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Modification of Paving Block Molding Machine with the Addition of an Automatic Control System Based on a Programmable Logic Controller (PLC)

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Abstract

Company X is a paving block molding machine fabrication company in Surabaya. However, the machine still has some shortcomings because it is still conventional or manually operated. Some of these shortcomings, such as being still prone to human error and being less consistent when operating, can affect the results of the amount of production. From this phenomenon, automation is very important in the industrial world. Therefore, by referring to previous phenomenon, through this research, an automatic control system is made on paving block molding machine using PLC. The results showed that PLC succeeded in developing a system that works automatically on the machine. Then, the ladder diagram used several instructions, including interlock, timer, counter, and set reset according to how the machine works. Then, the PLC-based automatic control system has a shorter cycle time than the original manual machine. Cycle time has decreased by 15.4%. From this decrease in cycle time, if simulated related to production capacity, an automatic control system can increase production per hour by 300 pcs more than the manually operated machine

Keywords: Paving Block Molding Machine; Automation; Programmable Logic Controller; Ladder Diagram, Cycle Time

1. Introduction

Company X is a paving block molding machine fabrication company in Surabaya. However, Based on Indonesian National Standar 03-0691-1996, a paving block is a composition of building materials made from a mixture of Portland cement or other hydraulic adhesives, water, and aggregate with or without other additives that do not reduce the quality of the concrete [1]. Various studies have attempted to recycle different types of waste materials and by-products into concrete paving blocks. However, the availability of literature on concrete paving blocks containing waste silt is quite scarce [2]. The paving blocks have numerous applications i.e., footways, parking areas, gas stations, patios, highway toll stations, bus stops and stations, etc. Specially designed paving blocks can withstand heavy static traffic loads like rigid pavements, and these can be re-adjusted easily if a change is needed in the layout of pavements [17].

The proposed information-based preprocessing method will be validated using process time series data from CPS' programmable logic controllers (PLC) [18]. PLC control system is a kind of industrial automation control system based on programmable logic controller, the system has the advantages of flexible, stable and reliable, convenient maintenance in automation control, it is based on the technical advantages to make it widely used in many industrial fields [3]. Programmable logic controller (PLC) is the core device of modern

industrial control, and its traditional logic driving mode gradually shows the bottleneck of algorithm solidification and dynamic adaptability when facing the nonlinear, time-varying and multi-disturbance compound action scenarios [4]. Therefore, through this research, an automatic control system is made on a PLC-based paving block molding machine. The process begins with observation at Company X to obtain machine data, followed by a literature study on PLC. The planning of the automatic control system is carried out, which includes determining the input output (I/O) of the PLC, placing additional sensors, and designing a new control panel. Selecting suitable components and creating detailed wiring diagrams ensured correct electrical connectivity, the general controller can use I/O communication according to the optional configuration Letter or wireless communication. [5].

Five control logic programming languages are defined for use on PLCs (Ladder Diagrams, Function Block Diagrams, Sequential Function Charts, Instruction Lists, and Structured Text), Ladder diagrams are used for

PLC programming, starting with identifying control system needs and determination of I/O addresses,[6]. Once the ladder diagram design is created, a simulation is performed to check for conformity with the machine's workings before uploading it to the PLC. Implementing the control system includes installing components on the electrical panel and additional sensors on the machine. Finally, an operational test of the machine ensures all inputs, outputs, and actuators function as planned [7]. PLC (Programmable Logic Controllers) based data collection is integral to industrial automation and data acquisition processes. The pipeline between the device and the database is a complex system with many components and often causes some time delay, due to the synchronization and the applied hardware and software components [19]. This research aims to develop an automatic control system for a conventional paving block molding machine. The ladder diagram created is expected to match the machine's actual workings. This research also compares the cycle times of manual and PLC-based automatic control systems.

2. Method

2.1 *Illustration*

This study focuses on modifying a paving block molding machine by integrating a PLC-based automatic control system. The research began with direct observation of the existing manual operation to identify inefficiencies, safety issues, and control limitations. A literature review was conducted to support the selection of control strategies and automation components.

Based on the analysis, an automatic control system architecture was designed. Key components, including a Programmable Logic Controller (PLC), Human–Machine Interface (HMI), sensors, actuators, and safety devices, were selected. The HMI interface, wiring diagram, and ladder logic program were then developed.

Prior to implementation, the ladder program was verified through simulation to ensure correct operational sequences. After validation, the system was implemented on the machine and subjected to operational testing. The system performance was evaluated by comparing the cycle time of the automatic control system with the manual system to assess efficiency improvement.

A. *Observation*

Observations were conducted at Company X, one of Surabaya's paving block molding machine fabrication companies. The observation results obtained include machine specifications, as shown in table 1 and how the machine works.

