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Development of a Machine for Printed Circuit Board Electrical Test Wire–Pin Fixture

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In this paper, we focus on the development of a machine for manufacturing needle probes used in the electrical testing of printed circuit board (PCB) in-circuit-test fixtures. Currently, the manufacturing process for needle probes involves manual tasks such as wire threading, soldering, heat shrink tubing application, heat shrink tubing heating, and placing cylindrical terminals into a needle disc. Owing to the time-consuming nature of this production process, automation is proposed for improvement. The system development involves programmable logic controller (PLC) control and pneumatic cylinder mechanisms to replicate the manual wire threading process. Pneumatic grippers are used to position cylindrical terminals and heat shrink tubing. Two stepper motors drive plastic rollers for copper wire extension by a rolling process along V-shaped groove straightening guides, reaching the wire insertion holes on the PCB. A *YZ*-axis servo stage with clamping fixtures secures the PCB and moves it to the wire insertion holes. Once the copper wire extends through the cylindrical terminal, the threading action for that PCB hole is completed. Subsequently, laser welding joins the cylindrical terminal with the copper wire, and a hot air blower fuses the heat shrink tubing with the cylindrical terminal. Pneumatic grippers grasp the threaded cylindrical terminals. Simultaneously, an *XY*-axis servo stage with clamping fixtures places the disc into the clamping fixture, moves it beneath the pneumatic grippers, and inserts the cylindrical terminals into the disc. After completion, a few centimeters of copper wire in front of the rollers are cut, marking the completion of the needle placement for that hole on the disc. The combination of PCB hole wire threading and disc hole needle placement constitutes one cycle of the wire threading fixture. The machine repeats this automated sequence until the entire needle probe fixture is produced.

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1. Introduction

As technology advances, the prevalence of electronic products continues to rise. Almost all electronic devices require the use of printed circuit boards (PCBs) to secure integrated circuits (ICs) and other electronic components.[1] During the PCB manufacturing process, various factors can lead to electrical issues such as short circuits, open circuits, or leakage. Additionally, PCB technology has evolved towards higher density and multiple layers.[2] Failing to identify and segregate defective boards in the production stage can result in increased cost wastage. Hence, PCB defect testing has become increasingly important.[3] Currently, the in-circuit test (ICT) is the primary method for testing PCBs. ICT involves three testing techniques: Flying Probe,[4] Dedicated Fixture Test,[5] and Universal on Grid.[6] In this study, we focus on the Dedicated Fixture Test, which utilizes wire probes for production. The manual process of threading and connecting wires for each circuit path can be time-consuming. In this research, we aim to enhance production efficiency by mimicking the manual wire threading process using automation technology.

During the development of this machine, careful consideration was given to whether the mechanical components used met the operational requirements. The suitability of pneumatic cylinders for clamping and movement during gripping was also taken into account. The overall architecture used in this study utilizes servo motors to replicate the actions of a wire-extending machine.[7] The primary action involves the rolling and threading of copper wire through two different and opposing plastic rollers without compressing the wire. Pneumatic components were employed for auxiliary functions, including the handling of cylindrical terminals and heat shrink tubes, feeding, and movement. Pneumatic components are commonly used in equipment manufacturing within the automation industry because of their ease of sourcing, relatively low cost, and a certain degree of precision. The initial step involved creating detailed drawings for all machine parts.[8] These drawings were then combined to form the mechanical structure, with careful consideration given to the placement of air pipes and wiring. The outer casing was designed, and finally, all components were integrated into a complete machine. The dual-axis servo slide stage was used for movement and positioning. The slide stage is controlled by stepper motors through a motor controller, ensuring the precise positioning of the slide stage over the wire threading holes. Two different axis platforms were employed: the *YZ* axis to ensure that the copper wire passed through the PCB holes and the cylindrical terminal threading holes in a straight line during wire movement, and the *XY* axis for implanting needles into pinholes after the completion of threading cylindrical terminals. In terms of control, a programmable logic controller (PLC) was employed to control electromagnetic valves and stepper motors. The PLC allowed for sequential control, step by step, in establishing an automated control system.

In the context of the increasing ubiquity of electronic products, the demand for PCBs has been steadily rising, and technological advancements have led to higher levels of complexity in these circuit boards.[9] After production, PCBs need to undergo testing to confirm their electrical performance, reducing the potential for errors and additional costs in subsequent processes. Currently, the production of wire–pin fixtures, predominantly used in the Dedicated ICT method within the PCB industry, heavily relies on manual labor. Wire–pin fixtures are specialized fixtures used in in-circuit testing machines for PCBs and are mainly designed for testing rigid PCBs and IC carrier boards. They offer advantages such as short testing times, accuracy, and the ability to test a large number of PCBs. These fixtures are primarily used to check for open and short circuits in various circuits, and they are known for their ease of operation, speed, and accurate fault localization.(10) Each different-sized single-board PCB requires its dedicated fixture. In-circuit testing is typically the first step in the PCB production process and provides real-time feedback on production status, facilitating technical improvements and enhancing efficiency. Wire-pin fixtures, owing to their precise fault localization and ease of repair, significantly improve production efficiency and reduce maintenance costs for tested faulty boards. The production process of wire–pin fixtures, as shown in Fig. 1, involves designing according to the PCB's dimensions, creating computer-aided design drawings, specifying hole numbering and circuit routing, programming numerical control drilling, fixture assembly, needle placement, wiring, fixture installation, and inspection.(11) The front-end processes are computer-designed whereas the assembly, needle placement, and wiring are performed manually. Figure 2 depicts manual wiring of the wire–pin fixture of a single-layer board.

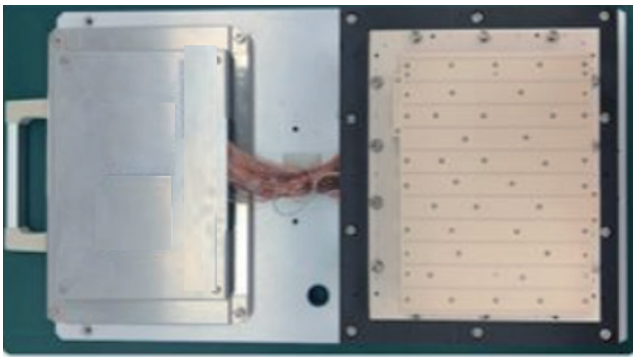


Fig. 1. (Color online) Wire–pin fixtures.

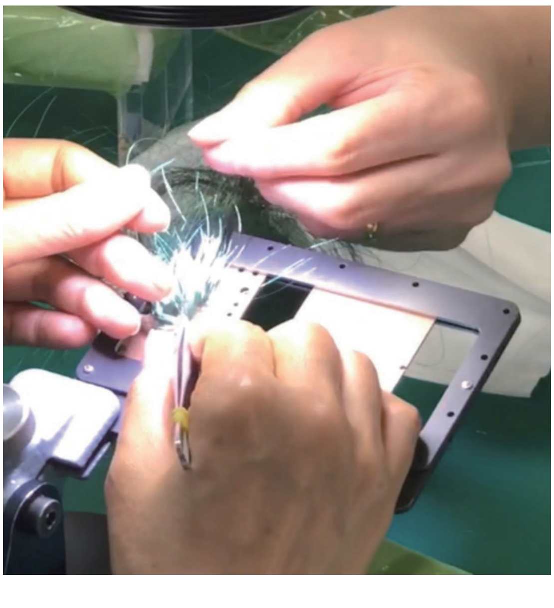


Fig. 2. (Color online) Manual wiring of wire–pin fixture of single-layer board.

