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# PLC Controlled Multiple Stepper Motors Using Various Excitation Methods

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**Abstract**— Stepper Motors (SMs) are precise and exact in generating discrete stationary angular revolutions, and for these reasons it has recently been used in Robotic Devices. This paper introduces a design and implementation of three methods to control a two SMs using Programmable Logic Controller (PLC). These methods are: wave, half, and full Stepping Excitation Method (SEM). The speed, number of rotations, and direction (Bi-directional) of SMs are manipulated in each one of these methods. Experimentally, Siemens LOGO! 230 RC (as a basic PLC unit), with the aide of Digital Module LOGO! DM8 230R (as an expansion module) has been used in our work. LOGO! Soft Comfort Version 8.2 has been used to build our algorithms for the speed, displacement of rotations, and direction control of SMs. Function Block Diagram (FBD) semantic design program is employed to achieve the proposed PLC controller programs for SMs. This paper highlights the simplicity of possibility to control the SMs by using any type of the SEMs based on PLC . Using the PLC will save electronic components used in the drive circuit because it is not required any interface circuit linking the PLC and the SMs, as a result this will minimizing the cost and develop the whole reliability of the controller.

**Keywords**— PLC, FBD, Wave SEM, Half SEM, Full SEM, and Robotic System.

## I. INTRODUCTION

In the industrialized world, automation is one of the basic factors for advance. It benefits to decrease the requisite for humans (i.e. reduce human mistakes), obtain additional accurate work, and increase production. The field of automation takes up great regions, typically in industrial manufacturing; as well the automation is functional to construct a great deal of sophisticated kit which is used daily as medical equipment X-ray machines, radiography, and automobiles, etc. Amongst entirely of these consequences, the Robotic Arm (RA) is important one of them [1, 2]. RA has a free turning joint plus a displacement joint for the movement of the arm as shown in Fig. 1. This arm movement is typically driven by an electrical driver (motor). These actuators are directed by a controller (CPU) [3, 4].

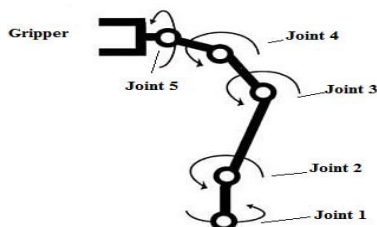


Fig. 1 RA

The finest motors which can be worked as actuator in RA are the SMs. As are move by a discrete angle called the step angle (Stride angle) in each step, are described by high torque and are accomplished of hold great loads through specific movements. The properties of SMs over other AC or DC motors comprise [5, 6]: It realize accurate control of displacement without any feedback sometimes, Non accumulative positional errors, Precise electronic speed controller via digital technology, are brushless, low inertia & high respond frequency, and therefore, it pertains numerous excellent characteristics as direct start and instantaneous stop.

Programming and controlling of SMs of the RA can be obtained by using different controller such as parallel port of PC [7], Microcontroller [5, 8], CPLD [9], FPGA [10], Arduino processor [11]. PLC is a typically a control device acting a major role in manufacturing automation. PLC offers higher degree of strength, cheaper than another options and ease of usage; So, PLCs are generally considered as low level systems, whose main purpose is to control using basic Boolean signals. However, modern PLCs have adequate computational power to execute complex mathematical calculations using several encoding languages [1, 3, and 12]. This allows developers to implement various algorithms for controlling the motors of RA on PLC instead of other previous mentioned processors. This paper investigates the possibility of using a PLC to control such motors using FBD language.

## II. SEMS OF SM

There are three modes of exciting a unipolar SM motor. The mode of operation is governed by the step sequence related to the windings of the SM, these are:

### A. Wave SEM

In this method, only a single coil of winding is excited as shown in Fig. (2 - a). Steps are applied in order starting step 1 towards step 4. Later step 4, the sequence is continual from step 1; then the motor will rotate clockwise. Swapping the order of step beginning from step 4 toward step 1 will force the motor to rotate anticlockwise direction as shown in Fig. (2-b) [13, 14 and 15].

