Technical Explanation for Temperature Controllers

Introduction

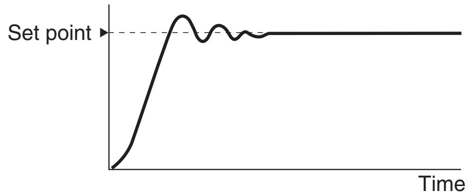
What Is a Temperature Controller?

A Temperature Controller is a device that is used to control a heater or other equipment by comparing a sensor signal with a set point and performing calculations according to the deviation between those values. Devices that can handle sensor signals other than for temperature, such as humidity, pressure, and flow rate, are called Controllers. Electronic controllers are specifically called Digital Controllers.

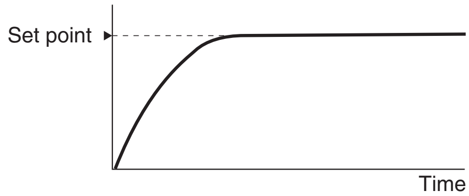
Temperature Control

Temperature Controllers control temperature so that the process value will be the same as the set point, but the response will differ due to the characteristics of the controlled object and the control method of the Temperature Controller. Typically, a response shown in Figure (2), where the set point is reached as quick as possible without overshooting, is required in a Temperature Controller. There are also cases such as the one shown in Figure (1), where a response quickly increases the temperature even if it overshoots is required, and the one shown in Figure (3), where a response slowly increases the temperature is required.

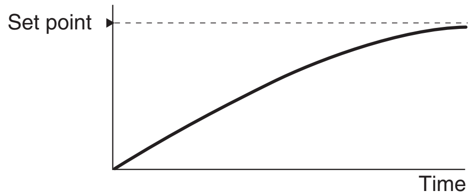
(1) Response where the process value settles on the set point while repeatedly overshooting and undershooting



(2) Proper response

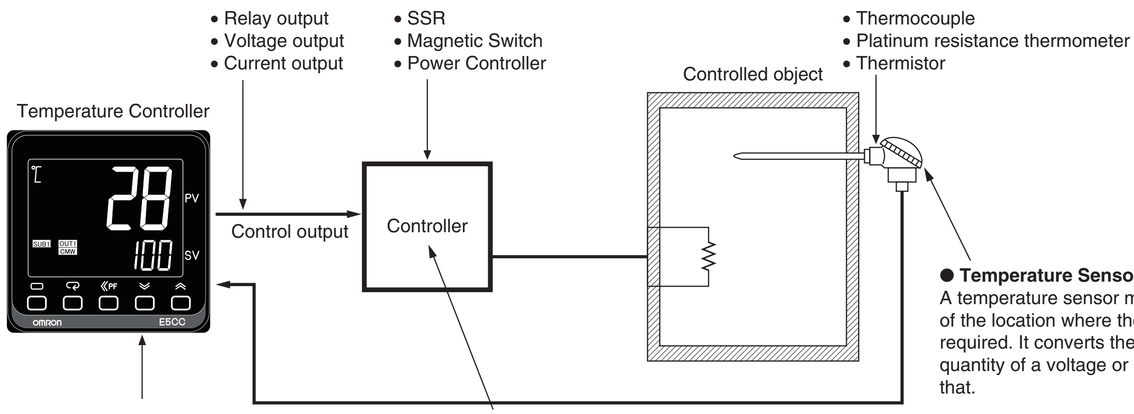


(3) Response where the process value slowly reaches the set point



Temperature Control Configuration Example

The following example describes the basic configuration for temperature control.



● **Temperature Sensor**
A temperature sensor measures the temperature of the location where the temperature control is required. It converts the temperature to a physical quantity of a voltage or resistance and outputs that.

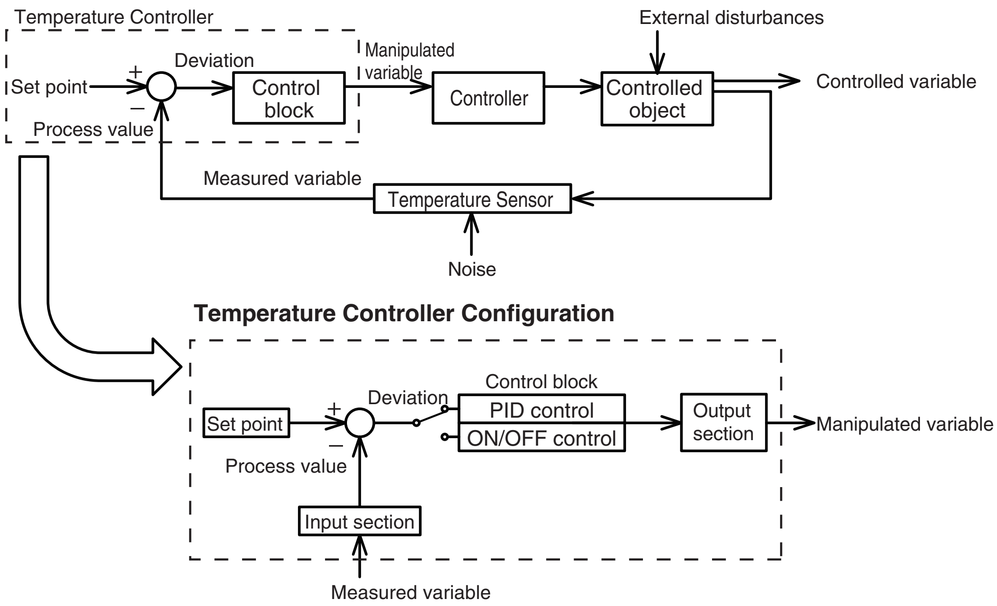
● **Temperature Controller**
A Temperature Controller converts the output from a temperature sensor to the process value and outputs the control output to the controller so the process value will approach the set point.

● **Controller**
A controller is a magnetic switch that turns the current to a heater ON and OFF, a valve that supplies fuel, or some other type of device that is used to heat or cool a furnace, tank, or other controlled object. If the output of the Temperature Controller is a relay output, a relay may also function as the controller.

Temperature Controller Principle

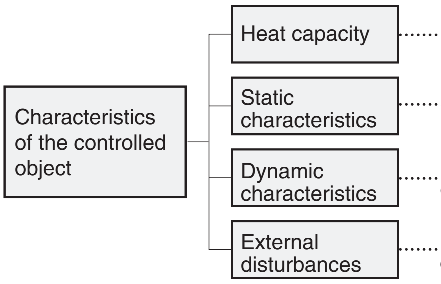
The following figure shows an example of a feedback control system used for temperature control.
The major parts of the feedback control system are built into the Temperature Controller. A feedback control system can be built and temperature can be controlled by combining a Temperature Controller with a controller and temperature sensor that are suitable for the controlled object.

Configuration of a Feedback Control System



Characteristics of the Controlled Object

Before selecting a Temperature Controller or temperature sensor, it is necessary to understand the thermal characteristics of the controlled object for proper temperature control.



Heat capacity, which indicates the ease of heating, varies with the capacity of the furnace.

Static characteristics, which indicate heating capability, vary with the capacity of the heater.

Dynamic characteristics, which indicate the startup characteristics (i.e. excessive response) of heating, vary with heater and furnace capacity that can affect each other in a complex way.

External disturbances cause temperature changes. For example, the opening or closing of a door on a constant temperature tank can cause external disturbances that generate temperature changes.

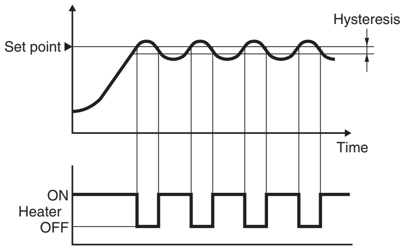
Sensors
Switches
Safety Components
Relays
Control Components
Automation Systems
Motion / Drives
Energy Conservation Support / Environment Measure Equipment
Power Supplies / In Addition
Others
Common

Control Methods

ON/OFF Control Action

As shown in the graph below, if the process value is lower than the set point, the output will be turned ON and power will be supplied to the heater. If the process value is higher than the set point, the output will be turned OFF and power to the heater will be shut off. This control method, in which the output is turned ON and OFF based on the set point in order to keep the temperature constant, is called ON/OFF control action. With this action, the temperature is controlled using two values (i.e., 0% and 100% of the set point). Therefore, the operation is also called two-position control action.

Characteristics of ON/OFF control action

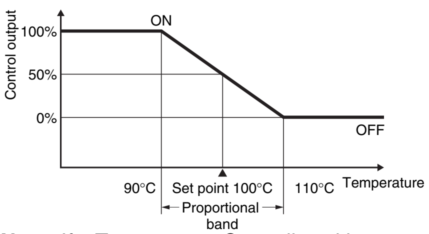


P Action (Proportional Control Action)

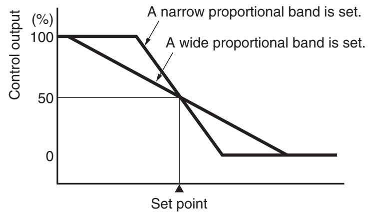
P action (or proportional control action) is used to output a manipulated variable (control output variable) that is proportional to the deviation in order to decrease the deviation between the process value and set point. A proportional band is set centering on the set point, and the output is determined with the following rules.

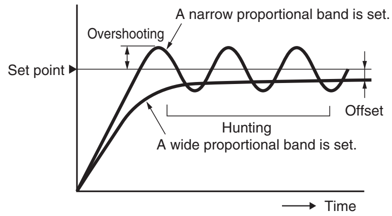
- A manipulated variable that is proportional to the deviation is output when the process value is within the proportional band.
- A 100% manipulated variable is output when the process value is lower than the proportional band.
- A 0% manipulated variable is output when the process value is higher than the proportional band.

