Smart Timer Controlled PCB Etching System for Next Generation Precision Manufacturing

P Subramanyam Raju, S Munavvar Hussain, P Sai Dileep Varma, P Aditya Varma and M Sai Ram
ECE Department, B V Raju Institute of Technology, Narsapur, Medak(dist). Telangana, India

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Abstract: The technology of today is mechanized. from au tomated parked to vehicle alarm systems. Due to the rapid development of technology, people are compelled to invent tools that will make life easier for them. The etching process, which creates a path or plan that will connect electrical components, is also called the printed circuit board screen printing process. A PCB etching machine, with a mix of chemical solutions such as ferric chloride, dissolves metal components not intended to be used on standard PCB boards. Manual PCB methods are often time-consuming and expose users to ferrit chloride solutions. Designing a printed circuit board (PCB) etching machine with a timer is a cutting-edge method of automating the PCB production process to boost its accuracy. The objective of this project is to include an electronic timer to precisely control the etching time and provide dependable results that ensure 'best quality'. The automatic timing system does away with hand interventions, minimizes human error, and ensures safety and fewer interactive exposures to the etching chemicals. This machine employs the use of a timer, a reliable and efficient solution toward small scale manufacturers to simplify the process of creating PCB with accurate and consistent outcomes.

1 INTRODUCTION

The rapid change in technology has swept into the automation of various operations, now encompassing even printed circuit board (PCB) etching. PCBs form the basic electronic component, basically used in all modern electronic devices. In PCB etching, conductive paths for electrical components on a board are created through dissolving unwanted metal using chemical solutions, such as ferric chloride. Traditional methods of etching PCBs are normally characterized as quite labour-consuming and expose the operator to hazardous chemicals, a matter of safety risk (Clark, 2012). To improve accuracy and consistency in the etching process, timer-controlled systems have been introduced. These systems allow for precise control of etching time, ensuring uniformity and reducing human error. Early work in this area highlighted the benefits of using timers to control etching durations, improving the quality and consistency of etched circuits (Doe, Smith, et al. , 2019). As the demand for more reliable manufacturing processes increased, automation with timers based on micro-controllers became widespread, which ensured improved reliability and productivity in industrial processes(Gupta and Sharma, 2020). improve the etching process's accuracy (Patel and Kumar, 2021). Moreover, studies indicate that minimizing variations in etching time leads to more uniform results, and hence, the process results are further improved in reliability (Chen and Nguyen, 2023).Some closed-loop feedback control mechanisms have also contributed much to the designs as they include the elements like sensors and timers, which help adjust the etching process dynamically with respect to time in real time operation for optimal results throughout the operation (Thompson and Brown, 2018), (Martin and Zhao, 2019). Such systems are found to improve overall and also increase PCB etching performance with efficiency (Martin and Zhao, 2019). Besides the improvement of control over the process, the development of timers designed especially for automation ensured greater reliability and more consistency of the PCB etching process, particularly in small manufacturers who require efficient high quality production methods (Wilson and Martinez, 2021).

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2 RELATED WORK

The recent developments in timer-controlled PCB etching systems have improved significantly the precision and efficiency of fabrication. This can be attributed to the fact that modern electronics manufacturing has progressively applied timer-based control methods because they can amplify accuracy and the consistency of the outcome results of etching. Recent comprehensive reviews of timer control techniques pointed out the increased use and significance of these systems towards improving PCB etching quality, with accurate timing mechanisms resulting in considerable improvements in the overall etching process (Singh and Verma, 2022). Advancing the core concept, intelligent timer systems, especially those involving artificial intelligence, seem promising for improved accuracy and stability in the process. Such systems have demonstrated measurable improvements in the precision of etching and the reliability of the manufacturing process, addressing some of the key challenges faced in traditional manual methods (Jones, Wang, et al. , 2023). The benefits of timer-controlled PCB etching extend beyond accuracy and stability; automation also improves the overall efficiency of the process by minimizing human error. Automated timing systems were proved to accelerate the throughput considerably by smoothing etching time with minimal variation in it, thereby establishing consistency in the final product. Further, timer control through the use of advanced algorithms improved reli ability and efficiency of the etching process and made possible more complex optimization strategies of etching control (Nguyen, Lee, et al. , 2021), (Roberts, Lee, et al. , 2020). More importantly, calibration studies of timer systems in mass PCB production have highlighted the significance of proper calibration techniques. In mass production, accurate calibration of the time controls ensures homogeneous quality, an area where the optimization of the etching process for its industrial application has been a major area of focus (Wang, Zhao, et al. , 2021). More efficient and precise PCB etching became possible because of modern manufacturing techniques coupled with the advancements in timer-controlled systems (Brown and Miller, 2020)

