بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

Palestine polytechnic university

Submitted to the college of engineering to fulfillment of the requirements for the Bachelor's degree in

Mechatronics Engineering

Project Title:

Automation Of A Manual Bending Machine

By:

Mousa Salameen ***Anas Asafra*** ***Marwan Taradeh***

Supervised By:

Dr. Zoheir Wazwaz

Hebron, PPU, Jun, 2021

Palestine Polytechnic University

Collage of Engineering

Mechanical Engineering Department

Mechatronics Engineering

Hebron – Palestine

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Project Team

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Supervisor Signature

.... 4/10/2021

Chair of the Department Signature

....

June 2021

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Abstract

The main idea in the project is to convert a manual bending machine into automatically and manually operative one, That by using electronic and electrical devices like(PLC), Rotary encoders, Variable frequency drive, touch screen, and other parts.

The major part of the project based on programmed logic control unit, we had programed it according to the equations which we must use in programming (PLC) with respect the correct electrical devices connection.

As a result, we obtained a machine with high specifications in terms of production speed, safety and product quality.

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1.1 Project overview

With the progression of time, and resultant of the technological development and the development of metal forming, there should be advanced machines for metal forming.

We noticed that the process of metal forming still classical process and it is depend on a traditional ways as a part of working steps, and it's need for a professional workers to use it, so the idea starting from the lack of advanced forming machines in the local factories and the low level of product quality, so the idea is improvements of the local metal forming machine and convert it to advanced machine to work automatically with more accurate so the product will be more quality, high production and simplify its use by any worker.

1.2 Motivations

1- More accurate in calculations.
2- More quality.
3- High production.
4- Ease of using.

1.3 Importance of the system

The importance of the system is represented in make automation for the manual bending machine using PLC, HMI touch screen, and manual controller, that to accomplish the desired goals as we mentioned before.

1.4 Problem statement

We want to solve many problems which it already presented in a handle bending machine which described as the following

1- The probability of errors due to the humanity calculations.
2- Failure to obtain the required diameter as much as the required accuracy resultant of the handle calibration.
3- Asymmetric bending at all parts of piece of work.

1.5 System objectives

1- Saving time and effort.
2- Supporting local industry.
3- Employing our mental capabilities and practical skills in the labor market which based on foundations scientific engineering.
4- Increase production.

1.6 Short description of the system

The machine does bend the iron metal whereas the desired radius and the thickness of a piece of work will enter by the worker into the machine using touch screen HMI as an interface tool between worker and the machine, whereas the machine will do the desired calculations automatically based on an equations we will describe it later. The machine will implement the system using the programmed logic control unit (PLC) and encoders. After entering the piece of the work into the machine and pressing on the start button, the machine will start in bending process step by step to reach to the end point.

1.7 List of requirements

1- Handle bending machine.
2- Programmed logic control unit (PLC).
3- Touch screen (HMI).
4- Rotary encoders.
5- Variable-frequency drive(V.F.D).
6- Manual controller.

1.8 Expected results

1- Contribute to local production.
2- Creating local and national capabilities in the field of the machines improvement.
3- Produce the product with high accuracy.

1.9 Time schedule for the introduction to graduation project

Table 1 Time schedule for the introduction to graduation project

No. of week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Identification of project idea	■	■													
Drafting a preliminary project proposal			■	■											
Introduction about project				■	■	■									
General description about project						■	■	■	■						
Mechaincal and electrical design										■	■	■	■	■	■

Chapter two

Literature review

2.1 Introduction.

2.2 Machine description.

2.3 General characteristic for MC 150B machine.

2.4 Important parts of the machine.

2.5 The traction roller for chosen machine.

2.6 Movement type.

2.7 Bending capacity.

2.8 Electrical map.

2.9 General notes.

2.1 Introduction

The machine which we choose to apply the project is MC150B bending machine. The MC150B bending is a machine specifically designed for bending profiles, the majority of which are metal, with different thicknesses and configurations, such as solid profiles, pipes, T-profiles, angles... The bending machine offers a set of standard tools, rollers, to allow the bending of profiles in a range of shapes and sizes. Apart from the standard rollers, the manufacturer also offers different types of additional rollers to produce other types of bending, according to the configuration of the material to be handled, as well as specific rollers for work with iron, stainless steel or aluminum, manufactured with * SUSTARIN for jobs in stainless steel or aluminum avoiding the material to be damaged or scratched**.{1}**

After applying the project, the machine will be able to work automatically, and reduce the expected risks on the worker when dealing with the classic machine, which will be explained in detail later.

2.2 Machine description

The bending machine has been designed for bending all kinds of profiles irrespective of their shape. The standard rolls included as standard on the bending machine allow the configuration of all kinds of handrails, angles, square, round pipes, etc., thanks to their multiple configurations**. {1}**

The following figures shows the structure of the handle machine and some types of bending process

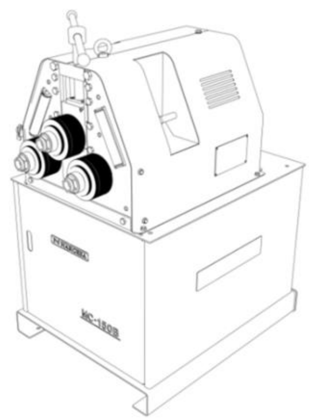


Figure 1 Manual Bending machine(MC 150B)

Figure 2

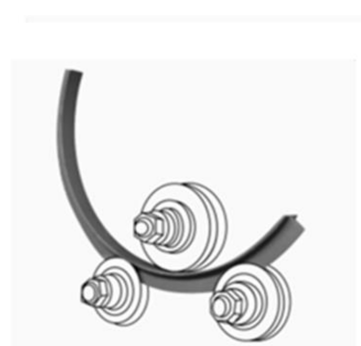


Figure 3

Figures (2, 3): Is an example of a bending process

2.3 General characteristic for MC 150B machine

General characteristics of the machine are summarized in terms of

Table 2 General characteristics for MC 150B machine

Motor power	0.75 Kw/1 CV a 1400 r.p.m.
Voltage	3 phased 230/400 V or 1 phased 230 V
Intensity	3.5 / 2 A
Type of pull	Two rollers
Roller speed	6 r.p.m.
Roll diameter	127 mm
Axes useful length	74 mm
Structure material	Plate
Total weight	270 Kg
Dimensions	690x943x1140 mm

2.4 Important parts of the machine

2.4.1 Main motor

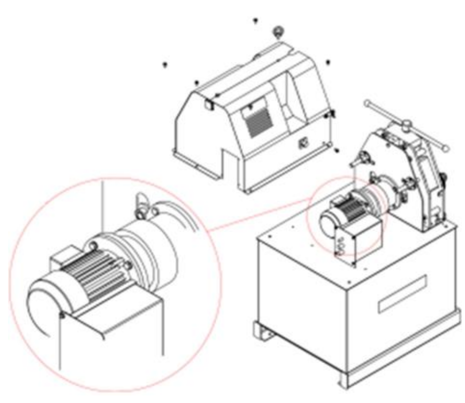


Figure 4 Main motor in manual bending machine

2.4.2 Rollers

The Rollers are made of (**Steel F-1140 and treated to 62 Rc)** or (**Sustarin){1},** where 1-st one suitable for bending all kind of round steel or stainless steel pipes. And the other is suitable for stainless steel pipes, aluminum and delicate materials with thickness not bigger than 2.5mm.The roller located in the front end of the machine, and we chose it based on shape of a work piece.

Figure 5 One of types of rollers

2.4.3 Supports

Located on the front of the machine, its main function is to fix the work piece, and reduce the vibrations during winding process.

Figure 6 Support arm

2.5 The traction roller for chosen machine

The MC 150B machine have a two traction roller, so the two lower axes is motorized whereas the upper one is no.

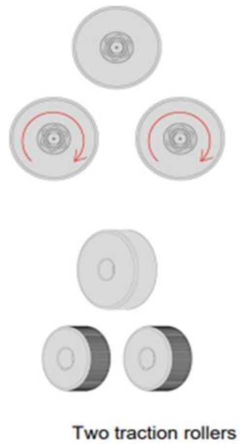


Figure 7 Two traction roller case

2.6 Movement type

The MC 150B is a Pyramidal bending machine , in The Pyramidal bending machine just the upper and central roller moves up and down, which make the machine work easier to bend pipes of a greater diameter as the distance between the centers of the lower axes is superior and always equal.

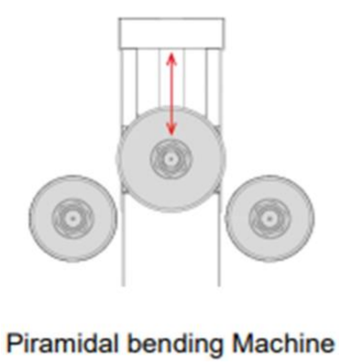


Figure 8

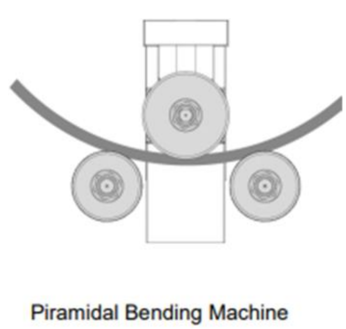


Figure 9

Figures (8, 9) Movement type in the (MC 150B) Machine

2.7 Bending capacity

Note: the bending capacity is varied based on the profile and the measures of the piece of the work as the following table.

Table 3 Bending capacity

	MC150B	
Profile	Measures	Min. radius
	50 x 8	300
	60 x 20	200
	25 x 25	200
	40 x 40 x 3	350
	40	200
	40	250
	50	200
	50	250
	40	500
	25	180
*	40 x 2 * 50,8 x 3 *	300 600

* Optional rollers

2.8 Electrical map

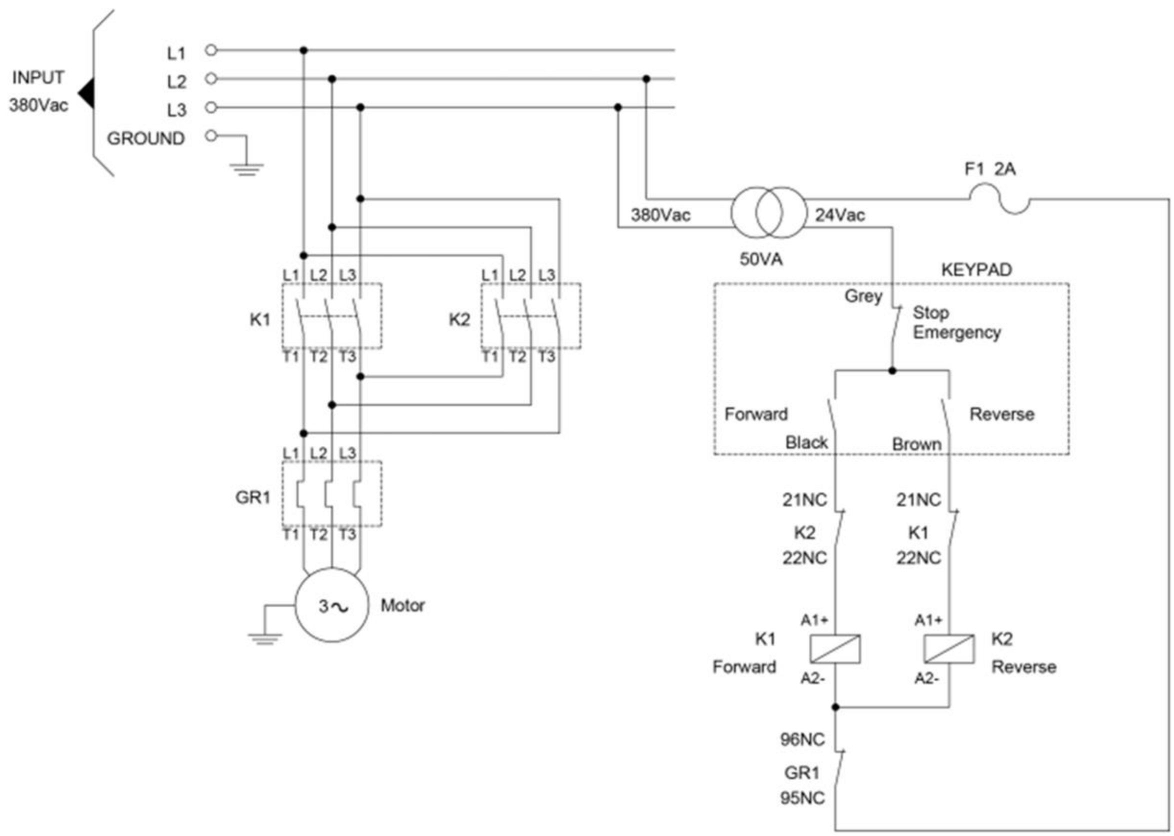


Figure10 Electrical Map for a manual machine

2.9 General notes

2.9.1 Can an iron bending machine be used for aluminum?

In most cases the iron bending machines are used to bend iron and there are specific aluminum machines to bend aluminum. To obtain a perfect curve on an iron profile it is important that the distance between the centers of the axes is a minimum, whereas the aluminum bending Machine has its axes further apart and the distance between them is easily adjustable.{1}

Chapter three

Design

3.1 Desired equations.

3.2 Mechanical design.

3.3 Electrical design.

3.1 Desired equations

The important part of the project is the equation needed to get the required radius, which we must applied the equation on (PLC) to adjust the feed amount for the upper roller {4}.

$Y^2 = R^2 - X^2$ ……………………………………………………………………………………………(1)
$S = R - Y$ ………………………………………………………………………………………….…...(2)

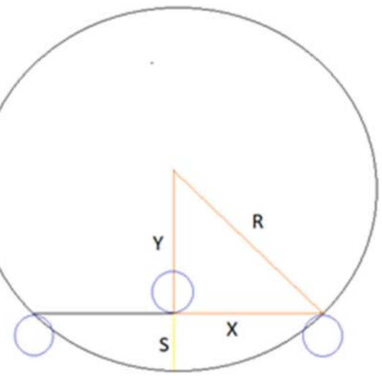


Figure11 Mathematical description of the machine’s work method

To find the circumference of a circle

Circumference of a circle = $(2*R) * \pi$ ………...……………………………………….………..(3)

3.2 Mechanical Design

3.2.1 Motor design

In mechanical design we will replace the manual calibration tool by a motor. To obtain the required radius we will calibrate this motor using PLC software according to a studied equation which we will explain later.

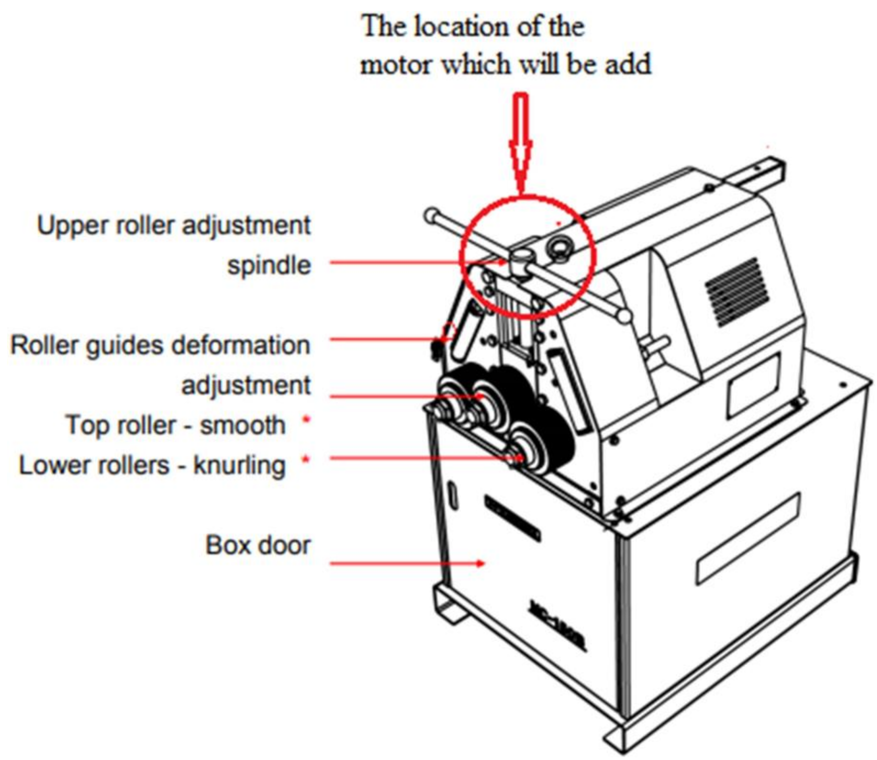
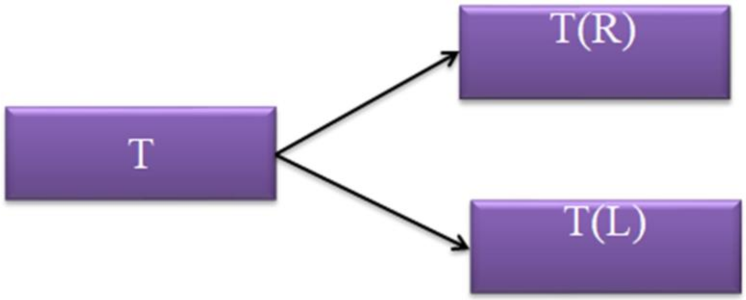


Figure 12 The location of the secondary motor which will be added

3.2.2 Calculations of the required motor power



For the torque required to raise the load sitting by T(R) and for the torque required to lower the load is T (L).