Smoother control than the ON/OFF control action is possible because the output is gradually changed near the set point according to deviation. However, if the temperature is controlled with the proportional action alone, it will stabilize at a temperature that is off from the set point (offset).



Note: If a Temperature Controller with a temperature range of 0°C to 400°C has a 5% proportional band, the width of the proportional band will be converted into a temperature range of 20°C. In this case, a full output is kept turned ON until the process value reaches 90°C, and the output is OFF periodically when the process value exceeds 90°C, provided the set point is 100°C. When the process value is 100°C, there will be no difference in time between the ON period and the OFF period (i.e. the output is turned ON and OFF 50% of the time.)

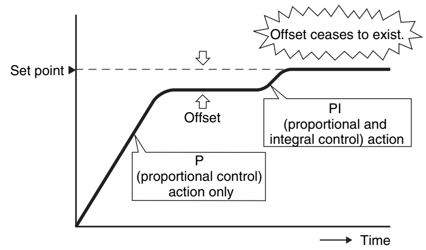


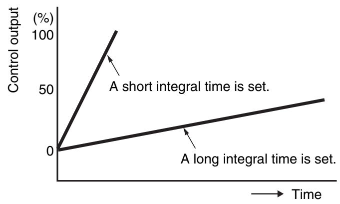


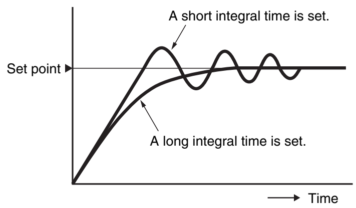
I Action (Integral Control Action)

I action (or integral action) increases or decreases the manipulated variable according to the size and duration of the deviation.

The temperature will stabilize at a temperature off from the set point (offset) with only the proportional action, but the deviation with the passage of time will be decreased and the process value will be the same as the set point by combining the proportional and integral actions.

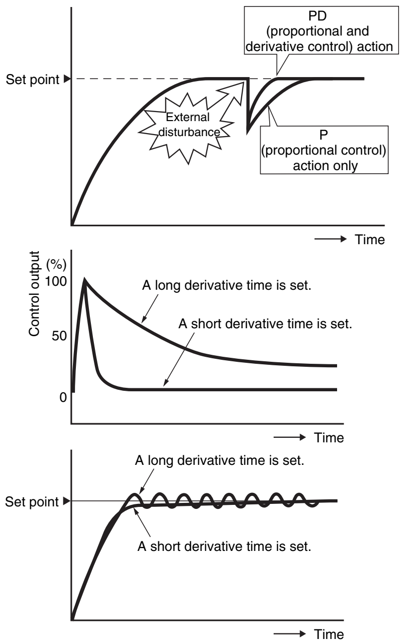






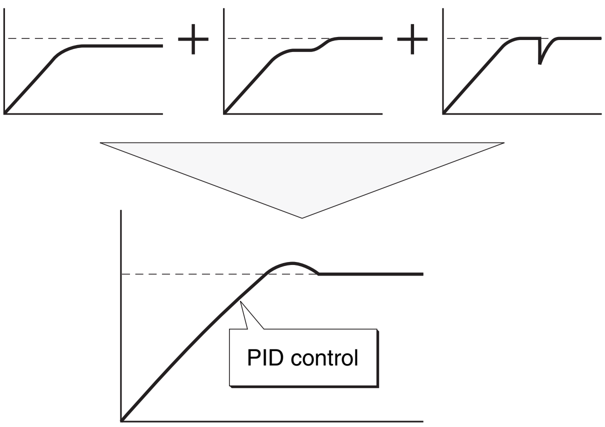
D Action (Derivative Control Action)

D action (or derivative action) provides a manipulated variable in response to abrupt changes in the process value, due to factors such as an external disturbance, so that control will quickly return to the original status.The proportional and integral actions both corrects the control results, so the response to abrupt changes is delayed. The derivative action compensates for that drawback and provides a large manipulated variable for rapid external disturbances.



PID Control

PID control is a combination of proportional, integral, and derivative control actions. The temperature is controlled smoothly here by proportional control action without hunting, automatic offset adjustment is made by integral control action, and quick response to an external disturbance is made possible by derivative control action.

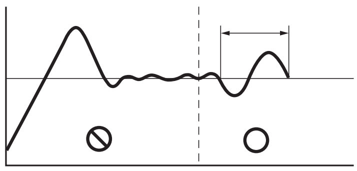


Two PID Control

Conventional PID control uses a single control block to control the responses of the Temperature Controller to a set point and to external disturbances. Therefore, the response to the set point will oscillate due to overshooting if importance is placed on responding to external disturbances with the P and I parameters set to small values and the D parameter set to a large value in the control block. On the other hand, the Temperature Controller will not be able to respond to external disturbances quickly if importance is placed on responding to the set point (i.e., the P and I parameters are set to large values). This makes it impossible to satisfy both the types of response in this case.
Two PID control provides good response for both response to the set point and an external disturbance.

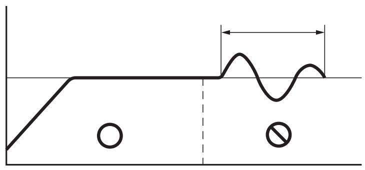
PID Control

(1)



Response to the set point will be slow if response to the external disturbance is improved.

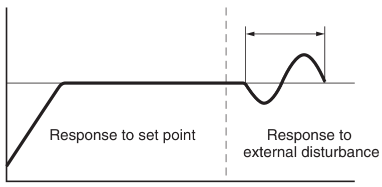
(2)



Response to the external disturbance will be slow if response to the set point is improved.

Two PID Control

(3)



Controls both the set point and the external disturbance response.

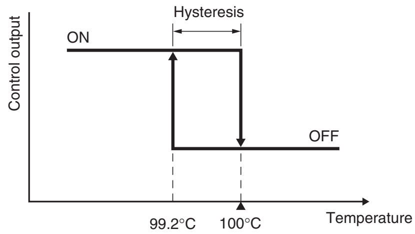
Explanation of Terms

Control Terminology

Hysteresis

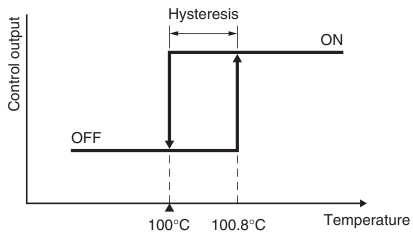
ON/OFF control turns the control output ON and OFF at the set point, so if there are small amounts of noise near the set point, the output will turn ON and OFF frequently (which is called chattering). This will shorten the life of the output relay or unfavorably affects some devices connected to the Temperature Controller. To prevent this from happening, a temperature band (hysteresis) is created between the ON and OFF operations. This gap is called hysteresis.

Hysteresis (Reverse Operation)



Note: Hysteresis indicates 0.8°C.

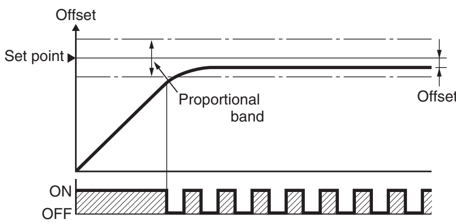
Hysteresis (Direct Operation)



Note: Hysteresis indicates 0.8°C.

Offset

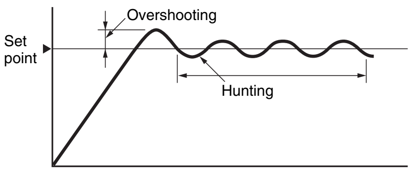
Proportional control action causes an error in the process value due to the heat capacity of the controlled object and the capacity of the heater. The result is a small discrepancy between the process value and the set point in stable operation. This error is called offset. Offset is the difference in temperature between the set point and the actual process temperature. It may exist above or below the set point.



Hunting and Overshooting

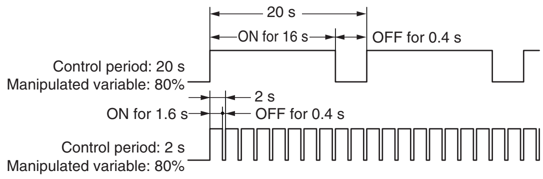
ON/OFF control action often involves the waveform shown in the following diagram. A temperature rise that exceeds the set point after temperature control starts is called overshooting. Temperature oscillation near the set point is called hunting. Improved temperature control is to be expected if the degree of overshooting and hunting are low.

Hunting and Overshooting in ON/OFF Control Action



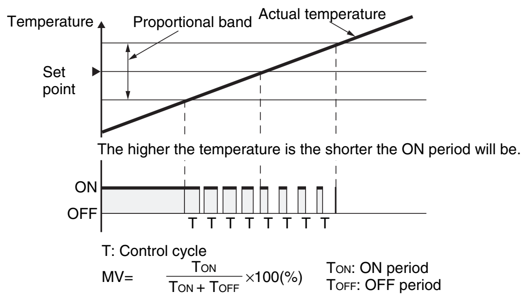
Time-proportioning Control Action

Relays and SSRs can output only ON (100%) and OFF (0%). PID control, however, outputs the manipulated variable between 0% and 100%. Time-proportioning control action is an output method that adds a time parameter (control period) to the manipulated variable, which allows for a 0% to 100% output when using an ON/OFF output. A manipulated variable between 0% and 100% can be output by turning the output ON for the control period (seconds) multiplied by the manipulated variable (%), and then turning the output OFF for the remainder of the control period. Because the output turns ON and OFF only once during the control period, a long control period delays the control response, and a short control period speeds up the control response. If the control period is short, the life expectancy of output devices with contacts such as relays will decrease. As a general rule, set the control period for relay outputs to 20 seconds, and set the control period for SSR outputs to 2 seconds.



