Vertical Transport Installations Balance Survey

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Abstract: -The operation of vertical transport installations are based on cable systems with electrical adjustable operation, which ensures the technical conditions regarding time variation in speed, the current in the main actuation engines and the acceleration during start-up and breaking. The actuation electrical systems are part of the category of the fast process of the automation equipment. For the vertical transport installation the size which has to be controlled from a command is the speed, the dependent factor being the tahogram. Adjusting determines the dependence of the sizes in the process, through a default law, both in relation to the independent sizes and in relation to the dependent ones from the process, assuring the reduction of the influence of harmful sizes to the process. The stability of an automatic system can be defined in different ways. We will consider stability of an automatic system, that feature which is that when it is subjected to the action of one harmful size of the moment the system will return in the end at the stationary phase. Thus, the Balance Survey also deals with the determination of variation functions in time of the current of the main actuation motor, of speed (main electrical actuation motor rpm) when starting the vertical transport installation, as well as the study in time of the variation of speed when applying loading shock.

Key-Words: - Nyquist stability criterion, place of transfer, transfer function, speed adjustment

1 The Nyquist stability criterion

This stability criterion is the most frequently used in the study of automatic linear systems, because it is based on the theory of functions of complex variable and it establishes the stability conditions of the closed system based on the analysis of the transfer of open system.

If to an automation element, linear or non linear, or to a system a step signal is applied at the entrance, the output size will have a transitional regime. As a consequence an element or a linear system is called stable if the transitional process of the output size fades in time, this one going to a final constant value if at the entry is applied a unit step signal.

The Nyquist stability criterion allows the deduction of behavior of the closed adjustment circuit from the analysis of the behavior of the open adjustment circuit. The answer to frequency of the open adjustment circuit can be presented by the following relation:

$$Y_d(j\omega) = k_a \cdot \frac{1}{\alpha} \cdot \frac{(1+j\omega T_{Z1})\cdot(1+j\omega T_{Z2})\cdots}{(1+j\omega T_{N1})\cdot(1+j\omega T_{N2})\cdots} = \frac{Z(j\omega)}{N(j\omega)} \quad (1)$$

The stability criterion is applied in the allowing hypothesis:

- the degree of the polynomial Z has to be smaller than that of the polynomial N;
- the open circuit is stable ($\alpha=1$) or they have an integral behavior ($\alpha=j\omega T$);

From those mentioned above, the Nyquist stability criterion can be state as: a closed adjustment circuit is table if the place to transfer the answer to frequency $Y_d(j\omega)$ of the open circuit does not surround the coordinate point (-1,j0).

The Nyquist stability criterion has the advantage that in can be applied in:

- If not all the blocks of a closed circuit are known, still the answer to the frequency can be measured;
- Allows observation on stability as well as on the amortization of the transitional process.

Figure 1 represents the transfer place of a stable system.

The phase φ_D to which the transfer place overlaps the radius of a circle the unity gives the information on the degree of amortization of the system, so that for values smaller than φ_D the amortization is stronger.

The stability of an adjustment circuit can be easily determined with the help of the frequency characteristics. This is usually not enough because very often the adjustment circuit has to have a certain dynamic input, and the unstable adjustment circuit has to be stable with the help of special measurements. Since the parameters of an automatic adjustment installation are given, the balance needs to be made with the help of the regulators. The calculation of an adjustment circuit need to lead to choosing such a regulator, so that from the action of the regulator, conjugated with the execution element the result to be the static and dynamic behavior of the adjustment.

