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Design of automatic control-based pneumatic system for material thickness measurement

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ABSTRACT

The manual measurement of materials using pneumatic systems for inspections remains prevalent, posing challenges in meeting the demands and speed of modern production processes. To address this, there is a critical need for an automated inspection tool capable of generating a significant number of inspection inputs. This research objectives to design and implement an automatic thickness inspection system, employing pneumatic technology and inductive proximity sensors. The study adopts an experimental research design, systematically progressing through literature review, algorithm design, PLC programming, and comprehensive testing. The pneumatic system, known for its high response speed and durability, is capable of accurately measuring material thickness and sorting items with precision. The integration of inductive proximity sensors enhances the system's efficiency in detecting both metallic and non-metallic objects. The research findings reveal a system effectiveness of 95.8% in the initial test and 91.7% in the subsequent test. Notably, deviations in the Ø12 sensor are identified in detecting NG minus material. Despite this, the system's overall effectiveness surpasses the 90% threshold, meeting stringent standard criteria. The study concludes with insights into the identified deviations and underscores the system's effectiveness in meeting high-standard criteria. Recommendations for improvement include modifications to the stopper or proximity sensor position, sensor recalibration, continuous monitoring, and material path separation.

Keyword: Proximity sensor; pneumatic system; PLC

1. INTRODUCTION

The evolution of modern industry underscores the crucial role of material thickness measurement in the stages of production and product development [1]. The precision and accuracy of material measurements have a fundamental impact on product quality and operational safety. Material measurement plays a significant role in determining the quality, strength, and durability of a product [2]. In vital sectors such as manufacturing, automotive, and construction, material measurement is not only a determinant of mechanical properties but also of structural performance, demanding accurate measurements as an essential prerequisite for the success of production processes and technological innovation.

Innovation in the automation domain enables high-quality production, significant volume, product consistency, shorter production periods, labor efficiency, and protection of the well-being of production workers [3]. For instance, one evolving technological device taught in vocational education and commonly applied in the industrial sector is the Programmable Logic Controller (PLC) [4], [5], [6]. As an industrial control instrument, the PLC has the capability to regulate processes sequentially and can be programmed flexibly according to specific needs [7],[8],[9]. This exemplifies the ongoing integration of advanced technologies into industrial practices, showcasing the pivotal role of automation in enhancing production efficiency and meeting evolving industry demands.

Within this framework, an automated control-based pneumatic system demonstrates the potential to offer effective solutions [10]. The high response speed and excellent durability make pneumatic systems an appealing choice for efficiently and accurately responding to the dynamics of material measurement and sorting [11]. The integration of automatic control in pneumatic systems, in turn, provides opportunities to optimize measurement processes, achieve high levels of accuracy, and minimize the potential for errors [12][13].

In-depth literature reviews have been conducted to comprehend the fundamental concepts of pneumatic technology and inductive proximity sensors. Previous relevant studies highlight the advantages of applying inductive proximity sensors in sorting both metallic and non-metallic items with high accuracy levels [14],[15],[16],[17]. Meanwhile, some earlier relevant studies also illustrate the applications of PLC technology and pneumatic systems in automatic checking and sorting, demonstrating rapid response and precise control [18],[19],[20],[21]. However, the integration of these two technologies in a material inspection system remains a relatively limited research area. Despite the significant potential in utilizing automated control-based pneumatic systems for material thickness measurement, detailed scientific studies detailing the design of such systems are still relatively scarce. Therefore, this research aims to fill this knowledge gap by designing a pneumatic system optimized specifically for material thickness measurement.

The identified literature gap pertains to the limited research combining pneumatic technology and inductive proximity sensors within a single system for material thickness inspection. This integration is deemed crucial for enhancing the overall accuracy and efficiency of material inspection. This study aims to design and develop a material thickness inspection system that leverages pneumatic technology and inductive proximity sensors. The integration of these two technologies is expected to provide a comprehensive solution for achieving superior material inspection. The primary motivation behind this research is to contribute to the advancement of material inspection technology.

Through a profound understanding of pneumatic technology and inductive proximity sensors, this research is anticipated to offer new insights and innovative solutions to enhance the efficiency and accuracy of material inspection. The main objective of this study is to design, implement, and evaluate a material thickness inspection system based on pneumatic technology and inductive proximity sensors. Consequently, it is expected to bridge the literature gap and make a positive contribution to the development of material inspection technology.