Proportional Band

The proportional band is a parameter that sets the range in which control performs the proportional action. When the process value enters the proportional band, the proportional action outputs a manipulated variable between 0% and 100% that is proportional to the deviation between the set point and the process value. When the process value is outside the proportional band in heating control, the manipulated variable is output at 100% when the process value is lower and 0% when higher than the band.



Example:
If the control cycle is 10 s with an 80% control output, the ON and OFF periods will be as follows.

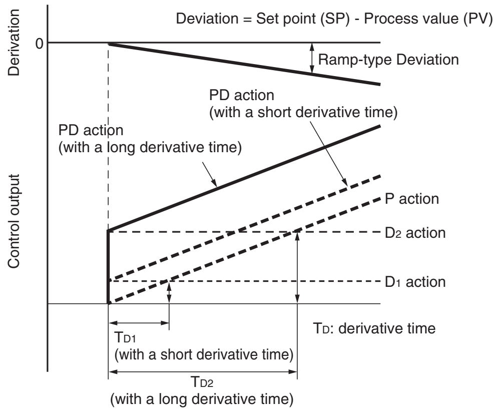
T_{ON}: 8 s

T_{OFF}: 2 s

Derivative Time

The derivative action are not used alone for control. It is used for control together with the proportional action. The control method that combines the proportional action and the derivative action is called the PD actions. When a ramp-type deviation (i.e., a deviation with a constant slope) is provided in the PD actions as shown in the figure, the time until the derivative manipulated variable reaches the same manipulated variable as the proportional action is called the derivative time. Therefore, this shows that the longer the derivative time is, the stronger the correction by the derivative action will be.

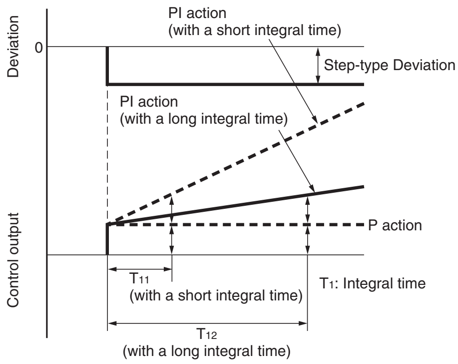
PD Action and Derivative Time



Integral Time

When a step-type deviation is added in the PI actions that combine the proportional and derivative actions or the PID actions that combine the proportional, integral, and derivative actions, the time until the integral manipulated variable reaches the same manipulated variable as the proportional action is called the integral time. Therefore, the shorter the integral time is, the stronger the integral action will be. But if the integral time is too short, the correction will be too strong and hunting may occur.

PI Action and Integral Time



Constant Value Control

For constant value control, control is preformed at a specific set point.

Program Control

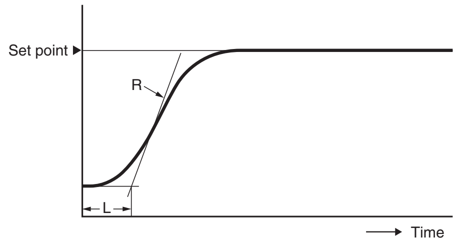
Program control is used to control temperature for a set point that will change at predetermined time interval according to a program.

Autotuning

The PID constants that can be used for good temperature control depend on the characteristics of the controlled object. The method to derive suitable PID constants for the differing characteristics of controlled objects is called autotuning. Typical methods are the step response method and limit cycle method.

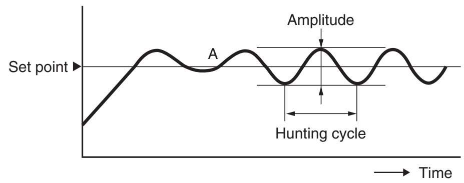
Step Response Method

A manipulated variable of 100% is output in steps, the maximum temperature ramp R and dead time L are measured from the response of the controlled object, and the PID constants are calculated from the values of R and L.



Limit Cycle Method

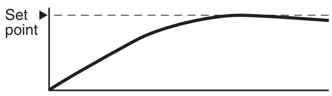
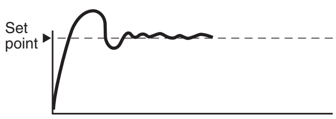
Outputs a manipulated variable at 100% and 0% alternately, and the PID constants are calculated from the hunting cycle and amplitude values that occur in the controlled object. Autotuning typically refers to the limit cycle method.



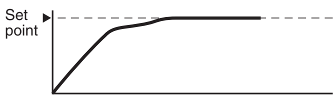
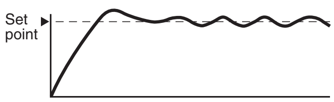
Readjusting PID Constants

Control can usually be performed without problems using the PID constants that are calculated with autotuning. Depending on the application, the priorities of overshooting suppression, response speed improvement, and stability improvement may be different. In those cases, the individual values of the PID constants can be adjusted by referring to the following examples to make the response behave closer to the anticipated response.

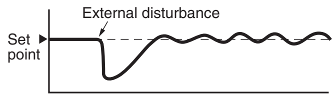
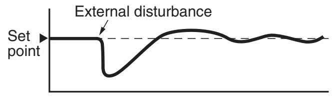
Response to Change in the Proportional Band

Wider		It is possible to suppress overshooting although a comparatively long startup time and set time will be required.
Nar-rower		The process value reaches the set point within a comparatively short time and keeps the temperature stable although overshooting and hunting will result until the temperature becomes stable.

Response to Change in Integral Time

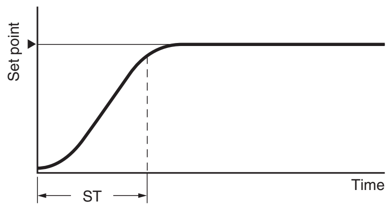
Wider		The set point takes longer to reach. It is possible to reduce hunting, overshooting, and undershooting although a comparatively long startup time and set time will be required.
Nar-rower		The process temperature reaches the set point within a comparatively short time although overshooting, undershooting, and hunting will result.

Response to Change in Derivative Time

Wider		The process value reaches the set point within a comparatively short time with comparatively small amounts of overshooting and undershooting. Fine-cycle hunting will result due to the change in process value.
Nar-rower		The process value will take a relatively long time to reach the set point with heavy overshooting and undershooting.

Self-tuning

The PID constants are calculated with the step response tuning when the Temperature Controller operation begins and when the set point is changed. Once the PID constants have been calculated, self-tuning is not executed when the next control operation is started as long as the set point remains unchanged.



Models and Tuning Methods

Model	Tuning Methods
E5□C	AT, ST
E5□N *	AT, ST
E5□R	AT
E5CS-U/E5CSV	AT, ST
E5CB	AT
EJ1	AT
E5ZN	AT
C200H-TC	AT
C200H-TV	AT
C200H-PID	AT

ST: Self-tuning
AT: Autotuning
Note: Not including the E5ZN

Control Outputs

- Control output
  - ON/OFF output
    - Relay output ····· Contact relay output used for control methods with comparatively low switching frequencies. A load may also be driven directly.
    - SSR output ····· Non-contact solid-state relay output for switching 1 A maximum.
    - Voltage output ····· Drives an external SSR with a large capacity by a 12-VDC ON/OFF pulse output. This output is ideal for a high switching frequency in ON/OFF control and the time-proportioning control action in PID control.
  - Linear output
    - Current output ····· Continuous 4- to 20-mA or 0- to 20-mA DC output used for driving power controllers and electromagnetic valves. Ideal for high-precision control. A preset linear output is produced if the load resistance falls below allowable levels.
    - Voltage output ····· Continuous 0 to 5 or 0 to 10 VDC output used for driving pressure controllers. Ideal for high-precision control.

Alarm Terminology

Alarm Output

Some Temperature Controllers output an alarm signal to the alarm output, while others allow you to assign an auxiliary output or control output as the output destination.

Alarm Operation

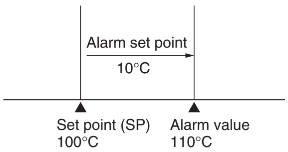
The process value, alarm value, and set point are compared, and a signal is output according to the operating mode specified by the alarm type. The main operating modes are a deviation alarm, absolute-value alarm, standby sequence alarm, heater burnout alarm, SSR failure alarm, and loop burnout alarm. These alarms may also be combined.

Deviation Alarm

The deviation alarm turns ON according to the deviation from the set point in the Temperature Controller.

Setting Example

Alarm temperature is set to 110°C.
The alarm set point is set to 10°C.

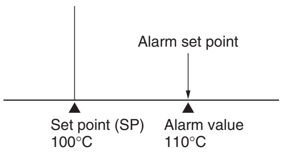


Absolute-value Alarm

The absolute-value alarm turns ON according to the alarm temperature regardless of the set point in the Temperature Controller.

Setting Example

Alarm temperature is set to 110°C.
The alarm set point is set to 110°C.

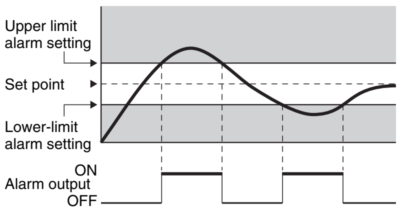


Standby Sequence Alarm

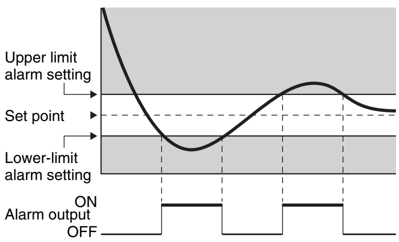
It may be difficult to keep the process value outside the specified alarm range in some cases (e.g., when starting up the Temperature Controller), and the alarm turns ON abruptly as a result. This can be prevented with the standby sequential function of the Temperature Controller. This function makes it possible to ignore the process value right after the Temperature Controller is turned ON or right after the Temperature Controller starts temperature control. In this case, the alarm will turn ON if the process value enters the alarm range after the process value has been once stabilized.