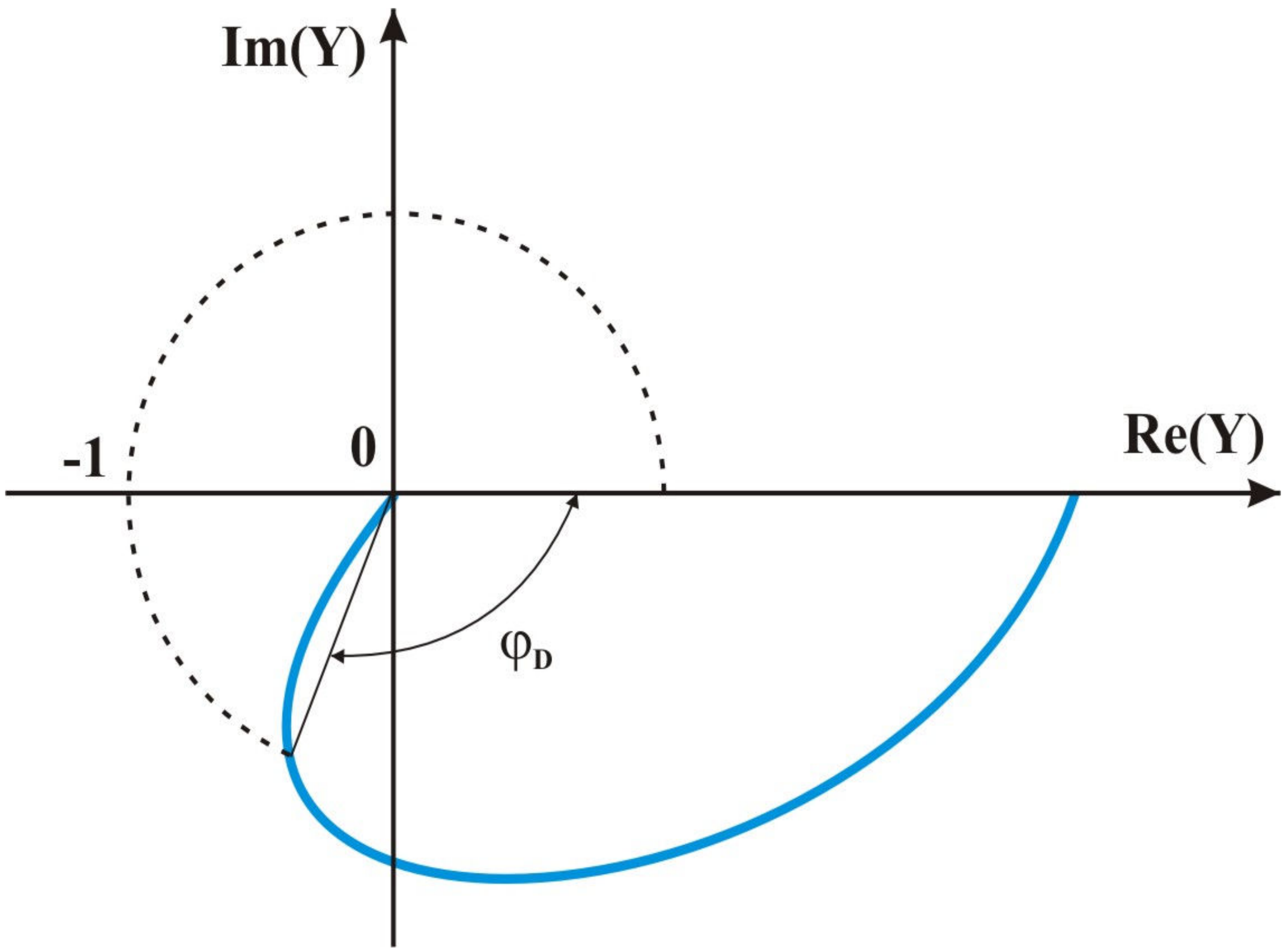

Fig.1 The place of transfer of a stable system

2 Determination of the parameters of the adjustment circuit for the vertical transport installation

The characteristics of the main electric actuator engine of the transformer and of the reactor of a vertical transport engine are represented in table 1. These will be the calculation to determine the parameters of the automatic adjustment system.

The resistance of the induced circuit of the main electric engine is determined by the relation:

$$R_A = \beta_T \cdot (R_I + R_C + R_a) + \frac{\Delta U_P}{I_N} \quad (2)$$

Where :

β_T - is the temperature coefficient for resistance to heat , β_T =1,24;

R_I - is the resistance of armature coiling of the main electric mototr;

R_C - is the resistance of compensation coiling;

R_a - is the resistance of the auxiliary coiling;

ΔU_P - is the voltage collapse in contacts with the brushes , ΔU_P =2V;

I_N - is the rated power of the induced electric engine.

$$R_A = 1,24 \cdot (0,021 + 0,01575 + 0,00275) + \frac{2}{1925} = 0,05 \quad \Omega$$

The active resistance of the coiling transformer has the following expression:

$$R_T = \frac{\Delta P_{CuT}}{I_{Nr}^2} \tag{3}$$

Table 1

Engine drive	
Type of engine	P2S-1000-213 4UHL4
Power	2x1200 kW
Stator voltage	720 V
Stator power	1925 A
Rotors voltage	200 V
Rotors power	110 A
Yield	85,6 %
Speed	54 rot/min
Electric reactor	
Type	SROSZ-1250 MUHL4
Rated power	2500 A
Inductance	0,32 mH
Rated voltage	800 V
Maximum power	5000 A
Power trasformer	
Type	TSZP-2500/IOHZ
Rated power	2509 kVA
Work frequency	60 Hz
Primary voltage	6000 V
Primary power	242 A
Secondary voltage	825 V
Secondary power	2500 A
Recovered voltage	720 V
Recovered power	2042 A
Involution	2042 A

Where:
ΔP_{CuT} - rated losses in copper of the transformer;
I_{Nr} - the rated power tilt up.

$$R_T = \frac{17500}{2500^2} = 0,028 \quad \Omega$$

The active resistance of the filter reactor will be:

$$R_R = \frac{\Delta P_{CuR}}{I_{Rr}^2} \tag{4}$$

Where :
ΔP_{CuR} - rated losses in cooper of the reactor ;
I_{Rr} - rated power of the reactor;

$$R_R = \frac{1930}{2500^2} = 0,0003 \quad \Omega$$

Determining the equivalent value of resistance of the transformer given by reactance vent is:

$$R_{Te} = 0,5 \cdot U_K \cdot \frac{E_{C0}}{I_{Nr}} \tag{5}$$

where :
U_K - short-circuit voltage of the transformer;
E_{C0} - the maximum electromotive voltage of the controller rectified diode converter;

$$R_{Te} = 0,5 \cdot 0,06 \cdot \frac{842,4}{2500} = 0,01 \quad \Omega$$

The equivalent resistance of the induced circuit of the main electric engine is derived from the sum of values determined above:

$$R_E = R_A + R_T + R_R + R_{Te} + R_{min} \tag{6}$$

Where:

