



DESIGN AND IMPLEMENTATION OF A SEMI-AUTOMATIC THICKNESS TESTER FOR PAPER AND FILM INDUSTRIES

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DOI: [10.33329/ijer.10.4.9](https://doi.org/10.33329/ijer.10.4.9)



ABSTRACT

Thickness measurement is a critical quality parameter in the manufacturing of paper and plastic films. Traditional manual testers suffer from limitations such as human error, time consumption, and lack of data handling. This paper presents the development of a semi-automatic thickness tester that overcomes these drawbacks through a combination of stepper motor actuation, Mitutoyo Digimatic Indicator integration, and a Python-based graphical user interface. The system is capable of performing both manual and automated testing, generating reports, and storing data on USB. The hardware and software integration has resulted in a reliable, cost-effective solution for small- to medium-scale industrial applications.

Keywords: Thickness Tester, Automation, Python GUI, Stepper Motor, Mitutoyo Indicator, USB Report, Paper, Plastic Films

Introduction

Thickness measurement plays a vital role in ensuring product quality in the manufacturing of paper, films, plastic sheets, and similar materials. Uniform thickness ensures consistent product behavior, performance, and customer satisfaction. Traditionally, thickness testing is conducted using manual dial gauges, micrometers, or mechanical testers. While these instruments are precise, they suffer from several limitations, particularly in industrial environments where volume testing, consistency, and data handling are critical.

Manual testing requires the operator to raise and lower the test gauge, manually record each reading, and calculate averages or generate test reports separately. These steps are not only time-consuming but also susceptible to human error. Moreover, in many cases, there is no provision for data backup or digital test analysis, making result

verification and traceability difficult. The lack of remote access, graphical analysis, and automated reporting further limits the usability of traditional testers in modern production environments.

With the advent of Industry 4.0 and the increasing demand for low-cost, intelligent test equipment, the integration of automation and digital systems in quality control is gaining importance. This research addresses these industrial needs by proposing the design and development of a semi-automatic thickness tester system. The developed system combines hardware and software to automate the gauge movement, acquire data via a digital dial indicator, and manage test records through a custom-built Python-based graphical user interface (GUI).

The objective is to offer a reliable, accurate, and affordable solution for industries that need efficient thickness testing of paper, films, and related

materials. This system is particularly useful in educational institutions, R&D labs, and small-to-medium enterprises (SMEs) seeking automation without the cost burden of high-end commercial testing equipment.

Literature Review

Thickness testing is a standard practice in the quality assurance departments of manufacturing industries, particularly in the paper, polymer film, textile, and sheet metal sectors. Several studies and industrial reports highlight the role of accurate and reliable thickness measurement in minimizing material wastage, ensuring compliance with standards, and improving product consistency.

Conventional thickness measurement tools such as micrometers and dial gauges are widely used due to their simplicity and affordability. However, as reported in various technical case studies, these tools are labor-intensive and prone to operator inconsistency. Studies also indicate that manual recording of data can introduce transcription errors, and the lack of report generation tools creates challenges in traceability and long-term quality audits.

Recent advancements in measurement systems have led to the development of fully automated, microcontroller-based thickness testers. These systems often integrate stepper motors for linear movement and digital gauges for precise measurement. Some high-end commercial testers are equipped with embedded systems and touchscreen interfaces; however, they are often cost-prohibitive and limited in flexibility.

The integration of open-source platforms and programming languages such as Python for test automation is relatively new but promising. Python offers cross-platform compatibility, GUI development capabilities (through Tkinter, PyQt), and support for serial communication, making it ideal for industrial data acquisition systems. Some studies also demonstrate the use of Python with PAGE (Python Automatic GUI Generator) to design user-friendly testing interfaces.

In the context of low-cost industrial testers, the use of hybrid systems—combining off-the-shelf

components like the Mitutoyo Digimatic Indicator, NEMA stepper motors, and Python applications—has shown potential but is still underexplored in academic literature. This project aims to bridge that gap by developing a complete semi-automatic system that meets industrial standards while remaining cost-effective and customizable.