2. METHOD.

2.1 Research design.

This study adopts an experimental research design with the aim of developing and implementing a material thickness inspection system based on pneumatic technology and inductive proximity sensors. The experimental design is chosen because it provides a suitable framework for testing the effectiveness of the proposed system. The stages involved in conducting the research include literature review, layout design, preparation of materials and components, tool testing, data collection, analysis, and drawing conclusions.

The choice of an experimental design is grounded in its ability to systematically assess the performance and functionality of the developed material thickness inspection system. The sequential steps, from the initial literature review to the conclusive analysis, ensure a comprehensive investigation of the proposed technology. The experimental design offers a structured approach to validate the hypothesis, test the reliability of the system, and draw meaningful conclusions regarding its feasibility and efficacy.

2.2 Research procedure.

The research procedures are conducted as follows:

a. Algorithm and Pseudocode Design: The material thickness inspection algorithm is designed to guide the overall workflow of the system. Pseudocode is implemented as a formal representation of the algorithm, providing a detailed overview of the steps taken by the system during the inspection.
b. Implementation of research program: The research program is implemented using PLC programming language and is designed to interact efficiently with pneumatic systems and

inductive proximity sensors. Strong references from scholarly literature support each section of the program to ensure continuity and accuracy.

c. System testing: System testing is conducted by implementing the algorithm in pre-planned testing scenarios. The testing process includes simulating various operational conditions and material thicknesses to ensure the system's reliability in diverse situations.
d. Data collection: Data obtained through system testing includes material thickness inspection results, system response time, and measurement efficiency. This data is carefully collected and recorded for further analysis.
e. Data analysis: Data analysis involves processing measurement results, evaluating system performance, and interpreting findings. The use of statistical methods and relevant data analysis techniques will aid in drawing reliable conclusions from the research results.
f. Data presentation: The analyzed data will be presented clearly and informatively through tables and graphs strategically placed within the manuscript.

2.3 Layout diagram.

In this phase, the precise design or block diagram is determined to establish the control system flow from start to finish.

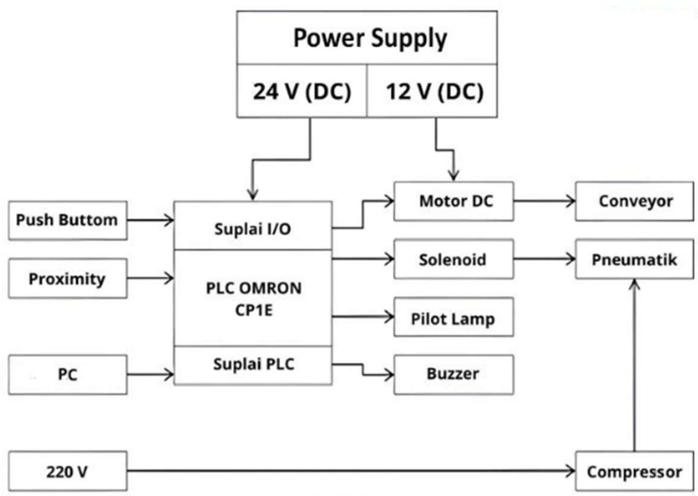

Figure 1. Pneumatic system block for material thickness inspection

The subsequent step involves determining the pneumatic flow diagram as per Figure 1. The pneumatic flow diagram is attached below. The explanation related to the pneumatic flow diagram is as follows: Material from the magazine is detected by the "magazine" proximity sensor, which then commands the cylinder to open the magazine door. The product then descends onto the conveyor by gravity. The material will move on the conveyor and pass through a proximity sensor that functions to inspect the material thickness.

If the proximity sensor does not detect the material, it indicates a negative material thickness (NG minus). In this case, the minus ejector cylinder will advance to push the material. Conversely, if the sensor detects the material, the ejector cylinder will not receive the forward command, and the material will continue to move. The material then passes through a second proximity sensor that functions to inspect positive or standard thickness material (OK). Its operation principle is opposite to the NG minus proximity sensor.

The NG plus proximity sensor will command the plus ejector cylinder to advance if it detects the material. If it does not detect, the material is considered OK. A capacitive sensor is used to detect non-metal workpieces. When the capacitive sensor light detects a non-metal object, the capacitive sensor light will illuminate, and the buzzer alarm will sound while the machine stops.

