Journal of Industrial Automation and Electrical Engineering
Vol. 02, No. 01, June 2025, pp. 133~140
ISSN: 3089-1159

Thrust Roller control in Kiln using PLC and HMI

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Article Info

Article history:

Received April 23, 2025
Revised May 11, 2025
Accepted May 29, 2025

Keywords:

Thrust Roller
Kiln
PLC dan HMI
Monitoring
Control

ABSTRACT

The thrust roller control and monitoring system is very important in the cement production process, especially in the cement processing process that occurs in the Kiln equipment. At PT. Semen Padang, the thrust roller control and monitoring process using a potentiometer sensor often experiences problems. Based on this, this study aims to develop a solution to the problem of the thrust roller control and monitoring system to make it more accurate. This study was conducted using an experimental method. With this method, the author took some test data on the ultrasonic sensor as a substitute for the potentiometer sensor and then compared the test data with the actual value to determine the level of feasibility and error in the system. The research instrument used in the test was a meter while the object of the study was the thrust roller prototype that had been made. Based on the test results, the thrust roller control and monitoring system has been successfully carried out where the thrust roller movement is displayed in the form of an HMI screen simulation with a small error rate, namely from 20 trials 18 of them were successful while the remaining two experienced errors.

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1. INTRODUCTION

In Indonesia, the cement industry plays a crucial role in supporting infrastructure development, including roads, ports, buildings, irrigation systems, and housing. This demand results in a substantial need for cement. According to [1], Indonesia has nine cement plants, three of which are part of the Semen Gresik Group, namely PT Semen Padang, PT Semen Gresik Tbk, and PT Semen Tonasa, with a combined production capacity of 16.92 million tons per year. Other companies include PT Holcim Indonesia Tbk (8.7 million tons), PT Indocement Tunggal Prakarsa Tbk (15.65 million tons), PT Semen Baturaja (1.25 million tons), PT Semen Andalas (1.4 million tons), PT Semen Kupang (570 thousand tons), and PT Semen Bosowa Maros (1.8 million tons).

Cement is a strategic commodity that utilizes non-metallic mineral resources such as limestone, clay, iron sand, and gypsum (imported), processed through high-temperature combustion [2]. This combustion occurs within a kiln, a rotating cylindrical vessel in which the raw materials come into contact with hot gases, resulting in the formation of cement compounds including C_3S, C_2S, C_3A, and C_4AF [3]. A rotary kiln typically has a horizontal inclination of 3–4% and rotates at a speed of 1–4 revolutions per minute. The raw material enters from the upper end and moves downward due to the kiln's slope [4]. To facilitate this movement, a thrust roller is installed at the lower end of the kiln [5]. Mechanically, the thrust roller is driven horizontally using a hydraulic actuator [6]-[8], representing an advancement in industrial automation technology within the cement industry. At PT Semen Padang, the thrust roller is controlled using limit switches and potentiometers, which are directly connected to a PLC [9]. Two limit switches are employed: one detects the kiln's lower position and the other detects the upper position. When the kiln is in the lowered position, the thrust roller activates the lower limit switch, which sends a digital signal input to the PLC [10]. For monitoring the vertical movement of the thrust roller, a Human-Machine Interface (HMI) is used.

The kiln movement monitoring system using HMI provides significant benefits to workers by allowing real-time observation of the production process. However, the use of potentiometers frequently encounters operational issues, such as sensor wear, which results in unreadable data [11]. This discrepancy leads to mismatched information between the HMI display and the actual conditions, potentially disrupting plant operations. One such issue is the inconsistency between the HMI-reported kiln position and the actual position, which may lead to inaccurate operational reports. Another problem is the frequent halting of kiln operation due to a false error indication on the HMI regarding thrust roller movement, even though no actual fault exists. This disrupts the cement production process and prolongs the clinker heating time. Extended heating increases electricity consumption required to operate machinery [12]. Moreover, prolonged clinker heating can degrade cement quality. Therefore, a technology-based innovation is needed to improve the thrust roller control system and simplify the existing setup, making it more practical and accurate. This would enable users to control and monitor the thrust roller more precisely using PLC and HMI.

