PERFORMANCE ASSESSMENT OF CONVEYOR OVEN SYSTEM ON PROPORTIONAL INTEGRAL DERIVATIVE AND PROGRAMMABLE LOGIC CONTROLLER BASE FUZZY LOGIC CONTROLLER

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A project report submitted in partial fulfillment of the requirements for the award of Master of Engineering (Electrical)

Faculty of Engineering and Science

UNIVERSITI TUNKU ABDUL RAHMAN

DECEMBER 2022

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"PERFORMANCE ASSESSMENT OF CONVEYOR OVEN SYSTEM ON PROPORTIONAL INTEGRAL DERIVATIVE AND PROGRAMMABLE LOGIC CONTROLLER BASE FUZZY LOGIC CONTROLLER"** was prepared by **YEOH KOK WEI** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Engineering (Electrical) at Universiti Tunku Abdul Rahman.

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ABSTRACT

In the industrial conveyor oven system, temperature stability and uniformity are important factors that need to be precisely controlled by temperature controller. Therefore, an existing industrial conveyor oven system for springs manufacturing industry is selected to perform the assessment of the temperature controlled by PID temperature controller and fuzzy logic system. In this project, real time temperature data of various type of springs that undergone heat treatment process at the oven is collected for analysis. The control of the oven is initially by PID temperature controller and then replaced with MATLAB simulink fuzzy logic model with PLC, the outcome of both system is analyze based on the temperature stability according to temperature setpoint defined by operator. Other than that, it is involved analyzing the heater current consumption, electro-mechanical contactor internal structure, and solid-state relay performance. All the collective data is analyzed, and modification is made based on the result outcome. In addition, the test run result of using matlab simulink fuzzy logic and PID temperature controller to control the oven temperature, it is found out that different temperature setpoint and different temperature monitoring location require different range of duty cycle for the solid-state relay operation as to maintain the temperature in the oven chamber accordingly to setpoint. Result of this study shows that PID temperature controller for the oven system control can maintain the oven temperature accordingly to different setpoint and no additional hardware is required.

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SSR	Solid State Relay
PLC	Programmable Logic Controller
PID	Proportional Integral Derivative
RTU	Remote Terminal Unit
RS	Recommended Standard

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1. INTRODUCTION

1.1 Background study

In the manufacturing industry, oven system is one of the machineries that is widely used for heating process for the purposes of drying, curing, annealing, stress relieving, tempering, bonding, preheating, and forming. As such, semi-finished goods such as metal, chemical, pharmaceuticals, and food may require to undergone heating process to become finished goods. In the oven system, heater element is one of the main components of oven system that able to generate heat source by applying voltage to the element coil, and then transferred to the products. There are several types of ovens in the industry such as drying oven, baking oven, conveyer oven, curing oven, batch oven etc. In this project industrial conveyor oven is selected. This machine is use in spring manufacturing industry for the heat treatment process for various type of spring products.

The spring products are placed on the rotating conveyor belt and move through heated chamber at constant speed. Temperature sensor installed in the heated chamber to provide measurement and feedback signal to temperature controller for the temperature control based on desire temperature setpoint. The temperature controller is using PID closed loop control system that react to the changes of temperature inside the chamber with respect to temperature setpoint. As the products travelling into the chamber, temperature inside chamber will be reduce due to heat being absorb by the products, and therefore temperature controller will react to issue an electrical signal to contactors for closing the contact and energize the heaters to heat up the chamber accordingly to temperature setpoint.

1.2 Problem statement

In the heat treatment process, oven system is to heat-up various type and size of spring. However, it is experiencing inconsistency temperature rise time and fluctuation inside the chamber of the oven for different type and size of springs. Therefore, the purpose of this research is to analyze the problem, and to compare the performance of PID temperature controller with fuzzy logic controller to improve the temperature stability inside the oven.

1.3 Objectives of the project

The objectives of this research are as listed.

1) Analyze the heater system of the existing industrial conveyor oven.
2) Collect temperature performance for various size of springs for analysis
3) Compare the temperature performance of PID temperature controller and fuzzy logic system in term of temperature stability.

2. LITERATURE REVIEW

2.1 Industrial conveyor oven system

There are many types of oven system in the market. Conveyor oven system is one of the types that move products through a heated chamber at a constant speed, and the temperatures inside chamber are set and maintained according to desire setpoint. Method of controlling the temperature has become more tedious when the ovens need to deal with different sizes and dimensions of products to be heated, as nonlinearities of product causes temperature fluctuation inside the chamber, in which the temperature controller react to control electrical signal apply to element coil.

Conventionally, temperature monitoring and controlling are implemented by temperature controller that receive feedback signal from temperature sensor, and then output a signal to heat-up the heaters when temperature inside the chamber is lower than setpoint. On the other hand, the signal is cutoff when temperature inside the chamber is higher than setpoint. As time goes on, the innovation of control technology can be classified into simple ON/OFF control, automated closed loop feedback control Proportional Integral Derivative (PID) controller, and intelligent control system controller that adapting flexible decision control method in achieving desired setpoint.
ON/OFF system are usually use in a simple control in which the control output signal is either turn ON when measured temperature lower from setpoint or turn

OFF when measured temperature near to, equal to or higher than setpoint. On the other hand, as for the PID control method that the control output is a linear combination of the error signal, its integral and derivative thus providing precise control. Moving toward more advancement, intelligent control that capable of applying human mind abilities in decisions making and provide the desire output. One of the mostly uses of intelligent control methods is fuzzy logic that convert linguistic control strategy based on expert knowledge into an automatic control strategy (Anil Kuma r .K, et al., 2014).

There are several techniques presented and discussed in the papers related to the temperature control system in various application of ovens and furnace system. Traditional PID control is a fixed parameter control, and it is hard to achieve the control of both stability and quality (XiaoHong, et al., 2017). In addition, there are some papers studies of using fuzzy control, fuzzy PID control and grey PID control and other intelligent algorithms to optimize the industrial furnace control with the achievement of good result (XiaoHong, et al., 2017).

In the paper presented by Md. Tauhidul Islam & Md. Saiful Islam, (2021) that self-turning fuzzy PID controller for controlling temperature system for furnace has a small amount of overshoot with better dynamic performance having low rise time than conventional PID. On the other hand, there is a studied about the temperature control by using two-layer cascade control based on Predictive Functional Control (PFC), and Fuzzy Logic Controller (FLC) in the industrial furnace system presented by XiaoHong, et al., (2017). Another approach studied by D. Pamela & M. S. Godwin Premi, (2017), adapting fuzzy PID controller and adaptive smith predictor in the oven for the temperature control.

Although there are much more different approach being studied and presented related to tempearature control in the industrial ovens and furnace system. The widely use Programmable Logic Controller (PLC) in the automation industry has not much being studied in the area of industrial conveyor ovens system temperature control with fuzzy logic.

2.2 Programmable logic controller

In modern world of the automation in the industry, Programmable Logic Controller (PLC) are widely use in various industry. The technology continues to grow in the applications, and complexity in the various industrial automation. The evolution of PLCs has made the system capable to handle higher memory, flexibility of programming, higher processing speed, more scalability and compact in size. In the manufacturing industry, machineries are mostly installed with PLC system for the monitoring and controlling based on operation requirement that the programmable controller with memory for storing instructions/program to carry out specific functions, such as logic, sequencing, timing, counting, and arithmetic to control machines and processes. Typically, PLC consists of processor, memory, power supply module, input/output module and human machine interface.

The flexibility of PLC system has made it applicable in many industries such as power plants, oil and gas, food, building etc. Various configuration of the input and output of PLC is feasible by adding modular type of device input/output such as digital input, digital output, analog input, analog output, resistance temperature detector input, etc. Other than input and output, there are various communication module is available to cater for different type of communication protocol such as modbus protocol, ethernet and so on. Hence, due to its flexibility for mix and match with variety of modular hardware to be selected based on the machine application, PLC has gain popularity in the industries.

Software programming in the PLC also serving an important role is the controlling and monitoring as programed by programmers, engineers, or technicians. It defines how, what, and when for the PLC system functionality based on the machine control philosophy.

There are several types of programming languages available in PLC which are ladder logic diagram, structured text, instruction list, function block diagram and sequential function chart. However, ladder logic diagram is mostly use for the programming, as it allows low-cost introduction for students, and therefore they are familiar with ladder logic (DeGuglielmo, N.P., et al., 2020).

In the previous studied conducted by Snejana, et al., (2020), they have implemented Fuzzy Logic Controller (FLC) using a low-cost general purpose industry programmable logic controller (PLC) in the level control of soda production. Hence, it has shown that the implementation of fuzzy logic controller using PLC is realistic and the application can be extended for temperature control in the industrial conveyor ovens system for further study.

2.3 Fuzzy logic

Fuzzy logic theory was first introduced by Lofti A.Zadeh in 1965. It mentioned that human thought is not able to be demonstrated with classical logic of (0,1) and found out that human thoughts have a fuzzy structure. It is mostly applicable in artificial intelligence application systems and process systems. The use of fuzzy logic in the process control application offers a fast decision capability, applicability to nonlinear systems, and intuitive definition of the controller behavior (Isaías González Pérez, et al., 2014). The use of fuzzy logic does not need complex mathematical model, it is using symbolic expressions. The theory of fuzzy logic enables the controllers to have the ability of processing data and work from people's knowledge and experiences. Expert-based control algorithms converted from linguistic expression by fuzzy logic control, hence it provides flexibility in the design of control system that complex system can be perform better than conventional methods (Melih Coban & Murat Fidan, 2019).

In the fuzzy logic controller, it is using fuzzy interference system that refers to the scheme which formulates the mapping of a given crisp input to a crisp output. There are two types of fuzzy interference, mamdani type and takagi-sugeno type (Anil Kuma r .K, et al., 2014). There are four processes involve in the fuzzy interference: 1) fuzzification, 2) rule ,3) decision making and 4) defuzzification. In the process of fuzzification, control data input from sensor is converted into linguistic expressions. Adapting the membership functions, the data then assign to fuzzy sets that it belongs, and then creating membership values. There are three curves of the fuzzy sets namely triangles, trapezoid, and bell available for selection. The rule is to define the linguistic expression, and then the decision-making process that handle fizzy concepts and making decision for the desire control output value.

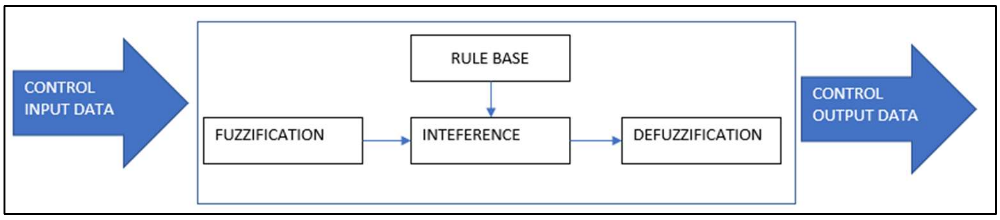


Figure 2.1: Overview of fuzzy logic process

Even though, there are theoretical development, it is reported that fuzzy logic controller industrial application is only few (Snejana, et al., 2020). In the application of temperature control, fuzzy logic is further incorporated with self-turning PID controller for in the furnace system (Md. Tauhidul Islam & Md. Saiful Islam, 2021). On the other hand, there was a study about the temperature control by using fuzzy logic implemented in labview software by S.Kavitha, et al., (2012) was done. Hence, fuzzy logic can be integrated into different software system.

2.4 Contactor

Electro-mechanical contactor is commonly used as a switch in the electrical circuit for control system. Contactor consists of two iron core which is movable part and lower part, these two parts will be closed by applying voltage to main coil, and moveable part iron moves toward the mail coil, thus pulling down the moving plate. The electrical circuit that connects to the main contacts at both ends would be connected and current flows through the moving plate. The main contact is opened by turning of the supply voltage to main coil, causing the coil to de-energize and then the movable part iron is pushed up by the energy store in the compression spring, hence breaking the contact.

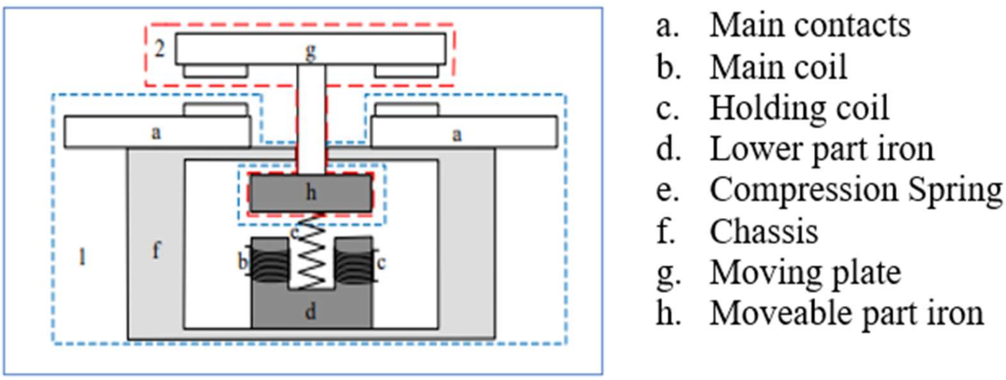


Figure 2.2: Overview of internal structure of electro-mechanical contactor [Source: *(J.-P. Martin, et al., 2017)*]

Contactor involves in the on and off operation would lead to the issue of durability, as frequent operation of turning on and off the contactors will have high tendency mechanical part degradation. Electro-mechanical contactor install in the conventional oven system for the temperature control are facing frequent on and off operation to maintain the temperature in the oven accordingly to setpoint. The contactors that connected to alternating current and heaters, for the control of supplying voltage to heaters. The electrical control system turns on the contactor when temperature in the oven is lower than setpoint, on the other hand the contactor turns off when temperature is near to or equal to setpoint.

The moving plate and main contacts are the main part that conducts load current and need to withstand high-temperature due to arcing phenomenon during off operation (Zheng, et al., 2018). Over a period of times, as the contactor constantly having electrical stress on the contact which lead to arc erosion on the contact and eventually causes contactor to breakdown (Li, et al., 2020). Hence, it is necessary to conduct an evaluation on the contactors that installed in the conveyor oven system that are experiencing temperature fluctuation in the chamber during operation.

3. METHODOLOGY

3.1 Introduction

In this project, existing conveyor oven system is selected for the performance study of the temperature controller by using conventional PID controller and fuzzy logic algorithm. The existing oven system is installed with contactors that controlled by temperature controllers that controlled based on the PID setting and temperature setpoint input by operators.

Refer to Figure 3.1, products are loaded into inlet of the oven, and moved through the heated chamber that controlled by inlet and outlet temperature controller. Once the products reach at the outlet section, it will be dropped onto the wooden box.

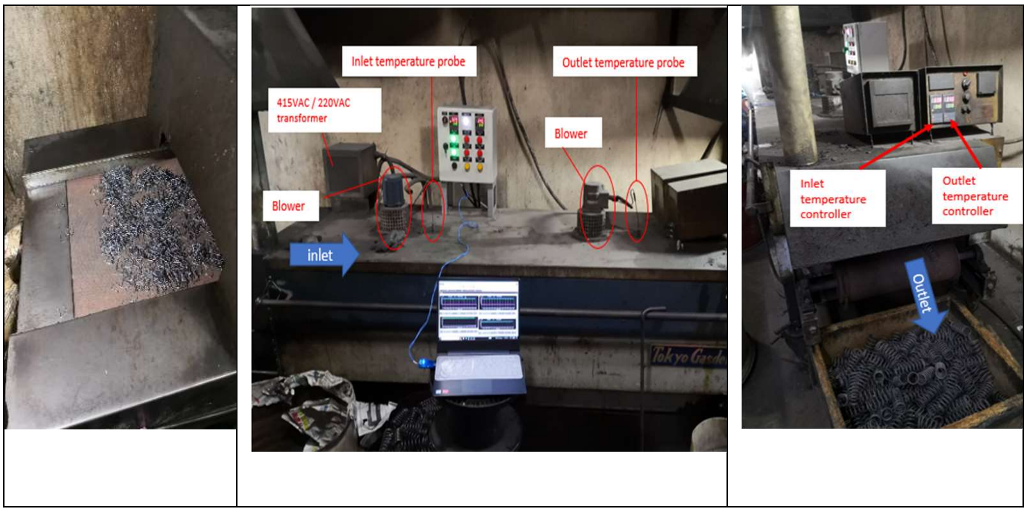


Figure 3.1: Photos of conveyor oven

Temperature inside the oven chamber is controlled by temperature controllers that controlling the on off operation of the contactors that supply voltage to heaters. Each of the heater has the same specification, which is 115V, 750W. Hence, from the calculation to obtain the resistance ohm value for each heater.

