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Development of a Cost-Effective and Reliable Spin Coating Device Promoting Local Enterprises to Meet the Research Needs

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ABSTRACT

Spin coating is a technique that can be used to apply a thin film layer on a selected substrate. While the substrate's rotational dynamics provide a centripetal force on the solution of material, surface tension and viscous forces enable to deposit of a thin uniform layer at the desired thickness.

This device has been designed to function similar to a commercially available spin coater. Small form factor and mostly commercially available electronics components give an extensive reduction in the cost of the interior design and easy maintenance. 12 kV DC brushless motor has been employed to rotate the spinner's chuck which could reach a maximum rpm of 12000. The exterior body has also been made with PETG (Glycol Modified Polyethylene Terephthalate) plastic material, and it is entirely produced with 3D printing technology. After considering all the facts, this device ultimately gives surprising results in the spin coating quality that is almost identical to that of a high-cost commercially available spin coater.

It was found that the thickness of the deposited film using this device is inversely proportional to the square root of the angular velocity, harmonizing with the theory. The thickness of the compound, which was made from TiO_2 suspended in water as the solvent, varied from 7.26 μm to 1.21 μm with the rotational speeds ranging from 1000 rpm to 6000 rpm respectively. Time taken for stabilization is independent of the set rpm (it reaches the maximum rpm within 7 seconds irrespective of any set rpm value) and power consumption diverge exponentially with the rotational speed.

1 INTRODUCTION

In general, spin coating utilizes thin-film production applications, which uniformly spreads a coating solution of the desired material on a selected substrate. The spin coating in electronics and nanotechnology is widespread and is also utilized in a broad range of technologies and industries such as solar cells, sensors, thin film transistors etc... The most fundamental advantage of spin coating over other methods is the producing fast and quality films without engaging in complex procedures [2].

Following four significant stages are usually seen in the spin coating process [2]. First, before the rotation, a small drop of a solution is placed on the substrate as in Figure 1a. While the substrate is rotated at high speed, almost all of the solution is flung off the sides (Figure 1b). More specifically, centripetal force combined with the surface tension and viscous forces of the solution causes uniform film covering the substrate with the

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solution. Airflow during the process dries off most of the solvent and the residual solution is formed as a wet-plasticized film (Figure 1c). Finally, all the solvent dries out coating the substrate only with the desired material (Figure 1d).

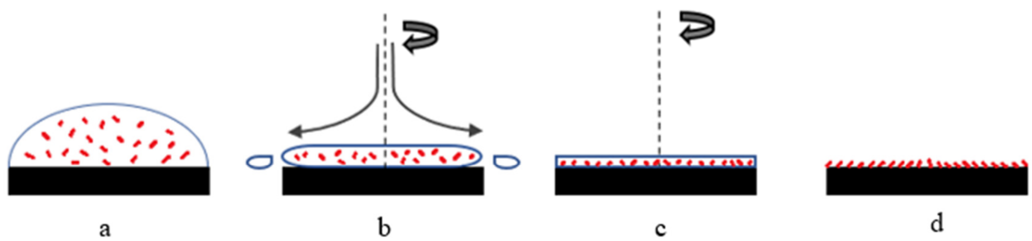

Figure 1: Example of the mechanism of spin coating technique

Same as in any other electronic device, it inherits both pros and cons. On the positive side, compared with other coating techniques, it creates precise and accurate thin film layers within a few seconds without any complicated setup procedure.

On the negative side, the actual material is relatively low, typically around 10%, because, most of the applied solution is flung off and wasted. Another drawback is relatively low throughput at a time.

The main objective was to design and build a spin coater, which function in parallel to the high-end machines, produced locally at a low cost. This device has been produced to use for the research-based thin-film coating process rather than for industrial purposes. Therefore, some drawbacks, which are mentioned above, have been intrinsically eliminated.

2 DESIGN AND EXPERIMENTAL PROCEDURE

2.1 Internal Designing Procedure

Mainly in internal design, hardware and software are the main sections. several electronic and mechanical components have been utilized in the hardware design to build the primary rotational mechanism and other sections such as user interface display, switching, and feedback mechanism.

