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Research Paper

PLC-controlled stepper motor drive for NC positioning system

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Abstract

In this paper, an electric drive system for precision control of numerically-controlled positioning system is designed, assembled and experimentally tested. The proposed drive system is based on PLC-controlled stepper motor. The PLC is used as an indexer to perform full stepping, half stepping and microstepping modes of operation of stepper motor. The drive system has been implemented in two-axes NC positioning system. The linear displacement for each machine axis has been evaluated and compared for the three stepping modes of stepper motor. Experimental and calculation results show that the response per pulse (resolution) for full stepping mode is $8.35000\mu m$, for half stepping mode is $4.17500\mu m$ and for microstepping mode is $1.04375\mu m$, which means that the microstepping mode is the best one for precision control of NC positioning system.

***Keywords**: Electric Drive, NC Positioning System, PLC, Stepper Motor, Stepping Mode.*

1. Introduction

The stepper motor is an electromechanical actuator which converts the input pulse train into a precisely defined increment in the shaft position. Each pulse moves the shaft through a fixed angle, called step angle. Stepper motors have emerged as cost-effective alternatives for DC servomotors in high-speed, motion control applications, where the high torque is not required, with the improvements in permanent magnets and the incorporation of solid-state circuitry and logic devices in their drive systems. These motors are commonly used in measurement and control applications, such as positioning systems for NC machines, ink jet printers, volumetric pumps, computer peripherals, automotive devices, and small business machines [1], [2].
A stepper motor system, as shown in figure 1, consists of the following three basic components, often combined with user interface [3-5]:

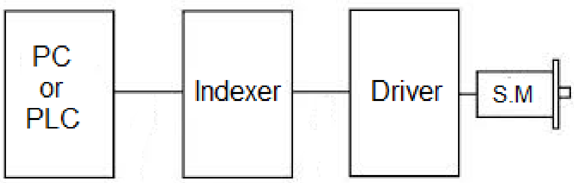

Fig. 1: Block Diagram of Stepper Motor System.

1) Indexer or controller used to generate pulse trains and perform other sophisticated command functions.
2) Driver (or amplifier) who converts the indexer command signals into the power necessary to energize the motor windings.
3) Stepper motor, which converts the pulses into mechanical motion.

According to their construction, stepper motors are classified into three types: variable reluctance, permanent magnet and hybrid. The variable reluctance stepper motor does not use a permanent magnet. As a result, the motor rotor can move without constraint or "detent" torque. The permanent magnet stepper motor has a permanent magnet rotor. It is

relatively low speed, low torque device with large step angles of either 45 or 90 degrees. Hybrid stepper motors combine the best characteristics of variable reluctance and permanent magnet motors.
According to the stator windings, stepper motors are classified into unipolar motors, as shown in figure 2, and bipolar motors, as shown in figure 3.

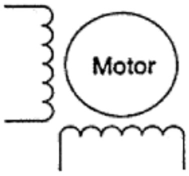

Fig. 2: 4-Lead Unipolar Motor.

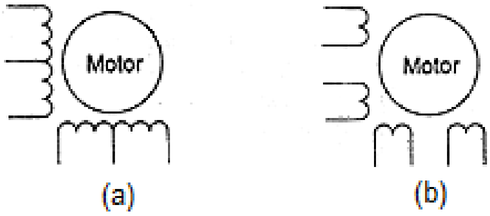

Fig. 3: 6-Lead (A) and 8-Lead (B) Bipolar Motor.

Depending on stepping mode (value of step angle), stepper motors drives are classified as:
1) Half stepping, where the drive alternates between two phases ON and a single phase ON. This increases the angular resolution.
2) Full stepping, where two phases are always ON, so the motor will provide its maximum rated torque.
3) Micro stepping, which is typically used in applications, requiring accurate positioning and fine resolution over a wide range of speeds [6-8].

In this paper, a control circuit of stepper motor based on PLC is designed, assembled and experimentally tested for two-axes, open-loop NC- positioning system. The control circuit enables the stepper motor to operate at any stepping mode. The machine axes can be controlled for three different levels of linear motion (velocity): slow, medium and fast.

2. Description of the proposed NC positioning system

The functional diagram of the proposed NC-positioning system is shown in figure 4 (for x-axis). The system is used for précised motion of the work table in x-y plane. The main components of the system are:
1) Two stepper motors for x and y-machine axes. The technical specifications of the selected motors are given in table 1.
2) Lead screw, with pitch $p = 1.67 mm / rev$
3) Work table
4) Frame of 62cm x 30 cm dimension.
5) Control circuit, which is shown in figure 5.