Example of Alarm Output with Standby Sequence Set

Temperature rise



Temperature drop



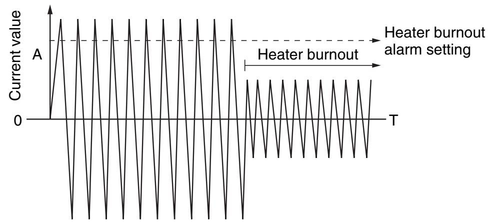
SSR Failure Alarm

SSRs often fail structurally in a short-circuit mode, and if there is a short-circuit failure, there is a risk of a hazardous situation where the temperature of the heater may continue to increase. The SSR failure alarm detects an SSR short-circuit failure and outputs an alarm. The heater current is detected using a current transformer (CT), and the SSR failure alarm is output if the current continues flowing to the heater even though the output from the Temperature Controller that drives the SSR is OFF.

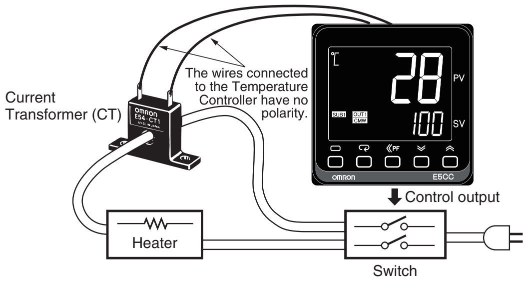
Heater Burnout Alarm

If equipment continues to operate when people are not aware that the heater has burned out, products may become faulty, and in the worst case, the equipment may be damaged. The heater burnout alarm detects burnouts in heaters and disconnected heater cables. The heater current is detected using a current transformer (CT), and the heater burnout alarm is output if the current does not flow to the heater even though the output of the Temperature Controller that drives the heater is ON. A heater burnout in a three-phase heater can also be detected if the type of Temperature Controller that can be connected to two current transformers (CTs) is used.

* When the Temperature Controller output is a current output, the heater burnout alarm cannot be used.

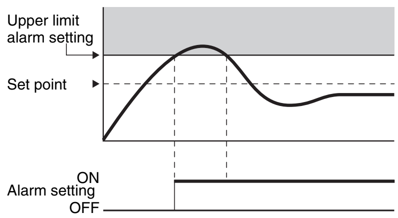


Heater current waveform (CT waveform)



Alarm Latch

An alarm latch can be used to keep the alarm ON until the latch is canceled regardless of the temperature after the alarm output has turned ON.



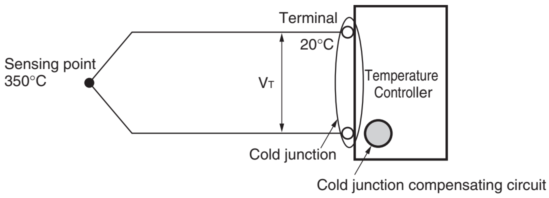
LBA (Loop Burnout Alarm)

An alarm is output by assuming the occurrence of control loop failure when deviation is a certain value or higher and the input does not change in the direction that reduces the deviation, even though control is being performed. This alarm can be used when operation is started but the sensor has not been installed after replacing the heater and as a method for detecting missing sensors.

Temperature Sensor Terminology

Cold Junction Compensation

A thermocouple produces a voltage (i.e., a thermoelectromotive force) from the temperature difference between the hot junction and the cold junction on the opposite side. For this reason, a thermocouple outputs a relative temperature, not an absolute temperature. In order for the Temperature Controller to calculate the absolute temperature from the relative temperature that is output by the thermocouple, the effect of the cold junction temperature is compensated for, or canceled out, by detecting the temperature of the cold junction and adding a thermoelectromotive force that corresponds to that temperature to the thermoelectromotive force of the thermocouple. The method of calculating the absolute temperature of the hot junction by adding a voltage is called cold junction compensation.



In the above diagram, the thermo-electromotive force (1) V_T that is measured at the input terminal of the Temperature Controller is equal to V (350, 20).

Here, V (A, B) gives the thermo-electromotive force when the cold junction is A °C and the cold junction is B °C.

Based on the law of intermediate temperatures, a basic behavior of thermocouples, (2) V (A, B) = V (A, C) - V(B, C).

When the ambient (terminal section) temperature is 20°C, the temperature sensor inside the Temperature Controller detects 20°C. If we add the voltage V(20, 0) that corresponds to 20°C in the standard electromotive force table to the right side, we get the following:

$$\underbrace{V(350, 20)}_{\text{Thermo-electromotive force from thermocouple}} + \underbrace{V(20, 0)}_{\text{Electromotive force generated by the cold junction compensation circuit}}$$

If we expand the first part of formula (2) with A = 350, B = 20, and C = 0, we get the following:
= V{(350, 0) – V(20, 0)} + V(20, 0) = V(350, 0).

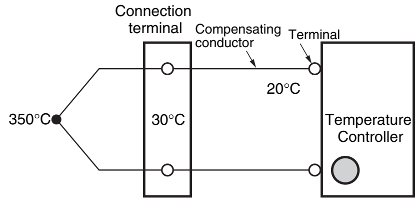
V(350, 0) is the thermo-electromotive force for a cold junction temperature of 0°C. This is the value that is defined as the standard thermo-electromotive force by JIS, so if we check the voltage, we can find the temperature of the hot junction (here, 350°C).

Compensating Conductor

If the thermocouple temperature sensor cable does not reach the Temperature Controller and the cable between the sensor and the Temperature Controller is extended with copper wire, a large temperature error will occur.

A compensating conductor must be used to extend the thermocouple temperature sensor cable. A compensating conductor is a cable that produces nearly the same thermoelectromotive force as the thermocouple around room temperature, and a compensating conductor that is suitable for the thermocouple must be used. Compared to a thermocouple cable, a compensating conductor is generally inexpensive. Compensating conductors suitable for various thermocouples are available commercially.

Example of Compensating Conductor Use



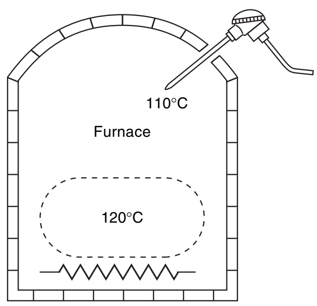
$$\underbrace{V(350, 30)}_{\text{Thermo-electromotive force from thermocouple}} + \underbrace{V(30, 20)}_{\text{Thermo-electromotive force from compensating conductors}} + \underbrace{V(20, 0)}_{\text{Voltage from cold junction compensation}}$$

= {V (350, 30) - V (30, 0)} + {V(30, 0) - V (20, 0)} + V (20, 0)
= V (350, 0)

If you extend the cable of a platinum resistance thermometer or thermistor temperature sensor, using a compensating conductor will actually cause a large temperature error. Extend the cable using a cable with sufficiently low conductor resistance.

Input Shift

As the process value, the Temperature Controller displays the result of adding an input shift to or subtracting it from the temperature measured by the temperature sensor. You can use the input shift to compensate the Temperature Controller display when the temperature sensor measurement point and the point at which you intend to measure temperature are different and the temperature difference is already known.

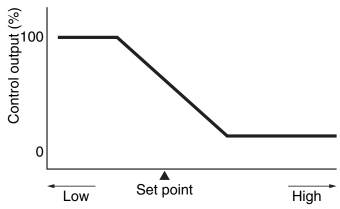


Input compensation value: 10°C (Displayed value is 120°C.)
(120 – 110 = 10)

Output Terminology

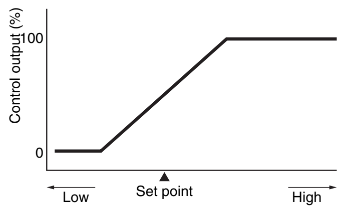
Reverse Operation (Heating)

Reverse operation is used to increase the manipulated variable when the temperature is lower than the set point. Heating control is reverse operation.



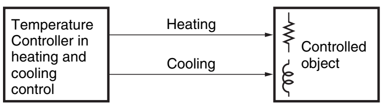
Direct Operation (Cooling)

Direct operation is used to increase the manipulated variable when the temperature is higher than the set point. Cooling control is direct operation.

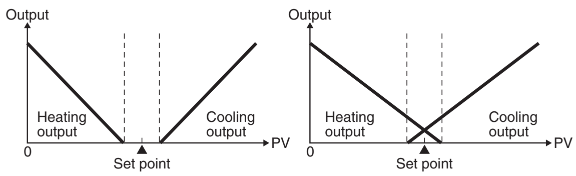


Heating and Cooling Control

Temperature control over a controlled object would be difficult if heating was the only type of control available, so cooling control was also added. Two control outputs (one for heating and one for cooling) can be provided by one Temperature Controller.

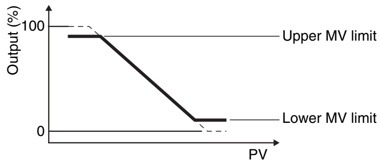


Heating and Cooling Outputs

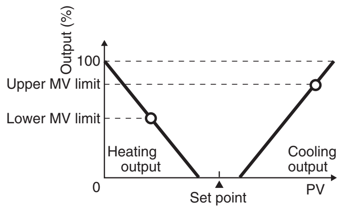


MV (Manipulated Variable) Limiter

The MV upper limit and MV lower limit are used to set the upper and lower limits of the manipulated variable that will be output. When the manipulated variable calculated by the Temperature Controller is outside the range of the MV limiter, the actual output will be the upper limit or the lower limit.

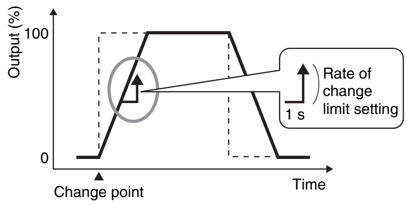


With heating and cooling control, the cooling MV is treated as a negative value. Generally speaking then, the upper limit (positive value) is set to the heating output and the lower limit (negative value) is set to the cooling output as shown in the following diagram.



