500).

3.1.12 Determination of the real equivalent torque

$$M_{re} = M_e \cdot \sqrt{\frac{ET_r}{ET_n}}, \qquad (3.18)$$

where ET_r as found in p. 3.1.6; ET_n - is given in Appendix B.

3.1.13 On the basis of the real equivalent torque, find the equivalent motor power (kW).

$$P_{re} = M_{re} \cdot \omega_n \cdot 10^{-3}, \qquad (3.19)$$

3.1.14 Testing of the selected motor (p.3.1.2) for heating. If $P_n \geq P_{re}$, then the motor is selected properly. If $P_{re} > P_n$, then you should choose another motor, that is the close to greater power and speed, - then realize calculations according to 3.1.7.-3.1.14.

3.1.15 Testing of the selected motor for overload capacity is carried out by comparing the maximum allowable motor torque M_{max} (Appendix B) with the maximum torque of the loading diagram M_1.

The relationship is to be observed:

$$M_{max} \geq M_l \,. \quad (3.20)$$

When the relationship is obtained, the motor will provide the preset acceleration on the definite distance, if the relationship is not satisfied, it is necessary to choose another motor of higher power with a M_{max} larger.

3.1.16 Calculation of the natural mechanical characteristics of the asynchronous motor with a phase rotor. Using the passport data (Appendix B), find the nominal motor torque.

$$M_n = \frac{P_n}{\omega_n} \cdot 10^3, \quad (3.21)$$

where P_n is nominal motor power (kW),

$$\omega_n = \frac{2 \cdot \pi \cdot n}{60}, \quad (3.22)$$

where ω_n is nominal angular velocity (rad / s).

Overload motor capacity λ:

$$\lambda = \frac{M_{max}}{M_n}, \quad (3.23)$$

where M_{max} is maximum torque of the motor (N·m).

Nominal slip

$$S_n = \frac{\omega_0 - \omega_n}{\omega_0}, \quad (3.24)$$

where ω_0 is synchronous angular velocity (rad / s) that equals to

$$\omega_0 = \frac{2 \cdot \pi \cdot f}{p}, \qquad (3.25)$$

where p is the number of pole pairs.

The number of poles defines to the last digit in the referential designation of the asynchronous motor type. For example, the motor MTH 612-10 has 10 poles, that is, p = 5, MTH 112-6 motor has 6 poles, that is the number of pole pairs is three.

Critical slip

$$S_{cr} = S_n \cdot (\lambda + \sqrt{\lambda^2 - 1}). \qquad (3.26)$$

Calculation of the natural mechanical characteristic of the asynchronous motor is carried out according to a simplified formula of the mechanical characteristic (Kos's formula).

$$M = \frac{2 \cdot M_{max}}{\frac{S_{cr}}{S} + \frac{S}{S_{cr}}}, \qquad (3.27)$$

where M, S - is situational values of torque and slip.

Set value S : (-)1; (-)0,7;(-)Sкр; (-)Sкр/2; 0; Sн; Sкр; 1; 1,5; 2, slip determines the situational value of the torque by the formula (3.27) and the angular velocity by the formula (3.28)

$$\omega = \omega_0 \cdot (1 - S) . \qquad (3.28)$$

The calculation data M, ω are entered into Table 3.1. According to calculations, the natural mechanical characteristic is building up.

Perform the calculation of the electromechanical characteristics in the relative units along with the given below calculations of the natural mechanical characteristics in the nominative units. For the base increment take the synchronous speed ω_0 and the nominal torque M_n

$$\omega_1 = \frac{\omega}{\omega_0}, \qquad (3.29)$$

$$I_1 = \sqrt{M_1 \cdot \frac{S}{S_n}}\,, \qquad (3.30)$$

$$M_1 = \frac{M}{M_n}\,. \qquad (3.31)$$

Calculations are entered into Table 3.1. According to calculations, build up the electrical characteristic in relative units.

Table 3.1 - Calculation data of the electromechanical characteristic

S	Ω	ω•	M•	I•
(-)1				
(-) 0,7				
.				
1,5				
2				

3.1.17 Calculation of the natural mechanical characteristic for the DC motor.

For a DC motor with separate excitation (DCM SE) natural mechanical characteristics is created by two points.