In this paper, we primarily focus on the automation improvement of manual wiring depicted in Fig. 2. Once the wire–pin fixture is automated, it is inspected by the operator on the testing machine, who checks for potential short circuits and open circuits, and also examines whether the fixture might press the PCBs with the same specifications intended for electrical testing. Additionally, the operator checks whether the total number of points on the design drawing is consistent, such as the numbers of open and short circuits. Once the fixture passes this inspection, it becomes eligible for electrical testing, along with PCBs that share the same specifications. With the increasing demand for fixtures, there is a risk of inadequate capacity, leading to supply shortages. Companies may need to hire more production staff or require existing personnel to work overtime to meet capacity demands, resulting in increased labor costs. Human errors during the manufacturing process can lead to unnecessary waste. Furthermore, the global manufacturing industry is facing challenges such as urbanization of labor, rising wages, declining birth rates, and an aging workforce.(12) By embracing automated production methods, precise manufacturing becomes possible, reducing production costs, increasing productivity, and meeting the demands of both businesses and customers.

2. System Architecture

In this section, we will discuss the automated fabrication process of the wire–pin fixture. The development of the machine involves various structural designs, including a cylindrical terminal feeding mechanism, a heat-shrink tubing feeding mechanism, a wire threading mechanism, a laser welding mechanism, a heat gun mechanism, and a dual-axis servo slide structure.

The system architecture is primarily built around a PLC, which serves as the central control unit for managing sensors of the solenoid valves. These sensors of the solenoid valves are responsible for actuating the extension and retraction of cylinders. Additionally, the PLC is also responsible for controlling a sensor of the stepper motor that drives the servo slide table, as depicted in Fig. 3. The design of the machine is aimed at the automation of the manufacturing process, which would enable tasks such as wire threading, welding, heat-shrink tubing

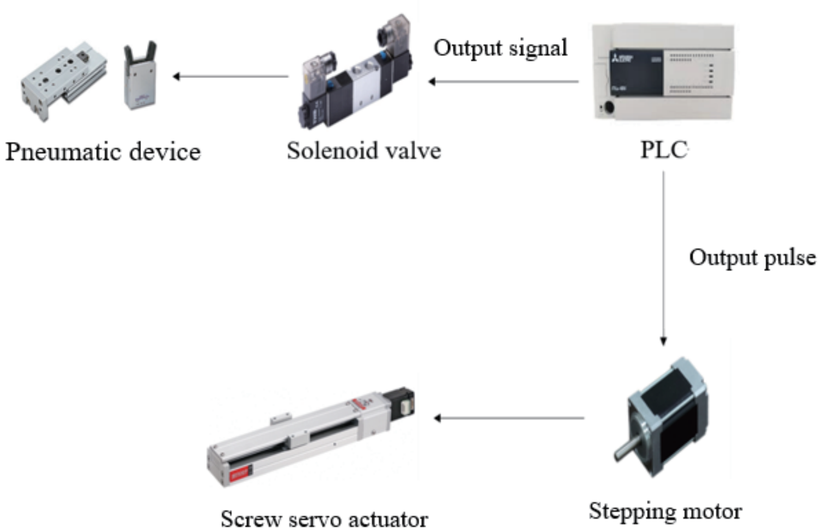
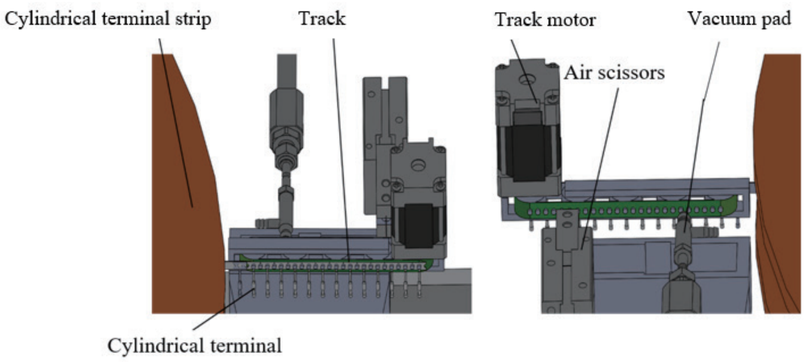


Fig. 3. (Color online) System structure.

application, and needle disk insertion. We will provide a detailed overview of the machine's overall structure, including mechanisms such as the cylindrical terminal feeding mechanism, heat-shrink tubing feeding mechanism, wire threading mechanism, laser welding mechanism, heat gun mechanism, and the dual-axis servo slide table configuration. We will also delve into the hardware components of the control interface and describe the system's operational workflow.

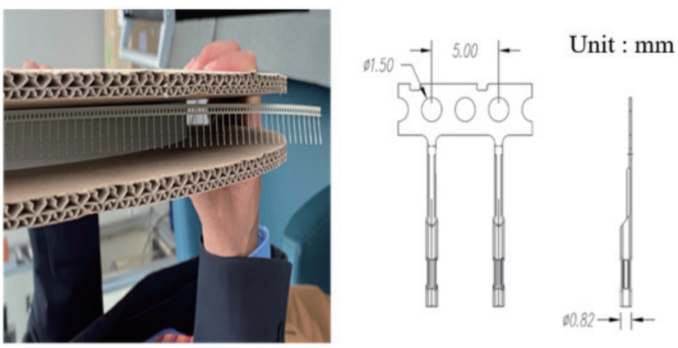
2.1 Cylindrical terminal feeding mechanism

The cylindrical terminal strip is placed on a fixed frame, and a section of it is pulled out. It is engaged with the track at the hole punched in the strip. The track is driven by a stepper motor, which feeds the strip with a fixed rotational distance. The cylindrical terminal at the front of the strip is the point of extraction for each wire threading operation. A pneumatic gripper is used to lift and hold the terminal after extraction, rotating it 90 degrees to align it with a V-shaped groove. The front view of the cylindrical terminal feeding mechanism is shown in Fig. 4(a), and the rear view is shown in Fig. 4(b). After each threading operation is completed, the next terminal is fed. The layout of the cylindrical terminal strip and the sizes of the cylindrical terminal are illustrated in Fig. 5. The track can accommodate up to 26 cylindrical terminals.



(a) (b)

Fig. 4. (Color online) Cylindrical terminal feed mechanism. (a) Front view of feeding mechanism and (b) rear view of feeding mechanism.



(a) (b)

Fig. 5. (Color online) Cylindrical terminal strip and size. (a) Cylindal terminal strip and (b) cylindrical terminal size.

When all 26 terminals have been used, a vacuum suction cup is activated to pick up the empty strip. Pneumatic scissors then cuts the empty strip, which falls into a recycling bin for operator retrieval, as shown in Fig. 6.

2.2 Heat shrink tubing feeding mechanism

The heat shrink tubing used in this study is the F34-1 heat shrink tubing. It has rapid shrinking capabilities with a shrinkage temperature of approximately 80 °C, as depicted in Fig. 7, which illustrates the installation method of the heat shrink tubing. After the soldering process for cylindrical terminals is completed, it is necessary to apply the heat shrink tubing to protect the copper wires and cylindrical terminals, ensuring their secure connection. In the mechanism for heat shrink tubing feeding, a stepper-motor-driven roller is used to advance the tubing strip, providing a predetermined length for each feeding cycle, as shown in Fig. 8. Following the completion of the feeding process, a pneumatic-controlled blade is employed for cutting the tubing, as illustrated in Fig. 9. After cutting, a vacuum suction cup is activated to pick up the heat shrink tubing, and a rotary cylinder performs a 90-degree rotation to position the tubing over the copper wire's threading path, thus completing the heat shrink tubing feeding process.

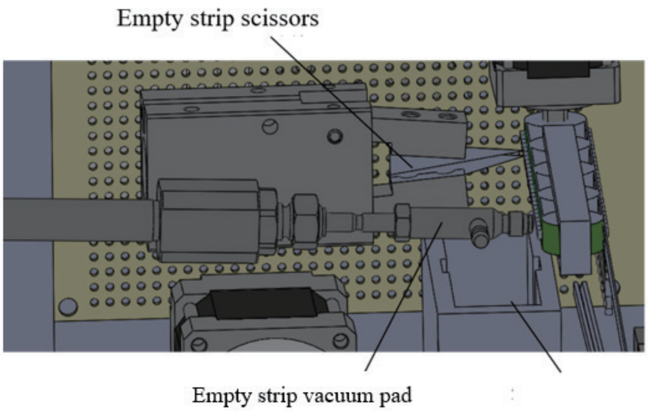


Fig. 6. (Color online) Empty material belt recovery mechanism.