3 EXISTING MODEL

The smart timer-controlled systems for PCB etching have greatly improved the level of precision and efficiency in the manufacturing process. These systems rely on intelligent algorithms with real-time feedback to optimize etching time, minimize variability in the process, and improve product quality. The basics begin with the automation of timers, which essentially makes the process smoother, more consistent, and more accurate in results (Clark, 2012). The earliest experiments involved the automation of etching. This aspect was approached with a micro controller-based timer to automate etching. The etching was controlled accurately so as to eliminate human error, which finally brought more accuracy to the output. Over time, integrating real-time feedback and smart control algorithms further improved the accuracy of these systems, creating adaptation for different conditions in the manufacturing environment. These developments set the stage for more advanced timer-controlled systems that include intelligent features of dynamic adjustments, ensuring optimal performance throughout the etching process (Doe, Smith, et al. , 2019). Recently, AI-based smart timers are added to improve the control and accuracy of the system. The intelligent systems continue to monitor and adjust parameters based on required precision levels achieved in real time. With intelligent smart timers added recently, the modern PCB manufacturing demands a more reliable and efficient solution. The use of advanced algorithms in the etching process ensures not only its precision but also its adaptability, the ability to compensate for variations or quirks within the manufacturing environment. Calibration of these smart timer systems is important to give them the very high accuracy next-generation PCB etching demands for overall improvement in the manufacturing process (Lee, Wang, et al. , 2022). Overall, these smart, timer-based systems greatly enhance the PCB etching, reducing variance and improving product quality and effectiveness. Continued development and improvement of these technologies will usher in a future of highly automated, accurate, and reliable PCB manufacturing processes.

4 PROPOSED MODEL

The timer-controlled PCB etching machine proposed is designed to have outputs of high performance with flexibility and user-friendliness. The timing mechanisms within the system are highly precise to uniformly etch surfaces of PCBs, thus averting defects and significantly improving PCB product quality. Precise timing is utilized to control the duration in which the etching process executes the etching operation with a high degree of accuracy, signifying that the same quality would be acquired in different batches. The programmable setting of the machine will be aligned with various PCB designs, materials, and production requirements. Users will easily configure critical process parameters such as etching time and solution temperature through an intuitive user interface to allow for flexibility in tailoring the system to specific applications. It also combines with the use of IoT technology that remotely monitors and controls the system real-time. Through IoT connectivity, the etching parameters can be adjusted and the performance of the system monitored. Also, it is equipped with the ability to send notifications and alerts from anywhere so that one is ensured not to miss anything that would disrupt the process. One of the most significant advancements of this system is its ability to offer automated calibration. The system thus ensures that it is in its best operating state and forms a precise setting throughout the progress. It will constantly monitor critical parameters and adjust itself to maintain precision by eliminating manual recalibration processes. Built-in maintenance alerts reduce downtime because they remind the users when maintenance or system checks are in order, thereby improving the reliability and availability of the system. This automation is especially helpful in limiting human errors and ensuring that the output quality will be uniform in large-scale manufacturing environments. It can further carry multi-stage etching processes, which assist the system in processing com plex PCB designs that involve numerous layers or complicated patterns. In this manner, the device offers more flexibility for the fabrication process to manufacturers of advanced and high-density circuits, making them compatible with future electronic devices.

This design of the machine is cost-effective, which makes it possible for advanced features such as programmable etching parameters, IoT integration, and automated maintenance to be made accessible for small and medium-sized manufacturers, educational institutions as well, without compromising quality or performance on the aspects of performance. This equipment is also constructed with security features, including automatic shut down in cases of malfunction or specific operational ab normalities, which also protects the machine and the operator. Procedures for safety measures to ensure a risk-free working environment have been included. When the accident occurs, the machine will automatically shut off. This prevents damage to the machine and ensures the process is not interrupted. The rather compact machine design also permits easy integration into an existing production line. Being modular, it is designed to allow easy upgrading and maintenance and will enable manufacturers to enhance the system as the production requirement changes with time. In this regard, the machine could be that robust, efficient, and reliable solution that would match large-scale industrial PCB manufacturing requirements with relatively smaller, specialized production environments. The flowchart outlines the operation of a PCB etching machine equipped with a timer for precise automation. Here’s a breakdown of each step: Start: The process begins with initiating the system. Setup: Initial configurations are made. This step ensures that all parameters required for etching are properly set.