Control and monitoring systems using PLC and HMI have been developed by several researchers. In [13], a study was conducted on the control and monitoring of the production process using an Industry 4.0-based SMI machine. The results showed that users could control the production process via HMI, view displayed data, perform calculations, monitor I/O, and receive error notifications, thereby reducing troubleshooting time. In addition, [14] conducted research on servo motor speed control and monitoring using PLC and HMI. This study compared servo motor speed data shown on a tachometer and HMI. The findings indicated that the motor speed was displayed in real-time on the HMI, with minimal differences from tachometer readings, demonstrating accurate monitoring results. Based on the aforementioned issues, the objective of this study is to develop a thrust roller control and monitoring system using PLC and HMI. Furthermore, this research proposes the use of an ultrasonic sensor for measuring the displacement of the thrust roller, as it provides accurate distance information [15]. The expected benefit of this study is to facilitate accurate thrust roller monitoring and control, thereby improving operational efficiency for plant personnel.

2. METHOD

Explaining The design process begins with the development of a block diagram. A block diagram provides a fundamental representation of the system to be designed, illustrated through interconnected blocks linked by lines that indicate the relationship between components [16],[17]. Each block within the system serves a specific function. The I/O block diagram of the device is shown in Figure 1.

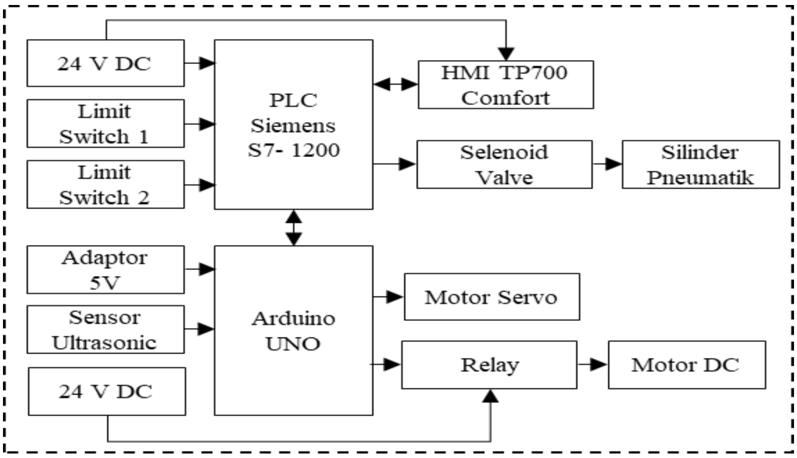
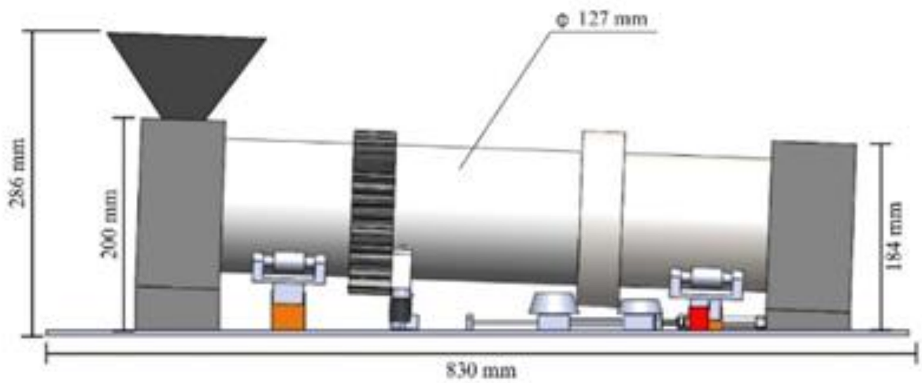