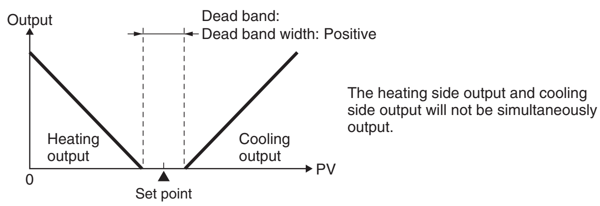
Rate of Change Limit

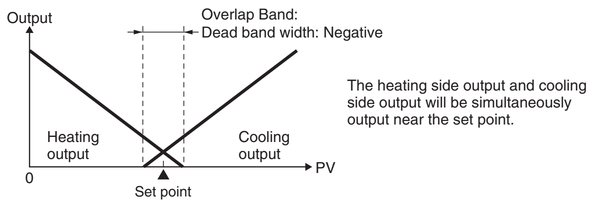
The rate of change limit for the MV sets the amount of change that occurs per second in the MV. If the MV calculated by the Temperature Controller changes significantly, the actual output follows the rate of change limiter setting for MV until it approaches the calculated value.



Dead Band

The overlap band and dead band are set for the cooling output. A negative value here produces an overlap band and a positive value produces a dead band.





Cooling Coefficient

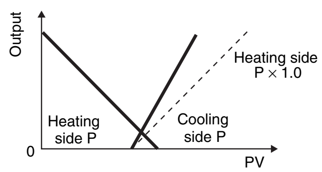
For Temperature Controllers capable of heating/cooling control that do not have separate PID constants for the heating and cooling, it may not be possible to obtain good control performance with the same PID constants when the heating and cooling characteristics of the controlled object differ greatly. In this case, adjust the proportional band on the cooling side (cooling side P) with the cooling coefficient until heating and cooling side control are balanced. The P for heating and cooling side can be calculated using the following formulas.

Heating side P = P

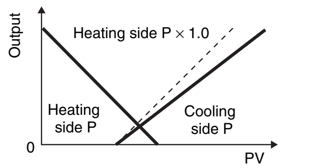
Cooling side P = Heating side P x cooling coefficient

For cooling side P control when heating side characteristics are different, multiply the heating side P by the cooling coefficient.

Heating Side P × 0.8



Heating Side P × 1.5



Heating/Cooling PID Control

For Temperature Controllers that can set PID control separately for heating and cooling, the PID constants for these will be automatically set by selecting an adjustment method with the heating/cooling tuning method according to the control characteristics of the cooling side, and then executing autotuning.

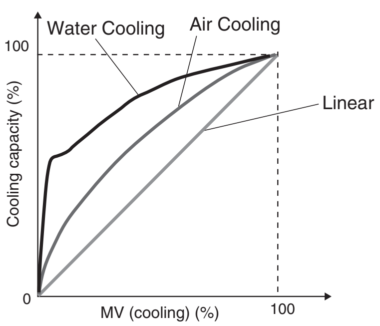
Parameter	Setting
Heating/Cooling Tuning Method	Same as heating control
	Linear
	Air cooling
	Water cooling

Linear Tuning

Control that is suitable for an application that has linear cooling characteristics is performed.

Air Cooling/Water Cooling Tuning

Control that is suitable for an application that does not have linear cooling characteristics (such as plastic molding machines) is performed. The response is fast and the response characteristics are stable.

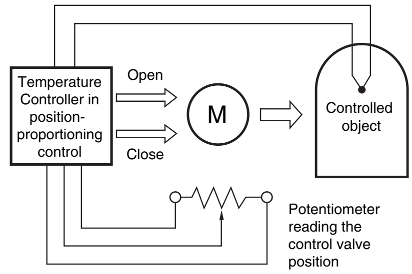


Cooling Characteristic

Positioning-Proportional Control

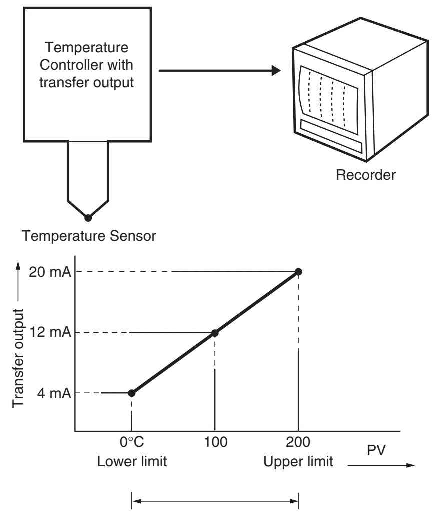
This is also called ON/OFF servo control. When a Control Motor or Modutrol Motor with a valve is used in this control system, a potentiometer for open/close control reads the degree of opening (position) of the control valve, outputs an open and close signal, and transmits the control output to Temperature Controller. The Temperature Controller outputs two signals: an open and close signal.

Floating control (feedback of the valve position is not provided with a potentiometer; control is possible even without a potentiometer) can also be selected.



Transfer Output

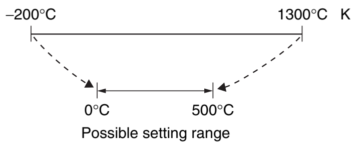
There may be situations where you want to send the process value and set point to a recorder, another Temperature Controller, or a PLC using a method other than communications. The transfer output converts one value out of process value, set point, or other value to a current between 4 and 20 mA and outputs it. The device that receives the transfer output must support a current input between 4 and 20 mA.



Setting Terminology

Set Limit

The range in which the set point can be set is determined by the type of temperature sensor, so a large value can be set. The set limit can restrict the temperature range that can be set in cases where the equipment will be damaged if a temperature is set that is higher than the temperature that will actually be used.

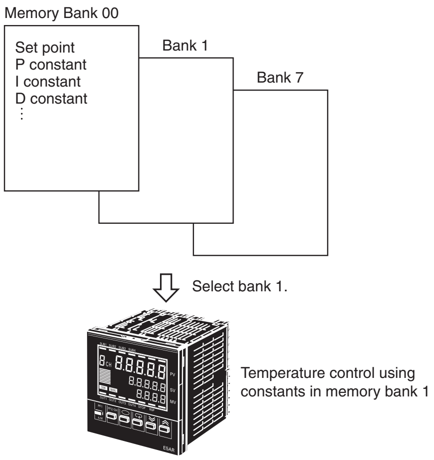


Multiple Set Points

Multiple set points can be preset and then switched using the front keys or event inputs.

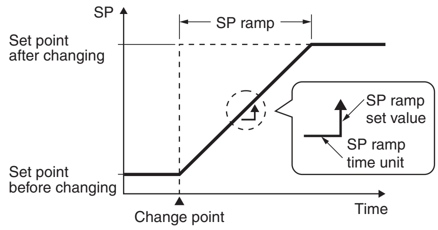
Setting Memory Banks

Temperature Controllers that have multiple set points, PID constants, and alarm values save these parameters in groups called banks. The parameters registered in a bank can be changed at once by switching banks during control.



Set Point (SP) Ramp

Use this function to increase the temperature at a predetermined rate or to increase the temperature to the target temperature in a predetermined time. When the SP ramp is enabled, the set point will be set and the temperature will be controlled until it reaches the set point as shown in the following figure.



Remote Set Point (SP) Input

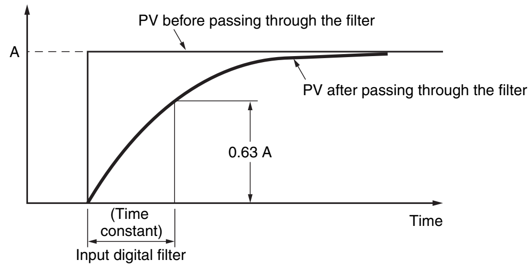
The remote SP is used to set and change the set point with an external analog signal (4 to 20 mA). Enable the remote SP to control the temperature using the remote SP as the set point.

Event Input

The event input is used to input an ON/OFF signal to the Temperature Controller. A function can be assigned to the input, such as switching multi-SPs or RUN/STOP, and this allows the Temperature Controller to be externally controlled.

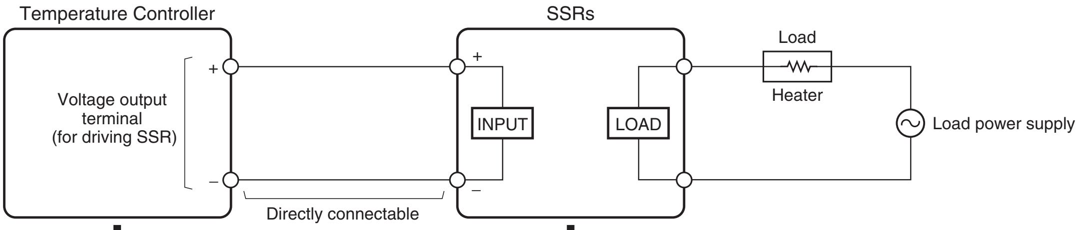
Input Digital Filter

The input digital filter is used when the external noise in the sensor input signal is large and control or measurements are unstable. The process value that will be used for control is a value that has passed through the input digital filter. The input digital filter setting value is the time constant of the digital filter. The following figure shows the relationship between the time constant and the process value (PV) after passing through the filter.



