

## THE WINDER CONTROL SYSTEM WITH ALTERNATIVE CURRENT DRIVE OF WIRE DRAWING LINE

*Cazac Vadim, lecturer*

*Technical University of Moldova*

### INTRODUCTION

For high speed wire drawing machine, coordination of speed between the wire drawing machine and winding mechanism is very important. Further, because of a wide range of processing diameters the demands on dynamic response of the speed controlling AC drives are critical. The article attempts to present a review on the a winding mechanism of wire drawing machine working up to 1200 m/min using high performance variable speed AC drive.

In an wire drawing process one of the biggest challenges is to keep the tension force of the wire almost constant or the maximum allowable, variation of the tension force may be within the range of 4 to 5% of the desired value.

### 1. THE ELECTRICAL DRIVE ISSUE OF WINDING MECHANISMS

During of the wire drawing process along with the electrical noise and transients process, the disturbances are too much and some of the essential controlled parameters like the wire thickness, wire straining may unnecessarily show variations which are highly unacceptable in industrial process control.

The main purposes in this paper are:

- the best mode to control identifying of three-phase motor with rotor in short circuit for winding mechanism using the frequency converters.
- the mathematical model and transfer function identification of the control system
- tension force loop parameter set for winding mechanism.
- the setting methodology identification of PID controller on the real frequency converter used for wire drawing machine drive.

The developed control system of the technological process must ensure following requirements:

- quick start of the wiredrawing machine without shocks of tension force,
- tension force keep constant for excluding the breaking of the wire at high speeds of winding.

The driving control systems typically have two working modes: motor speed control and torque control. The choosed control system of wire tensioning force must ensure the precisely and constant

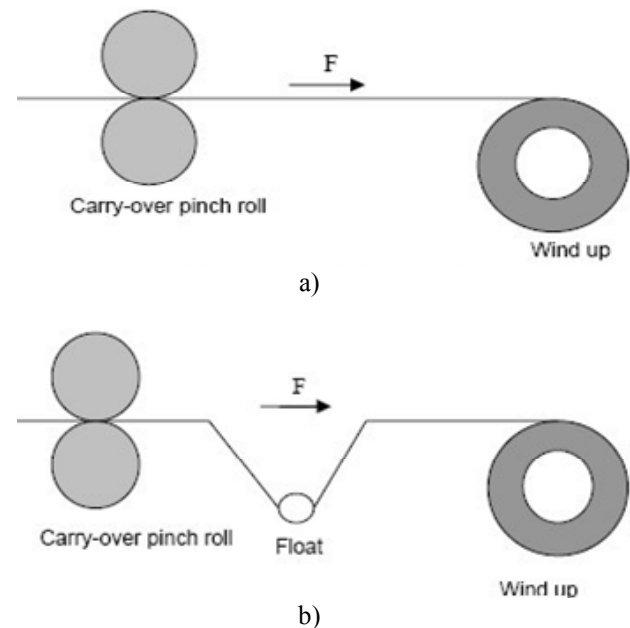
force about 3-10% depending on the destination (Fig.1).

In practice frequency converter can be used in three modes for winding function:

- Wind mode 1: In this mode, frequency converter can realize simple winding function. Generally, frequency converter can run normally with correct wiring and there is no need to configure any mechanical parameter.

- Wind mode 2: When frequency converter is in this mode, roll diameter can be calculated automatically to realize better tension control. Relevant mechanical parameters are required to be input.

- Wind mode 3: When frequency converter is in this mode, it's not necessary to acquire the speed of host, but winding frequency converter must start before drawing out wire [3], [4].



**Figure 1.** The diagrams of typical winding modes [3]: a-without feedback; b - with tension force feedback.

The process of wire drawing is carried out at speed of 50m/s (average 20–25m/s) [11]. 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 of the friction coefficient in the dies of the wire drawing machine Drive system of wire drawing machine must develop the power necessary

to overcome the drawing force and prescribed working speed [1], [2], [5].

The system consists of MA1 asynchrony motor, frequency converter with vector control CF1. Since the wire drawing machine does not require a drive with high dynamic parameters, the motor

MA1 operates on frequency characteristics, without feedback loops.

