Mechanical and Electronic Systems of an Open Source Based Spin and Dip Coater

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Abstract: The construction of an open source based spin and dip coater are presented. The mechanical systems and its gear ratio are discussed, as well as the electronic system and control unit. The instruments were assembled using low cost materials and share a common controller unit, which is programmed with an Arduino microcontroller. The total velocity range of the instruments are 300 to 10000 rpm for the spin coater and 0.6 cm/h to 30cm/min for the dip coater. The operation and use of the two instruments are discussed, which in both cases compare very favorably with commercial models.

Keywords: Spin coater, dip coater, open source, Arduino, low cost instrumentation, surface deposition.

Sistemas Mecánico y Electrónico de un Spin Coater y Dip Coater basado en Tecnología de Código Abierto

Resumen: Se presenta la construcción de un spin coater y dip coater basado en tecnología de código abierto. Se detalla el sistema mecánico así como la relación de engranes implementados. También, se habla del sistema electrónico así como el control de los equipos. Los instrumentos fueron ensamblados utilizando materiales de bajo costo y comparten una unidad de control común la cual fue programada en un microcontrolador Arduino. El rango de velocidad total de los instrumentos es de 300 a 10.000rpm para el spin coater y de 0,6cm/h a 30cm/min para el dip coater. Se da una pequeña reseña del funcionamiento de los dos equipos y su utilidad. En ambos casos se comparan de manera favorable con modelos comerciales**.**

Palabras clave: Spin coater, dip coater, Arduino, dnstrumentación de bajo coste, deposición superficial.

1. INTRODUCTION

A novel low cost method for the design and construction of prototypes of a spin coater and dip coater are presented. Each device is made of inexpensive and open source based mechanical components, at a fraction of the commercial cost and with operating parameters that compare very favourably to the equivalent commercial models. Furthermore, the control units of the spin coater and dip coater utilizes the same Arduino based microcontrollers and are interchangeable, needing only to be reprogrammed in order to be used in either one of the two instruments.

Open source technology has become one of the most powerful tools in order to design and build low-cost equipment. Nowadays, there are many applications which use open source technology like 3D printer, cell phone operating systems, software apps, robots, low-cost laboratory equipment, as an integral part of the manufacturing process. Fisher D. K et al. (2012) – Herrera R. (2013).

This paper presents a method in which open source technology has been utilized to build a spin and a dip coater. Besides the obvious cost advantage of building your own scientific equipment, another goal has been the opportunity to take complete control of the all the variables involved in the process of coating of the films.

Two of the most common methods by which to obtain thin films by deposition from a solvent are spin coating and dip coating. In spin coating a small amount of solution is deposited onto the centre of a substrate which is subsequently spun at high speeds. Spin coating is widely used in micro fabrication, where it can be used to create thin films with thicknesses below 10 nm. In spin coating the there are various parameters that need to be taken into consideration. Among them are the speed of spinning, the viscosity and concentration of the solution, acceleration, spin time and exhaust. However, the process parameters vary greatly for different materials and substrates so there are no fixed rules for spin coat processing, only general guidelines. Of critical importance is that the process is reproducible. Factors that affect the coating process

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include speed of spinning, acceleration, spin time, exhaust, the viscosity and concentration of the solution, Hall D. B et al. (1998). Another important factor in spin coating is repeatability, as subtle variations in the parameters that define a spin-coating process can result in drastic variations in the coated film.

Dip coaters are designed to deposit layers of materials in a controlled and repeatable way. Dip coating is used for the fabrication of thin films by self-assembly. of controlled thickness, determined mainly by the deposition speed and solution viscosity There are, just as in spin coating, a variety of factors to account for when determining the final state of the thin film when dip coating a given substrate.

Among the factors, that affect the process are the submersion time, withdrawal speed, number of dipping cycles, solution composition, concentration and temperature and environmental humidity. It works as a substrate is submerged in a solution and then in a controlled and constant fashion retracted from the solution, Puetz J. et al. (2004).

Dip coaters provide homogeneous and smooth films. The thickness and internal layer structure of such films can be adjusted by altering the concentration of the solution, retracting speed and/or by having multiple dipping cycles. Therefore, given their ease of use, spin and dip coaters are amongst the most ubiquitously used instruments for the fabrication of thin films in many laboratories. In both cases, care should be taken to be able to deposit the thin films in such a way as to achieve the desired characteristics regarding, film thickness, homogeneity and reproducibility of the thin films.