Figure 2 flowchart diagram of the pneumatic tool for material thickness inspection is presented above, accompanied by the following explanation: When the push button is pressed in the ON position, the conveyor motor becomes active (rotates), and the standby sensor prepares. The green pilot lamp will illuminate upon detecting the presence of material from the magazine through the "magazine" proximity sensor. This sensor will command the cylinder to open the magazine door, allowing the product to descend onto the conveyor by gravity.

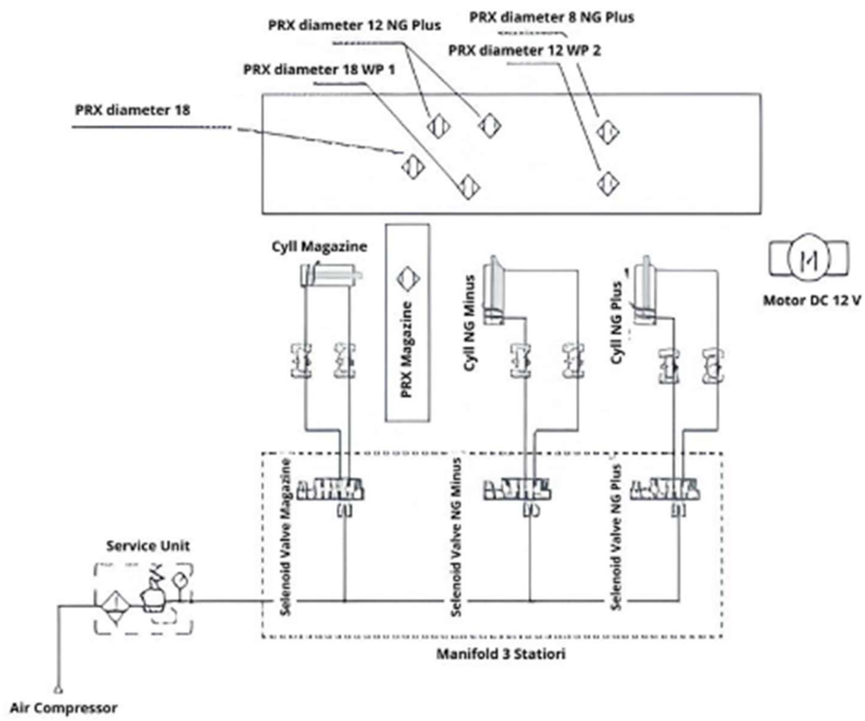

Figure 2. Pneumatic flow diagram

The product will move on the conveyor and pass through a proximity sensor designed to measure material thickness. If the proximity sensor does not detect material, indicating a negative material thickness (NG minus), the minus ejector cylinder will advance to push the material. Conversely, if the sensor detects material, there will be no forward command for the ejector cylinder, and the material will continue to move.

The material then undergoes detection by a second proximity sensor designed to inspect positive or standard material thickness (OK). Its operational principle is opposite to the NG minus proximity sensor. The NG plus proximity sensor will command the plus ejector cylinder to advance if it detects material, while if it does not detect, the material is considered OK. The buzzer will sound whenever the 12-diameter proximity sensor and the 8-diameter proximity sensor detect NG material. In Figure 3 and Figure 4, the meticulous design of the wiring diagram for this study is clearly evident.