Heater resistance value calculation:

$P = V^2 / R$

$R = (115)^2 / 750$

$R = 17.6$ ohm

It has 12 units of tubular heaters installed at the inlet and outlet section respectively. The overview diagram of conveyor oven system is shown in Figure 3.2.

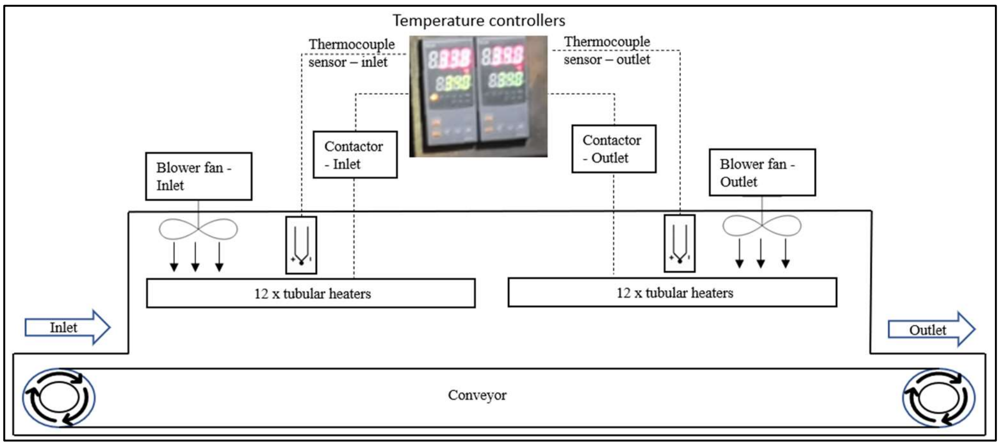


Figure 3.2: Overview diagram of conveyor oven system

The availability of springs product for heat treatment is based on the customer's order, it consists of various type and dimension of springs. The study process is started by loading batches of springs into conveyor oven system, and real time temperature data is recorded, this process is repeated done over for few months with other type of springs that is available.

After that the contactors would be replaced by solid-state relays, and it would be controlled by using matlab simulink fuzzy logic model instead of PID temperature controller. Based on the availability, same specification of various spring that was used during the previous data collection, it is loaded onto the oven, and data collected for comparison of the performance of PID temperature controller with fuzzy logic controller. Refer to Figure 3.3 for the overall flowchart of this project.

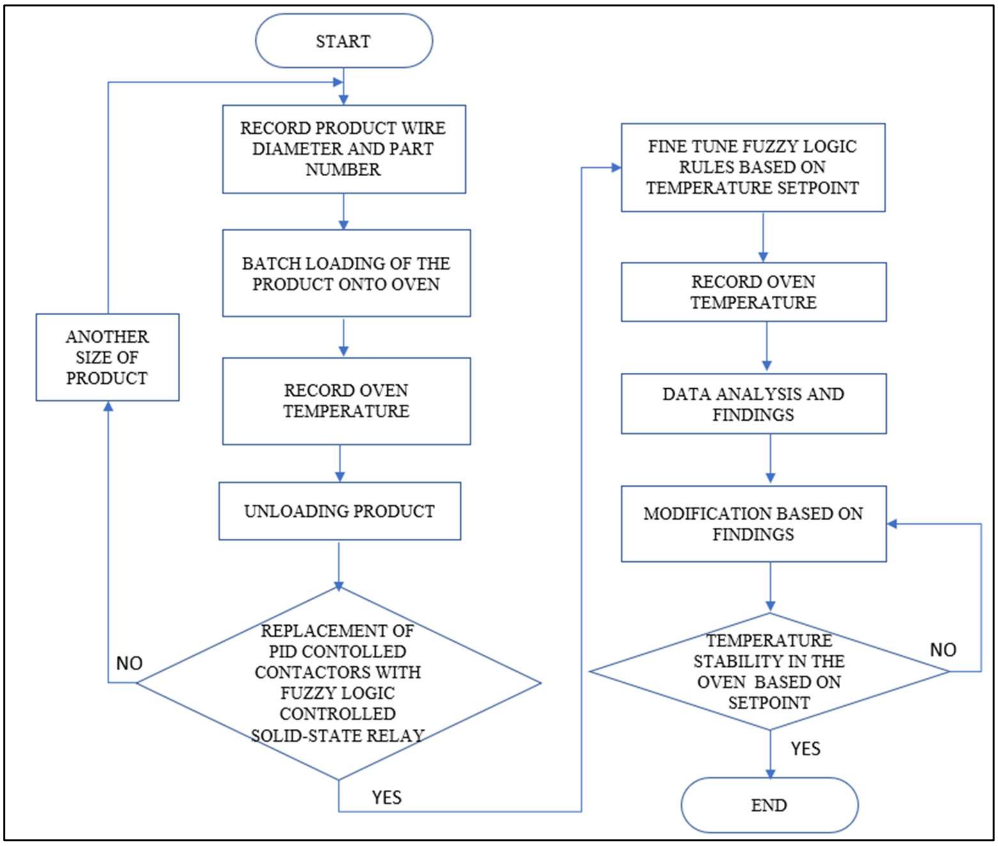


Figure 3.3: Overall flowchart

3.2 Data acquisition software

Temperature responds of the products are recorded using autonics DAQmaster software for the PID temperature controllers. Once the system is replaced with matlab simulink fuzzy logic model, the data is recorded using matlab data logger. In Figure 3.4 shown the overview of data acquisition by using autonics DAQmaster software.

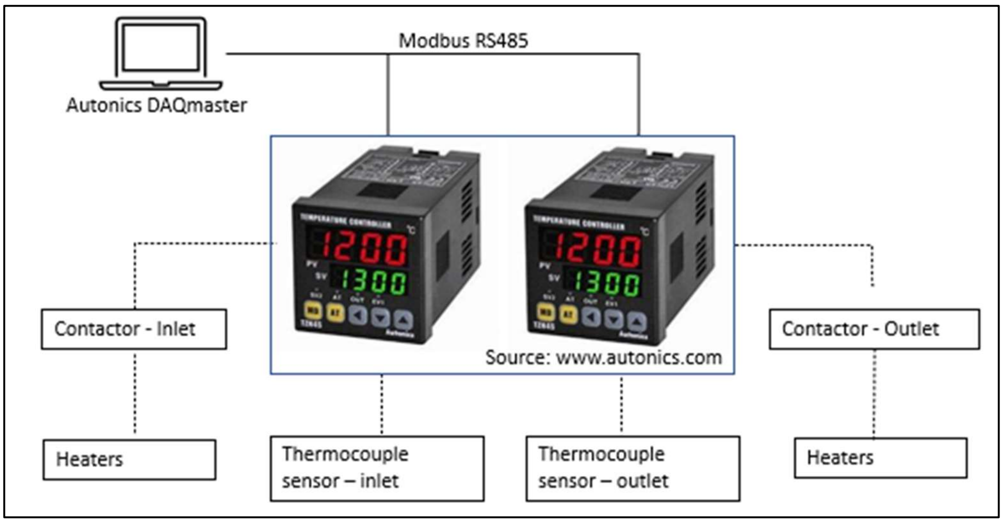


Figure 3.4: Overview of data acquisition using autonics DAQmaster software

3.3 System configuration

Micro programmable logic controller (PLC) OMRON model CP2E-S30DT-D is selected and installed inside panel as shown in Figure 3.5. This PLC consists of build-in one RS-485 port and one RS-232 port. The recommended standard (RS) 485 port is programmed as modbus remote terminal unit (RTU) master that pulled data from the temperature controllers. On the other hand, the RS-232 port is programmed as modbus RTU slave, that allow matlab software that programmed with fuzzy logic algorithm to read and write data from PLC as shown in Figure 3.6. The temperature controllers that connected with temperature sensor provide temperature data to PLC, and then matlab simulink model will read the temperatures process variable (PV) and temperature setpoint from the memory registers of PLC.

Figure 3.5: Programmable logic controller panel

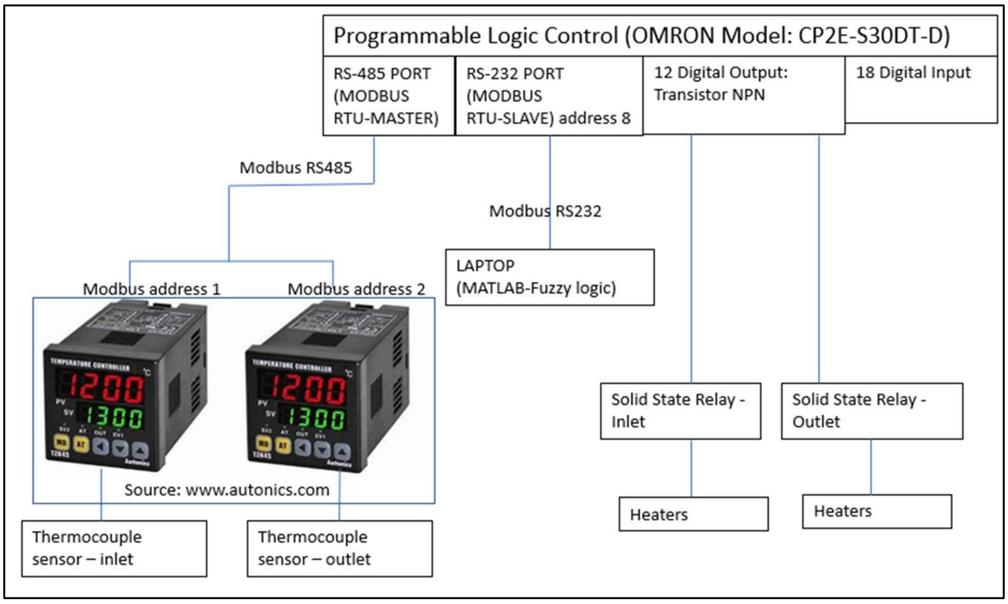


Figure 3.6: Overview of system configuration

Matlab simulink model as shown in Figure 3.7, the modbus read function block continuously read data from PLC, and feed into fuzzy contoller block for calculation. The calculated result output from fuzzy logic controller is then transfer to modbus write function block to write onto the memory register of PLC for the solid-state relay control.

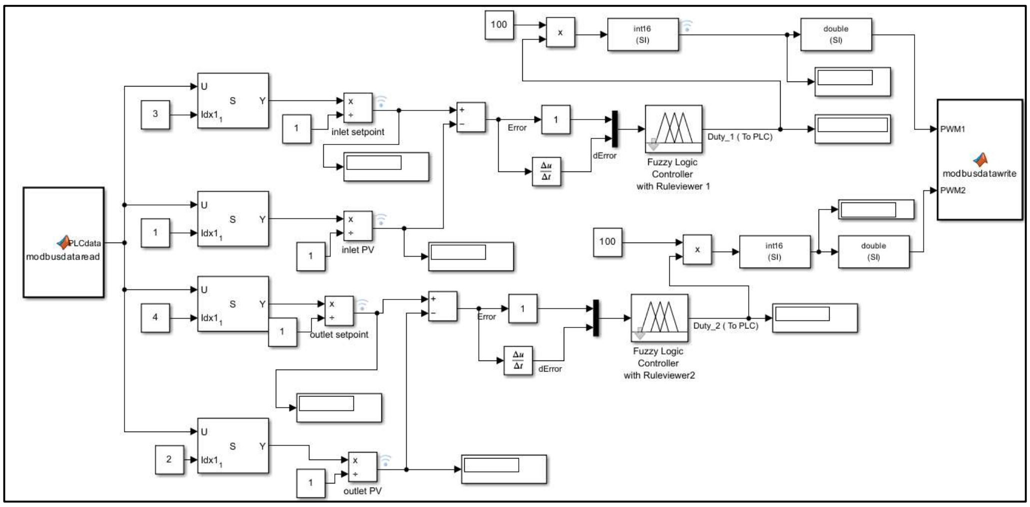


Figure 3.7: Matlab Simulink model

3.4 Data analysis approach

Comparison in term of the performance of the temperature performance with contactor PID temperature controller on/off control and solid-state relay fuzzy logic control is conducted by data collection, data tabulation in the table, and temperatures performance respond graph is plotted to study the temperature trend pattern.

4. RESULT AND DISCUSSION

The specification of the heaters installed in the oven is reflected into matlab simulink model for simulation and obtain the currents consumption and total resistance for each phase.

There are inlet and outlet section in the oven chamber. Each of the section is installed with 12 units of heater connected to three phase power supply. In each phase consists of 4 heaters connected in star connection. Refer to Figure 4.1 for the matlab simulink model arrange for the oven heaters.

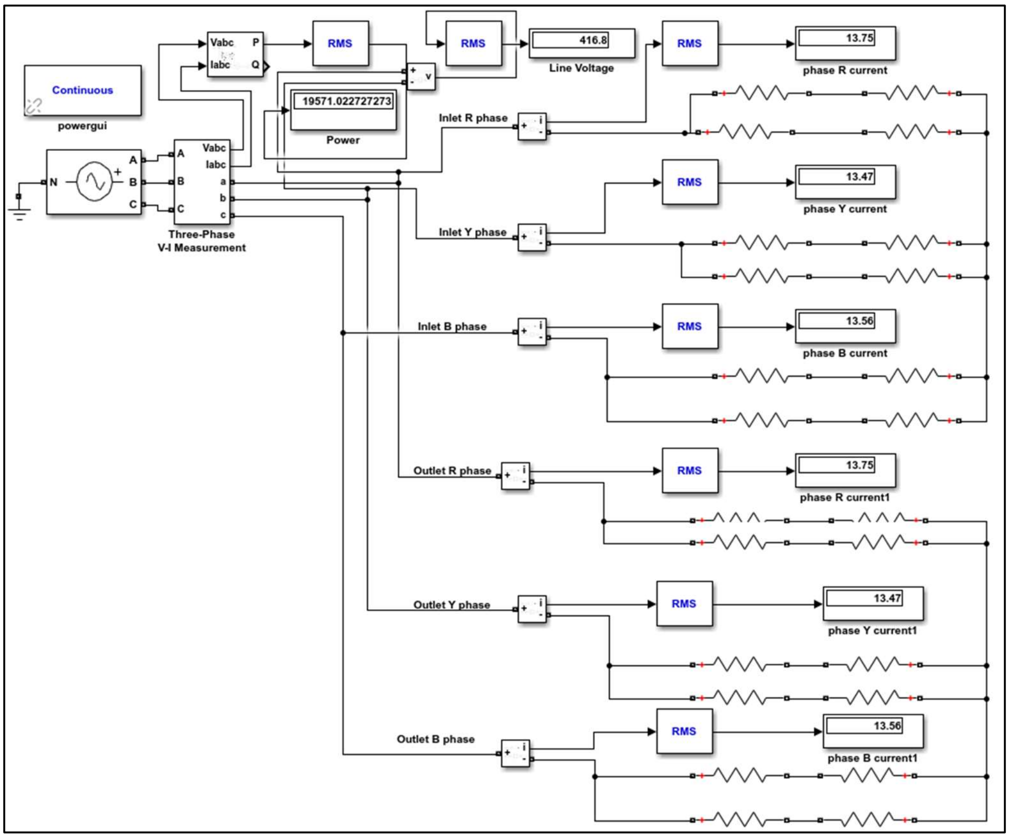


Figure 4.1: Matlab simulink of oven heaters

Other than that, matlab simulink fuzzy logic model for the oven control is conducted for this project, and further discussion in section 4.2.

4.1 Analysis and modifications

This section is conducted as listed for data measurement, comparison, and modifications.

1) Contact resistance and current measurement.
2) Phase-to-phase resistance measurement.
3) Product sample surface colour and temperature comparison.
4) Product placement and wire diameter effect to temperature.
5) Faulty contactor internal structure.
6) Solid state relay.

4.1.1 Contact resistance and current measurement.

The result of simulation in matlab shown that each of the phase current consumption is about 13.5Amp. Hence, each of the phase current measurement is carried out by using clamp meter at the outgoing of the contactors as shown in Figure 4.2. The measured data is recorded in Table 4.1.