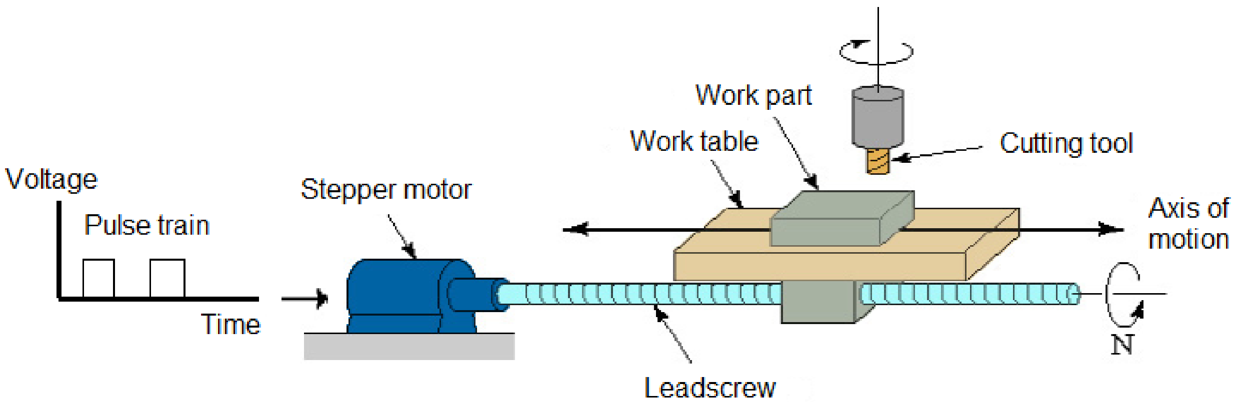

Fig. 4: Functional Diagram of Open-Loop NC Positioning System.

Table 1: Technical Specifications of Motors

Item	Motor 1	Motor 2
Name	Nippon pulse motor	Vexta stepping motor
Model	PF55-48015	C62244-9212K
Resistance	100 Ω	7.4 Ω
Step angle	7.5^o	1.8^o
Shaft diameter	4 mm	6 mm
Type	Hybrid HB	Hybrid HB

The control circuit consists of user interface, indexer and driver. The function of user interface is to determine the operation mode, select the machine axis, select the velocity of table and avoid the table to exceed the range of motion axis. The PLC is used as indexer. The 470Ω resistors in the PLC outputs are used for protection purpose. The dual-H bridge L298 (figure 6) is used to drive the stepper motors coils according to the required sequence of stepping.

The PLC is managed to achieve the following stepping modes:

1) Full stepping mode, according to the sequence shown in table 2.

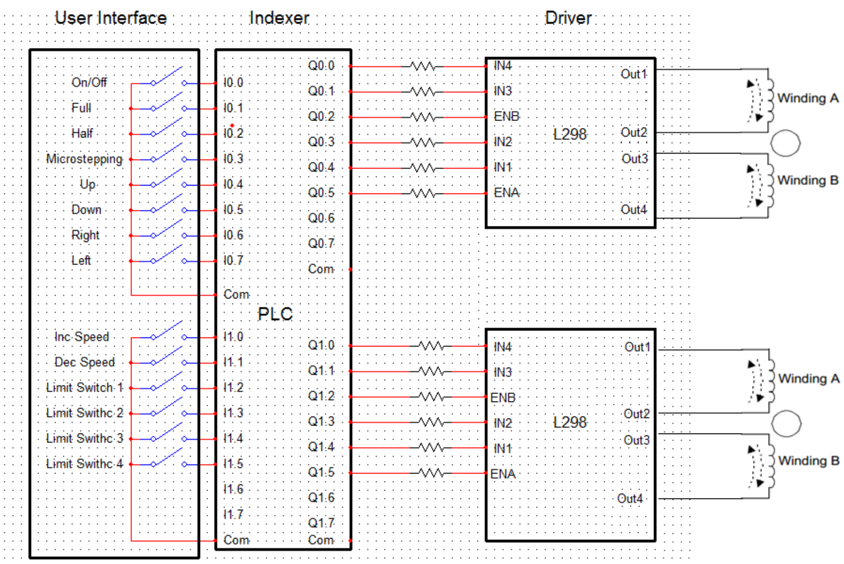

Fig. 5: Circuit Diagram of the Control System.

