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Modification of control system using PLC and HMI on drill oil hole machine to speed up piston model replacement process time in automotive manufacturing industry

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ABSTRACT

This research was conducted at an automotive manufacturing company specializing in piston production. The piston production process consists of two main stages: the first is the casting stage, also known as the foundry process, and the second is the parts manufacturing stage, referred to as the machining process. Within the machining stage, there is a piston drilling process for creating oil holes, which is carried out using a Drill Oil Hole (DOH) machine. This machine involves a clamping process using a pneumatic cylinder, point positioning with a servo motor, and drilling using a self-feeder motor. However, the DOH machine has a significant limitation—it still uses an outdated NC (Numerical Control) system. The NC control program is fixed and cannot be modified without contacting the vendor, which also results in lengthy troubleshooting procedures. To address these issues, this study proposes replacing the NC control system with a Programmable Logic Controller (PLC) system. This upgrade includes the addition of a piston template system aimed at reducing downtime and facilitating piston model changes. Furthermore, modifications were made to the HMI (Human-Machine Interface) display using the Omron NB10W, while the servo motor and its driver were replaced with the Delta ASDA-A2 servo system. After the control system was upgraded from NC-based to the PLC CJ2M CPU-11, the DOH machine was tested in accordance with operational standards. The integration of the HMI as the core for monitoring and machine operation has significantly improved usability for operators. It also introduced several new features, such as piston templates and sensor indicators, which were not available in the previous NC system. Importantly, future piston model changes can now be executed without causing machine downtime.

Keywords: Drill Oil Hole Machine, HMI Template Piston, Machine downtime, PLC

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INTRODUCTION

Companies in the automotive manufacturing industry continue to advance automation efforts in alignment with the implementation of Industry 4.0. This research was conducted within the automotive manufacturing sector in Indonesia, specifically focusing on piston production. The piston production process consists of two main stages: the Foundry Process and the Machining

Process, both of which fall under the Maintenance area responsible for carrying out preventive and corrective maintenance to ensure machines remain in optimal condition for production activities.

Based on our previous studies in the automotive manufacturing industry (Ardi & Al-Rasyid, 2016), we have carried out applied research on the design of a pokayoke sensor system for the Drill Oil Hole Machine to detect the presence of a drill using a PLC. Additionally, we have investigated the design of integrated SCADA systems in piston manufacturing, specifically addressing the conveyor, coolant, hydraulic, and alarm systems (Ardi et al., 2017). In another study, we designed a control system for an automatic air remaining machine using a PLC (Ardi et al., 2017). (Ardi & Cascarine, 2018) We also developed a control system for the Human Machine Interface (HMI) on the NTVS-2894 Seat Grinder Machine (Ardi & Ardyansyah, 2018), In the area of process control systems, we explored the modification of loading and unloading controls in an Oil Filling Machine using a PLC-based system (Ardi & Defi, 2018). and designed an automatic control system for the loader output of a Snap Gauge Machine (Ardi & Zuhdi, 2020). Furthermore, we have conducted research on the design of a SCADA-based monitoring and control system for a curing machine, utilizing PLC and HMI Wonderware InTouch (Ardi et al., n.d.).