Figure 4.2: Phase current measurement using clamp meter

Table 4.1: Phase current value and incoming to outgoing contact resistance of contactors

	BEFORE REPLACEMENT		AFTER REPLACEMENT	
OUTLET CONTACTORS-R	11.81 A	0.1 Ohm	13.34 A	0.1 Ohm
OUTLET CONTACTORS-Y	2.27 A	>10K Ohm	13.61 A	0.1 Ohm
OUTLET CONTACTORS-B	12.06 A	0.1 Ohm	13.43 A	0.1 Ohm
INLET CONTACTORS-R	14.18 A	0.1 Ohm	14.20 A	0.1 Ohm
INLET CONTACTORS-Y	14.24 A	0.5 Ohm	13.58 A	0.1 Ohm
INLET CONTACTORS-B	13.90 A	0.1 Ohm	13.54 A	0.1 Ohm

Measured result indicated that the Y-phase of the outlet contact faulty, with the unbalance current measurement. Hence, it is identified that the faulty contact has contributed to the temperature fluctuation. Action taken to replace both inlet and outlet contactors. As shown in Figure 4.3, photos showing before and after replacement.

The current measurement is carried out on the new contactors, and the result is recorded in Table 4.1.

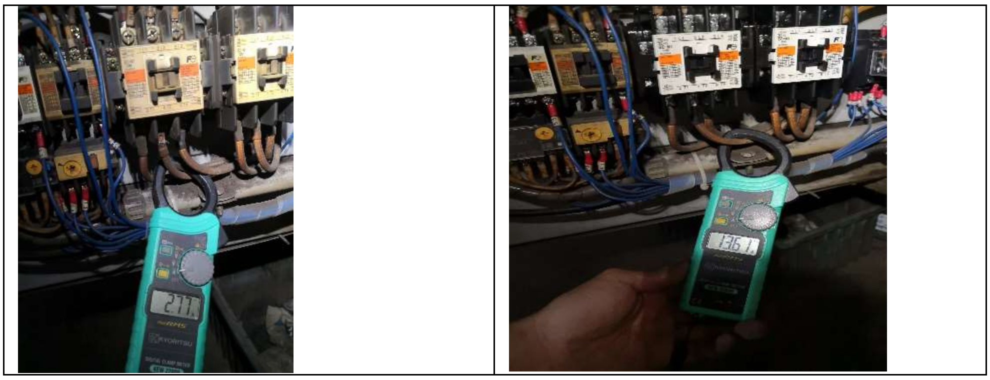


Figure 4.3: Photos of contactor before and after replacement

For comparison, similar type of springs has been selected for the heat treatment. The recorded temperature data is then plotted into two graphs that showing the respond of operated with faulty contactor and operated with new contactors as shown in Figure 4.4. The blue line indicate temperature respond, purple line indicates temperature setpoint, and red line indicate the signal trigger from temperature controller to close the contactors.

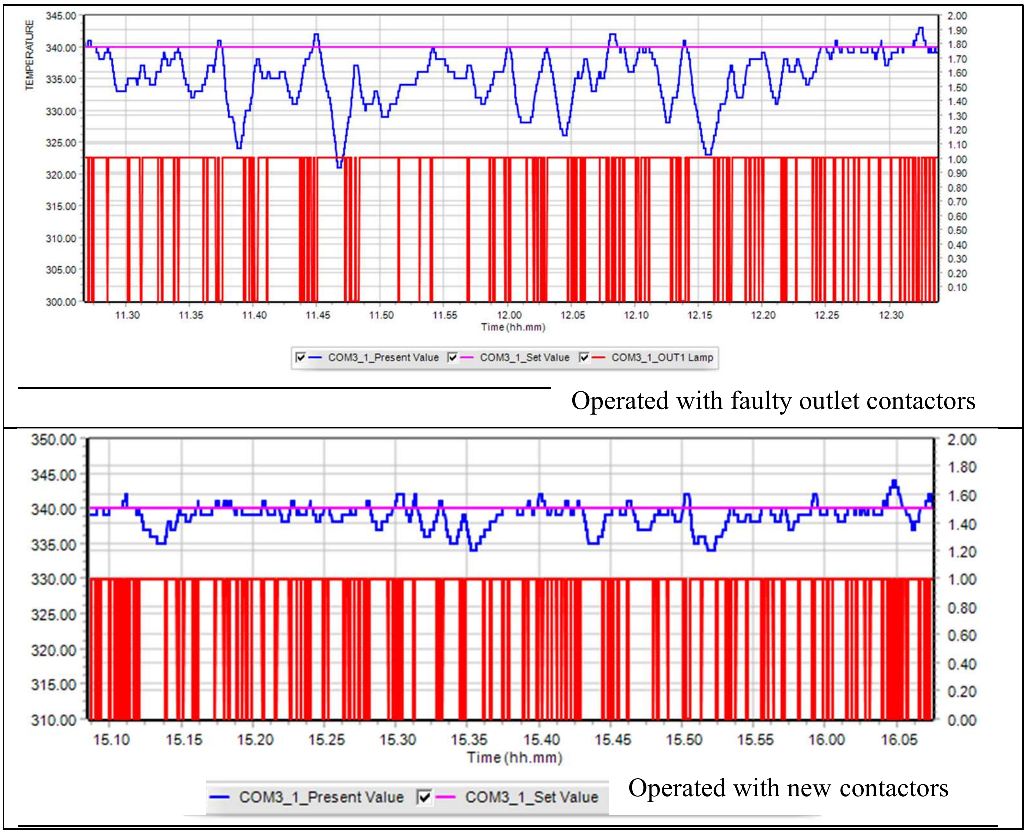


Figure 4.4: Comparison of temperature respond over faulty and new contactors

Observed from the Figure 4.4, the temperature responds raise time is quicker as when the new contactors signal is triggered. As compare with faulty contactor, the temperature raise time is slower.

On the other hand, the peak-to-peak temperature is also reduced from previously recorded of 22 °C to 10 °C as shown in Table 4.2

Table 4.2: Comparison of temperature data before and after replacement

Type	Application / function	Wire material	Weight (gram)	Wire Dia. (mm)	setpoint (°C)	Inlet PV Max (°C)	Inlet PV Min (°C)	Peak-peak (°C)	Avg. (°C)	Remarks.
Spring wire	clip	SWC	0.5	1.4	340	344	334	10	339	After replace
Spring wire	clip	SWC	0.6	1.3	340	343	321	22	335	Before replace

4.1.2 Phase-to-phase resistance measurement

The phase-to-phase resistance is also important parameter to detect any of the faulty heater. As calculated the total of each phase-to-phase resistance is 35.2 ohm. The ohm measurement is carried out by using clamp meter as shown in Figure 4.5 and result is recorded in Table 4.3 for comparison.

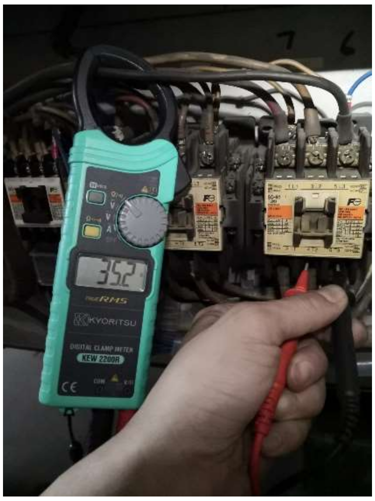


Figure 4.5: Phase-to-phase resistance measurement using clamp meter

Table 4.3: Resistance value

	Calculated	Measured
OUTLET CONTACTORS-R-Y	35.2 ohm	36.0 ohm
OUTLET CONTACTORS-R-B	35.2 ohm	36.5 ohm
OUTLET CONTACTORS-Y-B	35.2 ohm	36.1 ohm
INLET CONTACTORS-R-Y	35.2 ohm	34.8 ohm
INLET CONTACTORS-R-B	35.2 ohm	35.1 ohm
INLET CONTACTORS-Y-B	35.2 ohm	35.2 ohm

Based on the Table 4.3, it can be observed that the measured value is slightly different from ideal calculated value. This is due to the total loop resistance which include cable, connector, and fitting. Therefore, it is verified that the heaters are in good condition.

4.1.3 Product sample surface color and temperature comparison

Springs that undergone heat treatment process, the surface color changes due to oxide layer formed on the surface. Refer to Figure 4.6 of the colors steel under different temperature for reference and illustration.

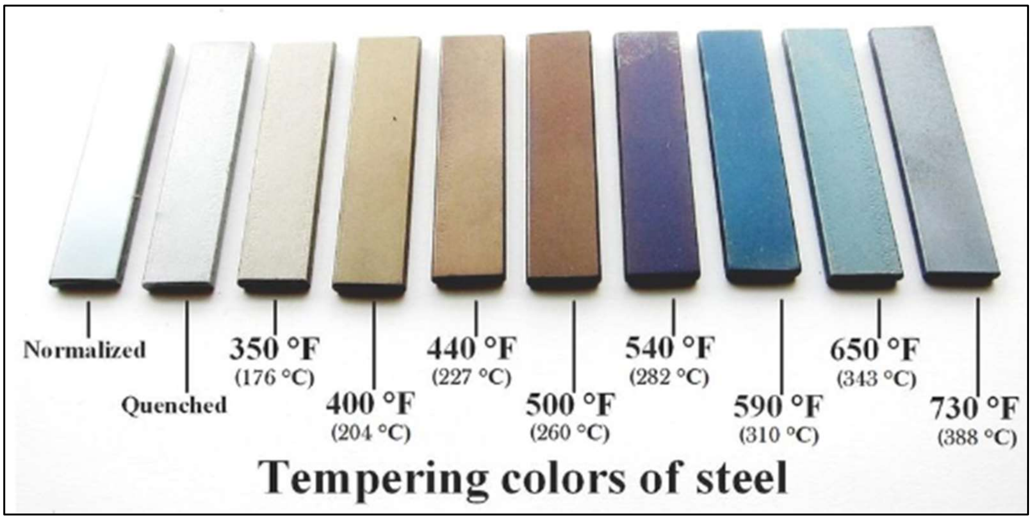


Figure 4.6: Tempering colors of steel [source:https://commons.wikimedia.org/]

Hence, refer to Figure 4.7(a) the product is expected to undergone heat treatment at setpoint temperature of 340 °C. The outcome of the product surface color can be seen uneven with the faulty contactor in operation. It shows that the products are experiencing uneven heated temperature in the oven chamber.

In comparison with the Figure 4.7(b) that after replacement of contactors, the surface color can be seen more even as compare with Figure 4.7(a).

Figure 4.7(a): Uneven surface color after heat treatment

Figure 4.7(b): Even surface color after heat treatment

4.1.4 Product placement and wire diameter effect to temperature

In another experiment conducted to find out whether the quantity of product placement in the conveyor, affecting the temperature respond. The experiment is tested with solid state relay for the PID on off control. For the result obtain in Figure 4.8, it is showing that the amount of spring placement is affecting the temperature raise time. As compare with Figure 4.9, the temperature respond is fast, and the peak-to-peak is also reduced.

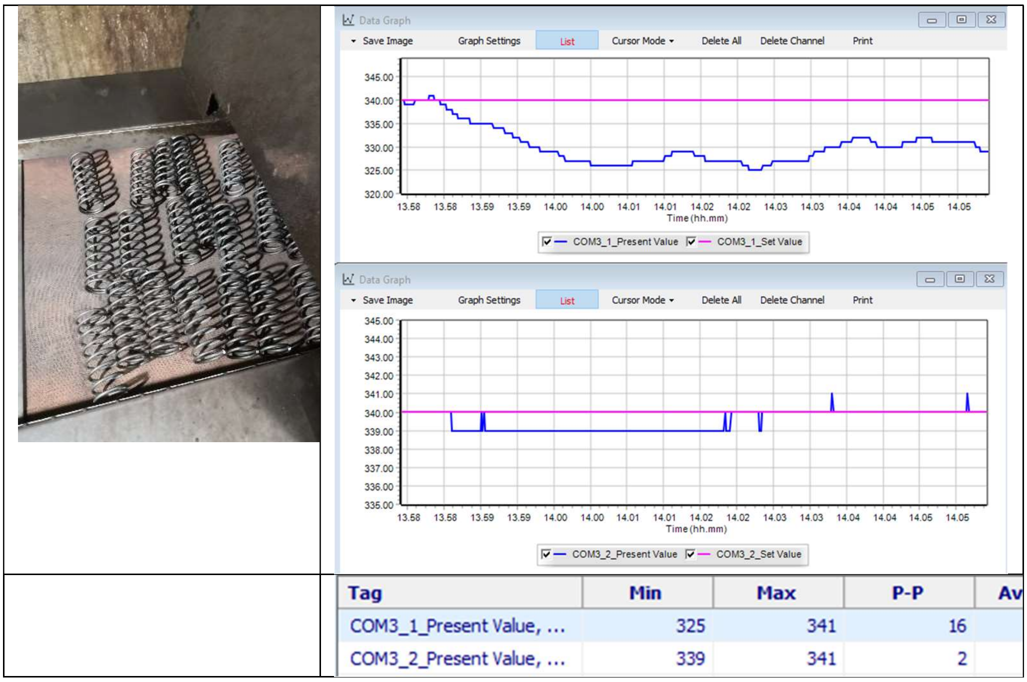


Figure 4.8: Product placement on the conveyor belt with not gap

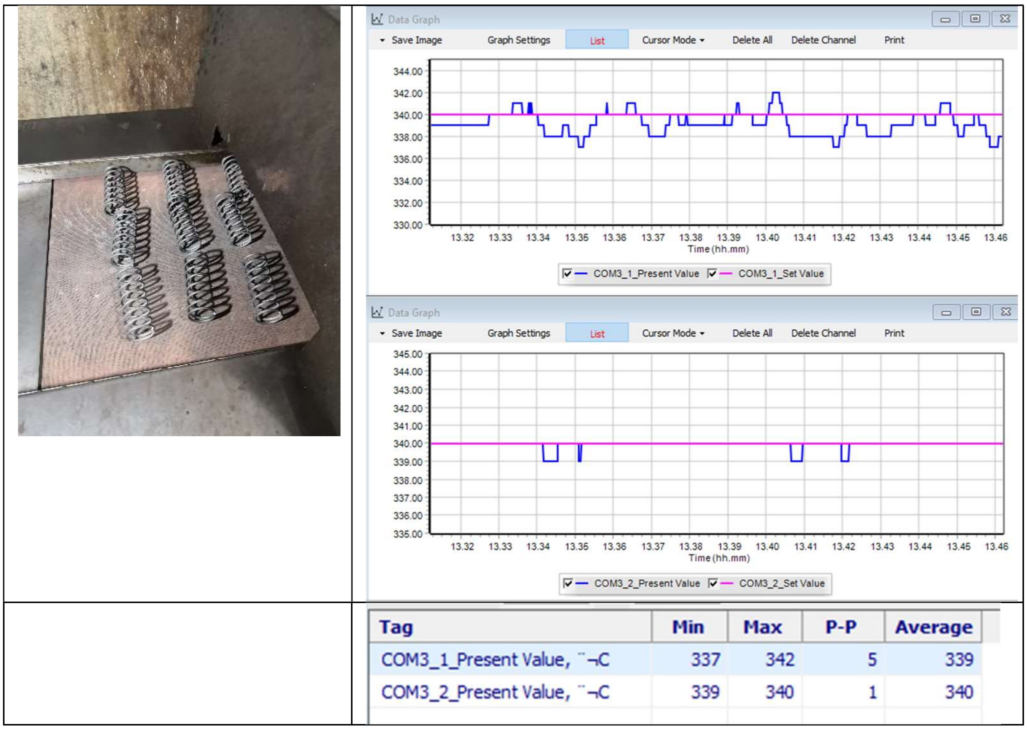


Figure 4.9: Product placement on the conveyor belt with gap

On the other hand, it is also observed from the data collected in Table 4.4 that the wire diameter of the springs does not significantly affecting the temperature performance, as the peak-to-peak recorded highest of 27 for 6mm wire diameter, and 1.4mm wire diameter respectively. As experiment in the

Figure 4.8 and 4.9, that the amount quality of springs loaded onto the conveyor oven is significantly affecting the temperature respond. To deal with higher quantity of products needed to be loaded, this can be improved by replacement of higher heaters rated power.