The point of idling mode (with coordinates $\omega = \omega_0$, $M = 0$) and the point of nominal mode (with coordinates $\omega = \omega_n$, $M = M_n$).

Using passport data (Appendix B) determine:

Motor nominal resistance

$$R_n = \frac{U_n}{I_n}\,, \qquad (3.32)$$

Efficiency at the nominal load Pn (kW) and the resistance of the armature circuit.

$$\eta_n = \frac{P_n}{U_n \cdot I_n} \cdot 10^3, \qquad (3.33)$$

$$R_a = 0.5 \cdot (1 - \eta_n) \cdot R_n. \quad (3.34)$$

Idle angular velocity

$$\omega_0 = \frac{U_n \cdot \omega_n}{U_n - R_a \cdot I_n}. \quad (3.35)$$

Nominal torque of the motor

$$M_n = \frac{P_n}{\omega_n} \cdot 10^3. \quad (3.36)$$

The natural mechanical characteristic is building up.based on the obtained coordinates of the points of the idle angular velocity and the nominal mode.

At the points of the idle angular velocity (with coordinates $\omega = \omega_0$; $M = 0$) and the short-circuit (with coordinates $\omega = 0$; $M = M_{sc}$), another mechanical characteristic is ploted, which should coincide with the characteristic obtained as to the idle angular velocity and nominal modes.

$$M_{sc} = \frac{I_{sc}}{I_n} \cdot M_n , \quad (3.37)$$

where I_{sc} is short circuit current, A,

$$I_{sc} = \frac{U_n}{R_a}. \quad (3.38)$$

Calculate and obtain the natural mechanical (electromechanical) characteristic in relative units. For the basic values take the idle angular velocity ω_0 and the nominal torque:

$$\omega_1 = \frac{\omega}{\omega_0}, \quad (3.39)$$

$$I_1 = \frac{I_{sc}}{I_n}, \quad (3.40)$$

$$M_1 = \frac{M}{M_n} . \qquad (3.41)$$

3.1.18 Calculations and obtaining of the artificial characteristics for the rheostat speed regulation of the motor. Calculate and build up an artificial characteristic with the torque $M = M_n$ and the motor angular velocity $\omega = 0{,}5 \cdot \omega_n$. Determine the additional resistance R.

$$R = \frac{R_2 \cdot (S_a - S_n)}{S_n} , \qquad (3.42)$$

where S_a is an artificial slip for the angular velocity $\omega = 0{,}5 \cdot \omega_n$, R_2 is an active resistance of the rotor phase,

$$R_2 = \frac{E_{2n} \cdot S_n}{\sqrt{3} \cdot I_{2n}} , \qquad (3.43)$$

where E_{2n}, I_{2n} is rotor voltage and current (Appendix B),

$$S_n = \frac{\omega_0 - 0.5 \cdot \omega_n}{\omega_0} . \qquad (3.44)$$

For the DCM SE

Calculate and build up an artificial characteristic for the angular velocity $\omega = 0{,}8;\ 0{,}7;\ 0{,}5;\ 0{,}3\ \omega_n$.

Determine the additional resistance R_{add}

For example, for $\omega = 0.5 \cdot \omega_n$

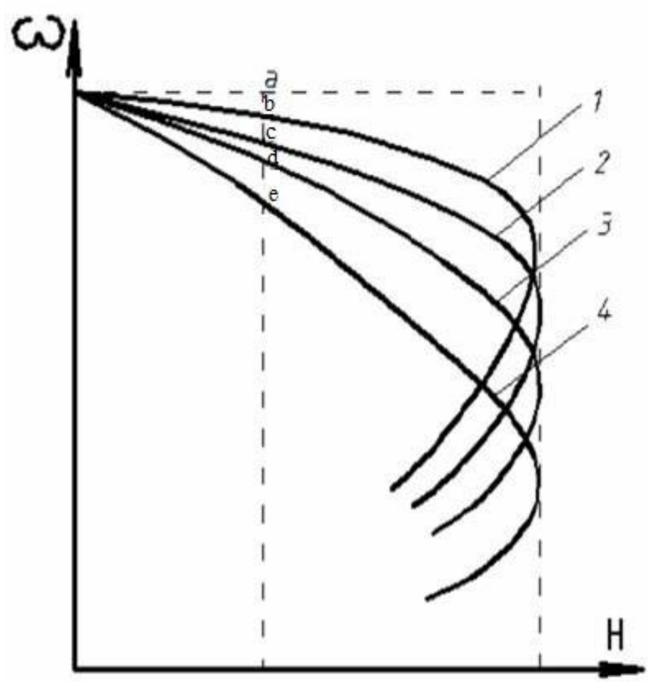
$$R = U_n \frac{(\omega_0 - 0.5 \cdot \omega_n)}{\omega_0 \cdot I}, \qquad (3.45)$$