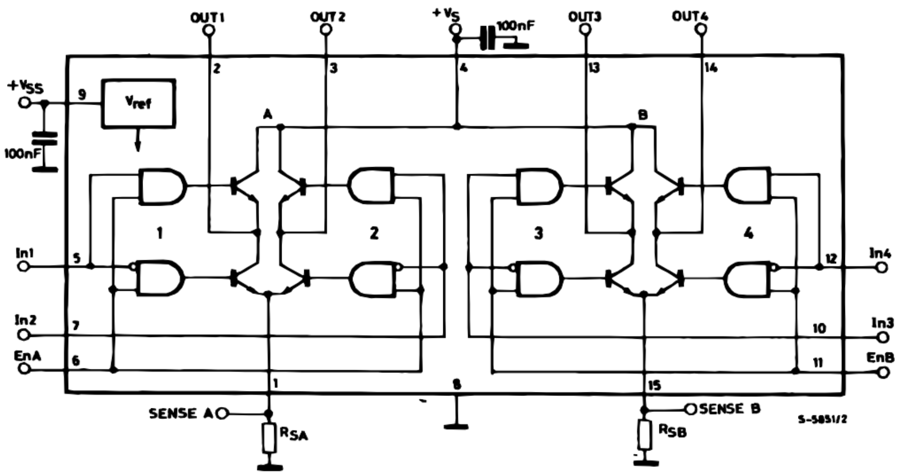

Fig. 6: Circuit Diagram of H-Bridge 298.

Table 2: Sequence for Full Stepping Mode

Winding A	Winding B	Step number
+	0	1
0	+	2
-	0	3
0	-	4

The legend "0" means coil OFF, "+" means current flows in one direction, and "-" means current flows in the opposite direction.
Figure 7 illustrates the voltage waveform for full stepping mode.

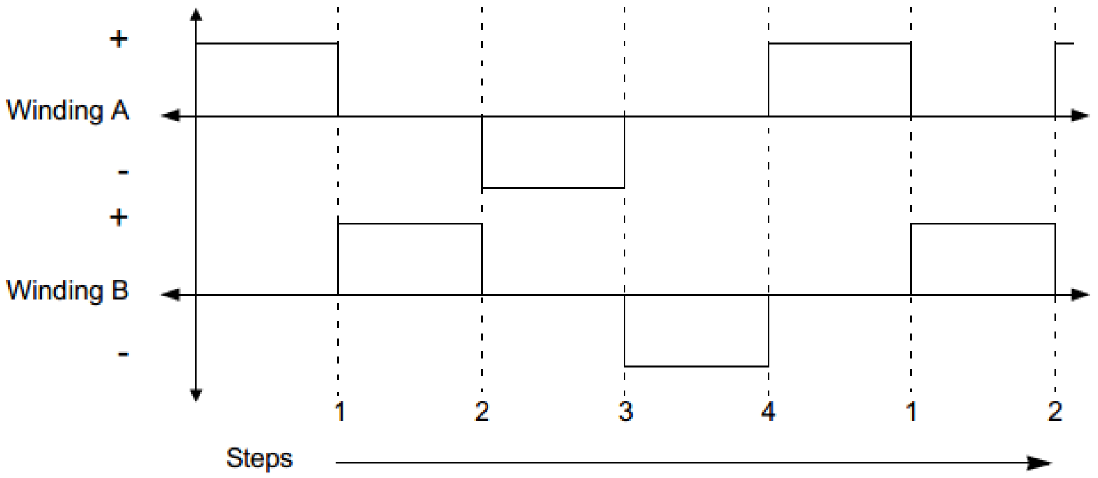

Fig. 7: Voltage Waveform for Full Stepping Mode.

To realize the previous sequence, the outputs of PLC (H-bridge inputs) are defined as in table 3.

Table 3: Definition of PLC Outputs

Step number	State
1	A+: IN1=1, ENA=1, IN2=0
2	B+: IN3=1, ENB=1, IN4=0
3	A-: IN1=0, ENA=1, IN2=1
4	B-: IN3=0, ENB=1, IN4=1

The block diagram for full stepping mode is shown in figure 8.