For excluding wire breakage, drive system of the winder ensure prescribed speed and tension force. Therefore it contains a MA2 asynchrony motor and frequency converter with vector control CF2.

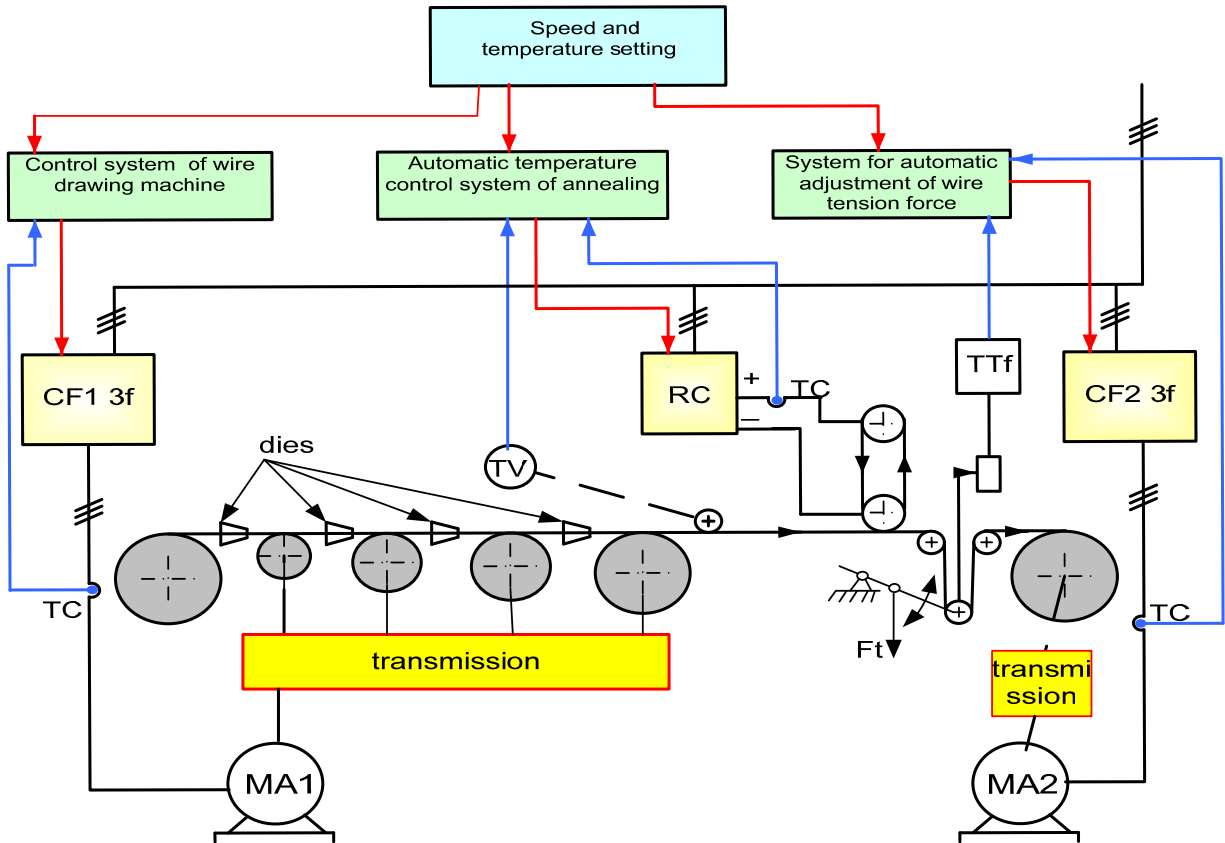


Figure. 2. Block diagram of power and control system of the wire drawing machine with annealing module and winder [8].

## 2. THE MATHEMATICAL MODEL OF WINDING MECHANISM

Tension force adjusting at winding can be do in two ways: direct measurement of the force from wire or by modifying some parameters indirectly [6].

### 2.1. The mathematical model of the spool

Spool diameter changes in time, depending upon linear velocity of the wire. The radius of spool any time can be estimate using following relationship [4], [8], [6]:

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

where:  $R_0$ – the initial radius of the spool,  $d$ –the diameter of wire,  $L_b$ – spool length.

