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Designing and construction of a mechanical electrode arm for electro-deposition of multi-layer thin films

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ABSTRACT

This work reports the design and construction of an automated device to fabricate multilayer thin films using electrodeposition technique. Deposition of such films takes times ranging from minute to hours. This device has been constructed in such a way that it can be used in such cases. The constructed mechanical device works as a robot consisting of two degrees of freedom enabling it to move in a Cartesian workspace. A microcontroller was employed for regulating all on-board operations and a stepper motor driver circuit controlled the two stepper motors. The device that has vertical and horizontal spans of approximately 0.12 m and 0.30 m respectively can be used for deposition times of seconds to days using multiple baths. With further modifications, the device can be developed as a commercial product.

1. INTRODUCTION

Fabrication of thin films using electrodeposition requires different times ranging from minutes to hours and sometimes even days depending on the thickness, the number of layers and the composition of the layered structures. An automated deposition mechanism helps such growth processes reducing the human involvement thus saving the time and money. This paper discusses the construction of such an automated mechanical device that can be used to fabricate multilayer thin films electrochemically using the multiple bath technique. It simply functions as a robot. The constructed robot is not really much faster than humans, but it is good at simply doing the same job over and over again.

The constructed robot consists of a manipulator, an end effecter controlling unit and a power unit. Manipulator is the mechanical unit that provides motions similar to that of a human arm. The individual joint motions are referred to as degrees of freedom and each axis is equal to one degree of freedom. End effector is the device that is mechanically opened and closed, as a part of the manipulator. Mechanical grippers are the most commonly used end effectors and they are equipped with two or more fingers. The function of the power unit is to provide and regulate energy that is required for the robot to be operated. The controller device initiates, terminates and coordinates the motions and their sequence. It accepts necessary inputs to the robot and provides the output driven signals to controlling motors or actuator to correspond with the robot movement and the outside world. Robots are classified [1] according to their “Arm geometry”,” Degrees of freedom”, “Power source”, “Path control” and ”Intelligent level”. The constructed robot has two degrees of freedom and it operates in Cartesian work space. The robot has been used to function totally by means of electrical power.

2. DESIGN AND CONSTRUCTION

2.1 Mechanical

In this design, a Cartesian type robot arm was constructed due to its simplicity, rigidity and suitability for pick and place type actions. Schematic of the basic structure is shown in the figure 1.

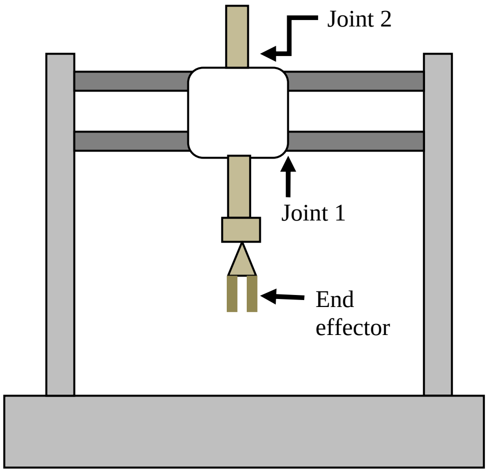

Table 1. Allocated joints for the robot arm

Joint	Type	Motion
Joint 1	prismatic	Horizontal
Joint 2	prismatic	Vertical
End effector	prismatic	Horizontal

Figure 1. Configuration of the Robot arm

In order to support the strong and rigid robot structure, a wooden base of dimensions 0.45 m× 0.30 m × 0.50 m (length× width× height) was used. Moving parts were made out of perspex due to its user-friendliness and lighter weight. In order to control the robot arm, two stepper motors powered by electrical means were used. Table 2 represents the characteristics of stepper motors that were used.

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Table 2. Characteristics of the stepper motors that were used for the joint

Joint	Degrees per step Degrees per step= $\frac{360^0}{S}$ (S=Number of Steps)	current	voltage	Resistance per winding
Prismatic joint 1	1.8	0.5A	12V	64 ohms
Prismatic joint 2	7.5	0.5A	12V	64 ohms

Horizontal arm is the main arm of the robot and it carries the whole weight of the system. For this purpose, a rack bar and a gear wheel were used. The driving power of the unit was reduced by using a gear box coupling between the motor and the rack bar. With this mechanism, the increased driving power made the movement smoother and carried a bigger load.

Figure 2 illustrates a schematic of the horizontal arm.

