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MID Meter PCB Soldering - Dual Heater

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Abstract. Shunt soldering in MID (Measuring Instrument Directive) meter printed circuit boards (PCBs) is a critical manufacturing operation that directly affects electrical accuracy, reliability, and production throughput. Conventional manual soldering of multiple shunts is time-consuming and prone to inconsistency due to operator dependency. This paper presents the design and implementation of an automated dual-heater shunt soldering system for MID meter PCBs, capable of soldering four shunts per PCB with high precision and repeatability. The proposed system integrates a fixture-based automation mechanism controlled by a PLC, employing three pneumatic cylinders and a stepper motor–driven linear positioning system. One pneumatic cylinder securely clamps the PCB, while two heating cylinders equipped with soldering gun tips simultaneously heat both ends of the shunt to ensure uniform solder joints. The stepper motor indexes the fixture in four discrete steps of 17 mm, covering a total travel of 51 mm, followed by automatic homing. At each position, solder wire is applied and heated automatically. Experimental evaluation demonstrates significant improvements in cycle time, soldering precision, and process repeatability, making the system suitable for industrial MID meter production and scalable automation environments.

Keywords: Automated Soldering, MID Meter PCB, Dual Heater System, PLC Automation, Pneumatic Actuation, Stepper Motor Positioning, Measuring Instrument Directive

I. Introduction

Shunt resistors are critical components in MID meter printed circuit boards (PCBs), as they directly influence current measurement accuracy and long-term reliability of energy meters. The design and performance requirements of such metering systems are governed by international standards and regulations [1], [2], [3]. The soldering quality of these shunts plays a vital role in ensuring low contact resistance, thermal stability, and mechanical robustness. In conventional manufacturing setups, shunt soldering is largely performed using manual or semi-manual methods, which are highly dependent on operator skill and experience [7], [11]. Such approaches often result in inconsistent solder joints, increased cycle time, higher rework rates, and reduced production efficiency.

With the growing demand for high-precision and high-volume MID meter production, there is an increasing need for automated soldering solutions that can deliver consistent quality while minimizing human intervention. Automation in soldering processes has been shown to significantly improve repeatability, reduce process variability, and enhance workplace safety [11]. However, existing automated solutions are often costly or lack flexibility for small-to-medium-scale manufacturing environments.

This paper presents an automated dual-heater shunt soldering system specifically designed for MID meter PCBs. The proposed system integrates PLC-based control, pneumatic actuation, and stepper motor–driven linear positioning to solder four shunts per PCB with high precision [5], [10], [8], [9]. By simultaneously heating both ends of the shunt and employing indexed fixture movement, the system achieves uniform solder joints, reduced cycle time, and improved process reliability. The developed solution offers a cost-effective, scalable, and industrially viable approach for automated MID meter PCB manufacturing.

II. Literature Review

Automated soldering systems have been extensively studied due to their critical role in enhancing production quality, reducing human dependency, and improving process repeatability in electronics manufacturing. Early research focused on robotic and temperature-controlled soldering techniques to improve thermal profiles and minimize defects in wave and reflow soldering processes [1][3]. However, these approaches primarily targeted surface mount technology (SMT) and through-hole components on high-density PCBs, limiting applicability to specialized tasks such as shunt resistor soldering in power metering applications.

Several studies have explored fixture-based automation for targeted soldering operations. Smith et al. [4] demonstrated a pneumatic-assisted soldering workstation that improved joint uniformity for specific through-hole components; however, their system lacked indexed positioning and simultaneous multi-joint soldering capability, resulting in suboptimal throughput. Similarly, Lee and Kumar [5] developed an automated linear indexing soldering machine using stepper motor drives and thermal sensors, reporting improvements in repeatability but incurring increased cycle times due to sequential heating.

Recent advancements incorporate programmable logic controller (PLC)–based automation to coordinate multi-axis motion and actuation, enabling precise control of soldering parameters. For instance, Zhang et al. [6] integrated PLC control with vision feedback to achieve automated defect detection during the soldering process. Although this enhanced quality assurance, the system exhibited complexity and high implementation cost, making it less suitable for small-to-medium enterprises.