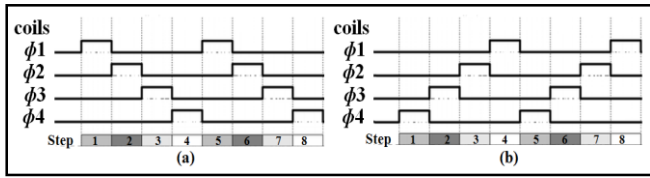


Fig. 2 Sequence of wave SEM: (a) Clockwise, (b) Anticlockwise

**B. Full SEM**

In this technique, double coils of windings of SM are activated instantaneously as shown in figure (3-a). Full natural steps revolution is realized in this technique so that it is named full SEM. Each time to trigger a different step, the polarity of the input winding, is inverted; this will creates a full rated torque [13, 14]. As in previous mode, reversing order causes it turn counter-clockwise as presented in figure (3-b) [5, 13].

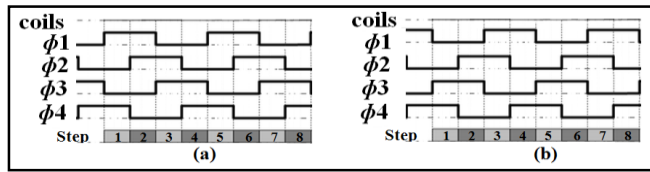


Fig. 3 Sequence of full SEM: (a) Clockwise, (b) Anticlockwise

**C. Half SEM**

This method is a mix of the previous two sequences. In this method of excitation, the step angle of the SM decreases to half the angle of the full mode, so that the resolution also improved (becomes twice the angular resolution as compared the full SEM). In this sequence, the No. of steps becomes doubled as that of full SEM. Fig. 4 shows the arrangement of stepping excitation of the coils in two directions [13].

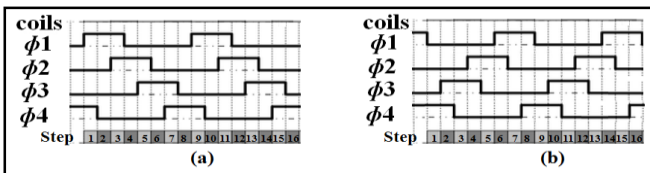


Fig. 4 Sequence of half SEM: (a) Clockwise, (b) Anticlockwise

**III. HARDWARE CONFIGURATION**

A PLC is a digitally operating electronic device which uses a programmable memory for internal storage of instructions for implementing specific functions, such as logic sequencing, timing, counting and control through digital or analog input/output modules. These inputs and outputs are logically programmed by a simulated program designed in a computer in different forms, such as a ladder diagram, a structural text and a FBD and stored in the PLC’s memory [1, 4].

The PLC that is used in the work is SIEMENS LOGO! 230 RC (0BA6 version) and known as (LOGO! Basic) [16]; which

has 115 – 240 V AC/DC input voltage, 8 AC/DC digital inputs, 4 relays (10 A) as a digital outputs which are mainly used to provide operating signal for the first SM. Digital Module (DM) (LOGO! DM8 230R with 4 relays (10 A) as a digital outputs) is added to the LOGO! Basic as an expansion module to increase the digital outputs for driving the second SM. It’s worth mentioning, one PLC unit can be controls many numbers of the SMs by adding an external module DM8 to the basic LOGO. Four of digital module (DM8) can be added to the LOGO! Basic which means that’s five of SM can be controlled. An external DC power supply (24V, 5A) is used to supply the SMs coils via PLC outputs .

The outputs of the LOGO! Basic (Q1, Q2, Q3, and Q4 as normally open relays contact) drive the first SM coils ( $\phi11$ ,  $\phi12$ ,  $\phi13$ , and  $\phi14$  respectively) as is shown in figure 6. Outputs of the DM8 (Q5, Q6, Q7, and Q8 also as normally open relay contact) are used to drive the second SM coils ( $\phi21$ ,  $\phi22$ ,  $\phi23$ , and  $\phi24$ ) respectively. The technical specifications of the SMs (two symmetrical motors) that are used in this work are: M35SP-5 series, Unipolar type, Hybrid coil type, 7.5 degree/pulse (step angle), 24V rated voltage, 173 mA rated current.