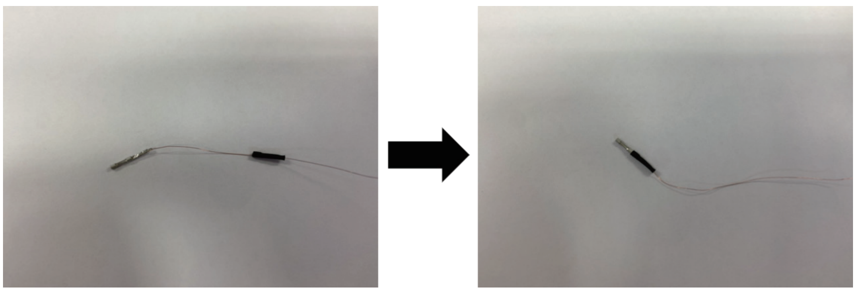


Fig. 7. (Color online) Heat shrink tubing installation.

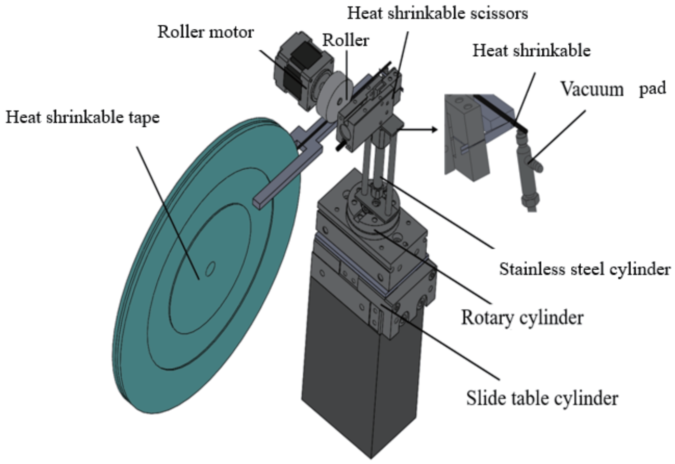


Fig. 8. (Color online) Heat shrink tube feeding mechanism.

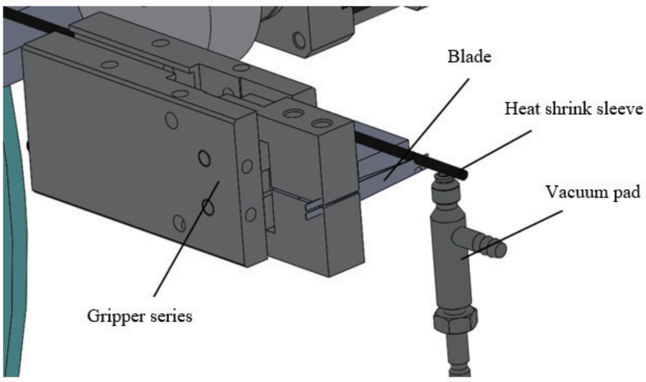


Fig. 9. (Color online) Cutting mechanism of pneumatic shrinkable tubing.

2.3 Wire threading mechanism

In wire–pin fixture production, a copper wire of 0.12 mm diameter, wound around a coil frame of 40 cm length and 12.5 cm width, is used. On the basis of the dimensions of the coil frame, a fixed bracket is designed to hold the copper wire coil. The copper wire is drawn from the coil, passed through four fixed pulleys, and then directed to a roller. When the roller is stationary, it maintains tension in the copper wire. Initiating the stepper motor rotates the roller, which propels the copper wire for stretching. The copper wire advances in a straight line along a V-shaped groove, passes through the PCB, and finally extends to the cylindrical terminal. This wire threading mechanism is illustrated in Fig. 10.

2.4 Laser welding mechanism

Laser welding is widely employed across various industries, including automotive, aerospace, defense, maritime and shipbuilding, healthcare, electronics, power generation and distribution,

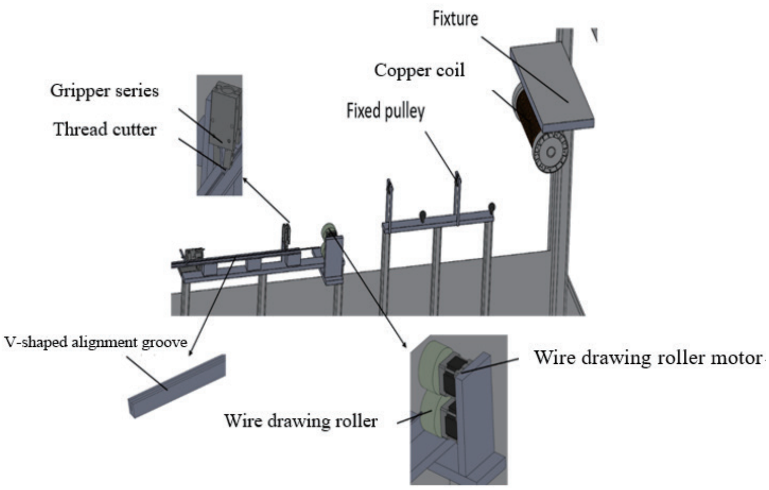


Fig. 10. (Color online) Threading mechanism.

chemical manufacturing, alternative energy (fuel cells, solar, and wind turbines), nuclear technology, petroleum, and natural gas, as well as nonroad transportation equipment and household appliances.(13) Its primary feature lies in its ability to perform microwelding, as lasers can be focused into very small spots, making them suitable for small-scale, high-volume production processes.(14) After the wire threading process is completed, the laser welding gun is driven into position by the sliding cylinder. It strikes the welding point on the rear end of the cylindrical terminal, approximately 3 mm from the end of the elongated flat rod, as shown in Fig. 11. By melting the surface of the elongated flat rod at the rear end of the cylindrical terminal, it effectively welds the copper wire to the cylindrical terminal, as illustrated in Fig. 12.

2.5 Heat gun mechanism

Heat shrink tubing with an initial inner diameter of 1.4 ±0.2 mm and a thickness of 0.1 mm is used. Following heating-induced contraction, the inner diameter was reduced to 0.5 mm with a thickness of 0.2 mm; we employed a heat gun developed by Han Electronics Technology for liquid-crystal displays (LCDs). This heat gun features rapid heating and LCD temperature display functions. After laser welding is completed, the slider cylinder advances to drive the entire vacuum suction mechanism, inserting the heat shrink tubing onto the cylindrical terminal. Once the tubing is in place, the vacuum suction is released, and the slider cylinder retracts the vacuum suction mechanism to its original position. Finally, the slider cylinder moves the heat gun down to a position 3 cm above the cylindrical terminal, as depicted in Fig. 13. The heat gun is preheated for 3–4 s until the temperature reaches approximately 180 °C. Shrinkage of the heat shrink tubing is completed in an additional 3–4 s.

2.6 Dual-axis servo slide mechanism

Servo slide mechanisms, widely used in various industries such as PC, PCB, LED, optoelectronics, semiconductors, dispensing, packaging, biotechnology, pharmaceuticals, and

Fig. 11. (Color online) Laser welding points.

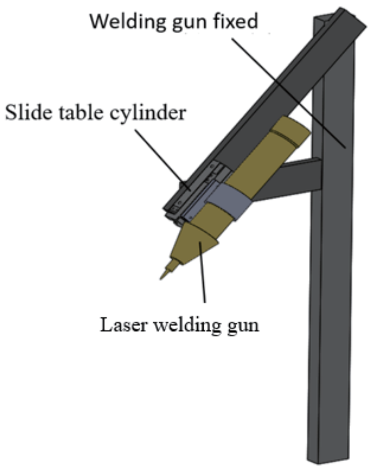


Fig. 12. (Color online) Laser welding mechanism.