$$R_{add} = R - R_a\ , \qquad (3.46)$$

where Ra is calculated by the formula (3.34).

3.1.19 Calculation of rheostat characteristics of the asynchronous motor for the pre-selected R_{add} (2-3 values).

Realize computations taking into account,that $M = M_n$. The value of the additional resistance R_{add} for the regulating characteristics that are plotted around b-e area (see Figure 3.2) to be determined graphically.



1 is the natural mechanical characteristic; 2,3,4 are the regulating mechanical characteristics.

Figure 3.2 – Family of the AM mechanical characteristics

An example to determine R_{add} for the artificial characteristic 2 (see Figure 3.2).

$$R_{add} = R_{2n} \cdot \frac{bc}{ae}, \qquad (3.47)$$

$$R_{2n} = \frac{E_{2n}}{\sqrt{3} \cdot I_{2n}} . \qquad (3.48)$$

Calculate and plot the artificial characteristics for the additional R_{add} resistance.

$$S_a = S_e \cdot \left(\frac{R_{add}}{R_2} + 1\right), \qquad (3.49)$$

where S_e – the value of the slip taken from the natural mechanical characteristic.

Realize the computation for the following values: S_e ; S_n; S_{cr}; S = 1 ;S = 0,2 .

Then the calculation according to formulas 3.26; 3.27.

3.1.18 Computation and plotting the startup diagram of the electric drive. In Figure 3.3 presented an approximate view of the startup and braking diagrams of the electric drive (for three stages of the drive).