For the rotational mechanism, mainly 12 kV DC brushless motor has been used to rotate the spinner's chuck and it was fixed on the basement of the spin coater with a shock-absorbing mechanism. The shock absorb mechanism plays a crucial role in durability in the dynamic situation. So, in this spin coater, durability has been guaranteed significantly by introducing such a mechanism. Other than that, force dispersion structure to the chuck-motor system has been added to enhance its robustness and durability.

In the feedback mechanism, the hall effect sensing method was used to monitor the chuck of the spin coater's rotational speed. This mechanism coupled with the microcontroller system gives a fully-controlled rotating mechanism to the spin coater.

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The real-time monitoring feature consists of 16×2 LCD panel that gives real-time rpm value and time-related details of the spinning. All the hardware sections in the spin coater are controlled by an 8-bit AVR microcontroller. The Following block diagram illustrates the flow control of the system.

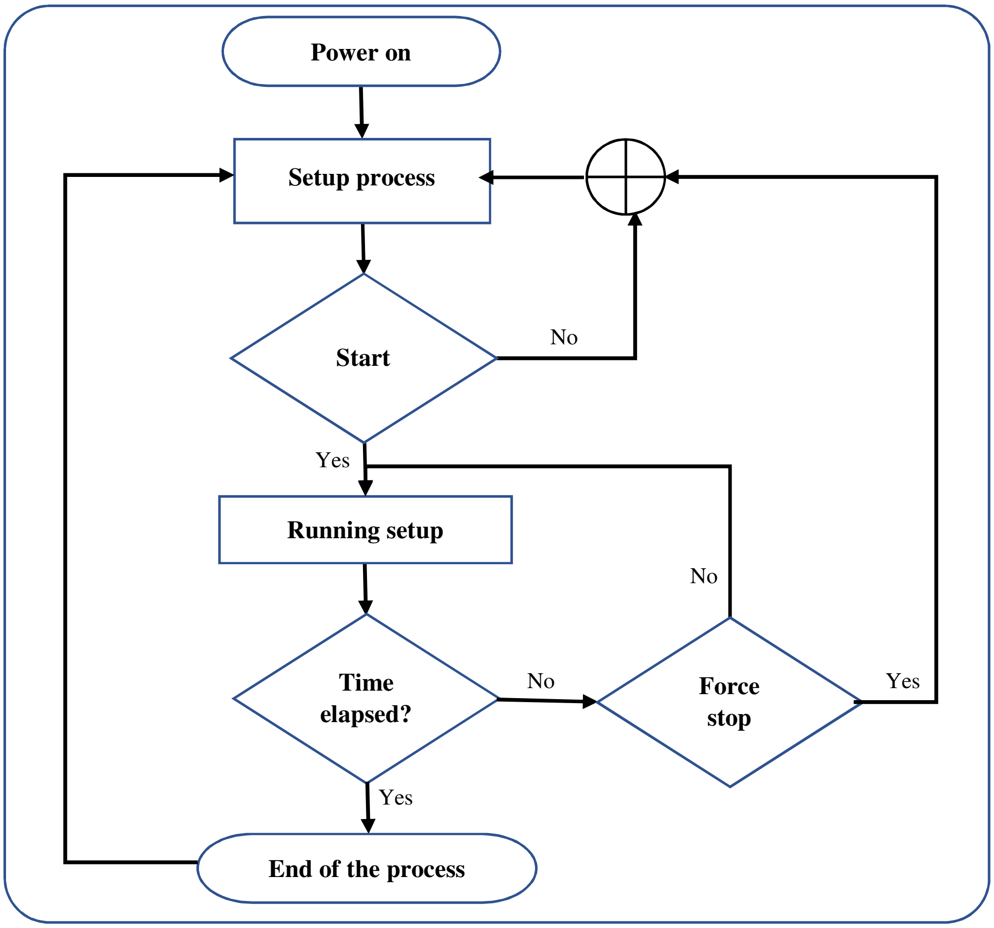

Figure 2: Flow control of the system

2.2 External Designing Procedure

For the exterior designing process, two main factors have been considered, which are the cost and the material to meet our original objective for cost-effective production.

Newly emerging technology, widely known as 3D printing, is the primary production tool of the spin coater's exterior design. With this technology, the quality and the precision of the exterior design are impressive compared with other mass-production techniques.