Table 1. Specification of paving block molding machine

Specifications	
Size of Machine Frame	170cm (p) x 100cm (l) x 270cm (t)
Material of Machine Frame	10mm Bending Plate and UNP 150
Type of Mold	12 pcs/one print (rectangular)
Engines	- 2 pieces 7.5 HP/3 phase motors, Bottom Vibrator - 1 piece 0.75 HP/3 phase motor, Upper Vibrator - 1 piece 5.5 HP/3 phase motor, Power Pack - 1 piece 10 HP/3 phase motor, Mixer - 1 piece 3 HP/3 phase motor, Conveyor
Violence Support	K350 - K500
Capacity	12000 - 15000 pcs/day

The manual operating steps were integrated into a PLC-based automatic sequence, beginning with the positioning of the mold onto the pallet followed by the automated movement of the material cart. Once positioned, a vibro motor is triggered for a set duration to achieve material compaction before the mold and pusher are lifted to complete the cycle. Unlike manual control, which is prone to operator fatigue and inconsistent cycle times due to manual handle operation, the PLC system ensures precise timing and positioning. This automation significantly improves operational consistency, enhances safety, and shortens the overall production cycle time for paving block molding.

B. Planning of automatic control system

The planning of the automatic control system on the paving block molding machine includes a plan for making a schematic diagram of the system, determining the input output (I / O) to determine the type of PLC that is suitable for use, determining the placement of additional sensors, making a new panel design to support the operation of the machine, and determining how PLC-based work.

C. Component selection

The selection of components is based on functions that are by the needs of the machine so that it can work optimally. Among them are determining specifications that are sufficient and compatible with PLC and HMI, determining sufficient electrical safety and motor safety current, and sensors that are suitable to support the machine work process. [8].

D. Human Machine Interface (HMI) design

Human Machine Interface (HMI) is interface software that connects humans and machines. The HMI design is made according to the machine's operation needs. HMI will later be connected to the PLC according to the address of the existing input output. In mechanical engineering, HMIs are decisive for accomplishing user-friendly, efficient, and effective machine control. Although various technologies, such as AR-glasses, have already been applied in industrial practice, mechanical engineering companies still face tremendous challenges in selecting and implementing suitable HMI devices [16].

E. Wiring diagram design

Wiring diagrams are graphical representations of a system's connections between electrical components. Wiring diagrams are created to illustrate the connectivity between each electrical component in the system. Ensuring that the wiring installation and electrical connections are done correctly is essential.

F. Ladder diagram design and simulation

Ladder diagrams are the language used in programming this research [10]. The first step in creating a ladder diagram is to identify the needs of the control system. This includes understanding the input outputs (I/O) used, such as types of sensors, push buttons, switches and tasks that need to be executed by the system. The ladder diagram visually illustrates how the system operates on the paving block molding machine.After completing the ladder diagram design, the simulation stage is needed to check whether the actual workings make the ladder diagram design of the paving block molding machine. If the simulation is by how the machine works, a ladder diagram can be uploaded to the PLC.

G. Implementation of control system

Control system implementation is installing and assembling all the components involved in the control system on the electrical panel of the machine. In this study, PLCs, IoT communication, and HMI interfaces form a closed-loop system that continuously processes and acts on sensor data. This design supports autonomous feedback, decentralized decision making, and real-time synchronization across devices. [9].

H. Operational testing of machines

After the implementation, the next stage is to test the operation of the paving block molding machine that has added a PLC-based automatic control system. Cycle time is the time required to complete one work cycle from start to finish. The results of the machine testing were taken cycle time data on manual and automatic control systems by testing as many as 10 trials. [10].

3. Results and Discussion

A. Planning of automatic control system

This section discusses the planning of an automatic control system on a paving block printing machine, including creating a system schematic diagram, determining the input output (I/O) on the PLC, determining the placement of additional sensors, creating a new panel design, and determining the PLC-based working method.

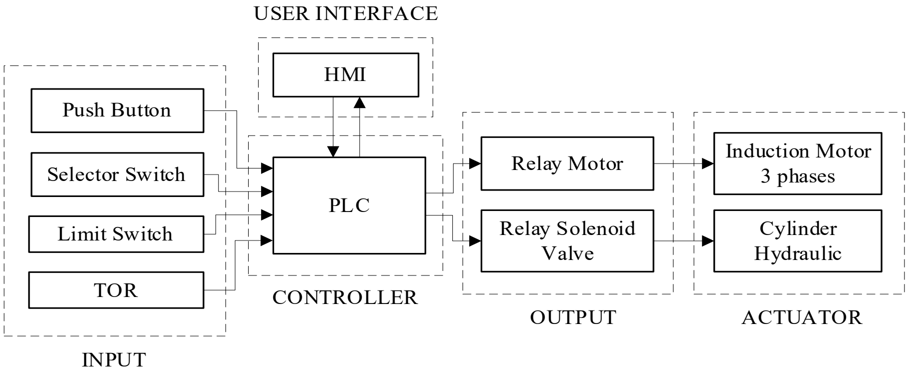


Figure 1. Schematic Diagram of System

Figure 1 shows the schematic diagram of the system used in the study. The PLC receives input signals from several devices, which will then be processed according to the program created. Then, the PLC will issue an output signal to control the output device and move the actuator on the machine. HMI here acts as an interface device that communicates with the PLC.