Where

$$T(R) = \frac{F * d_m}{2} \frac{(l + \pi * f * d_m)}{(\pi d_m - f * l)} \quad \text{...................................(4)}$$

$$T(L) = \frac{F * d_m}{2} \frac{(\pi * f * d_m - l)}{(\pi d_m - f * l)} \quad \text{...................................(5)}$$

The maximum bending force equation

$$F = \frac{K_{bf} * TS * W * T^2}{D} \quad \text{...................................(6)}$$

K (bf) = 1.33 for V-bending

TS: tensile strength of sheet metal, for cold drawn (CD) SAE 1020 = 470 MPa

W: part width in direction of bend axis = 60 mm

T: stock thickness = 20 mm

D: distance between two pulley rollers = 328 mm

F: The maximum bending force

d_m: Major diameter = 30mm

l: lead of the screw = 3.5 mm

f: Coefficient of friction factor, for dynamic coefficient of friction = 0.12, static coefficient of friction= 0.16.

T (R) for the start of applied torque = 137.2 N.m.

T (R) running torque = 108.3 N.m.

T (L) for the start of applied torque = 83.7 N.m

T (L) running torque = 56.5 N.m.

The power equation:

$$Power = \text{torque} * angular\ velocity \quad \text{...(7)}$$

Power = 651.6 W

Screw torque efficiency:

$$e = \frac{F * l}{2\pi * T(R)} * 100\% \quad \text{...(8)}$$

= 23.5%

We need a high value of worm gearbox ratio to get a small output rotational speed.

We choose the worm gear ratio = 100:1 –Suitable gear-

Figure 13 secondary motor

So:

$$\boldsymbol{Gear\ ratio = \frac{input\ speed(r.p.m)}{Output\ speed(r.p.m)} = \frac{T_2}{T_1}} \quad \textbf{..(9)}$$

Where

Gear ratio = 100:1.

T2 = 137.2; Output torque.

Input speed = 1400(r.p.m) rated speed.

$$100 = \frac{1400(r.p.m)}{Output\ speed(r.p.m)} = \frac{137.2\ N.m}{T_1}$$

Output speed = 14(r.p.m)

T1=1.372 N.m; for required motor.

$$Motor\ power = 1.372\ N.m\ x\ 1400(r.p.m)$$

= 1.92 Kw

Motor horsepower equation

$$\boldsymbol{hp(motor) = \frac{Motor\ power}{745.7}} \quad \textbf{..(10)}$$

= 2.57 ≈ 3 hp

3.3 Electrical design

3.3.1 Electronic devices needed

A. Programmed Logic Control Unit (PLC)

Is an industrial digital computer that has been ruggedized and adapted for the control of manufacturing processes, such as assembly lines, robotic devices, or any activity that requires high reliability, ease of programming, and process fault diagnosis, or any activity requires high reliability.

Figure 14 Delta PLC (one of types of PLC)

B. Rotary encoder

Is an electro-mechanical device that converts the angular position or motion of a shaft or axle to analog or digital output signals,{2} which we can connect the rotary encoder with (PLC) to be able to adjust the number of revolutions of the motor.

Figure 15 Rotary encoder

C. Variable-frequency drive(V.F.D)

Is a type of motor drive used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage.{3} So we can connect it with main motor which Responsible for a two traction roller.

Figure 16 Variable frequency drive

Benefits of using (VFD)

1. Motor speed control.
2. Control of motor start and stop time.
3. Motor protection.

D. Touch screen (HMI)

A user interface or dashboard function is to connected person to a machine, system, or device.

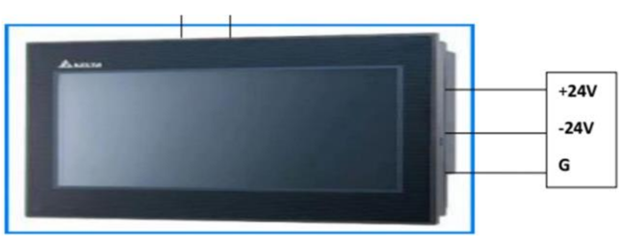


Figure 17 Touch screen (HMI)

3.3.2 Power and control circuits

A. Power circuit

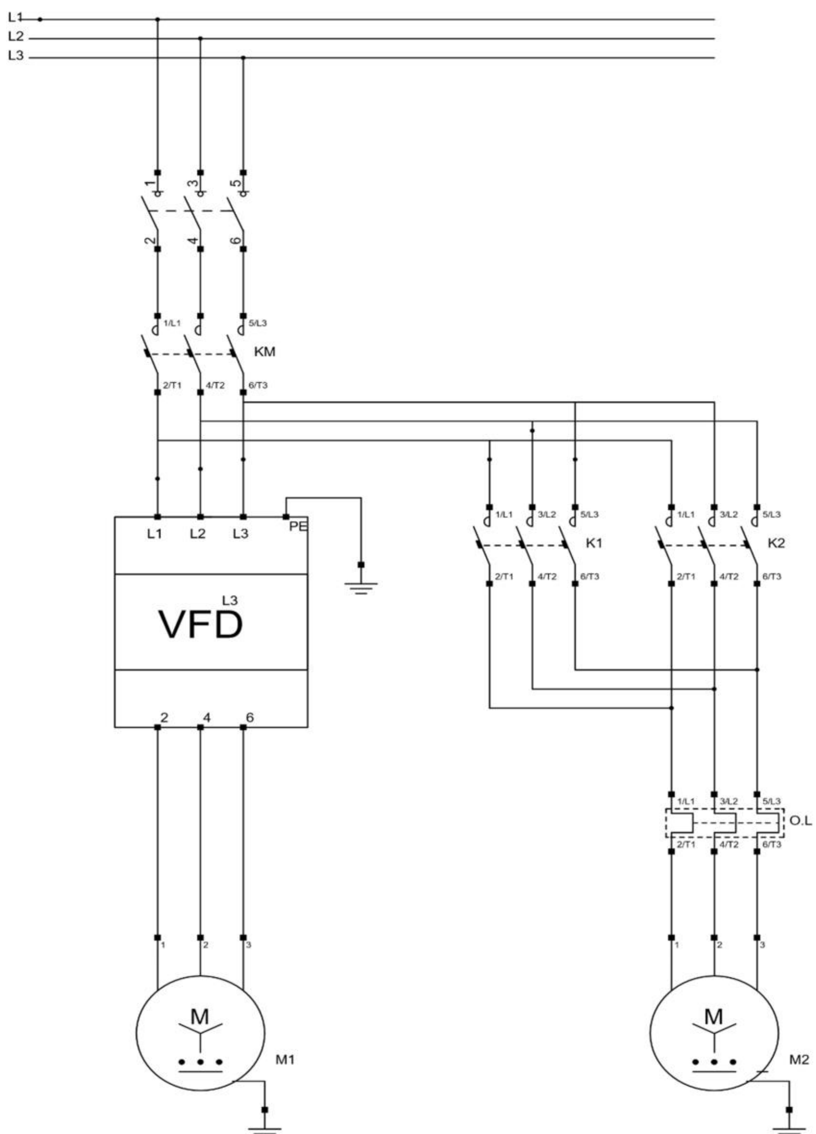


Figure 18 Power circuit design

Table4. Power circuit table

Symbols	Main function	Description
3 phase	3-phase feed source	L1,L2, L3
Circuit breaker	To protect the power circuit from high current	-----------
Km	Main contactor to operate the machine	----------
V.F.D	For motor speed control, and soft start	— 3 phase out —3 phase in
K1 & k2	Contactors to determine the direction of a secondary motor(CW or C.C.W)	-----------
M1	Main motor	-----------
M2	Secondary motor	-----------

B. Control circuit

The machine can be controlled manually or automatically, and both methods based on (PLC) so, the first control circuit describe the connection of PLC with Rotary encoders, touch screen(HMI) and manual control keypad as inputs, and four relays as an output whereas for each relay has a specific work.

***First control circuit**

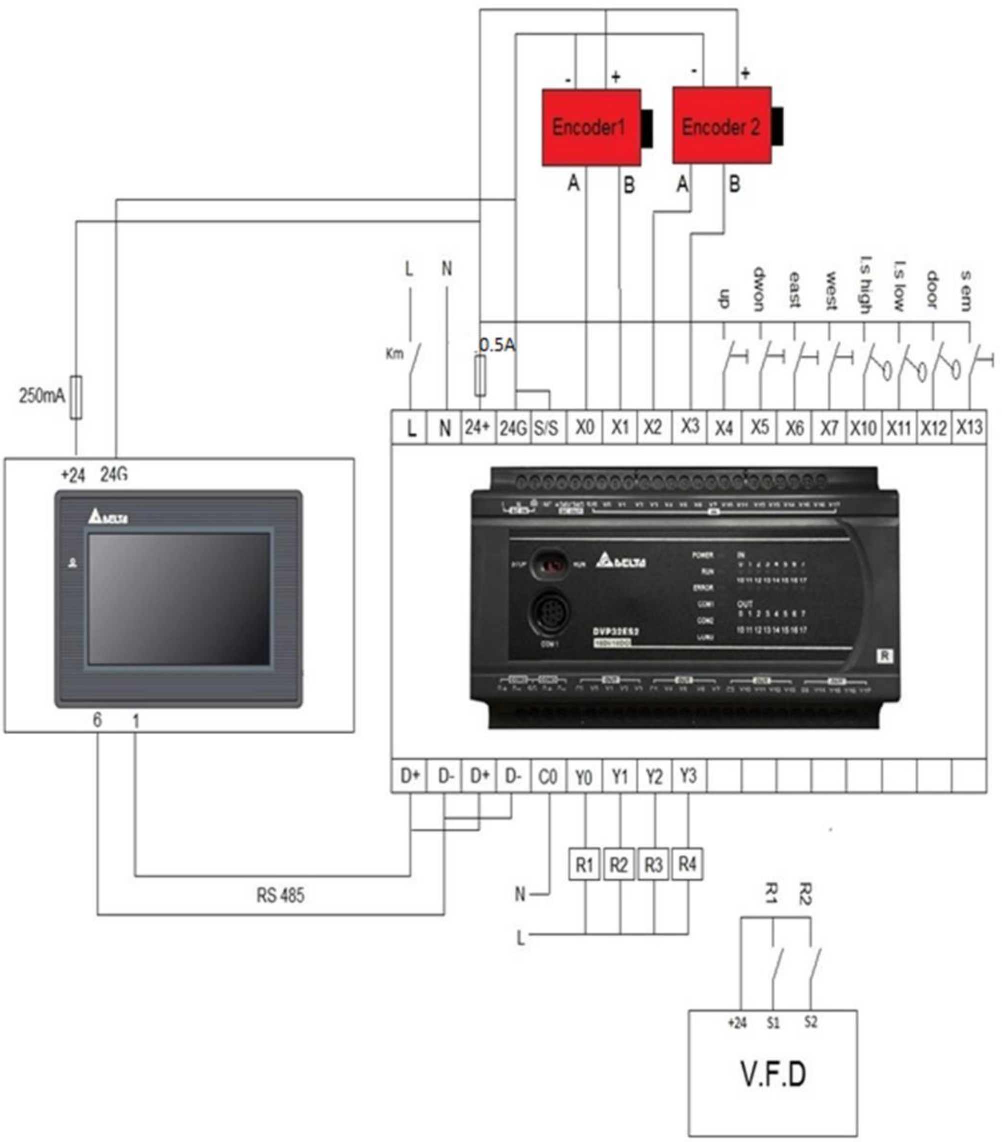


Figure 19 Automatic and manual control circuit design Part 1

***Second control circuit**

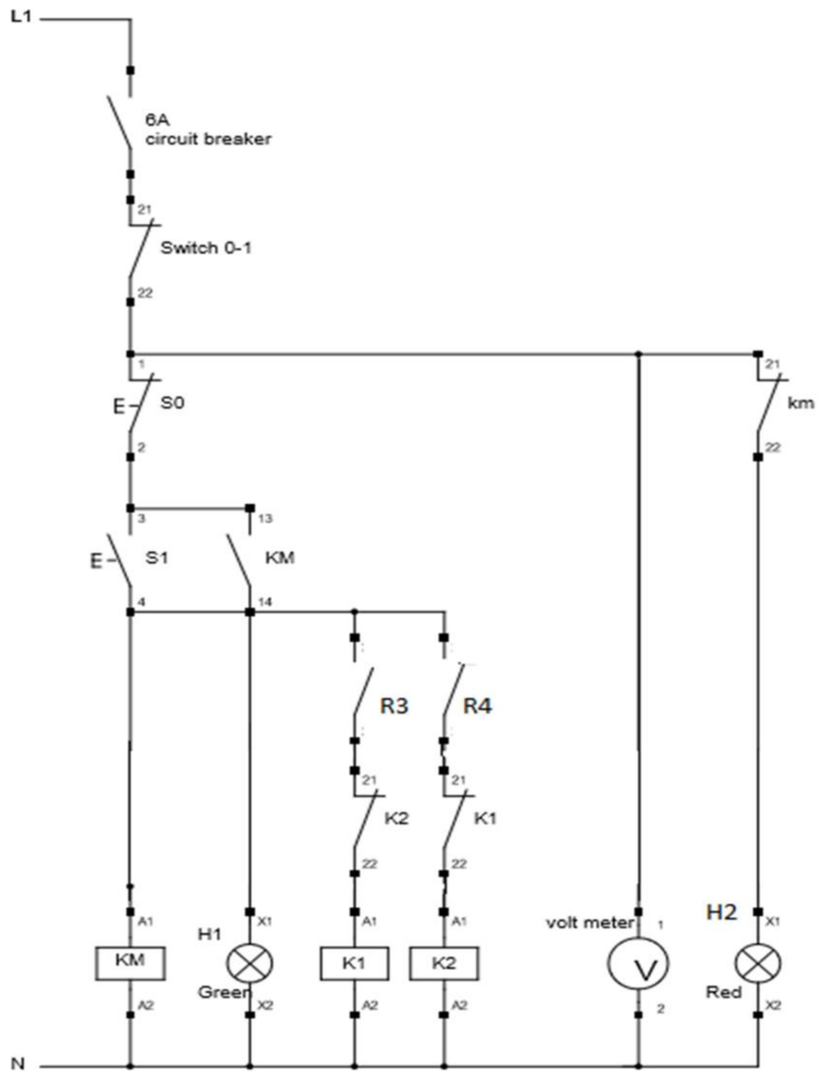


Figure 20 Automatic and manual control circuit design Part 2

Table5. Electrical circuit table

Symbols	Main function	Description
Circuit breaker	To protect the power circuit from high current	------------
S.S	Main switch	Select switch(1/0)
S0	To stop the machine	Push button (N.C)
S1	To activate the machine	Push button (N.O)
Encoder 1	connected with the screw to generate the pulses which send to the PLC	Rotary encoder
Encoder 2	connected with the Main motor spindle to generate the pulses which send to the PLC	Rotary encoder
HMI	interfacing tool between the user and PLC	Touch screen(HMI)
PLC	Used as a controller	Programmed Logic Control Unit
UP	To raise the upper roller	Push button(N.O)
Down	To take down the upper roller	Push button(N.O)
East	To drive the lower rollers forward	Push button(N.O)
West	To drive the lower rollers reverse	Push button(N.O)
Safety cover	Box on the upper motor for protection	Limit switch(N.C)
S. Emergency	For emergency	Limit switch(N.C)
R1 , R2	To control in the rotate direction of the main motor	Relays
R3 , R4	To control in the rotate direction of the secondary motor	Relays

Chapter four

Implementation and testing

4.1 Mechanical assembling.

4.2 Electrical wiring.

4.3 The Algorithm.

4.4 Programming.

4.5 Testing and results.

4.6 Recommendations.

4.7 Conclusion.

4.1 Mechanical assembling.

For this project, we designed a place for the electrical panel, HMI touch screen and set the calibration motor in his place at the bottom of the machine, that because of the mass of the motor is large, as it is preferable to place it at the bottom of the machine to make the center of gravity approximately at the bottom of the machine, which increases its stability.

