Automation Control Design of An Storage Machine Based on Omron PLC System

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***Abstract* — Industrial control is usually choosing Programmable Logic Control (PLC) as a system. An automotive manufacturing company that produces pistons as the main product has always made continuous improvements in the control process. This paper discusses one of our improvement that focuses on the storage system with the PLC controller. In this system, there is currently a line that can only accommodate the storage of a box in a cycle. That is not an effective process. The leg time on operator box's replacing can be avoided by storage more than a box in a cycle. The ineffectiveness also occurs on autoloading in this storage system because there is still a problem that the piston falls into an incorrect position. The problem comes from an electric motor on the piston placement to the container box. The authors made improvements in the control system design of a storage automation machine that aims to make the automation machine accommodate three boxes in a cycle and replace the motor in the autoloader process with a servo motor technology so that the piston falls into the correct position. The application of this design has the target to increase production efficiency by 2.5% of the total piston production in the storage automation machine.**

Keywords— PLC, storage system, automation, control design

I. Introduction

In manufacturing companies, a supervisor can easily monitor the manufacturing process by the control system. Programmable Logic Control (PLC) is the system usually used. This system has better reliability than others. In addition, the performance improvement using this control system will also be much more flexible. This paper discusses the research carried out on an automation machine based on the PLC control system.

The automation machine developed here is a combined machine consisting of a CBC (Center Bosh Cutting), engrave, autoloader, and storage system. The research carried out in this project is located in the autoloader and storage box sections. The current machine can only accommodate a box/cycle in the storage process. An ineffective time because after the box loaded by piston will be a leg time to replace the box with a new one to start the next cycle.

The research also is carried out on the autoloader automation machine process. The autoloader automation machine process still uses an electric motor and relies on photoelectric sensors to place the piston into the box. The result is imprecision in the position when the process takes place frequently occurs. The effect of the imprecise positioning of the piston causes the operator to manually correct the piston position, consequently increasing the cycle time of the process itself.

The author's research is to increase storage from a box/cycle into three boxes in every cycle. Another improvement point is changing the electric motor to a servo motor so that the placing process of the piston into the box becomes precise. This paper also will explain the calculation and conversion between pulse and also rotation of the servo motor. This research target is to increase production efficiency by 2.5% of the total piston production in the automation machine.

II. State of The Art and Theoretical

A. *State of The Art*

The discussion of PLC control in storage automation systems founds in many publications. In this study, the author refers to several previous studies with the title Design of Control System for Warehouse based on PLC [1]. Control system in a warehouse where a fully automatic stacking machine consists of five parts: the drive structure, the lifting structure, the platform. Generally, the system has a similar process with storage which is accessed equipment, support brackets, and electronic control devices in warehouse systems. In addition, The Design of Automatic Material Storage Control System [2] uses Siemens PLC control as a control system for several actuators, one of which is the servo motor in the warehouse system.

In this paper, the author uses a control system with PLC Omron and will perform calculations on the design of the servo motor movement against the signaling issued by the PLC. In this paper, the research conducts for the storage and load process in an automatic target.

B. *Theoretical*

As mentioned in the previous sub-chapter, the authors in this paper use a PLC from the Omron brand as the control system. The authors use reference that all data and specifications use on data from this brand, especially the CJIM type. The author also compares the calculation results by using a servo motor configuration system. Generally, the configuration shows in the figure below.

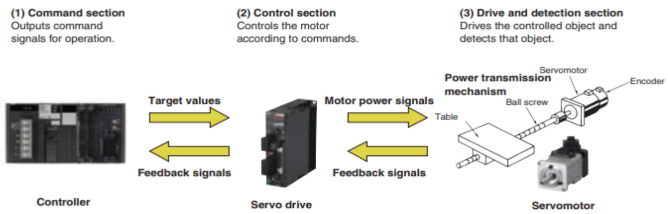


Fig. 1. Servo system configuration

AC servo motors use a closed-loop mechanism that incorporates positional feedback to control rotational or linear speed and position. Adjusting the frequency of the input voltage in a servo rotor can control the motor's speed. The encoder provides feedback in the form of position data so that the servo motor can work quickly and accurately following the instructions given.