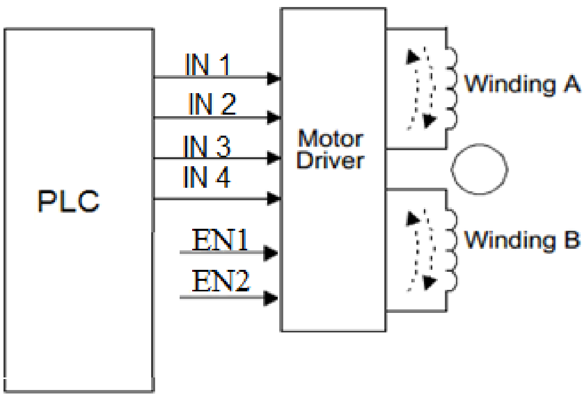

Fig. 8: Block Diagram for Full Mode Connection.

The above results are arranged in table 4. The decimal numbers are obtained from binary numbers, and they represent the PLC outputs from Q0.0 to Q0.7.

Table 4: Full Stepping Mode Sequence

Step number	ENA	IN1	EN2	INB	IN3	IN4	Decimal
1	1	1	0	0	0	0	48
2	0	0	0	1	1	0	6
3	1	0	1	0	0	0	40
4	0	0	0	1	0	1	5

2) Half stepping mode, according to table 5.

Table 5: Half Stepping Mode Sequence.

Step number	1	2	3	4	5	6	7	8 (0)
Rotor position	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4/0
Current in winding A	+	0	-	-	-	0	+	+
Current in winding B	+	+	+	0	-	-	-	0

Figure 9 illustrates the voltage waveform for full stepping mode.

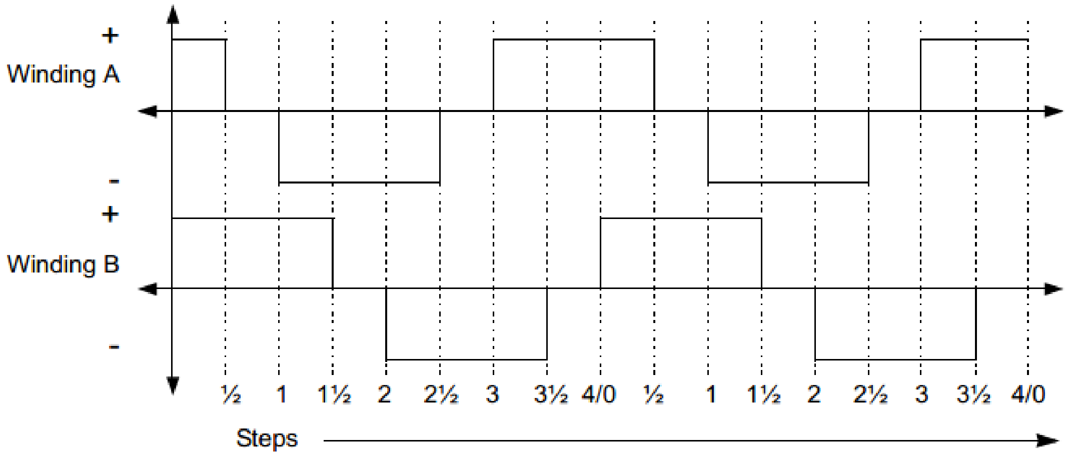

Fig. 9: Voltage Waveform for Half Stepping Mode.

To realize the previous sequence, the outputs of PLC (H-bridge inputs) are defined as in table 6.

Table 6: Definition of PLC Outputs for Half Stepping Mode

Step number	State
1	IN1=1, IN3=1, ENA=1, ENB=1, IN2=0, IN4=0
2	IN3=1, ENB=1, IN4=0
3	IN1=0, ENA=1, IN2=1, IN3=1, ENB=1, IN4=0
4	IN1=0, ENA=1, ENB=1
5	IN1=0, ENA=1, IN2=1, IN3=0, ENB=1, IN4=1
6	IN3=0, ENB=1, IN4=1
7	IN1=1, INA=1, IN2=0, IN3=0, ENB=1, IN4=1
8	IN1=1, ENA=1, IN2=0

The above results are arranged in table 7. The decimal numbers are obtained from binary numbers, and they represent the PLC outputs from Q0.0 to Q0.7.

3) Micro stepping mode, which can be achieved by one of the following methods: the first one is to make the current in winding A follow the $\sin\theta$ function, and the current in winding B follow the $\cos\theta$ function and the second method, the current in one winding is kept constant over half of the complete step and current in other winding is varied as a function of $\sin\theta$ to maximize the motor torque. The first method can be realized by varying PWM duty cycle to control the current through the coils. The resultant current in any coil at any angle θ should remain constant and equal to peak value.