Further Information

Connection Examples between Temperature Controllers and SSRs

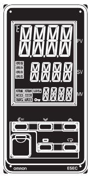


Number of Connectable SSRs in parallel

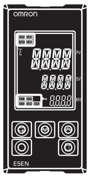
SSR	Temperature Controllers with voltage output of 40 mA at 12 VDC	Temperature Controllers with voltage output of 21 mA at 12 VDC
G3PF	8	4
G3PE (Single-phase)	5 *1	3 *2
G3PE (Three-phase)	4	2
G3PA	5 *3	3 *4
G3NA	5 *5	3 *6
G3NE	2	1
G3PH	8	4

Temperature Controllers with voltage output of 40 mA at 12 VDC

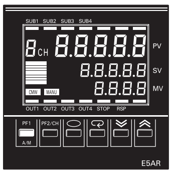
E5EC/E5AC
E5EC-T/E5AC-T



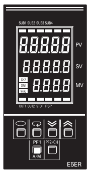
E5AN-H/E5EN-H



E5AR/E5AR-T

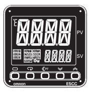


E5ER/E5ER-T



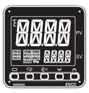
Temperature Controllers with voltage output of 21 mA at 12 VDC

E5CC/-T

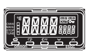


E5CN-H

E5CC-U

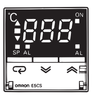


E5GC

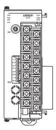


E5CB

E5CS Series



EJ1

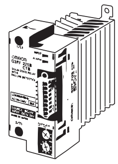


E5DC

G3PF (SSR with built-in Current Transformer)
25 A or 35 A at 240/480 VAC

Rated input voltage:
12 to 24 VDC

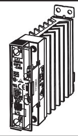
With built-in CT. Detects heater burnout and SSR short-circuit failures.



G3PE (Single-phase)
15 A, 25 A, 35 A, or 45 A at 240/480 VAC

Rated input voltage:
12 to 24 VDC

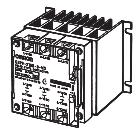
Extremely thin Relays integrated with heat sinks.



G3PE (Three-phase)
15 A, 25 A, 35 A, or 45 A at 240/480 VAC

Rated input voltage:
12 to 24 VDC

Slim design with 3-phase output and built-in heat sinks.

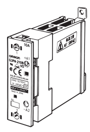


Note: Refer to your OMRON website for details.

G3PA
10 A, 20 A, 40 A, or 60 A at 240 VAC
20 A, 30 A, or 50 A at 480 VAC

Rated input voltage:
5 to 24 VDC
or 12 to 24 VDC

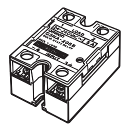
Thin Relays integrated with heat sinks.



G3NA
5 A, 10 A, 20 A, 40 A, 75 A, or 90 A at 240 VAC
10 A, 20 A, 40 A, 75 A, or 90 A at 480 VAC

Rated input voltage:
5 to 24 VDC

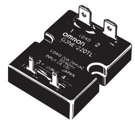
Standard model with screw terminals.



G3NE
5 A, 10 A, or 20 A at 240 VAC

Rated input voltage:
12 VDC

Compact, low-cost model with faston terminals.



G3PH
75 A or 150 A at 240/480 VAC

Rated input voltage:
5 to 24 VDC

For high-power heater control.

● Calculating the Number of Connectable SSRs in Parallel

(A): The maximum load current for the voltage output (for driving SSR) of each Temperature Controller.
(B): SSR input current
(A) ÷ (B) = Number of connectable SSRs

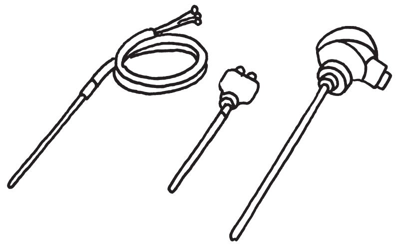
*1. Two G3PE-BL SSRs can be connected.
*2. One G3PE-BL SSR can be connected.
*3. Two G3PA-BL SSRs can be connected.
*4. One G3PA-BL SSR can be connected.
*5. Two of the -UTU models of the G3NA SSRs can be connected.
*6. One of the -UTU model of the G3NA SSRs can be connected.
Four of the 480-VAC models of the G3NA SSRs can be connected.

FAQs

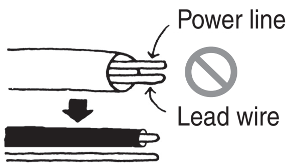
The temperature error of the Temperature Controller seems large. What is the cause of this?

The following are possible causes.

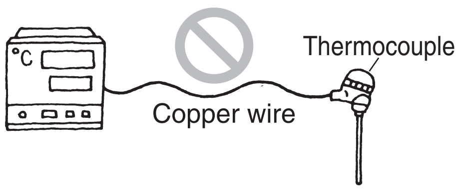
- The input type of the temperature sensor is incorrect (temperature sensor type setting).



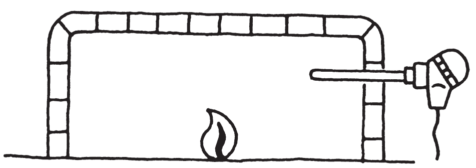
- Temperature sensor lead wires and power lines are in the same conduit, causing noise from the power lines (generally, display values will be
- unstable).
  Countermeasures
  Wire the lead wires and power lines in separate conduits, or wire them using a more direct path.



- Connection between the Temperature Controller and thermocouple is using copper wires.
  Countermeasures
  Connect the thermocouple's lead wires directly, or connect a compensating conductor that is suitable for the thermocouple.



- The measurement location of the temperature sensor is not suitable.



- The incorrect input shift value has been set.

Why does overshooting or undershooting occur?

The following are possible causes.
- Narrow proportional band or small P constant
- Short integral time or small I constant
- Long derivative time or large D constant
- ON/OFF control is enabled.
- Control period is long for a control system with a fast thermal response.
- Setting the overlap band in the heating and cooling control to a dead band by mistake.

Why are process values not being displayed correctly? And why is *S.Err* displayed?

The following are possible causes.
- The input type in the Initial Setting Level is set incorrectly.
- The temperature unit in the Initial Setting Level is set incorrectly.
- The input shift value in the Adjustment Level is set incorrectly.
- The data setting unit is incorrect.
- The temperature sensor polarity or connected terminals are incorrect.
- A temperature sensor has been connected that cannot be used with the installed Temperature Controller.
- The temperature sensor has burnt out, short-circuited, or deteriorated.
- The temperature sensor has not been connected.
- The thermocouple and compensating conductor types are incorrect.
- A device using metal other than a thermocouple or compensating conductor has been connected between the thermocouple and Temperature Controller.
- The connection terminal screws are loose and a contact failure occurs.
- The thermocouple lead wires or compensating conductors are too long and the conductor resistance is affecting the Temperature Controller.
- The resistance of the three conductors connected between the platinum resistance thermometer and the Temperature Controller terminals is different.
- Noise emitted by devices around the Temperature Controller is affecting the Temperature Controller.
- The temperature sensor lead wires and power lines are close, causing inductive noise from the power lines.
- The thermal response is slow because the installation location of the temperature sensor is far from the control point.
- The ambient operating temperature of the Temperature Controller exceeds the rating.
- A wireless device is used around the Temperature Controller.
- The temperature of the thermocouple-input-type terminal block varies due to heat radiated from peripheral devices.
- Wind is blowing on the thermocouple-input-type terminal block.

Why does the process value exceeds the set point?

The following are possible causes.

- The contacts for the relay driven by control outputs are welded.
- The SSR has a short-circuit fault.
- The PID constants are not suitable.
- Restricted MV limit values are set.
- The controlled object is heating by itself.

Why does the process value oscillate around the set point and not stabilize at the set point?

The following are possible causes.

- Narrow proportional band or small P constant
- Short integral time or small I constant
- Long derivative time or large D constant
- ON/OFF control is enabled.
- Control period is long for a control system with a fast thermal response.
- Setting the overlap band in the heating and cooling control to a dead band by mistake.
- The heating capacity of the heater is too large for the heating capacity of the controlled object.
- There is periodic external disturbance, which changes the heating capacity of the controlled object.
- AT execution is in progress.

Why are communications not possible or why are there communications errors?

The following are possible causes.

- The communications wiring is not correct.
- The communications line has become disconnected.
- The communications cable is broken.
- The communications cable is too long.
- The wrong communications cable has been used.
- More than the specified number of communications devices are connected to the same communications path. (RS-422/RS-485 only)
- Terminating resistance has not been connected at each end of the communications line. (RS-422/RS-485 only)
- The specified power supply voltage is not being supplied to the Temperature Controller.
- The specified power supply voltage is not being supplied to an Interface Converter (such as the K3SC).
- The same baud rate and communications method are not being used by all of the Temperature Controllers, host devices, and other devices on the same communications line.
- The unit number specified in the command frame is different from the unit number set by the Temperature Controller.
- The same unit number as the Temperature Controller is being used for another node on the same communications line. (RS-422/RS-485 only)
- There is a mistake in programming the host device.
- The host device detects an error before it receives a response from the Temperature Controller.
- The host device detects the absence of a response as an error after a broadcast command or a software reset command (except for SYSWAY).
- The host device sent another command before receiving a response from the Temperature Controller.
- The host device sent the next command too soon after receiving a response from the Temperature Controller.
- The communications line became unstable when the Temperature Controller power was turned ON or interrupted, and the host device read the unstable status as data.
- The communications data was corrupted by noise from the environment.