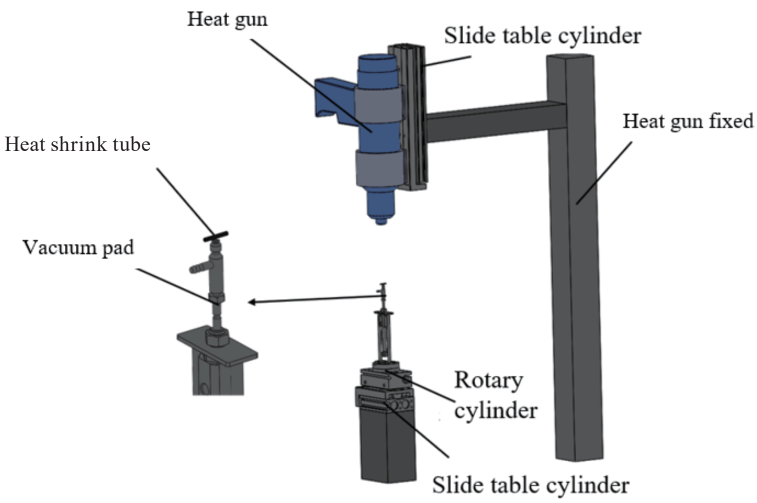


Fig. 13. (Color online) Heat shrink tube heating system.

cosmetics, fulfill the requirements of automated equipment, precise measurement design, and manufacturing. They offer advantages such as high efficiency, high precision, and high load capacity. The dual-axis servo slide used in this study is the AU-H integrated ball screw slide, which combines linear guides and ball screws into a single U-shaped design. It is suitable for installation in various orientations, including horizontal, vertical, wall-mounted, and suspended configurations. It meets the requirements for precision and load capacity and can be assembled into multiple slide units with different axes. Two models were used in this research, AU-65-H and AU-88-H. Both models have a 5 mm lead and a repeatable accuracy of ±0.008 mm. The purpose of using the servo slides is for short-distance positioning and movement, so the movement speed is not a consideration.

2.7 *YZ*-axis dual-axis servo slide

The combination of AU-65-H and AU-88-H creates a *YZ*-axis configuration, as shown in Fig. 14, representing the *YZ*-axis servo slide mechanism. This configuration is employed for the positioning and movement of PCBs. The clamping fixture is attached to the slide, and PCBs are inserted into the clamping fixture. The slide is controlled by a stepper motor, as depicted in Fig. 15, illustrating the PCB fixture mechanism. The clamping fixture is suspended primarily to avoid any obstruction when copper wires pass through the PCB. Additionally, this design allows for the easy removal of the PCB when the holes are fully threaded. Currently, our research focuses on PCB dimensions of 100 × 100 mm. In the future, even if there is a need to change the PCB dimensions, it can be accommodated by altering the size of the PCB clamping fixture, enabling the threading of PCBs of different sizes.

2.8 *XY*-axis dual-axis servo slide

Two AU-88-H servo slides are combined to form the *XY*-axis mode, as shown in Fig. 16, which depicts the *XY*-axis servo slide mechanism. The slide is controlled by a stepper motor. The

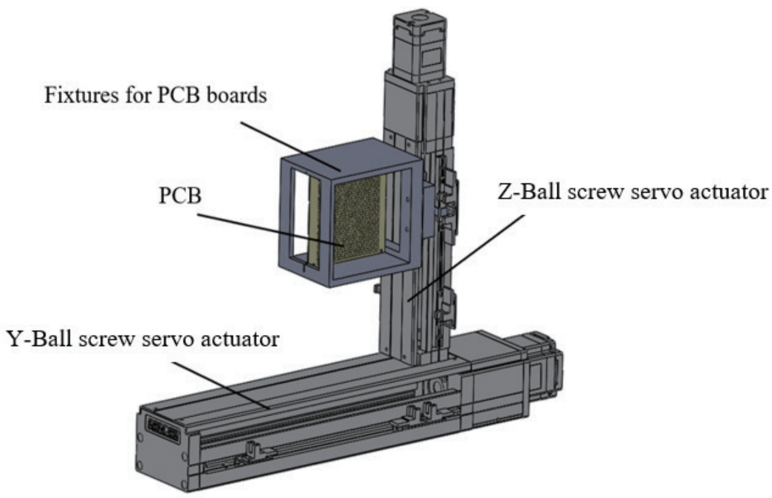


Fig. 14. (Color online) *YZ*-ball screw servo actuator mechanism.

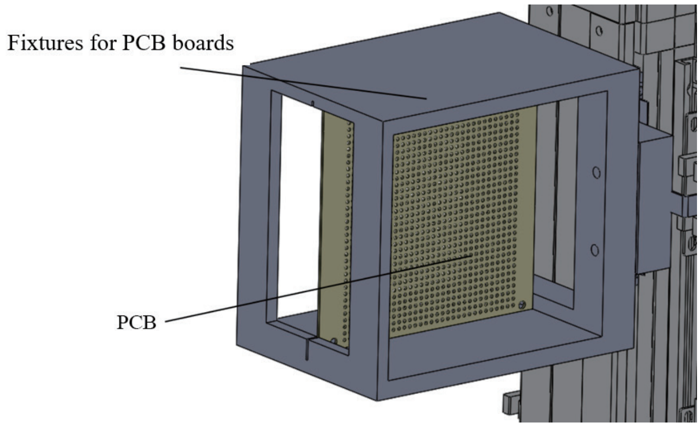


Fig. 15. (Color online) PCBs fixture mechanism.

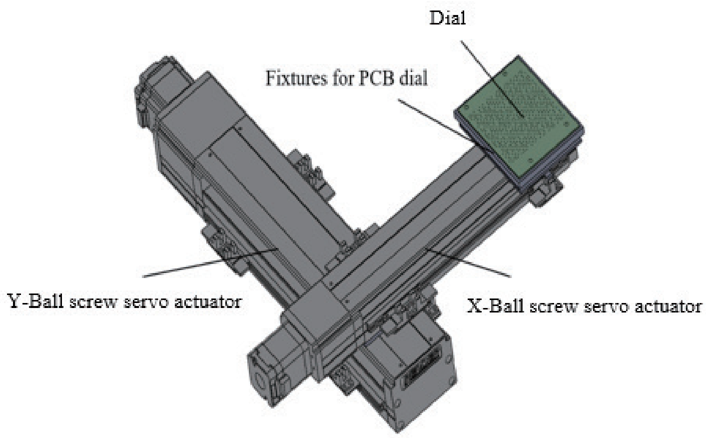


Fig. 16. (Color online) *XY*-axis servo slide mechanism.

clamping fixture is attached to the slide, and the needle disk is placed inside the clamping fixture. After the cylindrical terminals have been processed, the slide moves the clamping fixture, which contains the needle disk, below the completed cylindrical terminals. When the mechanical gripper is lowered, the cylindrical terminal can be directly inserted into the needle disk hole.

2.9 PLC control architecture

The PLC control architecture consists of several primary components, including the main unit, input/output interfaces, power supply, encoder, and expansion modules. It serves as a digital logic controller for automation control. It can load electronic control instructions into memory for storage and execution.[15] Additionally, it can receive and transmit various forms of electronic signals, controlling and supervising all automation equipment and power monitoring systems. PLCs are known for their versatility, wide applicability, high reliability, strong immunity to interference, and ease of program editing. The working principle of PLCs involves sequential control. They follow the instruction sequence, executing instructions from the first to the last in order, and then repeating the control process. This sequential control allows for the timely detection of errors in the program and enables quick corrections. In the context of the automated wire bonding fixture, the PLC controls pneumatic components through electromagnetic valves, which drive the extension of cylinders for laser welding and hot air gun operations in a straightforward manner. Additionally, the PLC controls stepper motors to drive the movement of the dual-axis platform's lead screw, establishing an automated control system.(16)

3. Experimental Analysis

In this section, we will elucidate the complete system construction process of the pneumatic control system in this study. It will include an analysis of the motion of the dual-axis servo slide, a stress analysis of the clamping fixture, and an explanation of the integration of the mechanisms into the simulation results of the automated system.