Table 4.4: Temperature responds for different type of spring wire diameter

Type of springs	Application/function springs	Wire material	Wire Dia. (mm)	setpoint (°C)	Inlet PV Max (°C)	Inlet PV Min (°C)	Peak-peak (°C)	Avg.
Spring wire	clip	SWC	6.0	350	353	326	27	343
Spring wire	clip	SWC	1.4	340	345	318	27	338
Spring wire	clip (90 DEG)	SWC	6.0	350	352	327	25	344
Extension	Pulling force	SWC	2.3	330	336	313	23	327
Extension	Pulling force	SWC	1.6	320	326	305	21	317
Extension	Pulling force	SWC	1.6	320	325	308	17	318
Compression	resistance against axially applied pressure.	SWC	3.2	340	341	325	16	330
Compression	resistance against axially applied pressure.	SWC	2.5	340	343	331	12	336
Compression	resistance against axially applied pressure.	SWC	1.0	320	324	313	11	320
Compression	resistance against axially applied pressure.	SWC	0.4	330	333	323	10	330
Spring wire	clip	SWC	1.4	340	344	334	10	339
Compression	resistance against axially applied pressure.	SWC	1.0	320	323	314	9	320

.

4.1.5 Faulty contactor internal structure

The internal structure of the contactor consists of moving and static contact as shown in Figure 4.10. Whenever the contactor is energized, the moving contact is moved to the static contact position to close the gap and allow current flow through. On the other hand, when the contactor is de-energized, the moving contact is pulled upward to its original position by energy store at the compression springs, and hence the gap is opened which disconnecting the current supply flow through.

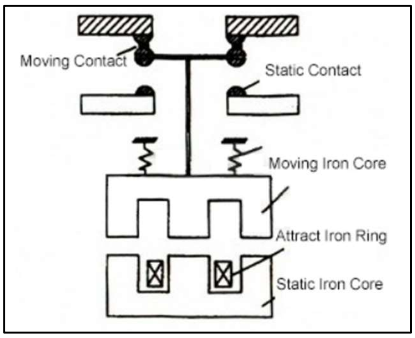


Figure 4.10: Overview of contactor internal structure
[SOURCE: www.txele.com/news_detail/371]

The faulty contactor is dismantled for further analysis. It is observed that at the contactor Y-phase static contact is damaged and having poor connectivity. This is due to the arc flashing occurs during breaking the gap of the contact over long period time of frequent operation. Refer to Figure 4.11 for the photo of the damaged area.

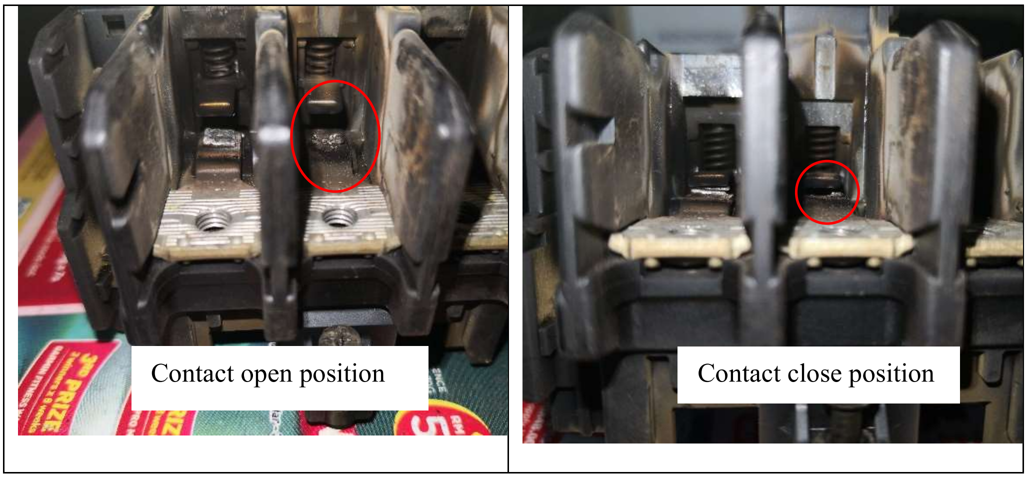


Figure 4.11: Internal view of damage part of the contactor

On the other hand, it is also observed that the moving contact has misalign as compared to the other. As a result of the deformation of the contact over long period, and frequent on off operation of the contact has led to the moving contact gradually misalign as shown in Figure 4.12.

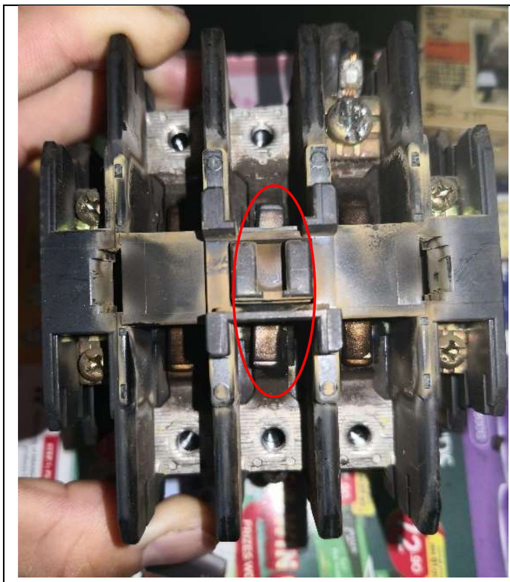


Figure 4.12: Moving contact Y phase misalign

Based on the analysis result, it is recommended that the solid-state relay to be replaced to avoid repetitive fault.

4.1.6 Solid state relay

To overcome the drawback of the electro-mechanical contact that could not withstand the frequent on off operation for the oven temperature control, hence it is further replaced with solid-state relay that do not have moving mechanical parts during operation and provide more precise controlling method that using cycle control.

Solid-state relay selected is applicable for heater load, and it is zero cross style. Refer to Figure 4.13 for the replacement of contactor with solid-state relay at the oven.

Figure 4.13: Replacement of contactors with solid-state relay

With the solid-state relay, the control of oven is tested using matlab fuzzy logic as presented in section 4.2

4.2 Matlab fuzzy logic

Fuzzy logic rules are designed using matlab simulink fuzzy logic designer model as shown in Figure 4.14(a) and 4.14(b). The fuzzy interference system selected for this project is mamdani type. The identify input into the fuzzy logic block is as listed:

1) Error = Temperature Setpoint (SP) – Present value (PV)
2) dError = Temperature rate of changes

Once the fuzzy logic block received the inputs data, it will be processed based on the rules defined, and issue duty ratio output signal.

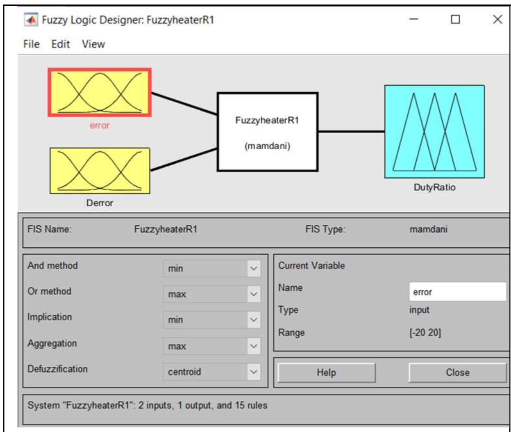


Figure 4.14(a): Fuzzy logic designer for inlet

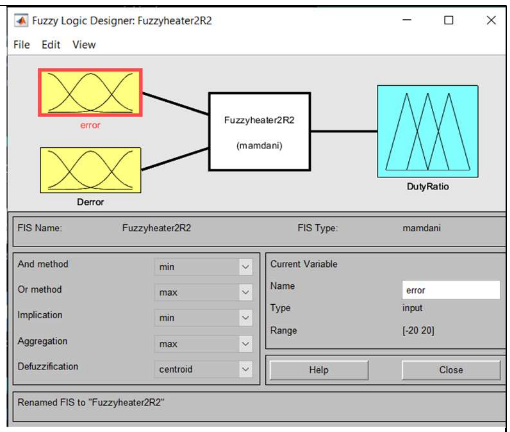


Figure 4.14(b): Fuzzy logic designer for outlet

The output from fuzzy logic is in the range from 0 to 10,000 (0 to 100.00%) that will be send to PLC memory register for the solid-state relay operation.

4.2.1 Fuzzy logic with 9 rules

The membership function input variable of Error and dError consists of positive(P), negative(N) and zero(Z) respectively. On the output variable, it consists of zero (Z), small(S), medium(M) and high (H). Inlet and outlet fuzzy rules are the same setup as shown in Figure 4.15.

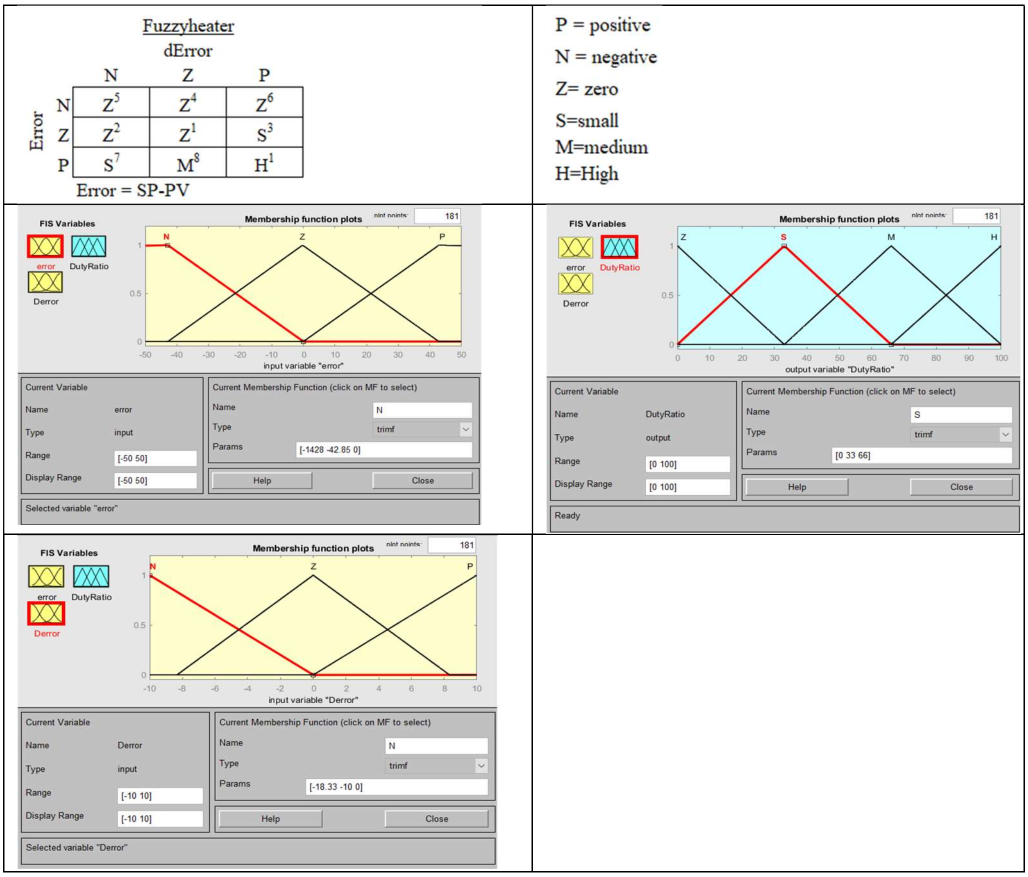


Figure 4.15: Fuzzy logic 9 rules and membership function design

The experimental off load test run of the fuzzy logic model integrated with PLC is setup at the oven, and result is recorded by using matlab data logger as shown in Figure 4.17.

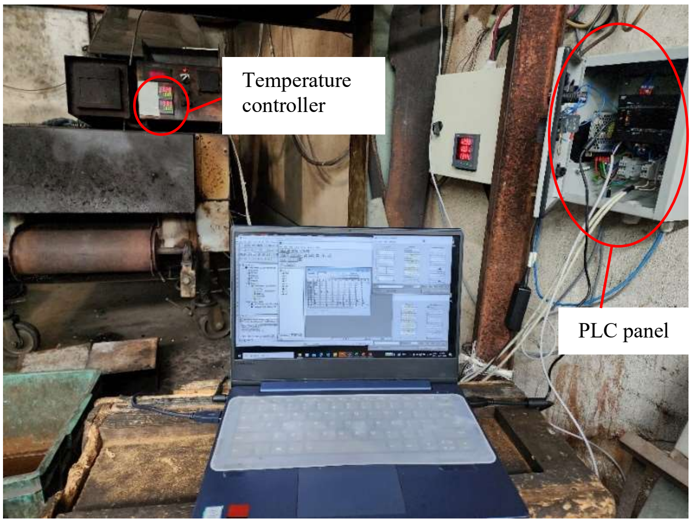


Figure 4.16: Matlab simulink fuzzy logic model,
PLC and oven interconnection setup

The experimental result is plotted in Figure 4.17. Temperature setpoint for this experiment is set at 340 °C. From the graph, purple line indicates inlet temperature, yellow line indicates outlet temperature, and red line indicates duty cycle signal issue to inlet solid-state relay.

It can be observed from the graph that both respond of inlet and outlet temperature could not reach at the desire setpoint of 340 °C, it shows insufficient duty cycle signal being issue to solid-state relay to heat up the heaters.

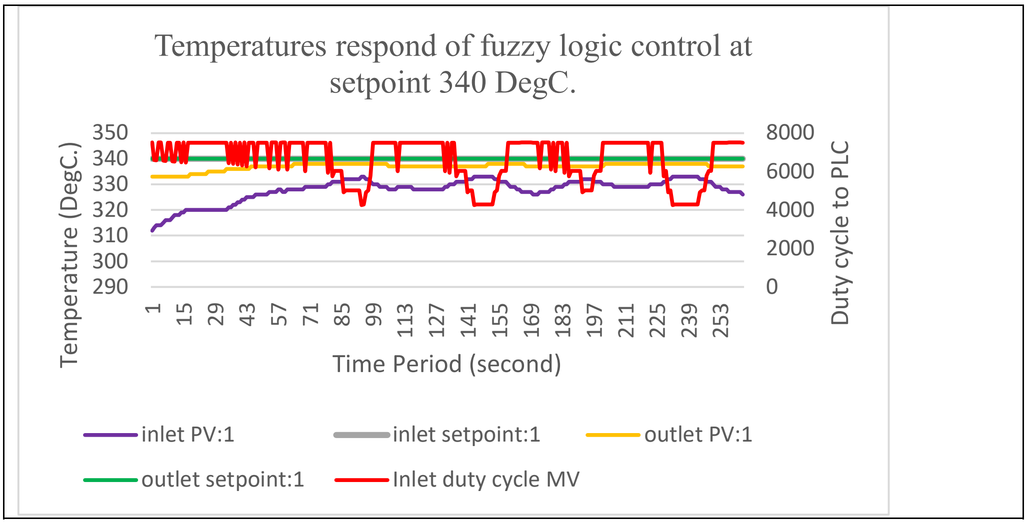


Figure 4.17: Fuzzy logic 9 rules for temperature respond

4.2.2 Fuzzy logic with 15 rules

The off load experiment is further tested with 15 rules to explore whether the temperature respond can be maintained at the desire setpoint of 330 °C. The input variable error is added with small negative (SN), and small positive (SP). Refer to Figure 4.18 for the variable membership setup.