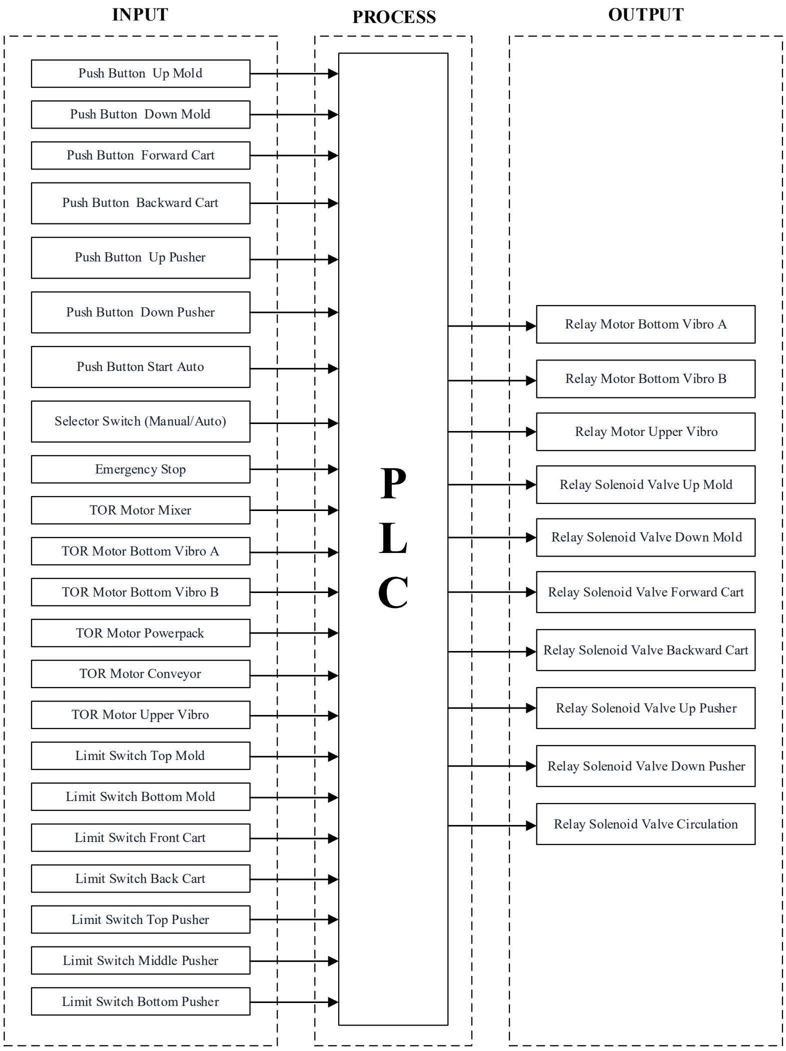


Figure 2. Inputs and Outputs on PLC

Figure 2 shows the inputs and outputs of the PLC used in the study. The inputs used are 22, and the outputs used are 10, adjusting the needs of the machine so that it can work optimally. The diagram illustrates the input–output (I/O) configuration of the PLC-based control system for the paving block molding machine. The PLC functions as the central controller that processes input signals from operator interfaces, protection devices, and position sensors, and then generates output signals to actuate motors and hydraulic solenoid valves.

Input signals consist of push buttons for manual operations, including mold up/down, cart forward/backward, and pusher up/down commands. A start button and a manual/automatic selector switch are provided to enable automatic operation. Safety and protection inputs include an emergency stop button and thermal overload relays (TOR) for the mixer motor, vibro motors, power pack motor, conveyor motor, and upper vibro motor. Additionally, multiple limit switches are installed to detect the positions of the mold, cart, and pusher at the top, middle, front, rear, and bottom positions.

Output signals from the PLC are connected to relay modules that drive the actuators. These outputs control the bottom vibro motors (A and B), the upper vibro motor, and solenoid valves responsible for mold lifting and lowering, cart forward and backward motion, pusher up and down movement, and hydraulic oil circulation.This I/O configuration ensures precise sequencing, safe operation, and reliable automation of the paving block molding process.