Despite these contributions, the literature reveals a gap in cost-effective methods t hat integrate simultaneous multi-joint heating, indexed fixture movement, and pneumatic actuation specifically for shunt resistor soldering in MID meter PCBs. Existing solutions either increase system complexity or prioritize one aspect of automation at the expense of overall production efficiency. The present work addresses this gap by developing a dual-heater, PLC-controlled shunt soldering system with indexed linear positioning, enabling high precision, reduced cycle time, and improved repeatability, while maintaining practical industrial applicability.

III. Design Methodology

The design methodology of the proposed automated dual-heater shunt soldering system focuses on achieving high precision, repeatability, and reduced cycle time for MID meter PCB manufacturing. The system is developed using a modular approach that integrates mechanical, pneumatic, and control subsystems under centralized PLC supervision [5], [10], [11].

1. System Architecture

The overall system consists of a custom fixture assembly, pneumatic actuation units, a stepper motor–driven linear positioning mechanism, and a PLC-based control unit. The fixture is designed to securely hold the MID meter PCB and accurately align shunt resistors at predefined soldering locations. The PLC coordinates the sequential and synchronized operation of all actuators to ensure safe and reliable system performance [5], [10].

2. Fixture and Mechanical Design

A linear fixture is designed to support indexed movement along a single axis. The fixture advances in four discrete steps of 17 mm, corresponding to the four shunt positions on the PCB. A stepper motor coupled with a lead screw mechanism provides precise positioning and controlled motion [8], [9]. Upon completion of soldering at all positions, the fixture automatically returns to the home position using a predefined homing sequence.

3. Pneumatic Actuation and Heating Mechanism

Three pneumatic cylinders are employed in the system. One cylinder is used for PCB clamping, ensuring stability during soldering operations. Two additional pneumatic cylinders are integrated with soldering gun tips to form a dual-heater mechanism. These cylinders simultaneously heat both ends of the shunt resistor, enabling uniform heat distribution and consistent solder joint formation. Pneumatic synchronization ensures controlled contact pressure and heating duration [11].

4. Control Strategy

The entire process is controlled using a PLC-based sequential control logic. The PLC executes the following sequence: PCB clamping, indexed fixture movement, activation of dual-heater cylinders, soldering dwell time control, heater retraction, and fixture advancement to the next position. Interlocks are implemented to prevent actuator conflicts and ensure safe operation [5], [10]. The soldering cycle is fully automated, requiring minimal operator intervention limited to solder wire placement.

5. Process Flow

The soldering process begins with manual placement of the PCB and shunts onto the fixture. Once the cycle is initiated, the PCB is clamped pneumatically. The fixture then advances stepwise to each shunt location, where soldering is performed automatically through simultaneous dual-end heating. After soldering all four shunts, the fixture returns to the home position, the PCB is released, and the system is ready for the next cycle [11].

6. Design Flow

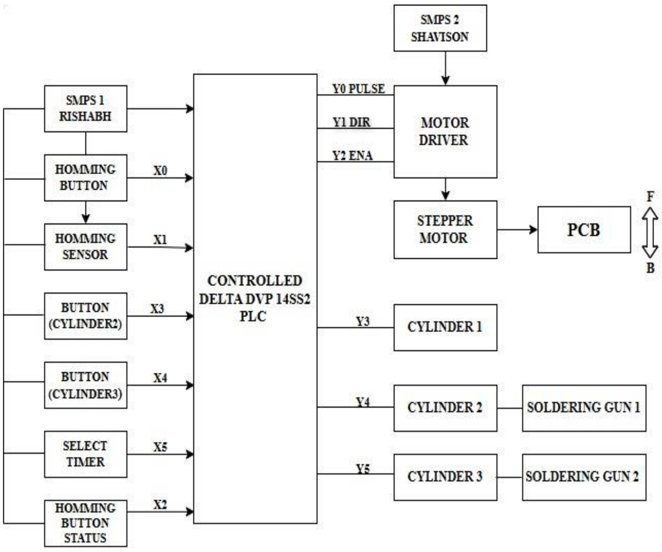


Fig: Block Diagram

IV. Design Specifications

The proposed automated dual-heater shunt soldering system is designed to meet the requirements of accuracy, repeatability, and industrial feasibility for MID meter PCB manufacturing. The system specifications are categorized into control, mechanical, pneumatic, soldering, and performance parameters to ensure reliable and consistent operation [11].