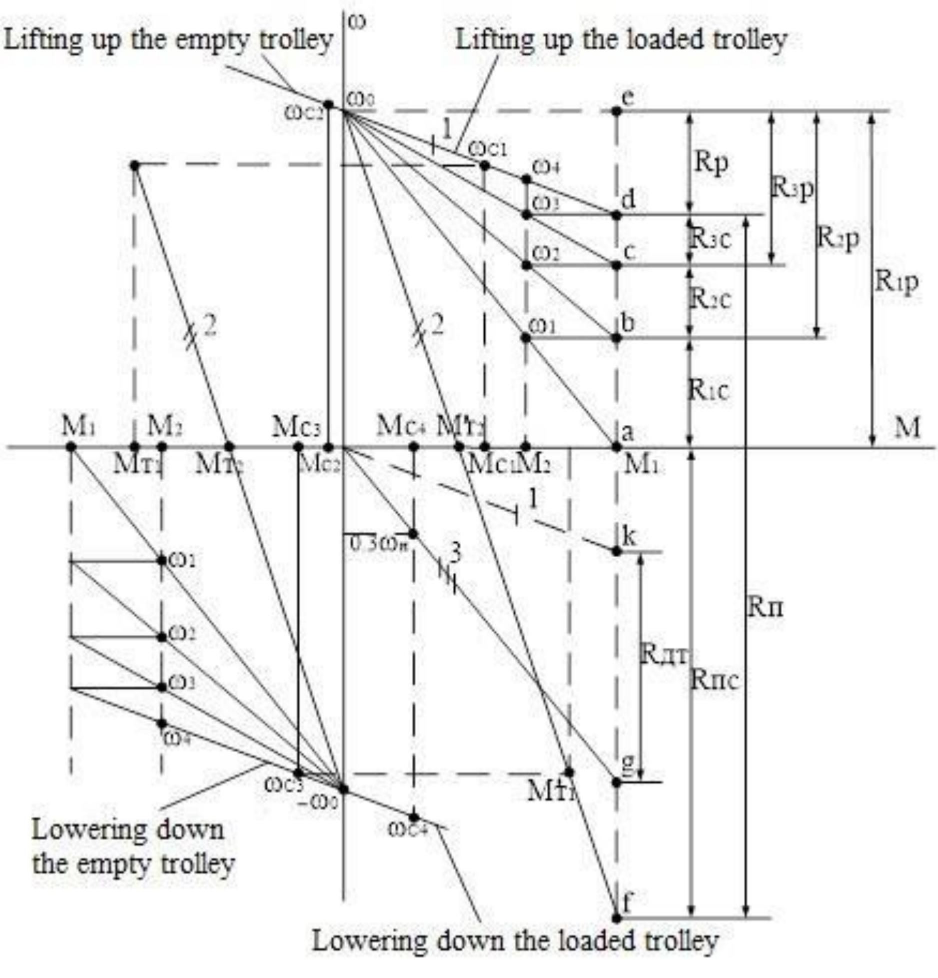


Figure 3.3 – Starting up and braking diagrams of the electric drive

Figure 3.3 presents four possible operational modes of the electric drive: lifting and lowering of the loaded cart, lifting and lowering of the empty cart; braking modes: dynamic braking (DCM SE), reverse-current braking (DCM SE and asynchronous motor). The necessary geometric constructions are made for determining the corresponding additional resistances graphically.

In the computational and graphical assignment the starting up diagram (lifting of the loaded trolley) and braking modes have been computed.

When building up the starting up diagram, the coefficient j is found analytically in advance.

For the asynchronous motor

$$J = \sqrt[m]{\frac{R_{1r}}{R_r}} , \qquad (3.50)$$

where m is given number of the starting stages; $R_r = R_2$;

R_r is an active component of the rotor resistance, Ohm (see 3.32);

R_2 is a resistance of the rotor phase winding of the asynchronous motor, Ohm;

R_2 = 0.12 Ohm (desirable);

$$R_{1r} = \frac{U_{2n}}{\sqrt{3} \cdot I_s} , \qquad (3.51)$$

where R_{1r} is impedance of the rotor phase; U_{2n} - rotor voltage, V (Appendix B);

I_s – motor starting current, A;

$$I_s = K_s \cdot I_{2n} , \qquad (3.52)$$

where K_s = 2.5 (desirable);

I_{2n} - nominal rotor current, A (Appendix B)

For the DCM

$$J = \sqrt[m]{\frac{R_1}{R_a}}, \qquad (3.53)$$

where R_1 - armature impedance , Ohm;

$$R_1 = \frac{U_n}{I_s}, \qquad (3.54)$$

where I_s – motor starting current, A;

$$I_s = \lambda \cdot I_n , \qquad (3.55)$$

where λ - overload capacity by the current (moment), $\lambda = (2 \div 2.3)$; I_n - nominal rotor current, A (Appendix B);
R_a - armature resistance, Ohm (see formula 3.34).

Find the moment of motor switching M_2 after determining the coefficient j.

$$M_2 = \frac{M_1}{J}, \qquad (3.56)$$

where $M_1 = \lambda \cdot M_n$ - starting torque, Nm .

In the asynchronous motors, the moment they develop is proportional to the square of the supply voltage, so even a slight drop of starting voltage significantly reduces the starting torque. For these reason, the chosen moment at start-up should be (15-20)% below the maximum moment which the motor develops at nominal voltage, ie

$$M_1 = \lambda \cdot M_n = (0.8 \div 0.85) \cdot M_{max} , \qquad (3.57)$$

For the DCM, the value of M1 is determined by the commutational and overload capacity and it should not exceed 2.7.

For the reliable motor start at the rated load, the torque which is developed when switching the speed of the starting rheostat should be chosen 10-20% higher than the total (nominal) statical moment of the resistance.

$$M_2 = (1.1 \div 1.2) \cdot M_n , \tag{3.58}$$

However, in this computational assignment, there might be cases when accordingly to the initial data, the choosen motor power will exceed the statical motor power, respectively, the given value of the final load (from the overload capacity test) and for this case, it is necessary to determine graphically the value of the switching (commutational) moment M_2 in order to obtain a specified number of switching stages of the starting rheostat.

