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Design of Servo Following Control System

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Abstract

Servo following control system is an important part of modern automatic control system. It takes various mechanical parameters as the control object to make the output variable automatically follow the change of the input variable and achieve fast and accurate effect.Nowadays,servo following control system, not only in industrial production, agricultural production or People's Daily life is widely used, but also in robot, automation equipment and other high-tech also begin to develop rapidly.Servo following control has the advantages of small following error and high precision, which can easily realize the real-time following of the rotary table.With Mitsubishi FX series, model for the selection of PLC FX3u - 48 MT, due to the type of PLC with high-speed pulse input and output module, encoder through gathering information to complete the data processing, to control the servo motor, realization cross flower-stand follow wheel run to achieve relatively static state, through the programming algorithms for data migration control electromagnetic pen move to draw the corresponding design. In this paper, programmable software GX works2 and GT Designer3 are selected for programming configuration. Sequence function diagram and ladder diagram language are mainly used to complete the program, which greatly simplifies the program structure. Due to the integrated circuit inside PLC, the whole design reduces the use of ordinary relays, thus increasing the service life of the system and optimizing the system performance.With GT Designer3 touch screen configuration software, operation and monitoring elements are added to make the program run more clearly and greatly save time.

Keywords

Following system, Servo motor, PLC, Frequency converter.

1. Introduction

1.1. Overview of Servo Following Control System

The servo following control system is an automatic control system with mechanical parameters as the control object, which makes the control output variable automatically follow the control system with the real-time change of the input variable, and realizes the speediness and accuracy of following, thus greatly improving the operation efficiency of the automation equipment.In recent years, with the continuous development of power electronic technology and modern control technology and the rapid improvement of servo motor technology, servo control technology has gradually developed.Servo control technology has been gradually applied to industrial production, agricultural production, People's Daily life and high-tech aspects, such as robots, office automation equipment and so on have entered our lives.

The main task of the servo system is to control signal transformation, power amplification and so on, so that the driving device can flexibly and conveniently control the output torque, speed and position.Servo control system is composed of upper computer, servo amplifier and servo motor.Among them, the upper computer is used to send instructions to the servo system, including PLC, industrial control computer, etc.The servo amplifier is mainly used to receive and process the instructions from the upper computer and control the motor to rotate at the specified Angle and speed.The servo motor is an actuator, and its encoder feeds the rotation

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Angle and speed of the motor back to the servo amplifier to form a closed-loop control system with feedback to ensure the control accuracy of the servo system.

1.2. Research Status of Servo Follow Control System

Nowadays, servo following control system, as one of the important drivers of industrial equipment, has excellent performance, so it is widely used in many fields, especially in automatic control technology, making the equipment show the characteristics of intelligence, network and humanization.The servo system enhances the processing of control signals with its own characteristics of high precision, good stability and rapid response, so as to effectively improve the efficiency and accuracy of the control system.Since the 1980s, with the rapid development of modern industry, people have put forward higher and higher requirements for servo system, and the research and development of high-performance servo system has become the common goal of researchers at home and abroad.

2. Introduction and Design Requirements of Servo Following Control System

2.1. Introduction to the Servo Following Control System

The working plate is controlled by AC frequency conversion, and white paper is fixed on the working plate (diameter about 300mm).In the figure, the upper end is the X/Y axis cross table (controlled by servo motor). Considering the mechanical strength, the Y axis has two parallel axes fixed, of which the left one is the active driving axis and the right one is the driven axis.X axis is equipped with a drawing electromagnetic marker (pen tip line width is 1mm);At the bottom is a rotating working plate, which is rotated by an AC motor (the speed of the motor is controlled by a frequency converter, and the reduction ratio of the AC motor is 1:15).

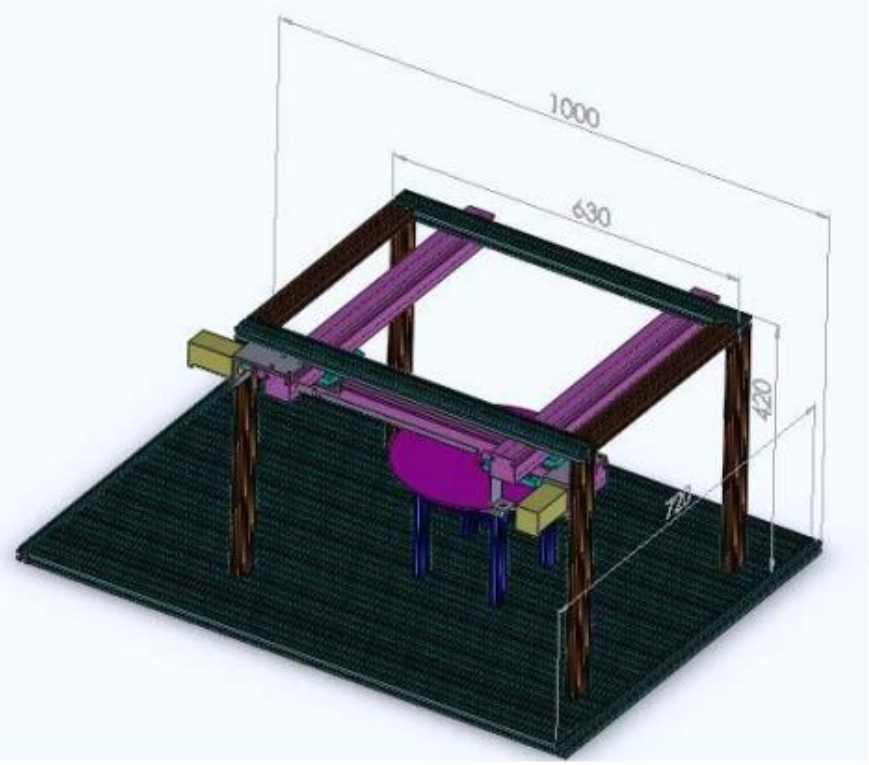

Fig 1. The three-dimensional structure diagram of the following system

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

2.2. Design Requirements

When the system starts, the X and Y axis first return to the original state, and the working disk starts to rotate, and always maintains this speed.As shown in Fig.2, take the center point of the working disk as the center of the circle, draw a circle with a diameter of 10cm, and then draw the radius of the circle with a dashed line (length is 5mm, interval is 5mm). After completion, the cross table returns to the origin.

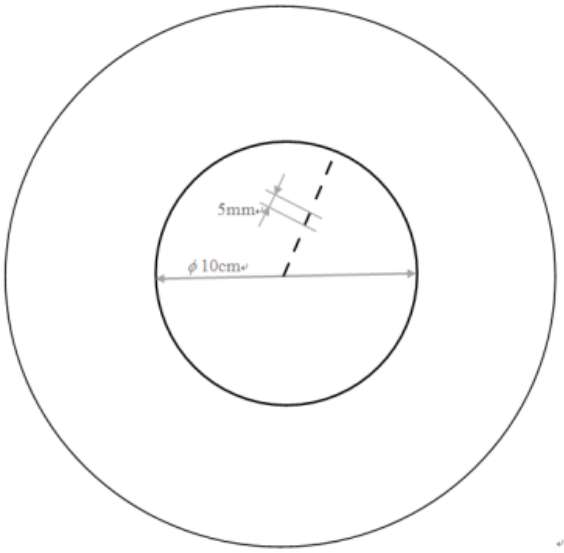

Fig 2. Schematic diagram of drawing requirements of servo following control system

3. Working Principle of Servo Follow Control System

3.1. Design of Servo Follow Control System

(1) Ethernet communication is adopted between HMI and upper computer software, and PLC and HMI are transparently transmitted through port 422 to realize program download and data transmission functions.

(2) Operate the HMI control system, conduct data acquisition and calculation processing by PLC, and control the operation of frequency converter and servo motor.

(3) The frequency converter controls the three-phase motor to drive the rotary table to run and feeds the encoder data back to PLC.

(4) Servo motor 1 drives X axis to move forward and backward, while servo motor 2 drives Y axis to move forward and backward.

(5) The solenoid valve is equipped with a marker that is moved up and down and fixed on the X-axis.