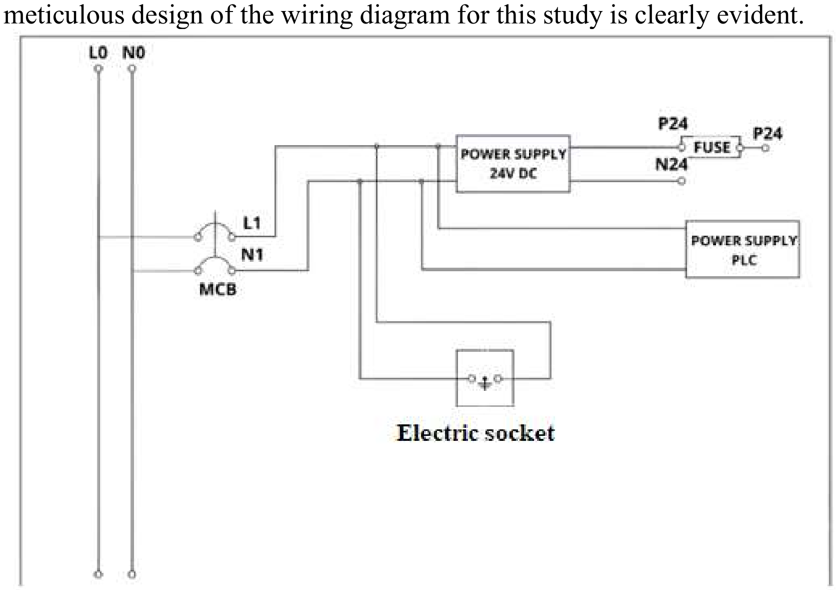

Figure 3. Wiring diagram electrical

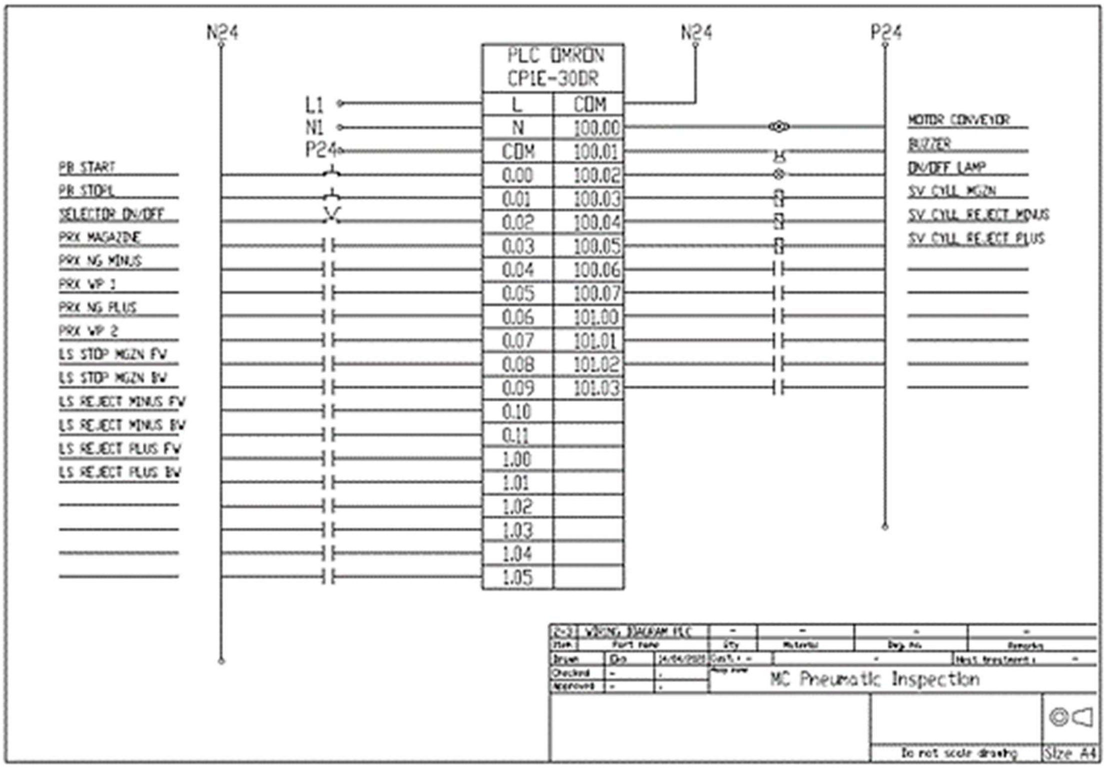

Figure 4. Wiring diagram PLC

3. RESULT AND DISCUSSION

Based on observations of the movement of the pneumatic tool employed for material thickness inspection, emphasis is placed on the accuracy level of the proximity sensor readings in assessing the thickness of materials, whether they meet the standard (OK) or fail to meet the standard (NG). The output from the proximity sensor serves as the primary driving factor for the pneumatic cylinder, and the explanation of this mechanism can be detailed as follows:

a. Magazine proximity sensor: The proximity sensor on the magazine functions to detect the presence of metallic objects, forming the basis for commanding the solenoid to actuate pneumatic cylinder 1. This action aims to open the material path cover, allowing material to flow onto the conveyor path. During the reading process on the sensor for NG minus parts, the proximity sensor instructs the solenoid to actuate the pneumatic cylinder to push thin or NG minus material into the thin NG box. If the proximity sensor does not detect material, the material will proceed to the next stage.
b. NG minus material reading sensor: When the NG minus material reading proximity sensor operates, it commands the solenoid to actuate the pneumatic cylinder. This action aims to push thin or NG minus material into the thin NG box. If the sensor does not detect material, the material will proceed to the next stage.
c. NG plus material reading sensor: In the NG plus material reading process, the proximity sensor commands the solenoid to actuate the pneumatic cylinder. This function is to push thick NG material into the thick NG box. If the sensor does not detect material, the material is considered OK and directed into the OK material box.

