Adjusting of the Control System of Asynchronous Motor Drive for Wire Drawing Machine and Winding Mechanism

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Abstract— **In this paper the drive system with asynchronous motor and vector control for Wire Drawing Machine and Winding Mechanism is analyzed. It describes how to use a frequency converter for controlling of the wire drawing machine, the main aspects for setting parameters of the PID controller of the converter, practical methods for adjusting of the speed loop PID of winding mechanism. The proposed method for controlling the operation of winding mechanisms demonstrated maximum efficiency for wire driving line and stability in wide range of operating speeds. The given method demonstrated high stability at acceleration, deceleration and emergency stop of the line without mechanical shocks that can lead to break the processed wire.**

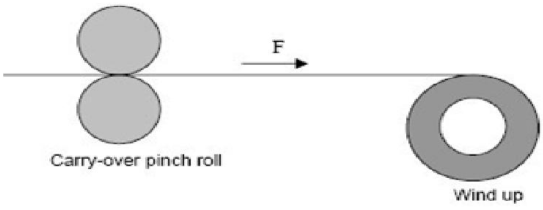
Keywords–wire drawing, winding mechanism, asynchronous motor, electric drive, vector control, PID controller

I. INTRODUCTION

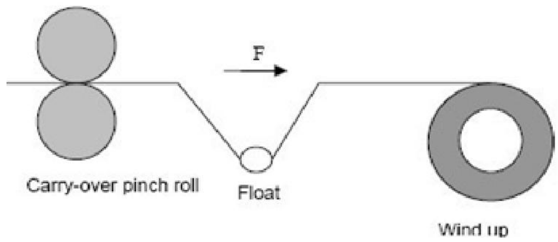
The main purpose in this paper is to identify the ways in which may be used a frequency converter to drive the wire drawing line, the main aspects related to parameter setting of PID controller in the converter, identifying practical method for determining the speed loop coefficients of PID regulator at winding. Identifying the methodology for setting of PID controller on the real frequency inverter type Inovance MD 380.

In practice can be used five application modes of inverter used for winding and unwinding function:

- Unwind mode: In this mode, inverter can realize unwinding function. Inverter can run normally with correct wiring, without the need to configure any parameter except for selecting the unwind mode and resetting inverter (special function).
- Wind mode 1: In this mode, inverter can realize simple winding function. Generally, inverter can run normally with correct wiring and there is no need to configure any mechanical parameter.
- Wind mode 2: When inverter is in this mode, roll diameter can be calculated automatically to realize better tension control. Relevant mechanical parameters are required to be input.
- Wire drawing mode: When inverter is in this mode, relevant wire drawing parameters are configured automatically for wire drawing control.
- Wind mode 3: When inverter is in this mode, it's not necessary to acquire the speed of host, but winding inverter must start before drawing out wire[3][4]



a)



b)

Fig. 1. Schematic diagram for typical tension control[3]
a-without tension feedback
b- with float roll tension feedback

The process of wire drawing is carried out at a speed of 50 m / s (average 20-25 m / s). Force for wire drawing thru dies is developed by drawing drums and friction force that occurs at the contact between the drum and processed wire. This largely depends on the coefficient of friction in the dies of the wire driving machine. Drive systems of wire driving machine must develop the power necessary to overcome the drawing force and prescribed working speed.[1][2]

The system consists of MA1 asynchronous motor, frequency converter with vector control CF1.

Since wire driving machine not require a drive with high dynamic parameters, the motor running on his frequential characteristics without feedback loops.

Drive systems of the winder ensures speed and tension force prescribed for excluding wire breakage. Therefore it contains a MA2 asynchronous motor and frequency converter with vector control CF2 (fig.1).