The thing that determines the level of precision on a servo motor lies in its resolution. This resolution means the number of pulses required for the servo motor to make a full rotation or pulse per rotation. Based on motor and servo specification the movement calculation refers to:

$$\boldsymbol{X} = \frac{\mathrm{A \times B}}{\mathrm{C}} \qquad (1)$$

$\boldsymbol{X}$ = movement (in cm)

A = 131,072 Counts

B = 0.1 micrometer/Counts

C = 1 cm = 10.000 micrometer

The calculation above refers to HIWIN servo motor specification in a 17-bit incremental encoder motor servo HIWIN and the linear movement. This movement affected on a production cycle time and effectiveness.

Cycle time is the time required by the operator to complete one cycle of work, including manual and walking work. Sometimes it is defined as the time it takes to produce one unit of product. In this case, it is determined from the longest process time, whether it is human or machine work. The product discussed is a piston. Piston manufacture process in several stages from raw material processing to the final stage, namely visual checking as quality control. The discusses stage here is machining. Overall illustration stages show in the image below:

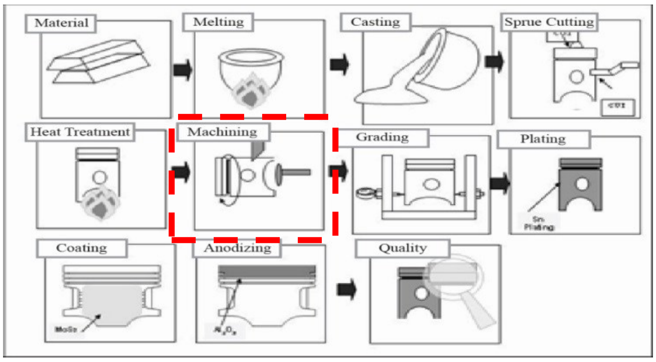


Fig. 2. Piston manufacturing illustration stages

In the machining area, there is an Automation Machine (ATM). The machine is a combination of several functions; (1). CBC, (2). Grapher, (3). Autoloader and (3). Storage machine. The ATM design for several functions are removing sprues and marking the piston type or shift number. In this discussion paper, the author will discuss the ATM in the autoloader and storage system function. The ATM illustration show in the image below.

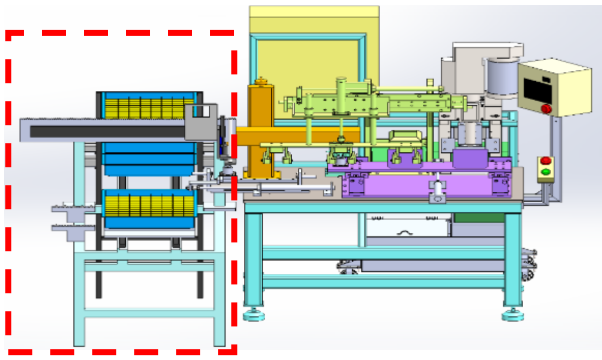


Fig. 3. ATM illustration parts

The autoloader and the storage system obtain cycle time in the use of manual processes. The manual process means an operator activity happens. The cycle time data shows in the following table:

TABLE I. CYCLE TIME CALCULATION RESULT

No	Operator Activities	Time (s)			Average Time (s)	Information
		1	2	3		
1	Box replacement	27	25	23	25	Storage
2	Corrects improper piston position	28	30	32	30	Autoloader
Total cycle time the storage and autoloader processes before improvement					***55***	

III. EXPERIMENT

These factory-applied experiments divide into mechanical, electrical, and control designs. In this paper, the authors will discuss more the electrical and control part will allude to a little about the general description of the mechanical design of the automatic storage machine.

A. Mecanical Design

The first improvement in storage machine design with a mechanical system increase the number of box/cycle storage. The second improvement is in the autoloader system, an electric motor replace with an adjusted servo motor that sets and eliminates proximity sensor use. The picture below is a machine design that the authors make.