Table 8 was designed to decide the values of the PWM through the duty cycle for $\sin\theta$ and $\cos\theta$ functions.

Table 7: Half Stepping Mode Sequence

Step	- 8	- 7	ENA 6	IN1 5	IN2 4	ENB 3	IN3 2	IN4 1	Decimal
1	0	0	1	1	0	1	1	0	54
2	0	0	0	0	0	1	1	0	6
3	0	0	1	0	1	1	1	0	46
4	0	0	1	0	1	0	0	0	40
5	0	0	1	0	1	1	0	1	45
6	0	0	0	0	0	1	0	1	5
7	0	0	1	1	0	1	0	1	53
8	0	0	1	1	0	0	0	0	48

Table 8: Micro stepping Sequence According to the First Method

No. of steps	Microstep Angle	Sine Function (with scale)	Cose Function (with scale)
0	0	0	160
1	2.8125	8	159
2	5.625	16	159
3	8.4375	24	158
4	11.25	32	156
5	14.0625	39	155
6	16.875	47	153
7	19.6875	54	150
8	22.5	62	147
9	25.3125	69	144
10	28.125	76	141
11	30.9375	83	137
12	33.75	89	133
13	36.5625	96	128
14	39.375	102	123
15	42.1875	108	118
16	45	114	113
17	47.8125	119	107
18	50.625	124	101
19	53.4375	129	95
20	56.25	134	88
21	59.0625	138	82
22	61.875	142	75
23	64.6875	145	68
24	67.5	148	61
25	70.3125	151	53
26	73.125	154	46
27	75.9375	156	38
28	78.75	157	31
29	81.5625	159	23
30	84.375	160	15
31	87.1875	160	7
32	90	160	0
33	92.8125	160	7
34	95.625	160	15
35	98.4375	159	23
36	101.25	157	31
37	104.0625	156	38
38	106.875	154	46
39	109.6875	151	53
40	112.5	148	61
41	115.3125	145	68
42	118.125	142	75
43	120.9375	138	82
44	123.75	134	88
45	126.5625	129	95
46	129.375	124	101
47	132.1875	119	107
48	135	114	113
49	137.8125	108	118
50	140.625	102	123
51	143.4375	96	128
52	146.25	89	133
53	149.0625	83	137
54	151.875	76	141
55	154.6875	69	144
56	157.5	62	147
57	160.3125	54	150
58	163.125	47	153
59	165.9375	39	155
60	168.75	32	156
61	171.5625	24	158
62	174.375	16	159
63	177.1875	8	159
64	180	1	160

The microstepping chart for the first method is shown in figure 10.

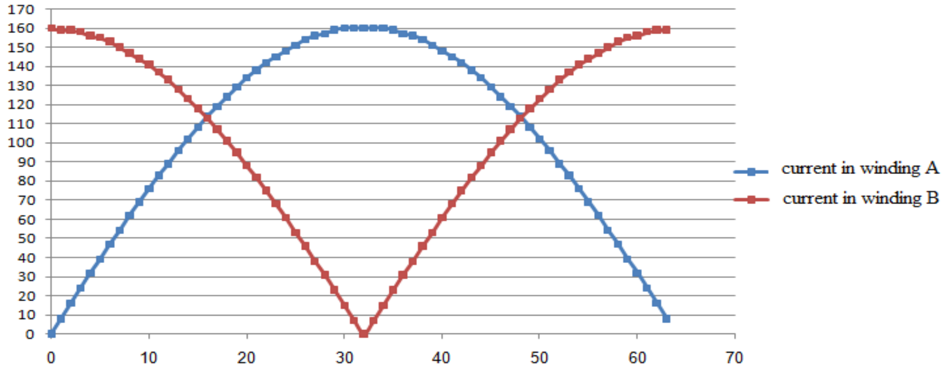

Fig. 10: Micro stepping Chart for the First Method.

In the second method of microstepping, the current in one winding is kept constant over a half of the complete step (90^0), and the current in the other winding varies as a function of $\sin\theta$ to maximize the motor torque.
Figure 11 illustrates the circuit for microstepping mode. PWM1 and PWM2 show the current percentage in each winding. CD1 and CD2 show the current direction in each winding, which determines the motor direction (FWD or REV).