Often commercial spin and dip coaters are prohibitively expensive and may have features are not necessarily needed for fabrication of thin films. To this end, there have been several reports of the construction of either low cost spin coaters or dip coaters in literature, Fardousi M. et al. (2014)-Leal D. et al. (2011). Our design offers solution to this problem by describing a low cost method with a flexible controller that can be used to control either of the low instruments, Loza Matovelle D. et al. (2014). An extensive description of the mechanical structure and electronic control system is presented for each of the two instruments.

2. RESULTS AND DISCUSSION

2.1 Construction of the spin coater

The three main components in the construction of the spin coater were; the mechanical system, the electronic control system and the user interface. The three main stages involved in the construction of the mechanical system of the spin coater were; the 3D prototyping, analysis of the mechanisms, and its manufacturing. A 3D model, as shown in Figure 1 and Table 1, was built in order to assure functionality of the system. It went through an iteration process since some adjustments had to be performed on the 3D models until the final assembly was completely developed.

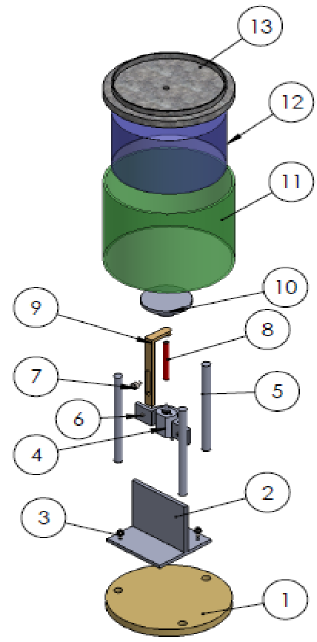

Figure 1. An expanded view of the 3D model of the spin coater.

Table 1. Nomenclature of the parts of the spin coater.

Part Nr.	Name
1	Base
2	Metallic support
3	Rivet
4	Electric motor
5	Support shaft
6	Electric motor support
7	Bolt
8	Motor shaft
9	Motor shaft guide
10	Superior rotating plate
11	Body protection
12	Superior protection
13	Fixed superior plate

Computer numerical control (CNC), "The fundamentals of CNC" Apr. (1997), processes have been used to build the mechanical components, such as plates and shafts; thus, assuring quality and precision regarding the overall functionality of the final setup. Because of the simplicity of the rotating mechanism, composed of the electric motor, motor shaft, and superior rotating plate, as shown in Figure 2, the losses in power and speed of the rotating plate due to friction can be neglected.

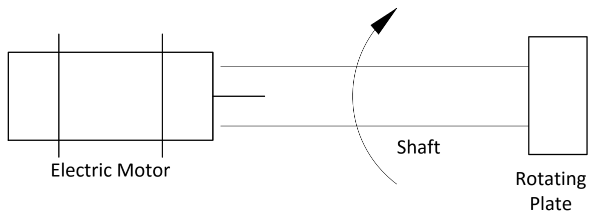

Figure 2. Schematic diagram of the rotating transmission mechanism.

As the electric motor is fixed to a support, and the forces generated from the testing material along the axial direction are considerably small, there is no presence of axial movement that can affect the functionality of the setup. Additionally, to prevent radial displacements, there is a metallic part that serves as a guide and support of the motor shaft; thus, ensuring the pure rotational movement which is indispensable for the equipment functionality.

2.2 Construction of the dip coater

Similarly to the spin coater, the dip coater device consists of three main parts; the mechanical system, the electronic control system and the user interface. The mechanical part of the system was designed in the same fashion as for the spin coater. A 3D model, as shown in Figure 3 and Table 2, was developed so that kinematics and functionality analysis were performed towards an adequate performance of the dip coater setup.

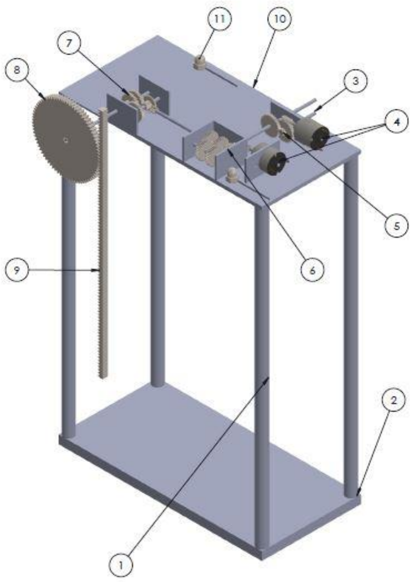

Figure 3. An expanded view of the 3D model of the dip coater.