Figure 1. Block Diagram I/O

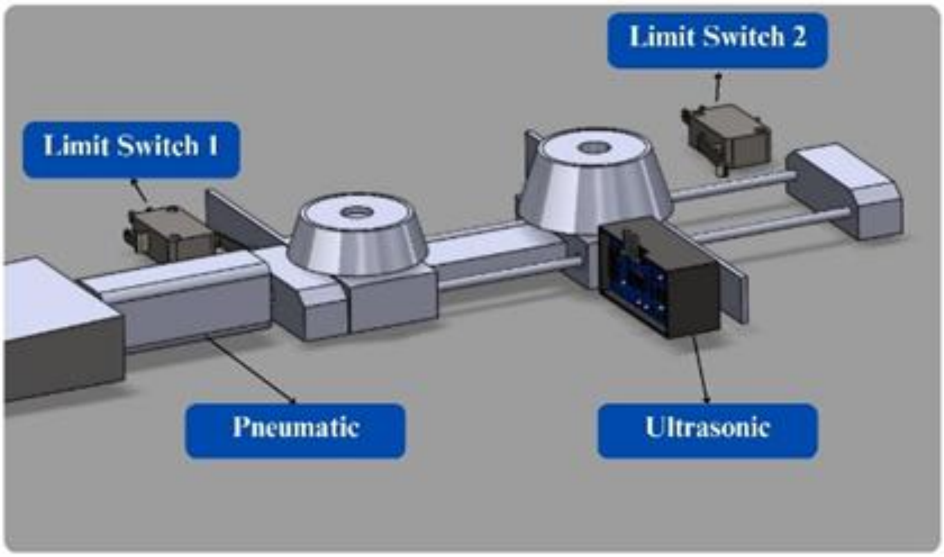
Based on Figure 1, the system comprises several main components. The HC-SR04 ultrasonic sensor detects the distance of the thrust roller. The limit switch halts the kiln movement by sending a signal to the PLC. The Arduino UNO processes data from the sensor before transmitting it to the PLC. The PLC controls the overall system, processes the data, and transmits information to the HMI. The solenoid valve regulates the airflow to the pneumatic cylinder. The HMI displays the distance data in both numerical and graphical formats. The pneumatic cylinder pushes the thrust roller vertically using air pressure. The DC motor rotates the kiln at a constant speed, while the servo motor operates the feeder by opening and closing it in the kiln prototype.

The designed prototype simulates the operational system of an industrial kiln. When a button on the HMI is pressed, the Arduino UNO sends a PWM signal to the motor driver, causing the DC motor to rotate at a constant speed. The ultrasonic sensor continuously measures the distance of the thrust roller and transmits the data to the Arduino, which then forwards it to the S7-1200 PLC. The PLC sends this data to the HMI, where it is displayed in numerical, graphical, and level formats to facilitate monitoring.

To activate the pneumatic system, the user presses a button on the HMI. Initially, Limit Switch 1 is in a normally closed (NC) state. Upon button activation, the PLC triggers the solenoid valve, causing the pneumatic cylinder to push the kiln horizontally. When the thrust roller contacts Limit Switch 2, the system pauses for 10 seconds, during which the servo motor is activated to open the feeder. Subsequently, the pneumatic cylinder retracts the kiln, and the servo motor closes the feeder. When the thrust roller reaches Limit Switch 1 again, the process pauses for another 10 seconds before the kiln is pushed forward once more. This cycle repeats automatically. The mechanical design includes the development of the frame structure for the device. The design was created in three-dimensional form using SolidWorks software. The 3D model of the proposed device is shown in Figure 2.



(a)



(b)

Figure 2. The model of the proposed device. a) Font view, b) component layout

Based on Figure 2(a), the designed device has a length of 840 mm, a height of 286 mm, and utilizes PVC with a diameter of 127 mm as a prototype of the kiln. detailed components of the thrust roller are shown in Figure 2(b). From Figures 2(b), it can be observed that the system consists of 15 individual components integrated into a single functional unit. The detailed view in Figure 4 reveals that the control and monitoring system of the thrust roller comprises four main components: the pneumatic actuator, ultrasonic sensor, Limit Switch 1, and Limit Switch 2. The schematic diagram of the system circuit is presented in Figure 3.