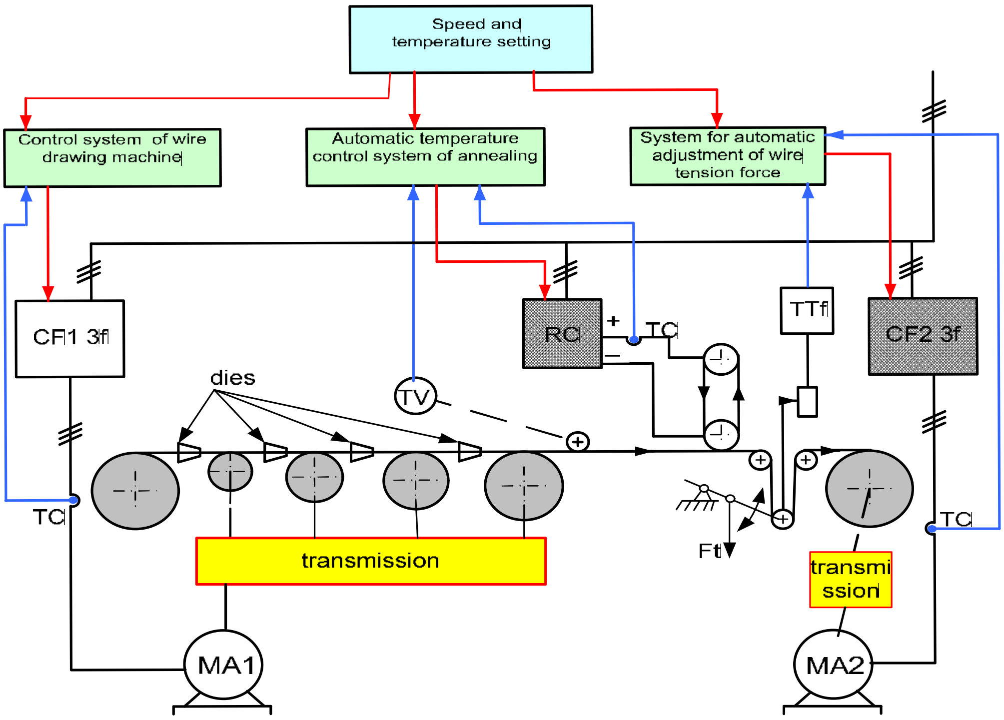


Fig. 2. Block diagram of the power and control system of the wire driving machine.[8]

II. Mathematical Model of Winding Mechanism.

The driving control systems typically have two working modes: motor speed control mode and the torque control mode fig.1. The choosing mode must ensure the precisely and constant thread tension of 3-10% depending on the destination.

The principles of regulation the tension force at winding can be do in two modes: direct measurement of the force from wire or by modifying some parameters indirectly.

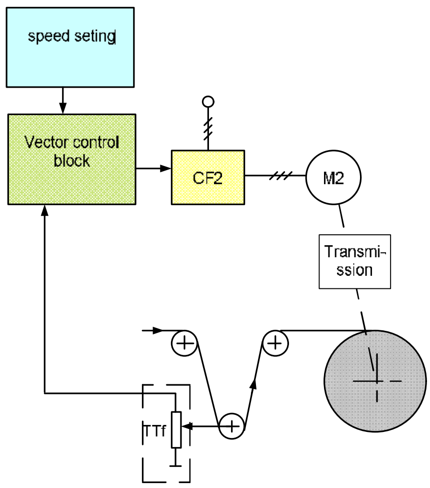


Fig.3 The diagram of the speed control system of winding mechanism in function of position of the compensation arm and the tension force[8]

A. *Estimating the diameter and the inertia of the spool*

Spool diameter changes over time depending on the linear velocity of the wire. The radius of coil any time can be estimated using the following relationship[4][8]:

$$R_b = \sqrt{R_0^2 + \frac{d^2}{\pi \cdot L_b}\int V_l dt} \qquad (1)$$

where: Ro- the initial radius of the spool, d-the diameter of the wire, L_b- spool length,m.

The moment of inertia of the spool according to the quantity of material that be spooled can be determined according to the relation (2):

$$J = J_0 + \frac{\pi L_b \rho}{2}(R_b^4 - R_0^4), \qquad (2)$$

where : J_0- moment of inertia of the spool wireless, ρ- he thread density and taking into account the filling factor

B. *Static torque of winding mechanism*

The value of of the wire tension force depends on its section and shall not exceed the amounts that would cause its thinning and breakage during the work. The tension force in the wire drawing machine is made by a pneumatic cylinder fed with compressed airflow through a pressure regulator that allows adjustment of the force.