$$R_{min} = 0,1 \cdot R_A = 0,1 \cdot 0,05 = 0,005 \quad \Omega \tag{7}$$

$$R_E = 0,05 + 0,0028 + 0,0003 + 0,01 + 0,005 = 0,0681 \ \Omega$$

The inductance of the induced of the main electric engine will be determined by the equation:

$$L_A = C_X \cdot \frac{U_N}{I_N \cdot p \cdot \omega_N} \tag{8}$$

where :
C_X - the constructive coefficient of the electric engine with involution compensation C_X=0,25;
p - the number of the pairs of poles of the main electric engine;
ω_N - the angular rated speed of the induced ω_N =4,8 rad/s;

$$L_A = 0,25 \cdot \frac{720}{1925 \cdot 10 \cdot 4,8} = 0,0019 \quad G$$

To determine the egress inductance of the transformer we use the equation:

$$L_T = U_K \cdot \frac{E_{C0}}{2 \cdot m \cdot f \cdot I_{Nr}} \quad (9)$$

where :
m - is the number of phases ;
f - is the frequency of the supply network ;

$$L_T = 0,06 \cdot \frac{842,4}{2 \cdot 6 \cdot 50 \cdot 2500} = 0,0000336 \quad G$$

The equivalent inductance of the main electric engine will be:

$$L_E = L_A + L_T + 2 \cdot L_F \quad (10)$$

$$L_E = 0,0019 + 0,0000336 + 2 \cdot 0,00032 = 0,00257 \quad [G]$$

The electromotive voltage of action of the main electric engine is:

$$E_N = U_N - I_N \cdot R_A = 720 - 1950 \cdot 0,05 = 623,75 \text{ V} \quad (11)$$

The electromagnetic time constant of the main electric driving engine circuit is determined by the equation:

$$T_E = \frac{L_E}{R_E} = \frac{0,00257}{0,0681} = 0,037 \text{ s} \quad (12)$$

The constructive coefficient of the main driving engine are:

$$K_E = \frac{E_N}{\omega_N} = \frac{623,75}{4,8} = 129,9 \quad \frac{V \cdot s}{rad} \quad (13)$$

$$K_M = \frac{M_N}{I_N} = \frac{212631,75}{1925} = 110,45 \quad \frac{N \cdot m}{A} \quad (14)$$

The electro mechanics time constant of the system is determined by the equation:

$$T_M = \frac{J_N \cdot R_A}{2 \cdot K_E \cdot K_M} \quad (15)$$

Where:
J_N - the moment of innate of all the parts of the vertical transport installation while moving, related to the main electric driving engine axis. The innate moment is determined by:

$$J_N = m \cdot R^2 \quad (16)$$

where:
m - the mass of all parts of the vertical transport installation on the move: m=19165,4 Kg;
R - radius engine wheels;

$$J_N = 18800 \cdot 2,5^2 = 119783,8 \quad Kg \cdot m^2$$

The innate moment can be express by the following equation:

$$J_N = J_{mas} + 2 \cdot J_r \quad (17)$$

where:
J_{mas} - is the moment of inertia of the whole main tree, which according to the technical book of the vertical transport equipment is J_{mas}=131250 Kg·m^2.
J_R - is the moment of inertia of the main electric engine drive the value of which according to the documentation is J_R=9499 Kg·m^2.

Considering the above mentioned conditions two different values will be determined for the electro mechanics time constant of the system, and for the study of stability for it, the highest value will be taken into consideration, meaning the one that has the increased inertia of the system.

$$T_M = \frac{119783,79 \cdot 0,05}{2 \cdot 129,9 \cdot 110,45} = 0,208 \quad s$$

$$T_M = \frac{150050 \cdot 0,05}{2 \cdot 129,9 \cdot 110,45} = 0,26 \quad s$$

3 The automatic speed setting system for the vertical transport installation

To automate the vertical transport equipment, compared to the control and regulation subordinate systems special requirements appear, because the electric drive operates under a rate of the speed stabilization in the uniform motion and of creep and change after a given time (a default chart) during the acceleration period and the deceleration period.

Under these circumstances the speed adjustment speed achieves a reverse reaction to speed, and according to the characteristics of the speed regulators systems these are a static order one or two.

3.1 Speed regulation system structural schematics

Figure 2 represents the structural schematics of speed regulation. We can see the blocks that correspond to the transfer function of the programming speed and of the power programming as well as the blocks corresponding to the transfer function of the power regulator and speed regulator. The speed regulator has a proportional feature. This ensures optimum acceleration during both the acceleration and the deceleration period.

The amplitude signal from the power regulator output will be placed in a range of values so that when a maximum signal enters the system, the moment developed by the main electric drive engine will not exceed the admitted values.