In the auto program interface, when the push button (PB) is pressed, the initial material reading proximity sensor (magazine) is automatically activated. This sensor instructs the solenoid to actuate the pneumatic piston cylinder to open the material path cover after the door is opened. After the pneumatic system touches the limit switch, the pneumatic piston cylinder will return to the initial position to close the material path door. There is a delay (2-second delay), during which the proximity sensor resumes its function to command the solenoid for the pneumatic piston cylinder to move, and this process repeats according to the path diagram shown Figure 5 in the program, highlighted in green.

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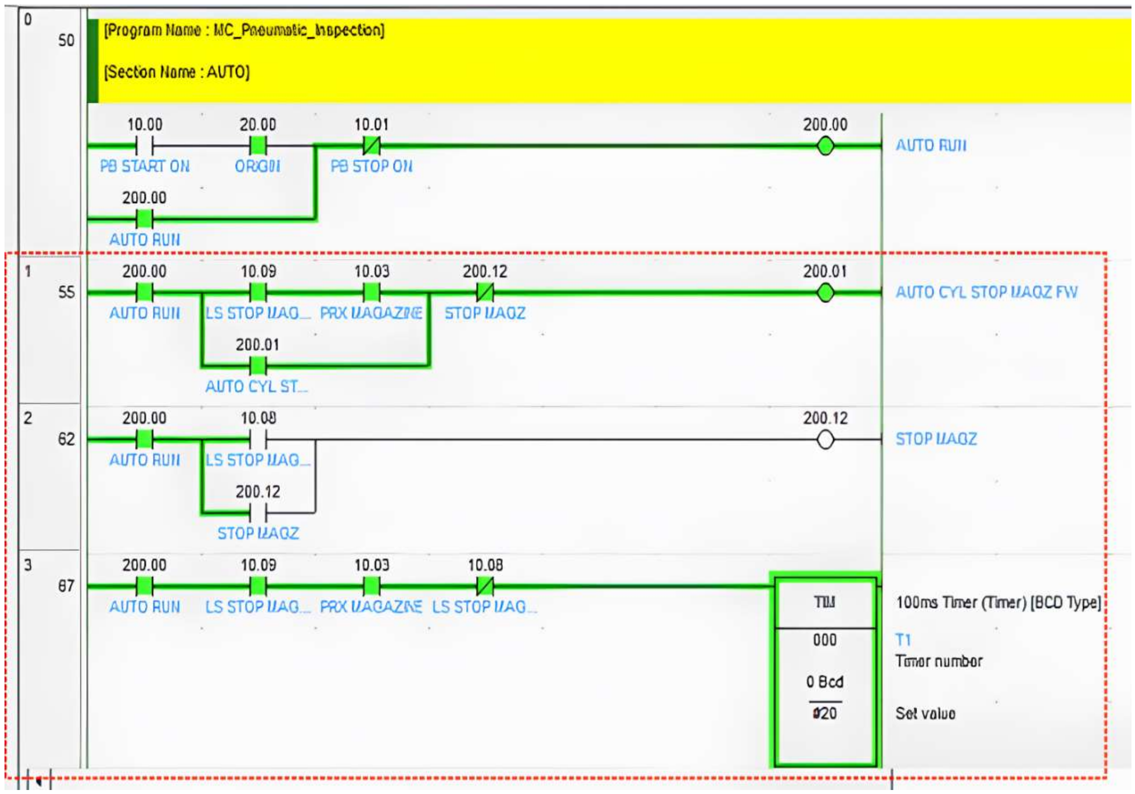