The tension force in the wire at winding

$$T = \frac{\sigma_{Al.}}{v_{rez.}}\left[\frac{N}{mm^2}\right] \qquad (3)$$

where σ_{Al} – the tensile strength of the metal, $\nu_{rez.}$- reserve ratio.

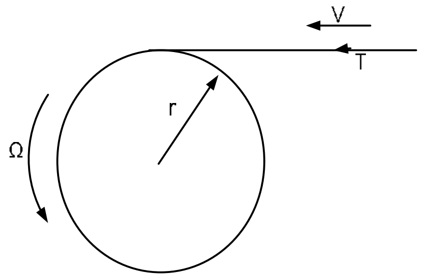


Fig.4 The mathematical description of the winding mechanism

Statical torque of load

$$M_s = T \cdot r \tag{4}$$

where: T- tension force in the wire; r - the radius of the spool for winding.

$$M_s = \frac{T \cdot v}{\Omega} = \frac{k}{\Omega} \tag{5}$$

C. Mathematical model of winding mechanism

The relationships (6) describes the dynamic processes of the winding mechanism depending on the linear velocity of the wire diameter of the coil and the moment of inertia which is also variable.

Being based on this model we can develop a system that will ensure high system stability at high speed winder make corrections in speed winder control system by estimating the radius and moment of inertia of the spool.

$$\left.\begin{aligned} F_T(S) &= (V_{LM2}(S) - V_{LM1}(S)) \cdot \frac{E \cdot S_{cond.}}{L_k(S)} \\ V_{LM2} &= \omega_{M2}(S) \cdot \frac{R_T(S)}{i_{red.}} \\ \omega_{M2}(S) &= M_{din}(S) \frac{1}{J_\Sigma(S)} \end{aligned}\right\} \tag{6}$$

where: F_T-tension force in the wire;

V_{LM1}-linear speed of the wire;

V_{LM2}-linear speed of the wire at spool;

$S_{cond.}$- the wire section;

L_k- Lungime de lucru al liniei de desen de sârmă;

R_T-radius of the spool;

E- the elasticity coefficient of the wire.

D. Modeling of the tension froce

For simplifying the grant of the system, the whole drive of the wiredrawer and of the winding mechanism is equated to a transfer function of second degree.

Following this equation are get the following structural scheme (fig.5).

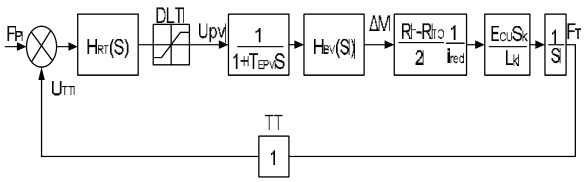


Fig.5. The simplified structural scheme of the drive system[9]

The transfer function of the speed loop:

$$H_{BV}(S) = \frac{k_{AE}}{2T_0^2 S^2 + 2T_0 S + 1} \tag{7}$$

where: $T_0 = 2T_{CF} = 0.01\ s$

$$k_{AE} = k_{EPV} \frac{1}{k_{TV}} \frac{R_T - R_{T0}}{2} \frac{1}{i_r} \cdot \frac{E_{Cu} S_{fir.}}{L_k} \tag{8}$$

$$k_{RT} = \frac{1}{2k_{AE} T_{\mu T}} \tag{9}$$

E. Results of simulation

In fig.6 is shown the simulation result of wire winder system with reaction loop depending on the value of tensioning force.

The value of force is prescribed from pressure regulator of the compensation arm with pneumatic cylinder.