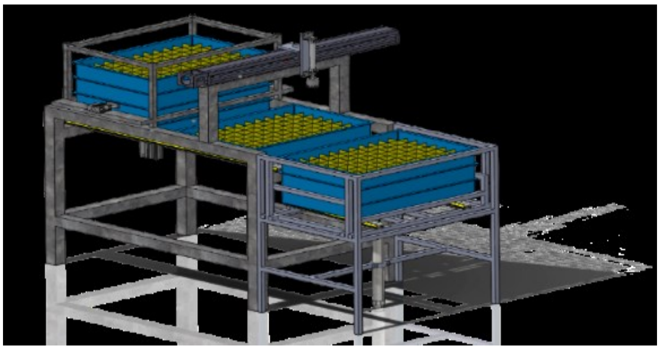


Fig. 4. storage automation machine design for three box/cycle

This project storage automation machine has manual and automatic process workflows. The workflow covers every step begins from selecting the mode on the Human Machine Interface (HMI). It happens until the box fill with pistons into the storage box.

B. Electrical Wiring Diagram

Storage machine control system with automation work divides into many circuit parts. They are a power circuit, PLC, a servo driver, PLC I/O module, and a pneumatic circuit. In this paper, the detailed discussion is on the power supply circuit, PLC, and servo driver.

The first discussion is about power circuit. The storage automation machine requires a power voltage of 220 VAC three-phase, but the source voltage owned by the factory is 380 VAC 3 phase. Therefore, the voltage must be lowered through a step-down transformer into a three-phase 220 VAC voltage. The 220 VAC three-phase voltage use for servo driver input, 24 VDC power supply input, servo motor, and several other components that require a 220 VAC voltage source. The figure below shows the power circuit.

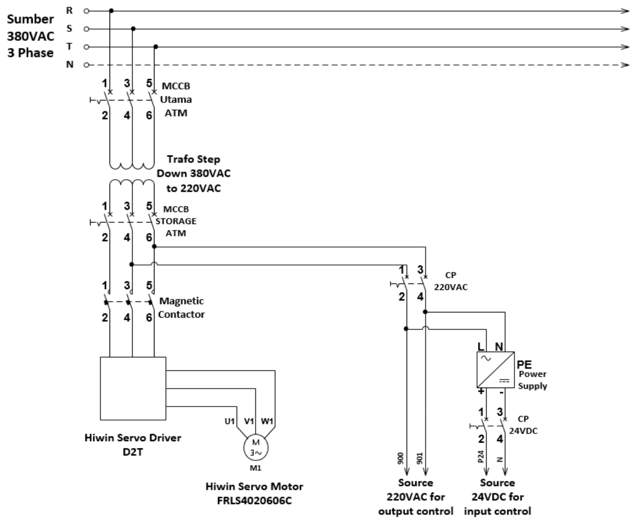


Fig. 5. Power circuit

The second is about PLC circuit. In the storage automation machine, the PLC input module uses CJ1W-ID211 which consists of a unit module. A unit input module includes input components such as a reed switch on the output solenoid, proximity sensor, and spare. The controller used in the storage automation machine is a PLC CJ1M CPU 21. The controller requires 220 VAC voltage of 220 VAC from the transformer conversion voltage. Figure below show detail connection on the circuit.

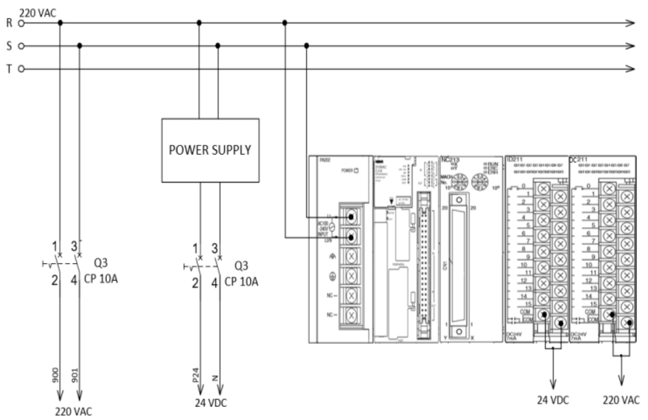


Fig. 6. PLC circuit

This third sub-chapter discusses electrical wiring on the Hiwin D2T0423SB4 servo driver with the host controller CJ1W PCU NC213. The servo driver circuit with the host controller drives the servo motor with the following working principle. The servo motor is drive with a pulse signal set from the PLC program, but the servo motor cannot directly communicate with the PLC, need an intermediary. The intermediary servo driver and a host controller trigger by some pulse signal set from the PLC program through the host controller and sent into the servo driver. Figure Hiwin D2T0423SB4 Servo Driver Configuration below show the configuration.