In addition, we conducted a comparative analysis by referring to several previous studies relevant to our research. For example, (Kumar et al., n.d.) explored real-time production performance monitoring systems as a production aid. (Thepmanee et al., 2022), investigated the implementation of control and SCADA systems for temperature regulation and device diagnostics. (Yadav & Paul, 2021), provided a review on the architecture and security of SCADA systems. (Turner et al., 2022), conducted a study on circular production and maintenance of automotive parts, proposing an Internet of Things (IoT) data framework and reviewing current practices. (Sean et al., 2020) discussed energy consumption analysis in wastewater treatment plants using simulation integrated with SCADA systems. (Than Min et al., 2019). (Moftah, n.d.), focused on the automation of a series tank level control system using PLC and HMI, while Moftah (n.d.) designed a control system for concrete machines based on PLC and HMI. Our colleagues, (Prasetyani et al., 2020), conducted research on control modification of a Drill Oil Hole Machine using the Omron CJ1M CPU-21 PLC. Similarly, (Setiawan et al., 2019), studied the use of SCADA systems with PLC and HMI to enhance the effectiveness and efficiency of production processes. (Prasetyo et al., 2024), examined the implementation of a three-phase motor protection system using PLC and HMI. (Chang et al., 2020), applied PLC and HMI in the development of a measurement and control platform for a single-tube heat transfer experimental rig. Lastly, (Hazaveh et al., 2024) researched the automation of an industrial dishwashing system using hardware-in-the-loop PLC simulation with Factory I/O.

In the machining process, oil hole drilling is performed using a Drill Oil Hole (DOH) machine. On this production line, there is a DOH machine that is currently inactive due to a malfunction, indicated by an x-axis pulse error alarm. This machine uses a Mini CNC control system, which does not allow modification of CNC programs unless a vendor is called—resulting in time-consuming troubleshooting procedures.

In this study, the Human-Machine Interface (HMI) was replaced with an Omron NB Series HMI. This change also aims to simplify future maintenance for other DOH machines that may experience HMI issues, especially since the previously used NS HMI is no longer available. The new Omron NB Series HMI, along with a pre-developed HMI program, can be directly installed on the DOH machine on line 35 as a replacement. Based on this background, the objective of this study is to modify the existing control system—from a Mini CNC-based system to one that utilizes a PLC and HMI-based configuration.

METHOD

Method DOH (Drill Oil Hole) Machine

Based on the DOH machine modification plan, a new DOH machine design was developed to address the previously identified problems. Figure 1 presents the redesigned DOH machine.

Figure 1. DOH Machine

The design process is undertaken to address existing problems by transforming outdated elements into improved, updated ones. The objective is to enhance the performance of the DOH machine. The users' requirements for this DOH machine are as follows:

- Replacing the Control System which was originally based on NC (Numerical Control) to PLC using a PLC with nine inputs and four outputs and by the old machine

- Angle adjustment is done by pressing the button provided where the angle list has been entered into the PLC first
- There is an HMI used by the operator to input angles
- There is an indicator system to check for damaged or non-working sensors
- Cycle time for motorcycle-type pistons is 30-35 seconds
- Has an angle accuracy of 0.1 °
- For PLC specifications, it can issue 500,000 pulses/second that enter and can drive a servo motor of 3000 rpm or 50Hz

DOH Machine Working Principle

A DOH machine is specifically designed to create oil holes in pistons. This machine utilizes a specialized mechanism known as a *Selfeeder*, which enables the drilling of pistons at various angles, depending on the piston type. The DOH machine operates through several sequential stages, all initiated by the operator. The process begins when the operator or the master control issues a start command by pressing the cycle start button. Once the machine receives this command, it activates the clamping mechanism to secure the piston in place, preventing any movement during drilling. Subsequently, the slide advances to position the piston so that it aligns precisely with the drilling tool. The machine then performs the drilling process according to the predetermined angle and number of oil holes. If the design of a specific piston requires oblique oil holes (as not all pistons do), the machine proceeds to drill at the specified oblique angles and hole quantities. Upon completion of the drilling process, the machine releases the clamp, allowing the piston to be removed from the jig. At this stage, the operator can extract the piston to proceed with the next machining steps. Figure 2 illustrates the operational flow of the DOH machine.