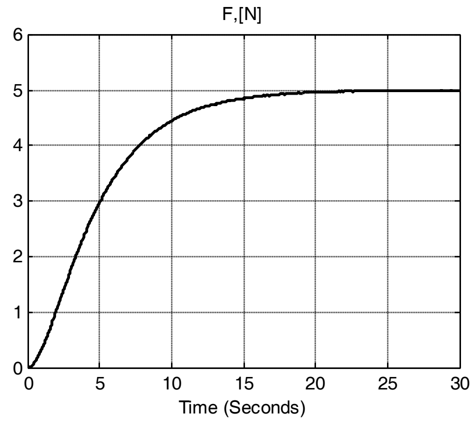


Fig. 6 The tension force when regulating with a reaction loop[9]

III. THE CONTROL SYSTEM WITH FREQUENCY CONVERTERS OF WIRE DRIVING LINE

In Fig. 7 is given the sketch that is used to drive the wire driving machine in the Tehelctro-SV company. In this system both motors are driven in vector control mode. Motor speed of wire driving machine is done by the operator from the control panel via a potentiometer the speed of winder motor is prescribed by main converter that drive the motor of wire driving machine through analog output MO, value of this signal depends on the transmission ratio of linear velocity of wire at output from wire driving machine and the linear speed of wire at input in the winding mechanism.

Fig. 7 General view of wire drawing line with annealing module

Further adjustment of speed of the wire winding is achieved with the potentiometer connected to the analog input SI that indicating the position of the compensation arm, which also performs the tension force of the wire by using a cylinder with a compressed airflow. This signal is used as correction signal for PID controller from inside of the inverter that is adjusted according by the algorithm shown in Figure 11.

Emergency stop of the wire driving line when for example the wire at entrance in the wire driving machine is entangled or is break and to exclude break it in the dies or in the annealing installation should be done in stages: firstly must receive command to emergency stop winding mechanism simultaneously with thermal processing installation, then when winder practically has zero speed, need to receive emergency stop command the control system of the wire driving machine, this will exclude the influence of the moment of inertia of the spool with wire that will exclude wire breakage in the dies and in the annealing installation.