The pneumatic system process, as shown in Fig. 17, operates as follows. High-pressure air is generated by an air compressor, and this air is first filtered (with built-in air filtration and drainage valves). It is then directed into an air reservoir tank (equipped with a drainage valve) after the initial filtration. From there, it is conveyed through air ducts to a three-point assembly. Since the compressed air produced by the air compressor may contain moisture and impurities, it undergoes further filtration using filters. Subsequently, the pressure is adjusted to the appropriate level for the cylinders through a pressure regulator. The pneumatic cylinders are controlled by sensors of the solenoid valves, which direct the airflow by inserting the air ducts into the pneumatic cylinder's inlet ports. These sensors of the solenoid valves are connected to the air

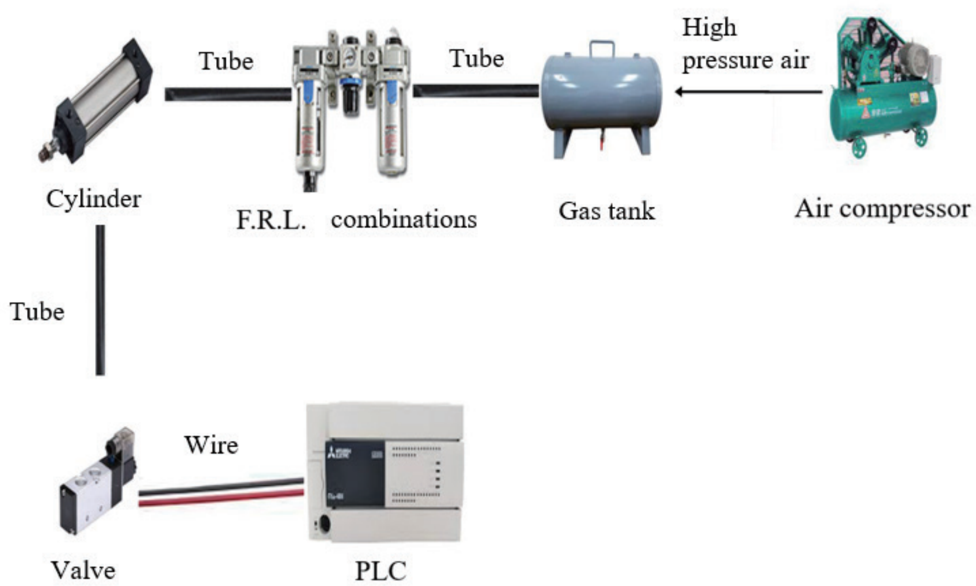


Fig. 17. (Color online) Air pressure system process.

ducts' inlet and outlet ports. Their operation is controlled by the PLC main unit.[17] In automated equipment, pneumatic control systems are often positioned at the bottom of the machine and protected by an enclosure. They are designed for easy maintenance and replacement, often with a side-mounted configuration for user convenience.

There are two types of servo systems in use, *YZ*-axis and *XY*-axis, each with its own analysis of motion methods involving the movement of the slide table with the clamping fixture, the distance it covers, and the sequencing of wire insertion. The servo slide table is driven by a stepper motor through an internal screw drive. The minimum movement distance is determined by the motor resolution, and we have selected a motor resolution of 1.8 degrees (200 steps/revolution). The board size is 100 × 100 mm^2, and the center-to-center spacing of the holes in the PCB is 2.54 mm, as shown in Fig. 18. The first hole for wire insertion is at the bottom left, and the last hole is at the top right, as shown in Fig. 18. The axial motion direction is as follows. The *X*-axis moves to the left, and the *Z*-axis moves downward. The servo slide table is moved to ensure that each wire insertion hole is fixed at the first hole position, and wire insertion proceeds sequentially until all holes are filled, as depicted in Fig. 19. When wire insertion is carried out using the wire clamping fixture, the wire passes through the front end of the machine's wire clamping fixture, through the PCB, and finally, into the rear end of the machine's wire clamping fixture, as shown in Fig. 20.

The needle plate has dimensions of 115 × 89 mm^2, and the center-to-center spacing of the needle plate holes is 2.54 mm, as shown in Fig. 21. The first hole for needle insertion in the needle plate is at the top right, and the last hole is at the bottom left, as illustrated in Fig. 21. The axial motion direction is as follows: the *X*-axis moves to the right, and the *Y*-axis moves upward. The servo slide table is moved to ensure that each needle plate hole is fixed at the first hole position, and needle insertion proceeds sequentially until all holes are filled, as depicted in Fig.

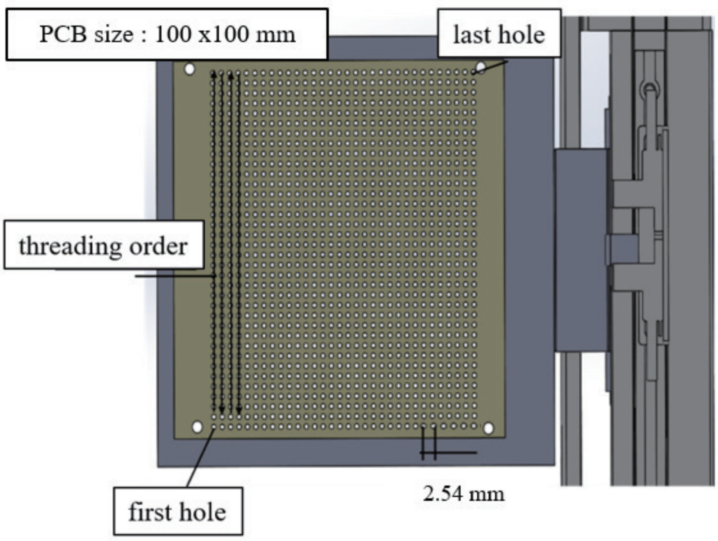


Fig. 18. (Color online) PCB center hole distance and threading order.

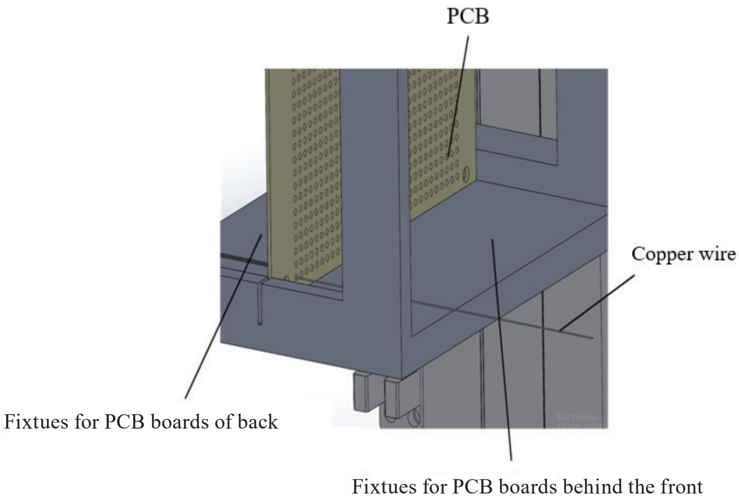


Fig. 19. (Color online) Movement direction of *YZ*-ball screw servo actuator.

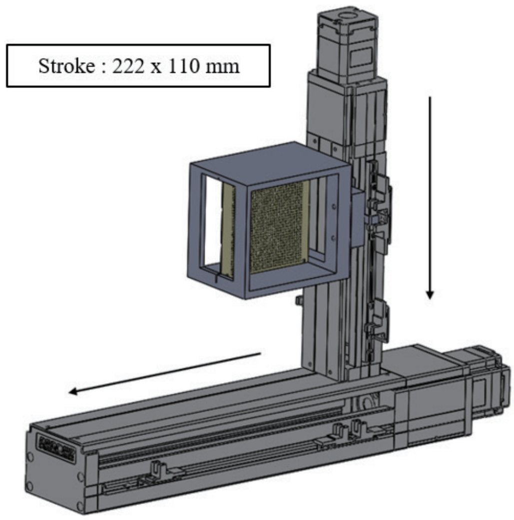


Fig. 20. (Color online) PCB placement machine wiring diagram.