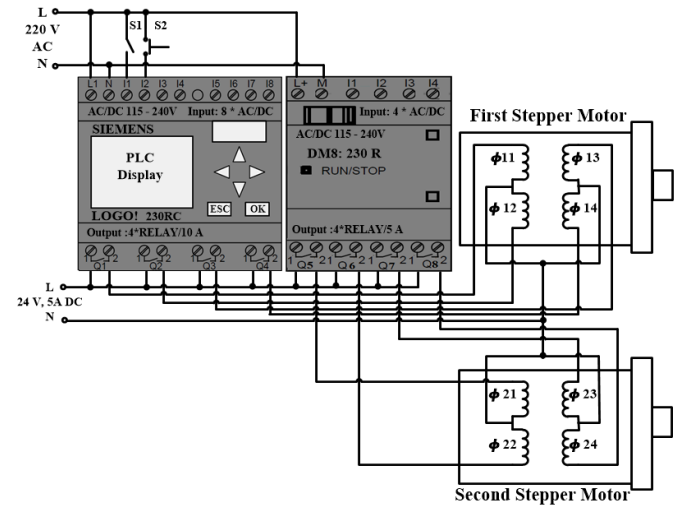


Fig. 5 PLC based SMs control connection diagram

**IV. SOFTWARE REALIZATION OF THE PROPOSED PLC PROGRAM STRUCTURES**

Three techniques of SEMs (Wave, Half, and Full) were employed for guiding the SMs, thus three of PLC program structure are designed and implemented for each situation. The PLC program structures are shaped in LOGO! Soft Comfort V8.2 by means of FBD language as will discussed in details later. LOGO! Soft Comfort program is available as a programming package for the PC. The general flow chart of the proposed programs for one of the SMs is shown in Fig. 6.

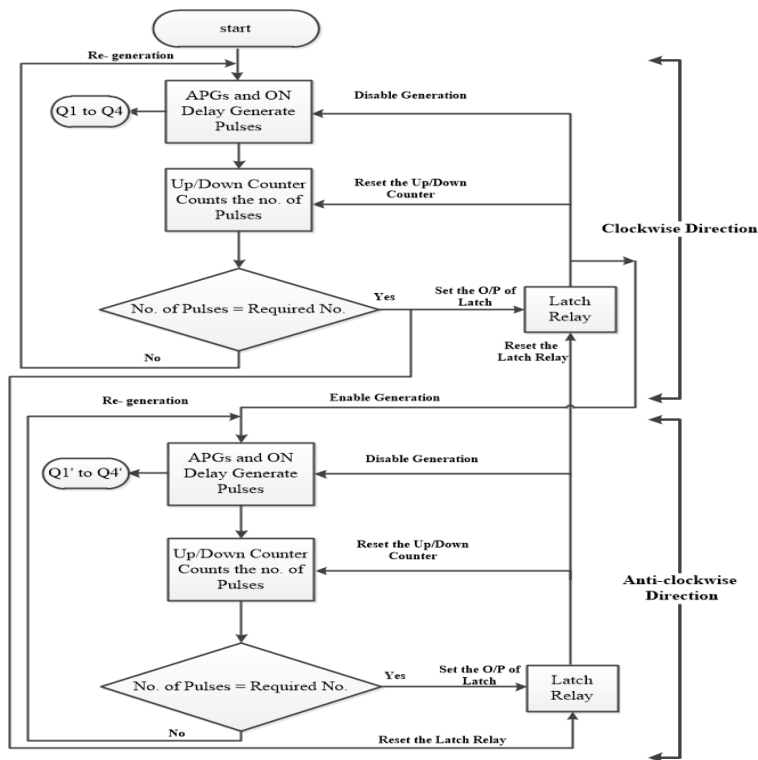


Fig. 6 Flow chart of the proposed controller for first SM

A. Implementation of Wave SEM:

The FBD control program of the SMs based on wave SEM is shown in Fig. 7.