The other fact is the material of the exterior body. A spin coater usually deals with chemicals all the time. Hence, the material should be chemically resistant as well as durable.

Polyethylene terephthalate glycol, also known as PETG, is a thermoplastic polyester that provides significant chemical resistance, durability, and excellent formability for

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manufacturing. This material perfectly matched our requirements to produce the exterior body as expected successfully. Solid works-aid 3D modeling technique has been used to design all the interior and exterior parts. The final 3D model design is shown in Figure 3.

Figure 3: 3D model designing and the final product

2.3 Experimental Procedure

Successful completion device's fabrication, some experiments were carried out to characterize the device's performance. The most important characteristic is the layer thickness variation with the rotational speed.

In order to analyze this variation with the new device, we have chosen TiO_2 as the coating material and water as the solvent. Also, a glass plate with known mass and surface area was used as the substrate. The coating was done for six different rotational speeds with five repetitions at each speed. The duration of the coating was limited to 30 seconds for all trials. After completion of each coating, the weight (substrate + deposited compound) was recorded so that, it can be used to determine the weight of the deposited material. By knowing the density of the material, the layer thickness could be calculated.

Variation of time taken to stabilize the substrate's speed for different rotational speeds was the second investigation. This is useful to identify the spin coating method, known as *Dynamic Dispense Spin Coating Technique*.

The final experiment was related to the power rating of the device. In order to characterize the power rating of the device, variation of the current drawn to the device with rotational speed was observed for one particular constant voltage.

3 RESULTS AND DISCUSSION

3.1 Variation of Film Thickness

Figure 4 shows a comparison of the quality of the deposited thin films at different rpm values. It can be significantly identified that the evenness of deposited thin film is greatly improved with the substrate's rotational speed.

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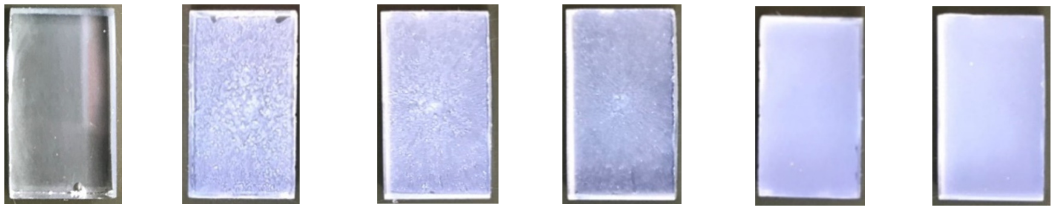

uncoated **2000 rpm** **3000 rpm** **4000 rpm** **5000 rpm** **6000 rpm**

Figure 4: Variation of layer quality with rotational speed

Layer thickness for six different rotational speeds has been calculated and depicted in table 1. These data were analyzed by plotting the graph in figure 5.

Table 1: Compound weigh, layer volume, and thickness for different rotational speeds

Speed (rpm)	Average layer weight (g)	Layer volume (cm^3)	Layer thickness (um)
1000	0.0018	0.001917	7.26
2000	0.0013	0.001384	5.24
3000	0.0009	0.000958	3.63
4000	0.0006	0.000639	2.42
5000	0.0004	0.000426	1.61
6000	0.0003	0.000320	1.21

The surface area, *A* of the substrate is (2.4×1.1) cm^2 and the relation given in equation 01 is used to calculate the thickness, *T* of the film when density, ρ and mass, *m* is known. The density of TiO2 was taken to be 0.9392 (g/ cm^3) in the calculation.

$$\boldsymbol{T} = \frac{\boldsymbol{m}}{\boldsymbol{A} \times \boldsymbol{\rho}} \qquad (01)$$

Figure 4 illustrates the variation of layer thickness with rotational speed. As given in the legend, continuous lines and dots represent the best-predicted curve and experimental data. Theoretically, the relationship of layer thickness with rotational speed is given by equation (02). The model used to fit the experimental data in this study is given in equation (03).

$$\boldsymbol{T} \propto \frac{\mathbf{1}}{\sqrt{\boldsymbol{\omega}}} \qquad (02)$$