(6) There are 4 limit switches before and after X and Y axes. When the actuator exceeds the operating range, it will make emergency stop.

(7) X and Y axis each have an origin limit switch, which is used for device reset to find the origin.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

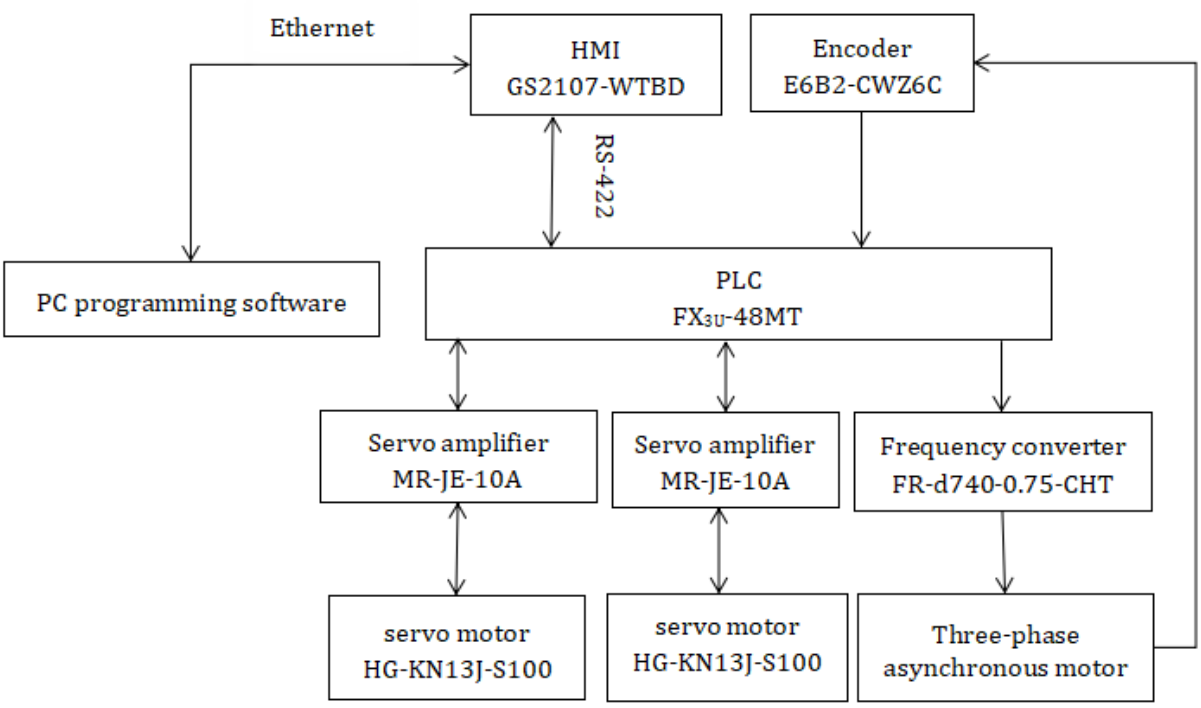

Fig 3. System block diagram

3.2. Positioning Calculation of Servo Tracking Control System

(1) Calculation of pulse radian of the rotary table: the rotary table sends out 2000 pulses after turning the encoder once, then

$$1rad / p = \frac{2000p}{360^{\circ}} \tag{1}$$

(2) Rotation angle of the rotary table:

$$\alpha = 1rad / p * \pi / 180 \tag{2}$$

(3) Servo offset pulse calculation:

$$\text{X-axis displacement pulse} = \alpha * \sin * 120^{\circ} \tag{3}$$

$$\text{Y-axis displacement pulse} = \alpha * \cos * 120^{\circ} \tag{4}$$

3.3. Servo Follow the Working Process of the Control System

(1) Reset:

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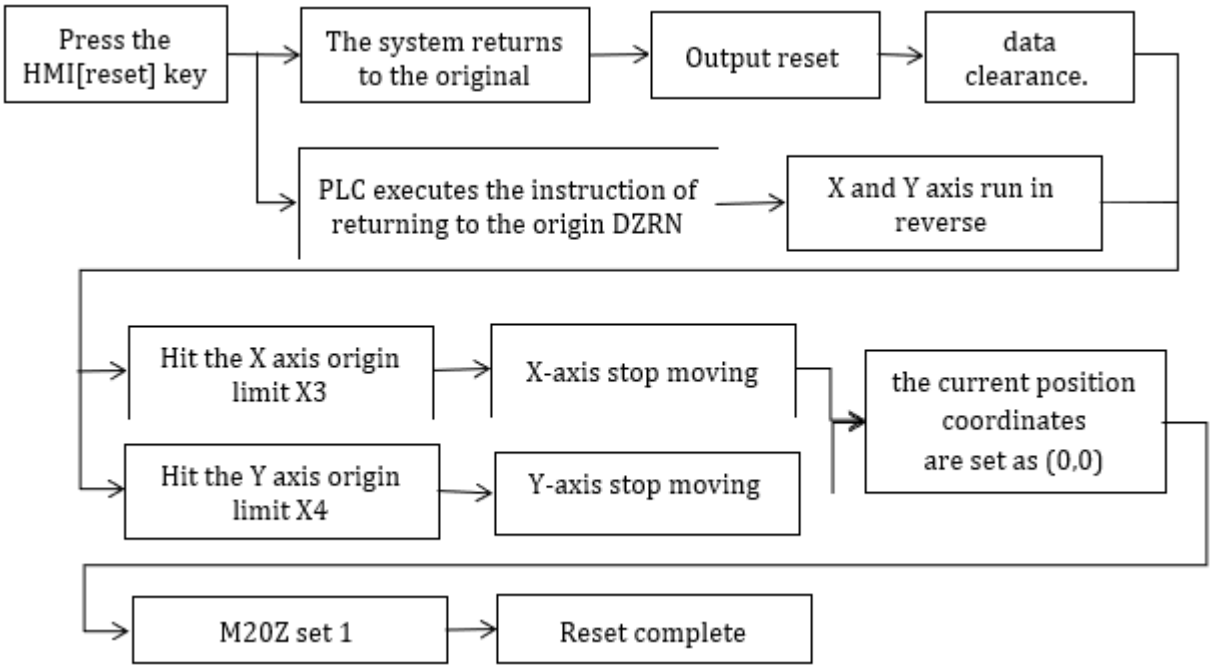


Fig 4. Reset flow chart

(2) Turntable operation:

press the HMI button→PLC Y12 set 1→forward operation of the frequency→feedback of encoder data to PLC→calculation of current angle,speed and other information→HMI display information →press the button again→ the turntable stops rotating.

(3) The system follows the drawing to run:

The system sets the diameter, and PLC calculates the angle, sine, cosine and other data according to the feedback data of the rotary encoder.Control servo motor operation.The formulas are:

$$Y = \sin(\pi/180 * \alpha) * r \tag{5}$$

$$X = \cos(\pi/180 * \alpha) * r \tag{6}$$

Press the HMI [start] button→X, Y axis is offset to the center of the circle→the current position coordinates are set to (0, 0) →diameter expanding at a constant speed→PLC control Y10 reset→Control the pen to draw a dotted line to move up and down→the radius is setting length→Drawing circle→Y10 reset pen up→X, Y reverse migration to the mechanical origin→record of running time and display on HMI→run over.

(4) Stop:

Press the HMI[Stop] button → All output reset → The device stops running → Reset is required and restart.