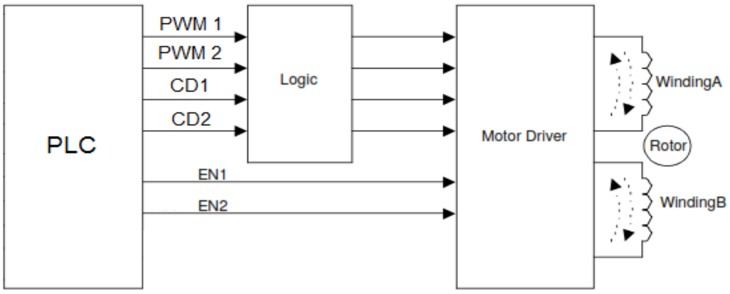

Fig. 11: Block Diagram For Microstepping Mode.

The microstepping sequence is shown in table 9 and the microstepping chart is shown in figure 12.
The first column in table 9 shows the number of steps or pulses, the second column shows the electrical angle for each pulse, the third one shows the current percentage in winding A, and the fourth one shows the current in winding B.
The PLC acts as indexer, which gives the desired pulses according to the stepping mode and table velocity. The logic block controls the current direction, which depends on the motor speed direction. The motor driver (dual H-bridge) enables the current in the same winding to flow in different directions. PLC here acts like an indexer, which give pulses decide the direction and the working mode (Full or Half or Microstepping mode) and the velocity, and make controlling for other things.

Table 9: Micro stepping Sequence (Second Method)

		PWM 1	PWM 2	CD1		CD2	
No. of steps	Microstep Angle	Current in winding A	Current in winding B	FWD	REV	FWD	REV
0	0.00	100%	0%	H	H	H	L
1	2.81	100%	5%	H	H	H	L
2	5.63	100%	10%	H	H	H	L
3	8.44	100%	15%	H	H	H	L
4	11.25	100%	20%	H	H	H	L
5	14.06	100%	25%	H	H	H	L
6	16.88	100%	30%	H	H	H	L
7	19.69	100%	34%	H	H	H	L
8	22.50	100%	39%	H	H	H	L
9	25.31	100%	43%	H	H	H	L
10	28.13	100%	48%	H	H	H	L
11	30.94	100%	52%	H	H	H	L
12	33.75	100%	56%	H	H	H	L
13	36.56	100%	60%	H	H	H	L
14	39.38	100%	64%	H	H	H	L
15	42.19	100%	68%	H	H	H	L
16	45.00	100%	71%	H	H	H	L
17	47.81	75%	100%	H	H	H	L
18	50.63	78%	100%	H	H	H	L
19	53.44	81%	100%	H	H	H	L
20	56.25	84%	100%	H	H	H	L
21	59.06	86%	100%	H	H	H	L
22	61.88	89%	100%	H	H	H	L
23	64.69	91%	100%	H	H	H	L
24	67.50	93%	100%	H	H	H	L
25	70.31	95%	100%	H	H	H	L
26	73.13	96%	100%	H	H	H	L
27	75.94	98%	100%	H	H	H	L
28	78.75	99%	100%	H	H	H	L
29	81.56	99%	100%	H	H	H	L
30	84.38	100%	100%	H	H	H	L
31	87.19	100%	100%	H	H	H	L
32	90.00	100%	100%	H	H	H	L
33	92.81	100%	100%	H	H	H	L
34	95.63	100%	100%	H	H	H	L
35	98.44	100%	99%	H	H	H	L
36	101.25	100%	99%	H	H	H	L
37	104.06	100%	98%	H	H	H	L
38	106.88	100%	96%	H	H	H	L
39	109.69	100%	95%	H	H	H	L
40	112.50	100%	93%	H	H	H	L
41	115.31	100%	91%	H	H	H	L
42	118.13	100%	89%	H	H	H	L
43	120.94	100%	86%	H	H	H	L
44	123.75	100%	84%	H	H	H	L
45	126.56	100%	81%	H	H	H	L
46	129.38	100%	78%	H	H	H	L
47	132.19	100%	75%	H	H	H	L
48	135.00	100%	71%	H	H	H	L
49	137.81	68%	100%	H	H	H	L
50	140.63	64%	100%	H	H	H	L
51	143.44	60%	100%	H	H	H	L
52	146.25	56%	100%	H	H	H	L
53	149.06	52%	100%	H	H	H	L
54	151.88	48%	100%	H	H	H	L
55	154.69	43%	100%	H	H	H	L
56	157.50	39%	100%	H	H	H	L
57	160.31	34%	100%	H	H	H	L
58	163.13	30%	100%	H	H	H	L
59	165.94	25%	100%	H	H	H	L
60	168.75	20%	100%	H	H	H	L
61	171.56	15%	100%	H	H	H	L
62	174.38	10%	100%	H	H	H	L
63	177.19	5%	100%	H	H	H	L
64	180.00	1%	100%	H	H	H	L