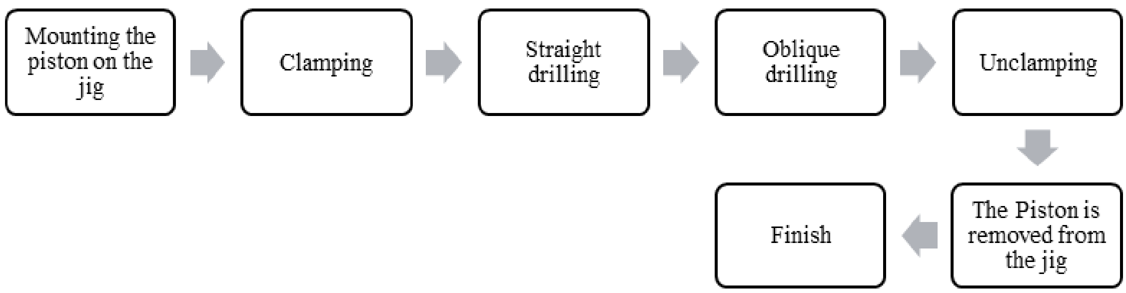

Figure 2. Flow Process of DOH machine

RESULTS AND DISCUSSION

Results

The DOH machine is a drilling machine used to create oil holes in pistons. However, the challenge lies in the fact that this machine is not dedicated to a single type of piston. Whenever the piston type on a production line is changed, a procedure known as the "Change Model" must be performed. This process involves modifying the settings and procedures to accommodate the new piston type. The division primarily responsible for executing the Change Model process is the Model Change Division, although in some cases, it may also be performed by the machine operator.

Therefore, the design and interface of the piston template programming are developed through several steps, namely:

- Knowing the needs
- Collecting information
- Creating concepts and designs
- Creating designs and programs
- Evaluation

It can be concluded that the improvement made—namely the creation of a piston template—can streamline the steps involved in the angle adjustment process. By using the piston template mode, the angle setting becomes more efficient and is expected to reduce machine downtime.

The Running Hours system was developed to facilitate Preventive Maintenance activities based on machine operating hours. This system enables users to monitor how long the machine has been operating and to identify parts that have reached their lifespan and need replacement. The Running Hours system is activated when the machine begins its cycle start process and can be reset after preventive maintenance has been completed.

The electrical design of the control system for the oil hole drilling machine is divided into four sections: power diagram, input devices, process control, and output devices. The 380 VAC power supply is first connected to the MCCB, and then to a contactor to distribute the 3-phase 380 VAC output. It is also connected to a transformer, which steps down the voltage to 220 VAC, feeding into the Circuit Protector and MCCB as safety components for both single-phase and three-phase systems. The 220 VAC three-phase power is routed to the Servo Amplifier, which serves as the servo motor driver. Meanwhile, the 220 VAC single-phase power is distributed to the PLC power supply, a 24VDC power supply, and other 220 VAC output components. The 24VDC power supply energizes DC-powered components of the DOH machine, such as the HMI, input devices, and output devices. Figure 3 illustrates the control system for the DOH machine's electrical components.