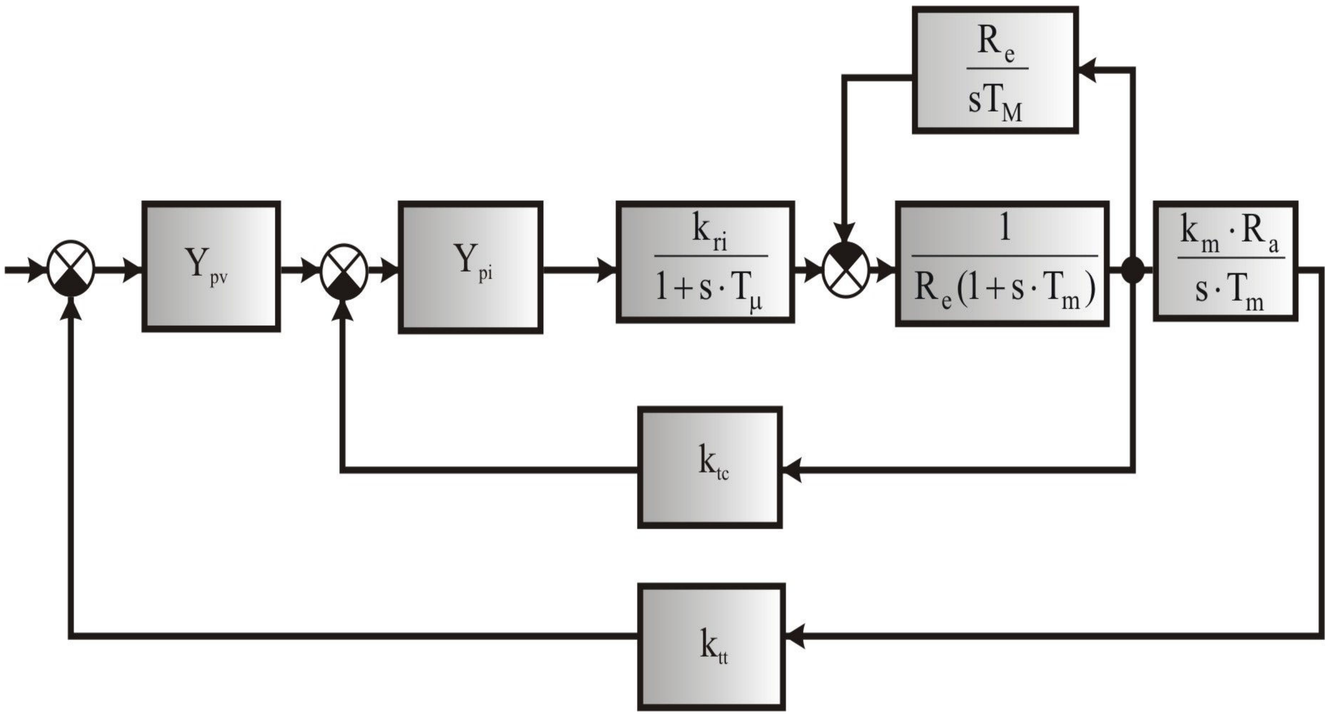

Fig.2 Speed regulation system structural schematics

3.2 Closed circuit transfer function determination of current regulation

It can be observed in figure2 the regulatory closed circuit of the power from the main actuation engine.

The reverse reaction presented by block $\frac{R_e}{sT_M}$ which includes a link of the induced circuit can be neglected.

The transfer function of the regulating closed circuit of the power from the main actuation engine is:

$$Y_2 = \frac{T_M}{2\cdot T_\mu}\cdot\frac{sT_E+1}{(sT_\mu+1)[sT_\mu(sT_E+1)+1]} \tag{18}$$

And in case of neglecting the intern reverse reaction the equation for the transfer function will be:

$$Y_1 = \frac{1}{2\cdot sT_\mu\cdot(sT_\mu+1)} \tag{19}$$

To evaluate the error we will assess the frequency characteristics of the adjustment closed circuit of power with and without highlighting the internal reverse reaction. The transfer functions in the frequency field will have the following expressions:

$$Y_1(j\omega) = \frac{\frac{1}{2\cdot T_\mu}}{j\omega\cdot(j\omega T_\mu+1)} \tag{20}$$

$$Y_2(j\omega) = \frac{\frac{T_M}{2\cdot T_\mu}\cdot(j\omega T_E+1)}{j\omega T_\mu\cdot[(j\omega)^2T_0^2+j\omega\cdot 2\cdot\xi\cdot T_0+1]} \tag{21}$$

Where:

$$T_0 = \sqrt{T_M \cdot T_E} \quad (22)$$

and:

$$\xi = \frac{1}{2} \cdot \sqrt{\frac{T_M}{T_\mu}} \quad (23)$$

Knowing the calculation values of electromagnetic time constant and of electromechanical time constant as well as the dead time of the moving system $T_\mu = 0,01\,s$ the transfer function in the frequency field for the structural scheme highlighting the internal reverse reaction will have the following equation:

$$\begin{aligned} Y_2 = & \frac{T_M}{2 \cdot T_\mu}\left[\frac{1+\omega^2 T_\mu (T_E - T_M) - \omega^4 T_M T_E^2 T_\mu}{\lambda}\right] - \\ & -j \cdot \frac{T_M}{2 \cdot T_\mu}\left[\frac{\omega(T_M + T_\mu - T_E) + \omega^3 T_M T_E^2}{\lambda}\right] \end{aligned} \quad (24)$$

where:

$$\begin{aligned} \lambda = & \omega^6 T_M^2 T_E^2 T_\mu^2 + \\ & +\omega^4 (T_M^2 T_E^2 + T_M^2 T_\mu^2 - 2T_E T_M T_\mu) \\ & +\omega^2 (T_\mu^2 + T_M^2 - 2T_M T_E) + 1 \end{aligned}$$