The spool inertia according to quantity of material that has been spooled can be determined by (2) [6]:

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

where:  $J_0$ – the empty spool moment of inertia,  $\rho$ – the wire density, taking into account filling factor.

### 2.2. The torque of winding mechanism

The value of 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 enable to set the stretch force.

The tension force calculus in the wire at winding:

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

where:  $\sigma_{Al}$ – the tensile strength of the metal,  $v_{rez.}$ – reserve ratio.

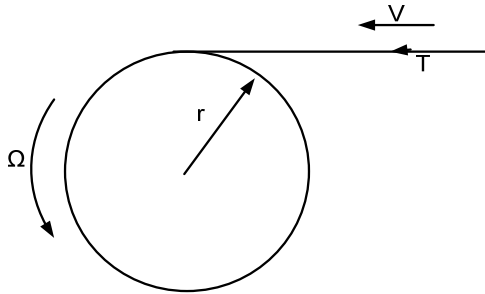


Figure 3. The mathematical description of the winding mechanism.

Static torque of spool:

$$M_s = T \cdot r \quad (4)$$

where:  $T$ –tension force in the wire;  $r$ –the radius of the spool.

$$M_s = \frac{T \cdot v}{\Omega} = \frac{k}{\Omega} \quad (5)$$

### 2.3. The dynamic relationships of winding mechanism

The relationships (6) describe the dynamic processes of winding mechanism in function of line

are velocity of the wire, spool diameter and inertia which are also variable. [8].Based on this model was developed a system that ensure a high stability of the control system at high speed of the wire winding, make corrections in control system by estimating the radius and inertia of the spool [11].

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

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;  
 $L_k$ –working length of the wire drawing machine;  
 $R_T$ –radius of the spool;  
 $E$ –the elasticity coefficient of wire.

### 3. THE VECTOR CONTROL SYSTEM OF WINDING MECHANISM

In this section is represented the simplified structure of the winding control system, the elements of this drive are shown in Figure 4. The wire tension force adjusting at winding takes places in a direct way, using a transducer for its measure, in the wire.

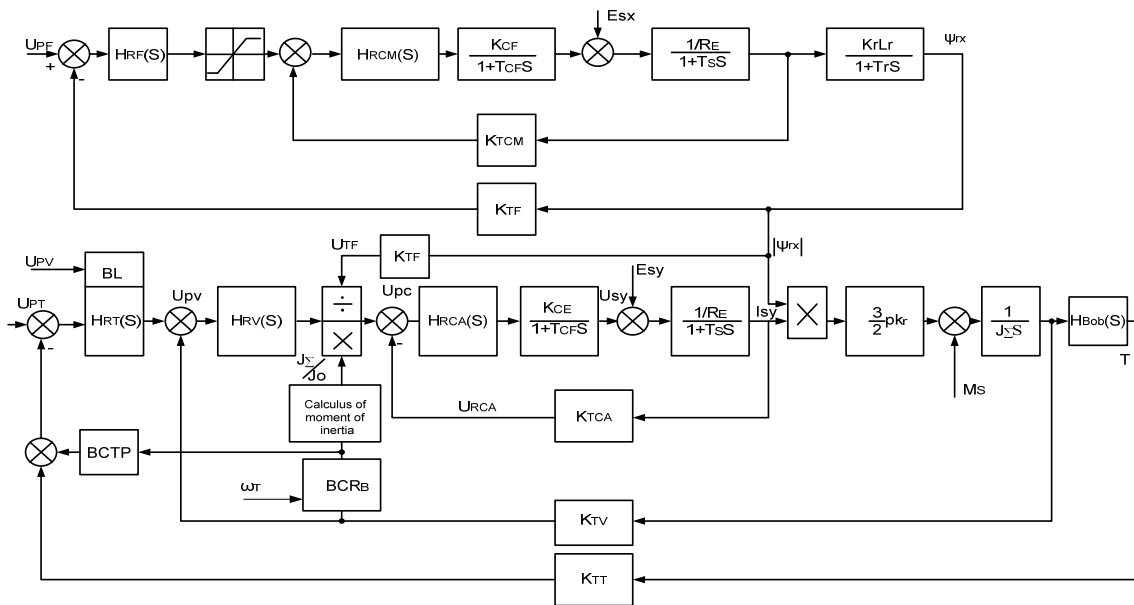


Figure 4. Simplified structural diagram of vector control system for adjusting winding speed and tension force [2], [10].