According to the above analysis, the flow chart of servo following control system is drawn as follows:

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

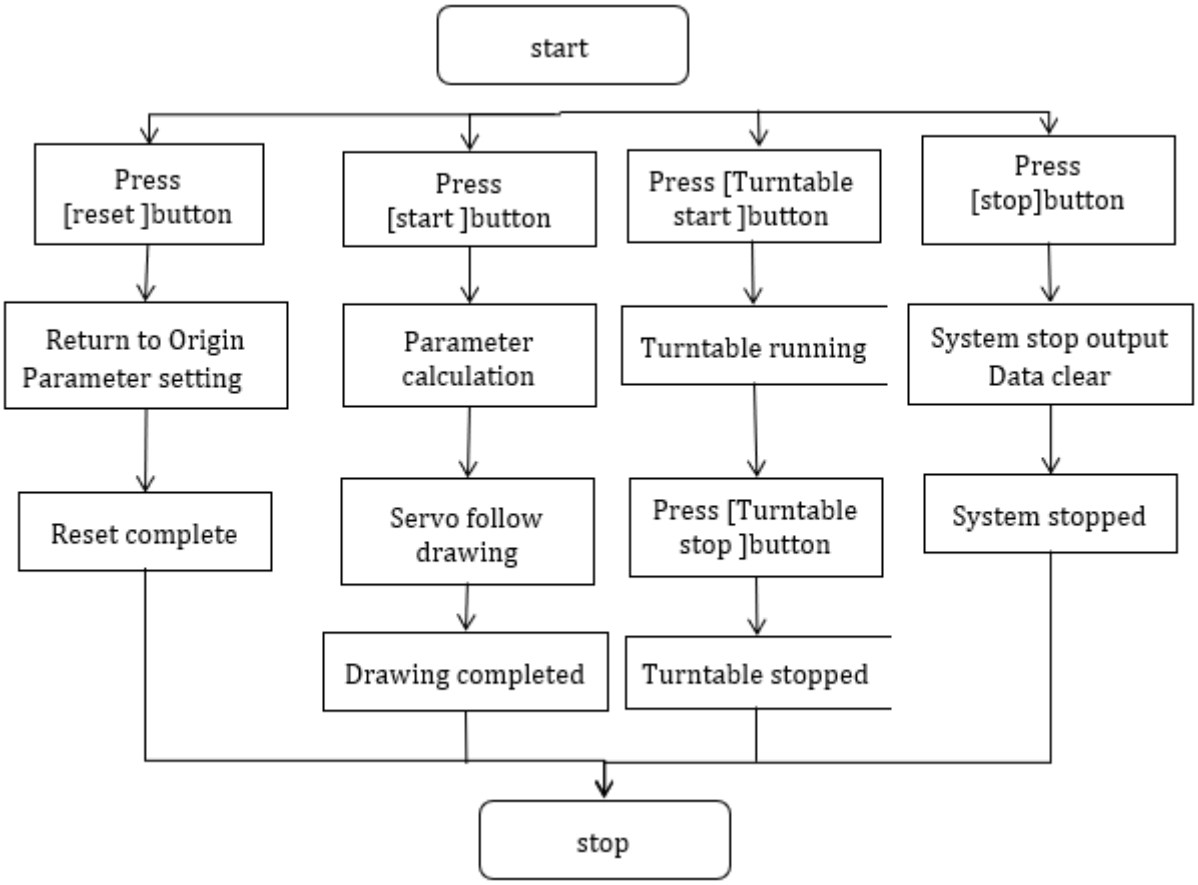


Fig 5. Flow chart of servo follow control system

4. Hardware Design of Servo Tracking System

4.1. Design Physical Drawing

The basic structure of this design is composed of frequency converter, three-phase asynchronous motor, encoder, rotary table, X-axis servo motor, Y-axis servo motor, electromagnetic pen, PLC, HMI, switching electrical appliances, etc. The physical design is shown in Fig.6:

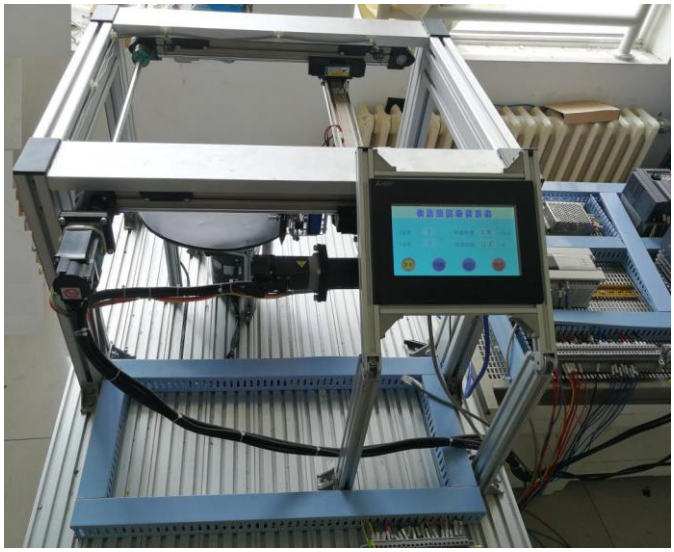


Fig 6. Servo follow control system

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

Longitudinal (X-axis) and transverse (Y-axis) servo motors are mounted on the top beam of the three-dimensional frame. The electromagnetic pen is fixed on the longitudinal (X-axis). The servo motor composed of transverse and longitudinal can do planar two-dimensional motion.The bottom platform is installed with three-phase asynchronous AC motor, and the white paper is affixed to the rotary table and fixed on the three-phase asynchronous AC motor shaft.

4.2. Components Required by the Equipment

According to the design requirements, complete the physical control diagram above, among which the main components are: air switch, switching power supply, frequency converter,PLC,servo motor,servo amplifier,etc, and the selection of each component is shown in Table 1.The most important components are frequency converter, PLC and servo amplifier, which will also be briefly introduced in this paper.

Table 1. Main Components Selection

number	device	model	component	quantity
1		BV-D 25A	4P1N 380V, 25A	1
2	Air circuit breakers	BH-D6 D6	2P1N 220V, 6A	1
3		BH-D6 C10	2P1N 220V, 10A	
4	Switching power supply		AC220V~DC24V	1
5	Frequency converter	FR-A740-0.75K-CHT	Input: 3.5A, AC380~480V, 50/60Hz Output:2.2A, AC380~480Vmax, 0.2-400Hz	1
6	PLC	FX3U-48MT	100-240VAC, 50/60Hz, 40W OUT: 5~30VDC, 0.5A	1
7	HMI	GS2107-WTBD	In: 204VDC POWER:6.5Wmax	1
8	Servo motor	HG-KN13J-S100	3AC 112V, 0.8A, 100W, 3000r/min (250Hz)	2
9	Three-phase AC asynchronous motor	5IK40GN-U	40W, 220/380V, 3φ 0.38/0.22A, 50Hz Cont 1350r/min	1
10	Encoder	E6B2-CWZ6C	Resolution: 1000P/R Voltage: 5~24VDC	1
11	Servo amplifier	MR-JE-10A	POWER:100W Input: 3AC/AC200-240V, 0.9/1.5A, 50/60Hz; Output: 3PH170V, 0~360Hz, 1.1A	2
12	Limit switch	SS-5GL2	5A 125VAD, 3A 250VAC	6
13	Terminal block	UK-2.5B	Rail type	…
14	Wire	RV	Hot RV0.75mm2/Black RV0.75mm2 Hot RV0.5mm2/Black RV0.5mm2 BlueRV0.3mm2/Yellow-green RV1mm2	…

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

Frequency converter is a device that converts fixed frequency alternating current into continuously adjustable frequency alternating current. It is an important part of the servo tracking control system and is irreplaceable.The relevant setting parameters of frequency converter are shown in Table 2:

Table 2. Parameter Settings of frequency converter

Components number	Components content	Setting
Pr.3	Rated frequency	50
Pr.7	Acceleration time	0.2
Pr.8	Deceleration time	0.2
Pr.79	Operation mode selection	3
Pr.53	Frequency setting operation selection	1

The Mitsubishi GENERAL-purpose AC servo MELTSERSO -JE family is based on the MELTSERSO -J4 family of AC servos that limit functionality while maintaining high performance.In its position control mode, it can support up to 4M pulses/s high-speed pulse train.Therefore, this servo system can be used for high precision positioning and smooth speed control of machine tools and common industrial machinery, and its application range is very wide.At the same time, it also supports single-key adjustment and real-time automatic adjustment functions. According to the machine, it can make simple automatic adjustment to the gain of 10 service of Institute of Automation and Electrical Engineering.Relevant parameter Settings of servo amplifier are shown in Table 3:

Table 3. Parameter Settings of servo amplifier

Components number	Components content	Setting
PA01	Control mode	1000
PA05	Number of pulses in one rotation of the motor	1000
PA06	Electronic gear ratio	1
PA13	Specify pulse method	11
PA04	Function selection	2000
PA14	Direction of rotation	0
PC01	acceleration time	0
PC02	deceleration time	0
PC03	Curve acceleration time	0
PD01	Input signal automatically NO	0C04

4.3. Electrical Schematic Diagram and PLC Wiring Diagram

Refer to the user's manual for each device, which shall be connected as follows.The power supply of the converter is 380V three-phase alternating current connected to the L1/L2/L3 junction post, and the UVW is connected to the motor. The control part can send a high level signal to STF.