The pulse of asymptote frequency characteristic corresponding to the system without highlighting internal reverse reaction is:

$$\omega_S = \frac{1}{2 \cdot T_\mu} \quad (25)$$

And the proper phase difference is:

$$\varphi = -\frac{\pi}{2} - \mathrm{arctg}\left(\frac{T_\mu}{2 \cdot T_\mu}\right) = 116,5^0 \quad (26)$$

Because for these systems $T_0 > 2 \cdot T_\mu$ and $T_E > 2 \cdot T_\mu$, the asymptote pulse feature for the case that shows the internal reverse reaction will be:

$$\omega_S = \frac{T_M \cdot T_E}{2 \cdot T_\mu \cdot T_0^2} = \frac{1}{2 \cdot T_\mu} \quad (27)$$

We can notice that the frequency relation is the same in both cases. The phase difference for the case in which they take into consideration the internal reverse reaction is:

$$\varphi = \mathrm{arctg}\left(\frac{T_E}{2T_\mu}\right) - \mathrm{arctg}\left(\frac{2\xi \frac{T_0}{T_\mu}}{1-\left(\frac{T_0}{2T_\mu}\right)^2}\right) - \mathrm{arctg}\left(\frac{T_0}{2T_\mu}\right) \quad (28)$$

Thus the supplementary phase difference due to eliminating the internal reverse reaction is:

$$\Delta\varphi = -\frac{\pi}{2} - \mathrm{arctg}\left(\frac{T_E}{2 \cdot T_\mu}\right) + \mathrm{arctg}\left[\frac{2 \cdot \xi \cdot \frac{T_0}{T_\mu}}{1-\left(\frac{T_0}{2 \cdot T_\mu}\right)^2}\right] \quad (29)$$

And in the end after several transformations we obtain the equation for the phase difference introduced by the internal reverse reaction:

$$\Delta\varphi = -\frac{\pi}{2} + \mathrm{arctg}\left[\frac{T_E}{2 \cdot T_\mu} - \frac{T_M}{2 \cdot T_\mu} \cdot \left(\frac{T_E^2}{4 \cdot T_\mu^2} + 1\right)\right] \quad (30)$$

The modulus and the phase error at the asymptote frequency characteristic increases as the time constant decreases T_E and T_M and the time constant increases T_μ. The analysis of the closed adjustment power system was made using the Nyquist method both for the case in which the internal reverse reaction was taken into consideration as well as in the case in which this reaction was neglected. The proper hodograph is represented in figure 3.

According to what we have presented in chapter 1, one can observe that the closed adjustment power system is stable both in the case in which the internal reverse reaction is taken into consideration as well as in the case in which this reaction is neglected. The absorption of the diagrams in both cases is strong.