The diagram has three loops with subordinate adjustment of the active current, speed and of the wire strain force is outer loop. Changing the regulating modes is performed automatically after influence of the tension force controller over limit block. In case if wire is not, integral component of the regulator bring the regulator in saturation. The limit value is prescribed by the signal  $U_{pv}$ , and prescribes the speed of the spool when it is empty. The tension force will start to rise and the tension force regulator will exit from saturation and allow the contour of tension force regulator to work, considering that, the angular velocity of the spool is prescribed to be higher that the linear speed of the spool.

At wire breakage a reverse process will start, the signal from the tension force regulator exit will start to rise until saturation. The winding speed will also start to rise. To stop a full spool it is necessary to decrease the limit value of the tension regulator until it reaches nil. The multiplication and division device provides the granting of the speed loop at function with weakened magnetic flow or with changing the summary inertia at the motor shaft. The law of modification for the wire tension force is ensured by the correction block of tension force prescription [8], [10].

The corrections bloc of the prescribed tension force BCTP represents a proportional controller with factor(7):

$$k_{CPT} = k_R \left( 1 - \frac{R_{TB}}{R_B} \right) \quad (7)$$

where:  $k_R$  –reserve coefficient, decreasing the influence of the spool radius on the tension force, being chosen  $k_R = 1$ ,

$R_{TB}$  –radius of the full spool;

$R_B$  –radius of the empty spool.

BCRB–is block of the winding spool radius calculus.

### 3.1. The magnetic flow channel calculus

The structural diagram of the magnetic flow channel at vector control includes two loops of automatic regulation: the internal loop of the reactive current of magnetizing  $I_{sx} = I_m$  and the outer loop of the magnetizing flow (Figure 5).

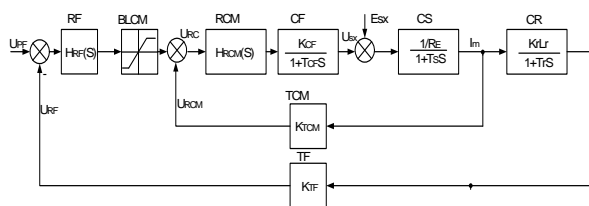


Figure 5. Structural diagram of the magnetic flow channel [9].

The turning system of coordinate x-y is oriented after the rotor magnetic flow  $\psi_r = \psi_{rx} = |\psi_r|, (\psi_{ry} = 0)$ , which ensure the simplest structure of the automatic control system.

The diagram from Figure.4 does not take into consideration the transformations ABC / $\alpha$ - $\beta$ ,  $\alpha$ - $\beta$ /x-y and reverse x-y/  $\alpha$ - $\beta$  and  $\alpha$ - $\beta$ /ABC. In the outer loop the limit block of magnetizing current is introduced in (BLCM).

### 3.2. The magnetizing current loop calculus

Having determined the parameters of the motor, belonging to the winging mechanism, we make for the system regulation loops calculus. The frequency converter can be approximated with a first order element>

$$H_{CF}(S) = \frac{U_{sx}(S)}{U_c(S)} = \frac{k_{CF}}{1 + T_{CF}S} \quad (8)$$

Where,

$$k_{CF} = \frac{U_{sx.N}}{U_{CN}} = \sqrt{\frac{2}{3}} \frac{U_s}{U_{CN}} \quad (9)$$

$T_{CF} = 0,005s$  –inner constant of the CF without a prescription integrator element.