FuzzyheaterR1

Error	Derivative Error N	Z	P
N	Z^{8}	Z^{7}	Z^{9}
SN	Z^{5}	Z^{4}	S^{6}
Z	S^{2}	M^{1}	M^{3}
SP	M^{11}	M^{10}	H^{12}
P	M^{14}	H^{13}	H^{15}

Fuzzyheater2R2

Error	Derivative Error N	Z	P
N	Z^{8}	Z^{7}	Z^{9}
SN	Z^{5}	Z^{4}	S^{6}
Z	S^{2}	Z^{1}	M^{3}
SP	M^{11}	H^{10}	H^{12}
P	M^{14}	H^{13}	H^{15}

P=Positive Z=Zero
SP=Small positive S=Small
N=Negative M=Medium
SN=Small Negative H=High

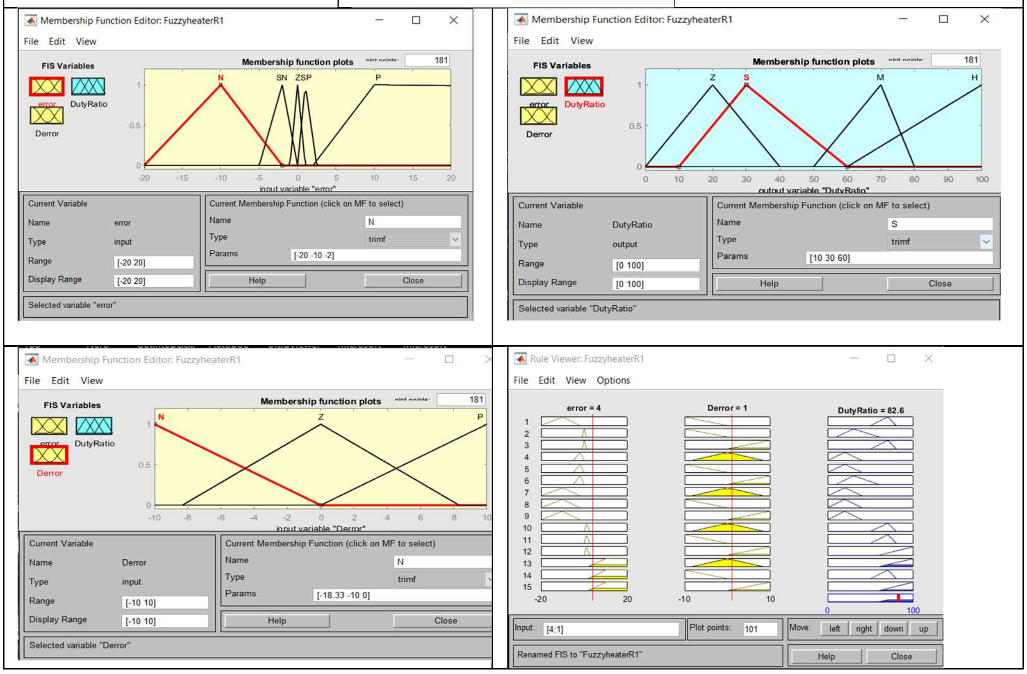


Figure 4.18: Fuzzy logic 15 rules and membership function design

The experiment outcome is plotted in Figure 4.19. It can be observed from the overall temperature respond is nearer to setpoint of 330 °C. The purple line indicates the inlet temperature is fluctuating in the range of 331 °C to 325 °C, whereas yellow line indicates the outlet temperature is fluctuating in the range of 332 °C to 329 °C.

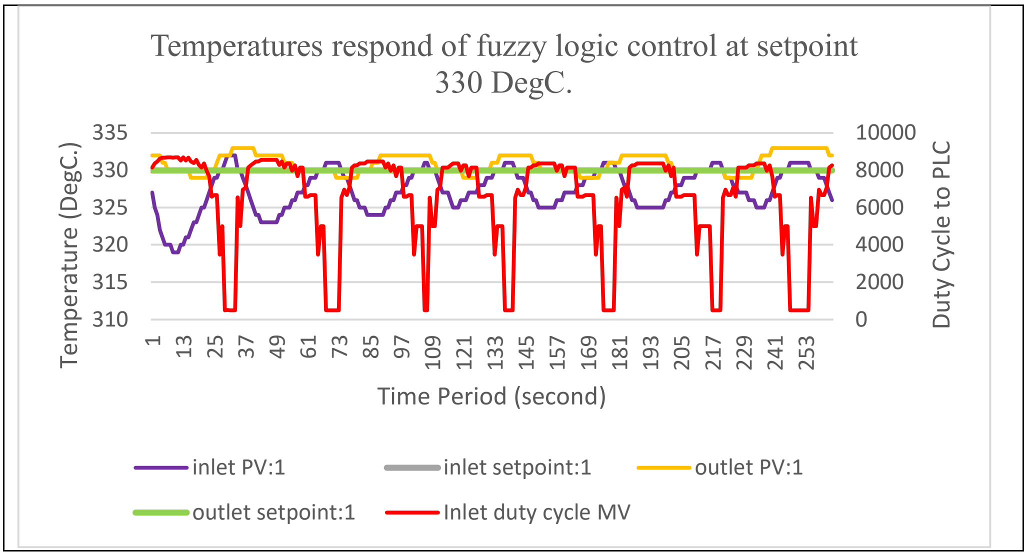


Figure 4.19: Fuzzy logic 15 rules for temperature respond

It can be observed that maintaining the temperature accordingly to the setpoint, there is a range of duty cycle is required. However, it is time consuming in searching for appropriate range of duty cycle for the temperature setpoint. Hence, another approach is needed as presented in the following section 4.3.

4.3 PID temperature controller

Another experiment is conducted by replacing the matlab fuzzy logic and PLC with PID temperature controller that equipped with solid-state relay control output. The temperature controller selected is autonics TK4S-T4SN model to drive the solid-state relay. Refer to Figure 4.20 for the overview of the setup.

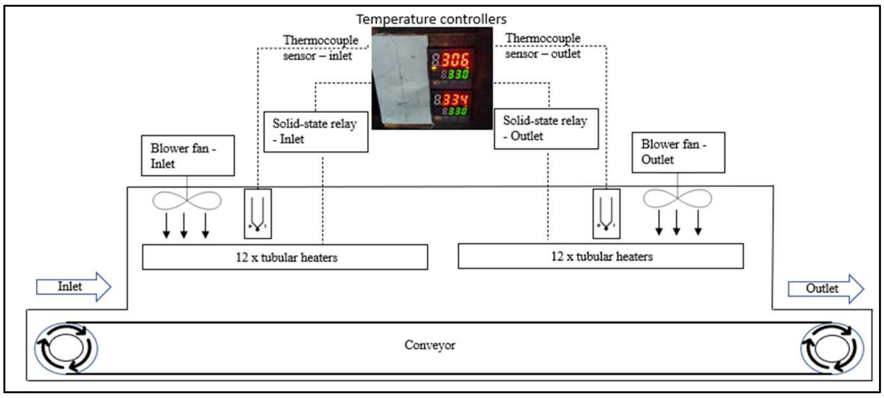


Figure 4.20: Oven installed with temperature controller for the solid-state relay control

The experiment is conducted in off load condition and tested with setpoint of 340°C, 300°C and 200°C. The result tabulated in Table 4.5.

Table 4.5: Performance of temperature respond with respect to setpoint

Sensor	Setpoint (°C)	Range of duty ratio (%)	Min. (°C)	Max. (°C)	Peak to peak (°C)
Inlet	340	53.2 - 94.3	339	341	2
Inlet	300	37.8 - 84.2	299	301	2
Inlet	200	26.3 - 44.5	199	200	1
Outlet	340	5.8 - 31.6	339	340	1
Outlet	300	0.2 - 22.0	299	300	1
Outlet	200	0.0 - 15.6	200	200	0

Referring to Table 4.5, it can be observed that different setpoint require different range of duty ratio for maintaining the temperature.

On the other hand, temperature performance of the respective setpoint in plotted in Figure 4.21, 4.22 and 4.23. It can be observed from the graphs that PID temperature controller can controlled and maintain the temperature at different setpoint.

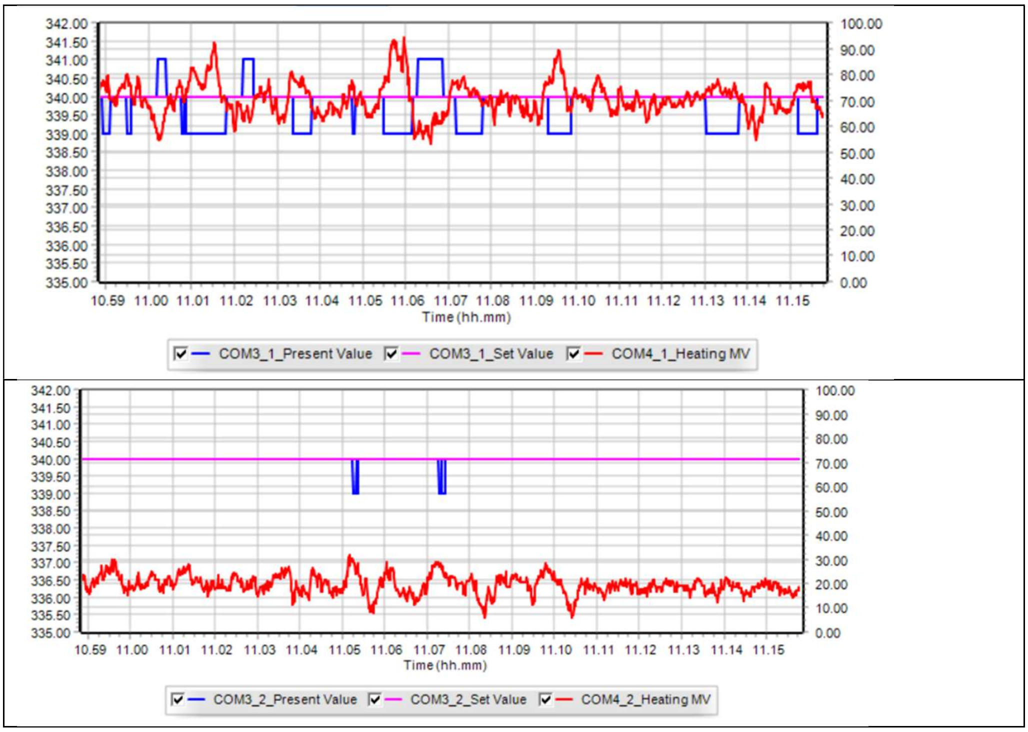


Figure 4.21: Setpoint at 340°C

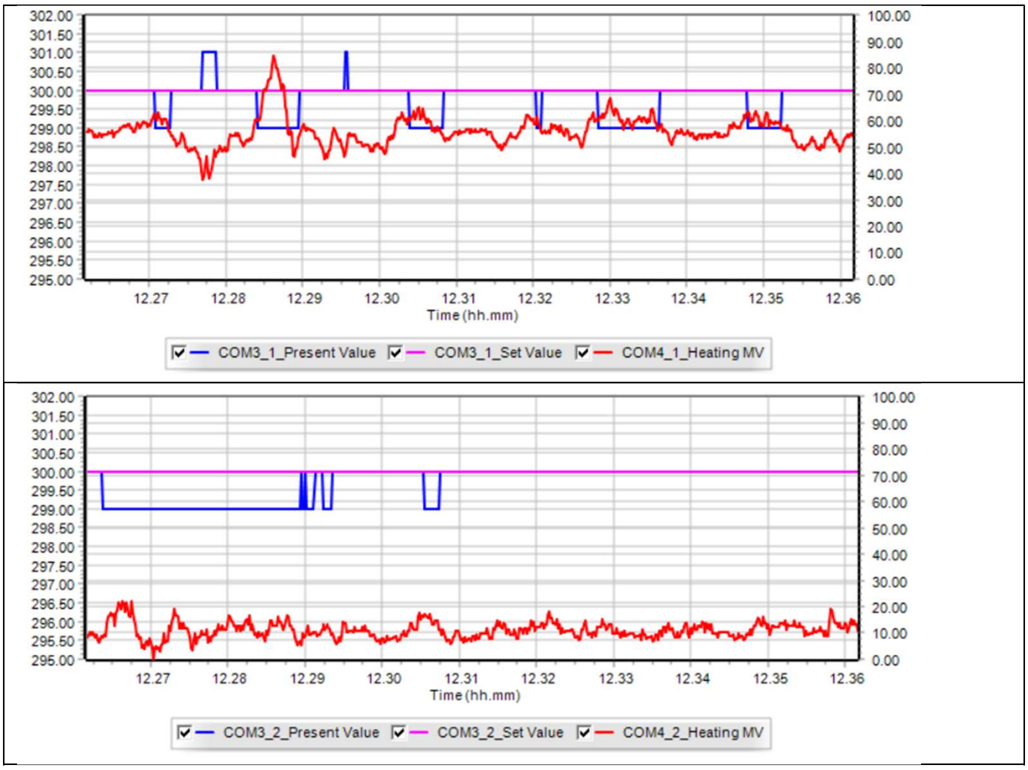


Figure 4.22: Setpoint at 300°C

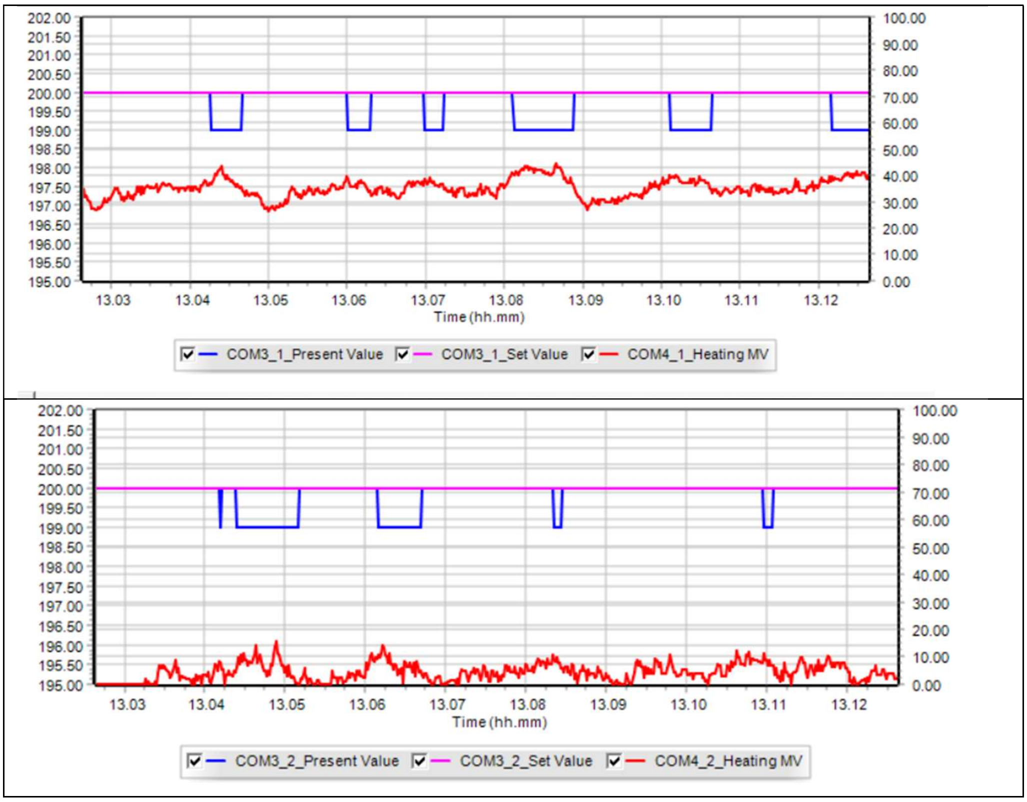


Figure 4.23: Setpoint at 200°C

Based on the result collected and validation of temperature stability, the conveyor oven machine is released to production for operation.

5 CONCLUSION AND RECOMMENDATION

The performance of the heaters is one of the important parts in the industrial conveyor oven system. From this project, it is learned that heaters performance can be monitored by measuring the currents consumption by each phase of the three-phase incoming supply. Hence, power quality meter panel is installed at the incoming three-phase power as shown in Figure 5.1.

Figure 5.1: Power quality meter panel

The performance of the contactor is unknown visually, as the contactor still able to be controlled on and off. However, damaged in the internal structure cannot be seen visually. As such, contactors are replaced with solid-state relay. To ensure the performance of the heaters supply with require current consumption, real time measurement of the currents supply monitoring system is needed to detect unbalance current.

The amount quantity of product placement on the conveyor belt, it is also affecting the temperature raise time as discussed in chapter 4.

Fuzzy logic implementation in PLC depends on the brand and range of the PLC. Some PLC manufacturer does have fuzzy logic designer software that can designed and compile the fuzzy program into the specify range of PLC without the needed of utilizing third party program such as matlab simulink for the fuzzy logic program that require additional computer.

In view of low budget allocation, micro-PLC is selected for the experiment of performance assessment of oven system control with fuzzy logic and conventional PID temperature controller. Throughout the experiment of controlling the oven temperature with fuzzy logic system, it can be concluded that different setpoint temperature do have different range of duty-ratio is needed to maintain the temperature as per setpoint. Hence, it involves multiple rules require to cater for variety of setpoint, and it is time consuming in fine tuning the fuzzy rules in seeking the range of duty ratio for the specify setpoint.

Lastly, fuzzy logic system is replaced with PID temperature controller for further assessment of the temperature stability according to temperature setpoint as discussed in chapter 4. Based on the configuration as discuss in the chapter 3, it can be concluded that PID temperature controller provide lower cost of implementation as compare with fuzzy logic that require to a computer, matlab software and PLC. Furthermore, it can perform as desire to maintain stable temperature in the oven chamber.

5.1 Recommendation for further study

Further study of fuzzy logic can be further explored using another type of membership function as show in Figure 5.2 of the drop-down list.