22. The mechanism for embedding cylindrical terminals into the needle plate is shown in Fig. 23, where the terminals are gripped and vertically embedded into the needle plate upon completion of processing.

The manufacturing of manual wire needle fixtures is intended to replace manual production with automation. The wire threading process involves threading copper wire into cylindrical terminals, soldering, inserting heat shrink tubes into the cylindrical terminals, heating the heat shrink tubes, and implanting cylindrical terminals into the needle plate. These processes are integrated into an automated machine, as illustrated in Fig. 24.

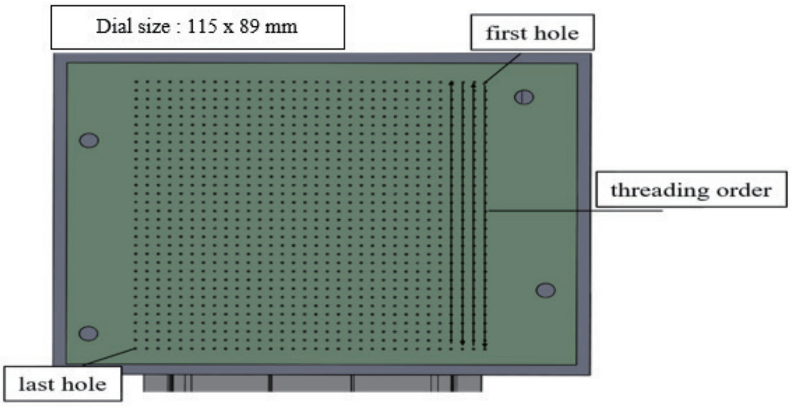


Fig. 21. (Color online) Dial center hole distance and threading order.

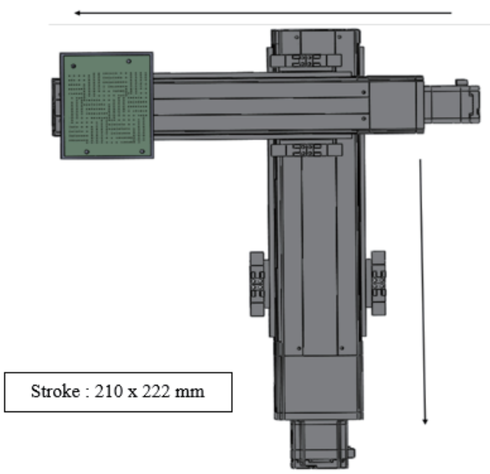


Fig. 22. (Color online) *XY*-ball screw servo actuator movement direction.

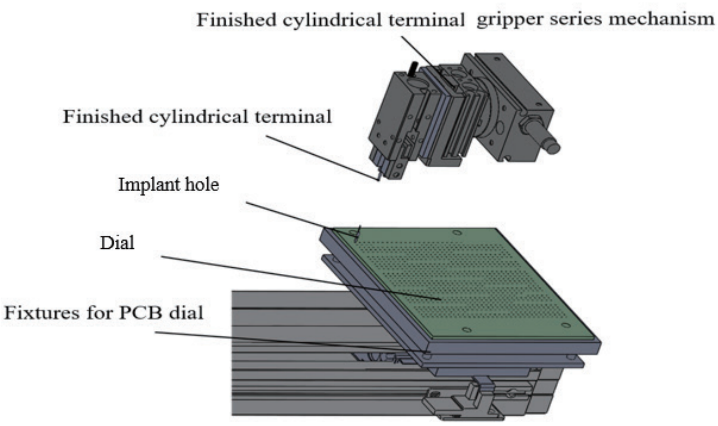


Fig. 23. (Color online) Schematic of cylindrical terminal implantation needle plate.

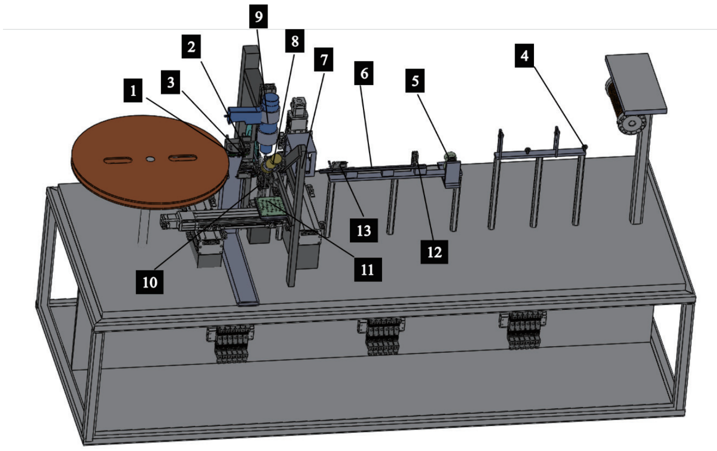


Fig. 24. (Color online) Machine action sequence position.

Let us break down the operations of its subsystems individually. In Fig. 24, we have the cylindrical terminals designed (labeled as 1 in Fig. 24) to match the size of tape punches on the conveyor, as depicted in Fig. 25(a). The machine in Fig. 24 uses manually punched tape; the designed cylindrical sleeve is inserted into the punched tape and then positioned onto the conveyor belt to complete the process. Circular holes with a diameter matching that of the punched tape holes are predesigned on the conveyor. Subsequently, upon starting the machine, the conveyor is advanced by a fixed distance using a stepper motor. The mechanical gripper is then activated to clamp the cylindrical terminal, remove it, and subsequently rotate the gripper 90 degrees to align the hole of the cylindrical terminal with the copper wire threading path while keeping it parallel and straight. Next, a stepper-motor-driven roller extends the heat shrink tube material to a specified length before stopping, as shown in Fig. 25(b). Furthermore, pneumatic control (labeled as 3 in Fig. 24) is used to cut the heat shrink tube material with a blade. Subsequently, the vacuum suction cup is activated to pick up the cut heat shrink tube. A rotary cylinder is employed to move the base of the vacuum suction cup, and the cylinder rotates 90 degrees to align the opening of the heat shrink tube with the copper wire threading path, as depicted in Fig. 25(c).

Four fixed pulleys (labeled as 4 in Fig. 24) are used to straighten the copper wire and tighten it to maintain tension. Then we place the copper wire in the two rolling wheels. We start the stepper motor to drive the rotation of the rolling wheels, and the copper wire will extend forward. We then stretch the wire, as shown in Fig. 26(a). Fig. 26 shows the forward extension of the copper wire (labeled as 5 in Fig. 24) guided along a V-shaped groove to maintain a straight path. This V-shaped groove ensures the straight progression of the copper wire, as shown in Fig. 26(b). In Fig. 26, the copper wire continues to extend along the V-shaped groove (labeled as 6 in Fig. 24) until it passes through the PCB, as depicted in Fig. 26(c). Finally, in Fig. 26, the copper wire extends through the PCB and stops at the rear end of the cylindrical terminal (labeled as 7 in Fig. 24), completing the wire threading process, as illustrated in Fig. 26(d).