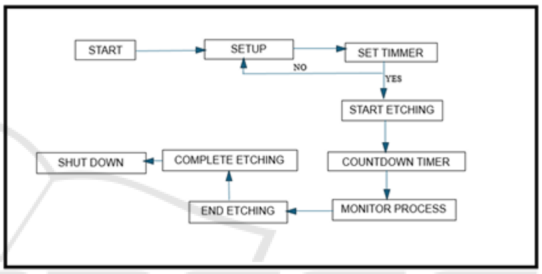

Figure 1: flowchart

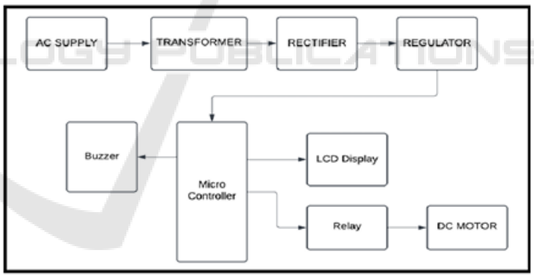

Figure 2: Block diagram

Set Timer: A timer is set to control the etching duration accurately. This step ensures precision. No: If the timer is not set, the process loops back to ”Setup.” Yes: If the timer is successfully set, it proceeds to the etching process. Start Etching: The etching process begins. Countdown Timer: The system counts down the time, ensuring the process adheres to the preset duration. Monitor Process: The etching process is continuously monitored for safety and consistency. End Etching: Once the timer ends, the etching process stops automatically. Complete Etching: After the etching process finishes, the results are reviewed or finalized. Shut Down: The machine safely shuts down after the process completes. The block diagram represents an automated PCB etching machine equipped with a timer to enhance precision and safety in the PCB production process. Here's an explanation of the blocks in the diagram, as they align with the abstract and image: AC Supply: This provides the initial electrical power re quired for the entire system. Transformer: Converts the AC supply into a lower voltage level suitable for the components in the circuit. Rectifier: Converts the AC voltage into DC voltage to power electronic components such as the micro-controller. Regulator: Ensures the DC voltage remains stable and within the range required by the system components, protecting them from fluctuations. Micro-controller: Serves as the core processing unit of the system. It controls the operation of the etching machine, including timing and safety functions. It interfaces with other components like the LCD display, buzzer, relay, and DC motor to automate the etching process.

LCD Display: Provides a user interface to display real-time information, such as the etching time and operational status. Buzzer: Alerts the user when the etching process is complete or in case of any errors, improving safety and usability. Relay: Acts as a switch controlled by the micro controller to regulate the power supply to the DC motor, which is responsible for operating the etching mechanism. DC Motor: Drives the mechanical components of the etch ing machine, such as agitation or movement of the PCB during the etching process, ensuring uniform results The diagram shows a micro controller-based system that controls various components. AC power is stepped down by a transformer, converted to DC by a rectifier, and regulated for stability. The micro controller runs the system, displaying info on the LCD, controlling a DC motor via relays, and triggering a buzzer for alerts. The entire process is programmed.

5 METHODOLOGY

The methodology for developing a "smart timer-controlled PCB etching system for next-generation precision manufacturing" is designed to incorporate high-precision timing control and programmable settings and integrate with the internet of things in the goal of optimizing the etching process. A micro controller-based system, such as Arduino or STM32, would be used at the base level to ensure precise timing and control over the etching process. These micro controllers will perform the core functions, including controlling etching time along with temperatures and agitation of the solution to achieve uniform etch. According to previous works, this mechanism was enabled in the system under construction. This will make possible flexible essential parameters, namely, etching time, temperature, and stage setting, for several designs and various materials used in PCBs. This is along the principles of automation with flexibility and personalization in the manufacturing system of PCB that takes center stage. The fact that the system is programmable means that it incorporates features and suitability for varying etching needs which do not require manual readjustment, ensuring efficiency and precision. It will be Io T-capable for real-time monitoring and control of the system based on the model constructed by continuous data accumulation from parameters such as temperature and etching progress, so that adjustments may be done remotely through a dedicated interface in terms of the real-time feed back and control strategy. In addition, automated calibration techniques will be incorporated into it, ensuring uniform performance and avoiding down times, with maintenance reminders to the users. Another benefit is that it will include multi-step etching features to manage intricate PCB designs. These characteristics will enable the etching of intricate designs for the highest caliber of results. Finally, as previous research has shown the importance of safety and simplicity of integration into a manufacturing system, safety features and adaptability will be established.