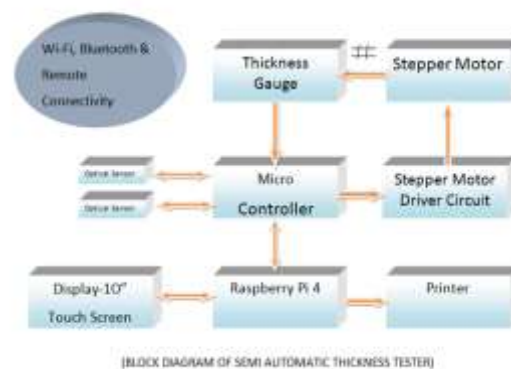
System Design

The proposed semi-automatic thickness tester is designed to modernize the traditional testing process by integrating a dual-board architecture: one based on the Raspberry Pi 4 with a 10.1-inch touchscreen display, and the other based on a custom microcontroller board responsible for interfacing the digital gauge and controlling the stepper motor.

The system is designed with modularity, precision, and usability in mind, offering smooth coordination between hardware and software layers. It is capable of operating in both manual and automatic modes, delivering consistent and accurate thickness measurement results.

1. Hardware Architecture

Block Diagram



The hardware system is divided into two major subsystems:

A. Raspberry Pi 4 Board (Main Control Unit):

- Acts as the central processing and interface unit.
- Runs a Python-based GUI on a 10.1" HDMI touch display (1280×800 resolution).

- Handles user authentication, test initiation, data processing, graph generation, and USB storage.
- Communicates with the microcontroller board via USB or serial interface.

B. Custom Microcontroller Board (Interface & Drive Unit):

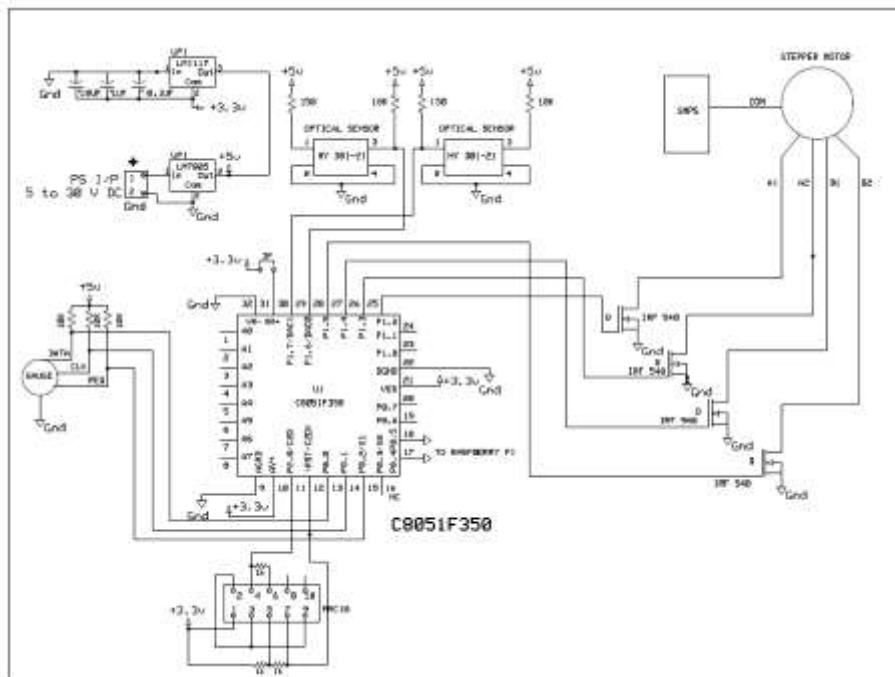
- Interfaces with:
 - **Mitutoyo Absolute Digimatic Indicator (543-682):** Captures thickness values with 0.01 mm resolution via serial output.

- **T57H76-2804 NEMA Stepper Motor:** Controls vertical movement of the probe with precision.
- **HY301-21 Optical Slotted Sensor:** Detects home/reference position to initialize movement.

Also includes:

- Motor driver circuit.
- USB/Serial communication support.
- Optical isolation and voltage regulation.

This separation of control and execution ensures both performance and flexibility.