If a Hall type current transducer is chosen, then it, can be described through a non inertial element.

$$k_{TCM} = \frac{U_{TCM.N}}{I_{SX.N}} \quad (10)$$

The RCM tuning is made, relative simply, based on module criteria the transfer function of the current closed loop is:

$$H_{d.c}^d(S) = \frac{1}{2T_{\mu c}S(T_{\mu c}S + 1)} \quad (11)$$

where:  $T_{\mu c}$  –the small constant (uncompensated by controller) of the current loop

The RCM regulation object

$$\begin{aligned} H_{ORC}(S) &= H_{CF}(S) \cdot H_{CS}(S) \cdot H_{TCM}(S) = \\ &= \frac{k_{CF}}{1 + T_{CF}(S)} \cdot \frac{1/R_E}{1 + T_S(S)} \cdot \frac{k_{TCM}}{1 + T_{TCM}S} = \\ &= \frac{k_{OR.C}}{(1 + T_{\mu c}S)(1 + T_S S)} \end{aligned} \quad (12)$$

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where:  $T_{\mu c} = T_{CF} = 0.005$  ;

$$k_{OR.C} = \frac{k_{CF} \cdot k_{TCM}}{R_E} \quad (13)$$



$$U_{PCA} = \frac{U_{RV}}{U_{TF}} \quad (26)$$

The division device at the RV exit is meant for the torque correction of drive motor, according to variable inertia of the spool.

### 3.5. The loop of active stator current calculation

The active stator current sensor must be chosen with the same output signal  $U_{TCA,N}=3,5V$  at a nominal current of 3.5 A. The current, being twice as much, at the RCA entrance and voltage divider with a 0,5 coefficient is introduced:

$$k_{TCA} = \frac{U_{TCA,N}}{I_{CA,N}} \quad (27)$$

The transfer function is the same as in the reactive stator current case:

$$H_{CF}(S) = \frac{k_{CF}}{1+T_{CF}S} \quad (28)$$

where:  $k_{CF} = \frac{U_{sy,N}}{U_{CN}}$ ;  $T_{CF} = 0.005 S$

$T_{\mu C} = T_{CF} = 0.005 S$ . – the uncompensated constant of the current loop.

Thanks to the current open loop, we get a current PI controller with transfer function:

$$H_{RCA}(S) = \frac{1+T_{IZ,C}S}{T_{I,C}S} = \frac{1+T_S S}{2k_{OR,A} \cdot T_{\mu C} S} \quad (29)$$

where:  $T_{IZ,C} = T_S = 0.248 S$ .

$$T_{I,C} = 2k_{OR,A} \cdot T_{\mu C} \quad (30)$$

The amplification coefficient of RCA

$$k_{RCA} = \frac{T_{IZ,C}}{T_{I,C}} \quad (31)$$

The stator current closed loop transfer function is:

$$H_{BC}(S) = \frac{1/k_{TCA}}{2T_{\mu C}S^2 + 2T_{\mu C}S + 1} = \frac{2}{2T_{\mu C}S^2 + 2T_{\mu C}S + 1} \quad (32)$$

### 3.6. The speed loop calculus

We pick a speed sensor with following transfer coefficient:

$$k_{TV} = \frac{U_{TC,V}}{\Omega_{rN}} \quad (33)$$

The inertia of the spool and of the driving motor is:

$$J_{\Sigma} = J_M + J_T = J_M + m_B \cdot (R_T^2 - R_{TO}^2) / i_r^2 \quad (34)$$

where:  $m_B=550kg$ ;  $R_T=0,6m$ ;  $R_{TO}=0,3m$ .

The speed control transfer functions of the object is:

$$H_{OR,V}(S) = H_{BC}(S) \cdot k_{TV} \cdot \Psi_r \frac{3}{2} p \cdot k_r / J_{\Sigma} S = \frac{k_{OR,V}}{S(T_{\mu C}^2 S^2 + 2T_{\mu C}S + 1)} \quad (35)$$

where  $k_{OR,V} = 1.346$

If we start from this transfer function, the speed closed loop transfer function is:

$$H_{d,v}^d(S) = \frac{1}{T_{\mu V} S(2T_{\mu C}S^2 + 2T_{\mu C}S + 1)} \quad (36)$$

Then was got a pure proportional regulator for speed:

$$H_{RV} = \frac{H_{d,v}^d}{H_{OR,V}} = \frac{1}{k_{OR,V} T_{\mu V}} = \frac{1}{2k_{OR,V} T_{\mu C}} \quad (37)$$

The transfer function of speed closed loop with a proportional regulator is:

$$H_{BV}(S) = \frac{1/k_{TV}}{2T_{\mu C}S(T_{\mu C}^2 S^2 + 2T_{\mu C}S + 1) + 1} \quad (38)$$

But a pure proportional speed regulator does not provide a stationary error, reported to the motor load couple. The wire winding mechanism does not require a null stationary error, therefore we choose a PI speed regulator.