Resistance of the starting rheostat (see Figure 3.3)

For the DCM

$$R_1 = R_a \cdot j^m , \tag{3.59}$$

$$R_{2r} = R_a \cdot j^{m-1} .$$

For the asynchronous motor

$$R_1 = R_2 \cdot j^m , \tag{3.60}$$

$$R_{2r} = R_2 \cdot j^{m-1} .$$

Resistance of the starting rheostat section

$$R_{1s} = R_1 - R_{2av} ,$$

$$(3.61)\ R_{2s} = R_{2r} - R_{3r} .$$

Starting rheostat impedance for the DCM

$$R_{rh} = R_1 - R_a . \qquad (3.62)$$

For the asynchronous motor

$$R_{rh} = R_1 - R_2 . \qquad (3.63)$$

In case of graphical calculation R_1 (formula 3.51 and 3.54) and resistance scale (see Figure 3.3) are computed in advance.

$$m_R = \frac{R_1}{\square\square} . \qquad (3.64)$$

Then the sections resistance and the starting rheostat impedance are to be determined.

$$R_{1s} = m_R \cdot ab , \quad R_{2s} = m_R \cdot bc , \quad R_{3s} = m_R \cdot cd , \qquad (3.65)$$

$$R_{rh} = m_R \cdot (ae - de) .$$

3.1.21 Computations and building up the breaking characteristics.

The building up the reverse-current braking characteristic is performed at two points (see Figure 3.3). (ω_c, M_T), (ω_0; M = 0).

Let's assume that the multiplicity of the maximum moment at the reverse-current braking equals to the multiplicity of the maximum moment at the lowering (see Formulas 3.50;3.53) i.e. $M_T = M_1$.

The Resistance of the reverse-current braking stage is determined by the graph in Figure 3.3.

$$R_{rc} = m_R \cdot df \,, \qquad (3.66)$$

The Resistance of the reverse-current braking stage Rrcs

$$R_{rcs} = R_{rc} - R_{rh} \,. \qquad (3.67)$$

The building up of the dynamic braking characteristic for the DCM is performed at two points (ω = 0; M = 0); ($ω_Д$ = 0.3 * $ω_n$; $M_Д$ = 0.8 * M_n).

The coordinates of the second point are set arbitrarily. Dynamic Braking Resistance Rd

$$R_{db} = m_R \cdot gk , \quad (3.68)$$

where gk – is obtained from the Figure 3.3 for which the OK segmet is built up, parallel to the natural characteristic.

Describe the processes when lowering the loaded (empty) trolley, that is, the displacement of the point characterizing the mode, on the basis of Figure 3.3.

3.1.22 Computation of the transient processes when motor start.

The computation includes finding the time at each stage and the type of the current (moment) changing exponent on transition from stage to stage. The computations is made for a loaded trolley. Combine the current (moment) diagam at startup with the speed diagram.

For the DCM, t_x motor acceleration time at the considered stage:

$$t_x = T_{mx} \cdot \ln \frac{I_1 - I_l}{I_2 - I_l} , \quad (3.69)$$

or

$$t_x = T_{mx} \cdot \ln \frac{M_1 - M_l}{M_2 - M_l} , \quad (3.70)$$

$$T_{mx} = \frac{I_{red} \cdot \omega_0}{M_{scx}} , \quad (3.71)$$

where T_{mx} is the electromechanical time constant of the same stage; I_l (M_l) - nominal loading current (moment) , A(Nm); I_{red} – reduced moment of inertia (kg/m^2) (see formula 3.8); M_{scx} – short-ciruit moment (N·m) of the mentioned stage"x";

$$M_{scx} = c \cdot I_{scx}\ , \qquad (3.72)$$

$$C = k \cdot \Phi = \frac{U_n - I_n \cdot R_a}{\omega_n}, \qquad (3.73)$$

$$I_{scx} = \frac{U_n}{R_{\Sigma X}}\ , \qquad (3.74)$$

where $R_{\Sigma X}$ – total armature resistance of the "x".

From the formulas (3.50 - 3.51) it is clear, that with the armature resistance decreasing , the motor steady state time at the given stage also decreases. When the motor returns back to its natural characteristic, the time to reach it the steady state speed value is taken to (3.4) the time constant T_{mx} at the given stage.