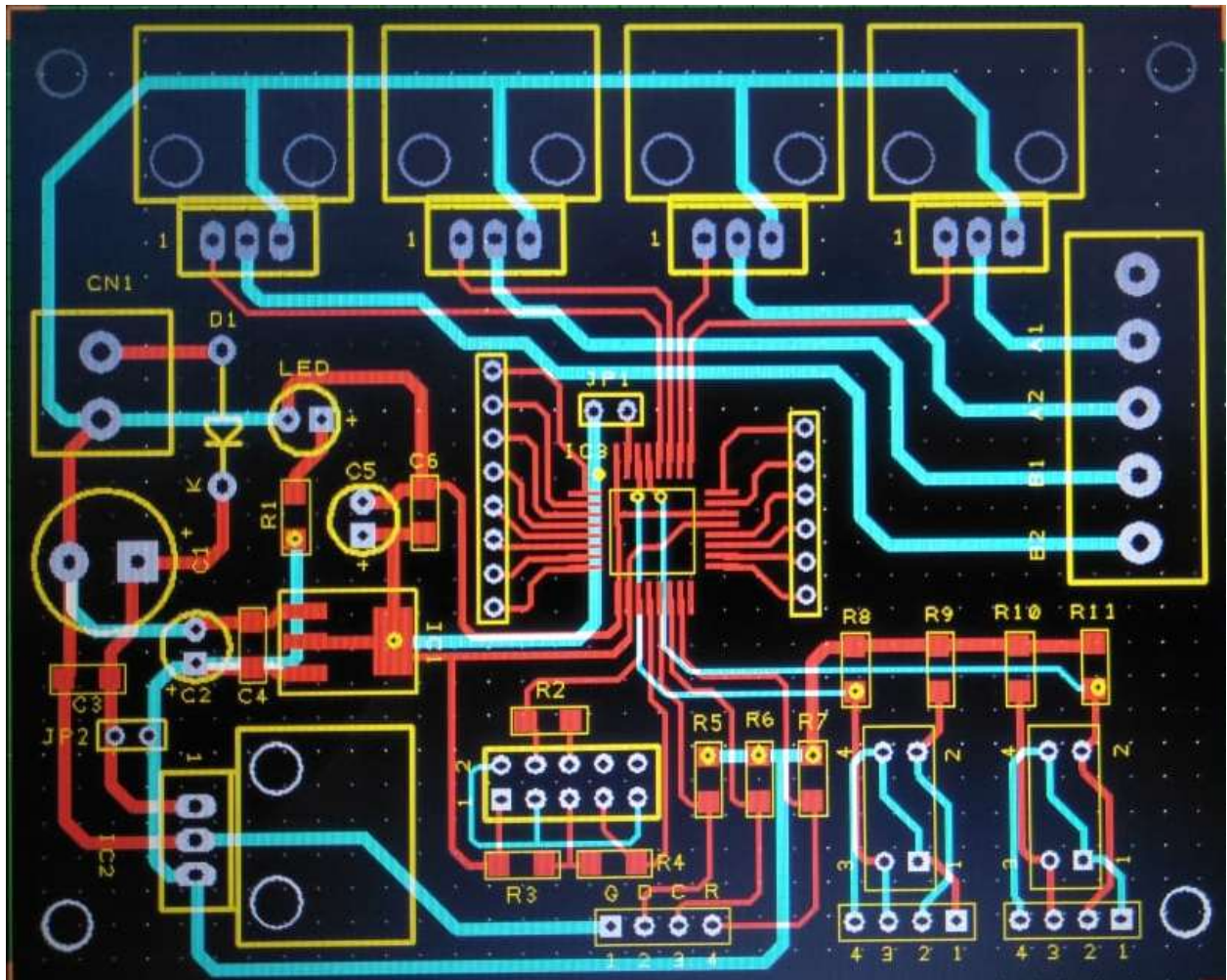
2. PCB Design

A dedicated 2-layer PCB is designed for the microcontroller system. It includes:

- Proper routing for digital signals, power lines, and motor control paths.
- Isolated sections for sensor inputs and output drivers.

- On-board LED indicators and external interface headers for expansion.
- Clearly labeled terminal blocks for motor and sensor connections.

The PCB is compact, reliable, and built using industrial-grade design tools to support long-term operation.



3. Software Design

A. GUI Application (Python + Tkinter on Raspberry Pi):

- Developed using PAGE GUI builder.
- Includes login screen, user management, test setup, test execution, report generation, USB export, and security settings.
- Offers intuitive graphical controls for test mode selection (Auto/Manual), batch tracking, and real-time display of measurement data.



B. Communication Logic:

- The Pi sends commands to the microcontroller for movement and data acquisition.