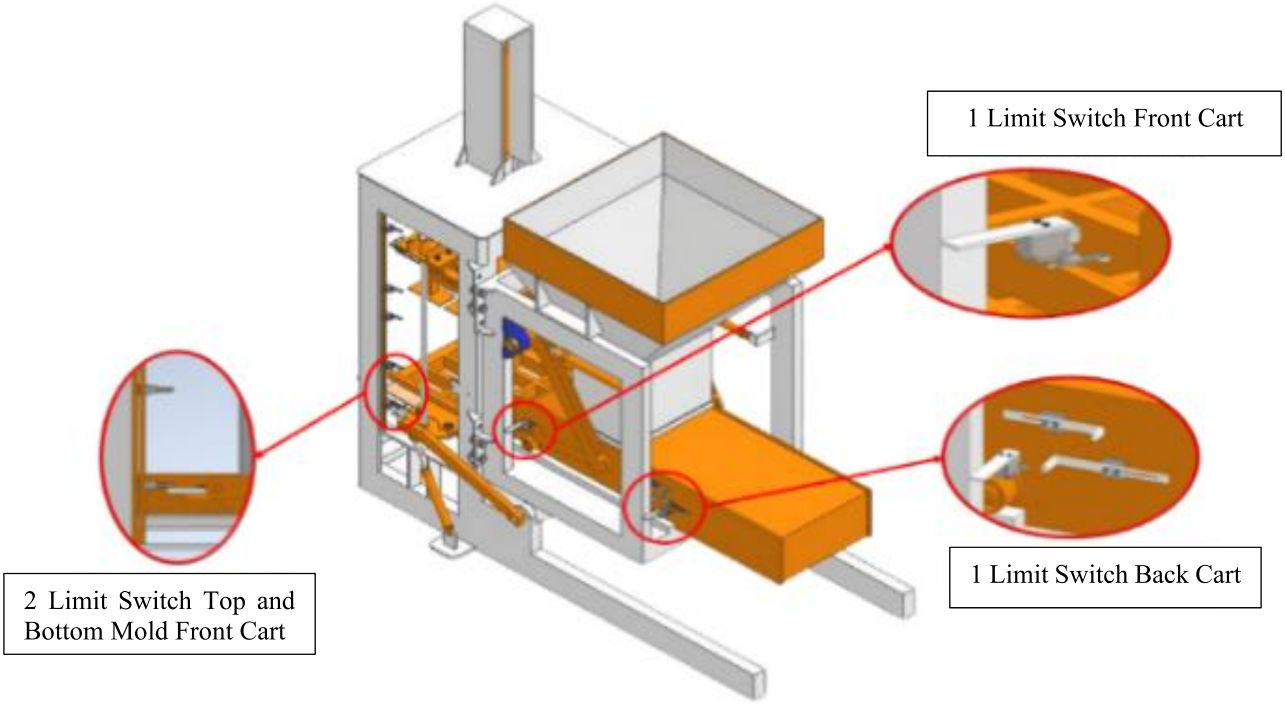


Figure 3. Placement of additional limit switch sensors

Figure 3 shows the placement of additional sensors; The figure illustrates the placement of limit switches used for position feedback in the PLC-based automatic control system of the paving block molding machine. A total of four limit switches are installed to monitor the positions of the mold and the cart during operation.

Two limit switches are mounted on the front mold mechanism to detect the top and bottom positions of the mold, ensuring accurate vertical movement control and preventing overtravel. Additionally, one limit switch is installed at the front end of the cart travel path to detect the forward position of the cart, while another limit switch is placed at the rear end to identify the backward position.

These limit switches provide discrete feedback signals to the PLC, enabling precise motion sequencing, position-based interlocking, and safe operation. The integration of limit switches ensures that each actuator is activated only when the machine components reach their designated positions, thereby improving operational reliability and preventing mechanical collisions.

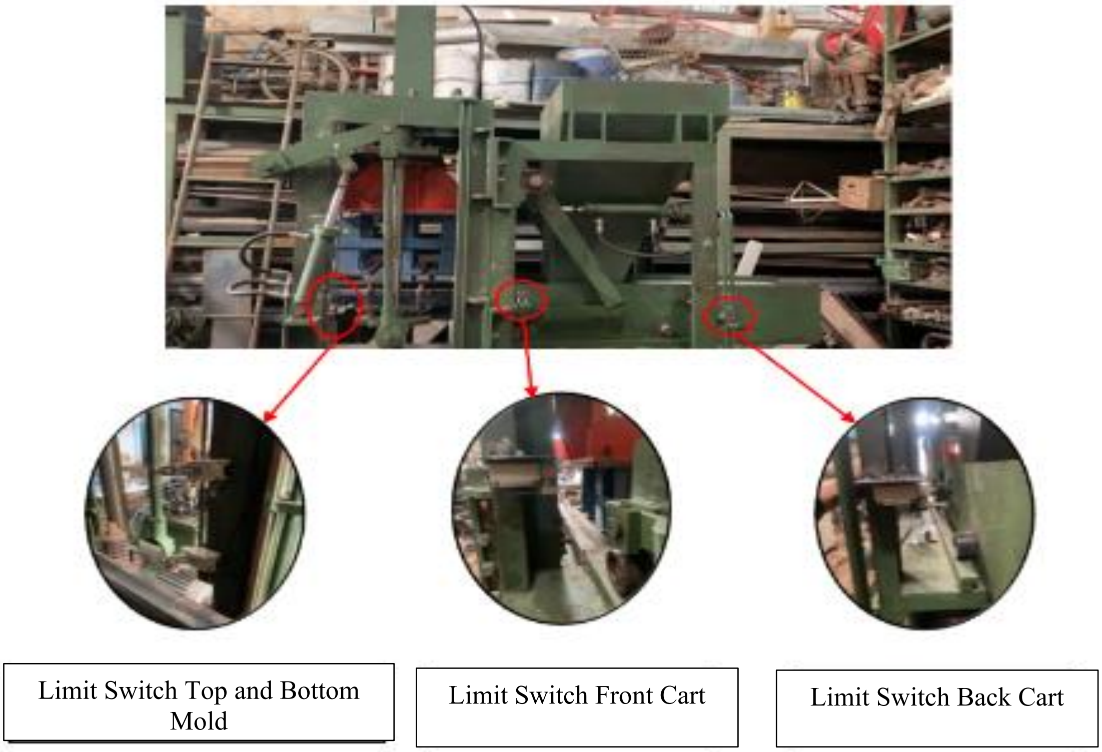


Figure 4. Result of limit switch sensors placement

Figure 4 shows the results of the implementation of adding a limit switch sensor to the machine. This limit switch sensor is a movement limiter for the cart and mold.