The nature of current(moment) exponential dependence is determined by

$$(I_1 - I_l) \cdot e^{-\frac{t_x}{T_{mx}}}. \qquad (3.75)$$

For the AC motor , acceleration time t_x on the stage "x" is

$$t_x = T_{mx} \cdot \ln \frac{M_1 - M_l}{M_2 - M_l}\ , \qquad (3.76)$$

where T_{mx} is the electromechanical time constant of the same stage;

$$T_{mx} = \frac{I_{red} \cdot \Delta\omega_x}{M_1 - M_2}\ , \qquad (3.77)$$

where I_{red} - reduced moment of inertia (kg/m^2) (see formula 3.8);
$\Delta\omega_x$ – velocity increment at each lowering stage.

$\Delta\omega_x$ is determined from the Figure 3.3. Thus:
-for the first lowering $\Delta\ \omega_x = \Delta\omega_1 = \omega_1$;
-for the second $\Delta\ \omega_x = \Delta\omega_2 = \omega_2 - \omega_1$;
-for the third $\Delta\ \omega_x = \omega_3 - \omega_2$;

-for the natural $\Delta\omega_x = \omega_4 - \omega_3$.

The motor acceleration time from ω_4 to ω_c is taken as $(3 \div 4)T_{mx}$, determined for the natural characteristic.

The nature of the exponent is determined by the value

$$(M_1 - M_l) \cdot e^{-\frac{t_x}{T_{mx}}}. \qquad (3.78)$$

3.1.23 Development of the principle control circuit for the motor starting up and braking.

The principle control circuit should enable to provide the gradual starting, reverse, carrying out the braking modes, positioning at the regulating characteristic; the control of electromagnetic brakes should be incorporated into the circuit.

Assignments for development of the principle circuit is agreed with each student individually.

Descriptions of the circuit functioning presented in the explanatory note.

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Appendix A

Table A.1 - Output data for the computations

Variant №	Utimate load, Q	Lifting speed	Tolerated acceleration (m/s^2)	Slope angle	Shaft rotational speed	Current type	Lifting height, H (m)	Delay in time between liftings	Voltage supply	Number of starting currents
1	1000	0,3	0,5	30	1000	=	16	20	220	4
2	2000	0,03	0,2	45	930	~	15	25	380	3
3	3000	0,08	0,7	45	705	~	14	60	380	3
4	4000	0,07	0,24	30	895	~	13	30	380	3
5	5000	0,07	0,5	45	540	=	12	30	220	4
6	8000	0,05	0,4	20	540	=	11	40	220	4
7	10000	0,3	0,8	45	490	~	15	25	380	3
8	12000	0,3	0,7	60	960	~	16	20	380	3
9	16000	0,06	0,2	30	700	~	14	30	380	3
10	20000	0,06	0,2	45	960	~	13	45	380	3
11	25000	0,08	0,2	30	930	~	12	60	380	3
12	30000	0,05	0,3	25	586	=	11	30	220	4
13	35000	0T25	0,6	60	600	=	15	20	220	4
14	50000	0,06	0,1	50	570	~	16	45	380	3
15	75000	0,1	0,4	30	584	=	14	50	440	4
16	80000	0,1	0,3	45	500	=	13	20	440	4
17	90000	0,05	0,1	60	510	=	12	25	440	4
18	100000	0,07	0,2	30	960	~	11	30	380	3
19	120000	0,05	0,1	45	600	~	16	45	380	3
20	125000	0,03	0,3	60	550	-	15	30	440	4
21	130000	0,02	0,1	60	575	-	15	60	380	3
22	140000	0,03	0,2	45	565	~	18	60	380	3
23	150000	0,07	0,3	30	470	=	14	45	220	4
24	200000	0,05	0,3	30	440	=	14	50	220	3
25	27000	0,04	0,2	35	695	=	14	60	220	4
26	30000	0,03	0,1	45	945	~	16	45	380	3
27	31000	0,08	0,2	30	720	~	14	30	380	3
28	32000	0,17	0,05	45	565	=	15	45	440	4
29	40000	0,08	0,07	45	980	=	12	60	440	4
30	33000	0,03	0,1	30	960	~	14	30	380	3