The servo driver power supply is 220V single-phase alternating current connected to the L1/L3 terminal, UVW is connected to the servo motor, The CN1 control part OPC and DICOM are connected to + 24V, DOCOM is connected to -24V, EM port is connected to the front and rear

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

limit switch of the shaft (low level operation), when it hits the limit, it stops the output, PP is connected to pulse signal, PN is connected to the direction signal.

The PLC power supply is 220V single-phase alternating current connected at L/N/ interface, the input end is connected to the encoder and the origin limit of the two axes, the output end is connected to the pulse and direction output of the two axes, the operation of the electromagnetic pen and the frequency converter.

According to the above requirements, draw the electrical schematic diagram and PLC wiring diagram, as shown in Fig.7 and Fig.8:

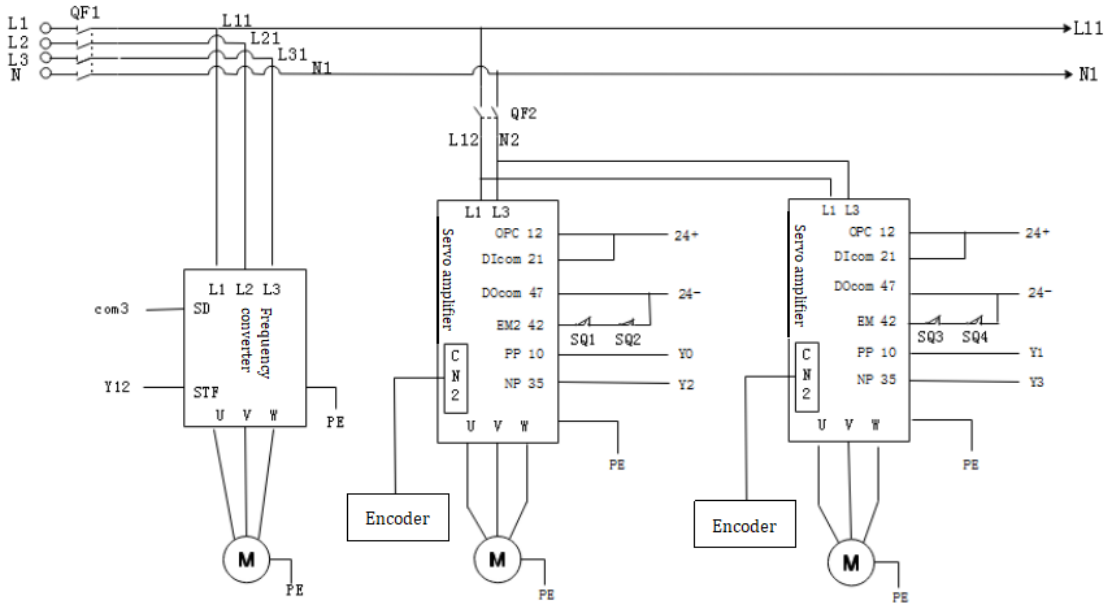


Fig 7. Electrical Schematic Diagram

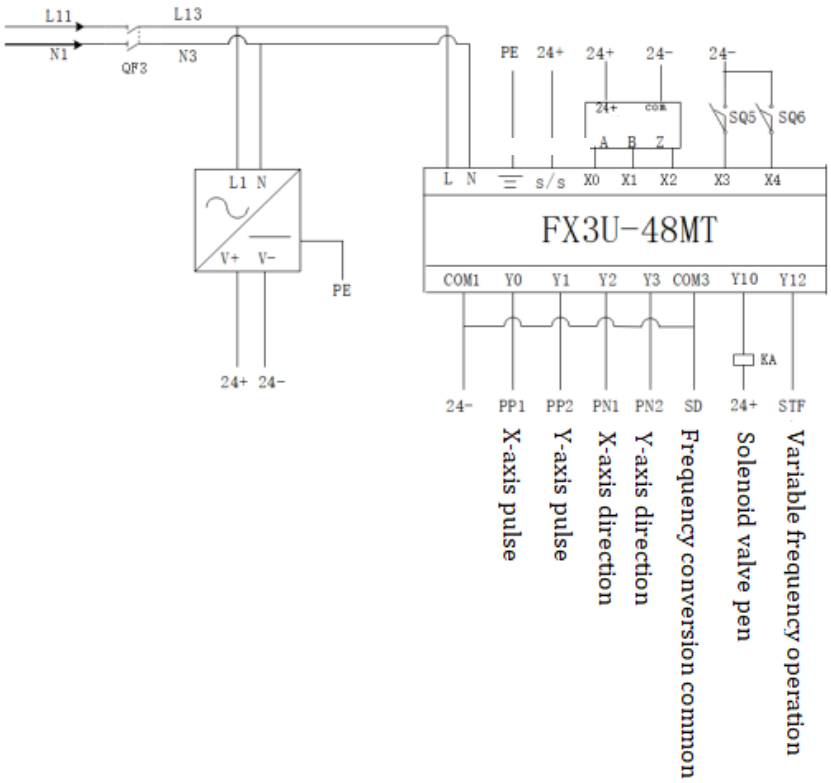


Fig 8. PLC wiring diagram

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

5. Software Design and Analysis

5.1. Introduction to Programming Software

GX works2 is Mitsubishi's software based on Windows platform, which can be used for Mitsubishi's full series OF PLC program development and simulation debugging.This design mainly USES sequence function diagram and ladder diagram language for programming, its control structure is simple and clear, easy to optimize.

And GTSimulator3 simulation software is integrated with the function of simulation.

5.2. I/O Allocation Table

Table 4. I/O Allocation Table

Input	Note	Output	Note
X0	Encoder Phase A	Y0	X-axis pulse
X1	Encoder Phase B	Y1	Y-axis pulse
X2	Encoder Phase Z	Y2	X-axis direction
X3	X-axis origin limit	Y3	Y-axis direction
X4	Y-axis origin limit	Y10	Electromagnetic pen
		Y12	Turntable running

5.3. Programming

The program is divided into five parts: main program (reset),return to the mechanical origin, circle calculation, rotation time calculation and flow.

(1) Main program (for initialization and reset)

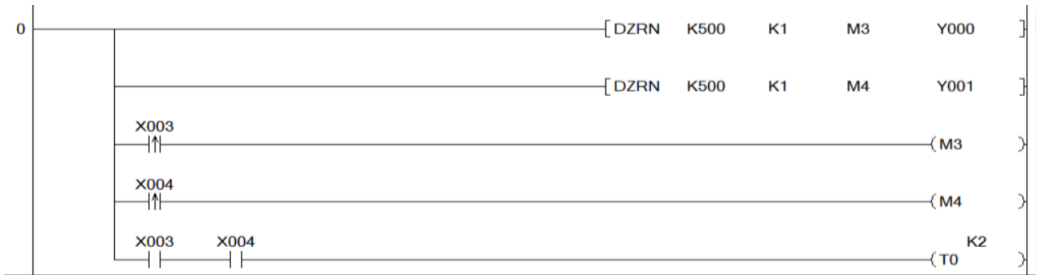
When the system power on the first cycle or when pressing the emergency stop and reset button, S1 and S0 is powered, so that "back to the mechanical origin" and "flow 1" two SFC language programming block initialization power. Clear D data from all registers.Reset all output points.Reset all S registers.

(2) Return to the mechanical origin

The program block using sequence flow chart SFC prepared, divided into two single branch.