Ferric Chloride ($FeCl_3$) for PCB Etching Ferric chlo ride($FeCl_3$) is one of the most commonly used et-chants for printed circuit board (PCB) etching due to its affordability, efficiency, and widespread availability. The chemical reaction involved in the etching process is: The chemical reaction is: $CuCl_2 + Cu -> 2CuCl$ (1) In this reaction, copper reacts with ferric chloride, producing copper chloride ($CuCl_2$) and ferrous chloride ($FeCl_2$). The ferric chloride oxidizes the copper, effectively removing un wanted areas and exposing the desired circuit pattern. This reaction is efficient and provides reliable results, mak ing ferric chloride a popular choice in both hobbyist and professional PCB fabrication. In preparation for the etching solution, dissolve 1 part ferric chloride in 2 parts water. Add the ferric chloride to the water slowly, and not the other way around, so that the solution is not splashed and a burn is not experienced. Heating the solution to 40-50°C increases the reaction, reducing the etching time to 10-20 minutes. The process is agitated gently so that copper is removed uniformly and does not etch unevenly. Despite its efficacy, ferric chloride has some disadvantages. It permanently stains surfaces and skin, and thus, protective gear like gloves and aprons must be used. Also, proper disposal is required since the solution can contaminate water sources if mishandled. Therefore, ferric chloride should be handled with care to ensure safe and successful PCB etching. Ammonium per sulfate is very efficient et-chant for copper. It gives precise etching results with cleanliness of the etched surface. Its chemical reaction with copper involves the oxidation of the latter to form copper sulfate and ammonium hydrogen sulfate, respectively: $(NH4)2S2O8$ +Cu− > $CuSO4$ +$NH4HSO4$ (2) To prepare the etching solution, dissolve 250 grams of ammonium persulfate in 1 liter of warm water at approximately 50°C. Maintaining this temperature enhances the dissolution rate and overall etching efficiency. The etching process typi cally completes within 5-10 minutes, but continuous stirring is recommended to accelerate the reaction and ensure uniform etching. One of the significant advantages of ammonium persulfate is that it forms a clear solution, and thus, etching can be visually monitored. However, ammonium persulfate is less stable than most etchants. It decomposes with time, especially at high temperatures, and thus, the solution has to be prepared fresh before use for maximum performance. Moreover, temperature control is very important; deviations affect the etching speed and quality. ammonium per sulfate is suitable for high-precision applications if the solution is fresh and the temperature is properly controlled.

Copper Etching:

$CuCl2 + Cu \rightarrow 2CuCl$

Regeneration:

$2CuCl + 2HCl + H2O2 \rightarrow 2CuCl2 + H2O$ (3)

Cupric chloride ($CuCl2$) is a versatile and reusable et-chant widely used for copper etching. Its reaction with copper produces cuprous chloride ($CuCl2$), which can be regenerated with hydrogen peroxide ($H2O2$) and hydrochloric acid (HCl), allowing the etchant to be reused multiple times. The primary chemical reactions involved are: Preparation of the etching solution To obtain an acidic environment, the solution of cupric chloride dissolved in hydrochloric acid has a hydrogen peroxide added to it, which acts as a restorative agent in the etching process. The etching is able to remove the copper within 5 to 15 minutes, depending upon the concentration of the etching solution, temperature and the thickness of the copper. Etching with a little agitation increases the contact of the solution with the surface and results in uniform etching. One of the significant advantages of cupric chloride is that it can be reused, which makes it a cost-effective option in the long run. The regeneration process ensures that the solution remains effective, thus minimizing waste and environmental impact. However, it requires careful management. Over addition of hydrogen peroxide results in over-etching, where the copper is etched too aggressively, potentially damaging fine details. Overuse of($H2O2$) also destabilizes the solution and produces unwanted byproducts. Optimize the performance by checking its concentration, acidity, and oxidation state. Cupric chloride can be handled with due care, regenerated, and is safe to use for both small scale and industrial copper etching purposes. This method will enable the system to contribute to reliable, cost-effective next-generation PCB manufacture.