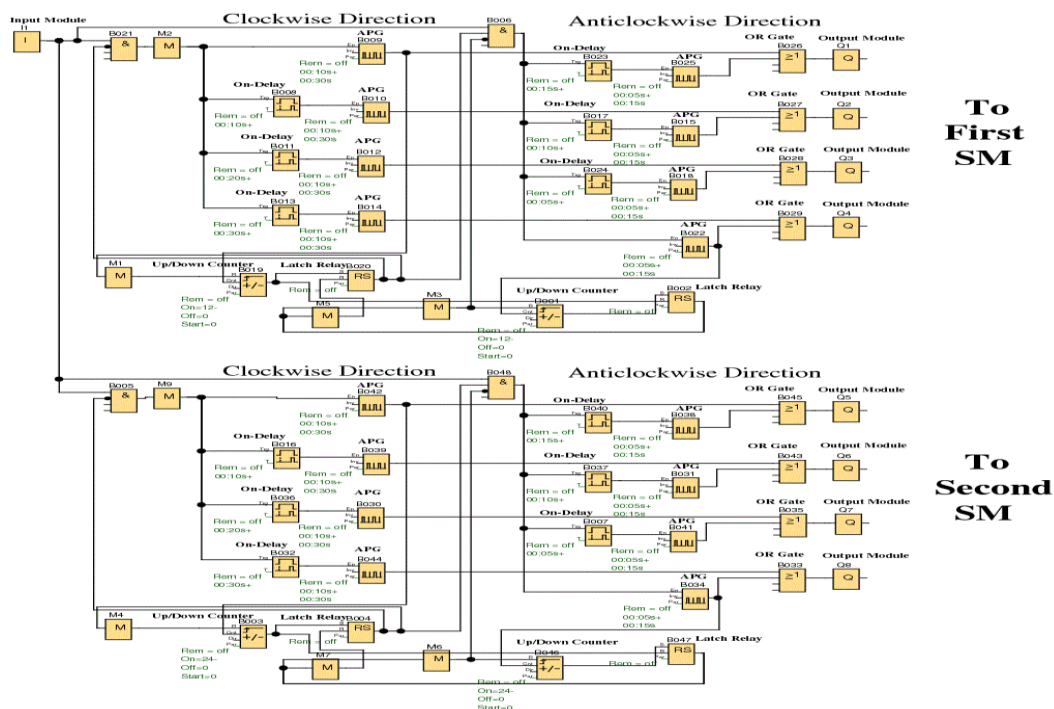


Fig. 7 FBD control program of the SMs based on wave SEM

The proposed program involved of collection of basic electronic logic devices are executes as following: - Switch (S1) on the Input Module (I1) of the PLC is utilized for enable the PLC proposed program.

- Asynchronous Pulse Generator (APG) units are utilized to produce the required pulses for the phases of SM in each direction.
- The speed of the motor is adjusted by controlling the pulse shape that generated from the APG; the pulse shape can be set by a configurable ON/OFF ratio by adjust the internal parameters of the APG: pulse width (or Time High TH) and the interpulse width (or Time Low TL).
- On-Delay units are used for delay the enables that is come from I1 the APG units in phase  $\phi_2$ ,  $\phi_3$  and  $\phi_4$ . Thus the function of the three on-delay timers in each direction is to adjust the wave SEM sequence of operating the SM coils see Fig. 2 .
- As the angular displacement of the SM is directly proportional to the numbers of pulses which applied to this motor according to equations 1

$$\text{Angular Displacement} = \text{No. of Pulses} * \text{Step Angle} \quad (1)$$

- So UP/down counter units are used for adjust (i.e counting) the number of pulses that generated by APG in each direction and as following equation:

$$\text{No. of pulses} = \text{No. of phases} * \text{No. of counter counts} \quad (2)$$

- Practically, SM that used in this work,  $7.5^\circ$  step angle, and it has 4 phases, so to realize a full cycle movement (i.e.  $360^\circ$ ) the UP/Down counter count must be 12 (On threshold number = 12) so that:

$$\text{Angular Displacement} = 7.5^\circ \times 4 \times 12 = 360^\circ .$$

- Latching Relay (RS) units are consumed for reset the UP/Down counter when it finishes the On threshold number to stop the present direction and then enables the next direction.
- Four OR gates (B026 to B029) are used for delivery the generated pulses for clockwise and the reversed direction to output terminals of LOGO! (Q1 to Q4).

- In clockwise movement, the output modules will activate in the flowing sequence [Q1 - to - Q4] see Fig. 2 (a) and this sequence will frequent periodically. The motor when rotate in the anticlockwise the output modules will triggered in the reverse sequence [Q4 - to - Q1] see Fig. 2 (b) and this sequence will frequent periodically too.

Thus, in this controller technique the first SM will revolve one cycle ( $360^\circ$  in 48 steps) in a clockwise direction in a (10 steps/sec) speed and then revolve the next one cycle also, but in an anticlockwise direction in speed differs from the speed of the first direction (in a 20 steps/sec) and this sequence of directions will repeated periodically. It's easily to update the program parameter to change the requirement of SM controller (speed, direction, and No. of rotations).