Table 2. Nomenclature of the parts of the dip coater.

Part Nr.	Name	Quantity
1	Rod	4
2	Base	1
3	Shaft	7
4	Electric motor	2
5	Gearbox I	1
6	Gearbox II	1
7	Gearbox III	1
8	Wheel	1
9	Rack gear	1
10	Removable plate	1
11	Bolt	4

As the transmission system of the dip coater mechanism is more complex than that of the sin coater, it is essential to ensure the accuracy on the built parts as well as good quality off-the-shelf parts, such as gearbox, to guarantee the performance of the results obtained with this setup. This means that the settings of the gearboxes, motors, and rack and wheel mechanisms should be secured to avoid vibrations which otherwise could be transmitted to the sample and cause defects such as jumps and holdups during the experiments. The mechanical system must also be very robust, and assembled on a totally flat surface. To this end, the base of the system was fitted with a protective layer of thick rubber.

The most salient feature of the transmission system is its three compound gear combinations. The first train contains a worm and worm wheel gear, the second gearbox consist of spur gears as does the third one. In order to get the vertical movement, a rack and pinion mechanism has been implemented. All these mechanisms are susceptible of power losses due to inherit efficiency of each type of gear, sliding effect, friction, and windage, Chaari F. et al. (2012). Most of the power losses are dissipated in a form of heat and it is more evident when the mechanism works at high rpms. Since the dip coater mechanism work at relatively low speeds, the power losses could be neglected. The estimation of the power losses as well as the equations and conditions that govern these phenomena are out of the scope of this paper.

To motion the system at different speed ranges, two DC motors, two power sources of 5 and 24 V along with the transmission system are available. The speed is controlled both electronically and mechanically. A pinion-rack system connected to the gearboxes enables the conversion of rotary motion to linear motion. To achieve as wide a range of velocities as possible the system was fitted with two interchangeable wheels. The larger wheel has a radius eight time the smaller wheel, meaning that the larger wheels will result in eight times the velocity of the smaller wheel for any given voltage, see Figure 4. As the system encompasses two independent DC motors, this effectively results in four distinct velocity ranges, see Figure 5. Furthermore, as both motors make use of the same axis, the one that is not in use must be manually disengaged before starting a new test to avoid damage to the mechanical system.

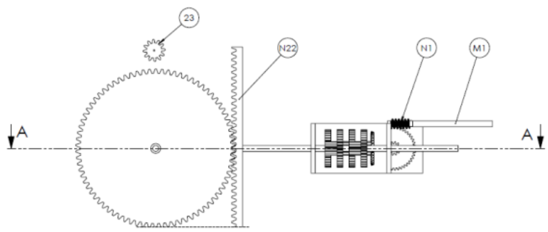

Figure 4. Sketch of the side by side view of the two wheels used for the dip coater. The smaller wheel has a radius eight times smaller than the larger wheel, meaning that for any given voltage its dipping speed would be eight times slower.

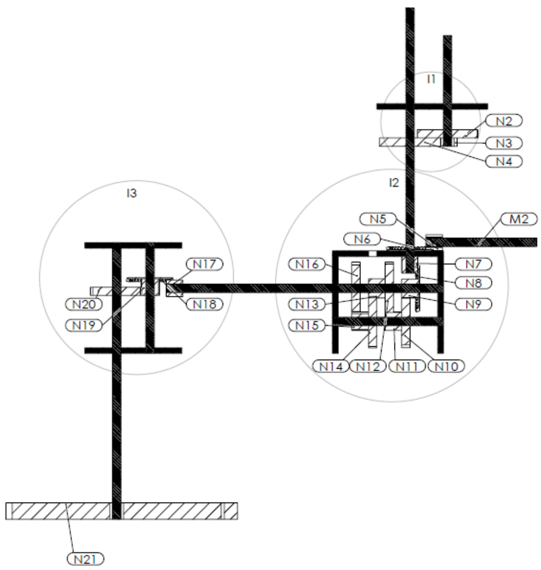

Figure 5. Sketch of the top view of the mechanical structure of the di coater with two independent DC motors.

2.3 Transmission train of the dip coater

Given the fact that rotational movement has to be translated to linear displacement, a mechanism of three gear boxes is assembled. The gear transmission system is composed by three gear boxes with different gear ratio each, as shown in Figure 6, in order to get the final linear velocity on the rack. To determine the gear-ratio of each gear box is important to get the teeth number of each gear as it is presented in Table 3.