When the reset signal M2 closes the X-axis and the Y-axis are not at the mechanical origin, S10 gets electricity.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

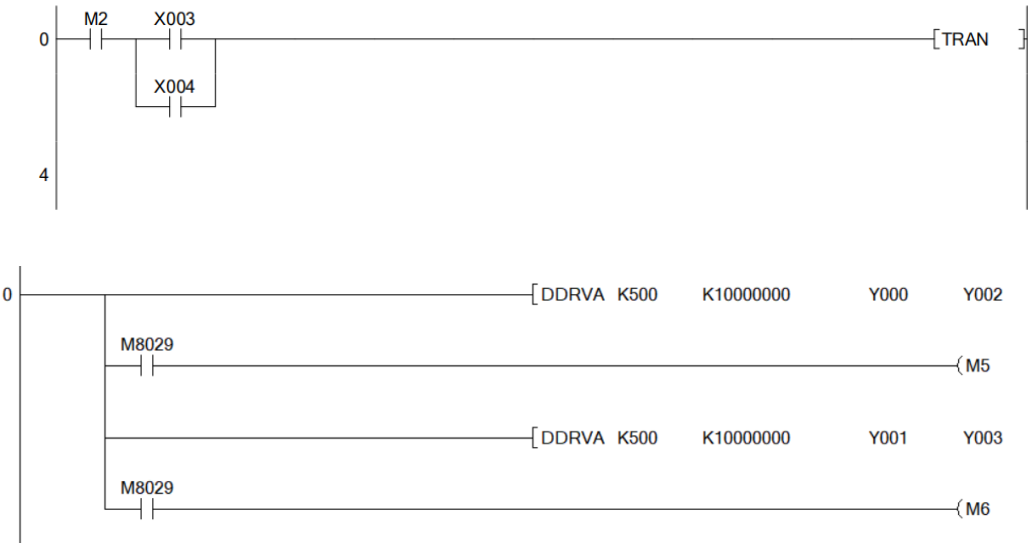


Execute the X-axis return to origin instruction at a speed of 500 pulses /s running in the negative direction. When limit switch X3 is hit, M3 is given a pulse signal to stop the X-axis return to origin instruction.

Execute the Y-axis return to origin instruction, speed is 500 pulse /s running in the negative direction.When limit switch X4 is hit, M4 is given a pulse signal to to stop the Y-axis return to origin instruction.

When X axis and Y axis return to the mechanical origin, delay 2S makes S11 get electricity.

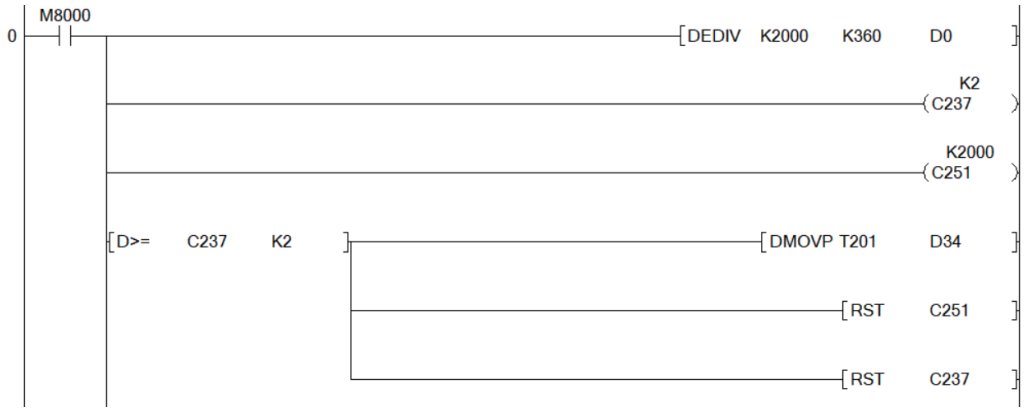
Set the M11 (reset complete) flag bit, and return the initial step S0.



When the reset signal M2 closes the X-axis and Y-axis with any one at the mechanical origin, S13 gets electricity. Execute a program that gives the X-axis and Y-axis a positive offset of 500 pulses at a speed of 10 million pulses per second.Execute M8029 to get power, jump to step 10 to execute back to the origin program.

(3) Circle calculation

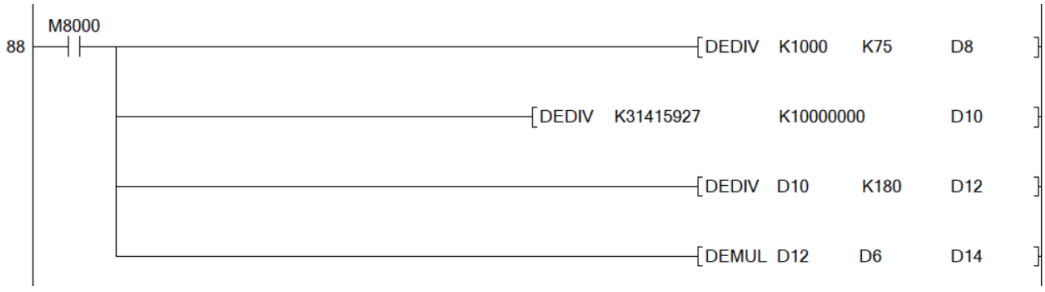
ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015



Each turn of the encoder sends out 2000 pulses of AB phase and 2 pulses of Z phase. In order to improve the accuracy, the high speed counter is cleared every turn.

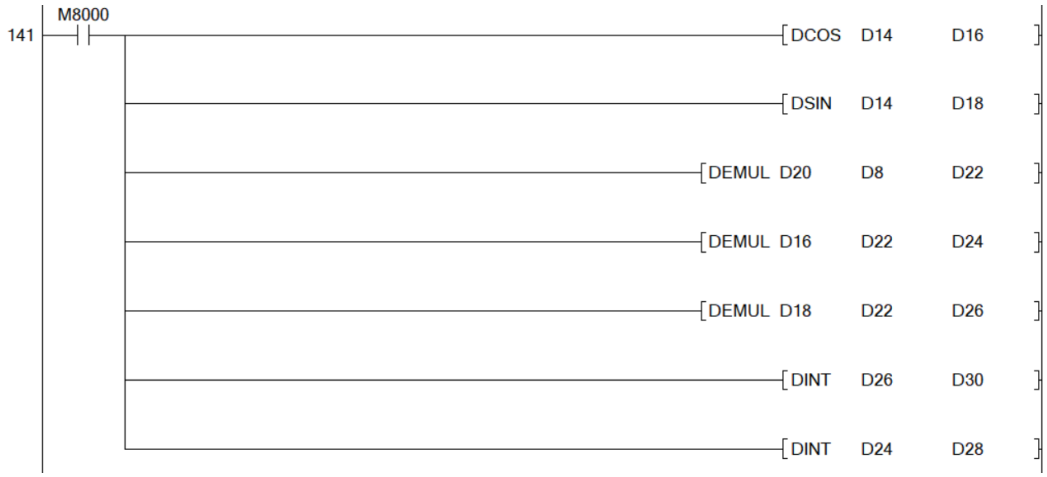
The number of 2000 pulses per turn divided by 360° is the number of pulses per rotation of the encoder, which is stored in register D0.

The number of pulses emitted by the encoder is captured by high-speed counter C251 and stored in D2, and then stored in D4 after floating point processing. The number of pulses divided by the number of pulses per degree of the encoder is the Angle of rotation of the dial. Plus the offset Angle calculated after that is the execution Angle stored in D6.



The PLC sends out 1000 pulses servo to rotate once, the lead screw drives the slider to move 75mm, so 1000 divided by 75 is the number of pulses per millimeter of movement on the X and Y axis. π/180° multiply by execution Angle D6 is stored in D14 as a radian Angle.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

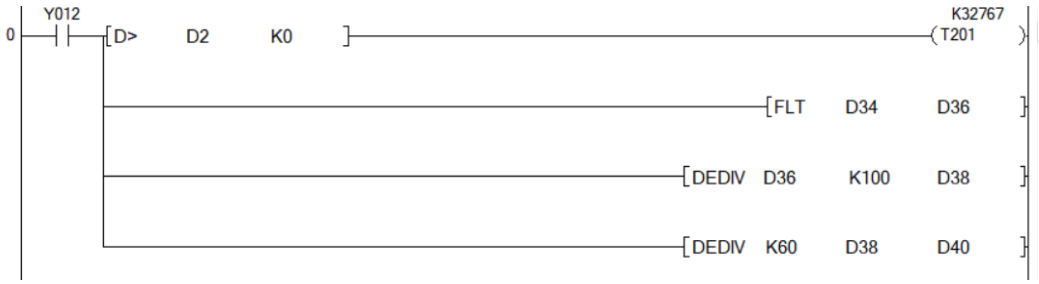


The number of pulses of cos (radian angle) multiply by radius is the number of pulses of the Y-axis to be moved.