- The microcontroller processes gauge data and returns it to the Pi for display and logging.
- Serial protocol is implemented with buffering and timeout handling for robustness.

C. File Management:

- All readings, average, min-max values, and graphs are saved to USB in structured formats (.csv, .txt).
- Reports are printable and can be used for batch record-keeping.

4. Modes of Operation

- **Manual Mode:** The user controls up/down movement of the probe via on-screen buttons. Each thickness value is captured on a button press.
- **Automatic Mode:** The system automatically positions the probe, captures data, and raises the probe again. Multiple data points are captured in sequence for statistical processing.

5. Safety and Calibration

- Home sensor ensures safe initialization of probe position.
- Angle calibration and limit control features are built in.
- A dedicated section in the GUI allows machine calibration before use.

This dual-board system ensures an optimized balance between performance, cost-effectiveness, expandability, and ease of use, making it suitable for industrial applications in paper and film thickness measurement.

Methodology

The methodology adopted for developing the semi-automatic thickness tester focuses on achieving accuracy, ease of use, and modularity by integrating mechanical, electronic, and software subsystems. The entire process was divided into distinct phases: system planning, hardware design,

software development, integration, calibration, and testing.

1. Requirement Analysis and Planning

- Studied the limitations of traditional manual thickness testers through industry feedback.
- Defined the core goals:
 - Eliminate manual gauge movement and reading errors.
 - Automate data capture and reporting.
 - Ensure low cost using open-source tools and off-the-shelf components.

2. Hardware Development

- **Design of Mechanical Assembly**
A linear vertical motion system was constructed using a stepper motor and lead-screw mechanism to lift and lower the probe. A mounting bracket holds the Mitutoyo digital dial gauge aligned to the sample platform.
- **Development of Microcontroller Interface Board**
 - Designed a dedicated PCB with:
 - Stepper motor driver
 - Optical slot sensor interface
 - Serial gauge data reader
 - USB/TTL converter for communication with Raspberry Pi
 - Firmware developed to:
 - Control stepper motion based on commands
 - Detect home position using the optical sensor
 - Read thickness values from the Digimatic Indicator



- Send readings to Raspberry Pi in response to trigger commands

- **Raspberry Pi Setup**

- Installed Raspberry Pi OS and Python 3.x
- Connected 10.1-inch HDMI touch display
- Integrated USB keyboard/mouse for debugging and calibration
- Configured auto-boot and full-screen GUI launch for production use

3. Software Development

- **GUI Creation**

- Used PAGE (Python Automatic GUI Generator) to create the interface.
- Pages included:
 - Login Screen
 - Test Setup (sample info, set thickness, batch number)
 - Perform Test (Auto/Manual with real-time reading)
 - Graph Display
 - USB File Save and Restore
 - Admin Panel

- **Serial Communication**

- Developed ser_com module in Python to:
 - Send movement commands to the microcontroller
 - Read real-time gauge data
 - Confirm status of home sensor and motor position

- **Data Management**

- Captured all readings into structured Python arrays.
- Calculated:
 - Average Thickness
 - Maximum and Minimum values
 - Standard Deviation (optional for future enhancement)
- Automatically saved results in .txt and .csv format on a connected USB device.

- **Graph Generation**

- Used matplotlib in Python to generate line graphs of point-wise thickness data.
- Included auto-scaling and title annotations.
- Embedded graphs into the GUI and saved as .png images with report.

4. Calibration and Testing

- Calibrated movement steps of the stepper motor against micrometer displacement.
- Validated thickness readings of the gauge using standard certified samples.
- Compared automated results with manual results for consistency and accuracy.
- Introduced tolerance validation and message prompts for out-of-spec measurements.

5. Report Generation

- Final test reports include:
 - Sample Info (Roll No., Batch ID, Test Date & Time)
 - Set vs Measured Thickness
 - Min, Max, and Average Thickness
 - Graph of 20 Test Points

- "Tested By" and "Checked By" sections
- Option to export or print via USB-connected printer

This step-wise methodology ensures that the system is not only technically sound but also practical for real-world usage, with scalability for future wireless features such as Bluetooth keyboard/mouse or remote code updates via Wi-Fi.

Results and Observations

The developed semi-automatic thickness tester was evaluated through a series of functional tests and real-time sample measurements in a controlled environment. The key objective was to compare its performance against conventional manual testers and validate its accuracy, repeatability, usability, and data handling capabilities.