## 4. THE CONTROL SYSTEM WITH FREQUENCY CONVERTERS OF WIRE DRAWING MACHINE

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

machine and the linear speed of wire at input in the winding mechanism.

Further set of speed of the wire winding is achieved with the potentiometer connected to the analog input SI that show 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 frequency converter.

Emergency stop of the wire drawing machine when for example the wire at entrance in the machine is entangled or is break and to exclude break of wire in the dies or in the annealing installation should be done in two stages:

- 1) Firstly winding mechanism at the same time with thermal processing installation must receive command to emergency stop.
- 2) Then when winder practically has zero speed, need to receive emergency stop command the control system of the wire drawing 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.

The 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 adjust the output frequency and constitutes a feedback system to stabilize the controlled counter around the target value.

Set of PID controller from frequency converter of winding mechanism requires a 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 of the reaction loop in the frequency converter by set 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 set are brought in Figure 8.

The PID set 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 set and PID feedback equal.

Start and stop of the wire driving machine is programmed in the converters to be carried out in 60sec. Dynamics of start and stop is smoothly, without shocks of the tension force in the wire.

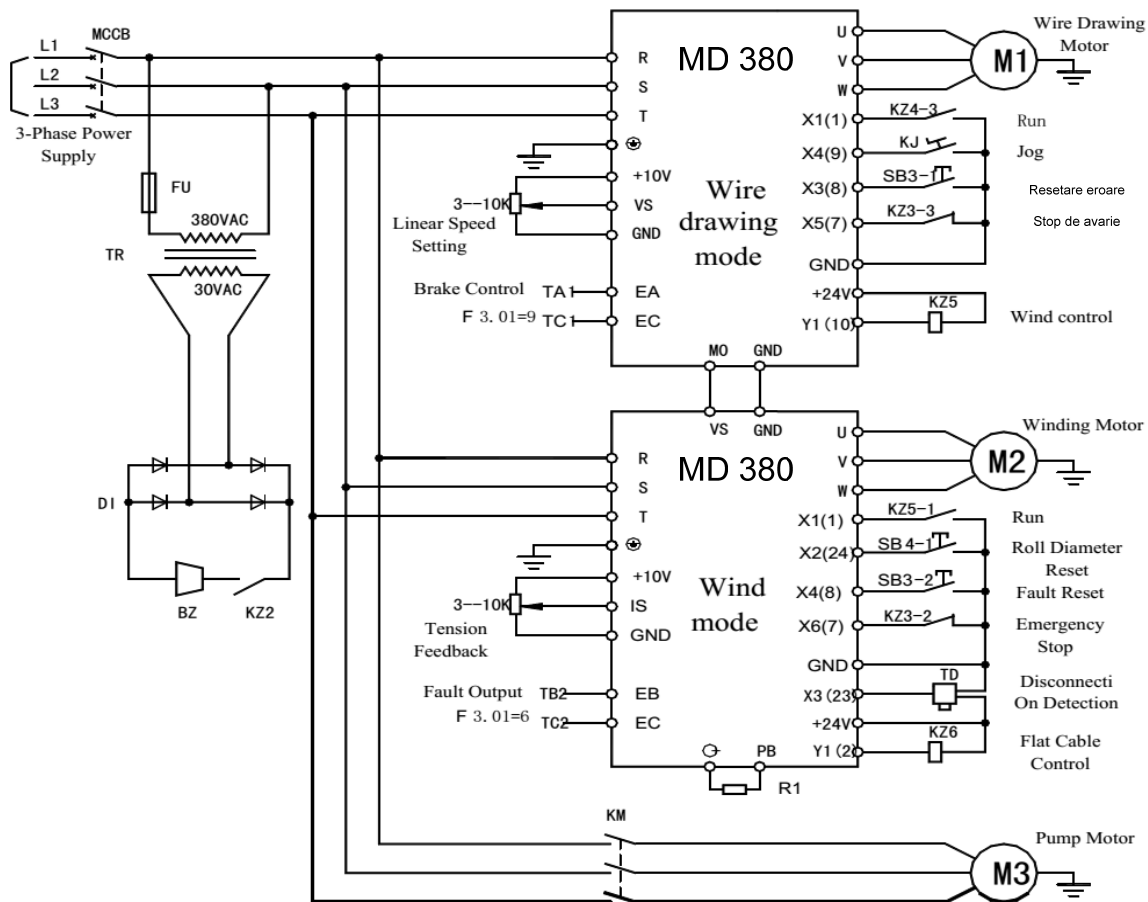