Figure 21 final view machine design

4.2 Electrical wiring.

4.2.1 Electrical panel

We have implemented the power and electrical circuits in the electrical panel, and then put them in its place on the machine -see fig (17, 18, and 19) -.

Fig 22 electrical panel assembly

4.2.1 HMI with PLC interfacing, and HMI wiring

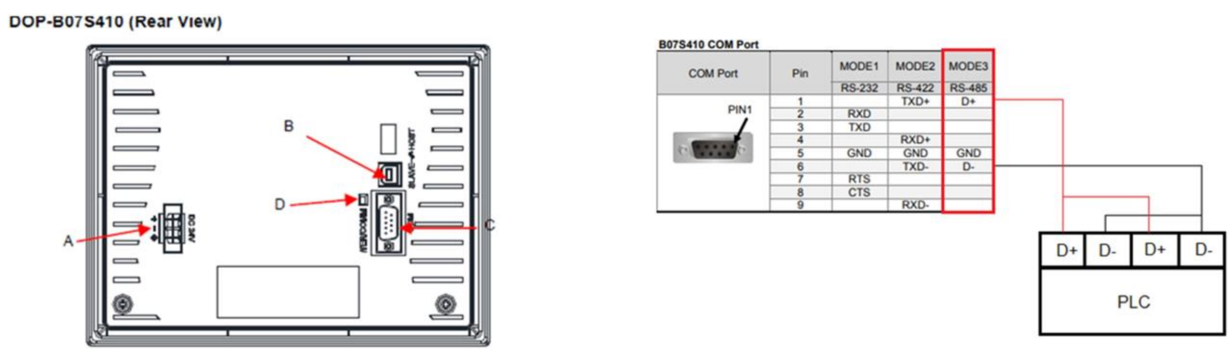


Fig 23 HMI with PLC wiring diagram

Such that:

A: Electrical feeding port (24V DC)

C: To Connect the HMI with the PLC

B: For programming wire (Connects with PC)

4.3 The algorithms

4.3.1 Algorithm path

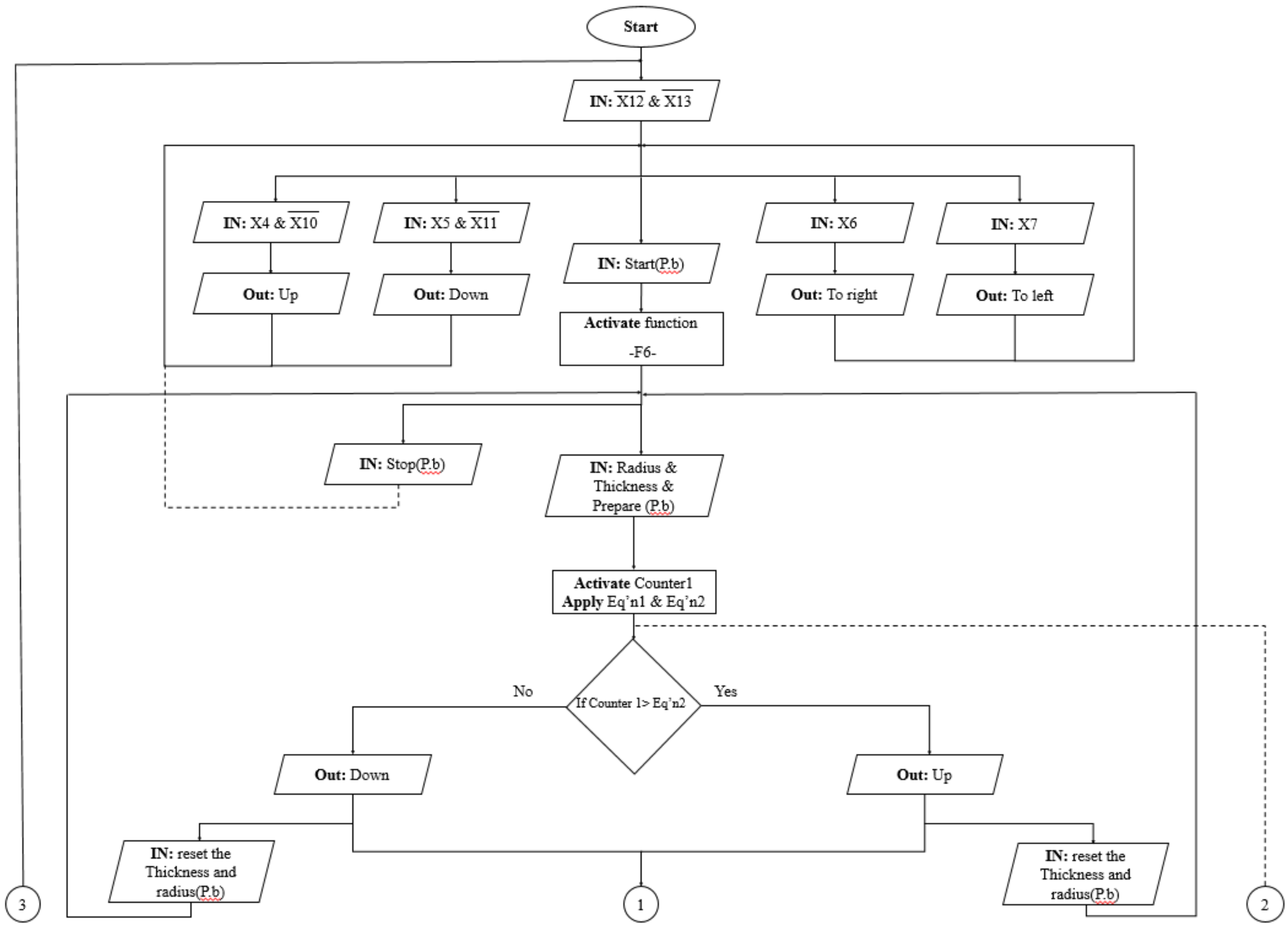


Figure 24 Main flowchart part 1

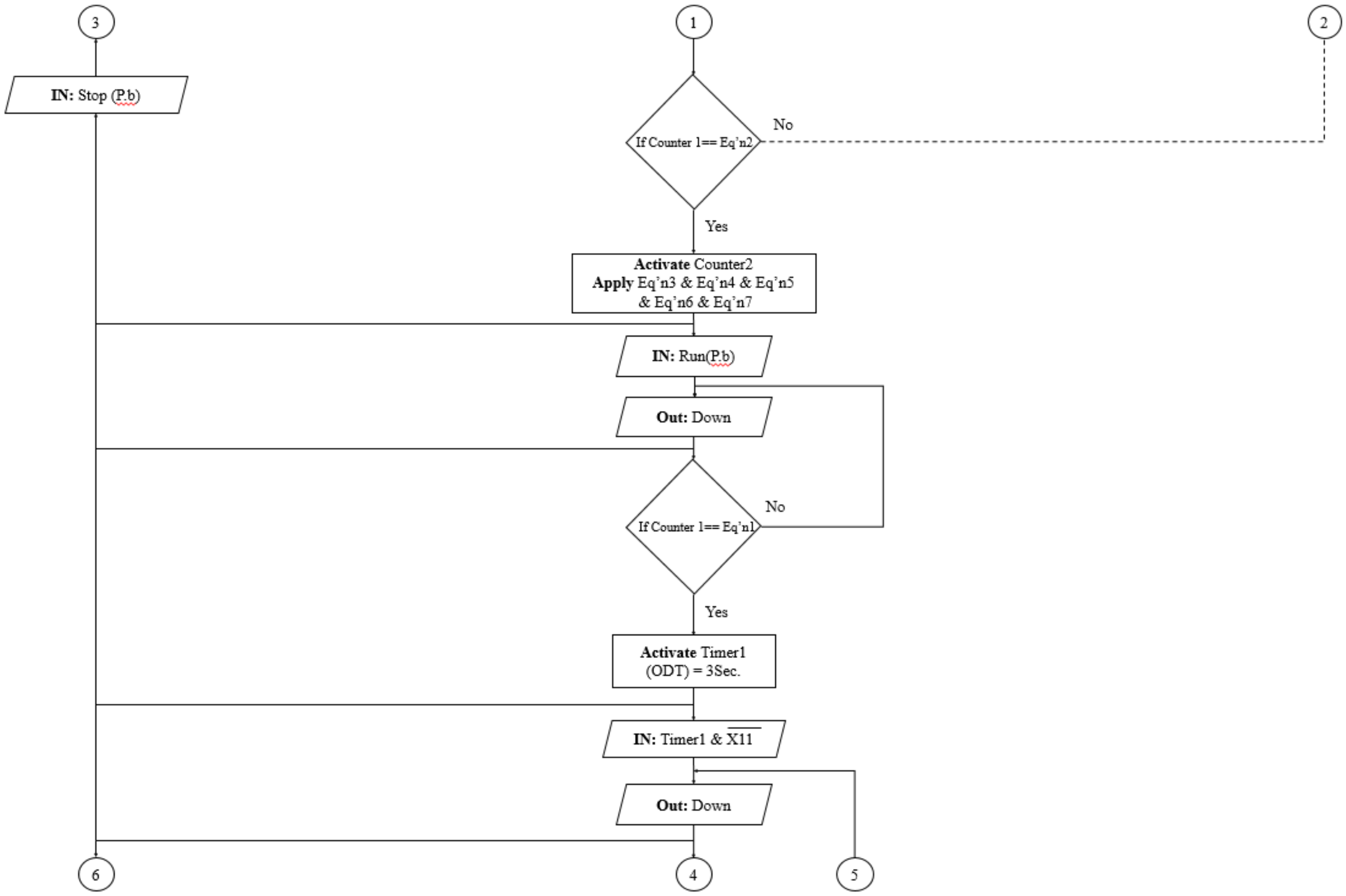


Figure 24 Main flowchart part 2

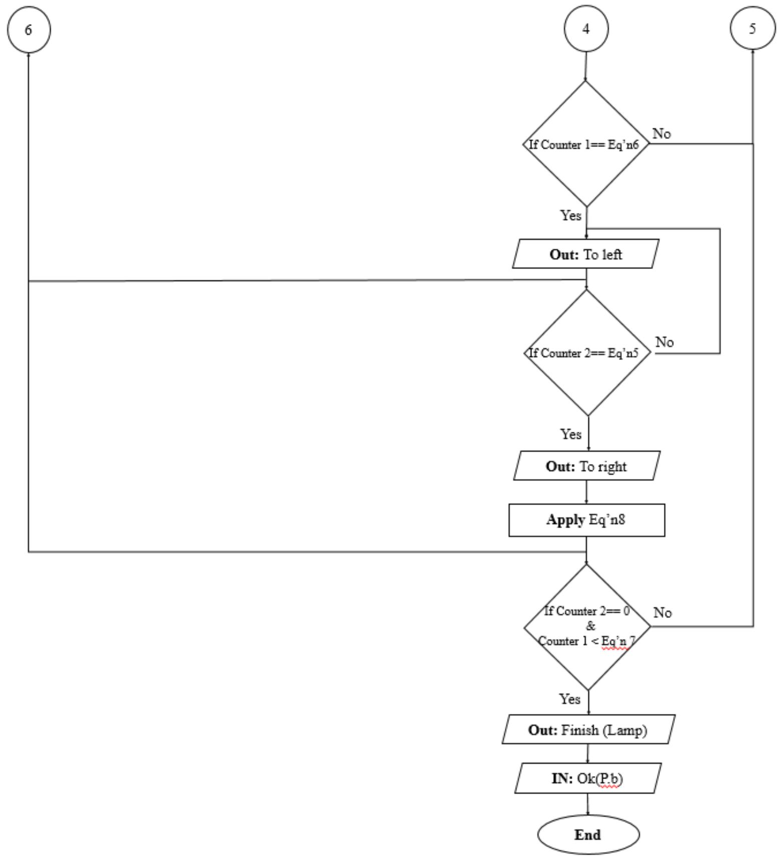


Figure 24 Main flowchart part 3

The symbols are as the following:

X4 ⟶ Up (Push button)

X5 ⟶ Down (Push button)

X6 ⟶ To right (Push button)

X7 ⟶ To left (Push button)

X10 ⟶ Highest level (Limit switch)

X11 ⟶ Lowest level (Limit switch)

X12 ⟶ Cover (Limit switch)

X13 ⟶ Emergency

4.3.2 The sequential function chart

The sequential function chart (SFC) is a geometric design applying as a preparation for the control system programming process for programmable logic controllers (PLCs) using ladder language.