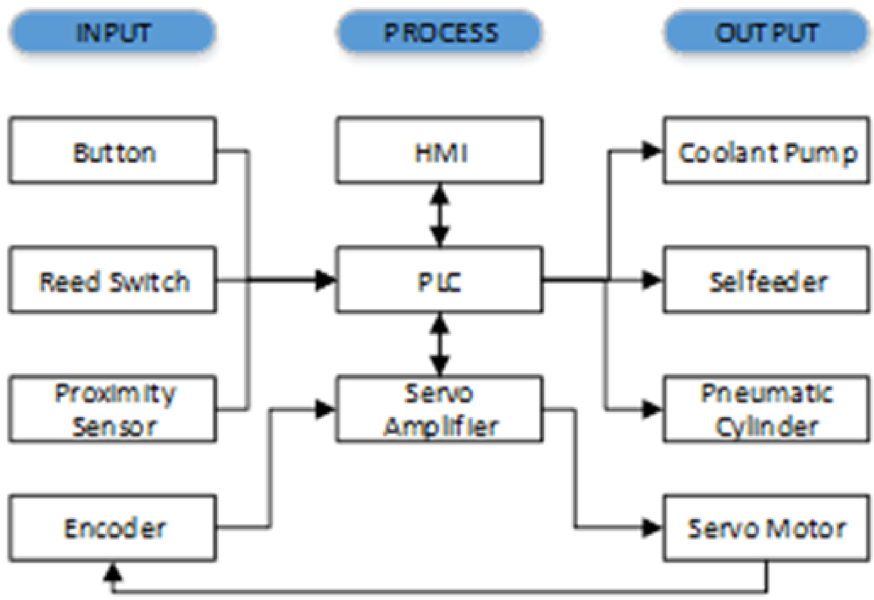

Figure 3. Design of DOH machine control system

The DOH machine is controlled using a Programmable Logic Controller (PLC). It incorporates input devices such as push buttons and sensors, as well as output devices including solenoids, indicator lights, pumps, and motors. Additionally, a Human-Machine Interface (HMI) is used to facilitate both input and output functions. The servo motor's rotation is managed by a Servo Amplifier, while an Inverter is used to control the speed of the three-phase induction motor. Table 1 presents the list of electrical components used in the DOH machine.

Table 1. List of the electrical components of the DOH machine

Components	Number
Push Button	1 pcs
Emergency Switch	1 pcs
Reed Switch	2 pcs
Proximity Switch	2 pcs
Positioning Module	1 pcs
Power Supply PLC	1 pcs
HMI	1 pcs
Servo Amplifier	1 pcs
Valve 5/2	2 pcs
Servo Motor	1 pcs
Coolant Pump	2 pcs
Input Module PLC	1 pcs
Circuit Protector	1 pcs

Output Module PLC	1 pcs
Silinder pneumatik	2 pcs
Magnetic Contactor	4 pcs
Trafo Step Down	1 pcs
Selfeeder	1 pcs
CPU PLC	1 pcs
Power Supply 24 VDC	1 pcs

Electrical wiring refers to the process of connecting one electrical component to another in order to ensure that the intended function can be fully achieved—this process is commonly referred to as wiring. Wiring design is typically divided into two categories: power wiring and control wiring. Power wiring involves connecting components solely for the purpose of supplying electrical current, whereas control wiring connects the input, process, and output lines to control system operations.

The DOH machine requires a power supply of 380VAC three-phase to operate two Selfeeder motors and two coolant motors. From this main voltage, power is stepped down to 220VAC three-phase to supply the servo driver's power input, and further reduced to 220VAC single-phase to serve as the source for the control circuits. This voltage is then fed into a power supply unit, which converts it into 24VDC. The 24VDC output is used for the control circuit of the PLC input and output modules. Figure 6 illustrates the power wiring diagram of the DOH machine.