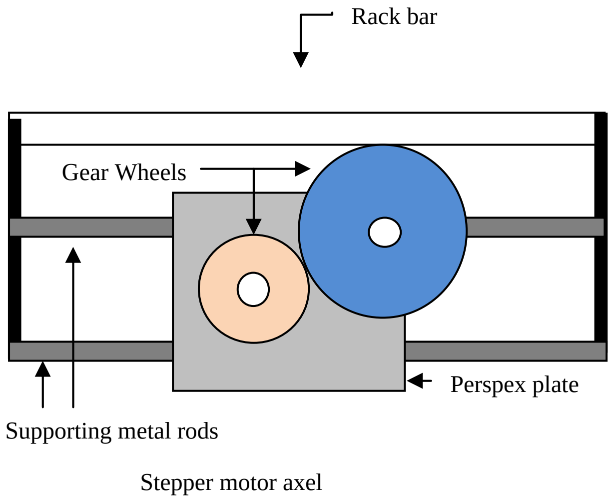

Figure 2. Mechanism of horizontal arm

For the design of the linear actuator of the vertical arm, instead of using the conventional belt and gear wheel combination, a nut that can advance through the thread bar was employed. The schematic of the linear actuator is shown in figure 3.

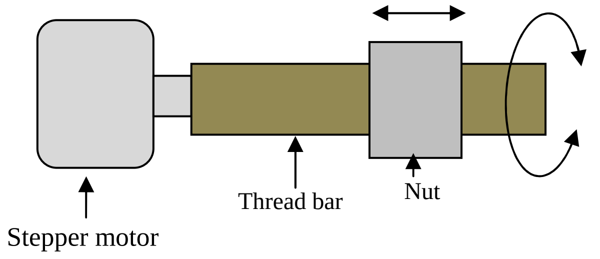

Figure 3. Designed linear actuator

By considering the weight of the end effector and the weight of the rest of the carrying parts, the motion of the nut was fixed and the stepper motor was allowed to move through the thread bar. This way the nut could bare the whole load making the motor to operate easily.

A copper bar was used as the thread bar and it had a double start mechanism (two sets of threads) and a 2 mm linear movement per rotation. The double start mechanism enabled a smoother movement of a larger load with high speed. The structure of the vertical arm is shown in figure 4.

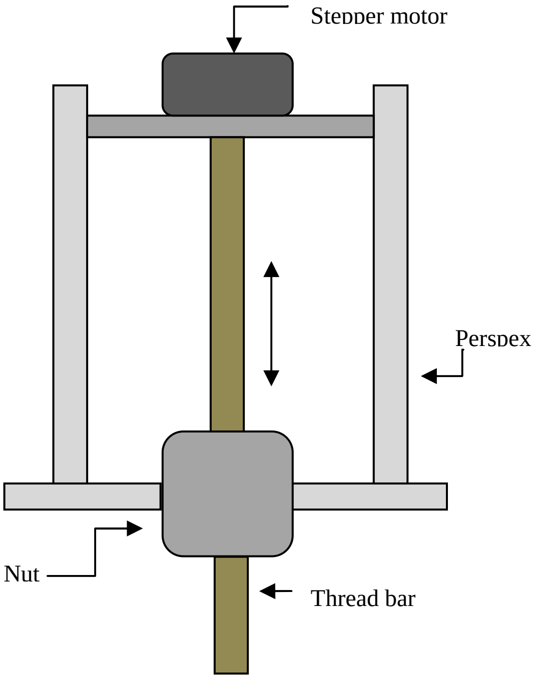

Figure 4. Vertical arm

The main requirement of the end effector [1, 2] was to hold the deposition plate. This was achieved using a solenoid magnet that can be energized by applying a voltage. When it is energized, the axel gets attracted into the solenoid and the gripper will open. This mechanism helped to hold substrate plates of thicknesses of the order of millimetres.

The “Pull type solenoid” which operates by 12 V was used to construct the gripper. The gripper functions through a spring as shown in figure 5, and goes through the ‘open’ and ‘close’ sequence when the solenoid is energized and de-energized. The two fingers of the gripper were made by aluminium plates so that it can conduct current to the deposition plate. A small rubber sheet was attached to one of the plates which hold the substrate tightly. Schematic of the end effector is shown in the figure 5.