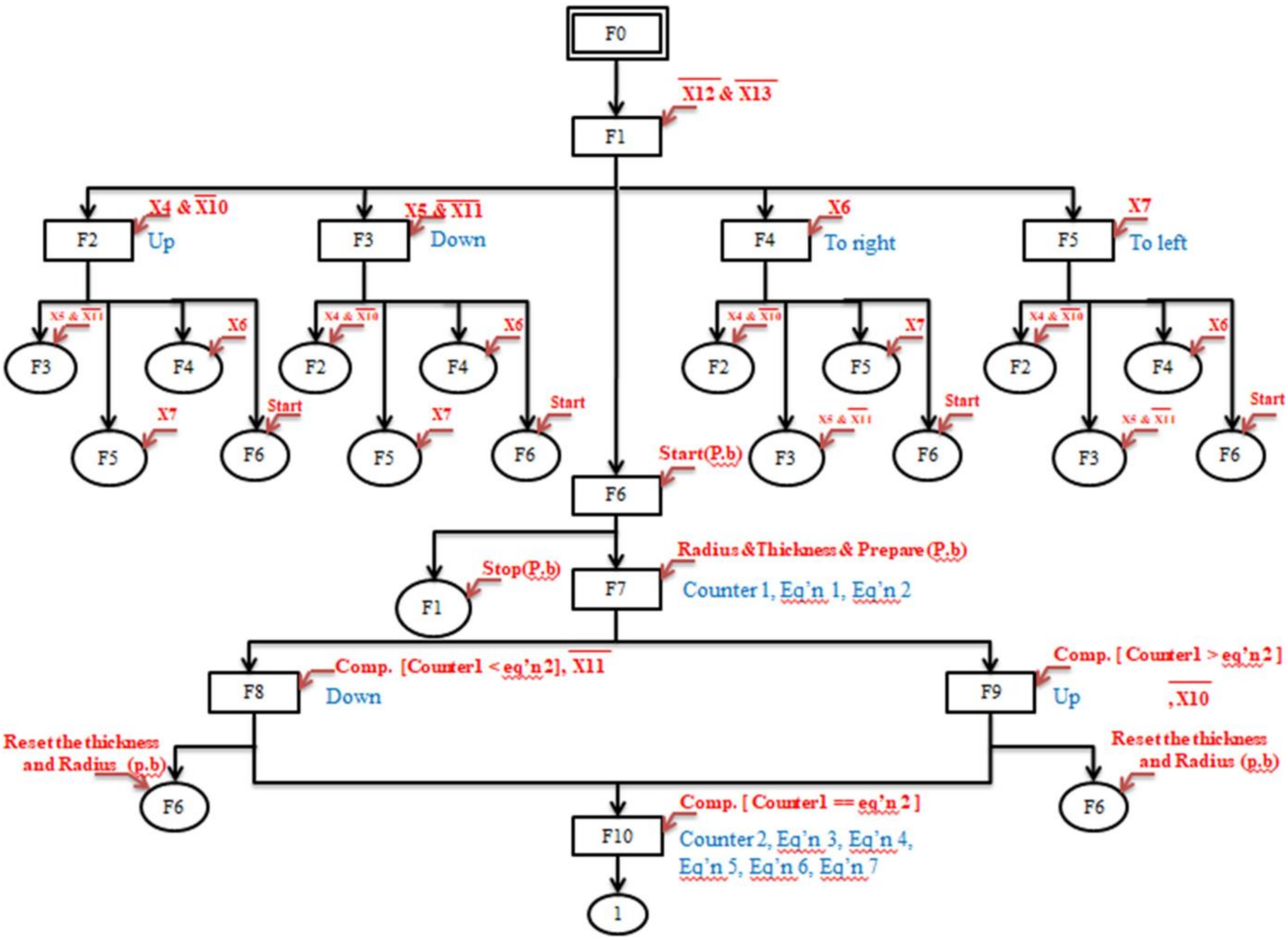


Figure 25 SFC flowchart part 1

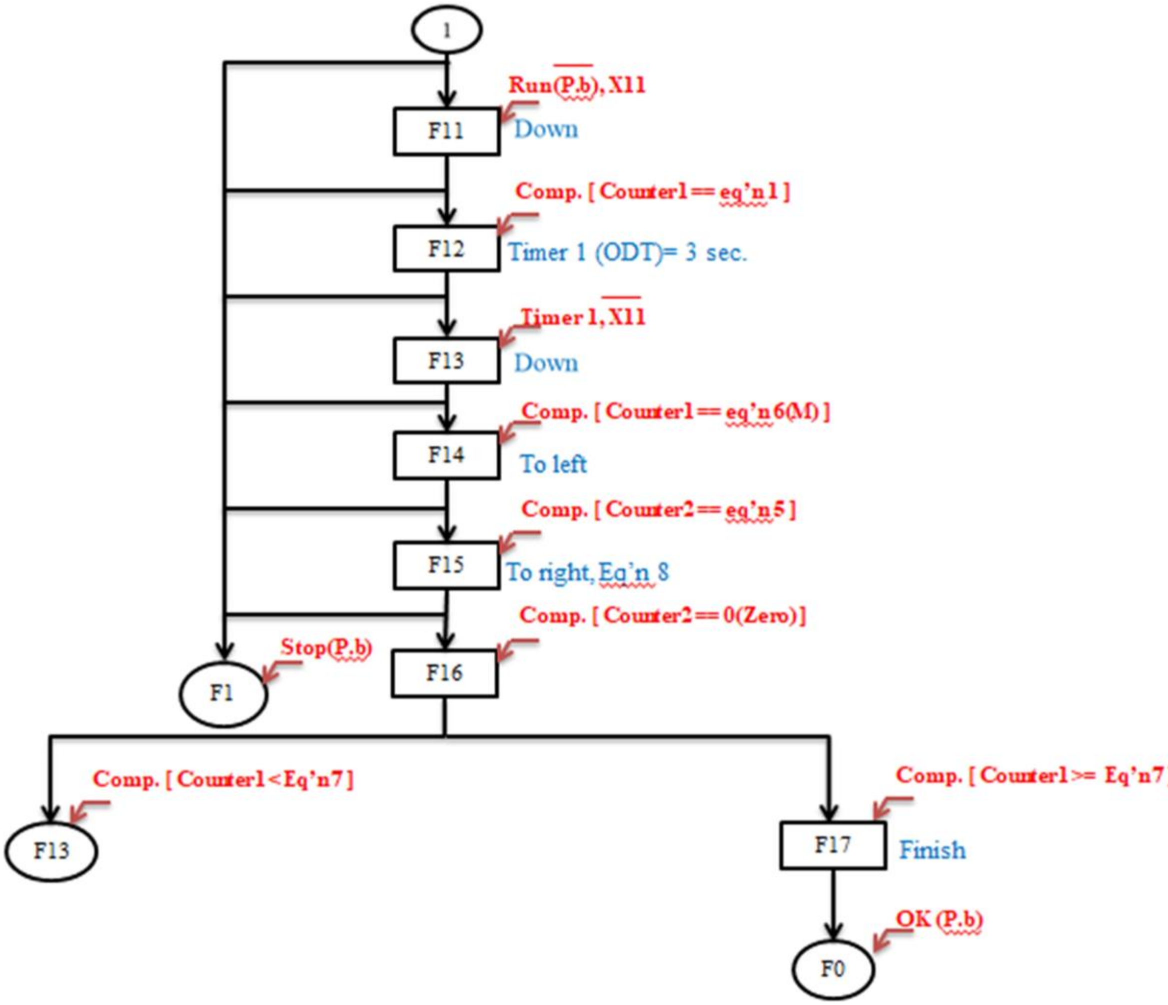


Figure 25 SFC flowchart part 2

Note: The SFC flowchart have the same symbols –See page 36-

The equations which we used in the programming process:

Eq'n1: $Is = [Rp + T]\, x - 1$

Where

Is: Initial step

Rp: Reference point = 1429 pulses.

T: Thickness of the piece (Cm).

Eq'n2: $Cs = Is + 5(cm) = Is + 7143 Pulses.$

Where

Cs: Calibration step

Eq'n3: $Y^2 = R^2 + X^2$

Where

Y:The distance between center of circle and reference point.

R: Radius of circle.

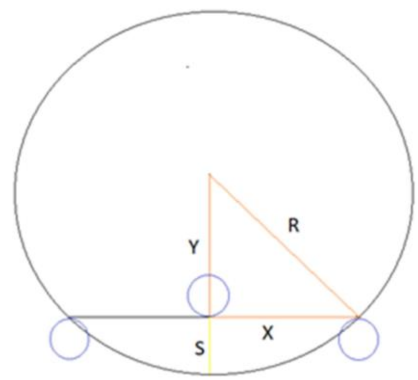


Figure 26 Mathematical description of the machine's work method

X=16.4(Cm): The half distance between supported points.

Eq'n4: $S = R - Y$

Where

S: Roller descent distance.

Eq'n5: $C = 2 * \pi * R$

Where

C: Circumference of the lower roller

Eq'n6: $M = Is + 0.1 * S$

Where

M: Is a cumulative value that depends on the value of (S) to make the roller go down 0.1 step for each revolution.

Eq'n7: $Ov = Is + S$

Where

Ov: The total descent distance of the roller relatively with reference point.

Eq'n8: $M = M + 0.1 * S$

4.4 Programming

4.4.1 PLC programming

We applied the (SFC) algorithm using ladder language by (WPLSoft) software that for ease of use it, and the ability to make any addition or Modification on it in the future.