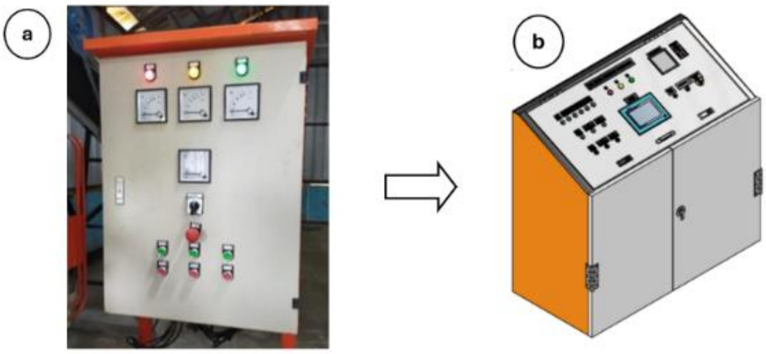


Figure 5. (a) Previous control panel, b) new control panel design

Figure 5 shows the design of the control panel with a piano-shaped design with a size of 110 (p) x 50 (l) x 100 (t), which aims to facilitate the operator in operating the machine and increase comfort during the production process.

Figure 6. Results of the new control panel

Figure 6 shows the results of the new control panel from a previously created design. This control panel is a controller for the machine's working system, which is already PLC-based.

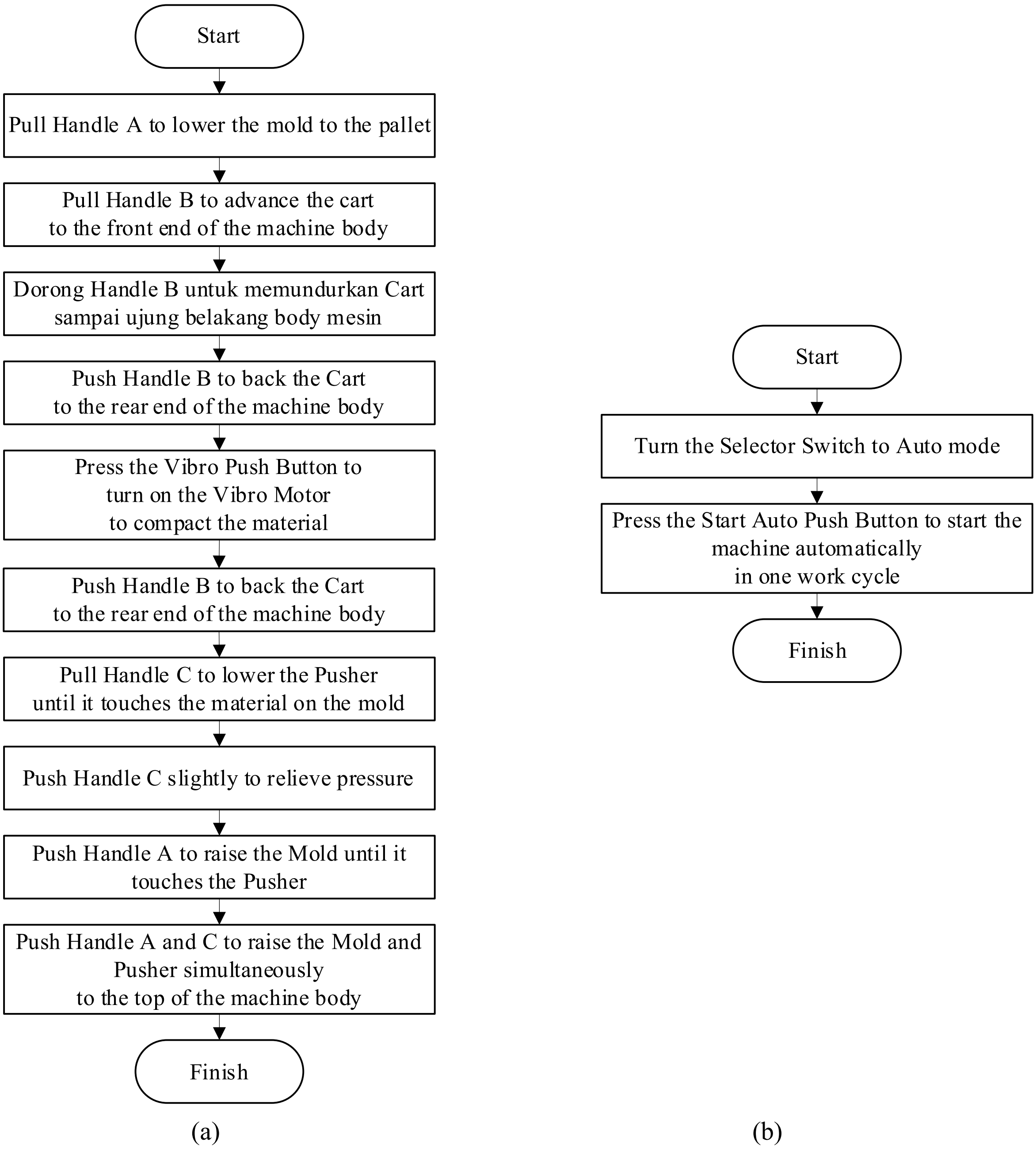


Figure 7. (a) Manual (Handle) Workings of the Previous Machine, (b). How PLC-based Automation Works

Figure 7 shows a change in the way the machine works, from using a handle manually to only using an automatic one-press button. The manual process begins with the operator pulling Handle A to lower the mold onto the pallet. Once the mold is set, the operator pulls Handle B to advance the material cart to the front of the machine, then pushes the same handle to return the cart to the rear. At this stage, the operator presses the Vibro Push Button to activate the motor and compact the material within the Mold. After compaction, Handle B is pushed once more to ensure the cart is fully retracted. To finish the product, the operator pulls Handle C to lower the pusher until it makes contact with the material, followed by a slight upward push on the same handle to relieve pressure. The final extraction involves pushing Handle A to raise the Mold until it meets the pusher; then, both Handle A and Handle C are pushed simultaneously to lift the entire assembly back to the top of the machine, completing the cycle.