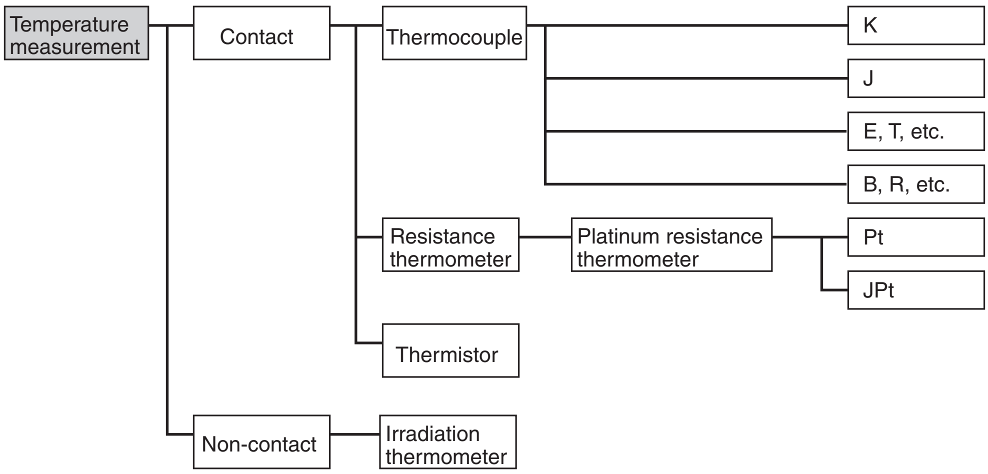
Introduction

What Is a Temperature Sensor?

A Temperature Sensor measures the temperature of a location where the temperature control is required. It converts the temperature to a physical quantity of a voltage or resistance and outputs that.

Temperature Measurement Categories

There are two categories of temperature measurement, as described below.



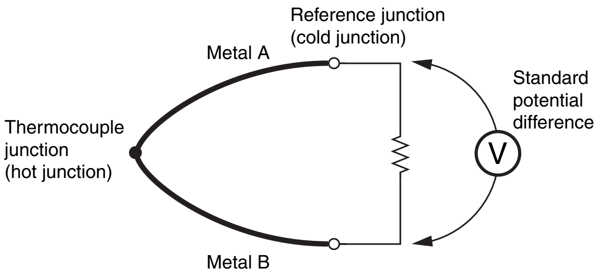
Thermocouple

Principle

A thermocouple is a temperature sensor that uses a phenomenon (i.e., the Seebeck effect) that generates a thermoelectromotive force according to the temperature difference between the joint end and the open end of different types of metal that have been joined together at one end. The combination of metals with high and stable thermoelectromotive force is called a thermocouple.
Thermocouples are widely used in industry.

The Law of Intermediate Temperatures and the Law of Intermediate Metals

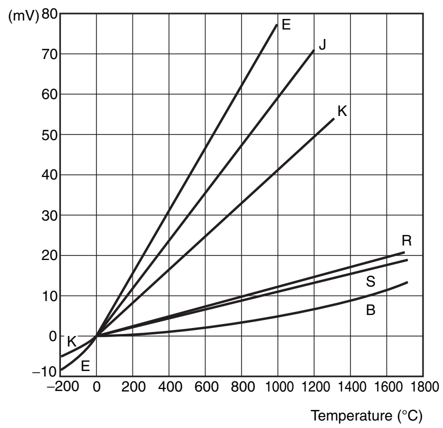
The size of the potential difference is determined by the two different materials of the metal wires and by the difference in temperature between the thermocouple junction (i.e., hot junction) and reference junction (i.e., cold junction). Any difference in temperature in between has no effect (Law of Intermediate Temperatures). There is also no effect if there are different types of metals in between as long as there is no difference in temperature (Law of Intermediate Metals).



Thermocouple Types

Among thermocouples, types K, E, J, and T use base metals, and types B, R, and S use noble metals.
The type of thermocouple is chosen based on the measurement temperature, environment, and accuracy. In general, however, types K, J, and R are commonly used.

Characteristics of Thermocouple Potential Difference



Compensating Lead Wire

If the thermocouple temperature sensor lead wire does not reach the temperature controller and the cable between the sensor and the temperature controller is extended with copper wire, a large temperature error will occur.
The thermocouple temperature sensor lead wires must be extended with compensating conductors.
A compensating conductor is a cable that produces nearly the same thermoelectromotive force as the thermocouple. There are general purpose cables (-20 to 90°C) and heat-resistant cables (0 to 150°C), depending on the ambient operating temperature. The characteristics of these cables are determined by JIS. Compensating conductors are available for each type of thermocouple. A compensating conductor that is suitable for the thermocouple must be used.

Platinum Resistance Thermometer

Resistance Thermometer

This device exploits the constant relation of metal resistance to temperature.
Conditions requited for metal wire material:

(1) High temperature coefficient of electrical resistance and good linearity
(2) Stability
(3) Ability to be used with a broad temperature range

The material which best meets these conditions is platinum.
Only the platinum resistance thermometer is prescribed by JIS.

Platinum Resistance Thermometer

This device uses the characteristic of platinum (Pt) that causes its electrical resistance to increase in proportion to temperature.
Based on the 1989 revision of the JIS standards, platinum resistance thermometers that conformed to the previous standards were called JPt, and those that conformed to the 1989 and later standards were called Pt, but JPt was abolished with the 1997 revision. However, there are still systems in operation that use JPt, so temperature controllers also support JPt. The characteristics of Pt and JPt are different, therefore, the input type of the temperature controller must be correctly set.

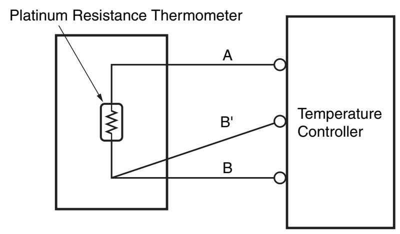
Compensating Lead Wire Types

The resistance of the Pt 100 platinum resistance thermometer is 100 Ω at 0°C, and the standard resistance ratio (R100/R0 value) of 1.3851 is low, so it will be greatly influenced by the compensating lead wire resistance.
Generally, wiring with a three-wire resistance thermometer is used to eliminate the influence of the compensating wire resistance.

Three-wire Resistance Thermometer

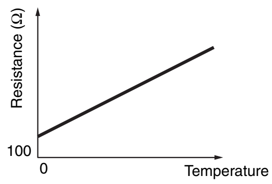
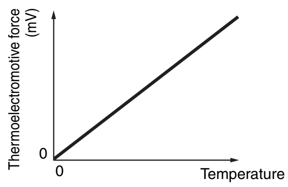
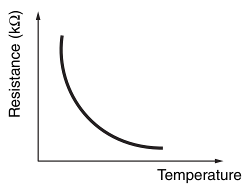
One resistance conductor is connected to two wires and the other is connected to another wire to eliminate the influence of resistance when lead wires are extended. All of OMRON's three-wire platinum resistance thermometers are configured this way.

Connection of Three-wire Platinum Resistance Thermometers



Explanation of Terms

Temperature Sensor Types and Features

<table>
<tr><th>Type</th><th>Principle and characteristics</th><th>Advantages</th><th>Disadvantages</th><th>Element type</th><th>Class</th></tr>
<tr>
<td>Platinum resistance thermometer</td>
<td>The electrical resistance of the metal used by platinum resistance thermometers has a fixed relationship to the temperature. Therefore, a platinum wire with extremely high purity is used for the resistor.
Temperature Characteristics
</td>
<td>• High precision</td>
<td>• Expensive
• Easily influenced by lead wire resistance (OMRON minimizes influence by using a 3-conductor system.)
• Slow thermal response
• Low resistance to shock and vibration</td>
<td>JPt100
Pt100</td>
<td>JIS Standard
<table>
<tr><th>Class</th><th>Tolerance</th></tr>
<tr><td>Class A</td><td>± (0.15+0.002│ t │) °C</td></tr>
<tr><td>Class B</td><td>± (0.3+0.005│ t │) °C</td></tr>
</table>
Note: │ t │ represents the absolute value of the temperature range.</td>
</tr>
<tr>
<td>Thermocouple</td>
<td>A thermocouple is a temperature sensor that uses a phenomenon (i.e., the Seebeck effect) that generates a thermoelectromotive force according to the temperature difference between the joint end (thermocouple junction) and the open end (cold junction) of different types of metal that have been joined together at one end. In principle, thermocouples can measure only relative temperatures, but the thermocouple junction temperature can be obtained by measuring the temperature of the cold junction and adding that to the relative temperature that is measured by the thermocouple (this is called cold junction compensation). Thermocouples can measure the highest temperatures among contact temperature sensors.
Standard Thermoelectromotive Force
</td>
<td>• Broad temperature range
• High-temperature measurement
• High resistance to shock and vibration
• Fast thermal response</td>
<td>• Compensating conductors are required when extending the lead wires</td>
<td>K (CA)
J (IC)
R (PR)</td>
<td>JIS Standard for Thermocouples
<table>
<tr><th>Material code</th><th>Model name</th><th>Temperature range</th><th>Class</th><th>Tolerance *</th></tr>
<tr><td>R</td><td>PR</td><td>0°C to 1,600°C</td><td>Class 2 (0.25)</td><td>±1.5°C or ±0.25% of measured temperature</td></tr>
<tr><td>K</td><td>CA</td><td>0°C to 1,200°C</td><td>Class 2 (0.75)</td><td>±2.5°C or ±0.75% of measured temperature</td></tr>
<tr><td>J</td><td>IC</td><td>0°C to 750°C</td><td>Class 2 (0.75)</td><td>±2.5°C or ±0.75% of measured temperature</td></tr>
</table>
* The tolerance is either the value in °C or %, whichever is larger.</td>
</tr>
<tr>
<td>Thermistor</td>
<td>A thermistor is a temperature sensor that uses a resistor with a resistance that changes by a large amount in response to a change in temperature. The relationship between temperature and resistance is non-linear. Resistance is high at low temperatures and low at high temperatures.
Temperature Characteristics
</td>
<td>• Fast thermal response
• Small error due to lead wire resistance</td>
<td>• Limited temperature range
• Low resistance to shock</td>
<td>Thermistor</td>
<td>JIS Standard Class 1
<table>
<tr><th>Measured temperature</th><th>Tolerance</th></tr>
<tr><td>–50 to 100°C</td><td>±1°C max.</td></tr>
<tr><td>100 to 350°C</td><td>±1% max. of measured temperature</td></tr>
</table></td>
</tr>
</table>

Pt100 and JPt100

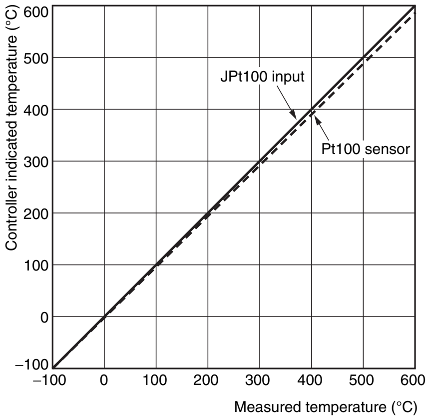
In January 1, 1989, the JIS standard for platinum resistance thermometers (Pt100) was revised to incorporate the IEC (International Electrotechnical Commission) standard. The new JIS standard was established on April 1, 1989. Platinum resistance thermometers prior to the JIS standard revision are distinguished as JPt100. Therefore, make sure that the correct platinum resistance thermometer is being used.