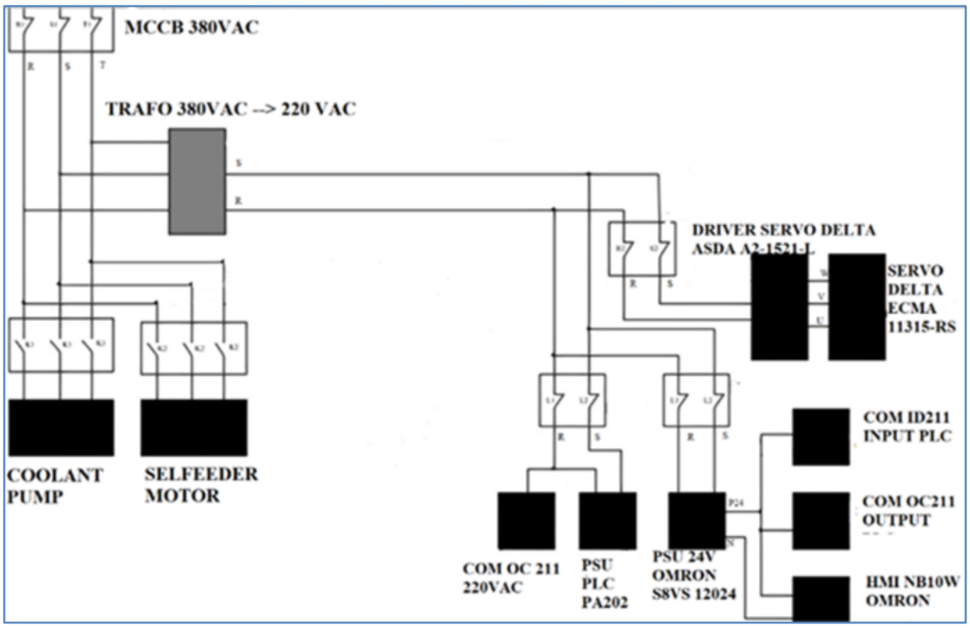

Figure 4. DOH Machine Power Circuit

The control circuit of the DOH machine utilizes a PLC-based control system, comprising two input modules and two output modules. The first input module functions as a signal receiver from the input devices, while the second input module receives input signals from the master PLC for the ABB robot via DeviceNet, intended for future integration with an ABB robot on line 35. The first output module serves as an AC voltage output module, as all outputs on the DOH machine operate on AC voltage. Meanwhile, the second output module transmits DC voltage signals to the master PLC via DeviceNet.

This pneumatic control system operates using pressurized clean air, with each movement regulated by a valve activated through an electrical system, where all movements are controlled by a PLC. Figure 5 presents the pneumatic diagram, while Table 3 provides the solenoid address data within the PLC. The control circuit of the DOH machine utilizes a PLC-based system, consisting of two input modules and two output modules. The first input module functions as a signal receiver from input devices, whereas the second input module receives input signals from the master PLC for the ABB robot via DeviceNet, in anticipation of the potential installation of an ABB robot on line 35. The first output module serves as an AC voltage output, as all outputs used in the DOH machine operate on AC voltage. The second output module functions as a signal transmitter to the master PLC via DeviceNet, utilizing DC voltage.

This pneumatic control system operates using pressurized clean air, with each movement regulated by a valve activated through an electrical system. The sequence of movements is controlled by a Programmable Logic Controller (PLC). Figure 5 presents the pneumatic diagram, while Table 2 provides the solenoid address data used in the PLC.

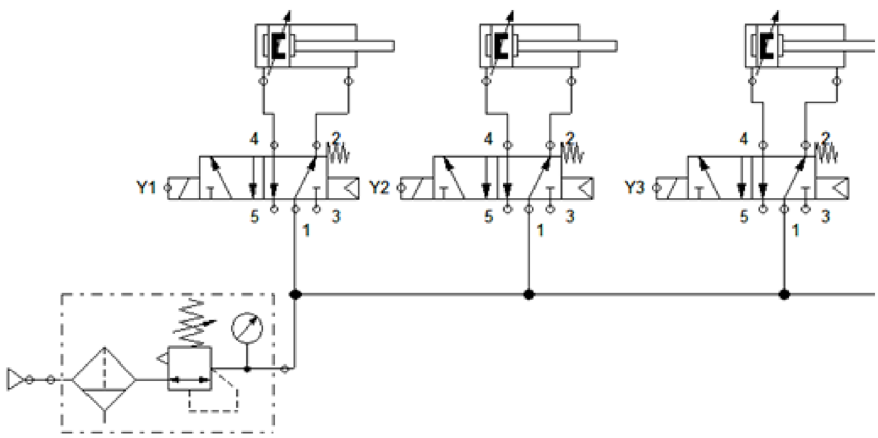

Figure 5. A pneumatic diagram

Table 2. The solenoid address data on the PLC.