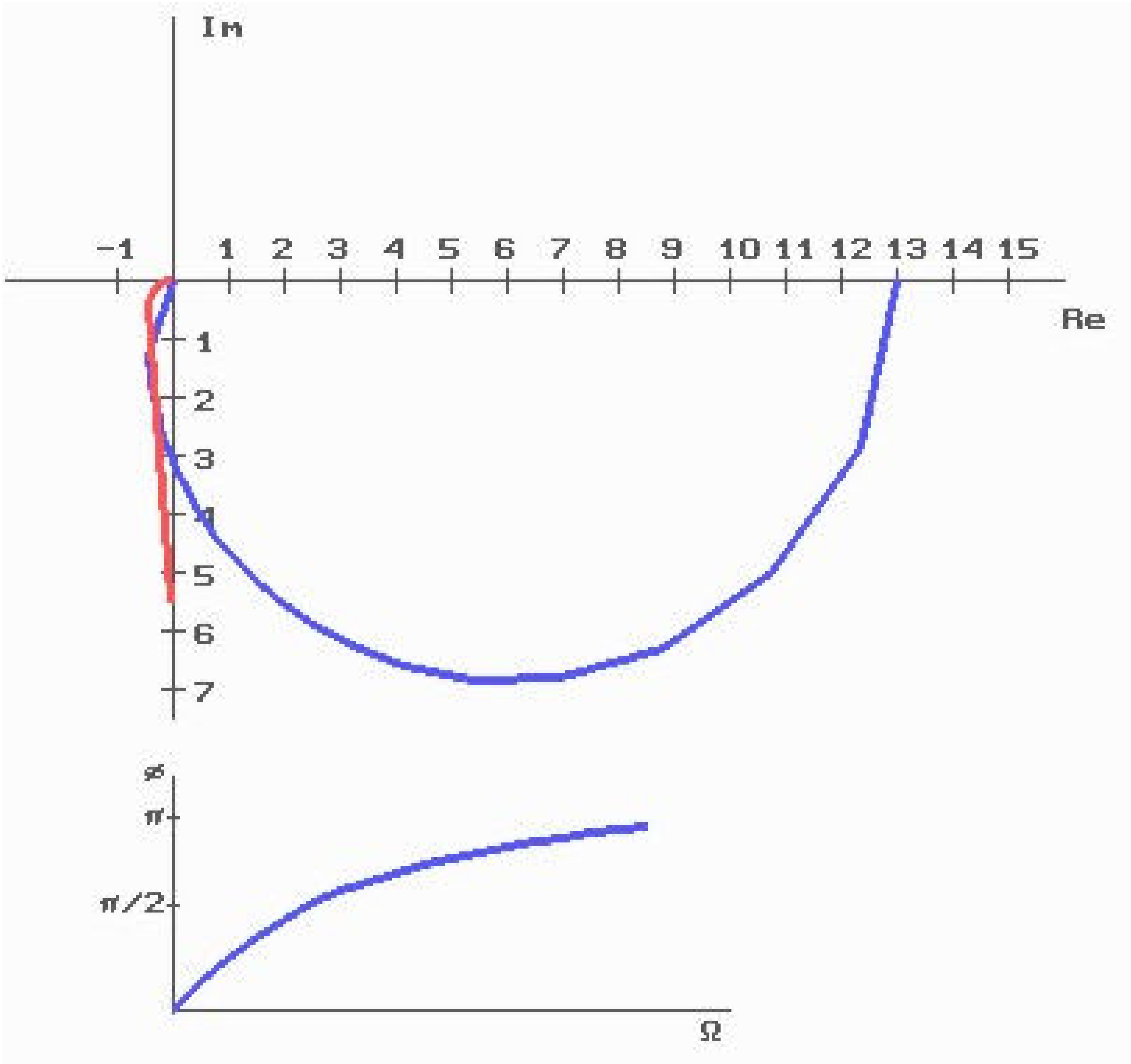

Fig.3 The hodograph of the closed adjustment power system

3.3 Determining the transfer function of the open and closed speed adjustment circuit

To assure the minimum period of time to the transfer process, it is necessary that the structure of the speed adjustment to be chosen from the optimal symmetric conditions. In this hypothesis the transfer function of the speed adjustment open system is:

$$Y_{SD} = \frac{1 + 4 \cdot T_{\mu} \cdot s}{16 \cdot T_{\mu}^2 \cdot s^2 \cdot (2 \cdot T_{\mu} \cdot s + 1)} \tag{31}$$

And for the closed speed adjustment system is:

$$Y_{SD} = \frac{1 + 4 \cdot T_{\mu} \cdot s}{1 + 4 \cdot T_{\mu} \cdot s + 16 \cdot T_{\mu}^2 \cdot s^2 \cdot (2 \cdot T_{\mu} \cdot s + 1)} \tag{32}$$

The result of the open and closed speed adjustment system analysis is presented in figure 4.

The analysis was made using the Nyquist method. It can be observed the fact that both the open speed adjustment system as well as the closed speed adjustment system are constant.

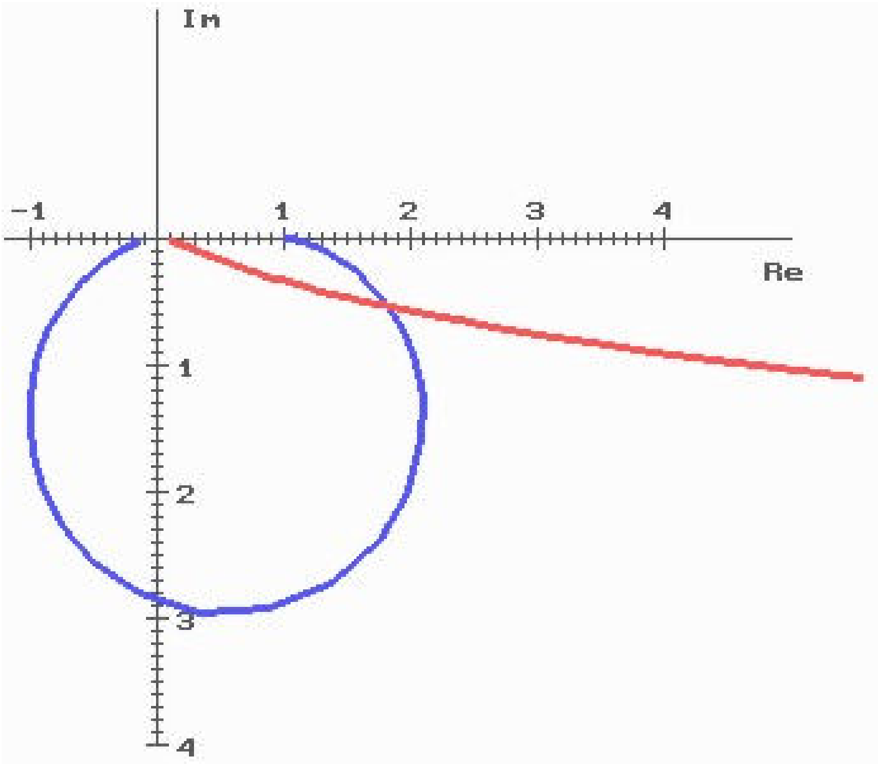

Fig.4 The hodograph of the open and closed speed adjustment system

3.4 Main operation motor ignition current variation determination in time

The current loop being optimized by the criterion of the module, the variation of the current during the ignition may be represented by the following relation:

$$i(t) = I \cdot \left[\ 1 - \sqrt{2}e^{-\frac{t}{2 \cdot T_\mu}} \cdot \cos\left(\frac{t}{2 \cdot T_\mu} - \frac{\pi}{4}\right)\ \right] [A] \quad (33)$$

Figure 5 represents the ignition current variation diagram in time from the armature of an electric motor.