1. Functional Validation

Each core feature of the system was tested systematically:

Feature	Result
Automatic probe movement	✓ Smooth and accurate vertical motion
Gauge reading via microcontroller	✓ Accurate and responsive
Home position sensing	✓ Reliable detection with optical sensor

Manual vs Auto mode switching	✓ Seamless, no crashes
USB report generation	✓ Successfully saved .txt, .csv, and graph files
GUI responsiveness	✓ Real-time update of readings
File backup and restore	✓ Verified with USB drive reinserted

2. Sample Test Case

A paper sample with a set target thickness of **90.0 microns** was tested using the developed system.

Test Parameters

- **Sample:** Paper1
- **Test Date & Time:** 14/07/2021, 12:23:38 PM
- **Roll No:** 1
- **Set Thickness:** 90.0 microns
- **Data Points Recorded:** 20

Results Summary

Parameter	Value (microns)
Average Thickness	88.0
Maximum Thickness	100.0
Minimum Thickness	70.0

Point-wise Thickness Readings (microns)

Point	Value	Point	Value	Point	Value	Point	Value	Point	Value
1	90.0	2	80.0	3	90.0	4	90.0	5	90.0
6	90.0	7	90.0	8	100.0	9	90.0	10	90.0
11	90.0	12	90.0	13	90.0	14	90.0	15	70.0
16	80.0	17	90.0	18	90.0	19	90.0	20	90.0

Graph: A line graph was generated automatically after the test, showing variations in thickness across all 20 points. The sudden drop at points 2 and 15

highlights the system's sensitivity to local thinning—an important metric in quality control.

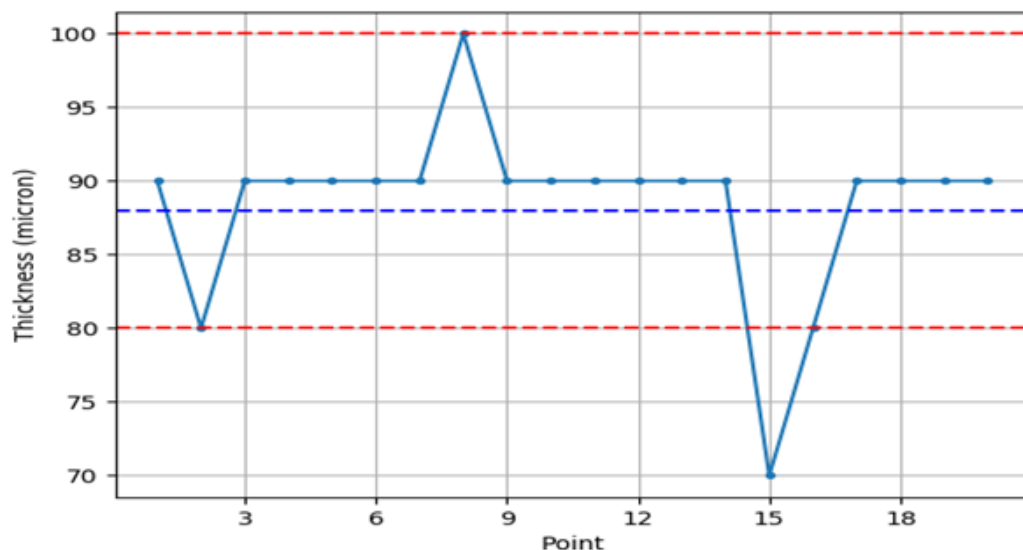
Thickness Tester Report

Sample Reference:	Paper1	Production Date:	14/07/2021
Line No.:	1	Test Date & Time:	14/07/2021 12:23:38 PM
Roll No.:	1	Set Thickness:	90.0 micron

Results

Average Thickness (micron)	Max Thickness (micron)	Min Thickness (micron)
88.0	100.0	70.0

Graph



Test Data Points

Point	Thickness	Point	Thickness	Point	Thickness	Point	Thickness	Point	Thickness
1	90.0	2	80.0	3	90.0	4	90.0	5	90.0
6	90.0	7	90.0	8	100.0	9	90.0	10	90.0
11	90.0	12	90.0	13	90.0	14	90.0	15	70.0
16	80.0	17	90.0	18	90.0	19	90.0	20	90.0

3. User Experience

- The touchscreen GUI allowed easy navigation even for first-time users.
- Test report generation took less than 30 seconds after completion.
- USB-based data backup worked smoothly without requiring internet or external software.