Where, *T* is the layer thickness and ω is the angular velocity of the spinning chuck

$$\boldsymbol{T}(\boldsymbol{x}) = \boldsymbol{\alpha} \times (\boldsymbol{x})^{\boldsymbol{\beta}} \qquad (03)$$

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Where, T is the layer thickness and x is the rotational speed in rpm. α *and* β are the coefficients of the model equation

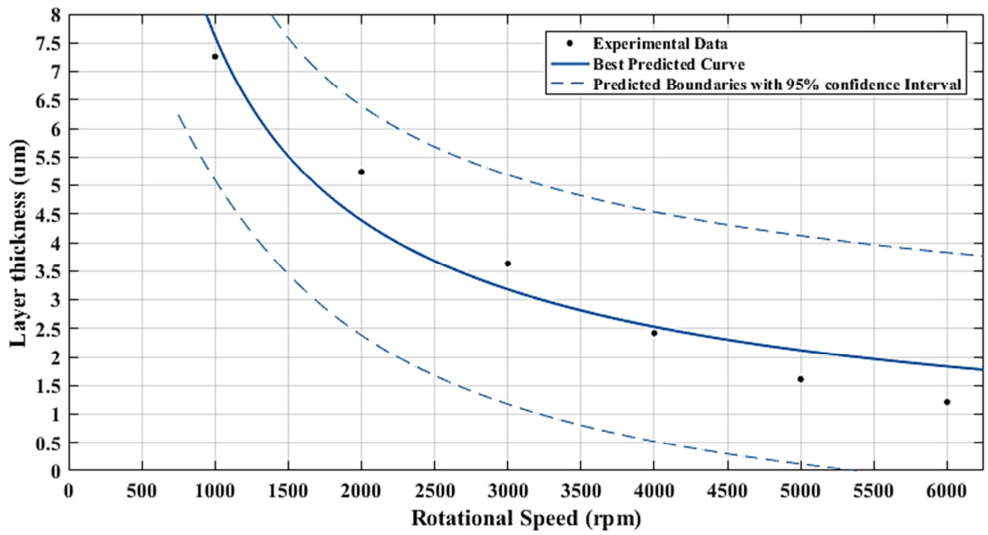

Figure 5: Variation of layer thickness with rotational speed

According to the calculations, the best value for the coefficient α is found to be 1842 and it lies in the range from -2348 to 6032. For the β, it is -0.7946 and the value is ranging from -1.102 to 0.4868. All the confidence boundaries are interpreted with a 95% significant level.

The proportional constant of equation (02) depends on various factors that relate to the system. From the model equation 03, it was found that this constant represented by coefficient α is 1842. Also, as given in equation (02), the power of ω is -0.5. For the model equation, the best-predicted power of ω is -0.7946 and it varies from -1.102 to 0.4868 in the 95% confidence interval. Hence, within the confidence interval range, the experimentally found model equation satisfies the theoretical equation.

3.2 Time Taken for Stabilization

The time, which was taken to stabilize the substrate at a given rotational speed was observed. Notably, the observation was done for 30 seconds period of time for each chosen speed. The graph of rotational speed variation with time for six different speeds is given in figure 6.

It can be clearly identified that the time taken to stabilize for all six different rotational speeds is equal which is about seven seconds. Also, after the stable point, small fluctuations can be seen when the rotational speed is increased.