### B. Implementation of Full SEM

The FBD program of full SEM is similar to the FBD program of wave SEM, but there are some differences :

- When the motor rotate in clockwise direction the output modules will activated in the flowing sequence [Q4 Q1 - Q1 Q2 - Q2 Q3 - Q3 Q4] see Fig. 3 (a) and this sequence will repeated periodically.
- The first APG (B009) generates  $\phi_1$  with 100 msec ON: 100 msec OFF.
- Second APG (B010) generates  $\phi_2$  with 100 msec ON: 100 msec OFF but after delay time generated by On-Delay (B008) equal to 50 msec.
- NOT Gate (B011) is used to reverse  $\phi_1$  to generate  $\phi_3$ , also NOT Gate (B012) is used to reverse  $\phi_2$  to generate  $\phi_4$  .
- The operation signals for an anticlockwise direction are generated in the same way of generation the operation signals in the clockwise direction but the sequence as follow: [Q4 Q3 - Q3 Q2 - Q2 Q1 - Q1 Q4] depending upon Fig. 3 (b) and this sequence will repeated periodically also. The FBD control program of the first SM based on full SEM is shown in Fig. 8.

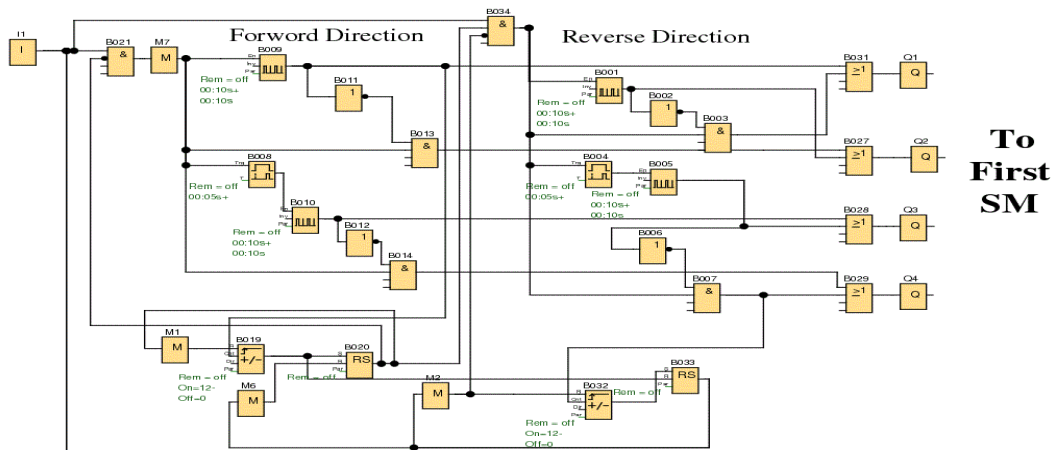


Fig. 8 FBD control program of the first SM based on full SEM

C. Implementation of Half SEM

The FBD program of half SEM is also similar to the FBD program of wave SEM, but there is some differences :

- When the motor rotate in clockwise direction the output modules will activated in the flowing sequence [Q1 Q4 - Q1 - Q1 Q2 - Q2 - Q2 Q3 - Q3 - Q3 Q4 - Q4] see Fig. 4 (a) and this sequence will repeated periodically.
- The first APG (BO24) generate  $\phi_1$  with 150 msec ON: 250 msec OFF, second APG (BO27) generate  $\phi_2$  also with 30S ON: 50S OFF but after delay time generated by On-Delay

(BO55) equal to 100 msec, third APG (BO28) generate  $\phi_3$  with 150 msec ON: 250 msec OFF but after delay time generated by On-Delay (BO22) equal to 100 msec.  $\phi_4$  is produced by an On-Delay, APG, and Not gate.

- In an anticlockwise direction the gropes of (APG and On-Delay) operate as the first gropes as in clockwise direction but in the following sequence: [Q4 - Q4 Q3 - Q3 - Q3 Q2 - Q2 - Q2 Q1 - Q1 - Q1 Q4] see Fig. 4 (b) and this sequence will repeat periodically also. The FBD control program of the SM based on half SEM is shown in Fig. 9.