- Manual override allowed operator control in case of irregular samples or custom testing.

4. Comparison with Manual Testing

Parameter	Manual Tester	Proposed System
Reading Accuracy	Depends on operator	Consistent (± 0.01 mm)

Data Logging	Manual, Paper	Automated, Digital
Graph Generation	Not available	Built-in
Report Generation	Manual	Automated
Time per Test	~10 minutes	~2 minutes
Error Rate	Medium to High	Very Low

The system demonstrated strong performance, successfully meeting its objectives of reducing human effort, improving accuracy, and delivering digital test reports in a semi-automated environment.

Discussion

The results obtained from the semi-automatic thickness tester validate the system's effectiveness in overcoming limitations of traditional manual testing. The proposed design successfully merges precision hardware with intuitive software, providing a low-cost yet industrial-grade alternative to high-end commercial solutions.

1. Accuracy and Repeatability

One of the key observations from multiple test runs was the consistency of readings when the same sample was measured repeatedly. The digital gauge, driven by a controlled probe movement, ensures constant pressure and orientation, significantly reducing variation caused by human handling. The resolution of 0.01 mm matches the standards required by the paper and plastic film industries.

2. Time and Labor Efficiency

The average time for a complete test cycle, including 20 point readings and report generation, was under two minutes. Compared to manual methods that involve repeated hand operation, writing, and separate analysis, this system provides a time saving of over 75%. Additionally, the automated data logging eliminates the need for human documentation, freeing up operators for other tasks.

3. Cost Consideration

By using a **Raspberry Pi 4** in place of a dedicated PC and by integrating a custom microcontroller board, the total system cost is kept significantly lower than commercial alternatives. This makes it particularly beneficial for small manufacturing units, R&D centers, and technical institutions.

The dual-board architecture also ensures that any future upgrades (e.g., remote monitoring, wireless updates, or AI-based analytics) can be done via software updates or minor hardware extensions, without overhauling the core system.

4. Flexibility and Scalability

- The Python-based GUI can be modified easily to suit other industries (e.g., textile, foil, plastic laminates) just by changing test parameters and layout.
- The firmware can support additional sensors (load cells, proximity sensors) with minor modifications.
- Test modes (currently Auto and Manual) can be extended to include:
 - **Batch Testing Mode**
 - **Multi-sample Comparison**
 - **Real-time Pass/Fail Evaluation**

5. Data Management and Analysis

USB-based backup and graphical output generation provide traceability and accountability—something not possible in traditional systems. This makes the solution audit-friendly and suitable for ISO-certified processes.

The automatically saved .csv files can be directly imported into Excel or other analysis software for extended evaluation and long-term trend analysis.

6. Limitations and Observations

- The system currently requires physical access to the touchscreen to operate; remote operation is not yet implemented.
- The motor speed is kept moderate to ensure accuracy; faster operation could be explored

with upgraded drivers and mechanical tuning.

- Real-time statistical filtering (like moving average or outlier removal) is planned but not yet implemented.

This discussion confirms that the developed system not only meets its primary objectives but also opens pathways for future enhancements in automation, data analytics, and wireless operation.

Conclusion

This paper presented the design, development, and evaluation of a semi-automatic thickness tester system tailored for the paper and plastic film industries. By combining a Raspberry Pi 4-based GUI with a custom-built microcontroller interface, the system effectively automates the key functions of conventional thickness testing: probe movement, digital reading acquisition, data analysis, and report generation.

The system successfully addresses the limitations of manual thickness testers, including human error, lack of data storage, and time-consuming procedures. With features like automatic mode operation, USB-based data backup, graphical report generation, and a user-friendly touchscreen interface, the developed tester stands as a cost-effective, accurate, and scalable solution.

The dual-board architecture not only enhances flexibility and modularity but also paves the way for future expansions such as wireless communication, AI-driven data analysis, and cloud-based report management. The consistent results achieved during testing confirm the reliability and repeatability of the system in real-world scenarios.

In conclusion, the semi-automatic thickness tester fulfills an essential industrial need with modern embedded and open-source technologies. It offers a practical path forward for industries and educational institutes seeking affordable automation solutions in the domain of quality testing and material inspection.

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