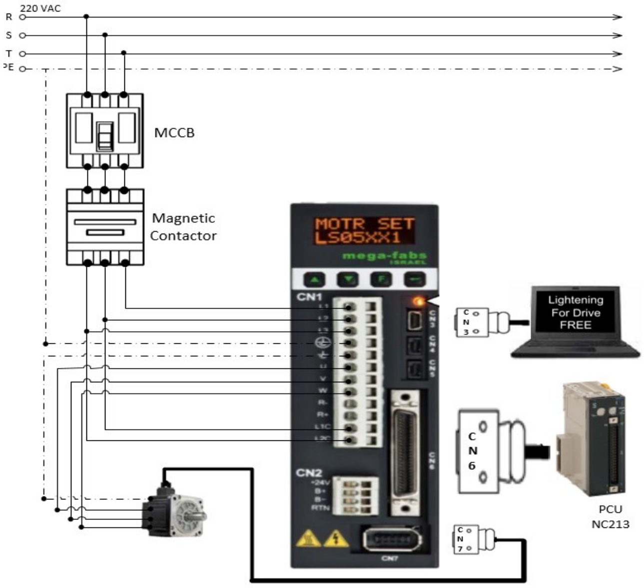


Fig. 7. Hiwin D2T0423SB4 Servo Driver Configuration

The servo driver instructs the servo motor to move according to the pulse signal received from the host controller. When the servo motor moves, the encoder sends a digital signal to the servo driver continuously to make corrections when there are deviations. Figure 3.34 shows the HIWIN D2T0423SB4 servo driver configuration.

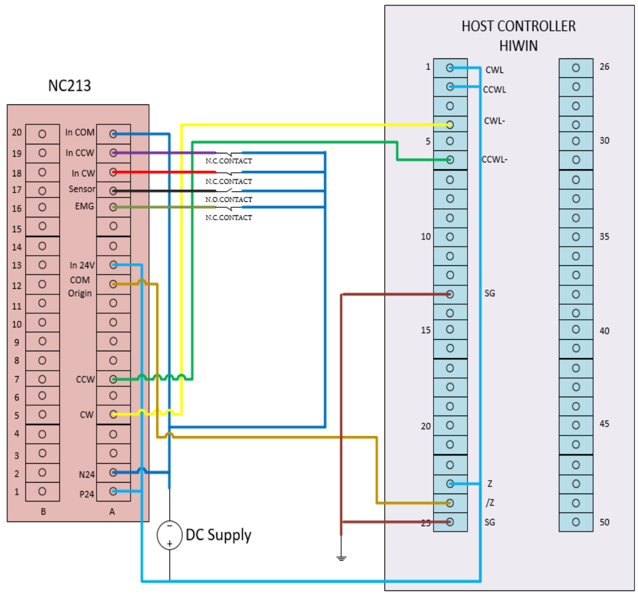


Fig. 8. Hiwin D2T0423SB4 servo driver pin connection with host controller pin CJ1W PCU NC213

In the storage machine, the servo motor control by the CJ1W PCU NC213 host controller. The host controller determines servo motor movement. The movement control consists of the direction of rotation, position target due to reach the desired speed. This NC213 PCU host controller has its characteristics addressing that define in the datasheet. This host needs to set the address as follows: (a). Area address; m = D20000 + 100 x unit number; (b). I/O relay area; n = CIO 2000 + 10 x unit number. (c). Operation memory area and (d). Operation data area.

Control of direction and position on the storage automation machine project using the CJ1W PCU NC213 host controller. In a direction controller, it is necessary to set several parameters and input. The positive input value will direct into Clock Wise (CW) and the negative input value for Counter Clock Wise (CCW) in the position area of the data operation.

C. *HMI and PLC Programming*

The display of the HMI storage automation machine makes to fulfill the needs. The program for the example manual push-button, auto start push-button, manual reset push-button, proximity sensor as input and solenoid, servo motor for X-axis and Y-axis as output, with a description of the 5x5 box as the output of the filled piston. The figure below shows the HMI storage automation machine display.