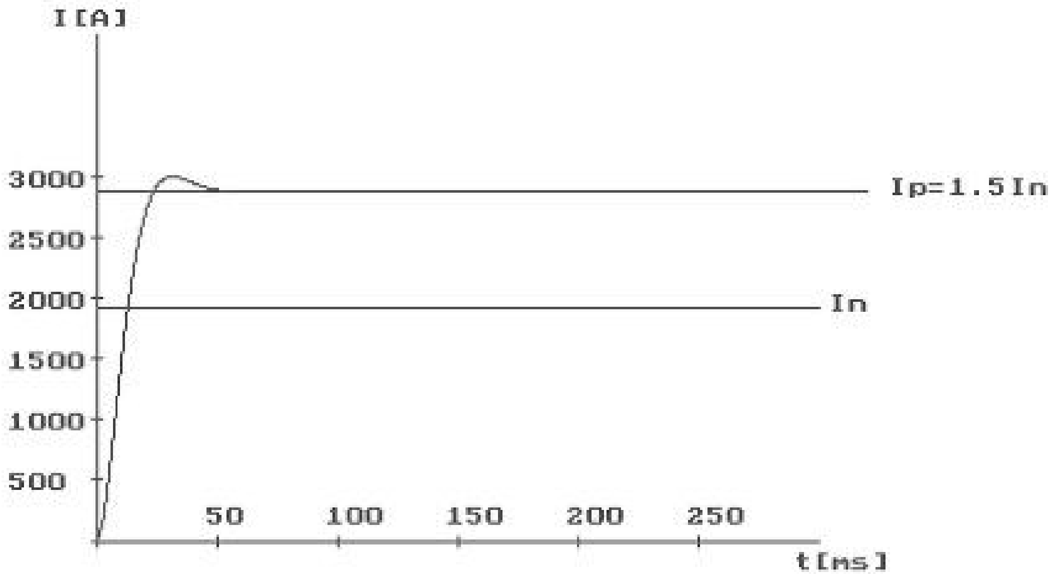

Fig.5 Current variations within the ignition of the main operation motor

3.5 Ignition speed variation determination in time

The variation in time of the ignition speed of the vertical transport installation is represented by the following relation:

$$\Omega(t)=\Omega\left[1-e^{-\frac{t}{2T_\mu}}-\frac{2}{\sqrt{3}}e^{-\frac{2t}{4T_\mu}}\sin\left(\frac{\sqrt{3}t}{4T_\mu}\right)\right]\text{[rad/s]}\quad(34)$$

Figure 6 represents the ignition speed variation in time of the vertical transport installation.

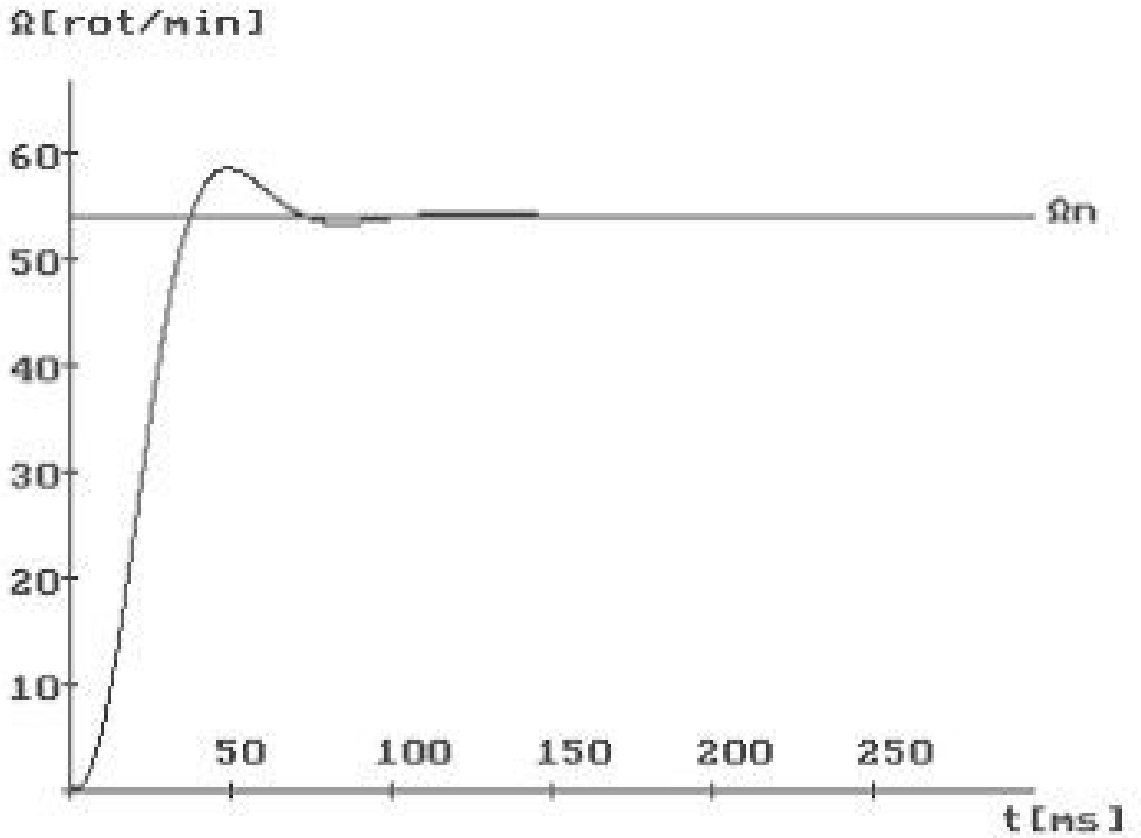

Fig.6 Ignition speed variation diagram

3.6 Speed variation in time during a considerable load variation

When a considerable load variation appears during the operation of a vertical transport installation which may vary between $0{,}2M_N$ and M_N, speed variation depends on the following relation:

$$\Omega(t)=2\nu_0 T_\mu \Omega\left[e^{-\frac{t}{4\cdot T_\mu}}-2e^{-\frac{t}{4\cdot T_\mu}}\cos\left(\frac{\sqrt{3}}{4T_\mu}+\frac{\pi}{3}\right)\right]\quad(35)$$

where :

$$\nu_0=\frac{R_A}{K_E^2}\cdot\frac{\Delta M_S}{T_M}\quad(36)$$

$$K_E=\frac{E_N}{\omega_N}\quad K_M=\frac{M_N}{I_N}\quad T_M=\frac{J_N\cdot R_A}{2\cdot K_E\cdot K_M}\quad(37)$$

The speed variation diagram during a considerable load variation from $0{,}2M_N$ la M_N is represented by figure 7.

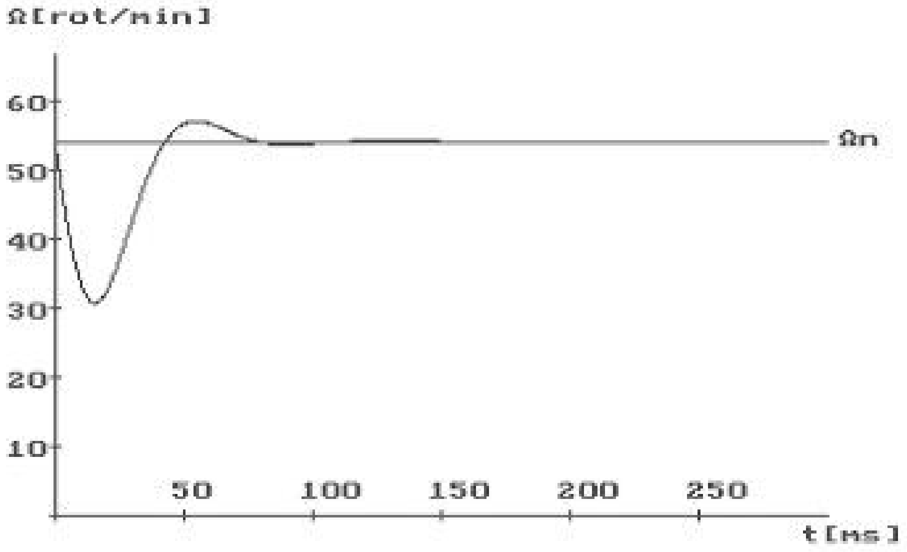

Fig.7 Speed variation diagram during a considerable load variation

4 Conclusion

The stability of the speed adjustment system of transport was analyzed using the Nyquist stability criterion, which has the advantage that can be applied without knowing the equations of the closed circuit blocks, but measuring the answer to frequency. This stability criterion has also the advantage of giving the information regarding the absorption degree.

The analysis in the field of frequency of the adjustment power system form the induced of the main driving engine revealed according to the Nyquist stability criterion, that stability is ensured both in the case in which the internal reverse reaction is taken into consideration, as well as in the case in which the reaction is neglected. The absorption is strong in both cases.

It was determined that the modulus and phase error increases as the time constant decreases T_M (the electro mechanics time constant of the system) and T_E (the electro mechanics time constant of the main circuit) and the T constant increases (dead time of the moving system).

Analyzing the stability based on the same criterion the closed and open speed adjustment system, the conclusion was that this system also is constant and has a very good absorption.

The determination of variation functions in time for the current and speed of the main actuation motor (rotation of the main electrical actuation motor) during the ignition of the vertical transport installation as well as their grapho-analytical study have led to the conclusion that both the current of the ignition of the installation and the speed are stabilized in time after approximately 50 ms, allowing us to state that the installation behaves as a rapid response system.

Speed variation study in time during the application of a considerable load variation has proved that it will be stabilized in time (at a nominal value) after an approximate period of 75ms. This is an essential factor for a vertical transport installation because one of the basic requirements imposed by the automation is that of ensuring the speed stability indifferent of the main actuation electric motor load.

References:

[1] Fransua Alexandru, *Maşini şi sisteme de acţionări electice – Probleme fundamentale*, Editura tehnică, Bucureşti, 1978;

[2] Pop Emil, *Automatizări în industria minieră,* Editura Didactică şi Pedagogică, Bucureşti, 1983;

[3] Mitran Ilie, *Optimalité Minmax, monographs*, AMSE, France, 1992;

[3] Popescu Florin, *Programarea şi utilizarea calculatoarelor*, Editura Sigma Plus Deva, 2002

[4] Popescu Florin, *Calculatorul numeric în industria extractivă*, Editura Universitas Petroşani, 2004

[5] Popescu Florin Dumitru, *Aplicaţii industriale ale tehnicii de calcul (Computer systems for industrial applications)*, Editura AGIR Bucureşti, 2009;

[6] Tunsoiu Gheorghe, *Acţionări electrice*, Editura Didactică şi Pedagogică, Bucureşti, 1982.