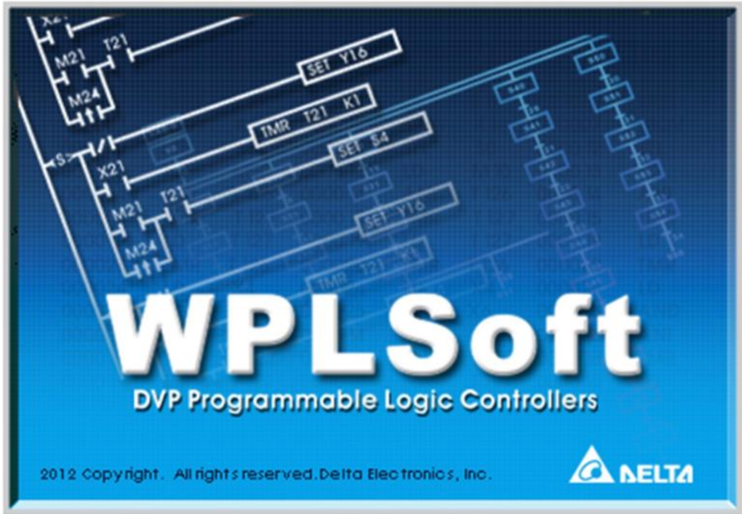


Figure 27 WPLsoft software

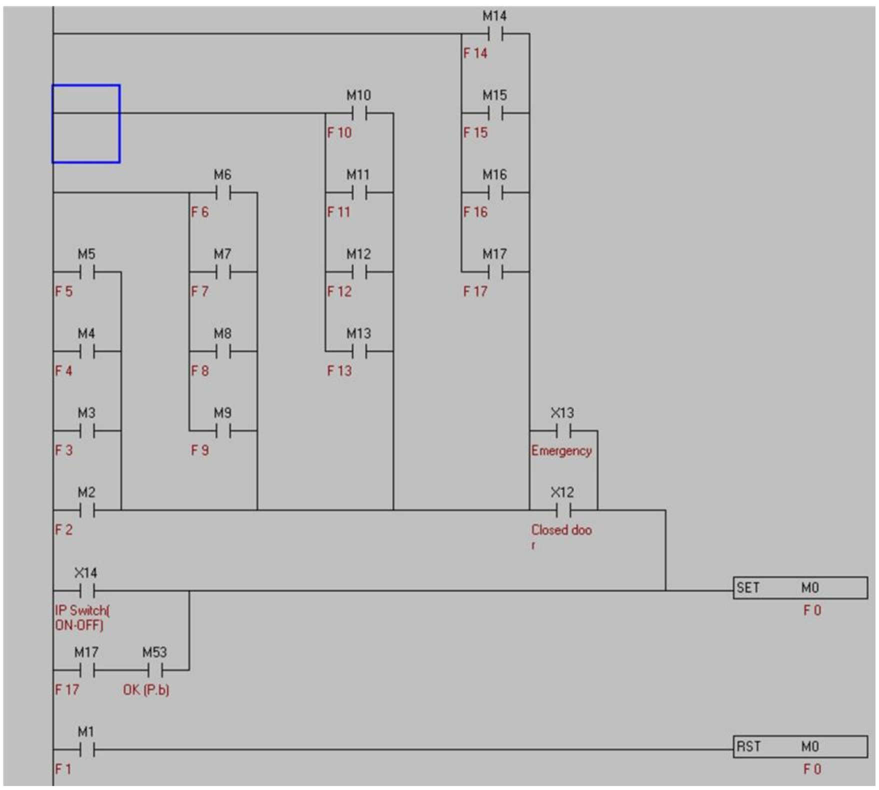


Figure 28 Ladder programing part 1

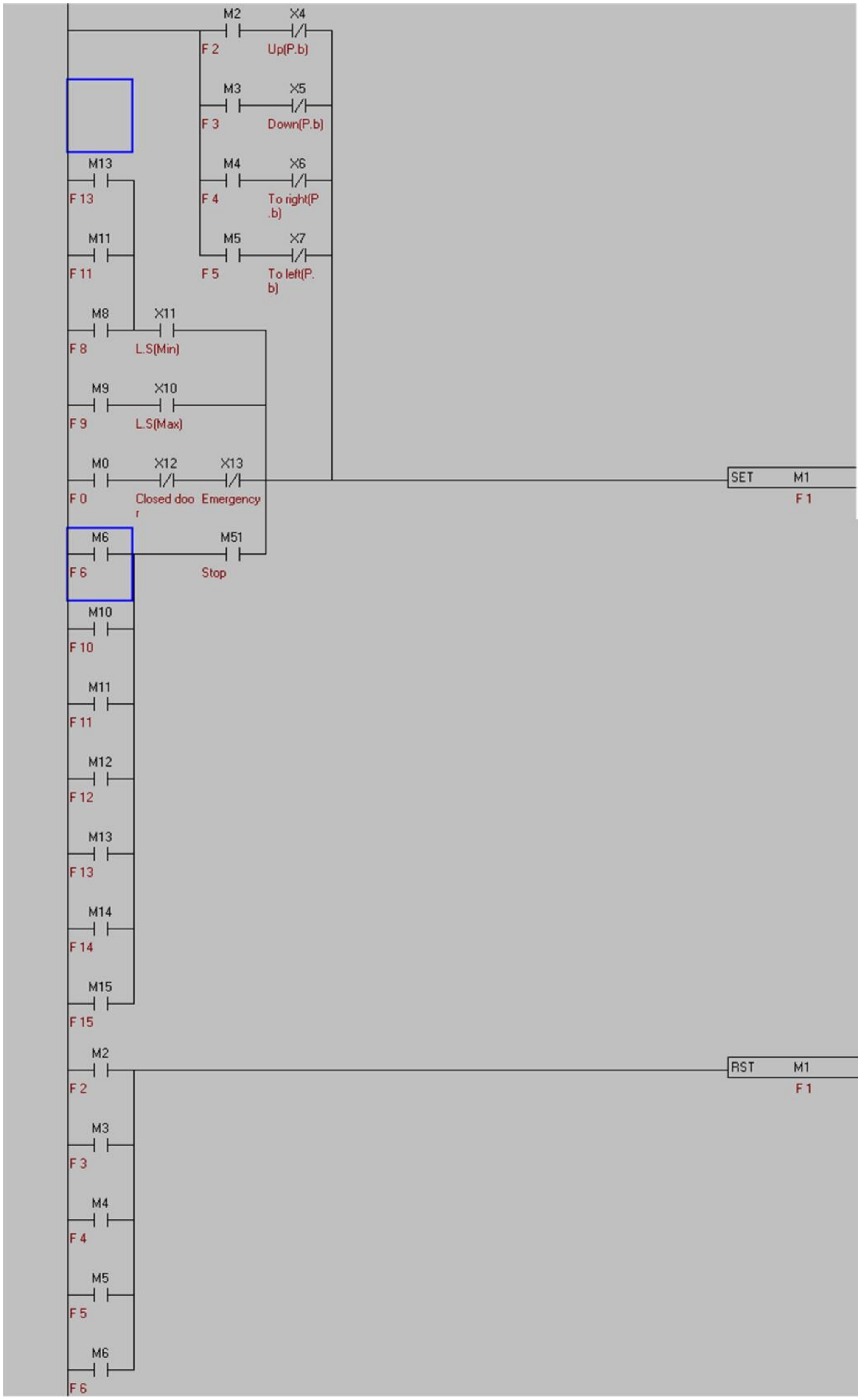


Figure 28 Ladder programing part2

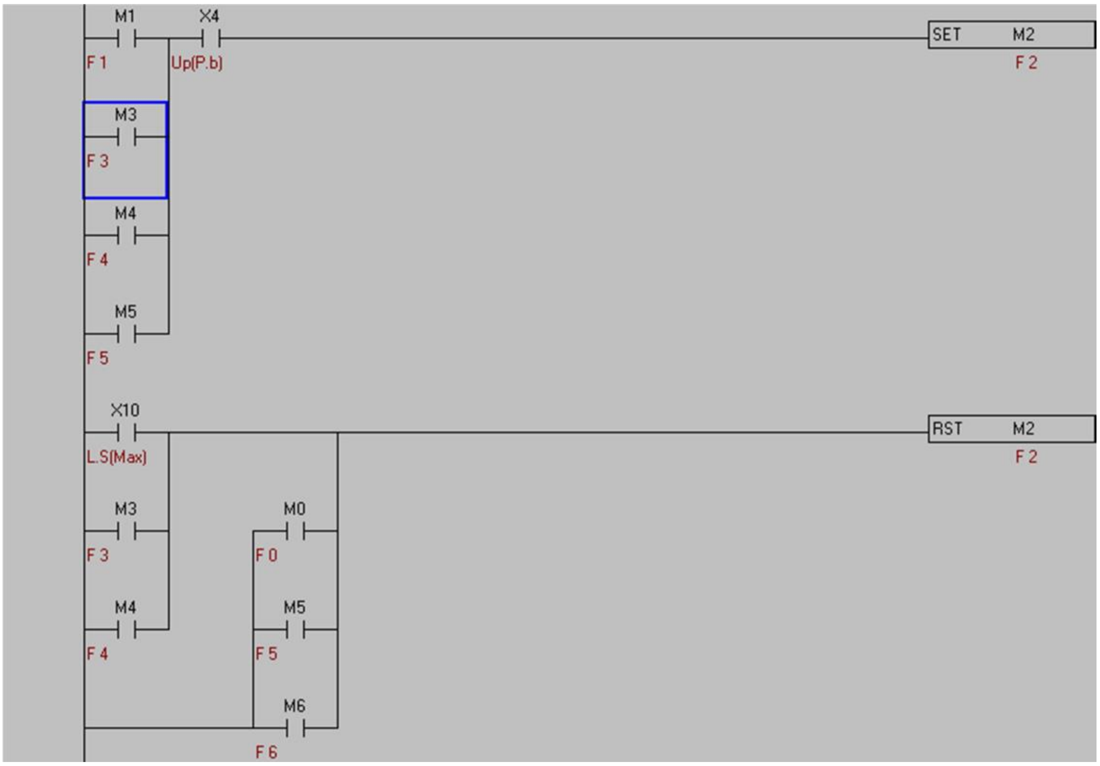


Figure 28 Ladder programing part3

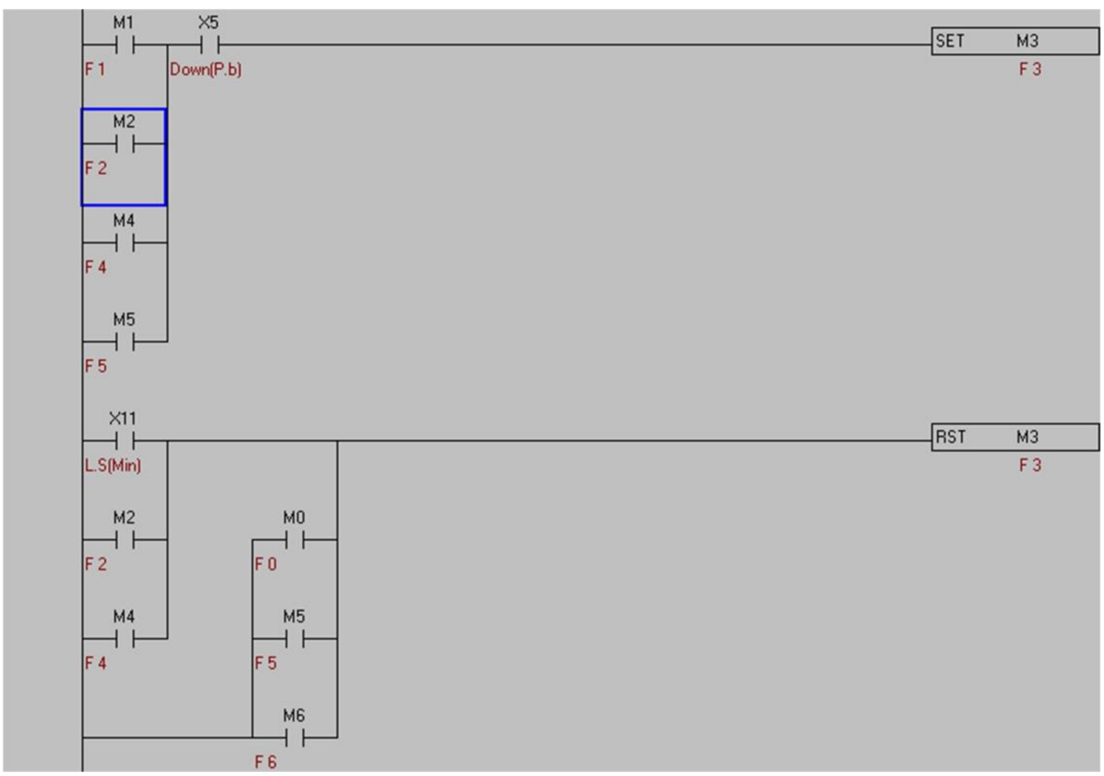


Figure 28 Ladder programing part 4

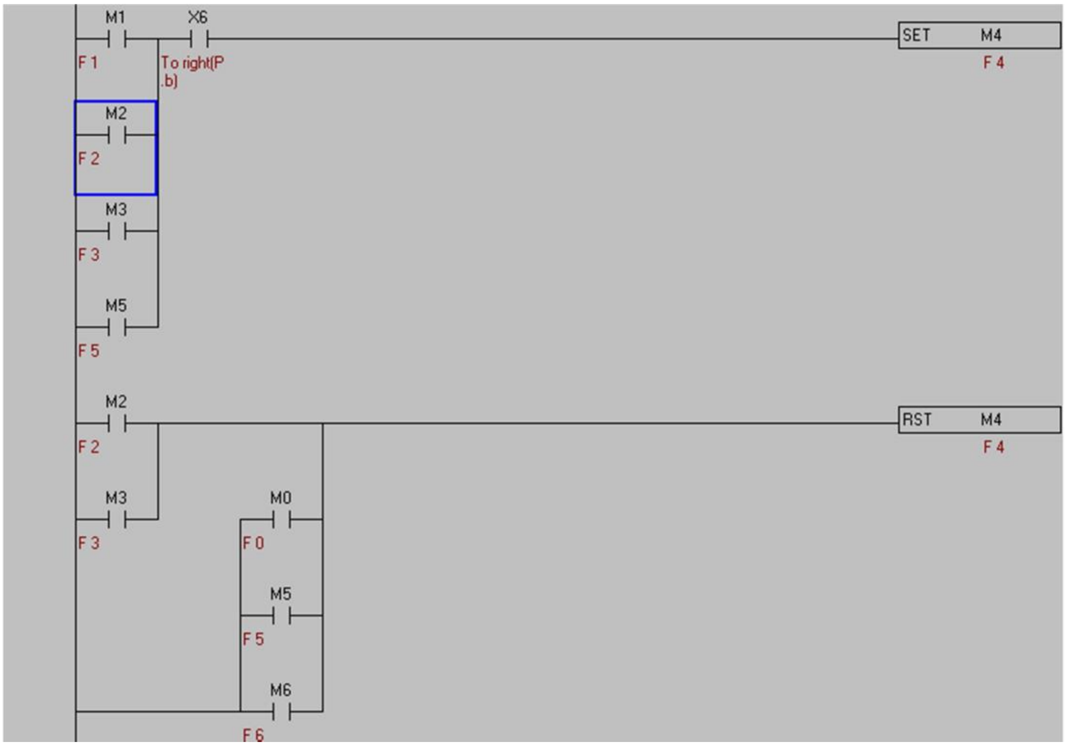


Figure 28 Ladder programing part 5

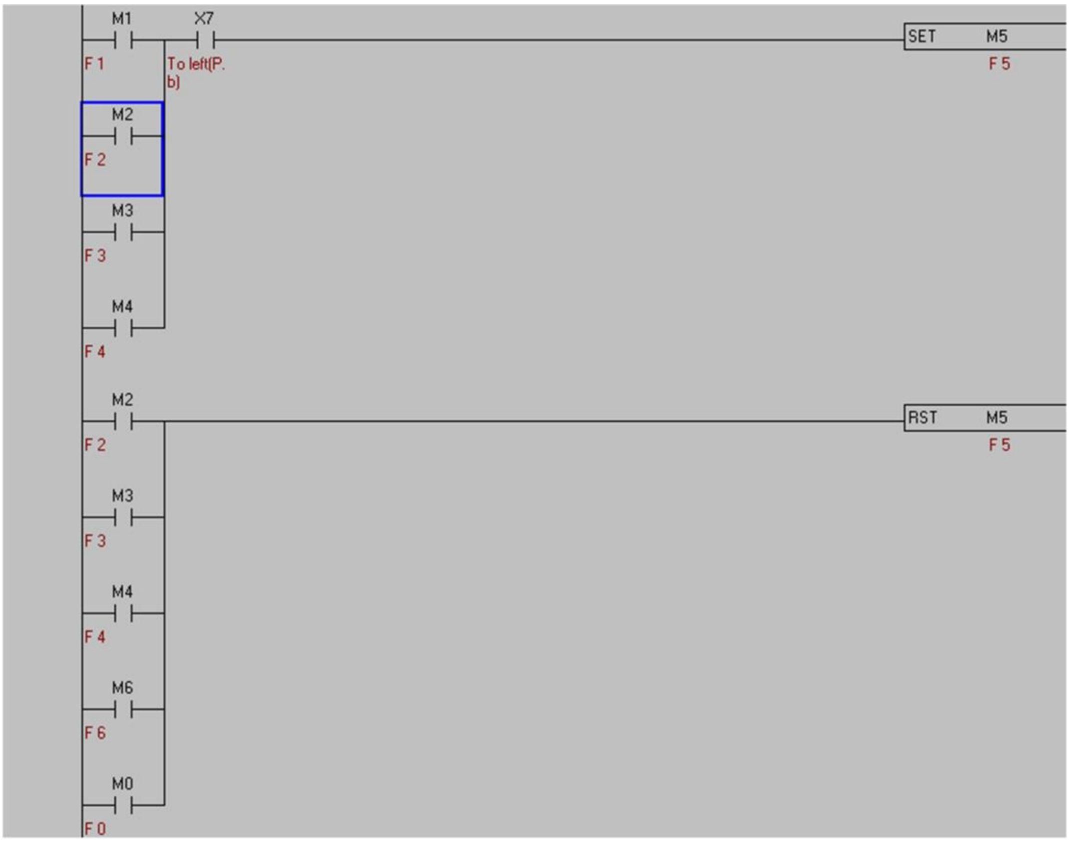


Figure 28 Ladder programing part 6

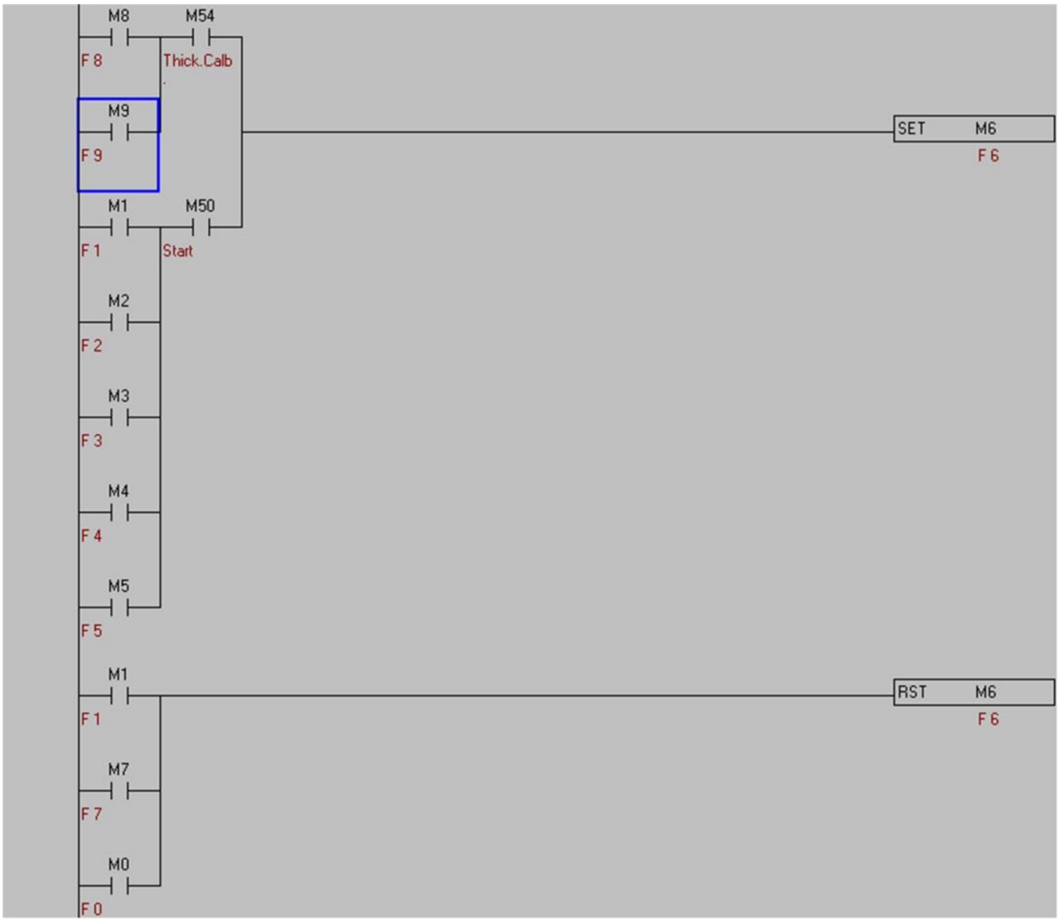


Figure 28 Ladder programing part 7

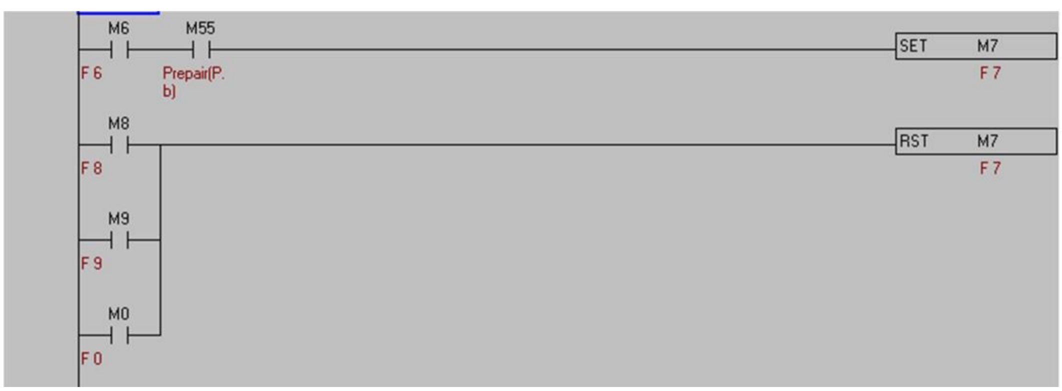


Figure 28 Ladder programing part 8

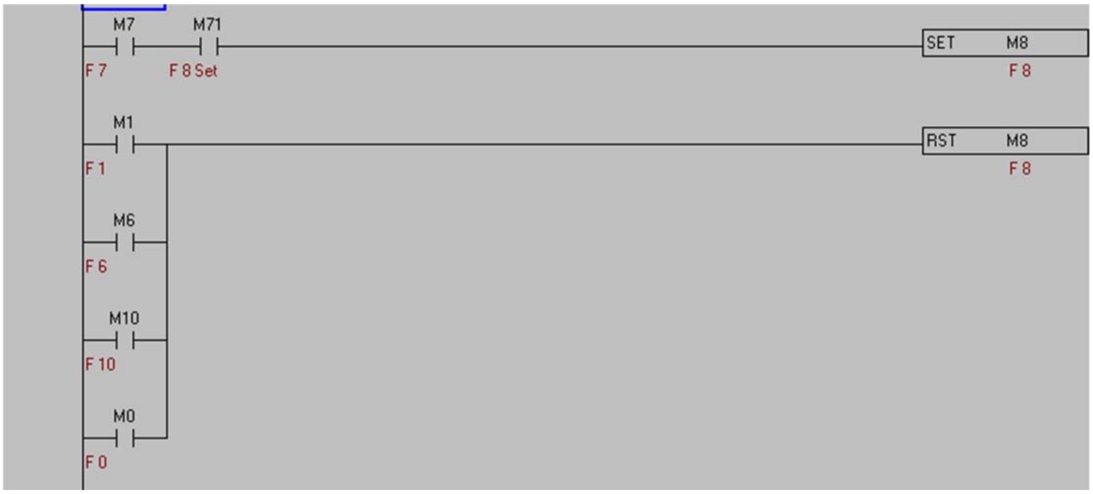


Figure 28 Ladder programing part 9

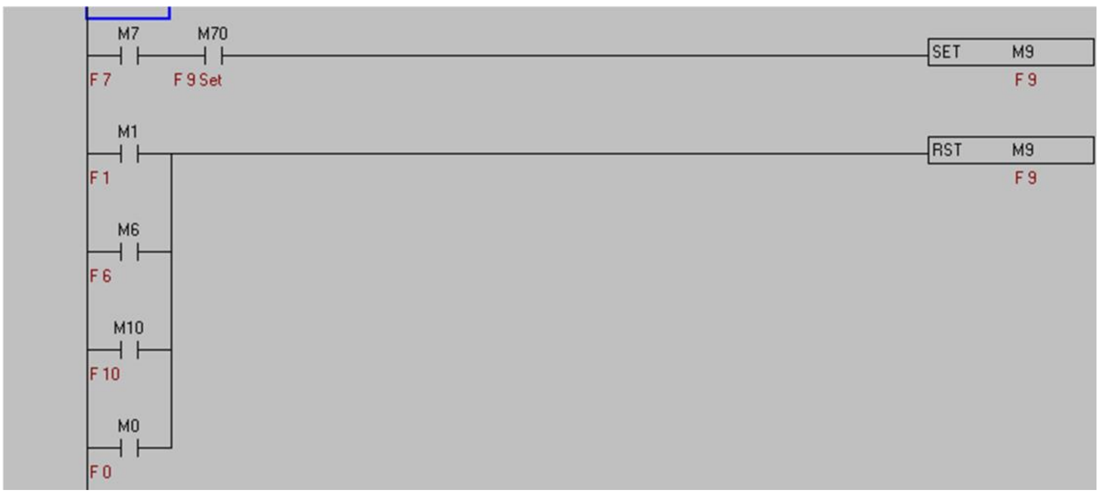


Figure 28 Ladder programing part 10

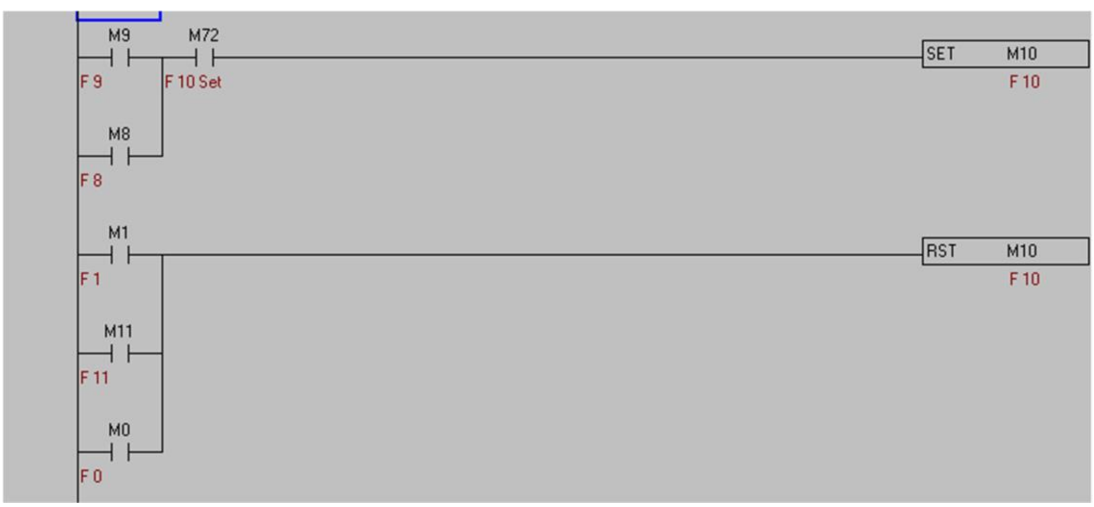


Figure 28 Ladder programing part 11

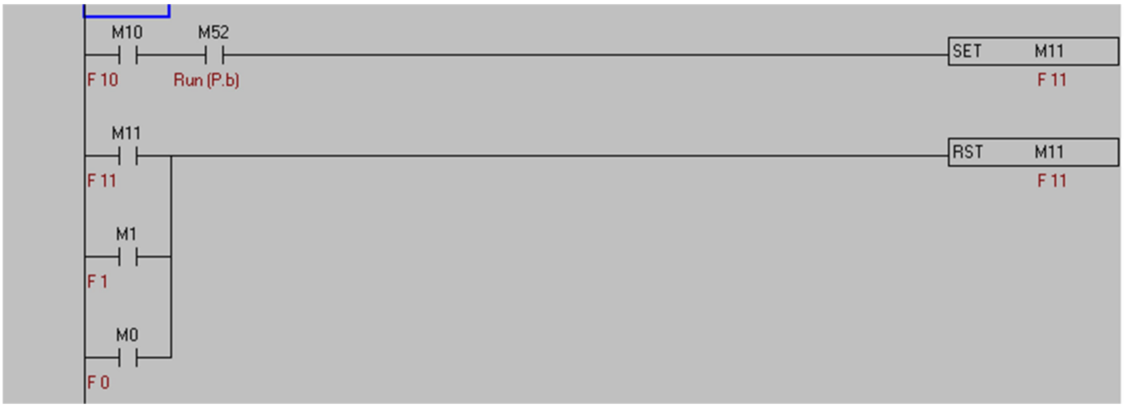


Figure 28 Ladder programing part 12

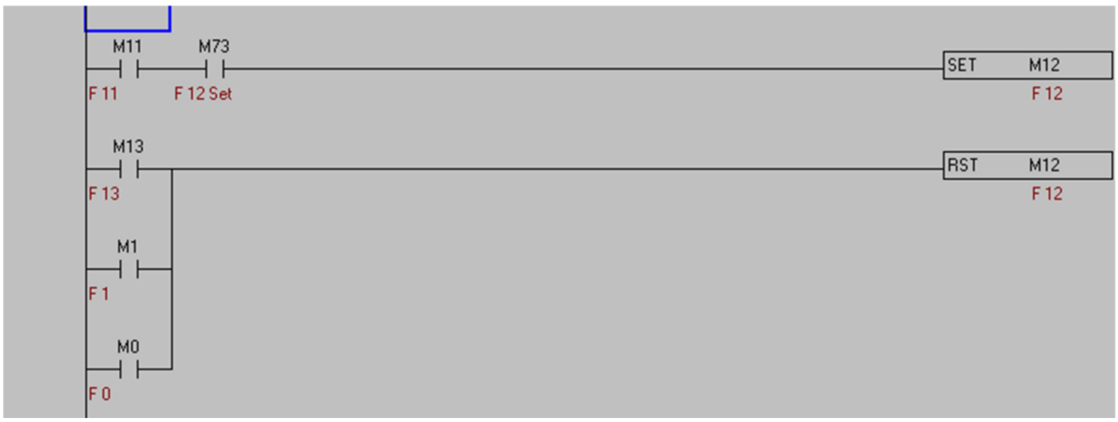


Figure 28 Ladder programing part 13

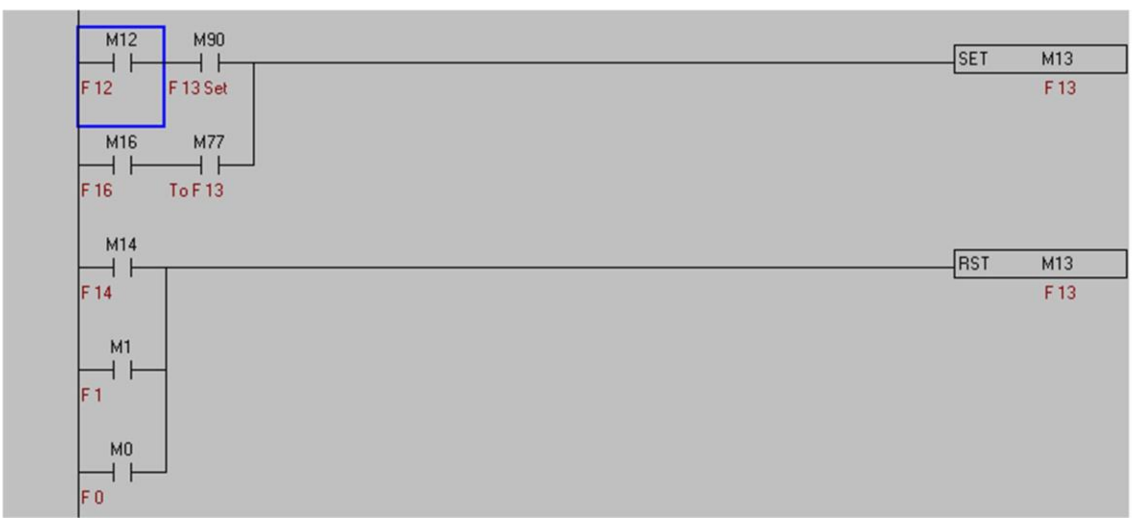


Figure 28 Ladder programing part 14