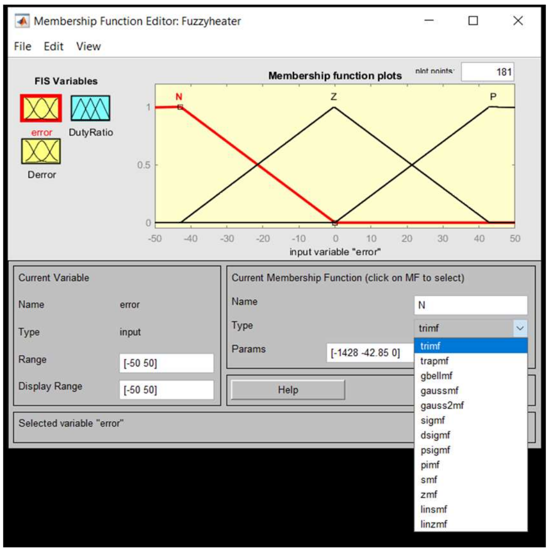


Figure 5.2: Type of membership function selection.

In addition to that, create multiple matlab simulink modelling as to cater for multiple selection of temperature setpoint that corresponding to its duty ratio range.

REFERENCES

Anil Kuma r .K, Jyoshna . P & Seshadri .G, 2014. Realization of Fuzzy Logic in Temperature Control System over PID. *International Journal of Engineering Research & Technology,* 3(7).

D. Pamela & M. S. Godwin Premi, 2017. Wireless Control and Automation of Hot Air Temperature in Oven for Sterilization using Fuzzy PID Controller and Adaptive Smith Predictor. *Wireless Personal Communications,* 94(4), pp. 2055-2065.

DeGuglielmo, N.P., Basnet, S.M.S. & Dow, D.E., 2020. *Introduce Ladder Logic and Programmable Logic Controller (PLC).* s.l., IEEE.

Isaías González Pérez, A. José Calderón Godoy & Manuel Calderón Godoy, 2014. *Fuzzy Controller based on PLC S7-1200 Application to a servomotor.* s.l., SCITEPRESS (Science and Technology Publications,Lda.), pp. 156-163.

J.-P. M.et al., 2017. *Study of the Electric Arc in DC Contactors: Modeling, Simulation and Experimental Validation.* s.l., https://www.reserachhate.net/publication/917256411.

Li, K. et al., 2020. Electrical Performance degration Model and Residual Electrical Life Prediction for AC Contactor. *IEEE,* 10(3).

Md. Tauhidul Islam & Md. Saiful Islam, 2021. *Design and optimization of a self-tuning PID controller based on Fuzzy Logic for Temperature Control System of Furnace.* Khulna, International Conference on Electronics, Communications and Information Technology.

Melih Coban & Murat Fidan, 2019. *Fuzzy Logic Based Temperature Control.* Ankara, Turkey, IEEE.

S.Kavitha, B.Chinthamani & S.Joshibha Ponmalar, 2012. Fuzzy Based Control Using Lab view For Temperature Process. *International Journal of Advanced Computer Research,* 2(6).

Snejana, . Y., Branimir, G. & Milen, S., 2020. Design and industrial implementation of fuzzy logic control of level in soda production. *Engineering Science and Technology, an International Journal,* 23(3), pp. 691-699.

XiaoHong, P., ShiYi, X., Liang, C. & DongYa, W., 2017. Temperature prediction model of two-layer cascade control industrial furnace based on PFC-FLC-DE. *Journal of Computational Methods in Sciences and Engineering,* 17(3), p. 481–495.

Zheng, S. et al., 2018. Analysis of Electrical Life Distribution Characteristics of AC Contactor Based on Performance Degration. *IEEE,* 8(9).

APPENDICES

Appendix A KYOTTO AC Solid state relay

AC SOLID STATE RELAY

K3P40C25DA K3P40C75DA
K3P40C40DA K3P40C90DA
K3P40C50DA K3P40C100DA

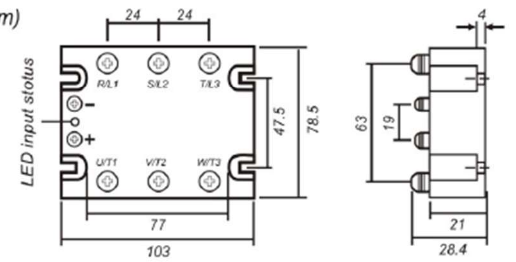
(HEATER LOAD ONLY)
3PHASE SERIES

SPECIFICATIONS

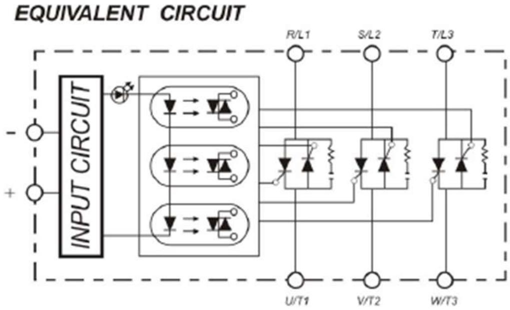
MODEL NO.	CONTROL VOLTAGE RANGE	MUST TURN OFF VOLTAGE	INPUT IMPEDANCE	MAX LOAD CURRENT	LOAD VOLTAGE RANGE	MIN BLOCKING VOLTAGE	MAX OFF-STATE LEAKAGE	FREQUENCY RANGE	MAX 1-CYCLE PEAK SURGE
K3P40C25DA	12 TO 32VDC	MAX 9.5 VDC	1.5Kohm	25 A	48-480VAC	1200VAC	LESS 10 mA	47-63HZ	315A
K3P40C40DA	12 TO 32VDC	MAX 9.5 VDC	1.5Kohm	40 A	48-480VAC	1200VAC	LESS 10 mA	47-63HZ	450A
K3P40C50DA	12 TO 32VDC	MAX 9.5 VDC	1.5Kohm	50 A	48-480VAC	1200VAC	LESS 10 mA	47-63HZ	560A
K3P40C75DA	12 TO 32VDC	MAX 9.5 VDC	1.5Kohm	75 A	48-480VAC	1200VAC	LESS 10 mA	47-63HZ	750A
K3P40C90DA	12 TO 32VDC	MAX 9.5 VDC	1.5Kohm	90 A	48-480VAC	1200VAC	LESS 10 mA	47-63HZ	900A
K3P40C100DA	12 TO 32VDC	MAX 9.5 VDC	1.5Kohm	100A	48-480VAC	1200VAC	LESS 10 mA	47-63HZ	1030A

MODEL NO.	MAX OFF STATE dv/dt	MAX ON-STATE VOLTAGE DROP	ISOLATE IMPEDENCE	DIELECTRIC STRENGTH INPUT-OUTPUT	DIELECTRIC STRENGTH INPUT,OUTPUT-CASE	TURN ON TIME	TURN OFF TIME	CAPACITANCE IN-OUT	WEIGHT (g)
K3P40C25DA	500V/μSEC	1.6Vrms	10^9 ohm	2500Vrms	2500Vrms	LESS1/2mSee	LESS1/2cycle	LESS473pf	600 g
K3P40C40DA	500V/μSEC	1.6Vrms	10^9 ohm	2500Vrms	2500Vrms	LESS1/2mSee	LESS1/2cycle	LESS473pf	600 g
K3P40C50DA	500V/μSEC	1.6Vrms	10^9 ohm	2500Vrms	2500Vrms	LESS1/2mSee	LESS1/2cycle	LESS473pf	600 g
K3P40C75DA	500V/μSEC	1.6Vrms	10^9 ohm	2500Vrms	2500Vrms	LESS1/2mSee	LESS1/2cycle	LESS473pf	600 g
K3P40C90DA	500V/μSEC	1.6Vrms	10^9 ohm	2500Vrms	2500Vrms	LESS1/2mSee	LESS1/2cycle	LESS473pf	600 g
K3P40C100DA	500V/μSEC	1.6Vrms	10^9 ohm	2500Vrms	2500Vrms	LESS1/2mSee	LESS1/2cycle	LESS473pf	600 g

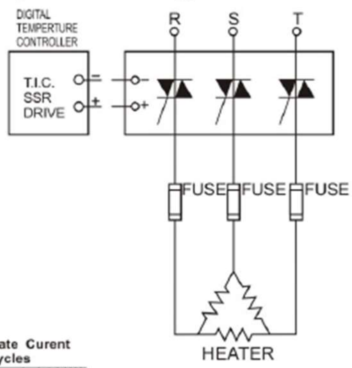
OUTLINE DIMENSIONS (unit:mm)



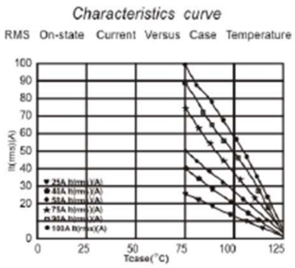
EQUIVALENT CIRCUIT

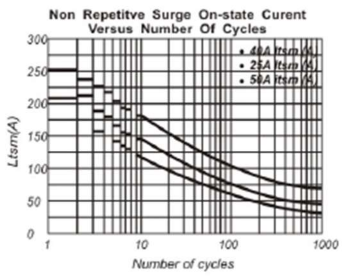


Example of 3Φ SSR Application



CHARACTERISTIC CURVES





Appendix B Autonics PID temperature controller

TCD210240AB **Autonics**

Simultaneous Heating&Cooling Output PID Temperature Controllers

TK Series

CATALOG

For your safety, read and follow the considerations written in the instruction manual, other manuals and Autonics website.
The specifications, dimensions, etc are subject to change without notice for product improvement Some models may be discontinued without notice.

Features

- 50ms high-speed sampling rate and ±0.3% display accuracy
- Simultaneous heating and cooling control function (patent) *
- Switch between current output and SSR drive output
- SSR drive output (SSRP function) control options : ON/OFF control, cycle control, phase control
- Communication output models available : RS485 (Modbus RTU)
- Parameter configuration via PC (RS485 communication)
  - DAQMaster software included (comprehensive device management software)
  - Communication converter sold separately : SCM-US (USB to serial converter), SCM-38I (RS-232C to RS485 converter), SCM-US48I (USB to RS485 converter)
- User-friendly parameter features
- Heater disconnect alarm function (CT input)
  - Current transformer (CT) sold separately : CSTC-E80LN, CSTC-E200LN, CSTS-E80PP
- SV preset function (up to 4 set values) using digital input terminals
- Available in various DIN sizes : (48×24, 48×48, 72×72, 96×48, 48×96, 96×96 mm)

*Korea Patent Registration 10-1002582, U.S.A. Patent Registration 8645000, Japan Patent Registration 3184816, China Patent Registration ZL200980111733.X, Vietnam Patent Registration 1-0012131, India Patent Registration 291573, Indonesia Patent Registration IDP0032166

CE cRUus EAC

Ordering Information

This is only for reference, the actual product does not support all combinations.
For selecting the specified model, follow the Autonics website.

T K 4 ❶ - ❷ ❸ ❹ ❺

❶ Size
N: DIN W 48 × H 24 mm
SP: DIN W 48 × H 48 mm (11 pin plug type)
S: DIN W 48 × H 48 mm
M: DIN W 72 × H 72 mm
W: DIN W 96 × H 48 mm
H: DIN W 48 × H 96 mm
L: DIN W 96 × H 96 mm

❷ Option in/output

Size: N		
PN	**OUT2**	**Function**
1	Normal type[01]	Alarm 1 + CT input
	Heating & Cooling	Alarm 2
2	Normal type	Alarm 1 + Alarm 2
D	Normal type	Alarm 1 + Digital input 1/2
	Heating & Cooling	Digital input 1/2
R	Normal type	Alarm 1+Transmission output
	Heating & Cooling	Transmission output
T	Normal type	Alarm output 1 + RS485 communication
	Heating & Cooling	RS485 communication

Size: SP	
PN	**Function**
1	Alarm 1

Size: S, M, W, H, L	
PN	**Function**
1	Alarm 1
2	Alarm 1 + Alarm output 2
R	Alarm 1 + Transmission output
T	Alarm 1 + RS485 communication
A	Alarm 1 + Alarm 2 + Transmission output
B	Alarm 1 + Alarm 2 + RS485 communication
D	Alarm 1 + Alarm 2 + Digital input 1/2[02]

❸ Power supply
2: 24 VAC∼ 50/60 Hz, 24-48 VDC⎓
4: 100-240 VAC∼ 50/60 Hz

❹ OUT1 Control output
R: Relay
S: SSR drive
C: Selectable current or SSR drive output

❺ OUT2 Control output
N: Normal type [No OUT2 (Heating or Cooling)]
R: Heating & Cooling type [Relay output][03]
C: Heating & Cooling type [Selectable current or SSR drive output][04]

01) The CT input model of TK4N can be selected only in the normal type model with alarm output 1. (except TK4SP)
02) Only for TK4S-D, OUT2 output terminal is used as DI-2 input terminal.
03) When operating mode is heating or cooling control, OUT2 can be used as alarm output 3 (except TK4N).
04) When operating mode is heating or cooling control, OUT2 can be used as transmission output 2.

Software

Download the installation file and the manuals from the Autonics website.

■ **DAQMaster**
DAQMaster is comprehensive device management program. It is available for parameter setting, monitoring.

Specifications

Series		TK4N	TK4SP	TK4S	TK4M
Power supply	AC type	100 - 240 VAC~ 50/60 Hz ±10%			
	AC/DC type	-	24 VAC~ 50/60 Hz ±10%, 24-48 VDC⎓ ±10%		
Power consumption	AC type	≤ 6 VA	≤ 8 VA		
	AC/DC type	-	AC: ≤ 8 VA, DC ≤ 5W		
Unit weight (packaged)		≈ 70 g (≈ 140 g)	≈ 85 g (≈ 130 g)	≈ 105 g (≈ 150 g)	≈ 140 g (≈ 210 g)

Series		TK4W	TK4H	TK4L
Power supply	AC type	100 - 240 VAC~ 50/60 Hz ±10%		
	AC/DC type	24 VAC~ 50/60 Hz ±10%, 24-48 VDC⎓ ±10%		
Power consumption	AC type	≤ 8 VA		
	AC/DC type	AC: ≤ 8 VA, DC ≤ 5W		
Unit weight (packaged)		≈ 141 g (≈ 211 g)	≈ 141 g (≈ 211 g)	≈ 198 g (≈ 294 g)

Sampling period		50 ms
Input specification		Refer to 'Input Type and Using Range'
Option input	CT input	• 0.0-50.0 A (primary current measurement range) • CT ratio: 1/1,000 • Measurement accuracy: ±5% F.S. ±1digit
	Digital input	• Contact - ON: ≤ 2 kΩ, OFF: ≥ 90 kΩ • Non contact - residual voltage ≤ 1.0 V, leakage current ≤ 0.1 mA • Outflow current: ≈ 0.5 mA per input
Control output	Relay	250 VAC~ 3 A, 30 VDC⎓ 3 A 1a
	SSR	11 VDC⎓ ±2 V, ≤ 20 mA
	Current	DC 4-20 mA or DC 0-20 mA (parameter), Load resistance: ≤ 500 Ω
Alarm output	Relay	AL1, AL2: 250 VAC~ 3 A 1a • TK4N AL2: 250 VAC~ 0.5 A 1a (≤ 125 VA)
Option output	Transmission	DC 4 - 20 mA (Load resistance: ≤ 500 Ω, Output accuracy: ±0.3% F.S.)
	RS485 comm.	Modbus RTU
Display type		7 segment (red, green, yellow), LED type
Control type	Heating, Cooling	ON/OFF, P, PI, PD, PID Control
	Heating & Cooling	
Hysteresis		• Thermocouple, RTD: 1 to 100 (0.1 to 100.0) °C/°F • Analog: 1 to 100 digit
Proportional band (P)		0.1 to 999.9 °C/°F (0.1 to 999.9%)
Integral time (I)		0 to 9,999 sec
Derivative time (D)		0 to 9,999 sec
Control cycle (T)		• Relay output, SSR drive output: 0.1 to 120.0 sec • Selectable current or SSR drive output: 1.0 to 120.0 sec
Manual reset		0.0 to 100.0%
Relay life cycle	Mechanical	OUT1/2: ≥ 5,000,000 operations AL1/2: ≥ 20,000,000 operations (TK4H/W/L: ≥ 5,000,000 operations)
	Electrical	≥ 100,000 operations
Dielectric strength		Between power source terminal and input terminal: 2,000 VAC~ 50/60 Hz for 1 min
Vibration		0.75 mm amplitude at frequency of 5 to 55 Hz (for 1 min) in each X, Y, Z direction for 2 hours
Insulation resistance		≥ 100 MΩ (500 VDC⎓ megger)
Noise immunity		±2 kV square shaped noise by noise simulator (pulse width: 1 μs) R-phase, S-phase
Memory retention		≈ 10 years (non-volatile semiconductor memory type)
Ambient temperature		-10 to 50 °C, storage: -20 to 60 °C (no freezing or condensation)
Ambient humidity		35 to 85%RH, storage: 35 to 85%RH (no freezing or condensation)
Protection structure		IP65 (Front panel, IEC standards) • TK4SP: IP50 (Front panel, IEC standards)
Insulation type		Double insulation or reinforced insulation (mark: ⧈, dielectric strength between the measuring input part and the power part: 2 kV)
Accessory		Bracket, Terminal protection cover (TK4N)
Approval		CE cULus EAC

Communication Interface

■ RS485

Comm. protocol	Modbus RTU
Connection type	RS485
Application standard	EIA RS485 compliance with
Maximum connection	31 units (address: 01 to 99)
Synchronous method	Asynchronous
Comm. Method	Two-wire half duplex
Comm. effective range	≤ 800 m
Comm. speed	2,400 / 4,800 / 9,600 (default) / 19,200 / 38,400 bps (parameter)
Response time	5 to 99 ms (default: 20 ms)
Start bit	1 bit (fixed)
Data bit	8 bit (fixed)
Parity bit	None (default), Odd, Even
Stop bit	1 bit, 2 bit (default)
EEPROM life cycle	≈ 1,000,000 operations (Erase / Write)

Input Type and Using Range

The setting range of some parameters is limited when using the decimal point display.