The automatic cycle is a significantly streamlined process designed for efficiency. To begin, the operator simply rotates the Selector Switch to "Auto" mode. Once the mode is engaged, the operator presses the Start Auto Push Button, which triggers the machine to perform the entire work cycle, including material movement, compaction, and extraction—automatically without further manual intervention. The sequence concludes once the single work cycle is finished.

B. Component Selection

This section discusses component selection based on functions that suit the machine's needs so that it can work optimally, It eliminates the shortcomings of previous methods like use of hierarchical process, ignorance of non-functional requirements, mismatch handling etc. This thorough assessment offers significant insights into the selection of materials for different mechanical applications, based on particular criteria like as stress, modulus, and toughness. [11]. Among them is determining adequate specifications compatible with the PLC and HMI and the right sensors to support the machine work process, he PLC and HMI based industrial level automation system was developed to validate the simulation results experimentally and to record the current values. [12]. The PLC-based control system is a microprocessor-based controller. In this memory, a special programmable memory is used to store various instructions and functions such us PLC control the sequence and timing of various steps in the production process on the machine [13]. This research used PLC Omron with the considerations listed in Table 2 and Table 3.

Table 1. PLC needs

Needs
It has a minimum I/O of 22/10.
It has 2 Ethernet ports that are compatible with HMI.

Table 2. PLC comparison

Types	Advantages	Disadvantages	Selected.
PLC Omron CP2EN40DRA 	Lower price Readily available in the market More familiar program	Lower durability	☑
PLCSchneider TM221C40R 	Stronger durability	More expensive price Hard to find in the market Less familiar program	☐

The HMI is an interface device that operators use to monitor and control machine operations. HMI is used to monitor and operate the process in online - real time, for easy control of the operations [20]. This research used HMI Kinco GL070E with the considerations listed in table 4 and table 5.

Table 3. HMI needs

Needs
It has an ethernet port that is compatible with the PLC used.
It has a 7-inch screen to adjust the space on the control panel.

Table 4. PLC comparison

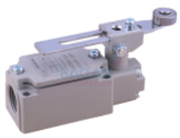
Types	Advantages	Disadvantages	Selected
HMI Kinco GL070E 	Much cheaper price	Lower durability Less familiar program Limited features	☑
HMI Omron NB7W-TW01B 	Durability is more durable. More advanced features More familiar programs	Much more expensive	☐

The limit switch functions as a stopper sensor to detect the movement limits of the machine actuator, namely the mold, cart, and pusher. A microphone is already part of the setup for the purpose of signal recording; therefore, using it to provide acoustic feedback allows one to calibrate and position the system without additional sensors, apart from simple limit switches. [14]. This research used a limit switch Hanyoung M904 with the considerations listed in table 6 and table 7 below.

Table 5. Limit switch needs

Needs
The Variable Roller Lever type adjusts the way the machine works.
Has iron material to make it strong against the movement of the machine.
Has an adjustable roller head for easy placement.

Table 6. Limit switch comparison

Types	Advantages	Disadvantages	Selected
Limit Switch Hanyoung M904 	Lower price Easily available in market	Lower durability	☑
Limit Switch Omron D4N-212G 	Durability is more durable.	More expensive price Hard to find in the market	☐

C. *Human Machine Interface (HMI) design*

This section discusses the HMI design made using Kinco D-tools software from the Kinco HMI product type GL070E.

Figure 8. HMI Design

Figure 8 shows the results of the HMI design. This HMI feature consists of several indicators to monitor the machine's condition, such as limit switch indicators, alarm information, timer on, running time, and counter. and a virtual push button for the manual control system.

D. Wiring diagram design

In this section, before creating a wiring diagram design, the input output address is determined first from the pins on the PLC, which are used to facilitate the wiring process as shown in tables 8 and 9 below.

Table 7. Input address on PLC

Number	Address	Input	Number	Address	Input
1	1.05	Push Button Up Mold	12	1.02	TOR Upper Vibro
2	1.06	Push Button Down Mold	13	1.03	Push Button Start Auto
3	1.07	Push Button Forward Cart	14	1.04	Selector Switch
4	1.08	Push Button Back Cart	15	0.00	Emergency Stop
5	1.09	Push Button Up Pusher	16	0.02	Limit Switch Top Mold
6	1.10	Push Button Down Pusher	17	0.03	Limit Switch Bottom Mold
7	0.09	TOR Motor Mixer	18	0.04	Limit Switch Front Cart
8	0.10	TOR Motor Bottom Vibro A	19	0.05	Limit Switch Back Cart
9	0.11	TOR Motor Bottom Vibro B	20	0.06	Limit Switch Top Pusher
10	1.00	TOR Motor Powerpack	21	0.07	Limit Switch Bottom Pusher
11	1.01	TOR Motor Conveyor	22	0.08	Limit Switch Middle Pusher