31	35000	0,07	0,12	45	980	=	11	45	220	4

Continuation of the table A.1

32	3700	0,17	0,05	45	565	=	15	45	440	4
33	3900	0,08	0,07	45	980	=	12	60	440	4
34	4000	0,03	0,1	30	960	~	14	30	380	3
35	4100	0,07	0,12	45	980	=	11	45	220	4
36	41000	0,17	0,05	45	565	=	15	45	440	4
37	42000	0,08	0,07	45	980	=	12	60	440	4
38	42500	0,03	0,1	30	960	~	14	30	380	3
39	43000	0,07	0,12	45	980	=	11	45	220	4
40	45000	0,1	0,1	45	540	=	14	60	220	3
41	50000	0,08	0,1	30	800	=	12	60	220	4
42	10000	0,5	0,14	45	520	=	14	35	220	4
43	25000	0,09	0,3	30	940	~	12	60	380	3
44	4000	0,35	0,5	40	965	~	14	45	380	3
45	5000	0,55	0,55	45	580	=	12	60	220	4
46	70000	0,12	0,3	30	490	=	14	45	220	4
47	8000	0,5	0,4	40	520	=	12	60	440	4
48	80000	0,13	0,4	35	450	=	14	50	220	3
49	1000	0,2	0,3	45	950	~	12	60	380	3
50	15000	0,08	0,28	40	955	~	12	45	380	3
51	17000	0,08	0,3	45	710	~	14	60	380	3
52	19000	0,06	0,25	30	950	~	12	45	380	3
53	2500	0,45	0,25	40	970	~	13	60	380	3
54	32000	0,33	0,29	45	480	=	14	45	220	4
55	1250	0,33	0,38	40	1070	=	12	60	220	4
57	1400	0,5	0,25	40	770	=	11	60	220	4
58	12000	0,3	0,65	60	1000	=	14	30	220	4
59	50000	0,06	0,1	25	600	=	16	45	440	4
60	35000	0,25	0,5	60	600	~	14	60	380	3
61	30000	0,05	0,2	25	570	~	12	45	380	3
62	1000	0,3	0,6	30	950	~	18	40	380	3
63	2000	0.03	0,4	45	980	=	15	25	220	4

Appendix B

Direct current motors of separate (parallel) excitation of the closed type with natural cooling in short-time mode (60 min.) and protected with independent venting in long-term mode (ET_n=100%)

Table B.1 - Technical data of the electric motors

Motor type	Power P_n, kW	Current I_n, A	Rotational speed, r / min		Maximum speed, rev / min	Armature inertia moment, I_m кg/m^2	Maximum torque, M_{max} (N · m)		Performance at voltage power supply
			With stabilizing winding	Without stabil. winding			With stabilizing winding	Without stabil. winding	
Д12	2,5	14,6	1140	1180	3600	0,05	63	54	Low-speed motor 220V
Д21	4,5	26	1000	2030	3600	0,12	128	113	
Д22	6	33	1070	1100	3600	0,15	161	137	
.Д31	8	44	820	840	3600	0,30	280	245	
Д32	12	65	740	770	3300	0,42	456	402	
Д41	16	86	670	690	3000	0,80	686	598	
Д806	22	116	635	650	3600	1,00	981	872	
Д806	37	192	565	575	2300	2,00	1860	1655	
Д810	55	280	540	550	2200	3,6	2880	2550	
Д812	75	380	500	515	1900	7,0	4260	3720	
Д814	110	550	490	500	1700	10,25	5420	5680	
Д816	150	740	470	480	1600	16,25	9120	8040	
Д818	185	920	440	450	1500	22,5	12050	10600	
Д21	5	31,0	1400	1400	3600	0,12	113	98	High-speed motor 220V
Д22	8	43,5	1450	1510	3600	0,15	157	137	
Д31	12	64	1310	1360	3600	0,30	255	225	
Д32	18	94	1140	1190	3300	0,42	451	382	
Д41	24	124	1060	1100	3600	0,8	648	559	
Д806	32	165	980	1000	2600	1,0	930	823	
Д808	47	240	770	800	2300	2,0	1715	1510	