Solenoid	Device	Address
Y1	Clamp	1.03
Y2	Selfeeder 1	1.04
Y3	Selfeeder 2	1.05

Wiring is the process of connecting the HMI device to the PLC. Not all input pins on the PLC are utilized, as the use of the Human Machine Interface (HMI) simplifies the wiring diagram of the oil hole drilling machine. The HMI screen is designed to facilitate machine operation and allow the operator to monitor the internal processes of the DOH machine more efficiently. The HMI includes eight main screens dedicated to operating the DOH machine. One of these is the Preparation screen, which serves to assist the operator in performing the initial setup before operating the machine. Figure 6 illustrates the display of the Preparation screen.

Figure 6. The preparation screen display

Figure 7 presents the HMI mapping of the DOH machine. The interface begins with the initial screen, known as the Preparation Screen, from which users can navigate to the Auto, Manual, Information, and Setting Value screens. When accessing the Information screen, users are given two options: the Machine Information screen and the Limit Switch Status screen. Similarly, selecting the Setting Value screen leads to two further options: the Piston Template screen and the Input Sequence screen. The Input Sequence screen itself provides two additional options, namely, the Setting Oblique Drill screen and the Setting Straight Drill screen.

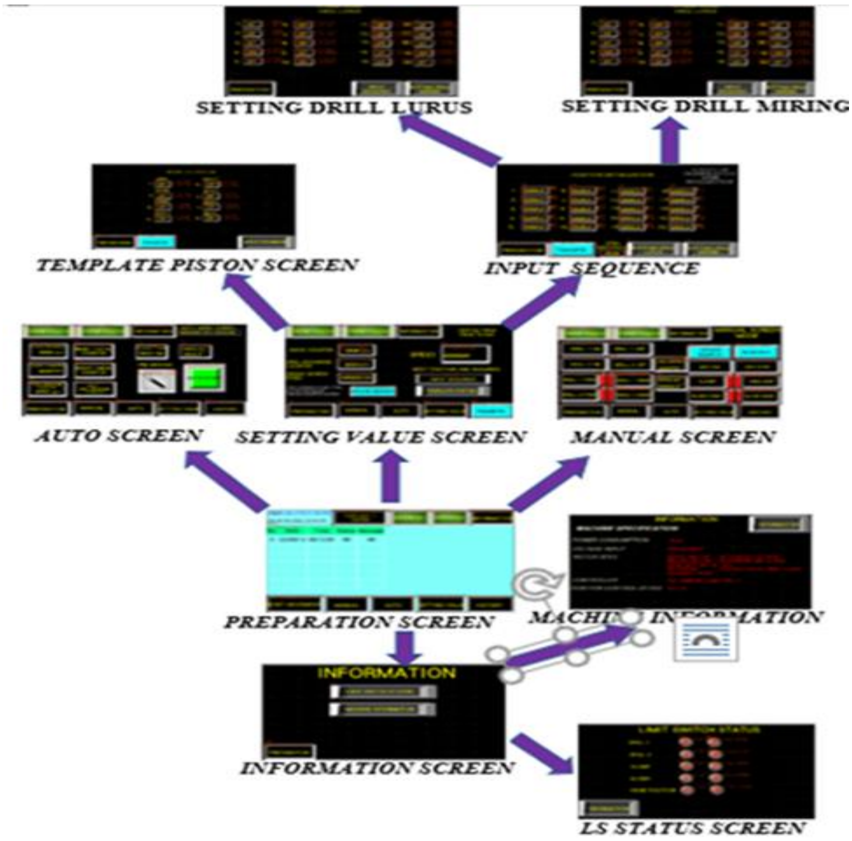

Figure 7. The HMI Mapping of DOH machine

DOH machines can operate in both manual and automatic modes. The manual mode is used during maintenance or when the machine is being adjusted to accommodate a new piston type. In this mode, input-output checks and all outputs can be manually controlled via the buttons available on the Human-Machine Interface (HMI). The automatic mode becomes active once production activities begin. Figure 8 illustrates the manual operation flowchart of the DOH machine. Based on this flowchart, it can be concluded that each output can be manually activated using the designated buttons. Additionally, certain safeguards are implemented for specific outputs to prevent undesirable incidents. For example, when the drill is activated and the solenoid is advanced, the piston or workpiece must first be in a clamped position to ensure it remains secure during the manual drilling process.