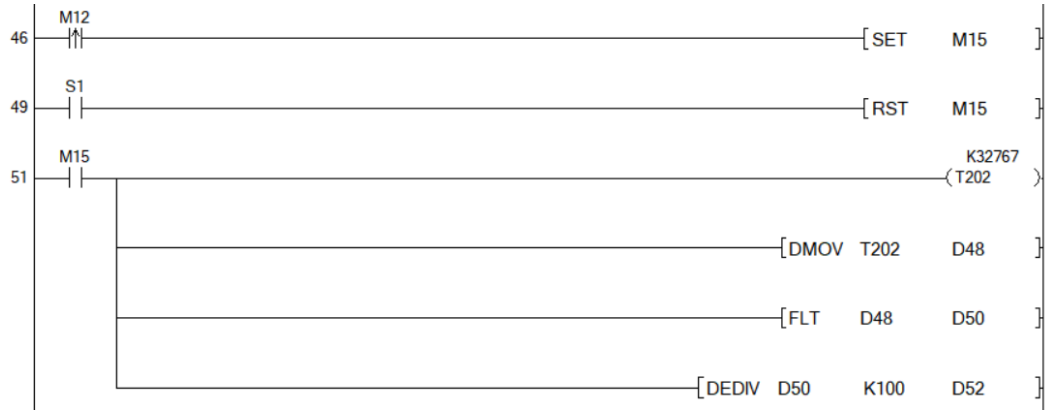
The number of pulses of sin (radian angle) multiply by radius is the number of pulses of the distance to be moved along the X-axis.

The X-axis data is integrated and stored in register D30, and the Y-axis data is integrated and stored in register D28.

(4) Rotation time calculation



When the rotary table is rotating, (the number of current pulses of the encoder - the number of pulses in the last second) divided by the number of pulses per degree is the Angle of rotation of the rotary table for 1S.



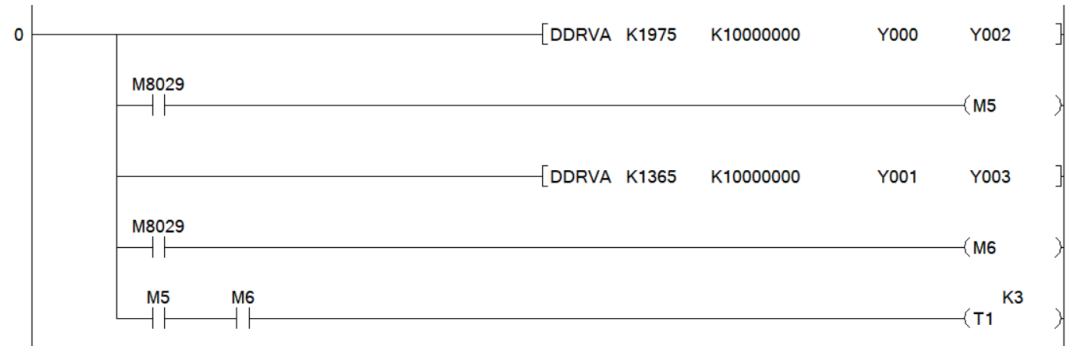
The elapsed time from start to finish is stored in the D52 register.

(5) Flow

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

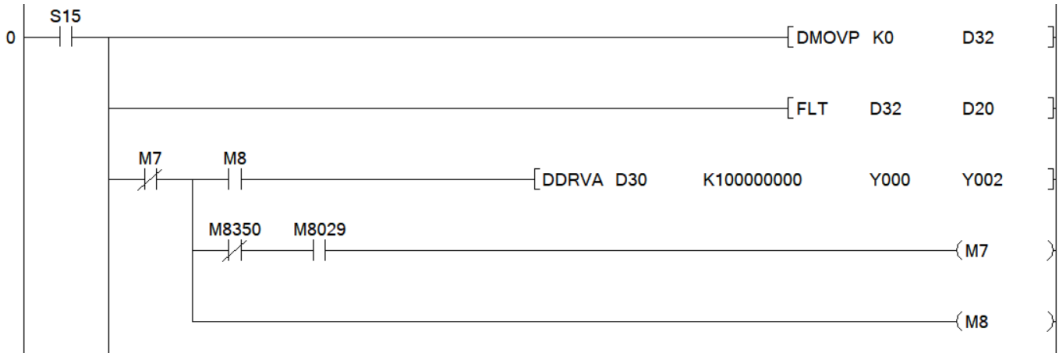
This program block uses SFC language to write, there is a sequence of flow to complete the need to draw the pattern of the whole process.

When the system is initialized and reset, the operation signal S12 is received.



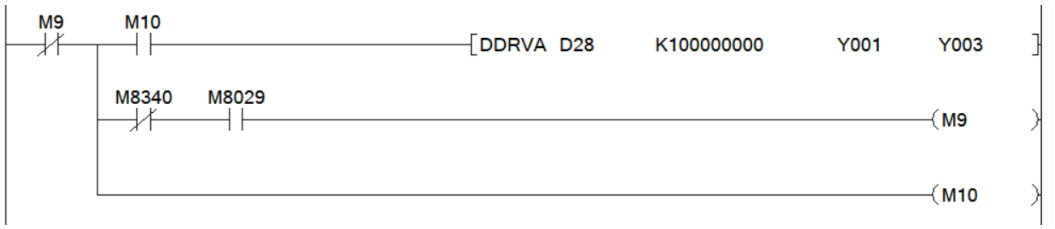
A fixed offset is given to the X-axis and Y-axis from the mechanical origin to make the electromagnetic pen move directly above the center of the turntable. After completion, the electric power is generated by the delay of 0.3S, then S14 get electricity.

Set the absolute pulse number of the current X and Y axes to 0, namely the coordinate of the electromagnetic pen to be (0,0), and the rotation Angle to be 0°.Delay 0.2S,then S15 get electricity.

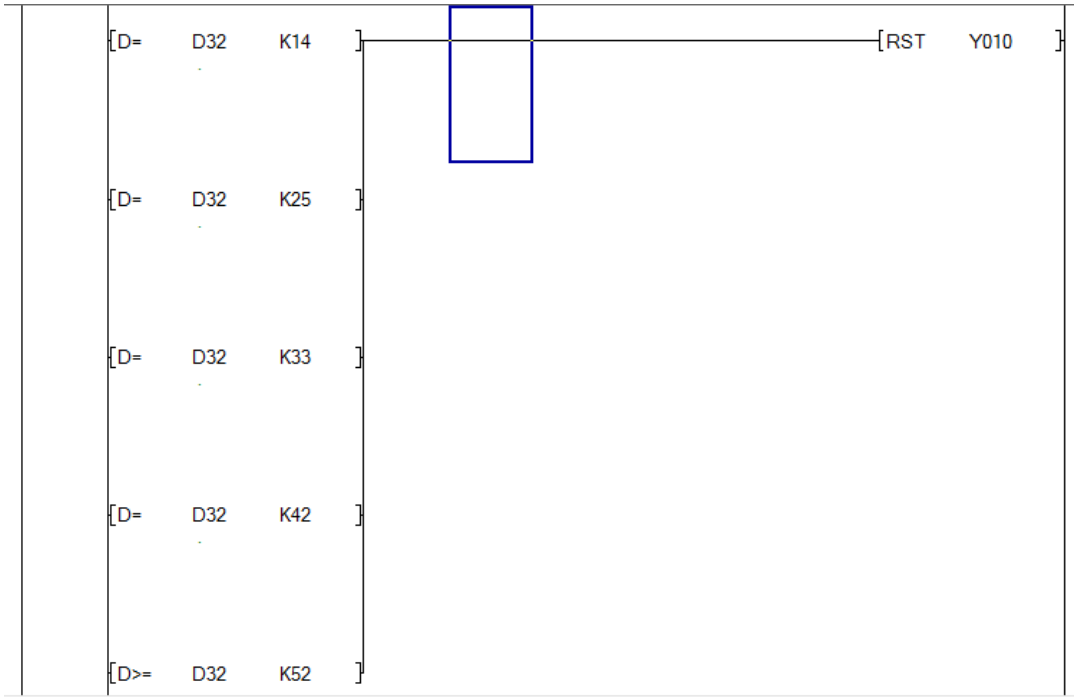


ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

The current radius is set to 0, and the X-axis follows the turntable Angle through the data processing of the "circle calculation" block.