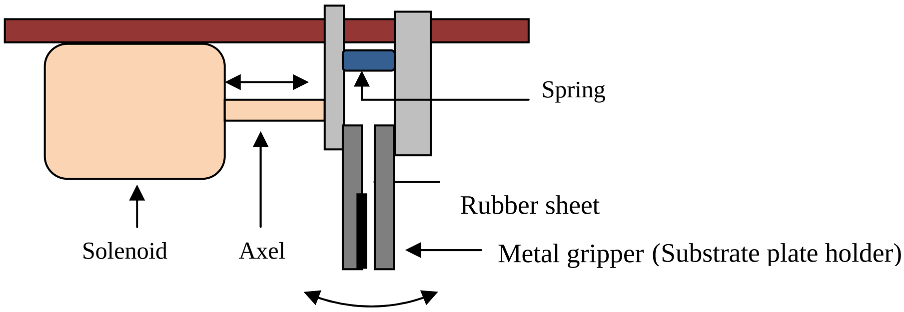

Figure 5. End Effector

2.2 Electrical and Electronic

The brain of the electronic circuit was a PIC microcontroller (16F877A) [3] which control the robot arm and its functionalities. By providing a sufficient current to the motors, they were rotated in both forward and reverse directions. This was achieved by a stepper motor driver circuit. The stepper motor driver circuit consists of a L297 Stepper Motor Controller IC [4] and L298 power driver IC [4]. This combination has several advantages such as, use of a very few components, easy software development and smaller load on the microcontroller.

The L297 stepper motor controller can generate "HALF" and "FULL" step sequences in both clockwise and counter clockwise directions. The L298 power driver can drive a maximum DC current of 4.0 A and its maximum operating voltage is 46 V. It has two full bridge drivers and each can be enabled separately. The L298 power driver was originally designed to drive bipolar stepper motors, but it can be used to drive unipolar stepper motors by changing the input sequence of L298 as shown in the figure 6. The microcontroller was used to count the number of steps. Therefore, an external counter was not required.

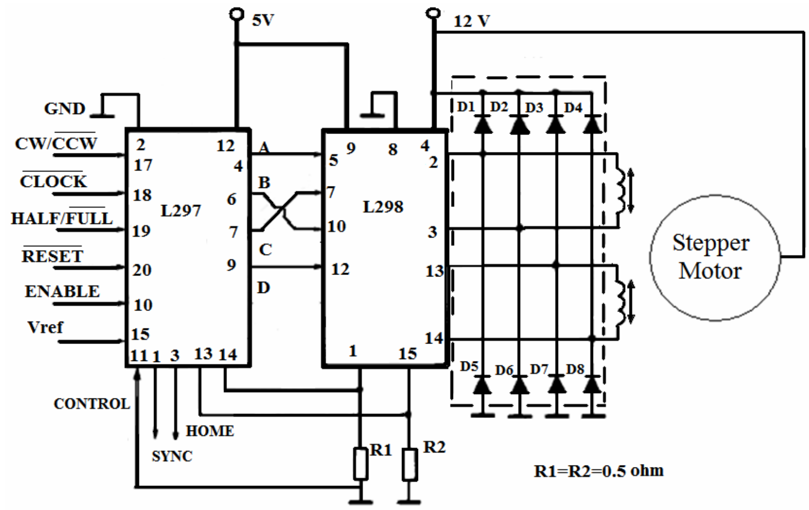

Figure 6. Stepper motor driver circuit

An LCD was used to monitor and guide the operating procedure of the robot. This made sure that the given data was correct or not. This was the main feedback system that was used in the robot arm. A Hitachi compatible LCD unit was used to accomplish the above task. The used LCD has 16 characters and 2 lines which can be operated in both 4-bit and 8-bit data transfer modes. In this work, the 4-bit mode was used since it reduced the number of pins that had to be allocated by the microcontroller. Two control lines and 4 data lines were used to control the LCD.

The constructed robot arm performs all its actions according to the reference position. Therefore, a sensing mechanism was implemented. When each of the arms approached its reference position, the sensors were able to detect it and send a logic signal to the microcontroller. Two mechanical switches (which are used in the paper load section of the printer) were used as sensors due to its low cost.