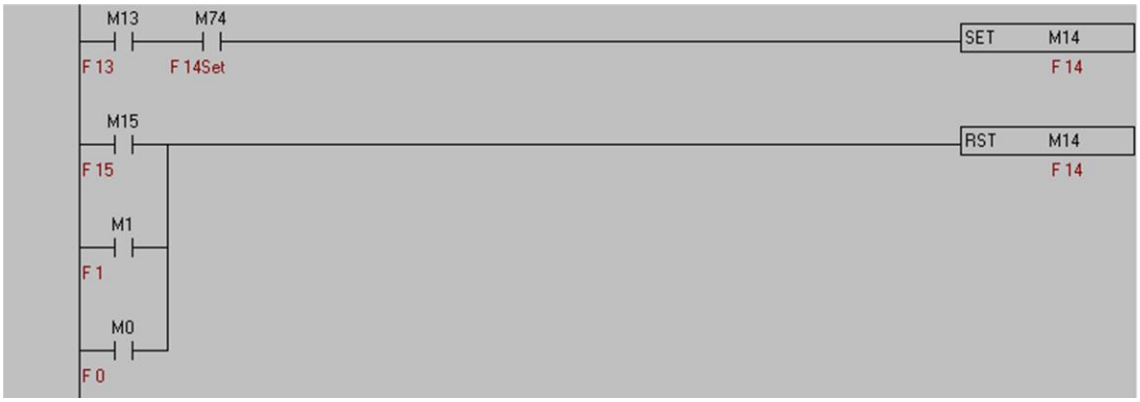


Figure 28 Ladder programing part 15

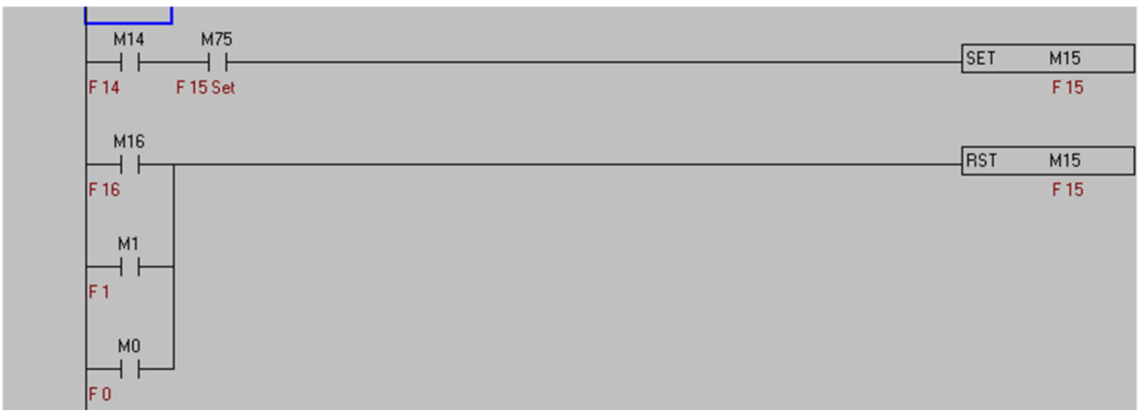


Figure 28 Ladder programing part 16

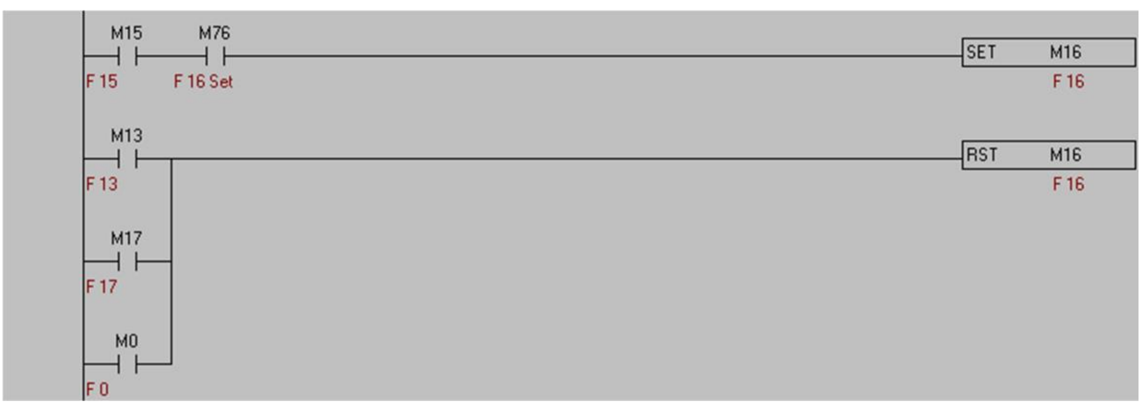


Figure 28 Ladder programing part 17

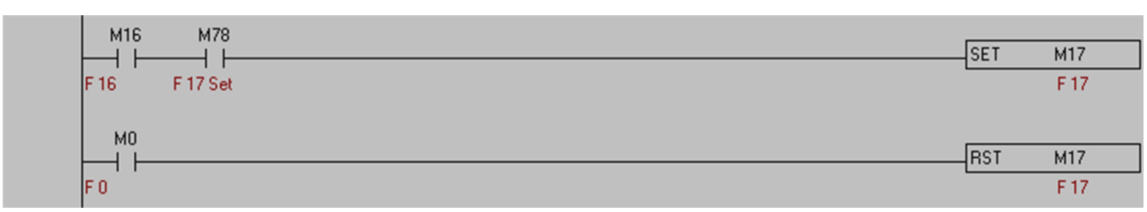


Figure 28 Ladder programing part 18

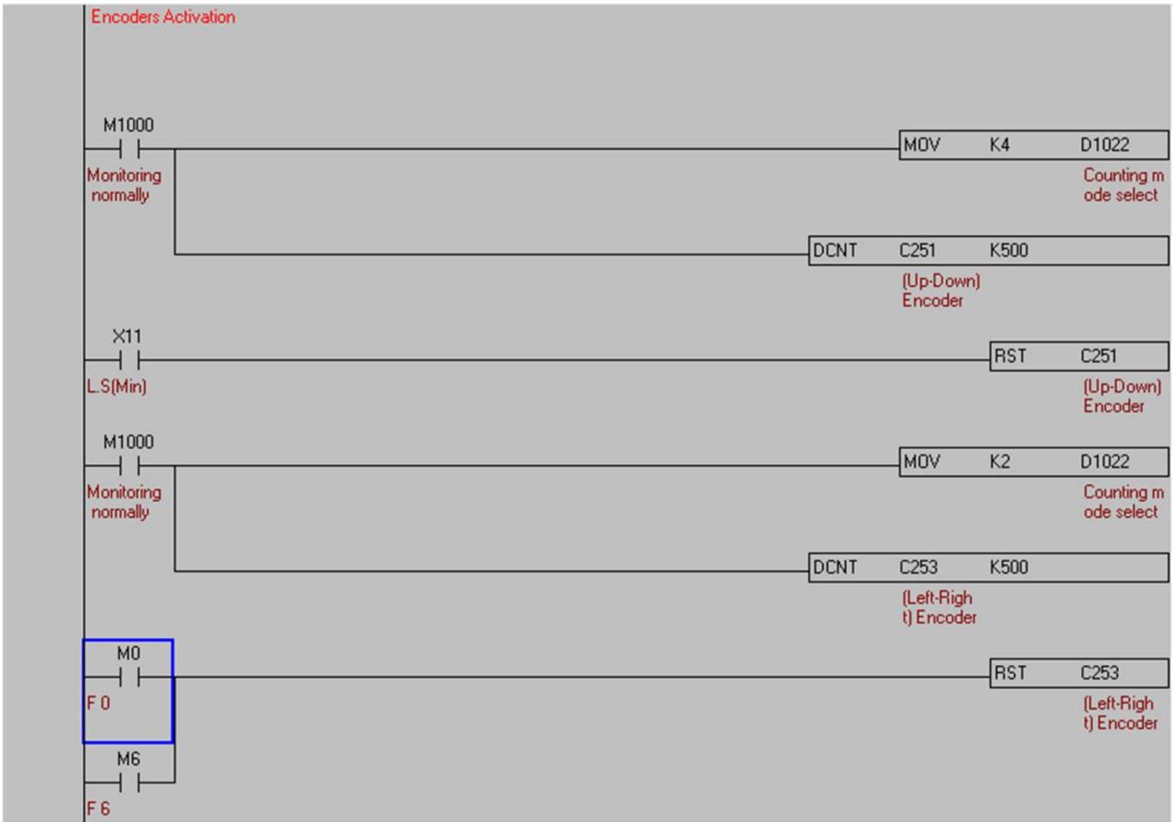


Figure 28 Ladder programing part 19

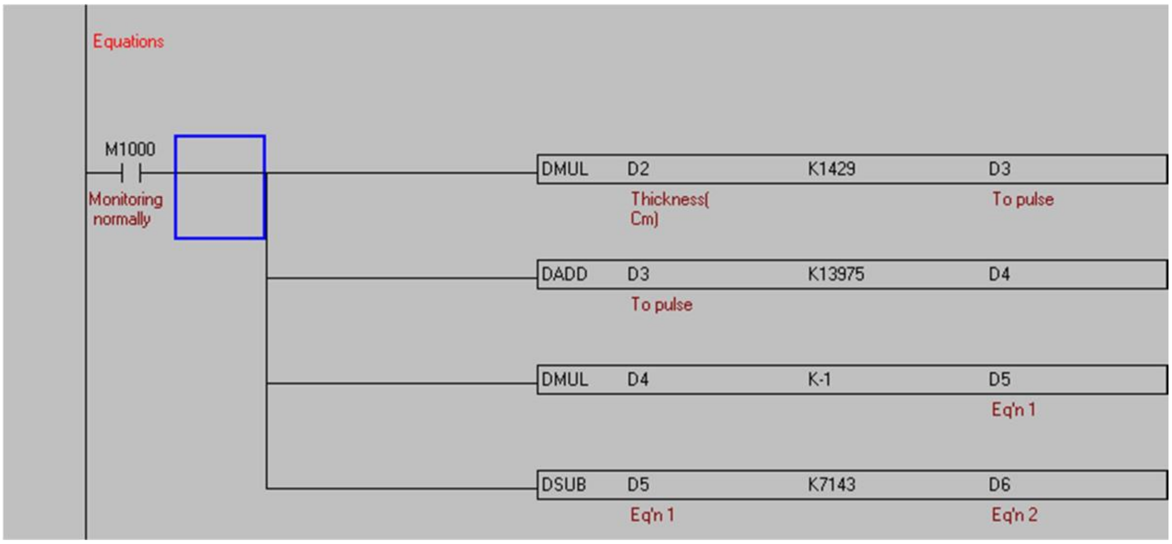


Figure 28 Ladder programing part 20

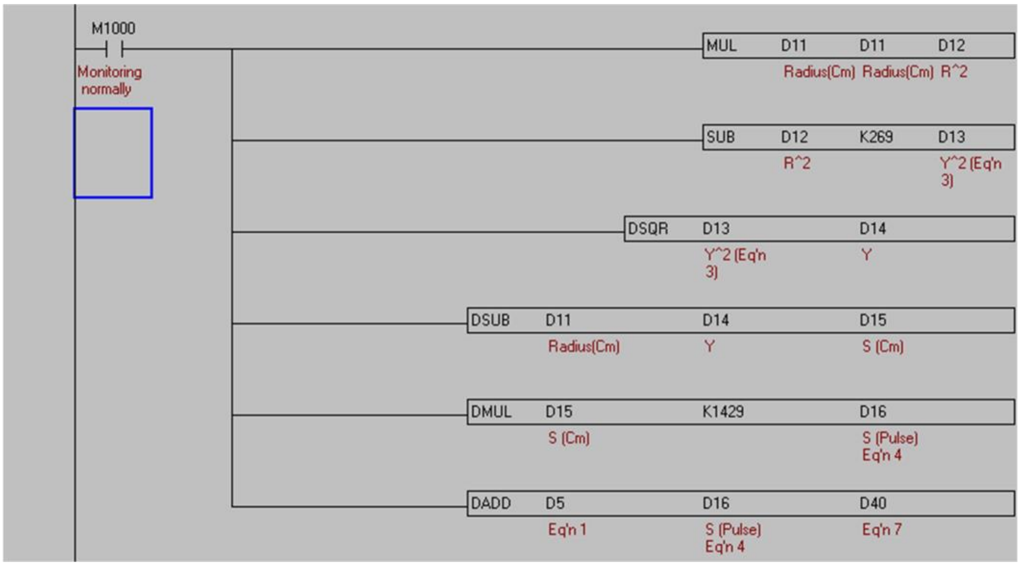


Figure 28 Ladder programing part 21

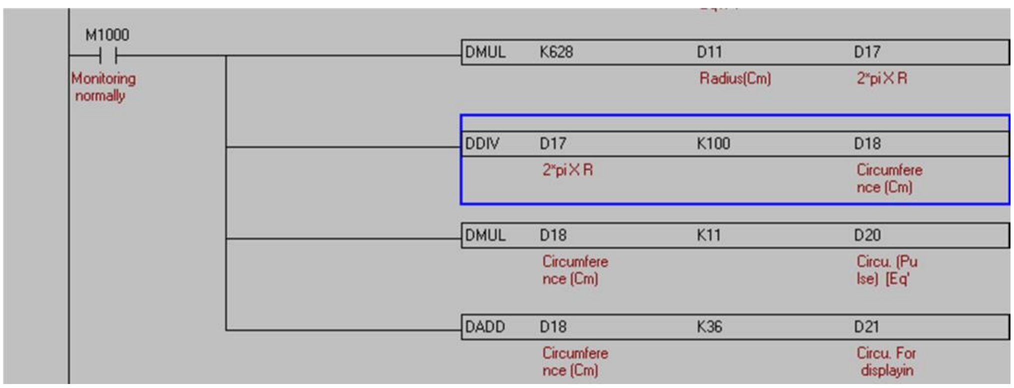


Figure 28 Ladder programing part 22

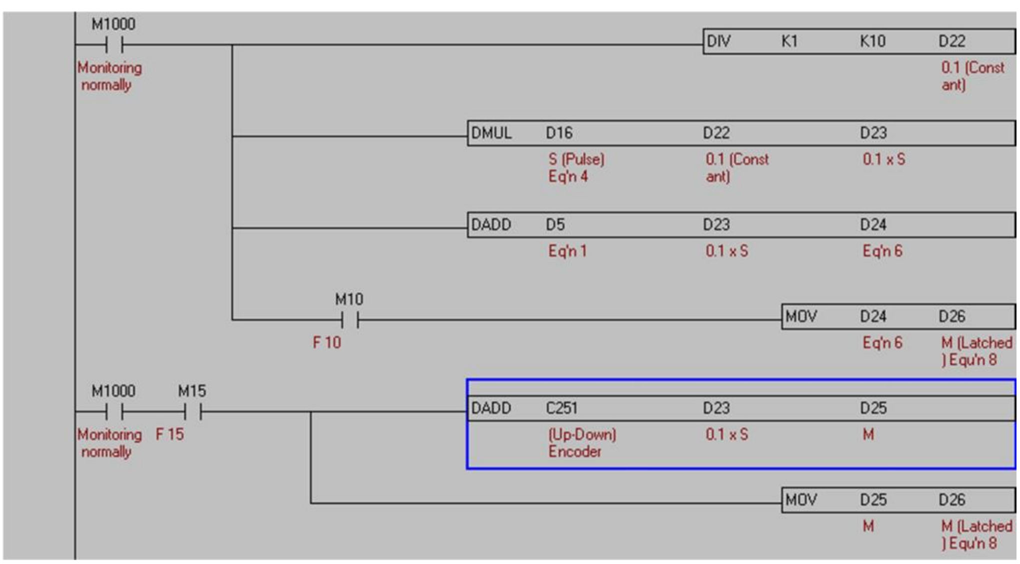


Figure 28 Ladder programing part 23

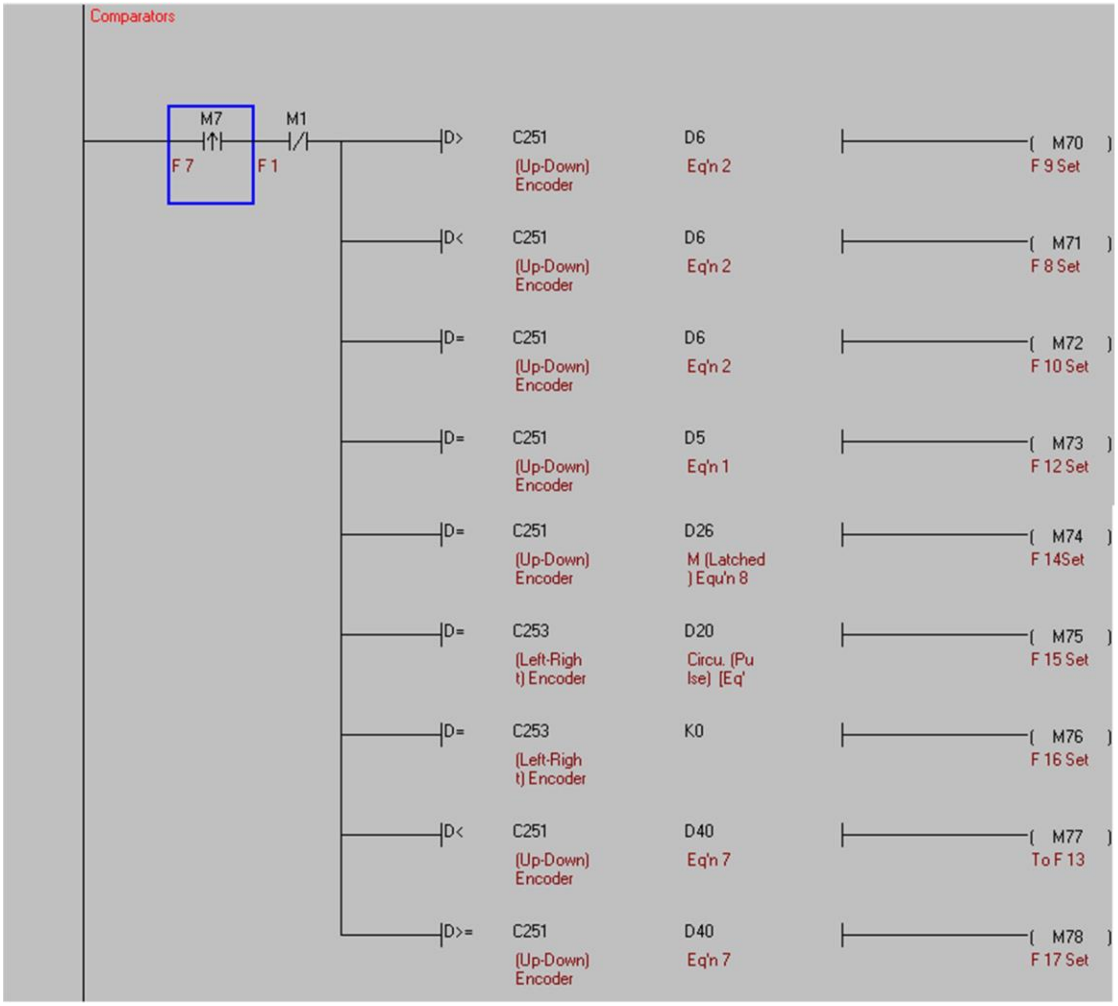


Figure 28 Ladder programing part 24

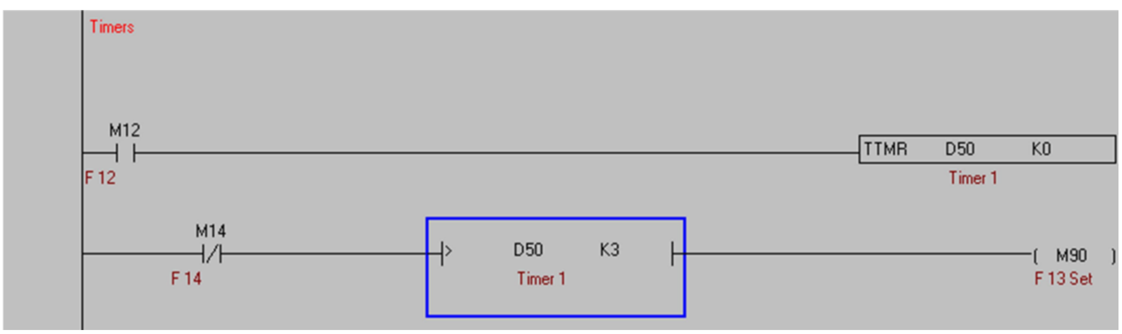


Figure 28 Ladder programing part 25

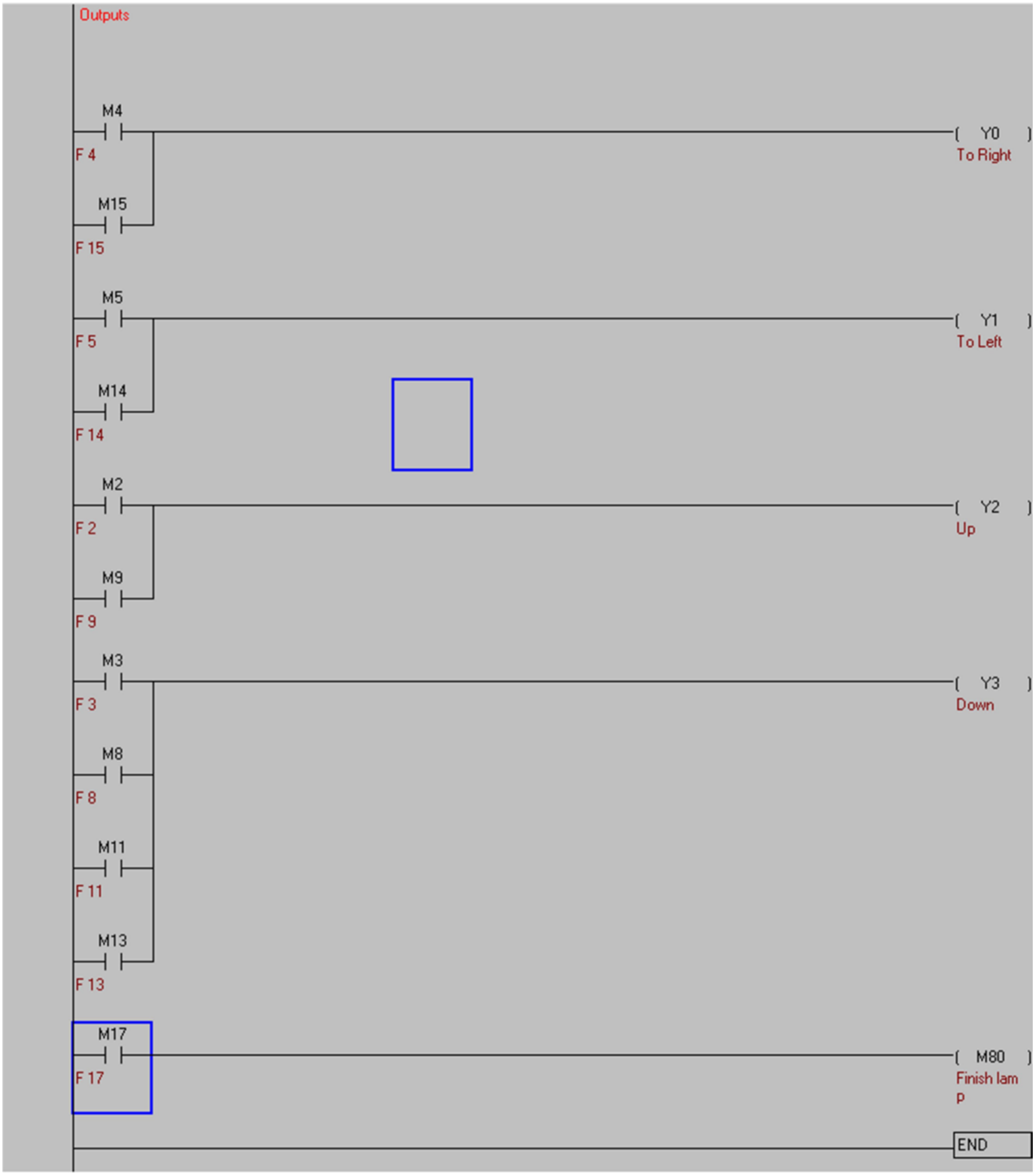


Figure 28 Ladder programing part 26

Description of the required equations to convert the displacement values which they describe the motion of the machine from (cm) scale to pulses

(Up-Down) motion equation:

$$\boldsymbol{P = \frac{X\ x\ N}{Tp}}$$

Where

P: Number of pulses.

X: Distance (Cm).