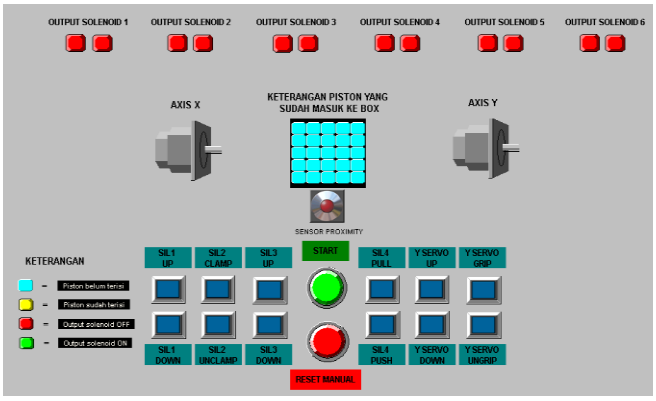
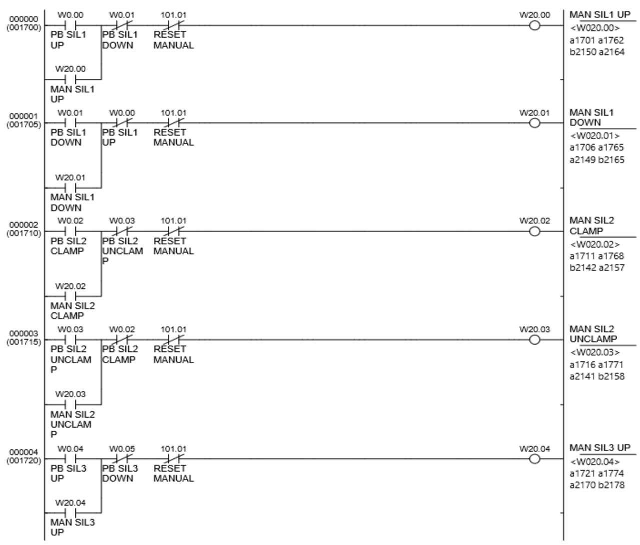


Fig. 9. HMI storage automation machine display

The storage automation machine program consists of two main programs. Both are manual programs and automatic programs. The manual program has a role as an initial setting for the engine condition before the main program is running. The initial position sample setas the first cylinder must be in the down position, second cylinder two must be in the clamp box position, and so on. While the auto program functions to execute the workflow of the storage automation machine automatically. The author uses CX-Programmer software to make the ladder diagram. The figure below shows a snippet of the program manually and the automatic program.



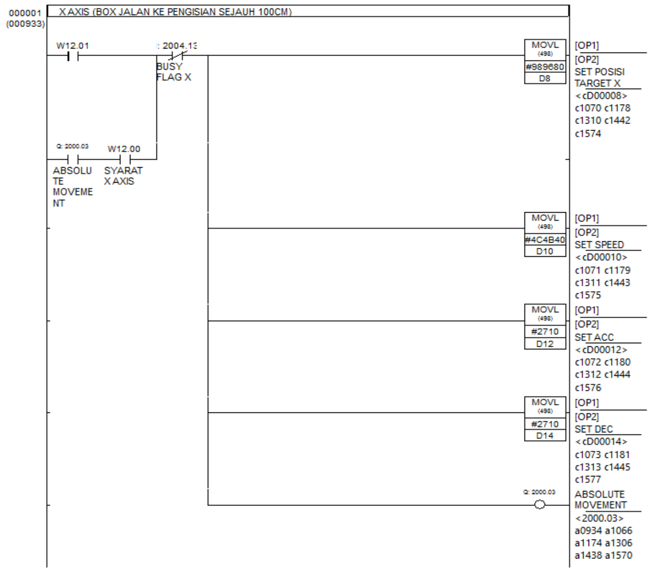


Fig. 10. Manual and aoutomatic ladder diagram programming snippet

IV. Result and Discussion

This PLC program simulation is carried out using a "work online simulator" on the CX-Programmer software and connected to the CX-Designer software. This use to see the process workflow of the PLC program. This method checks whether the PLC program creates before has the same as the process workflow of the storage automation machine. The PLC program simulates in two stages they are manual program simulation and the auto program.