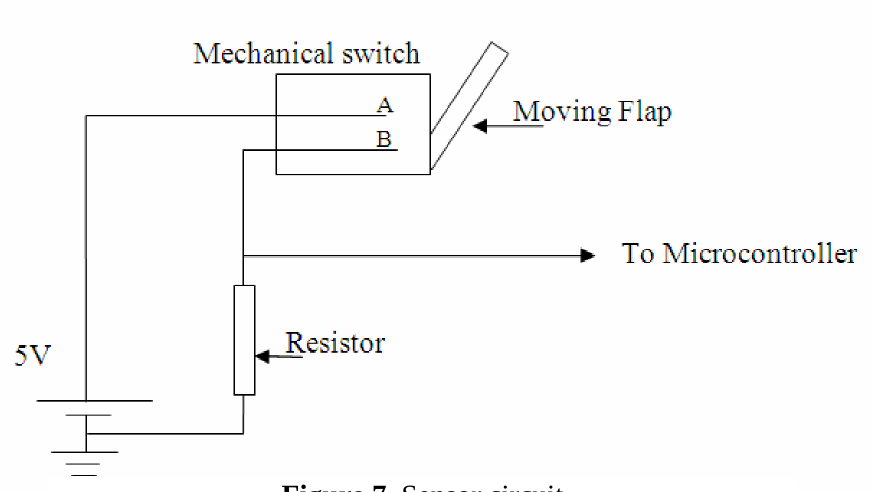

Figure 7. Sensor circuit

The moving flap of the sensor originally is at open position (due to the spring in it).When the moving flap hits an obstacle, it will fold and connect “A” and “B”, providing a 5V signal (shown in figure 7). If the flap is at open position, then the microcontroller gets 0 V signal. The purpose of the resistor was to prevent the voltage fluctuations at the microcontroller input. Thus the microcontroller always gets either 0 V or 5 V.

The relay circuit provides the voltages required for electrodeposition whenever necessary and is controlled by the microcontroller. A D400 transistor was used for this purpose. The schematic is shown in figure 8.

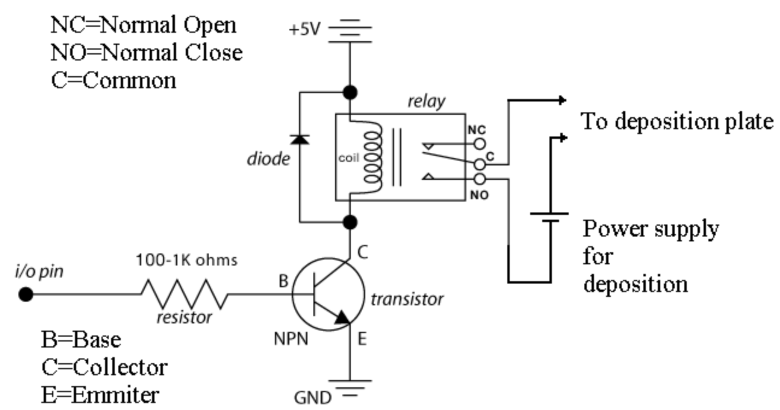

Figure 8. Relay circuit

All the on board operations and sub-systems were controlled by the microcontroller. The PIC microcontroller PIC16f877A was selected for this purpose. It operates at 20 MHz and has 8k words of program space along with 256 bytes of EEPROM and 368 bytes of data memory. This particular type of microcontroller has a sufficient number of pins, a memory space and EEPROM to accommodate other components, sub-systems and data. Also it can operate at high clock speeds to process information while controlling the components of the robot. The parallel communication interface was implemented to communicate with computer via a parallel port, and it was used to download and modify the software written to the microcontroller.

3. DISCUSSION AND CONCLUSIONS

Developing a mechanical arm to fabricate multi-layer thin films by electrodeposition was the main goal of this study. This construction was successful completed. It minimizes the human involvement in thin film fabrication using electrodeposition. When larger deposition times are required, the device can be programmed and left in operation without any attendance. The lager horizontal arm allows electrodeposition using multiple baths (three to four different electrochemical baths). This design resulted in following features.

Table 3. Features of robot arm.

Maximum vertical span	11.875 cm (2850 steps)
Maximum horizontal span	30.324 cm (715 steps)
Maximum Deposition time	24 hours
Maximum number of layers	5

The bi-layer and multilayer thin films could be obtained by the constructed robot arm automatically. After analysing various robot models, Cartesian type robot was developed to accomplish the goal. To enhance the workspace and good manoeuvrability "revolute coordinate [5, 6]" type robot was proposed as a further development. The constructed robot arm can be improved to an intelligent system and a "Force sensor" can be introduced to the end effector. As further improvements, automated temperature controlling of the baths and substrate plate holding tray can be incorporated. This can be developed to a commercial product for pick-and–place type jobs in general.

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