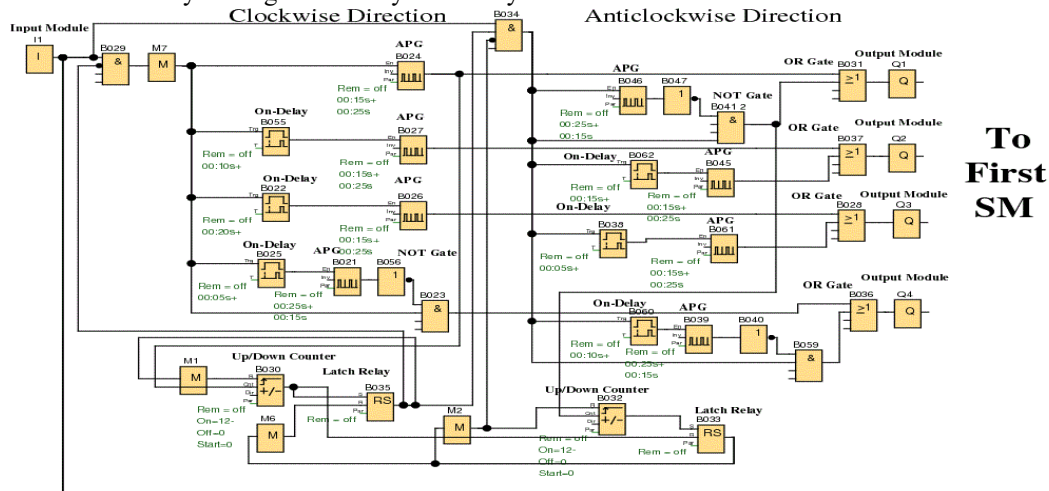
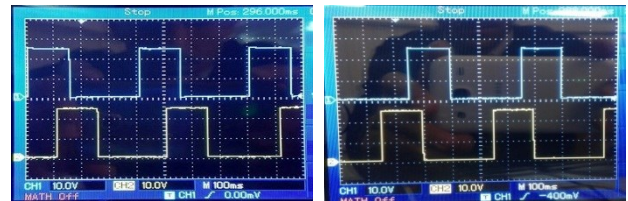


Fig. 9 FBD control program of the first SM based on half SEM

The FBD control programs of the SMs are simulated through a simulator of LOGO! Soft Comfort program before its practical implemented in the system and then the programs are transferred from the PC to LOGO! through special cables called (PC - LOGO! cable) between computer and LOGO!.

V. EXPERIMENTAL RESULTS

Figure 10 show the experimental output waveforms from PLC (Q1and Q2) for three types of controllers for SM (wave, full, and half SEMs respectively).



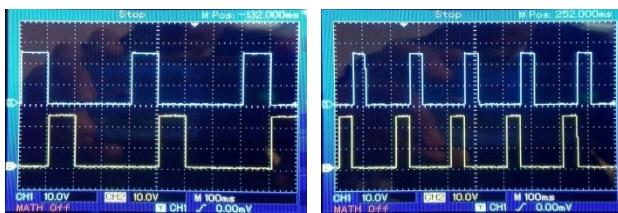
Half SEM: (a) (b)

Fig. 10 Experimental result shows the sequence of wave, full, and half SEMs: (a) Clockwise, (b) Anticlockwise

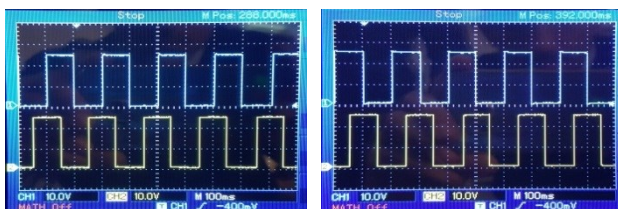
Smooth revolution of SMs has been noticed in wave SEM, in addition to minimal power requirement as compared with the other SEMs. But, at higher speeds, it shows lesser stability. In full SEM, movement is not soft, as compared with the first method; power requirement is important but, it developed better torque because the reversal of the input polarity of the phases to perform a new step. Compared to the other SEM, the half SEM has the highest torque and stability at high speeds furthermore to highest resolution.

VI. CONCLUSIONS

In this work the motion control algorithm of two of SM has been performed successfully; Three parameters of each one of the SMs were controlled and as follows: (1) Direction (clockwise or anticlockwise): it was changed by changing sequence of pulses applied to coils of SMs. (2) No. of rotations or angular displacement was controlled by counting the number



Wave SEM: (a) (b)



Full SEM: (a) (b)

of input electrical pulses that is directly applied to SMs coils. (3) Speed: the pulse period determines the angular speed of the SM. These parameters easily are updated to implement any desired function if these motors were used in RAs. Further, one PLC may control more than two motor via programming extra inputs and outputs already implemented in the PLC or simply by adding an expansion input/output modules; to implement required action based as a robot arm in the industrial factories. Motion control for SMs was experimentally implemented without using any drive or any interface circuits, thus this method is considered as simple and economy method. Where the SMs are powered from an external power supply (does not from PLC), the output module of PLC (PLC coils) is connected in series between the power supply and the motors. Although, the SMs can be controlled in open loop effectively, it's easily to addition sensors to the PLC controller for improvement the overall controller performance.

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