Figure 5. PLC program on auto magazine cylinder

In scenarios where non-metal workpieces flow onto the conveyor, the capacitive proximity sensor automatically detects non-metal objects. In response, the alarm buzzer activates, and the machine stops. This creates an automatic safety layer to halt the process if a non-metal object is detected, preventing potential damage to the system or product. Additionally, for the pressure switch operation, if the air pressure falls below 2 bars, the alarm buzzer sounds, and the machine instantly stops operating. The machine cannot be operated until the air pressure reaches adequate conditions, and only then can the machine be reactivated. This system is designed to ensure operational safety and optimal work quality, with automatic responses to conditions that may pose potential risks. The results of the PLC program sequence for the NG minus cylinder are elucidated as follows:

a. Proximity sensor Ø12 NG minus: As the material moves automatically along the conveyor, the Ø12 proximity sensor for NG minus automatically reads the presence of the material. If this sensor detects material with an NG minus status, the next step is initiated.
b. Proximity sensor Ø18: Subsequently, the material is read by the Ø18 proximity sensor, which functions as a verification step. This sensor is used to ensure the material's presence and validate its status.
c. Proximity Sensor Ø12 NG Minus (Second Checking): After the verification step, the material is re-read by the Ø12 NG minus proximity sensor in the second stage. This is done to ensure that the material remains classified as NG minus throughout its journey.
d. Solenoid activation and pneumatic piston cylinder: After the material's presence is confirmed as NG minus by the second Ø12 sensor, the solenoid activates to command the pneumatic piston cylinder. The pneumatic piston cylinder then moves forward to push the NG minus material.
e. Return of pneumatic piston cylinder to original position: After touching the limit switch, the pneumatic piston cylinder returns to its initial position. This process repeats automatically according to the programmed logic in Figure 6.

These steps form an automatic cycle where material detected as NG minus is processed by the pneumatic cylinder, and this cycle repeats as the material moves along the conveyor. Figure 6 provides a visual representation of this flow in the PLC program for the NG minus cylinder.

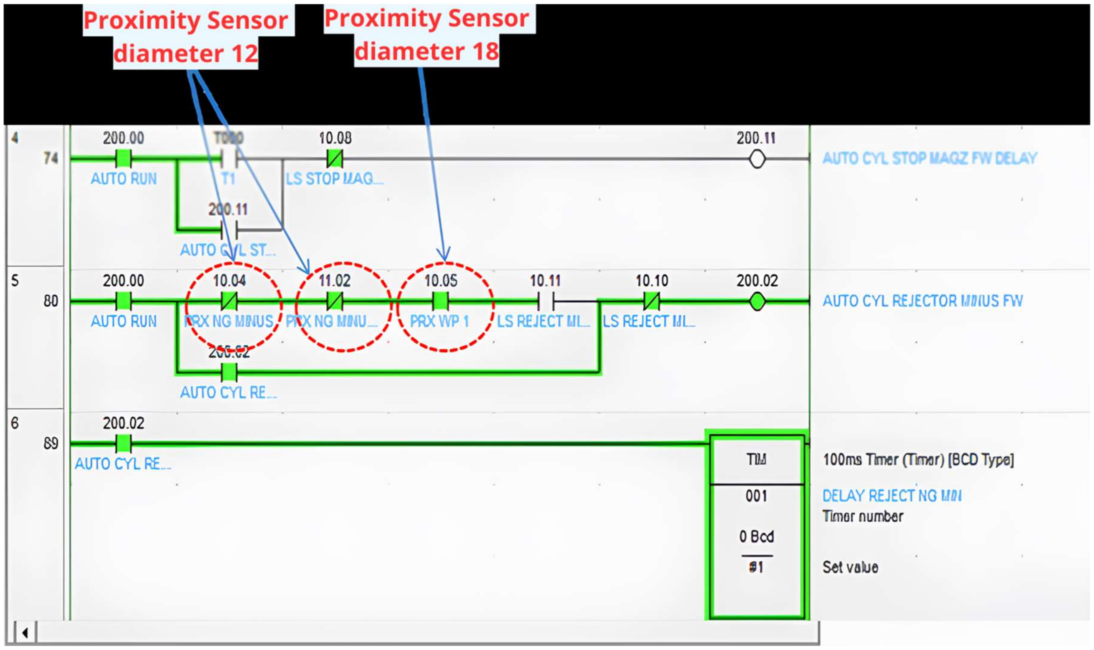

Figure 6. Display of the auto process program for NG minus cylinder

The steps in the PLC program sequence for the NG plus cylinder are outlined as follows:

a. Proximity Sensor Ø8 NG Minus: As the material moves automatically along the conveyor, firstly, the Ø8 proximity sensor for NG minus reads the presence of the material. If the material is not detected as NG minus by this sensor, the next step is executed.
b. Proximity Sensor Ø18: Subsequently, the material is read by the Ø18 proximity sensor for further confirmation and verification. This sensor ensures that the material has passed the previous NG minus sensor and is now ready for classification as NG plus.
c. Solenoid Activation and Pneumatic Piston Cylinder: After the presence of the material is confirmed by both sensors, the solenoid activates to command the pneumatic piston cylinder. The pneumatic piston cylinder then moves forward to push the NG plus material.
d. Return of Pneumatic Piston Cylinder to Original Position: After touching the limit switch, the pneumatic piston cylinder returns to its initial position. This process is repeated automatically according to the programmed logic in Figure 7.