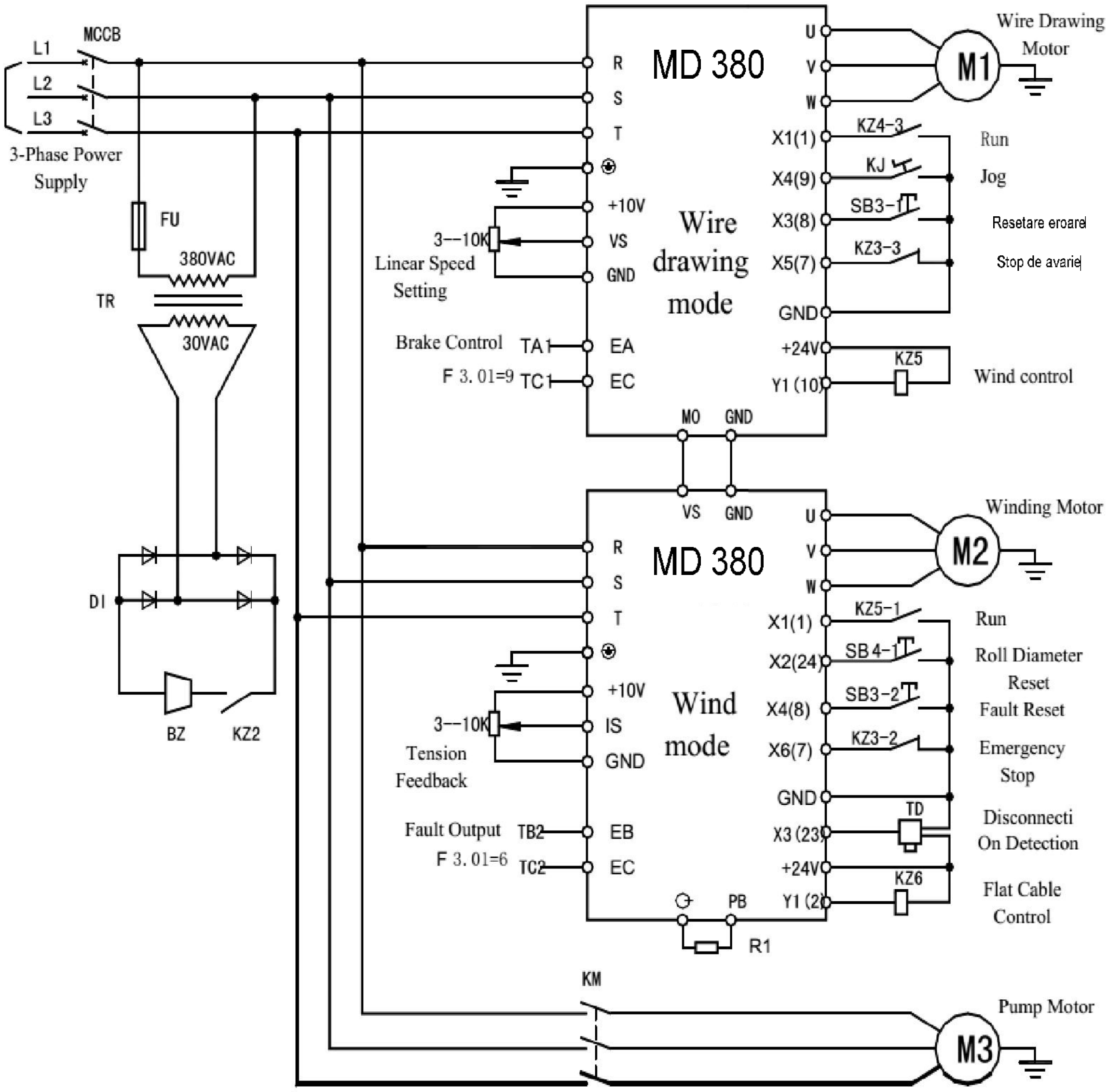


Fig.8 Typical sketch of the control system of wire drawing line with frequency converters INOVANCE MD 380[9]

The main features of scheme from Fig.8:

1. Connecting terminals of inverter in the figure 8 above correspond to defaults of wire drawing mode and winding mode.

2. Linear speed setting potentiometer can be a common potentiometer , but tension feedback potentiometer must be 360°precise potentiometer.

3. Winding inverter has automatic disconnection detection function, but it does not support disconnection detection proximity switch.

4. The contact connected to terminal X5 of wire drawing inverter can be changed to connect terminal X2 . In this way, wire drawing inverter can stop rapidly in case of winding fault or emergency stop.

5. Winding inverter does not need roll diameter reset button, if wind mode 1 is adopted.

Fig. 9 Power cabinet of wire drawing line

PID control is a general process control method. By performing proportional, integral and differential operations on the difference between the feedback signal and the target signal, it adjusts the output frequency and constitutes a feedback system to stabilize the controlled counter around the target value.

Setting of PID controller from frequency converter of spooling mechanism requires an very precisely calculation to ensure good stability of the system in a wide speed range and excluding wire breakage.

A very important step is to adjust the control system and calibration the reaction signals in the frequency converter by setting maximum and minimum value of signals (V/Hz) and their relative value in percentage to the basic signal, which is done using F4-13-F4-32 functions (for MD 380). Explanations of this stage of setting is brought in Fig. 11.

The PID setting is a relative value and ranges from 0.0% to 100.0%.

The PID feedback is also a relative value. The purpose of PID control is to make the PID setting and PID feedback equal.

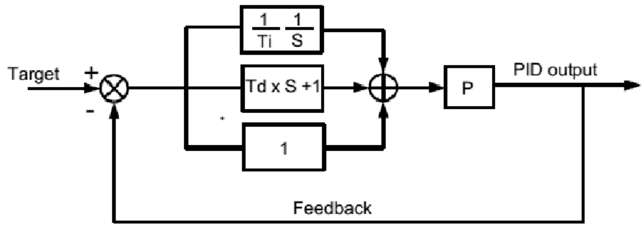


Fig. 10 The principle block diagram of PID regulator[7]

Proportional gain Kp1

It decides the regulating intensity of the PID regulator. The higher the Kp1 is, the larger the regulating intensity is. The value 100.0 indicates when the deviation between PID feedback and PID setting is 100.0%, the adjustment amplitude of the PID regulator on the output frequency reference is the maximum frequency.