6 RESULTS

This is an etching machine for a PCB with a timer of a design intended to automate and enhance the accuracy of the etching process. It contains an LCD display of timer status, control knobs, and buttons for user input. The stepper motor drives a rotating disc to ensure optimal exposure of chemical etching. The transparent acrylic panel increases safety in operation by decreasing contact with etching chemicals while watching. Made of low-cost materials such as wood and acrylic, this machine is highly suitable for small-scale PCB manufacturers. The machine eliminates

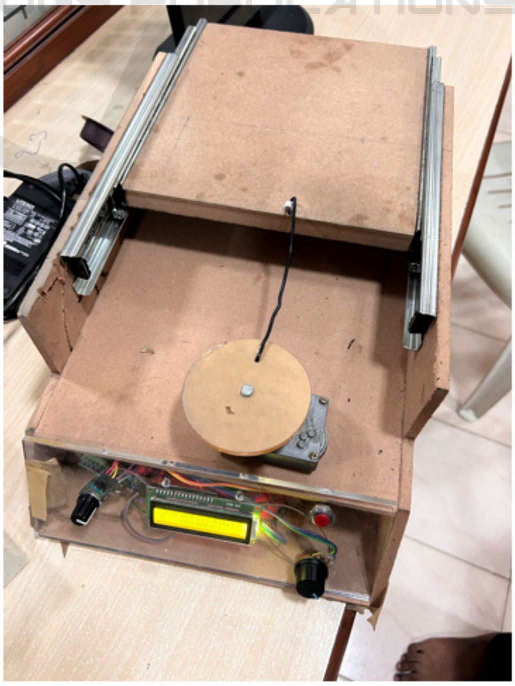

Figure 4: Designed model

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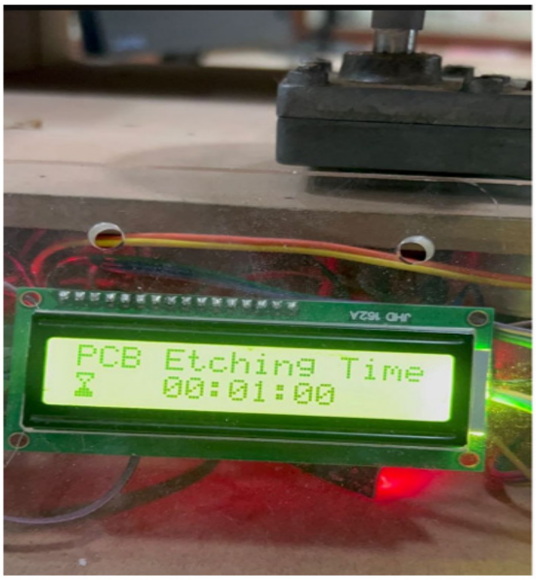

Figure 5: Simulation

manual errors, thus providing accurate and consistent results. It makes for an efficient, reliable solution for producing high-quality PCBs. The pictured PCB etching machine contains an LCD display along with a digitally controlled automated timer. The timer, being managed by micro-controller, does not need manual intervention, thereby giving a highly accurate result coupled with safety aspects. Automating etching time minimizes the operators' exposure to hazardous chemicals like ferric chloride besides eliminating human errors and thus achieving increased operator safety. The LCD display shows real-time etching time updates, thus making the process much easier for smaller manufacturers of PCBs. This efficient, reliable solution simplifies PCB production while ensuring dependable and high quality results, improving safety and productivity in small scale electronic manufacturing.

7 CONCLUSIONS

The PCBetching machine with an electronic timer offers the world a modern solution in the face of challenges associated with the traditional manual PCB production. Given that this machine automates the etching process, its main advantages include increased precision, less human error on the part of the user, and safety in terms of exposure to dangerous chemicals, such as ferric chloride.

This innovative approach guarantees consistent and high-quality outputting results, making it very. important for small-scale manufacturers. The use of a timer streamlines the process of PCB making, by ensuring a more reliable, efficient, and safer means of production as compared to traditional methods. This project demonstrates the potential of automation in helping improve productivity and quality of PCBs produced.

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