Table 8. Output address on PLC

Number	Address	Output	Number	Address	Output
1	100.05	Relay Motor Bottom Vibro	6	101.02	Relay Solenoid Valve Forward Cart
2	100.06	Relay Motor Bottom Vibro B	7	101.03	Relay Solenoid Valve Backwards Cart
3	100.07	Relay Motor Vibro Atas	8	101.04	Relay Solenoid Valve Up Pusher
4	101.00	Relay Solenoid Valve Up Mold	9	101.05	Relay Solenoid Valve Down Pusher
5	101.01	Relay Solenoid Valve Down Mold	10	101.06	Relay Solenoid Valve Circulation

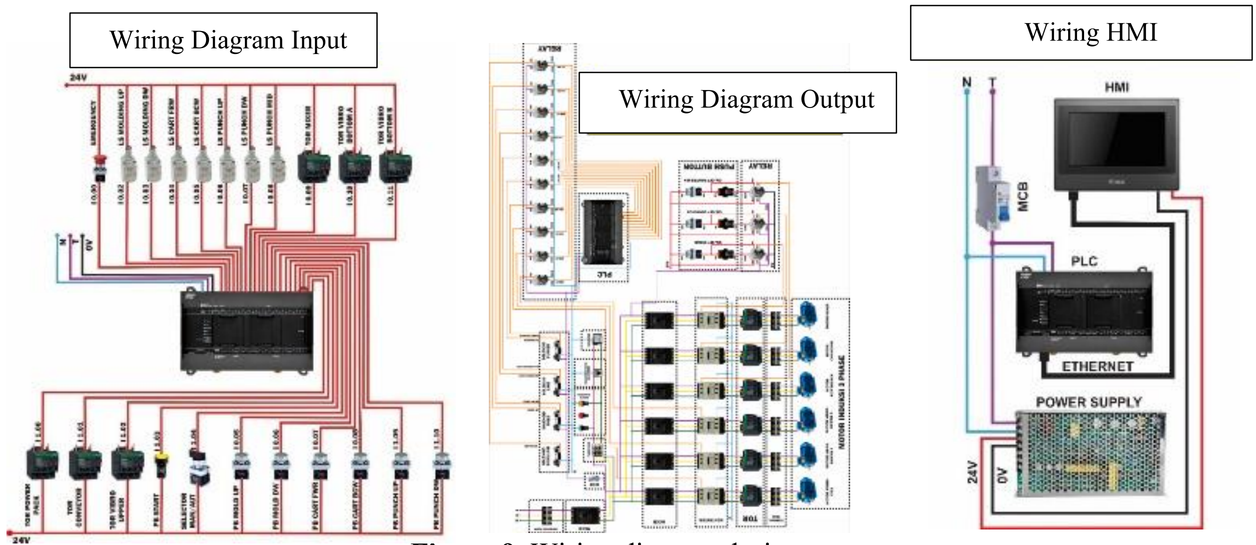


Figure 9. Wiring diagram design

Figure 9 shows the results of the wiring diagram design. These inputs wiring so that the PLC input can turn on must have a different standard voltage and input voltage on the PLC. In this system, the standard uses a voltage of 0 VDC, while the input uses 24 VDC. For the PLC output to work, the standard voltage and output voltage on the PLC must also be different. The standard voltage used is neutral, and the output voltage used is 1 phase (T). Wiring this HMI so that the HMI can turn on a 24 VDC voltage is needed, namely by using a power supply [15].

E. Ladder diagram design

This section discusses the ladder diagram design created using CX-Programmer software from Omron PLC products. Ladder diagrams are made by adjusting the way the actual machine works. [10].The ladder diagram of this system using interlock instructions. The purpose of this interlock instruction is so that when the manual system is used, the automatic system cannot be run and vice versa. Therefore, the interlock instruction in this system is used as a safety feature so that no actuator movement can damage the system. This ladder diagram also uses set, reset, counter and timer instructions.

F. Ladder Diagram Simulation

This section discusses the ladder diagram simulations that need to be carried out to ensure whether the ladder diagram design results contain the input and output requirements of the machine and whether the work sequence is by the way the machine works.

Simulation is needed to find out whether the ladder diagram design that has been made is based on the way the machine works or not.

G. Data Analysis and Discussion

This section discusses the data from the test results analysed to compare cycle time on manual and automatic control systems and determine the effect on machine productivity.

Table 9. Cycle time comparison results of manual and automatic control systems

Number	***Cycle Time* (sec)**	
	Manual	**Automatic**
1	26.98	22.66
2	26.15	22.36
3	26.33	22.12
4	26.36.	22.63
5	26.77	22.83
6	27.31	22.28
7	26.74	22.10

8	26.39	22.14
9	27.63	22.75
10	26.60	22.19

Table 10 shows the fastest cycle time data, namely the 2nd test data (manual) and the 7th test data (automatics), to be compared. The values obtained were 26.15 seconds (manual) and 22.10 seconds (automatic).