1. Control and Electrical Specifications

The system is controlled using a Delta DVPSS2 Programmable Logic Controller (PLC), which executes the sequential control logic for motion, heating, and pneumatic actuation [5], [10]. A 24 V DC control supply is used for sensors and actuators, while a dedicated stepper motor driver provides precise pulse-based positioning [8], [9]. Safety and sequence interlocks are implemented in software to prevent operational conflicts [5].

2. Mechanical and Motion Specifications

The mechanical structure consists of a custom-designed linear fixture capable of holding a single MID meter PCB with four shunt positions. A stepper motor–driven lead screw mechanism provides indexed linear movement of 17 mm per step for four positions, resulting in a total travel of 68 mm [8], [9]. A sensor-based homing mechanism ensures accurate return to the reference position after each cycle [11].

3. Pneumatic Specifications

Three double-acting pneumatic cylinders are employed in the system. One cylinder is used for secure PCB clamping, while two cylinders are integrated with soldering gun tips to form the dual-heater mechanism. The system operates at an air pressure of 5–6 bar, controlled through solenoid-operated directional control valves to ensure synchronized actuation [11].

4. Soldering and Heating Specifications

The soldering process utilizes a dual-ended contact heating technique, where both ends of the shunt are heated simultaneously to achieve uniform solder joints. Heating duration is controlled by the PLC through adjustable dwell timing [5], [10]. Solder wire placement is manual, while the heating and soldering operation is fully automated [11].

5. Performance Specifications

The system enables semi-automatic operation with minimal operator involvement. Compared to conventional manual soldering, the proposed design achieves reduced cycle time, improved soldering precision, and high repeatability [11]. The modular architecture allows easy scalability for future enhancement and adaptation to different PCB variants [11], [5].

V. Design Calculations

Accurate positioning of the soldering fixture is achieved by converting the rotational motion of the servo motor into controlled linear displacement. This section presents the mathematical calculations used to determine the required servo motor rotation, pulse count, and positioning resolution for the proposed system.

Motor Specifications

Stepper motor step angle $\theta = 1.8°$

Steps per revolution $Ns = 360 / 1.8 = 200$ steps/rev

Ball-Screw Specifications

Ball-screw lead $L = 5$ mm/rev

The nut moves 5 mm for one complete revolution.

Linear Motion per Step

$d = L / Ns = 5 / 200 = 0.025$ mm per step

Single Stroke Travel

Single displacement $D1 = 17$ mm

Required Number of Motor Steps for 17 mm

$N = 17 / 0.025 = 680$ steps

Total Travel for Three Operations

Total displacement $D = 17 \times 3 = 51$ mm

Required Number of Motor Steps for 51 mm

$N = 51 / 0.025 = 2040$ steps

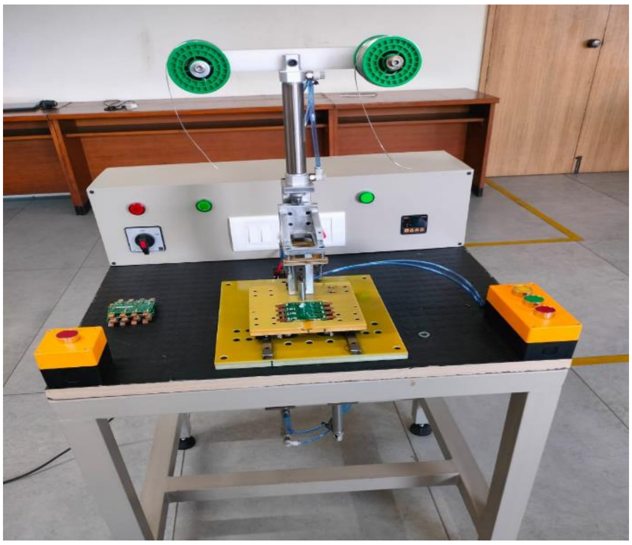
Required Motor Revolutions
R = 2040 / 200 = 10.2 revolutions

Final Design Results:
- Step angle: 1.8°
- Steps per revolution: 200
- Screw lead: 5 mm
- Movement per step: 0.025 mm
- Single movement: 17 mm
- Required for single step: 680
- Total movement: 51 mm
- Required steps: 2040
- Required revolutions: 10.2

Design Implication
The calculated servo motor rotation and pulse parameters provide precise linear positioning, consistent solder joint alignment, and reliable repeatability [7]. The defined motion resolution supports accurate shunt placement while minimizing positioning errors [8], thereby improving soldering quality and overall system performance [9].