Integral time Ti1

It decides the integral regulating intensity. The shorter the integral time is, the larger the regulating intensity is. When the deviation between PID feedback and PID setting is 100.0%, the integral regulator performs continuous adjustment for the time set in FA-06. Then the adjustment amplitude reaches the maximum frequency.

Differential time Td1

It decides the regulating intensity of the PID regulator on the deviation change. The longer the differential time is, the larger the regulating intensity is. Differential time is the time within which the feedback value change reaches 100.0%, and then the adjustment amplitude reaches the maximum frequency.

After adjustment of PID regulator parameters of the winding mechanism was obtained the following values of coefficients: in the first was concluded that the best stability and high dynamic parameters can ensure the PI regulator with following coefficients kp = 4 and ki =6. given coefficients have been obtained using procedure described above.

After adjustment of reaction loop has managed to reach of working speed up to 1100 m / min, while it is processed the wire with diameter 1,3 (at the entrance is wire with 3mm diameter). Initial coil mass is 110 kg and final mass 550 kg with final diameter of 600mm.

Starting and stopping of the wire driving line is programmed in the converters to be carried out in 60 sec. Dynamics of start and stop is smoothly, without shocks of the tensioning force in the wire.

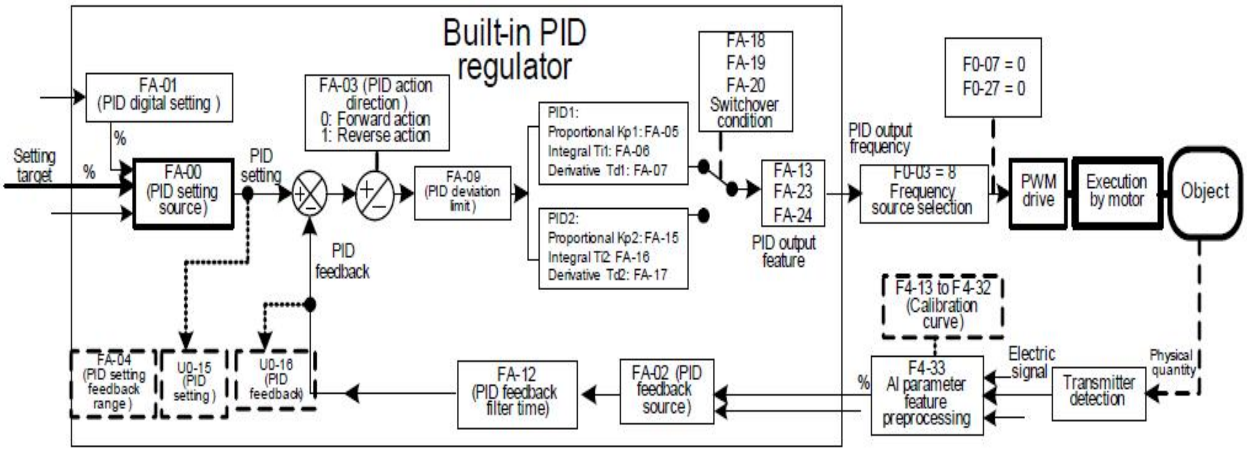


Fig. 11 Setting the PID controller into frequency inverters MD380 INOVANCE [7]

IV. Conclusions

The practical value of work consists in researching and implementing automated control system of wire drawing machine and winding mechanism that should ensure fine adjustment of the technological process, increasing productivity and quality of cooper wire.

Based on the theoretical and practicals methodes was adjusted the loop of the automatic control system of tensioning force in the wire.

Based on studies was identified the optimal method of control for winding mechanism driving with the asincron motor and frequency converter.

The proposed method for controlling the operation of winding mechanisms demonstrated maximum efficiency for wire driving line and stability in wide range of operating speeds.

The given method demonstrated high stability at acceleration, deceleration and emergency stop of the line without mechanical shocks that can lead to break the processed wire.

The practical research on this topic was made at the company Tehelectro-SV, which produces electrical wires and cables.

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