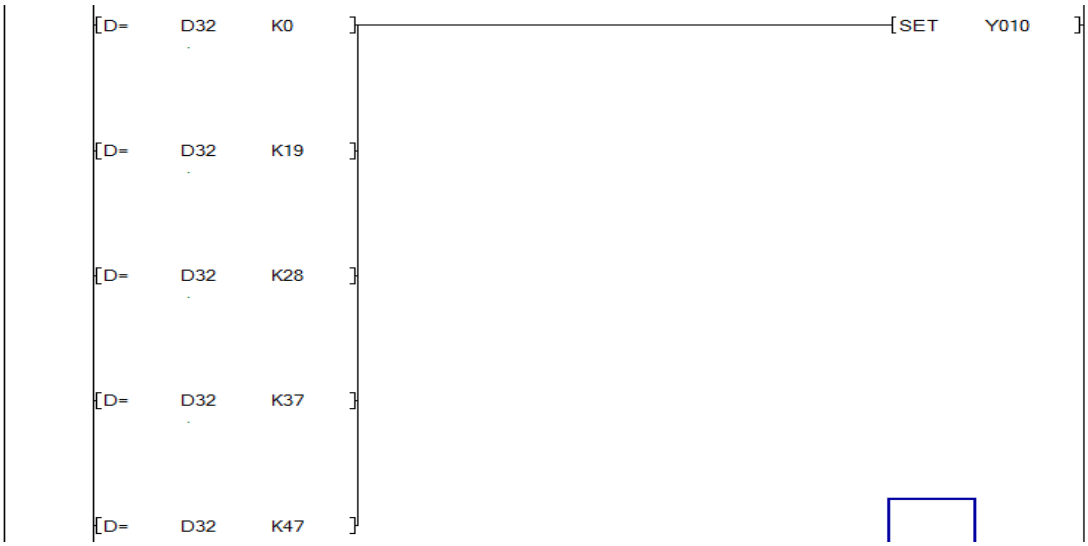


Through the data processing of the "circle calculation" block, the X-axis follows the rotation Angle.

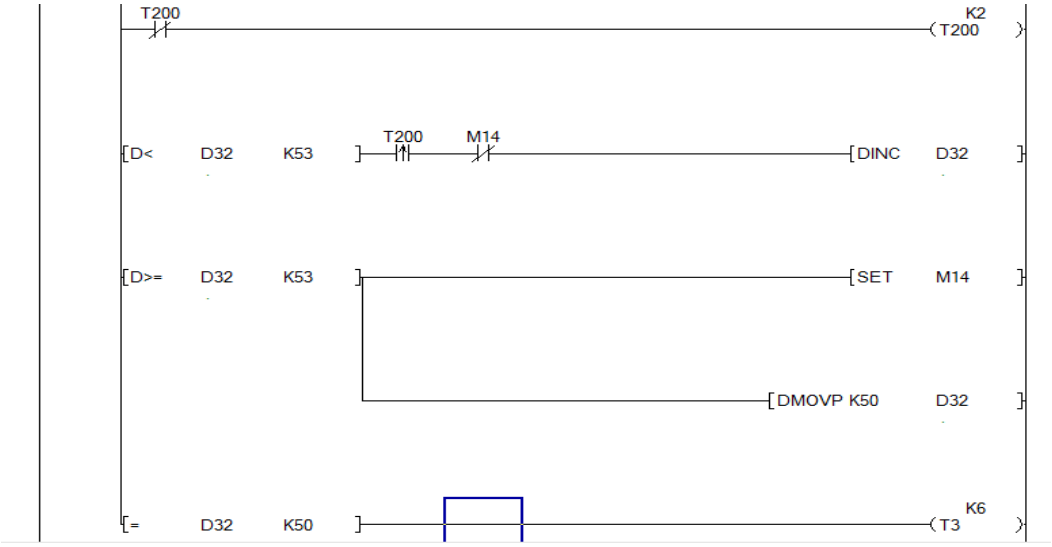


The dotted line of the drawn radius (length is 5mm, interval is 5mm) is constituted, and the electromagnetic pen needs to be absorbed and released accordingly with the expansion of the radius.Circle radius of 50 mm in radius (5, 15, 25, 35, 45) electromagnetic pen need to release, but through the actual debugging found that PLC after the input signal processing, and output to two servo drive, such as electromagnetic pen arrived at the desired location, the wheel is no longer in situ, the error of time, after many debugging find rule changes to the data in the program, the radius (14, 25, 33, 42, 52) released when electromagnetic pen.The size of the design drawn is the most standard.

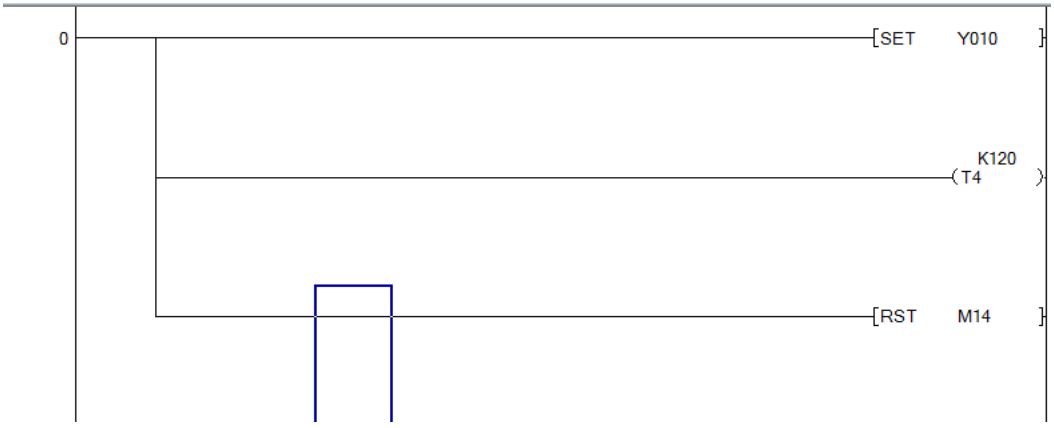
ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015



The magnet pen is attracted at radius (0, 19, 28, 37, 47).

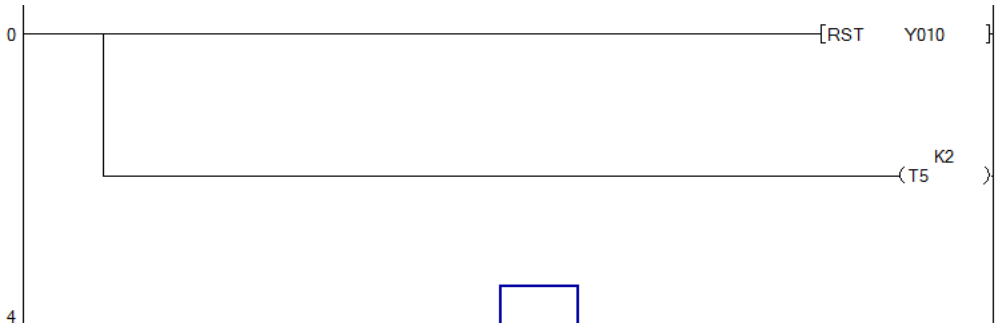


A 0.02s oscillation signal is used to gradually increase the radius. When the radius is 50, it means that the pattern of the drawn radius has been completed. The delay time of 0.6S then S16 generates electricity.