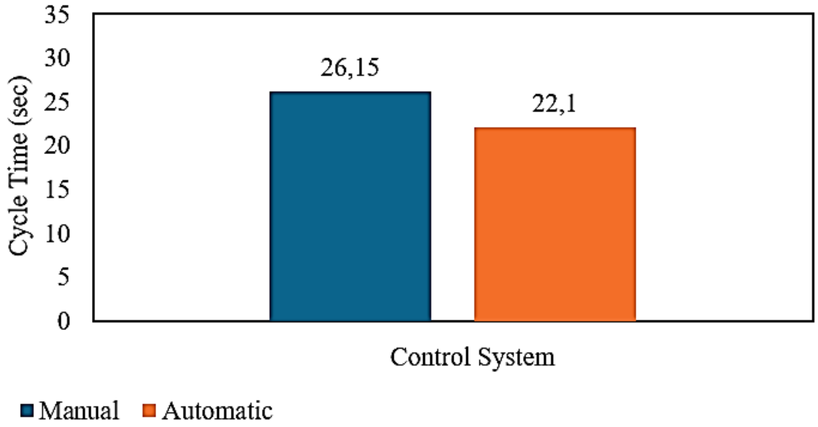


Figure 1. Cycle time improvement graph

Figure 10 shows a graph of the cycle time reduction of 4.05 seconds. This means that the automatic control system is faster than the manual control system, with a cycle time reduction percentage of 15.4%.

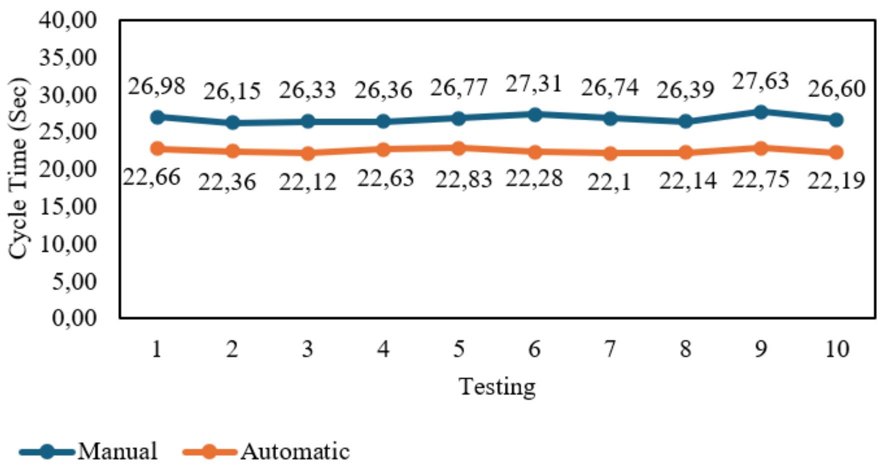


Figure 11. Cycle time consistency graph

Figure 11 shows that the cycle time graph of the automatic control system is faster and more consistent, with a cycle time of 22 seconds. The manual control system is longer and less consistent, with a cycle time of 26 to 27 seconds.

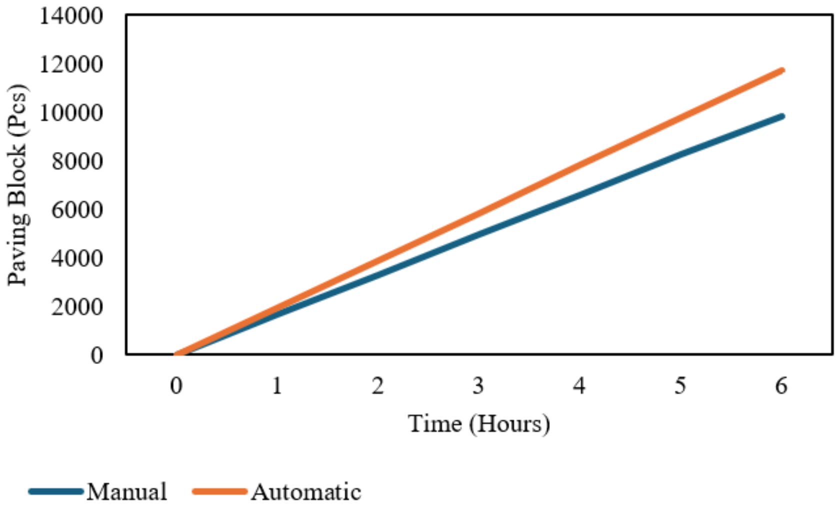


Figure 12. Production performance chart of both control systems

Figure 12 shows the performance graph of the automatic control system which is better and more productive than the manual control system.

4. Conclusions

After researching the modification of the paving block molding machine with the addition of a PLC-based automatic control system, the following conclusion points were obtained:

1. The Automatic control system is developed by using a controller called PLC. PLC functions as a brain to run the machine automatically, which initially worked manually using a handle, changed to using only one push button. This automation is focused on machine actuators, including mold, cart, and pusher
2. The Ladder diagram comprises several parts such as the ladder diagram for the manual control system, the ladder diagram for the stop actuator, the ladder diagram for the automatic control system, and the ladder diagram for actuator control. This ladder diagram used several instructions, including interlock, timer, counter, and set reset.
3. The PLC-based automatic control system has a shorter cycle time than the manual control system. Cycle time has decreased by 15.4%. From this decrease in cycle time, if simulated related to production capacity, an automatic control system can increase the number of productions per hour by 300 pcs more than the manual control system.

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