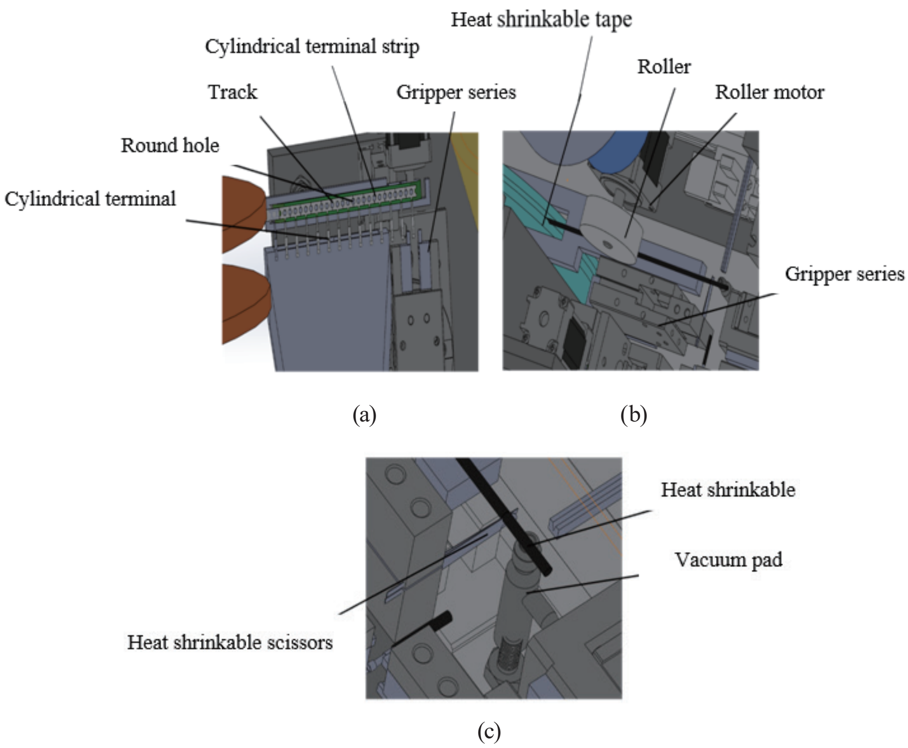


Fig. 25. (Color online) Feeding action simulation. (a) Cylindal terminal mechanism, (b) heat shrinkable sleeve mechanism, and (c) heat shrinkable sleeve.

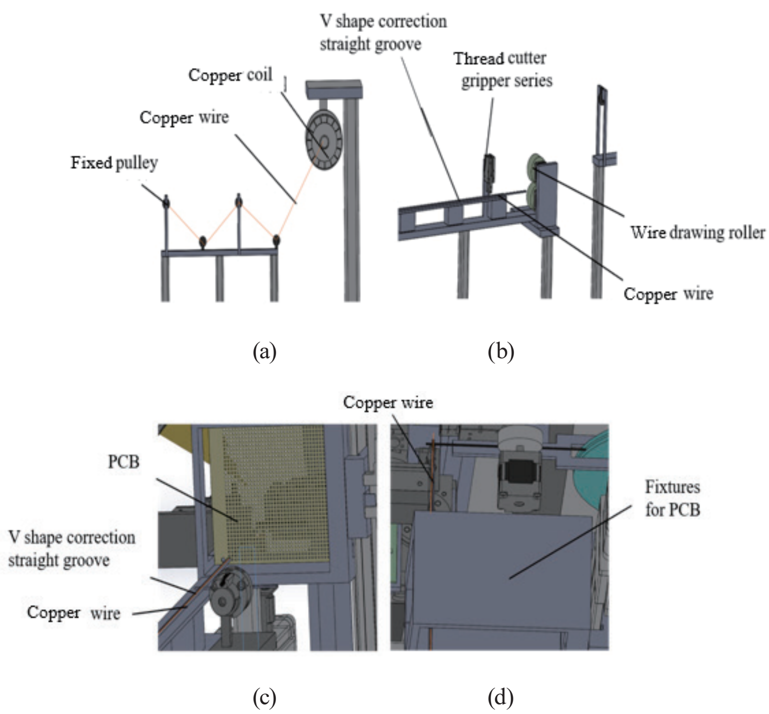


Fig. 26. (Color online) Threading action simulation. (a) Copper wire position, (b) front view of copper wire extension, (c) rear view of copper wire extension, and (d) thread through cylindrical terminal.

In Fig. 24, after the wire threading is completed, the sliding table cylinder (labeled as 8 in Fig. 24) moves the laser welding gun to strike the welding point on the elongated flat bar at the rear end of the cylindrical terminal. Subsequently, the laser welding gun is activated, melting the surface of the elongated flat bar at the rear end of the cylindrical terminal to weld it to the copper wire, as illustrated in Fig. 27.

The sliding table cylinder (labeled as 9 in Fig. 24) drives the vacuum suction cup base forward, inserting the heat shrink tube into the cylindrical terminal that has just been welded. Then, the sliding table cylinder moves the heat gun down to a position approximately 5 cm above the cylindrical terminal. The heat gun is activated to heat the heat shrink tube, as depicted in Fig. 28.

The side mechanical gripper (labeled as 10 in Fig. 24) at the cylindrical terminal processing station is reactivated. It grips the finished cylindrical terminal and rotates downward by 90 degrees, as shown in Fig. 29, completing the positioning of the gripper for the processed cylindrical terminal.

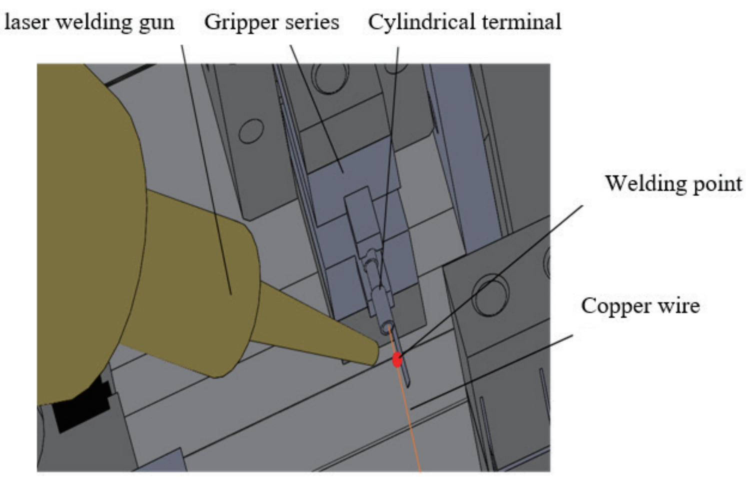


Fig. 27. (Color online) Laser welding simulation.

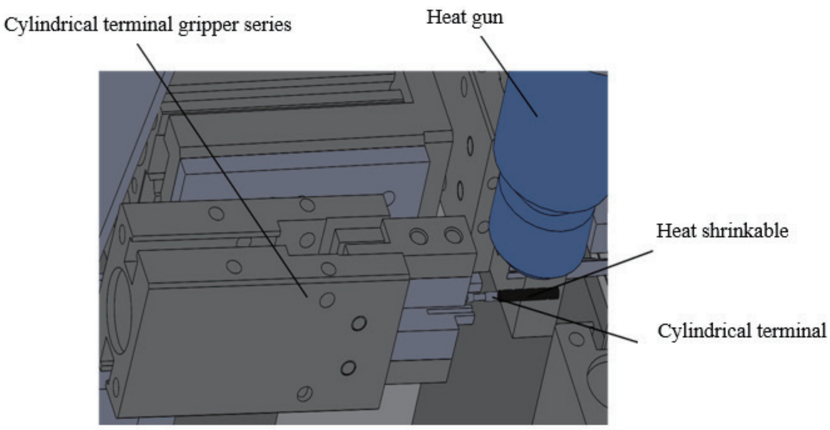


Fig. 28. (Color online) Heat shrink tube heating simulation.