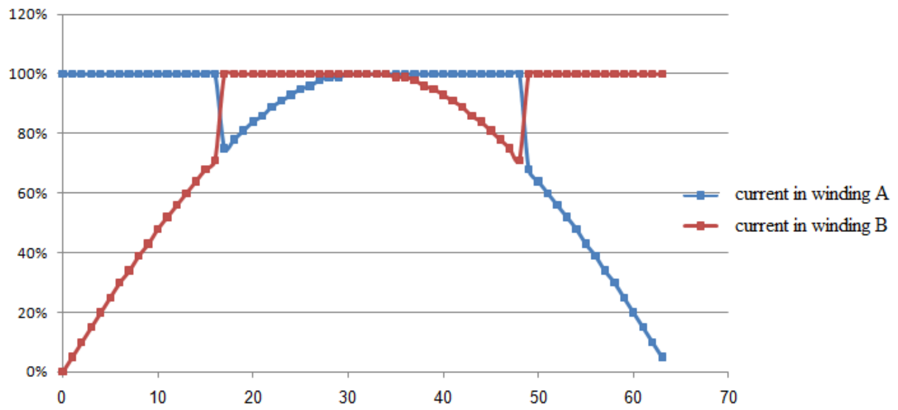

Fig. 12: Micro stepping Chart (Second Method).

The control panel is shown in figure 13. It contains ON/ OFF push button to turn ON or OFF the system, stepping mode selector, two push buttons to change the speed, and four push buttons to select the direction.

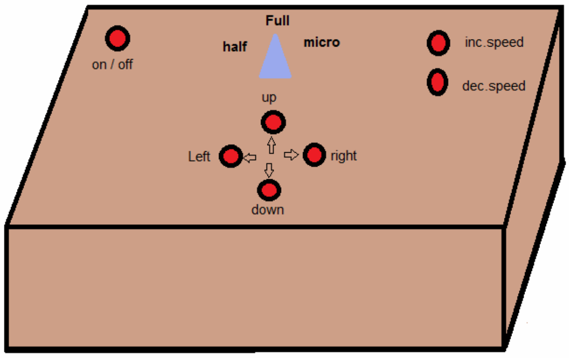

Fig. 13: Control Panel.

The PLC has been programmed to perform the desired tasks according to the different stepping modes.

3. Main results

The proposed system was assembled, programmed and tested to control NC positioning system according to three stepping modes. The results are given in tables (10-12).

Table 10: Results for Full Stepping Mode

Indicator	Slow speed	Medium speed	High speed
Step time, ms	50.75	25.75	11.5
Rotational speed, rpm	5.91	11.65	26.1
Linear velocity, mm/min	9.87	19.46	43.59
Resolution, μm	8.3500	8.3500	8.3500
Accuracy, μm	4.8000	4.8000	4.8000

Table 11: Results for Half Stepping Mode

Indicator	Slow speed	Medium speed	High speed
Step time, ms	25.37	12.87	5.75
Rotational speed, rpm	5.91	11.65	26.1
Linear velocity, mm/min	9.87	19.46	43.59
Resolution, μm	4.1750	4.1750	4.1750
Accuracy, μm	2.5000	2.5000	2.5000

Table 12: Results for Micro stepping Mode

Indicator	Slow speed	Medium speed	High speed
Step time, ms	6.34	3.22	1.44
Rotational speed, rpm	5.91	11.65	26.1
Linear velocity, mm/min	9.87	19.46	43.59
Resolution, μm	1.0437	1.0437	1.0437
Accuracy, μm	0.6500	0.6500	0.6500

4. Conclusion

In this paper, a PLC-based control scheme is proposed to provide any stepping mode of stepper motor to control the motion of two-axes NC positioning system with high accuracy. Experimental and calculation results confirm the validity of the proposed system. The main advantage of the proposed system is its simplicity, high accuracy and it does not need conventional programming codes.

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