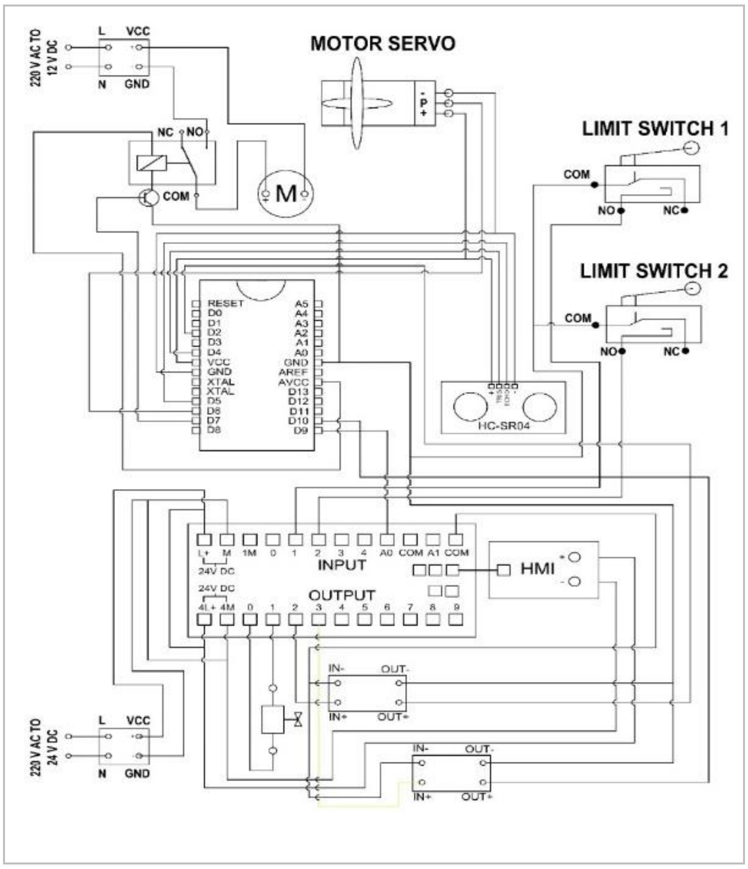
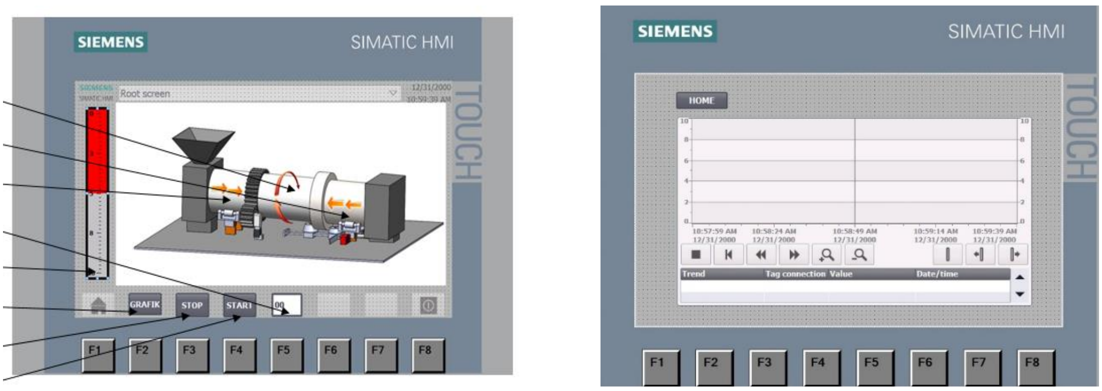


Figure 3. Overall circuit schematic

The software design involves the development of the HMI interface, which serves as the central control and monitoring unit for the thrust roller displacement on the kiln prototype. In addition to functioning as a monitoring interface, the designed HMI is also capable of executing control operations such as starting the device, stopping the device, and running the motor. The HMI display design is shown in Figure 4



(a) (b)

Figure 4. HMI design (a) Dashboard (b) Graphic Display

Based on Figure 4, the software interface consists of two main sections. Display (a) represents the dashboard or main page, where the movement of the thrust roller can be directly observed in both numerical and level-based simulations. Figure 4(b) shows the graphical display, which illustrates the distance readings of the thrust roller movement in both forward and backward directions. A flowchart is a diagram that illustrates the sequence of steps and decision-making processes involved in executing a program. The flowchart of the thrust roller control and monitoring system is presented in Figure 5.