N: The number of encoder pulses per revolution.

Tp: Thread pitches (Cm).

From the previous equation, the conversion of 1(Cm) to pulses

$$P = \frac{1(Cm)x\ 500}{0.35} = 1428.6 \ \approx 1429\ Pulses$$

$$RE(P)\% = \frac{1429 - 1428.6}{1429}\ x\ 100\%$$

$$= 0.028\%$$

(To left-To right) motion equation:

$$\boldsymbol{P = \frac{X\ x\ N}{C}}$$

Where

C= 2π x R. Circumference of the lower roller

From the previous equation, the conversion of 1(Cm) to pulses

$$P = \frac{1(Cm)x\ 500}{2\pi\ x\ 7.4(Cm)} = 10.75 \ \approx 11\ Pulses$$

$$\boldsymbol{RE(P)\% = \frac{11 - 10.75}{11}\ x\ 100\%} \quad \text{………....……….…………....…..(11)}$$

$$= 2.27\%$$

4.4.2 HMI programming

We used the (DOPSoft) software to program the delta HMI touch screen.

Figure 29 DOPSoft software

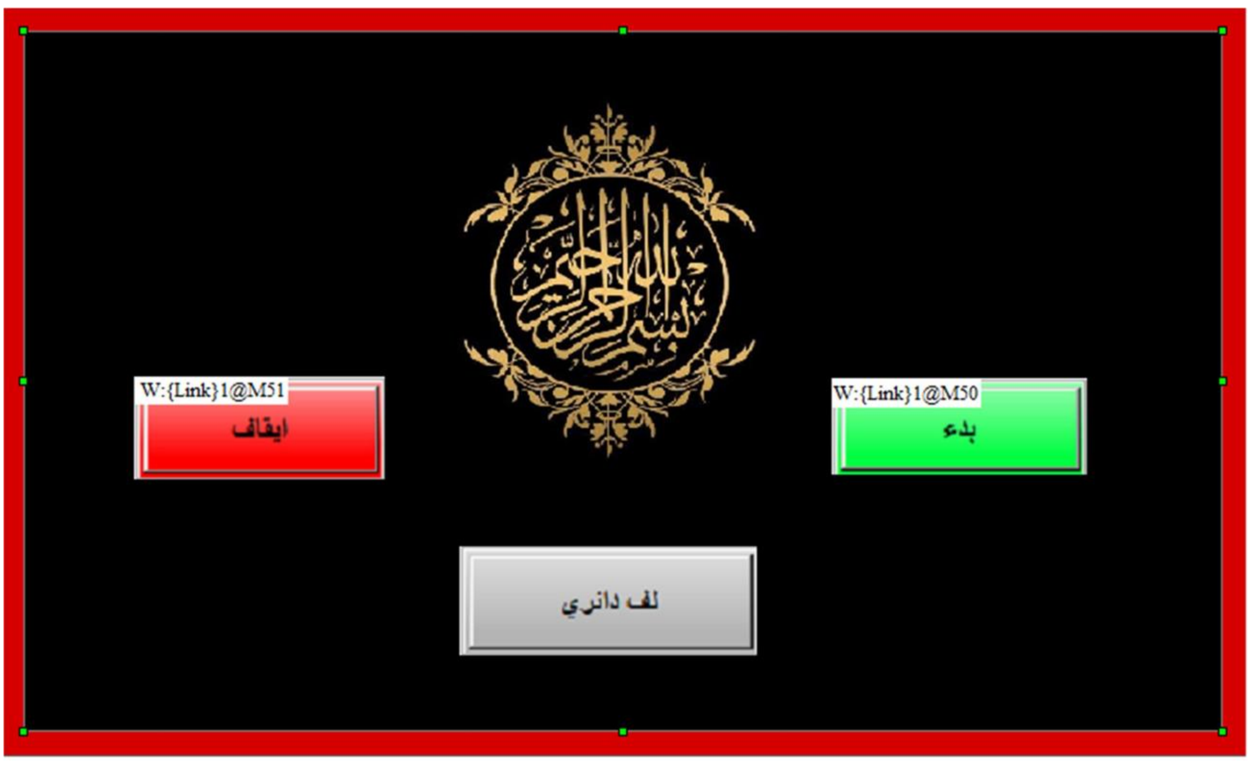


Figure30 HMI programming and design panel 1

Figure31 HMI programming and design panel 2

4.5 Testing and results.

Due to inability to buy a secondary motor and invalidity of 3-phase electrical support, we made a simulation for the control system on PLC with HMI touch screen and manual controller to ensure that the program is working properly and within the required path.