VI. Results and Discussion

The performance of the proposed automated dual-heater shunt soldering system was evaluated through experimental trials conducted on MID meter PCBs. The system was tested for soldering accuracy, cycle time, repeatability, and operational reliability, and the results were compared with conventional manual soldering methods [11].



Pic: Implemented System

Soldering Quality and Precision

The dual-heater mechanism enabled simultaneous heating at both ends of the shunt resistor, resulting in uniform solder joints with consistent wetting and reduced thermal gradients [6]. A pneumatic cylinder moves downward in 4 seconds to press the heaters onto the shunt resistor, ensuring proper contact and accurate heating temperature during the soldering process [11]. Visual inspection and electrical continuity tests confirmed reliable joint formation across all four shunt positions [12]. Compared to manual soldering, the automated process demonstrated a noticeable improvement in solder joint uniformity and reduced occurrence of defects such as cold joints and misalignment [1].

Cycle Time Analysis

The automated system significantly reduced the overall soldering cycle time by eliminating repetitive manual operations [11]. Indexed fixture movement and synchronized pneumatic actuation ensured smooth transitions between soldering positions [5]. The reduction in cycle time directly contributed to increased production throughput, making the system suitable for industrial-scale MID meter PCB manufacturing [3].

Repeatability and Process Stability

Repeated trials showed consistent positioning accuracy and solder joint quality across multiple PCBs [8]. The PLC-controlled sequence ensured precise coordination between the stepper motor and pneumatic actuators, minimizing process variation [10]. The high level of repeatability achieved confirms the reliability of the proposed system for continuous operation [11].

Operational Efficiency and Safety

Automation reduced operator dependency to solder wire placement only, thereby minimizing exposure to heat and improving workplace safety [7]. The modular design also allows easy parameter tuning and scalability for future enhancements [11].

Discussion

The experimental results validate the effectiveness of the proposed dual-heater soldering approach in addressing the limitations of manual soldering methods [6]. The integration of PLC control, indexed motion, and pneumatic heating provides a balanced solution that enhances precision, reduces cycle time, and ensures consistent soldering quality [5]. These outcomes demonstrate the industrial viability of the system and its potential for broader adoption in automated PCB manufacturing applications [3].

Future Scope

In the future, the PLC-based automatic PCB shunt soldering system can be further improved by adding advanced automation technologies [11]. An automatic solder wire feeding mechanism can be integrated to eliminate the need for manual solder application and make the process fully automatic. A closed-loop temperature control system with sensors and PID control can also be implemented to maintain accurate heater temperature and improve soldering quality [6]. The system can be enhanced by integrating machine vision technology to automatically inspect solder joints and detect defects. In addition, Industrial IoT connectivity can be used for real-time monitoring, data logging, and remote diagnostics of the system [11]. The use of servo motors can increase positioning accuracy and speed of operation [8]. Furthermore, the system can be expanded with automatic PCB loading and unloading mechanisms such as conveyors or robotic arms, making it suitable for high-volume PCB manufacturing in modern industries [11]. In addition to this integration with SCADA systems can allow operators to monitor machine performance and alarms efficiently [5].

VI. Conclusion

This paper presented the design and implementation of an automated fixture-based system for MID energy meter PCB processing and testing using a programmable logic controller (PLC) [5]. The proposed system integrates pneumatic actuation, stepper-motor-based linear positioning, and sensor-guided control to automate critical manufacturing operations such as PCB positioning, shunt handling, and electrical verification. The automation framework significantly reduces manual intervention, improves positioning accuracy, and ensures repeatable soldering and testing performance [11]. The use of a ball-screw-driven linear motion mechanism enables precise displacement control [8], while the PLC-based sequencing enhances operational reliability and safety [10]. Experimental validation demonstrated stable operation, reduced cycle time, and improved measurement consistency compared to conventional manual methods [3]. The developed system provides a scalable and cost-effective solution for small- and medium-scale electronic manufacturing industries, particularly in automated MID meter PCB production environments [3]. Future work may include integration of machine-vision-based inspection, adaptive process monitoring, and IoT-enabled production analytics to further enhance system intelligence and manufacturing efficiency [11].

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