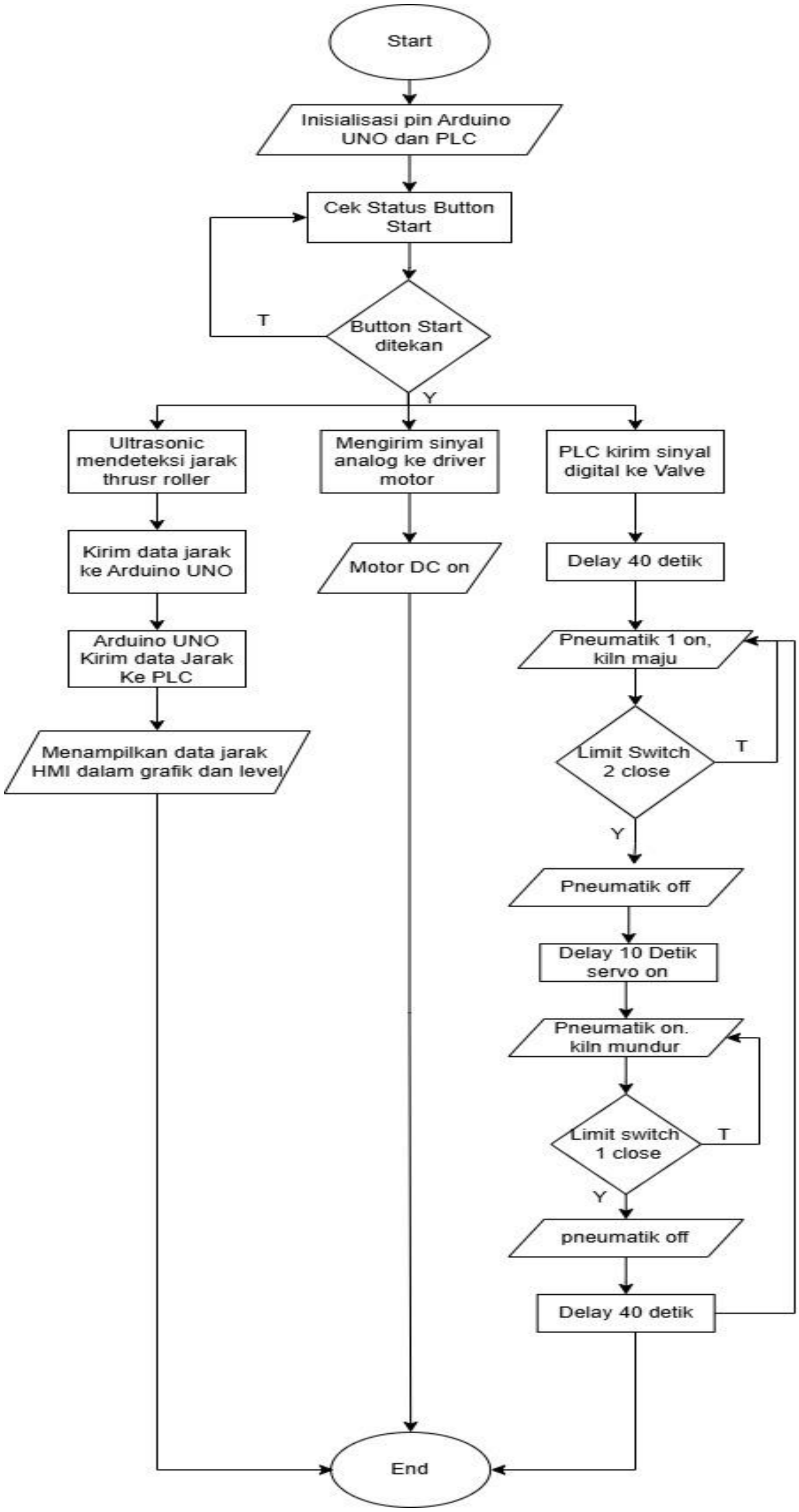


Figure 5. Plowchart of the proposed system

3. RESULTS AND DISCUSSION

This section presents the testing of the horizontal movement of the kiln's thrust roller within a specific time interval. The purpose of this test is to evaluate the effectiveness of the thrust roller in pushing and pulling the kiln prototype automatically using a delay timer. The components involved in this test include limit switches to stop the thrust roller's motion, pneumatic actuators to push and pull the kiln upward and downward, and the mechanical support structure of the thrust roller. The test results for the vertical movement of the kiln are shown in Table 1.

Table 1. Thrust roller movement test data

Time (Sec)	Wind Pressure (Bar)	Limit Switch Status		Pneumatic status	Information
		Limit Switch 1	Limit Switch 2		
0	4	NC	NO	STOP	Succeed
10	4	NO	NO	PUSH	Succeed
21	4	NO	NC	STOP	Succeed
32	4	NO	NO	PULL	Succeed
43	4	NC	NO	STOP	Succeed
54	4	NO	NO	PUSH	Succeed
65	4	NO	NC	STOP	Succeed
76	4	NO	NO	PULL	Succeed

Based on Table 1, tests were conducted on the push and pull movements of the thrust roller to evaluate the automatic horizontal motion (up and down) of the kiln prototype using a timer. The test was carried out over a duration of 3 minutes with continuous cyclic operation. During this period, the system successfully performed its intended functions. Hardware material testing was conducted to evaluate the performance and reliability of the designed thrust roller control system for the kiln, which was developed using a Programmable Logic Controller (PLC) and a Human Machine Interface (HMI). The primary objective of this testing is to ensure that the control system operates according to the expected specifications and can regulate the movement of the thrust roller with precision in supporting the output process of the kiln prototype. Table 2, Table 3, and Table 4 present the experimental results for Material 1, Material 2, and Material 3, respectively.