Input type		Decimal point	Display	Using range (°C)	Using range (°F)
Thermo-couple	K (CA)	1	KCAH	-200 to 1,350	-328 to 2,463
		0.1	KCAL	-199.9 to 999.9	-199.9 to 999.9
	J (IC)	1	JIC.H	-200 to 800	-328 to 1,472
		0.1	JIC.L	-199.9 to 800.0	-199.9 to 999.9
	E (CR)	1	ECr.H	-200 to 800	-328 to 1,472
		0.1	ECr.L	-199.9 to 800.0	-199.9 to 999.9
	T (CC)	1	tCC.H	-200 to 400	-328 to 752
		0.1	tCC.L	-199.9 to 400.0	-199.9 to 752.0
	B (PR)	1	b Pr	0 to 1,800	32 to 3,272
	R (PR)	1	r Pr	0 to 1,750	32 to 3,182
	S (PR)	1	S Pr	0 to 1,750	32 to 3,182
	N (NN)	1	n nn	-200 to 1,300	-328 to 2,372
	C (TT)[01]	1	C tt	0 to 2,300	32 to 4,172
	G (TT)[02]	1	G tt	0 to 2,300	32 to 4,172
	L (IC)	1	LIC.H	-200 to 900	-328 to 1,652
		0.1	LIC.L	-199.9 to 900.0	-199.9 to 999.9
	U (CC)	1	UCC.H	-200 to 400	-328 to 752
		0.1	UCC.L	-199.9 to 400.0	-199.9 to 752.0
	Platinel II	1	PLII	0 to 1,390	32 to 2,534
RTD	Cu50 Ω	0.1	CU 5	-199.9 to 200.0	-199.9 to 392.0
	Cu100 Ω	0.1	CU 10	-199.9 to 200.0	-199.9 to 392.0
	JPt100 Ω	1	JPt.H	-200 to 650	-328 to 1,202
		0.1	JPt.L	-199.9 to 650.0	-199.9 to 999.9
	DPt50 Ω	0.1	dPt5	-199.9 to 600.0	-199.9 to 999.9
	DPt100 Ω	1	dPt.H	-200 to 650	-328 to 1,202
		0.1	dPt.L	-199.9 to 650.0	-199.9 to 999.9
	Nickel120 Ω	1	nI 12	-80 to 200	-112 to 392
Analog	0 to 10 V	-	Av1	0 to 10 V	
	0 to 5 V	-	Av2	0 to 5 V	
	1 to 5 V	-	Av3	1 to 5 V	
	0 to 100 mV	-	AmV1	0 to 100 mV	
	0 to 20 mA	-	AmA1	0 to 20 mA	
	4 to 20 mA	-	AmA2	4 to 20 mA	

01) C (TT): Same as existing W5 (TT) type sensor

02) G (TT): Same as existing W (TT) type sensor

- Permissible line resistance per line: ≤ 5 Ω

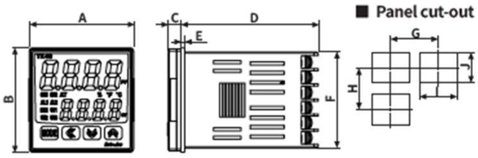
■ Display accuracy

Input type	Using temperature	Display accuracy
Thermo-couple RTD	At room temperature (23°C ±5 °C)	(PV ±0.3% or ±1 °C higher one) ±1-digit • Thermocouple K, J, T, N, E below -100 °C and L, U, PLII, RTD Cu50 Ω, DPt50 Ω: (PV ±0.3% or ±2 °C higher one) ±1-digit • Thermocouple C, G and R, S below 200 °C: (PV ±0.3% or ±3 °C higher one) ±1-digit • Thermocouple B below 400 °C: There is no accuracy standards
	Out of room temperature range	(PV ±0.5% or ±2 °C higher one) ±1-digit • RTD Cu50 Ω, DPt50 Ω: (PV ±0.5% or ±3 °C higher one) ±1-digit • Thermocouple R, S, B, C, G: (PV ±0.5% or ±5 °C higher one) ±1-digit • Other sensors: ≤ ±5 °C (≤-100 °C)
Analog	At room temperature (23°C ±5 °C)	±0.3% F.S. ±1-digit
	Out of room temperature range	±0.5% F.S. ±1-digit

- In case of TK4SP Series, ±1 °C will be added to the degree standard.

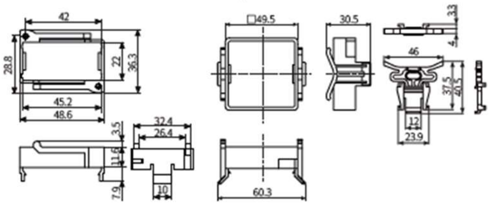
Dimensions

- Unit: mm, For the detailed drawings, follow the Autonics website.
- Below is based on TK4S Series.



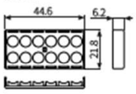
	Body						Panel cut-out			
	A	B	C	D	E	F	G	H	I	J
TK4N	48	24	3	91.8	-	21.8	≥ 55	≥ 37	$45^{+0.6}_{0}$	$22.2^{+0.3}_{0}$
TK4S	48	48	6	64.5	1.7	45	≥ 65	≥ 65	$45^{+0.6}_{0}$	$45^{+0.6}_{0}$
TK4SP	48	48	6	72.2	-	44.8	≥ 65	≥ 65	$45^{+0.6}_{0}$	$45^{+0.6}_{0}$
TK4M	72	72	6	64.5	1.7	67.5	≥ 90	≥ 90	$68^{+0.7}_{0}$	$68^{+0.7}_{0}$
TK4W	96	48	6	64.5	1.5	44.7	≥ 115	≥ 65	$92^{+0.8}_{0}$	$45^{+0.6}_{0}$
TK4H	48	96	6	64.5	1.5	91.5	≥ 65	≥ 115	$45^{+0.6}_{0}$	$92^{+0.8}_{0}$
TK4L	96	96	6	64.5	1.5	91.5	≥ 115	≥ 115	$92^{+0.8}_{0}$	$92^{+0.8}_{0}$

■ Bracket



■ Terminal protection cover

TK4N



Unit Descriptions

1. PV display part (Red)
- Run mode: Displays PV (Present value).
- Setting mode: Displays parameter name.

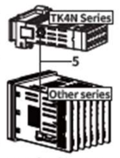
2. SV display part (Green)
- Run mode: Displays SV (Setting value).
- Setting mode: Displays parameter setting value.

3. Input key

Display	Name
[A/M]	Control switching key
[MODE]	Mode key
[◀], [▼], [▲]	Setting value control key

4. Indicator

Display	Name	Description
°C, %, °F	Unit	Displays selected unit (parameter)
AT	Auto tuning	Flashes during auto tuning every 1 sec
OUT1/2	Control output	Turns ON when the control output is ON • SSR output (cycle/phase control) MV over 5% ON • Current output Manual control: 0% OFF, over ON Auto control: below 2% OFF, over 3% ON
AL1/2	Alarm output	Turns ON when the alarm output is ON
MAN	Manual control	Turns ON during manual control
SV1/2/3	Multi SV	The SV indicator is ON which is currently displayed. (When using multi SV function)



5. PC loader port: For connecting communication converter (SCM series).

- For the details about old model, refer to the user manual. Download the manuals from the Autonics website.

Sold Separately

- 11 pin socket: PG-11, PS-11 (N)
- Current transformer (CT)
- Terminal protection cover: RSA / RMA / RHA / RLA Cover
- Communication converter: SCM Series

Appendix C Micro programmable logic controller

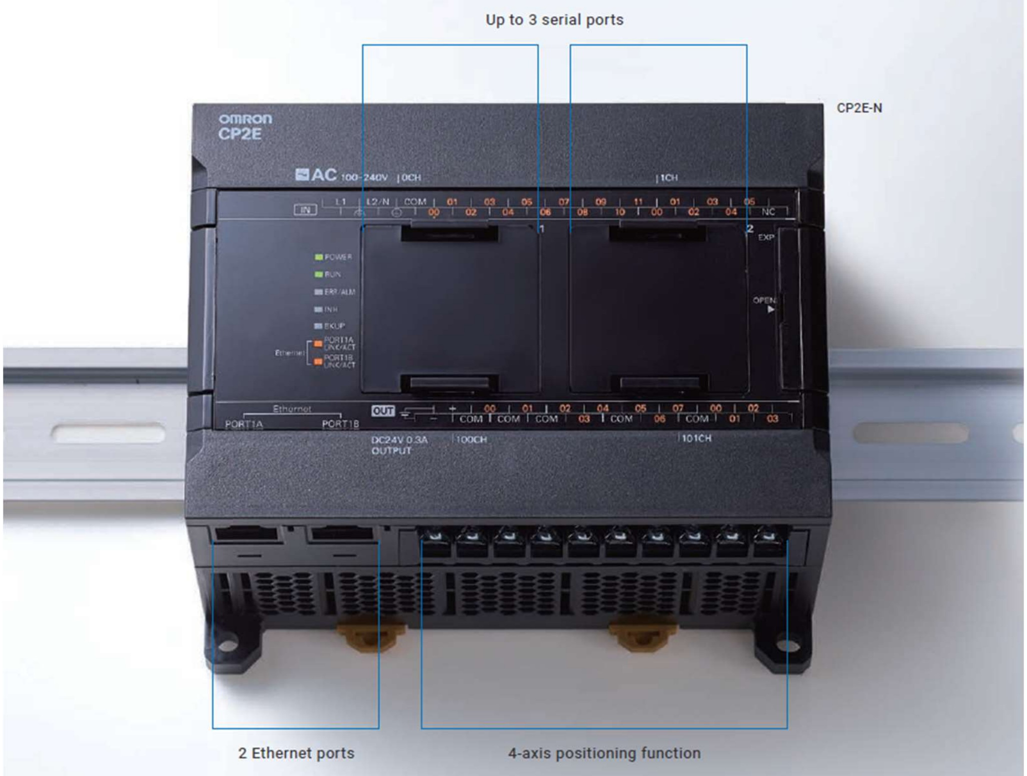
Programmable Controller
CP2E

OMRON

Micro PLC designed to support data collection and Machine to Machine communication

Diverse range of functions for your machine

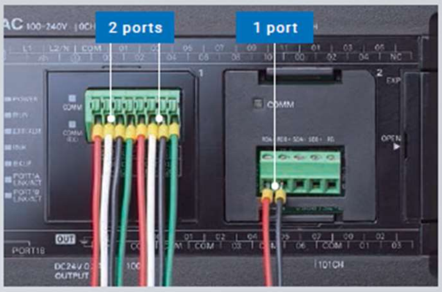
Efficient solution for a flexible production, traceability and monitoring of machine key assets, to respond to operational excellence.
Improved connectivity to networking and serial devices.
Reduced development time with function blocks (FBs) programming.
Battery-free operation increases robustness and reduces maintenance. The extended operating temperature range increase reliability for special applications.



Note: Please check datasheet (Cat. No. P145) to select your controller. Available functions differ model by model.

Improved connectivity for ethernet and serial devices P.4-5


Built-in Ethernet switching function



Serial open protocols and Modbus communication

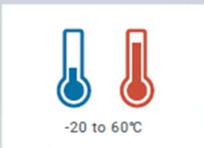
Reduced effort to realize complex machines P.6-7


4-axis positioning function with linear interpolation

Try Omron Function blocks for positioning, Machine to Machine communication and predictive maintenance

Download from
www.ia.omron.com/cp_fb

Install and forget: reliable solution for all environmental conditions P.7



Extended operational temperature range


Battery-free operation*


Input/output terminal LED indicators for quick troubleshooting

Automatic Recovery by electric interferences

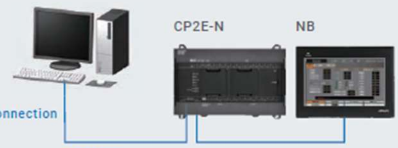
* Needed only in case Real Time Clock is used.

Improved connectivity for ethernet and serial devices

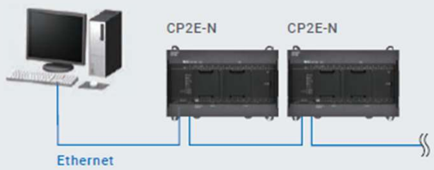
Ready for Machine to Machine communication CP2E-N

Connect machines to networks to collect field data.
Two built-in Ethernet ports eliminate the need for switching hubs. One port is connected to the host, and another can be connected to an HMI, PLC, or PC running support software or reserved.

Host and HMI connectivity



Machine to Machine connectivity



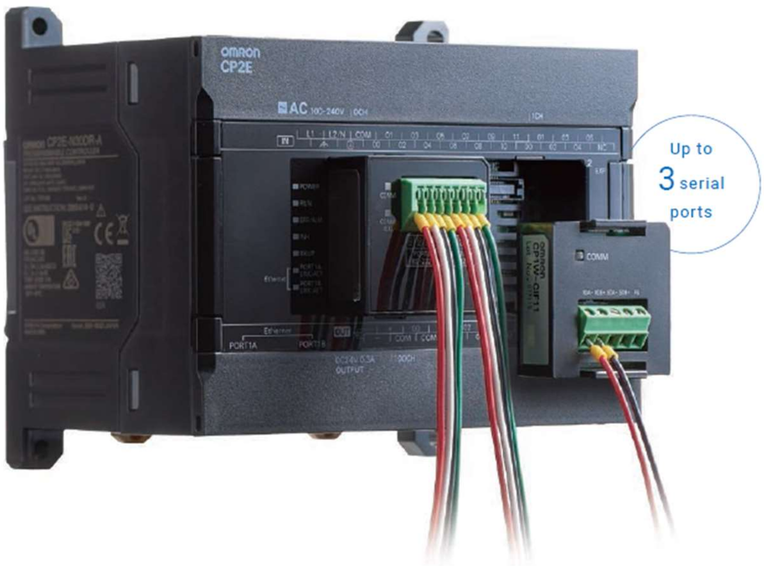
Note: The L2 Switching Hub function is built in.
Two Ethernet ports on the CP2E share the same IP address.

FB Ethernet Send/Receive Data

Reduce programming time by Ethernet Send/Receive Data FB to easily exchange data between controllers.

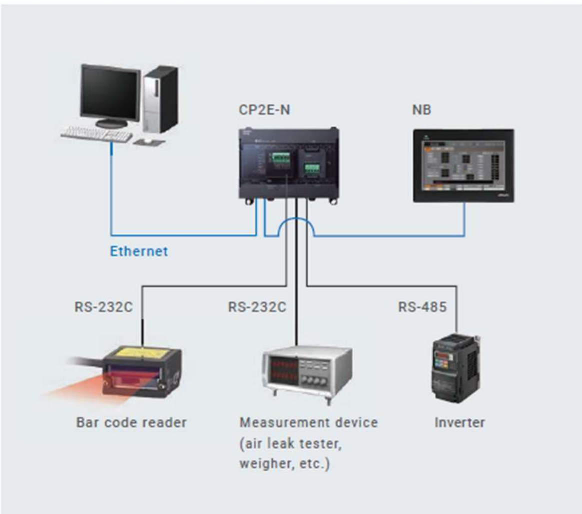
Assembling lines

Improve design efficiency and productivity reducing development time with a modular conception of the machine



Open connectivity to serial devices CP2E-N

CP2E-N can use up to 3 serial ports by mounting option boards.
Data collection, Control and Monitoring of serial devices is easy and flexible.