Figure 7. Typical diagram of wire drawing machine control system with frequency converters [9].

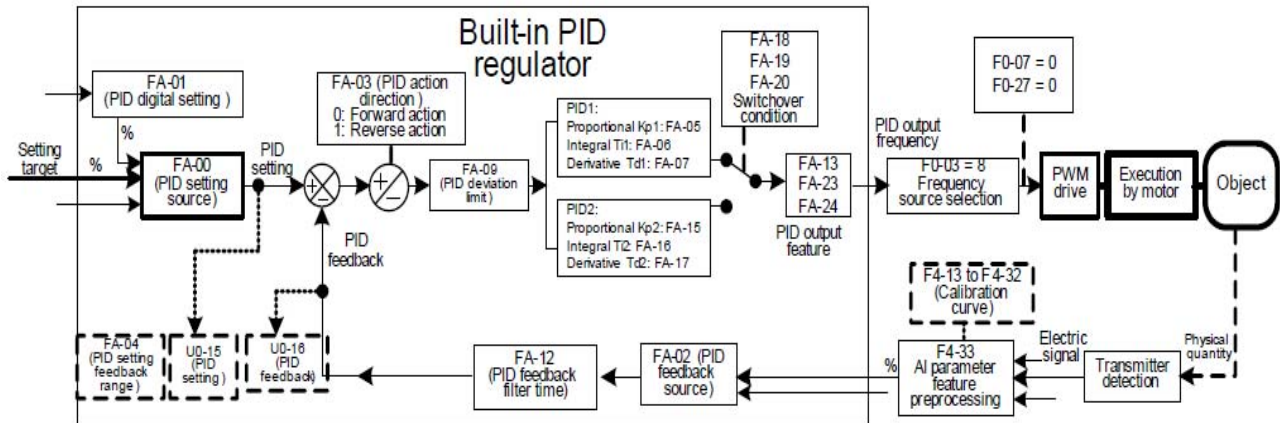


Figure 8. The PID controller setting into frequency converter [7].

#### 4.1. Results analysis

After set of PID regulator 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  $k_p=4$  and  $k_i=6$ . These coefficients have been obtained using results of modelling and Ziegler–Nichols tuning method. After setting of reaction loop has managed to reach of working speed up to 1200m/min, while it is processed the wire with diameter 1,3mm (at the entrance is wire with diameter 3mm). Initial spool weight is 110kg and final weight 550 kg with final diameter 600mm.

### 5. CONCLUSIONS

Based on the theoretical and practical methods was set the loop of the automatic control system of tension force from wire.

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

The proposed control method of winding mechanism demonstrated high efficiency for wire driving machine and stability in wide range of operation speeds, high stability at acceleration, deceleration and emergency stop of the machine without mechanical shocks that can lead to break the processed wire.

The developed control system proves: the adequate behaving of the wiredrawing machine for different variations of the target signals and for different perturbations; the optimization of the dynamic and static processes vs. the quickness and exclusion of oscillations and overregulation of the controlled winding tension force. The practical research on this topic was made in Tehelectro-SV company, which is a factory of electrical wires and power cables.

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