Table 2. Results of material experiment 1

No	Time (Sec)	Target Output (gram)	Experimental Results (gram)	Error (%)
1	40	50	37	26,00%
2	40	50	43	14,00%
3	40	50	40	20,00%
4	40	50	36	28,00%
5	40	50	39	22,00%
6	40	50	41	18,00%
7	40	50	40	20,00%
8	40	50	38	24,00%
9	40	50	39	22,00%
10	40	50	42	16,00%
			Average Error	21,00%

Table 3. Results of material experiment 2

No	Time (Sec)	Target Output (gram)	Experimental Results (gram)	Error (%)
1	60	50	59	18,00%
2	60	50	60	20,00%
3	60	50	64	28,00%
4	60	50	56	12,00%
5	60	50	54	8,00%
6	60	50	58	16,00%
7	60	50	57	14,00%
8	60	50	60	20,00%
9	60	50	57	14,00%
10	60	50	55	10,00%
			Average Error	16,00%

Table 4. Results of material experiment 3

No	Time (Sec)	Target Output (gram)	Experimental Results (gram)	Error (%)
1	50	50	46	8,00%
2	50	50	53	6,00%
3	50	50	44	12,00%
4	50	50	49	2,00%
5	50	50	51	2,00%
6	50	50	52	4,00%
7	50	50	55	10,00%
8	50	50	46	8,00%
9	50	50	45	10,00%
10	50	50	48	4,00%
			Average Error	6,60%

Here is the comparative error (%) graph for a target output of 50 grams at durations of 40, 50, and 60 seconds. 40 seconds (blue): Exhibits the highest and most variable error.50 seconds (green): Produces the lowest and most stable error. 60 seconds (red): Error is higher than at 50 seconds but more stable compared to 40 seconds, as shown in Figure 6. Based on actual industrial data, the Indarung IV kiln is capable of producing approximately 110 tons of clinker in 30 minutes, indicating a high production rate in large-scale industrial operations. As a comparison, in the prototype kiln developed, a simulation test was conducted by operating the system for 50 seconds, resulting in the production of approximately ±50 grams of clinker. When this result is scaled proportionally, 50 grams in 50 seconds is equivalent to 110 tons in 30 minutes, or approximately 3.67 tons per minute, which is comparable to the production rate of the actual kiln system. 110 ton / 30 Menit = 50 gram / 50 detik

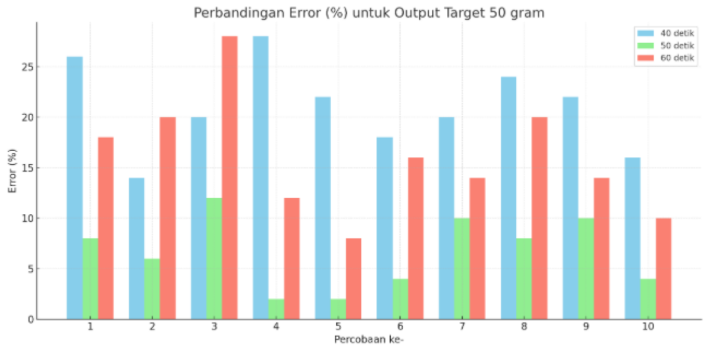


Figure 6. Experimental results.

Software testing was conducted by evaluating the performance of the designed system, particularly focusing on the control and monitoring of the thrust roller using a Programmable Logic Controller (PLC) and Human-Machine Interface (HMI). In this section, a comprehensive system test was performed to assess the overall performance of the control and monitoring system in real-time thrust roller movement. The HMI interface designed prior to system operation is shown in Figure 7.

(a) (b)

Figure 7. HMI display

4. CONCLUSION

Based on the testing results, the development of thrust roller monitoring and control technology has been successfully achieved. The test results confirmed that the designed system is capable of performing accurate and efficient control and monitoring of thrust roller movement. The push and pull motion of the thrust roller can be directly monitored on the HMI screen. The use of an ultrasonic sensor to detect the distance of thrust roller movement demonstrated a low error rate, with 18 successful readings out of 20 trials and only 2 trials showing measurement errors.

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