FB Modbus RTU master

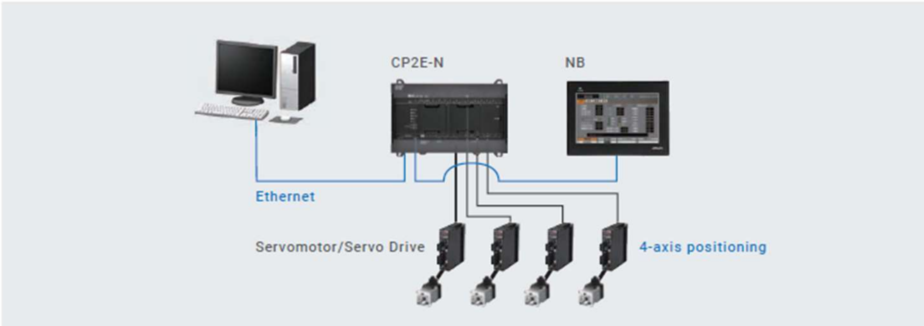
Reduce programming time by Modbus FB to easily communicate with serial devices.

Semiautomatic assembling machines

Connect bar code readers for traceability and monitor state of machine

Reduced effort to realize complex machines

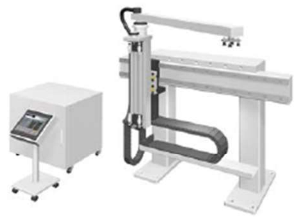
Up to 4-axis linear interpolation CP2E-N



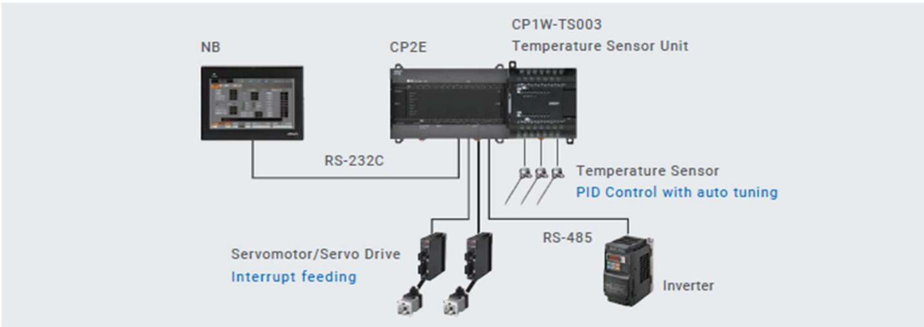
FB Linear interpolation

Simplified positioning:
4-axis can operate simultaneously for a faster positioning.

Pick and Place
Operate with 4-axis simultaneously to reduce machine cycle time

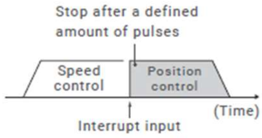


Positioning on mark for Packaging Machines CP2E-N/CP2E-S



Instruction Fixed positioning on interrupt (IFEED instruction)

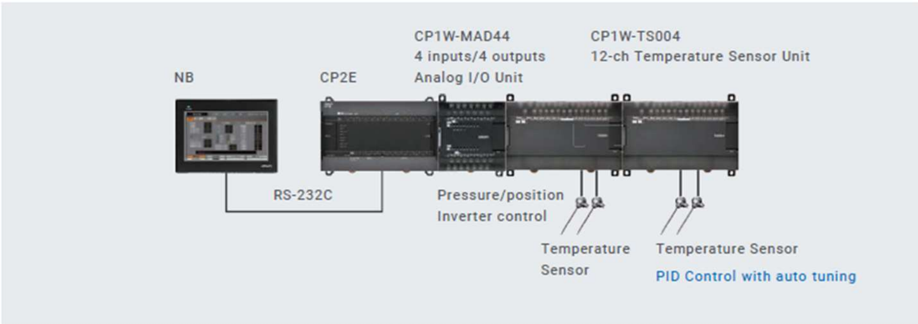
With one instruction you can execute a fixed positioning on Interrupt input (mark) independently by PLC cycle time.



Packaging machine
Constant movement from mark detection to seal position

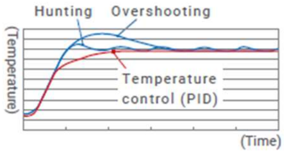
Stable temperature control with autotuning function

CP2E-N/CP2E-S/CP2E-E



FB PID Control with auto tuning

PID with Autotuning function enable stable temperature control reducing start-up time. Connection with stand alone temperature control is also available.



Small extrusion machine

Stable multipoint temperature control, setting via NB series HMI

Install and forget: reliable solution for all environmental conditions

CP2E-N/CP2E-S/CP2E-E

Extended operational temperature range

-20 to 60℃

Increase reliability in special applications

Multi-level parking

Waste disposal equipment

Grain storage facility

Battery-free operation*

Cost reduction in maintenance, logistic/stock

* Needed only in case Real Time Clock is used.

I/O LED indicators

Reduce installation time and easily check wiring errors by LED indicators

Automatic Recovery by electric interferences.

Normal operation continues

CP2E detects and recovers in real-time operation a bit corruption.

Increase machine efficiency avoiding CPU stops.

Product lineup

CP2E-N Network Model: Ethernet connectivity, 4-axis positioning, FB programming

CPU unit with 30, 40, or 60 I/O points

2 Ethernet ports	Up to 3 serial ports	4-axis positioning	2 option boards	3 expansion units
Memory 10K steps	Clock	Battery-free	-20 to 60℃	USB port

CPU unit with 14 or 20 I/O points

1 Ethernet port	Up to 2 serial ports	2-axis positioning	1 option board	Expansion unit
Memory 10K steps	Clock	Battery-free	-20 to 60℃	USB port

CP2E-S Standard Model: 2 serial ports, 2-axis positioning, FB programming

CPU unit with 30, 40, or 60 I/O points

Ethernet	1 x RS-232C port 1 x RS-485 port*1	2-axis positioning	option board	3 expansion units
Memory 8K steps	Clock	Battery-free	-20 to 60℃	USB port

CP2E-E Essential Model: 1 serial port, FB programming

CPU unit with 30, 40, or 60 I/O points

Ethernet	1 x RS-232C port*1	positioning	option board	3 expansion units
Memory 4K steps	Clock	Battery-free	-20 to 60℃	USB port

CPU unit with 14 or 20 I/O points

Ethernet	1 x RS-232C port*1	positioning	option board	Expansion unit
Memory 4K steps	Clock	Battery-free	-20 to 60℃	USB port

*1. RS-232C: Screwless terminal block (6 terminals), RS-485: Screwless terminal block (3 terminals)

Option Board (for CP2E-N-type CPU Units)

1-port Serial Option Board


RS-232C


RS-422A/485


RS-422A/485
(isolated)

2-port Serial Option Board *2


RS-232C
RS-232C


RS-232C
RS-485 (isolated)


RS-485 (isolated)
RS-485 (isolated)

Analog Option Board *2


2 analog inputs
0 to 10 V,
0 to 20 mA


2 analog outputs
0 to 10 V


2 analog inputs
0 to 10 V, 0 to 20 mA
2 analog outputs
0 to 10 V

*2. Two 2-port serial option boards cannot be mounted in a CPU unit.
Two analog option boards also cannot be mounted in a CPU unit.

Expansion I/O Unit and Expansion Unit


40-point I/O Unit
32-point Output Unit


20-point I/O Unit
16-point Output Unit


8-point Input Unit
8-point Output Unit


Analog Input Unit
Analog Output Unit
Analog I/O Unit


4-ch Temperature
Sensor Unit
2-ch Temperature
Sensor Unit


12-ch Temperature
Sensor Unit


I/O Connecting Cable

Battery


Battery: only for Real time
Clock function-
CP2E-N/CP2E-S CPU Unit

Ordering Information

CPU Units

CP2E-N/Network Models

I/O points	Specifications						
	Power supply	Inputs	Outputs	Output type	Program capacity	DM Area capacity	Model
14	100 to 240 VAC	8	6	Relay	10K steps	16K words	CP2E-N14DR-A
				Transistor (sinking)			CP2E-N14DT-A
	24 VDC			Relay			CP2E-N14DR-D
				Transistor (sinking)			CP2E-N14DT-D
				Transistor (sourcing)			CP2E-N14DT1-D
20	100 to 240 VAC	12	8	Relay			CP2E-N20DR-A
				Transistor (sinking)			CP2E-N20DT-A
	24 VDC			Relay			CP2E-N20DR-D
				Transistor (sinking)			CP2E-N20DT-D
				Transistor (sourcing)			CP2E-N20DT1-D
30	100 to 240 VAC	18	12	Relay			CP2E-N30DR-A
				Transistor (sinking)			CP2E-N30DT-A
	24 VDC			Relay			CP2E-N30DR-D
				Transistor (sinking)			CP2E-N30DT-D
				Transistor (sourcing)			CP2E-N30DT1-D
40	100 to 240 VAC	24	16	Relay			CP2E-N40DR-A
				Transistor (sinking)			CP2E-N40DT-A
	24 VDC			Relay			CP2E-N40DR-D
				Transistor (sinking)			CP2E-N40DT-D
				Transistor (sourcing)			CP2E-N40DT1-D
60	100 to 240 VAC	36	24	Relay			CP2E-N60DR-A
				Transistor (sinking)			CP2E-N60DT-A
	24 VDC			Relay			CP2E-N60DR-D
				Transistor (sinking)			CP2E-N60DT-D
				Transistor (sourcing)			CP2E-N60DT1-D

CP2E-S/Standard Models

I/O points	Specifications						
	Power supply	Inputs	Outputs	Output type	Program capacity	DM Area capacity	Model
30	100 to 240 VAC	18	12	Relay	8K steps	8K words	CP2E-S30DR-A
	24 VDC			Transistor (sinking)			CP2E-S30DT-D
				Transistor (sourcing)			CP2E-S30DT1-D
40	100 to 240 VAC	24	16	Relay			CP2E-S40DR-A
	24 VDC			Transistor (sinking)			CP2E-S40DT-D
				Transistor (sourcing)			CP2E-S40DT1-D
60	100 to 240 VAC	36	24	Relay			CP2E-S60DR-A
	24 VDC			Transistor (sinking)			CP2E-S60DT-D
				Transistor (sourcing)			CP2E-S60DT1-D

CP2E-E/Essential Models

I/O points	Specifications						
	Power supply	Inputs	Outputs	Output type	Program capacity	DM Area capacity	Model
14	100 to 240 VAC	8	6	Relay	4K steps	4K words	CP2E-E14DR-A
20		12	8	Relay			CP2E-E20DR-A
30		18	12	Relay			CP2E-E30DR-A
40		24	16	Relay			CP2E-E40DR-A
60		36	24	Relay			CP2E-E60DR-A

For details, refer to datasheet of CP2E (Cat.No. P145).

FB Function Blocks are available to download free of charge from Omron website. (www.ia.omron.com/cp_fb)

Optional Products

Battery: only for Real time Clock function- CP2E-N/CP2E-S CPU Unit

Product name	Specifications	Model
Battery	CP2E-N, CP2E-S dedicated battery. Install when using the clock function	CP2W-BAT02

Option Boards for CP2E-N

Product name	Specifications	Model
1-port Serial Option Board	RS-232C	CP1W-CIF01
	RS-422A/485	CP1W-CIF11
	RS-422A/485 (isolated)	CP1W-CIF12-V1
2-port Serial Option Board *1	RS-232C 2port	CP2W-CIFD1
	RS-232C, RS-485 (isolated)	CP2W-CIFD2
	RS-485 (isolated) 2port	CP2W-CIFD3
Analog Option Board *1	2 analog inputs. 0 to 10 V (resolution: 1/4000), 0 to 20 mA (resolution: 1/2000)	CP1W-ADB21
	2 analog outputs. 0 to 10 V (resolution: 1/4000)	CP1W-DAB21V
	2 analog inputs. 0 to 10 V (resolution: 1/4000), 0 to 20 mA (resolution: 1/2000) 2 analog outputs. 0 to 10 V (resolution: 1/4000)	CP1W-MAB221

*1.Two 2-port serial option boards cannot be mounted in a CPU unit. Two analog option boards also cannot be mounted in a CPU unit.

Expansion I/O Units and Expansion Units

Unit type	Product name	Inputs	Outputs	Specifications	Model
CP1W Expansion I/O Unit	Input Unit	8	—	24 VDC input	CP1W-8ED
	Output Unit	—	8	Relay	CP1W-8ER
			8	Transistor (sinking)	CP1W-8ET
			8	Transistor (sourcing)	CP1W-8ET1
			16	Relay	CP1W-16ER
			16	Transistor (sinking)	CP1W-16ET
			16	Transistor (sourcing)	CP1W-16ET1
			32	Relay	CP1W-32ER
			32	Transistor (sinking)	CP1W-32ET
			32	Transistor (sourcing)	CP1W-32ET1
	I/O Unit	12	8	Relay	CP1W-20EDR1
		12	8	Transistor (sinking)	CP1W-20EDT
		12	8	Transistor (sourcing)	CP1W-20EDT1
		24	16	Relay	CP1W-40EDR
		24	16	Transistor (sinking)	CP1W-40EDT
		24	16	Transistor (sourcing)	CP1W-40EDT1
CP1W Expansion Unit	Analog Input Unit	4 ch	—	Input range: 0 to 5 V, 1 to 5 V, 0 to 10 V, -10 to 10 V, 0 to 20 mA, or 4 to 20 mA. Resolution: 1/6000	CP1W-AD041
		4 ch		Input range: 0 to 5 V, 1 to 5 V, 0 to 10 V, -10 to 10 V, 0 to 20 mA, or 4 to 20 mA. Resolution: 1/12000	CP1W-AD042
	Analog Output Unit	—	2 ch	Output range: 1 to 5 V, 0 to 10 V, -10 to 10 V, 0 to 20 mA, or 4 to 20 mA. Resolution: 1/6000	CP1W-DA021
			4 ch		CP1W-DA041
			4 ch	Output range: 1 to 5 V, 0 to 10 V, -10 to 10 V, 0 to 20 mA, or 4 to 20 mA. Resolution: 1/12000	CP1W-DA042
	Analog I/O Unit	2 ch	1 ch	Input range: 0 to 5 V, 1 to 5 V, 0 to 10 V, -10 to 10 V, 0 to 20 mA, or 4 to 20 mA. Output range: 1 to 5 V, 0 to 10 V, -10 to 10 V, 0 to 20 mA, or 4 to 20 mA. Resolution: 1/6000	CP1W-MAD11
		4 ch	2 ch	Input range: 0 to 5 V, 1 to 5 V, 0 to 10 V, -10 to 10 V, 0 to 20 mA, or 4 to 20 mA. Output range: 1 to 5 V, 0 to 10 V, -10 to 10 V, 0 to 20 mA, or 4 to 20 mA. Resolution: 1/12000	CP1W-MAD42
		4 ch	4 ch		CP1W-MAD44
	Temperature Sensor Unit	2 ch	—	Sensor type: Thermocouple (K or J)	CP1W-TS001
		4 ch			CP1W-TS002
		2 ch		Sensor type: Platinum resistance thermometer (Pt100 or JPt100)	CP1W-TS101
		4 ch			CP1W-TS102
		4 ch		Sensor type: Thermocouple (K or J). 4 ch or 2 analog inputs. Input range: 0 to 10 V, 1 to 5 V, or 4 to 20 mA. Resolution: 1/12000	CP1W-TS003
		12 ch		Sensor type: Thermocouple (K or J)	CP1W-TS004
I/O Connecting Cable		800 mm extension cable for CP1W Expansion I/O Units and CP1W Expansion Units. Only one I/O Connecting Cable can be used in each PLC			CP1W-CN811

Software

Product name	Specifications	License	Media	Model
CX-One Lite Ver4.□	A subset of the complete CX-One package that provides only the support software required for compact PLC applications	1	DVD	CXONE-LT01D-V4
Cx-One Ver4.□	A comprehensive software package that integrates support software for Omron PLCs and components	1	DVD	CXONE-AL01D-V4