Continuation of Table B.1

Д21	4.0	12	1200	1220	3600	0,12	76	68	Low-speed motor 440 V
Д31	6,7	19	850	875	3600	0,30	175	157	
Д41	15	40	695	710	3000	0,80	490	436	
Д808	37	96	565	575	2300	2,00	1470	1320	
Д810	55	140	550	560	2200	3,60	2250	2010	
Д812	70	176	510	520	1900	7,00	3130	2750	
Д814	110	274	490	500	1700	10,25	5150	4510	
Д816	150	370	480	490	1600	16,25	7150	6320	
Д818	115	460	440	450	1500	22,50	9600	8480	
Д22	7	19.5	1420	1460	3600	0,15	113	98	High-speed motor 440V
Д32	17	45	1150	1190	3300	0,42	330	294	
Д806	32	82	980	1000	2600	1,00	745	657	

Appendix C

Asynchronous motors with phase rotor at the voltage supply of 380 V and the frequency of 50 Hz (ET_n =40%).

Table C.1 - Parameters of asynchronous motors with phase rotor

Motor type	Power Pn, кW	Rotational speed, n rev / min	Stator current In,A	Power factor	Rotor current In,A	Rotor current En,V	Maximum torque Nm	Flywheel moment кg▪m^2	Motor mass, кg▪m	Efficiency %
MTT 011-6	1,4	885	5,3	0,65	9,1	116	39	0,085	51	61,5
MTT 012-6	2,2	890	7,6	0,68	11,5	144	56	0,115	58	64,5
MTT 111-6	3,5	895	10,4	0,73	15	176	85	0,195	76	70
MTT 111-6	3,0	895	10,5	0,67	13,2	176	83	0,19	76	65
MTT 112-6	5,0	930	4,4	0,7	15,7	216	137	0,27	88	75
MTH 112-6	4,5	910	13,9	0,71	15,6	203	118	0,27	88	69
MTT 211-6	7,5	930	21	0,7	19,8	256	191	0,46	120	77
MTH 211-6	7,0	920	22,5	0,64	19,5	236	196	0,46	120	73
MTT 31 1-8	7,5	695	22,8	0,68	21	245	265	1,1	170	73
MTH 311-8	7,5	690	23	0,68	21	245	265	1,1	170	71,5
MTT 311-6	11	945	30,5	0,69	42	172	314	0,9	170	79
MTH 311-6	11	940	31,5	0,69	42	172	314	0,9	170	78
MTT 312-8	11	705	30,5	0,71	43	165	422	1,25	210	77
MTH 312-8	11	700	31	0,69	43	165	422	1,25	210	78
MTT 312-6	15	955	38	0,73	60	235	638	1,25	210	83,5
MTH 312-6	15	950	38,5	0,73	46	219	471	1,25	210	81
MTT 41 1-8	15	710	42	0,67	48	206	569	2,15	280	81
MTH 411-8	15	705	43	0,67	48	206	569	2,15	280	79
MTT 411-6	22	965	55	0,73	60	235	638	2,0	280	83,5
MTH 411-6	22	960	55	0.73	60	235	638	2,0	280	82,5
MTT 412-8	22	720	65	0,63	57	248	883	3,0	345	82
MTH 412-8	22	715	66	0,63	57	248	883	3,0	345	80,5
MTT 412-6	30	970	75	0,71	73	255	932	2,7	345	85,5
MTH 4 12-6	30	965	76	0,71	73	255	932	2,7	345	84,5
MTH 5 11-8	28	705	71	0,72	54	281	1000	4,3	470	83
MTH 512-8	38	705	89	0,74	77	305	1370	5,7	570	85
MTH 512-6	55	960	120	0,79	10	340	1630	4,1	520	88
MTH 611-10	45	570	112	0,72	154	185	2320	17	900	84
MTH 611-6	75	950	154	0,85	180	270	2610	13,1	810	87
MTH 612-10	60	565	147	0,78	154	248	2140	21	1070	85
MTH 6 12-6	95	960	193	0,85	176	366	3580	16,5	930	88
MTH 613-10	75	575	180	0,72	145	320	4120	25	1240	88
MTH 613-6	118	960	237	0,84	160	473	4660	20,4	1100	90
MTH 711-10	100	584	246	0,69	233	272	4560	41	1550	89,5
MTH 712-10	125	585	300	0,7	237	327	5690	51	1700	90,3