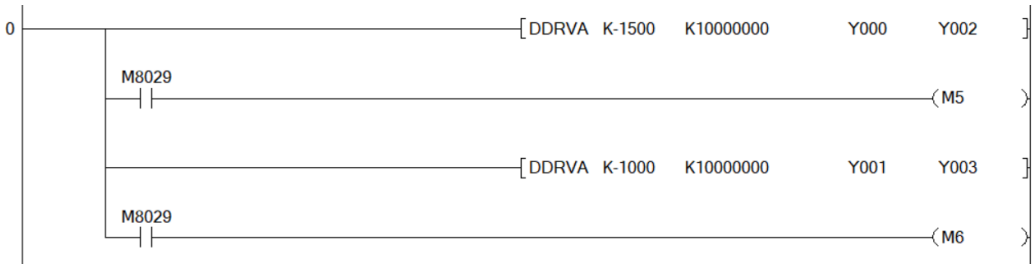


ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

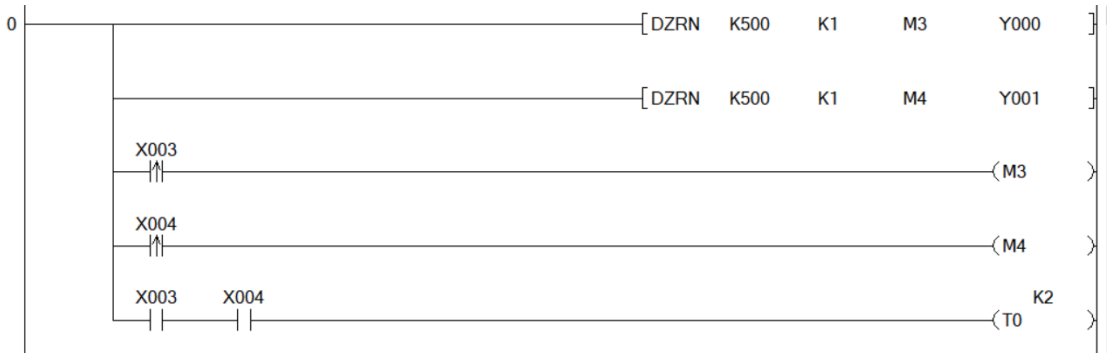
Cause the electromagnetic pen to snap and begin to draw a circle. After painting, S18 gets electricity.



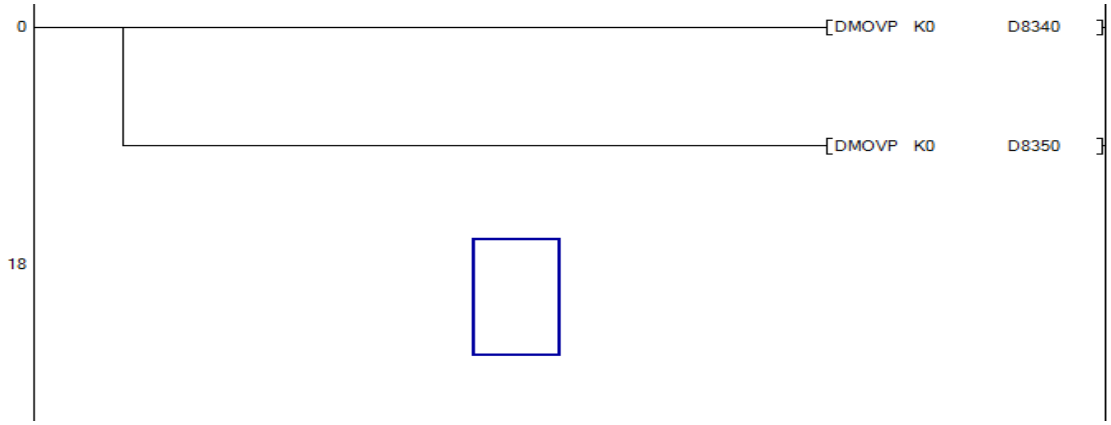
Release the electromagnetic pen after painting. S19 gets electricity after 0.2s.



Give an offset to the X and Y axes to make the electromagnetic pen move to the middle point after S21 electricity.



Perform the back to origin program to move the X and Y axes to the mechanical origin

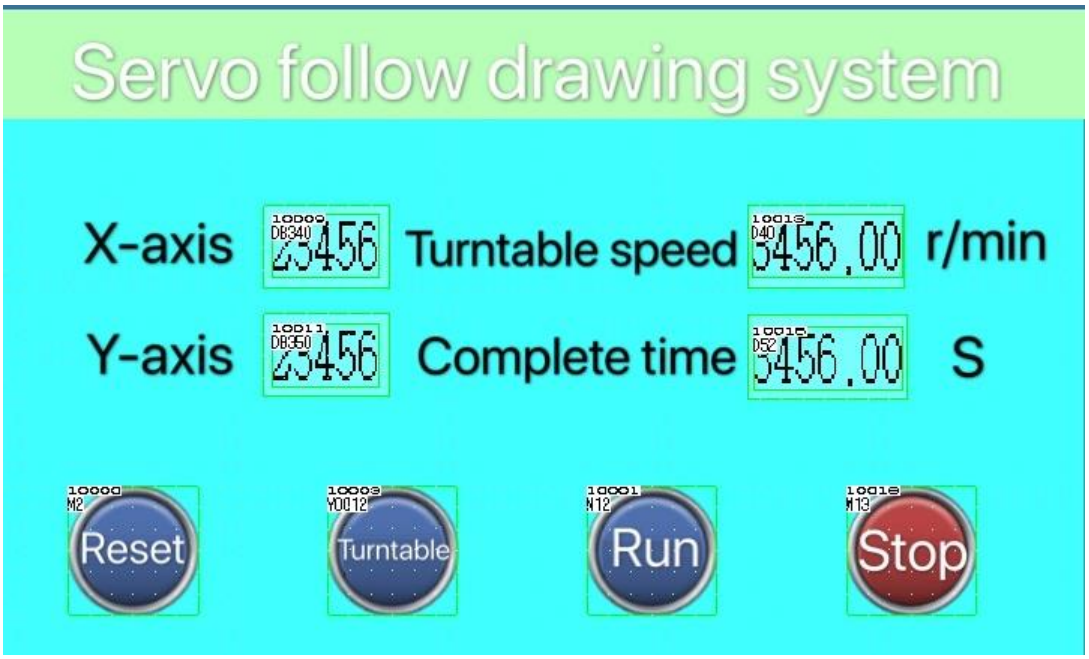


ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202012_3(12).0015

The absolute positions of X and Y axis are cleared, and the execution of following drawing program is completed this time.

5.4. Touch Screen Configuration Screen

AS Fig.9 shows, D8340 is the number of absolute pulses in X-axis, D8350 is the number of absolute pulses in Y-axis, D40 shows the current rotation speed of the rotary table, and D52 shows the time from start to finish. At the same time, four buttons are configured: reset M2, turntable start Y12, system run M12, system stop M13.



6. Conclusion

According to the design requirements, I finally completed the writing of this thesis.In this process, I not only enrich the brain, and improve their practical ability.In two months, I through access to relevant data, more widely realized the importance of servo control in the design, have a deeper understanding in this respect, learned about the design of programming and hardware installation, follow the system based on servo motor, through the project design requirements, induces has achieved the following results:

1. Completed the hardware design of the servo tracking control system, including: the construction of the cross flower table, the design of the electromagnetic pen, the design of the main circuit, the drawing of PLC I/O wiring diagram, etc.

2. Through the preparatory work of this design, we have a further understanding of Mitsubishi products.Systematically studied the use of each device, and programming skills.

3. Due to the relationship between time and resources, the controller used is older and the processing error of arc is relatively large, so the running speed cannot be too high. After that, I will definitely re-plan and upgrade the equipment to achieve the ideal effect.

Acknowledgements

This design is carried out under the guidance of Teacher Liu,from the topic selection to the overall proposal, system design, hardware construction, programming and debugging have been carefully guided by the teacher.Here, I would like to express my heartfelt thanks to Mr Liu!At the same time, I would like to thank my upperclassmen senior and enthusiastic

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