Table 3. Teeth number distribution of the gears of the transmission train.

Part Nr.	Number of teeth
N1	1
M1	DC Motor
N2	42
N3	12
N4	42
M2	DC Motor
N5	8
N6	34
N7	12
N8	34
N9	12
N10	36
N11	12
N12	36
N13	12
N14	36
N15	12
N16	36
N17	8
N18	34
N19	12
N20	36
N21	78
N22	88
N23	12

Two motors can be engaged to get the desired rack linear velocity. If M1 (see Figure 5) is utilized, the rack velocity is computed by using the relation from multiplying I1, I2, and I3. If M2 is engaged, the output velocity is then calculated by using the result of multiplying I2 and I3.

Two pinions are available to control the linear velocity. The radio of the biggest gear is eight times larger than the radio of the small one. The linear velocity can be computed as in Equation (1).

$$V_{sal} = \omega_{sal} \cdot R \tag{1}$$

Where, V_{sal} is the linear velocity of the rack, ω_{sal} is the angular velocity of the pinion (N21 or N23), and R is the radio of the pinion (N21 or N23). The transmission system is designed is such a way that the total range of velocity varies from 0.6 cm/h to 30 cm/min. Although some inherit losses of the gearboxes can derivate in variations that can affect the final linear speed, this effect can be compensated by the speed controller developed in this study.

2.4 Electronic system of the spin and dip coater

A great advantage of the designed systems is the use of one single control unit. A schematic view is presented in Figure 6.

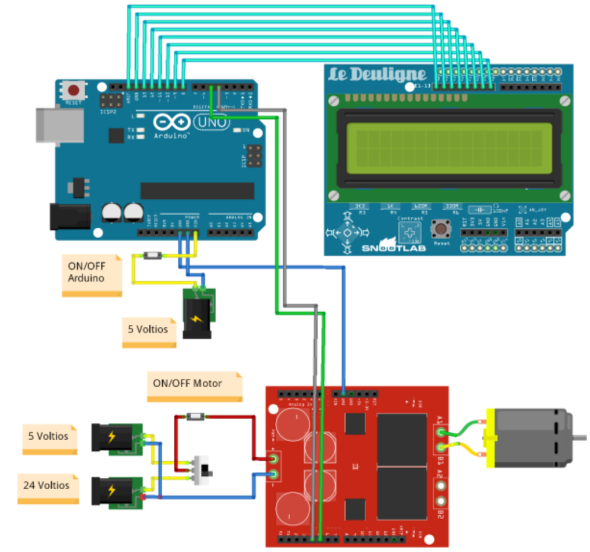

Figure 6. Schematic overview of the electronic system of the spin and dip coater.

The electronic components of the spin and dip coaters are is based on open-source Arduino platform. A UNO board is used to control the Dip and Spin coater because of machine requirements as well as for ease of handling. In order to enter and show both speed and operating-time variables an embedded Arduino shield that has a keyboard and a liquid crystal display was implemented. Entered variables are sent to the main program into the Arduino board, which uses pulse-width-modulated signal to control the motor. However, the control board sends a low-level-current signal, which cannot be connected directly to the motor. This is the main reason why a L298N H-bridge shield is added to the electronic component.

The shield amplifies the Arduino UNO signal so that the motor can spin. Furthermore, the dip coater mechanical design involves two motors with slow and high revolution models. The first motor works with 24 volts and the second with 5 volts, which means that the H-bridge shield requires two power sources and a commutable switch to avoid short circuits. Besides, two hand switches are used to turn on/off DIP coater controller and motors.

2.5 Control system of the spin and dip coater

The control system of both the spin and dip coater have been developed with Arduino UNO, Arduino Uno (2015). The purpose of the control system is to drive the device. Its main component is an Arduino UNO free microcontroller. It is able to receive data from the user interface, process the data and to send it to the DC motor. The microcontroller drives the device by using an open-loop control algorithm in order to regulate the speeding spin. The control system is responsible for maintaining constant speeds and spin duration according to user selection. The rotational movement of the spin coater is provided by a single 12W DC electric motor. The speed of the motor is controlled by varying the voltage according to the pulse width modulation technique (PWM). The Arduino UNO sends bits between 0 and 255 to control the motor. The process begins with a start signal. After that, speed and operation time must be entered. The input variables of Arduino Uno are reflected in PWM signals that permit to control motor duty cycle. Speed variations of the spin coater were conditioned to be between 300 and 10000 rpm for up to three minutes. Similarly, for the dip coater, the connection between the microcontroller and the Arduino DC motor is achieved by a L298N shield to control the two motors, and both the speed and direction of the rotation. A complete diagram of the mechanical and electronic components is shown in Figure 7. For both systems a KeyPad and LCD was employed which provides a graphical and simple to use controlling device. A complete diagram of the mechanical and electronic components is shown in Figure 7.