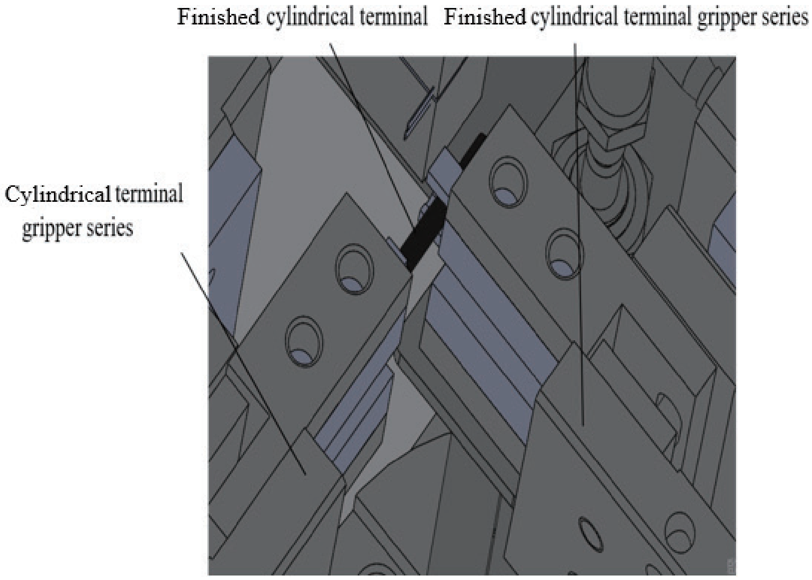


Fig. 29. (Color online) Completed cylindrical terminal jaw simulation.

Next, the *XY*-axis dual-axis servo slide table (labeled as 11 in Fig. 24), equipped with the needle disk holding fixture, is moved below the mechanical gripper that holds the cylindrical terminal. The mechanical gripper moves downward to insert the cylindrical terminal into the needle disk holding fixture, as shown in Fig. 30, completing the insertion of the cylindrical terminal into the needle disk.

The mechanical gripper (labeled as 12 in Fig. 24) is used once again to drive the scissor blade, cutting the copper wire inside the V-shaped groove, as depicted in Fig. 31.

Finally, the rotary cylinder (labeled as 13 in Fig. 24) is activated to rotate the wire-displacing crossbar, moving the severed copper wire away from the V-shaped groove, as shown in Fig. 32. The machine completes the aforementioned actions to finish one wire threading cycle. It will repeat these actions until the PCB and needle disk are threaded with cylindrical terminals and wires, at which point the PCB and needle disk can be removed. A new set of threading materials is then installed to commence the next threading cycle.

Once the PCB testing pin fixture on the machine has been threaded, the completed wire-threading fixture shown in Fig. 33 is obtained. Owing to the positioning of holes on the PCB, whether regular or irregular, it is necessary to arrange them in a regular pattern using the needle disk. This arrangement is crucial to achieve connection to the test points of the electrical testing machine, which is the primary purpose of the wire-threading fixture studied in this work.

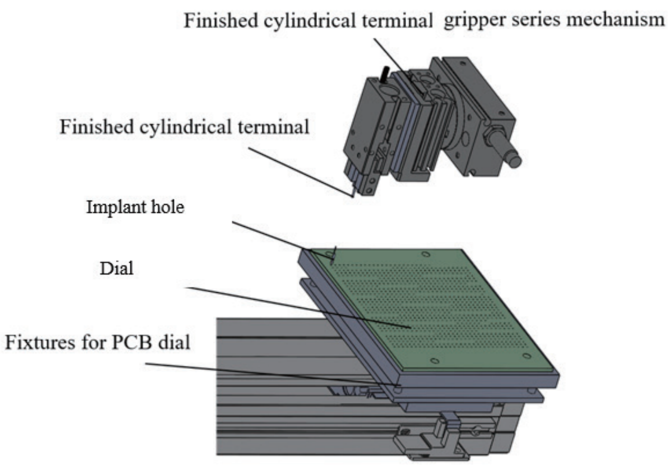


Fig. 30. (Color online) Cylindrical terminal implanted pin tray simulation.

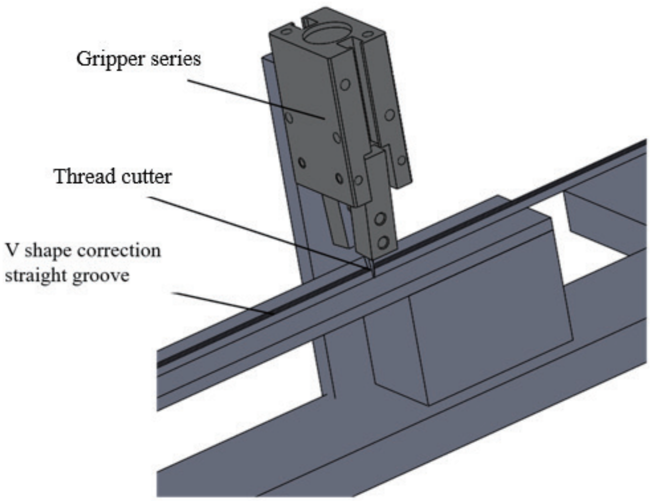


Fig. 31. (Color online) Simulation of copper wire shearing in V-shaped groove.

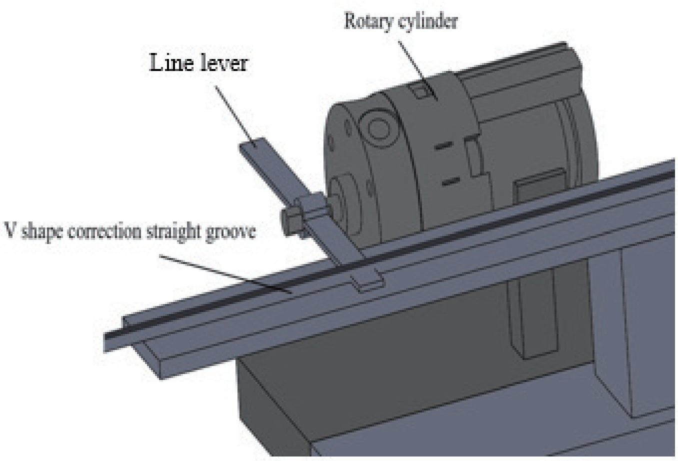


Fig. 32. (Color online) Stripping mechanism simulation.

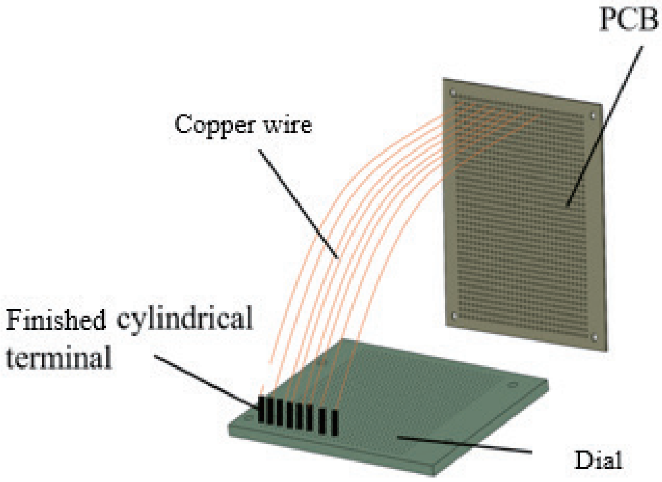


Fig. 33. (Color online) Threading needle fixture.

4. Conclusion

In this study, we addressed the issues of time consumption and production volume associated with the manual production of wire-threading fixtures through the implementation of an automated system. Automation not only ensures consistent production volumes but also standardizes quality. Herein, we focused on the design and motion simulation of an automated machine for PCB electrical testing pin fixtures, utilizing drawing software. The automation was achieved by employing PLC for pneumatic control and motor controllers for servo slide control. The machine system was divided into several key components, including the cylindrical terminal feeder mechanism, heat shrink tubing feeder mechanism, wire-threading mechanism, laser welding, and hot air gun mechanism. Through the integration of these systems, the manual manufacturing of electrical testing pin fixtures was automated. Control of the machine was facilitated through the PLC's program interface. This allowed for the real-time identification of issues in different parts of the machine during operation, such as irregular feeding or misalignment of the gripper, enabling timely manual adjustments. In cases where the dimensions of the PCB change, resulting in alterations in hole positions, adjustments can be made by changing the pulse count of the stepper motor to align with the PCB's hole positions. This achieved the automation of the wire-threading fixture, thereby reducing the manual threading workload.

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