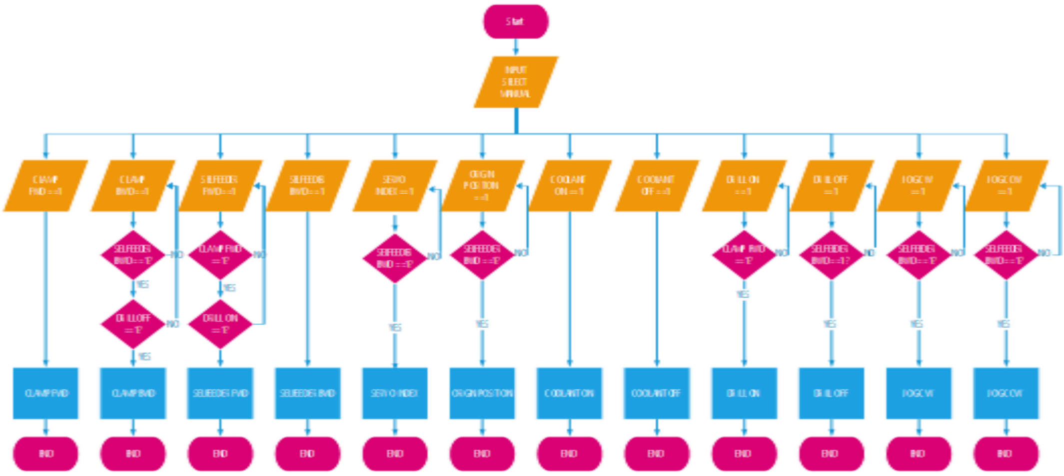

Figure 8. The manual flowchart of the DOH machine mode.

After the machine successfully operated according to the specified sequence, it was appropriate to conduct a piston product test to evaluate whether the machine was suitable for producing pistons with dimensions that meet the established work standards. In this test, the measurement method employed involved assessing the distance between specific angles on the piston. This angle measurement process was carried out in the Quality Laboratory.

Discussion

Following the testing phase, the next step was to analyze the results to determine whether the engine modifications met expectations. The outcomes of the modified machine will be described as follows. After the implementation of a new control system, the DOH machine demonstrated several advantages compared to the previous version, which used an NC control system. These advantages include:

- The system is now PLC-based, and the integration of an HMI has significantly improved usability for the Maintenance team. It facilitates model changes and even allows the Machining team to modify piston models, as piston templates are already embedded within the HMI system
- Troubleshooting time has been reduced, and the diagnostic process is more efficient due to the implementation of the PLC control system
- Additionally, the use of the NB10W-type HMI is a strategic step, as it is expected to become the master HMI for all DOH engines in the company, serving as a replacement if the currently used NS8 HMI encounters any issues.

Figure 9 (a) and (b) show the DOH machine control before and after modification.

(a) (b)

Figure 9 (a) and (b). The DOH machine control before and after modification

CONCLUSION

The modification of the DOH Engine Control System has demonstrated that the newly developed and arranged control system can be effectively applied to the production process. The control system has been upgraded from an NC-based system to a PLC CJ2M CPU-11, with the specified input and output configurations. Testing of the DOH engine was conducted in accordance with established procedures. The implementation of the Human-Machine Interface (HMI) for monitoring and operating the engine has significantly improved usability for operators and introduced several additional features, such as piston templates and sensor indicators—features not available in the previous numerical control system. The inclusion of the piston template function enables the model change team to input angle settings for all types of pistons produced on the line. This allows model changes to be executed without requiring machine downtime, reducing the previous 30-minute delay to zero. Further development of the DOH engine may include the addition of a slider system, allowing the jig position on the engine to be adjusted more flexibly.

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