A. *X and Y Axis Movement Analysis*

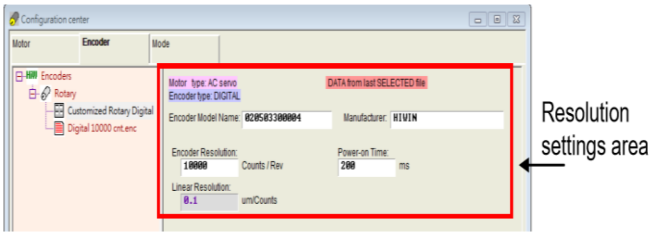


Fig. 11. Linear value HIWIN motor

The X-axis can be calculate and compare with the value at the figure above. The linear value of the HIWIN servo motor is based on the equation to find the movement of the servo motor for one revolution. Based on equation (1), the calculation of the X-axis movement can be calculated by.

$$X = \frac{\text{A x B}}{\text{C}}$$

$$X = \frac{131.072 \text{ x } 0,1}{10.000}$$

$$X = 1,31072 \text{ cm} \sim 1,31 \text{ cm}$$

The storage automation machine project uses "I" (beginning word of operating data) "0" because the value of I used is 0 then to adjust the position of the X-axis is D8 memory data, D10 speed, D12 acceleration, and D14 deceleration. Furthermore, if you already know the memory data used to control the X-axis, the next step is to fill in the value of each data operation. The data value of the operation using the hexadecimal data type. For example, to fill in the pulse target position as far as 100cm requires the number of counts as much as 10,000,000, then to fill that value in the D8 memory data must first convert it to a hexadecimal value to "#989680".

The Y-axis movement data infer from the CJ1W PCU NC213 datasheet. In the example, charging pulses for a target position of 50cm CW requires a total of 5,000,000 counts. So to fill in the value in the D20 memory data, you must first convert it to a hexadecimal value to #4C4B40. Meanwhile, a pulse for the target position 50cm CCW in Y-axis counts use is 5,000,000 but in the form of (-). So to fill this value in the D20 memory, the hexadecimal value used to target the 50cm CCW position is "#B3B4C".

B. Cycle time and Machine Effectivness

Total cycle time (CT) have the storage and autoloader processes before improvement is 55 minutes. This value mention before.

Number of production boxes per day = 28 boxes (3 boxes / shift). Machine capacity becomes 3 boxes so that it can reduce 9 cycle boxes / shift to 3 cycle boxes / shift and use servo motors so that the pistons are in a standard position of placement)

Box change time	= 25 seconds/cycle box
Piston justification time	= 0 seconds
Amount per day	= 25 seconds/cycle box x 3 cycle box/shift
	= 75 seconds/shift
	= 225 seconds/day

Based on production data on the automation machine in one month, the number of pistons produced is 30,800 pcs, so in one day 1400 pcs can be produced in 22 working days. The calculation of the time saved can be seen as follows:

- Production time savings:

  t = CT before – CT after

  t = 1,540 seconds/day – 225 seconds/day

  t = 1.315 seconds

After getting the time saved, then calculate the number of additional products that can be produced. The calculation is as follows:

- In a day

  X=(Time saved)/(1 piston cycle time)

  X=(1.315 seconds)/(36 seconds)

  X=36pcs/day

- Improved efficiency

$$Eff = \frac{\text{Peningkatan produksi piston per hari}}{\text{Produksi piston per hari}} \text{ x } 100\%$$

Eff = (36 pcs)/ (1400 pcs) x 100%

$\boldsymbol{Eff}$ **= 2.5%.**

V. CONCLUSION

Base on the result of automation control design, the authors obtain the following conclusions:

- An effective operator performance increase in a significant number. These show by a three-time replacement of the piston box now only one step needed.
- The design of this control system targeted to increase production efficiency by 2.5% of the total piston production in the automation machine. This technology can eliminate some operator activities example correcting the position of the piston.
- The design of the control system for the storage automation machine project is to calculate conversion motor rotation and pulse needed.

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