These steps form an automatic cycle where material that has passed the NG minus sensor is identified and classified as NG plus. Subsequently, this material is processed by the pneumatic cylinder, and this cycle continues as the material moves along the conveyor according to Figure 7 in the PLC program for the NG plus cylinder. For material that is not detected by both the NG minus proximity sensor and the NG plus proximity sensor, the material goes directly to the OK part box.

The validation of the pneumatic system against the workpiece is conducted with the aim of measuring the variation in measurement results obtained from a single measuring instrument used multiple times by one observer when measuring the same characteristics on identical parts (workpieces). In this validation process, the sequence of placing the workpieces is created with variations that include the thickness of NG minus workpieces, OK thickness, and Plus thickness. The testing sequence for each stage is as follows:

1) Stage One: This process is repeated three times (3X) by exchanging the positions of the workpieces between minus thickness and plus thickness at the initial stage.
   a. Sequence No 1 to No 3: Thickness of NG minus workpieces (8.29 - 8.35)
   b. Sequence No 4 to No 10: Thickness of OK workpieces (9.63 - 10.11)
   c. Sequence No 11 to No 13: Thickness of Plus workpieces (11.06 – 12.11)
   d. Sequence No 14 to No 16: Thickness of OK workpieces
2) Stage two: This process is repeated three times (3X) in testing.

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a. Sequence No 1 to No 3: Thickness of OK workpieces (9.63 - 10.11)
b. Sequence No 4 to No 6: Thickness of Plus workpieces (11.06 - 12.11)
c. Sequence No 7 to No 13: Thickness of OK workpieces (9.63 - 10.11)
d. Sequence No 14 to No 16: Thickness of Minus workpieces

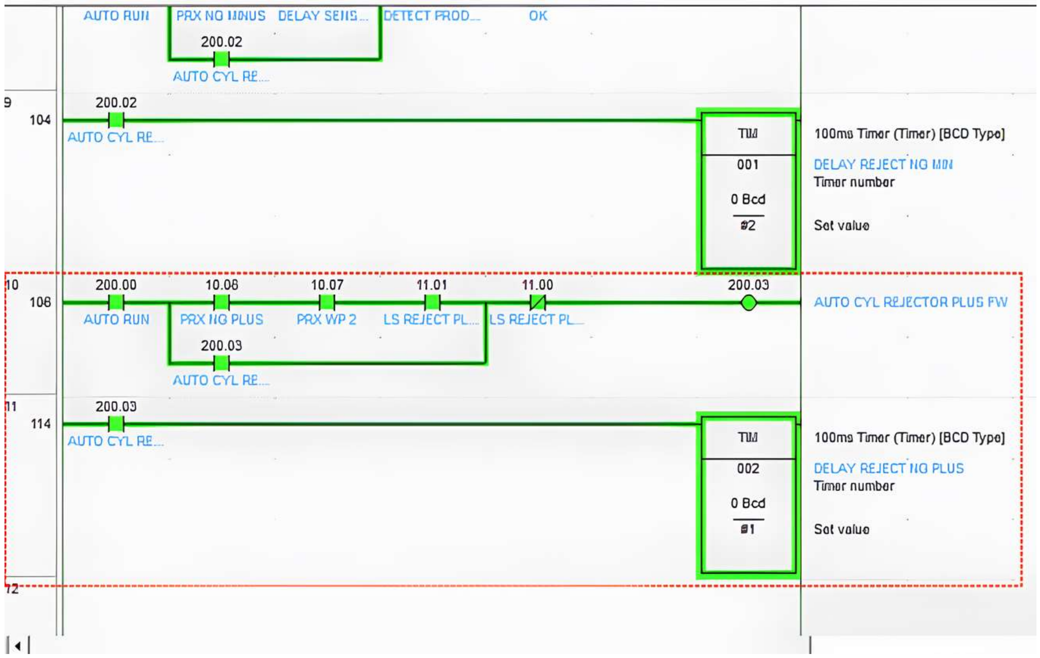

Figure 7. Display of the auto process program for NG plus cylinder

This validation allows us to assess the extent of measurement result variations that may occur under different testing conditions. By conducting tests at each stage and repeating them three times, we can ensure the reliability of the pneumatic system in accurately and consistently measuring the characteristics of the workpiece in Table 1.