Notes:

- *For the relative error in (Up-Down) motion equation, we can reduce his effect on the accuracy by do homing for the machine that after the automatic processing for 20 times as maximum.*
- *For the relative error in (To left-To right) motion equation, we can compensate it by adding a little bit of the piece length value, such that the length added will be cut after finishing the process.*

4.6 Recommendations.

- Improve the algorithm in order to bend arc form automatically.
- Transform the forming process of circular helical form from manual to automatic method.
- Adding the ability to self-holding automatic process means come back to its last state.

4.7 Conclusion.

Its design helps the workers for the following updates, for the first update of this machine is to automate the machine control to let it drive automatically with high level of safety, which its design connect to raise the level of accuracy and the production speed, however its design helps the normal worker who is not has the high level of experience to drive the machine, and for whole machine purpose is bending process.

References

{1}-SECTION BENDING MACHINE, MC150B, INSTRUCTIONS BOOK, from: www.nargesa.com.

{2}-[Murray, Mike (15 December 2019). "How Rotary Encoders Work". The Geek Pub. Retrieved 3 September 2019.].

{3}- Campbell, Sylvester J. (1987). Solid-State AC Motor Controls. New York: Marcel Dekker, Inc. pp. 79–189.

{4}- Gerd Baumann, Mathematica for Theoretical Physics: Electrodynamics, Quantum Mechanics, General Relativity and Fractals, United States of America, New York, 2005- related to eq'n(1), eq'n(2), eq'n(3).

{5}-Delta Electronics, Inc-Delta Programmable Logic Controller DVP Series-Taoyuan Technology Center-No.18, Xinglong Rd., Taoyuan District-Taoyuan City 33068, Taiwan from web site : www.deltaww.com

{6}-PLC (Application Programming) Manual Delta Electronics, Inc-Delta Programmable Logic Controller DVP Series-Taoyuan Technology Center-No.18, Xinglong Rd., Taoyuan District-Taoyuan City 33068, Taiwan from web site: www.deltaww.com

{7}-Mechanical Engineering Design-Richard G. Budynas and J.Keith Nisbett- Ninth edition 2011- related to eq'n(7), eq'n(8), eq'n(9) , eq'n(10), eq'n(11).

{8}-Manufacturing Engineering and Technology-Serope Kalpakjian-Steven R. Schmid-K. S. Vijay Sekar-seventh edition-2014- related to eq'n(4), eq'n(5), eq'n(6).

Appendix

†Often preferred.

Table A–5

Physical Constants of Materials

Material	Modulus of Elasticity E Mpsi	GPa	Modulus of Rigidity G Mpsi	GPa	Poisson's Ratio ν	Unit Weight w lbf/in³	lbf/ft³	kN/m³
Aluminum (all alloys)	10.4	71.7	3.9	26.9	0.333	0.098	169	26.6
Beryllium copper	18.0	124.0	7.0	48.3	0.285	0.297	513	80.6
Brass	15.4	106.0	5.82	40.1	0.324	0.309	534	83.8
Carbon steel	30.0	207.0	11.5	79.3	0.292	0.282	487	76.5
Cast iron (gray)	14.5	100.0	6.0	41.4	0.211	0.260	450	70.6
Copper	17.2	119.0	6.49	44.7	0.326	0.322	556	87.3
Douglas fir	1.6	11.0	0.6	4.1	0.33	0.016	28	4.3
Glass	6.7	46.2	2.7	18.6	0.245	0.094	162	25.4
Inconel	31.0	214.0	11.0	75.8	0.290	0.307	530	83.3
Lead	5.3	36.5	1.9	13.1	0.425	0.411	710	111.5
Magnesium	6.5	44.8	2.4	16.5	0.350	0.065	112	17.6
Molybdenum	48.0	331.0	17.0	117.0	0.307	0.368	636	100.0
Monel metal	26.0	179.0	9.5	65.5	0.320	0.319	551	86.6
Nickel silver	18.5	127.0	7.0	48.3	0.322	0.316	546	85.8
Nickel steel	30.0	207.0	11.5	79.3	0.291	0.280	484	76.0
Phosphor bronze	16.1	111.0	6.0	41.4	0.349	0.295	510	80.1
Stainless steel (18-8)	27.6	190.0	10.6	73.1	0.305	0.280	484	76.0
Titanium alloys	16.5	114.0	6.2	42.4	0.340	0.160	276	43.4

Table 8–1

Diameters and Areas of Coarse-Pitch and Fine-Pitch Metric Threads.*

Nominal Major Diameter d mm	Coarse-Pitch Series: Pitch p mm	Coarse-Pitch Series: Tensile-Stress Area A_t mm²	Coarse-Pitch Series: Minor-Diameter Area A_r mm²	Fine-Pitch Series: Pitch p mm	Fine-Pitch Series: Tensile-Stress Area A_t mm²	Fine-Pitch Series: Minor-Diameter Area A_r mm²
1.6	0.35	1.27	1.07			
2	0.40	2.07	1.79			
2.5	0.45	3.39	2.98			
3	0.5	5.03	4.47			
3.5	0.6	6.78	6.00			
4	0.7	8.78	7.75			
5	0.8	14.2	12.7			
6	1	20.1	17.9			
8	1.25	36.6	32.8	1	39.2	36.0
10	1.5	58.0	52.3	1.25	61.2	56.3
12	1.75	84.3	76.3	1.25	92.1	86.0
14	2	115	104	1.5	125	116
16	2	157	144	1.5	167	157
20	2.5	245	225	1.5	272	259
24	3	353	324	2	384	365
30	3.5	561	519	2	621	596
36	4	817	759	2	915	884
42	4.5	1120	1050	2	1260	1230
48	5	1470	1380	2	1670	1630
56	5.5	2030	1910	2	2300	2250
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table A–20

Deterministic ASTM Minimum Tensile and Yield Strengths for Some Hot-Rolled (HR) and Cold-Drawn (CD) Steels [The strengths listed are estimated ASTM minimum values in the size range 18 to 32 mm ($\frac{3}{4}$ to $1\frac{1}{4}$ in). These strengths are suitable for use with the design factor defined in Sec. 1–10, provided the materials conform to ASTM A6 or A568 requirements or are required in the purchase specifications. Remember that a numbering system is not a specification.] *Source:* 1986 SAE Handbook, p. 2.15.

1 UNS No.	2 SAE and/or AISI No.	3 Process-ing	4 Tensile Strength, MPa (kpsi)	5 Yield Strength, MPa (kpsi)	6 Elongation in 2 in, %	7 Reduction in Area, %	8 Brinell Hardness
G10060	1006	HR	300 (43)	170 (24)	30	55	86
		CD	330 (48)	280 (41)	20	45	95
G10100	1010	HR	320 (47)	180 (26)	28	50	95
		CD	370 (53)	300 (44)	20	40	105
G10150	1015	HR	340 (50)	190 (27.5)	28	50	101
		CD	390 (56)	320 (47)	18	40	111
G10180	1018	HR	400 (58)	220 (32)	25	50	116
		CD	440 (64)	370 (54)	15	40	126
G10200	1020	HR	380 (55)	210 (30)	25	50	111
		CD	470 (68)	390 (57)	15	40	131
G10300	1030	HR	470 (68)	260 (37.5)	20	42	137
		CD	520 (76)	440 (64)	12	35	149
G10350	1035	HR	500 (72)	270 (39.5)	18	40	143
		CD	550 (80)	460 (67)	12	35	163
G10400	1040	HR	520 (76)	290 (42)	18	40	149
		CD	590 (85)	490 (71)	12	35	170
G10450	1045	HR	570 (82)	310 (45)	16	40	163
		CD	630 (91)	530 (77)	12	35	179
G10500	1050	HR	620 (90)	340 (49.5)	15	35	179
		CD	690 (100)	580 (84)	10	30	197
G10600	1060	HR	680 (98)	370 (54)	12	30	201
G10800	1080	HR	770 (112)	420 (61.5)	10	25	229
G10950	1095	HR	830 (120)	460 (66)	10	25	248

ES2/EX2 series:

Specifications						
Control Method					Stored program, cyclic scan system	
I/O Processing Method					Batch processing method (when END instruction is executed)	
Execution Speed					LD instructions – 0.54μs, MOV instructions – 3.4μs	
Program language					Instruction List + Ladder + SFC	
Program Capacity					15872 steps	
Bit Contacts	X	External inputs			X0~X377, octal number system, 256 points max, (*4)	Total 256+16 I/O
Bit Contacts	Y	External outputs			Y0~Y377, octal number system, 256 points max, (*4)	Total 256+16 I/O
Bit Contacts	M	Auxiliary relay	General		M0~M511, 512 points, (*1) M768~M999, 232 points, (*1) M2000~M2047, 48 points, (*1)	Total 4096 points
Bit Contacts	M	Auxiliary relay	Latched		M512~M767, 256 points, (*2) M2048~M4095, 2048 points, (*2)	Total 4096 points
Bit Contacts	M	Auxiliary relay	Special		M1000~M1999, 1000 points, some are latched	Total 4096 points
Bit Contacts	T	Timer	100ms (M1028=ON, T64~T126: 10ms)		T0~T126, 127 points, (*1) T128~T183, 56 points, (*1)	Total 256 points
Bit Contacts	T	Timer	100ms (M1028=ON, T64~T126: 10ms)		T184~T199 for Subroutines, 16 points, (*1)	Total 256 points
Bit Contacts	T	Timer	100ms (M1028=ON, T64~T126: 10ms)		T250~T255(accumulative), 6 points (*1)	Total 256 points
Bit Contacts	T	Timer	10ms (M1038=ON, T200~T245: 1ms)		T200~T239, 40 points, (*1)	Total 256 points
Bit Contacts	T	Timer	10ms (M1038=ON, T200~T245: 1ms)		T240~T245(accumulative), 6 points, (*1)	Total 256 points
Bit Contacts	T	Timer	1ms		T127, 1 points, (*1) T246~T249(accumulative), 4 points, (*1)	Total 256 points
Bit Contacts	C	Counter	16-bit count up		C0~C111, 112 points, (*1) C128~C199,72 points, (*1)	Total 232 points
Bit Contacts	C	Counter	16-bit count up		C112~C127,16 points, (*2)	Total 232 points
Bit Contacts	C	Counter	32-bit count up/down		C200~C223, 24 points, (*1)	Total 232 points
Bit Contacts	C	Counter	32-bit count up/down		C224~C231, 8 points, (*2)	Total 232 points
Bit Contacts	C	Counter	32bit high-speed count up/down	Soft-ware	C235~C242, 1 phase 1 input, 8 points, (*2)	Total 23 points
Bit Contacts	C	Counter	32bit high-speed count up/down	Soft-ware	C232~C234, 2 phase 2 input, 3 points, (*2)	Total 23 points
Bit Contacts	C	Counter	32bit high-speed count up/down	Hard-ware	C243~C244, 1 phase 1 input, 2 points, (*2)	Total 23 points
Bit Contacts	C	Counter	32bit high-speed count up/down	Hard-ware	C245~C250, 1 phase 2 input, 6 points, (*2)	Total 23 points
Bit Contacts	C	Counter	32bit high-speed count up/down	Hard-ware	C251~C254 2 phase 2 input, 4 points, (*2)	Total 23 points
Bit Contacts	S	Step point	Initial step point		S0~S9, 10 points, (*2)	Total 1024 points
Bit Contacts	S	Step point	Zero point return		S10~S19, 10 points (use with IST instruction), (*2)	Total 1024 points
Bit Contacts	S	Step point	Latched		S20~S127, 108 points, (*2)	Total 1024 points
Bit Contacts	S	Step point	General		S128~S911, 784 points, (*1)	Total 1024 points
Bit Contacts	S	Step point	Alarm		S912~S1023, 112 points, (*2)	Total 1024 points
Word Register	T	Current value			T0~T255, 256 words	
Word Register	C	Current value			C0~C199, 16-bit counter, 200 words	

<table>
<tr><th colspan="6">Specifications</th></tr>
<tr><td rowspan="7"></td><td></td><td colspan="2"></td><td colspan="2">C200~C254, 32-bit counter, 55 words</td></tr>
<tr><td rowspan="6">D</td><td rowspan="6">Data register</td><td>General</td><td>D0~D407, 408 words, (*1)
D600~D999, 400 words, (*1)
D3920~D9999, 6080 words, (*1)</td><td rowspan="6">Total
10000 points</td></tr>
<tr><td>Latched</td><td>D408~D599, 192 words, (*2)
D2000~D3919, 1920 words, (*2)</td></tr>
<tr><td>Special</td><td>D1000~D1999, 1000 words, some are latched</td></tr>
<tr><td>For Special mudules</td><td>D9900~D9999，100 words, (*1), (*5)</td></tr>
<tr><td>Index</td><td>E0~E7, F0~F7, 16 words, (*1)</td></tr>
<tr><td colspan="2" style="display:none"></td></tr>
<tr><td rowspan="6">Pointer</td><td>N</td><td colspan="2">Master control loop</td><td colspan="2">N0~N7, 8 points</td></tr>
<tr><td>P</td><td colspan="2">Pointer</td><td colspan="2">P0~P255, 256 points</td></tr>
<tr><td rowspan="4">I</td><td rowspan="4">Interrupt Service</td><td>External interrupt</td><td colspan="2">I000/I001(X0), I100/I101(X1), I200/I201(X2), I300/I301(X3), I400/I401(X4), I500/I501(X5), I600/I601(X6), I700/I701(X7), 8 points (01: rising-edge trigger , 00: falling-edge trigger)</td></tr>
<tr><td>Timer interrupt</td><td colspan="2">I602~I699, I702~I799, 2 points (Timer resolution = 1ms)
I805~I899, 1 point (Timer resolution = 0.1ms) (Supported by V2.00 and above)</td></tr>
<tr><td>High-speed counter interrupt</td><td colspan="2">I010, I020, I030, I040, I050, I060, I070, I080,8 points</td></tr>
<tr><td>Communication interrupt</td><td colspan="2">I140(COM1), I150(COM2), I160(COM3), 3 points, (*3)</td></tr>
<tr><td rowspan="2">Constant</td><td>K</td><td colspan="2">Decimal</td><td colspan="2">K-32,768 ~ K32,767 (16-bit operation),
K-2,147,483,648 ~ K2,147,483,647 (32-bit operation)</td></tr>
<tr><td>H</td><td colspan="2">Hexadecimal</td><td colspan="2">H0000 ~ HFFFF (16-bit operation),
H00000000 ~HFFFFFFFF (32-bit operation)</td></tr>
<tr><td colspan="4">Serial ports</td><td colspan="2">COM1: built-in RS-232 ((Master/Slave)
COM2: built-in RS-485 (Master/Slave)
COM3: built-in RS-485 (Master/Slave)
COM1 is typically the programming port.</td></tr>
<tr><td colspan="4">Real Time Clock</td><td colspan="2">Year, Month, Day, Week, Hours, Minutes, Seconds</td></tr>
<tr><td colspan="4">Special I/O Modules</td><td colspan="2">Up to 8 special I/O modules can be connected</td></tr>
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