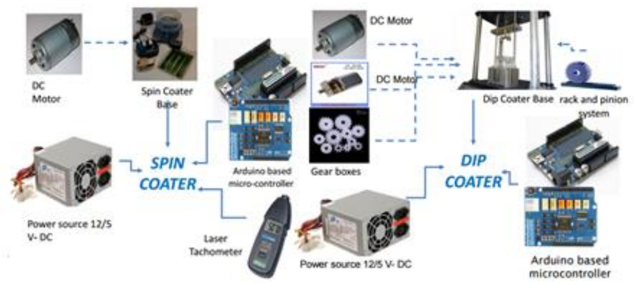

Figure 7. An overview of the mechanical and electronic components used.

2.4 Mechanical maintenance

Performing maintenance to the testing equipment is very import to ensure accurate, reliable, and timely testing. Also, authorized personnel should do the tests to guarantee the correct operation of the equipment (spin and dip coater) as it is stated in the 5.5.3 item of the ISO/IEC 17025(2005) (E)

Activities such as cleaning and lubrication are implemented periodically for the equipment. This is based on a preventive maintenance plan developed by the manufacturing processes laboratory, under which the new equipment is operating. Since the majority of the equipment is constructed from steel, lubrication has to be added carefully to prevent it from corrosion. The equipment shall not be exposed to high temperatures (above 210 °F), Chaari F. et al. (2012), because the acrylic and plastic gear-boxes (for the dip coater) could deform or melt easily, then affecting the performance and results of the tests

2.4 Operation of the spin and dip coater

In the case of the spin coater, the substrate is mounted on the spinning plate of the spin coater using a double-side tape. . The system allows depositing thin films of any dissolved materials at rotational speeds between 300 and 10000 rpm with an error of ± 1 % rpm. The magnitude of variation of the spin velocity is constant and attributed to the fluctuations of the mains voltage which feeds the Arduino. It is comparable to many commercial models and does not impede the reproducibility of the obtained thin film. Typically for spin coating the user selects two velocities for each deposition. A low velocity of 500 rpm is initially chosen for about three seconds. The purpose of this is to dispense the fluid on top of the substrate and to spread the fluid over the substrate. This is followed by an instantaneous switch in velocity up to anywhere from 1000 to 10000 rpm. The purpose of this high speed spin step is to thin the fluid, to eliminate excess solvents from the resulting film by drying it.

The dip coater system allows the deposition of thin films at speeds ranging between 0,6 cm/h and 30 cm/min with an error of ±2 % due to voltage variation of the mains network. The electronic control system and user interface are basically identical to that of the spin coater, with the added option to change the direction of the rotation. This is due to the fact that often different speeds are required for approaching (lowering) and retraction (lifting) of the sample. Before each experiment the user selects the approaching and retracting speeds independently with push button switches.

The amount of time that the system is retracting can also be set. However the system is designed such that the approach takes place by keeping the approach button pressed in. This facilitates the entry of the sample probe into the solution, as it offer a higher degree of control to terminate the approach at exactly the desired point, which is usually just beneath the solution level, when the sample is totally immersed into the solution. It is also a practical measure as approaching speeds are generally much higher than retraction speeds.

The retraction speed is considered considerably more critical as it must be very uniform and constant. To this end the user can select the time it could take for the sample to withdraw from the solution. The available options range from minutes to hours, even for samples as small 1x1 cm^2.

3. CONCLUSIONS

The mechanical and electronic systems of an open source based, low cost, spin and dip coater have been presented and discussed. The presented models provide a proven method to manufacture high quality scientific instruments for thin film deposition by using readily available mechanical parts and open source software. The instruments are easy to use and program. A description of their mechanical maintenance is also given. The mechanical properties of the spin coater (speed range from 500 to 10,000 rpm) and dip coater (withdrawing speed range: from 0,6 cm/h to 30 cm/min) compare favorably with commercial models. The presented models will allow research groups the possibility to prepare thin films with an accuracy that was previously out of reach due to the prohibitive costs that until very recently were associated with such instruments.

ACKNOWLEDGMENTS

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