Table 1. Measurement system effectiveness

No.	Measurement System Decision	Effectiveness
1	Accepted	> 90%
2	Needs Improvement	80 – 90 %
3	Rejected	< 80%

Table 2. OK/NG test results with MSA system

Character:	Thickness: 9,8 (+0,5/0,5)							
Sample Part	Standard	Testing 1			Standard	Testing 2		
		1	2	3		1	2	3
1	NG	NG	NG	NG	OK	OK	OK	OK
2	NG	NG	NG	NG	OK	OK	OK	OK
3	NG	NG	NG	NG	OK	OK	OK	NG
4	OK	OK	OK	OK	NG	NG	NG	NG
5	OK	OK	OK	OK	NG	NG	NG	NG
6	OK	OK	OK	OK	NG	NG	NG	NG
7	OK	OK	OK	OK	OK	OK	OK	OK
8	OK	OK	OK	OK	OK	OK	OK	OK
9	OK	OK	OK	OK	OK	OK	OK	NG
10	OK	OK	OK	OK	OK	OK	OK	OK
11	NG	NG	NG	NG	OK	OK	OK	OK

Character:		Thickness: 9,8 (+0,5/0,5)						
Sample Part	Standard	Testing 1			Standard	Testing 2		
		1	2	3		1	2	3
12	NG	NG	NG	NG	OK	OK	OK	OK
13	NG	NG	NG	NG	OK	NG	OK	OK
14	OK	OK	NG	OK	NG	NG	NG	NG
15	OK	OK	OK	OK	NG	NG	OK	NG
16	OK	OK	OK	NG	NG	NG	NG	NG
Total of Checking		48				48		
Total Conformance		48				44		
Effectiveness		95,80%				91,70%		
Decision		OK				OK		

Table 2 from the results of the first test, the effectiveness value obtained is 95.8%, while the second test shows an effectiveness value of 91.7%. Both effectiveness values are above 90%, which is the standard criteria for high effectiveness. Therefore, the pneumatic system for the workpiece is considered acceptable. The MSA study results indicate some deviations in the proximity sensor readings, as depicted in the highlighted yellow areas. In the ideal conditions, these should be categorized as OK, but the actual test results show NG conditions. Conversely, there are also conditions that should be categorized as NG, but actual test results show OK conditions. From the above test results, there are deviations from the standards, primarily related to the Ø12 proximity sensor in sensing NG minus workpieces. This deviation is caused by constraints during the material movement from the initial stage, where the material sometimes encounters resistance or gets stuck at the Ø12 proximity sensor stopper. This occurrence impacts changes in the sensing of the Ø12 proximity sensor, causing workpieces that should go to the OK box to enter the NG minus thick box. This is due to the detection by the Ø12 proximity sensor affected by the material getting stuck.

4. CONCLUSION.

In conclusion, this research has successfully identified and analyzed critical aspects pertaining to the pneumatic system utilized for thickness measurement through proximity sensors. Test results have revealed deviations from standards, particularly in relation to the Ø12 proximity sensor's detection of NG minus workpieces. This discrepancy is attributed to constraints in the material process, leading to potential jamming at the proximity sensor stopper, resulting in unintended detection and material ingress into the NG minus thickness box. Despite these deviations, the pneumatic system demonstrated an effectiveness of 95.8% in the first test and 91.7% in the second test, meeting the established criteria of over 90%. Proposed solutions encompass adjustments to the stopper or proximity sensor positions, recalibration of proximity sensors, continuous monitoring, and material path separation to bolster system reliability. To further enhance the performance of the thickness measurement tool, recommendations include additional research efforts, such as extending the conveyor length to mitigate sensor errors, incorporating capacitive proximity sensors to detect non-metallic materials, and installing a pressure switch as an alarm for air pressure drops. Implementation of these measures is anticipated to augment overall system effectiveness and reliability, albeit necessitating further evaluation and testing for successful integration.

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