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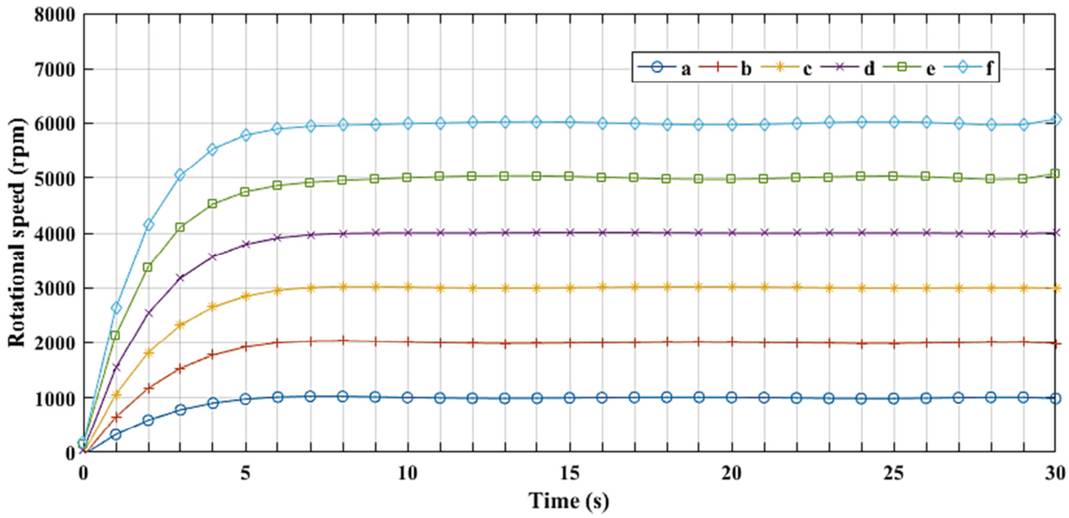

Figure 6: Variation of rotational speed with time (a-1000 rpm, b-2000 rpm, c-3000 rpm, d-4000 rpm, e-5000 rpm, f-6000 rpm)

3.3 Variation of Power Consumption

Finally, the variation of the power consumption with the rotational speed of the spin coater was analyzed. Figure 7 shows the variation of power with rotational speed. The best-predicted curve was calculated using the experiment data and the model equation given below.

$$\boldsymbol{P(x) = a \times e^{(bx)} + c \times e^{(dx)}}$$

Where, P is power consumption, x represents rpm, a, b, c, and d are calculated coefficients

The best-predicted values for coefficients are found to be $a = 3.389 \times 10^{-15}$, $b = 26.15$, $c = 3.91$, and $d = 0.43$ respectively.

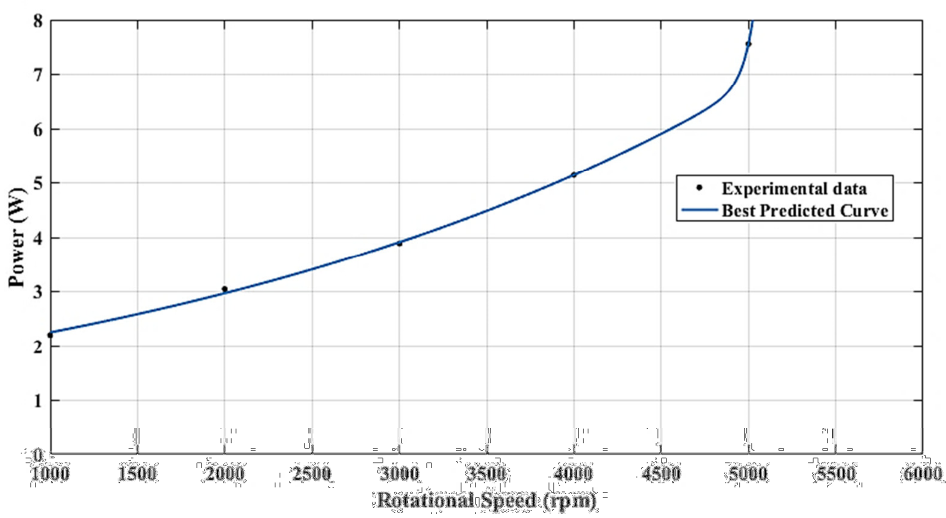

Figure 7: Variation of power with rotational speed

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4 CONCLUSION

A reliable and cost-effective spin coater was successfully developed. After completing the testing procedure, quality of the thin film and technical specifications of newly designed spin coater was able to determine.

It was found from the experimental results, that the thickness of the compound, which was made from TiO_2 suspended in water as the solvent, varied from 7.26 μm to 1.21 μm with the rotational speeds ranging from 1000 rpm to 6000 rpm respectively, harmonizing with theory. The spin coater reaches the maximum rpm within 7 seconds irrespective of any set rpm value. Maximum power consumption was recorded as 7.56 W at 5000 rpm, whereas the minimum was 2.21 W at 1000 rpm.

After all testing procedure, it can be concluded that the desired objective was successful achieved within the frame of limited resources and time.

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