• The following table shows the differences in appearance of the Pt100 and JPt100.

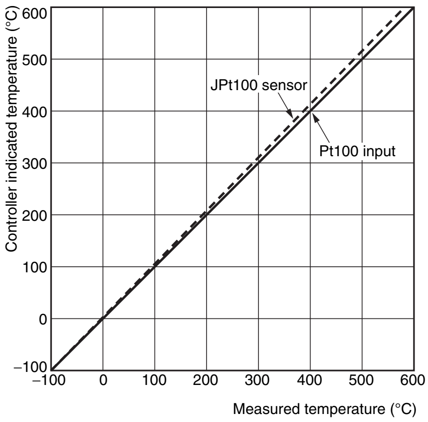
	Classification by model
Pt100 (New JIS standard)	E52-P15AY Pt100 is indicated as P.
JPt100 (Previous JIS standard)	E52-PT15A * JPt100 is indicated as PT.

* OMRON discontinued production of JPt100 Sensors in March of 2003.

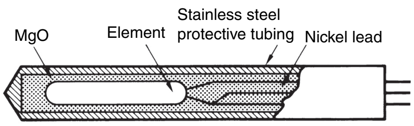
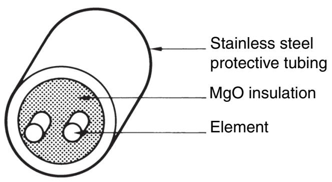
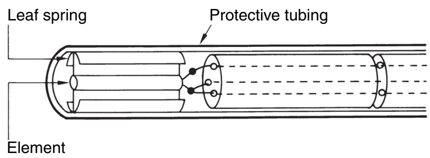
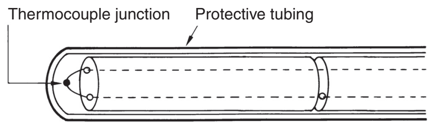
Indicated Temperature when Connecting Pt100 Sensor to JPt100 Input



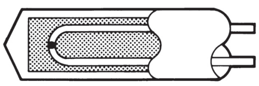
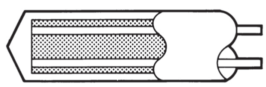
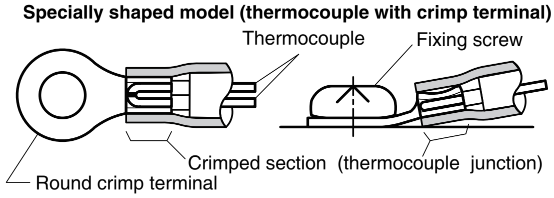
Indicated Temperature when Connecting JPt100 Sensor to Pt100 Input



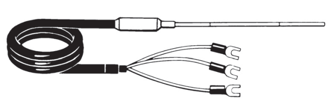
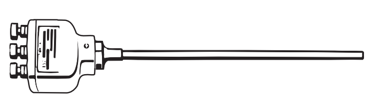
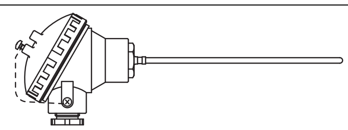
Temperature Sensor Construction

	Sheathed	Standard
Features	• Compared with standard models, these sensors have high resistance to vibration and shock. • The finished outer diameter is extremely slim enabling easy insertion in small sensing objects, and low heat capacity enables fast response to changes in temperature. • The sheathed tubing is flexible, enabling insertion and measurement within complex machinery. • The airtight construction provides high sensitivity and prevents oxidation, for superior heat resistance and durability.	• Compared with the sheathed models, the thick tubing diameter provides strength and durability. • Slow response speed.
Internal structure	**Sheathed** platinum resistance thermometer  **Sheathed** thermocouple 	**Standard** platinum resistance thermometer  **Standard** thermocouple 

Thermocouple Junction Construction

	Non-grounded models	Grounded models
Features	• Fully isolated thermocouple junction and protective tubing • Response is inferior to grounded models, but noise resistance is high. • Widely used for general-purpose applications.	• Soldered ends of thermocouple junction protective tubing. • Fast response but noise resistance is low. • High productivity at a low cost.
Internal construction	**Non-grounded model**  The protective tubing and thermocouple are insulated.	**Grounded model**  There is no insulation between the protective tubing and thermocouple. **Specially shaped model (thermocouple with crimp terminal)**  There is no insulation between the crimp terminal and thermocouple. A temperature difference occurs between the screw fixing section and the thermocouple junction.

Terminal Block Appearance

	Exposed lead wires	Exposed terminals	Enclosed terminals
Features	Lead wires directly extend from protective tubing, enabling low-cost manufacturing without requiring more space. ➜ For building into machines	Construction uses exposed terminal screws for easy maintenance. ➜ For general-purpose indoor use	Construction with enclosed terminal screws enables broad range of applications. ➜ For indoor industrial equipment
Appearance			
Permissible temperature in dry air	• Sleeve Standard: 0 to +70°C Heat Resistive: 0 to +100°C • Lead wire (platinum resistance thermometer) Standard (vinyl-covered): –20 to +70°C Heat resistive (glass-wool-covered with stainless-steel external shield): 0 to 180°C • Lead wire (compensating conductor) Standard (vinyl-covered): –20 to +70°C Heat resistive (glass-wool-covered with stainless-steel external shield): 0 to 150°C	Permissible temperature in dry air for terminal box: 0 to +100°C	Permissible temperature in dry air for terminal box: 0 to +90°C

Temperature Sensor Thermal Response

A temperature sensor has a thermal capacity. That means that time is required from when the temperature sensor touches the sensing object until the temperature sensor and sensing object reach the same temperature. For a thermocouple, the response time is the time required for the temperature sensor to reach 63.2% of temperature of the sensing object. For a resistance thermometer, the response time is the time to reach 50% of temperature of the sensing object.

Thermal Response of Sheathed Temperature Sensors (Reference Value)

Protective tubing: ASTM316L

Test conditions	Static water, room temperature to 100 °C				
Protective tubing dia. (mm)	1.0 dia.	1.6 dia.	4.8 dia.		8 dia.
Indicated value	Thermocouple	Thermocouple	Thermocouple	Platinum resistance thermometer	Platinum resistance thermometer
Response time	1 s max.	1 s max.	1.8 s	3 s	6.5 s

Standard Temperature Sensors

Thermal Response of Platinum Resistance Thermometer (Reference Value) Protective tubing: SUS316

Test conditions	Static water, room temperature to 100°C
Protective tubing dia. (mm) / Indicated value	10 dia.
Response time	12.8 s

Vibration and Shock Resistance

The testing standards for temperature sensors specified by JIS are provided in the tables on the right. Refer to these standards and provide sufficient margins for the application conditions.

Vibration Resistance

Thermocouple (Conforms to JIS C1602-2015)

Test item	Frequency (Hz)	Double amplitude (mm)	Testing tim (min)		Vibration direction
			Sweeps	Destruction	
Resonance test	30 to 100	0.05	2	---	Two axis directions including length direction
Fixed frequency durability test	100	0.02	---	60	

Note: This test is not performed for Sensors with non-metal protective tubing.
Fixed frequency durability tests are conducted at 70 Hz when the resonance point is 100 Hz.

Platinum Resistance Thermometer (Conforms to JIS C1604-2013)

Frequency (Hz)	Acceleration (m/s²)	Sweeps per minute	No. of sweeps
10 to 150	10 to 20	2	10

Note: This test is not performed for Sensors with non-metal protective tubing.

Shock Resistance

Holding the test product on its side, the product is then dropped from a height of 250 mm onto a steel plate 6 mm thick placed on a hard floor. This process is repeated 10 times, after which the product is checked for electrical faults in the thermocouple junctions and terminal contacts. This test is not performed, however, on products with non-metal protective tubing (conforms to JIS C1602-2015 and JIS C1604-2013).

Permissible Temperature in Dry Air

The permissible temperature is the temperature limit for continuous usage in air.
For thermocouples with protective tubes, the permissible temperature is determined collectively by the type of thermocouple, the element diameters, the insulating tube material, protective tube materials, heat resistance, and other factors. The permissible temperature is also called the usage limit.
Generally speaking, lowering the usage temperature will increase the life of a thermocouple. Allow sufficient leeway in the permissible temperature.

Sheathed

Thermocouple Permissible Temperature in Dry Air

M: Protective tubing material
D: Protective tubing diameter (mm)

Element M / D	K (CA) ASTM316L	J (IC) ASTM316L
1 dia.	650°C	450°C
1.6 dia.	650°C	450°C
3.2 dia.	750°C	650°C
4.8 dia.	800°C	750°C
6.4 dia.	800°C	750°C
8.0 dia.	900°C	750°C

Standard

Thermocouple Permissible Temperature in Dry Air

M: Protective tubing material
D: Protective tubing diameter (mm)

Element M / D	K (CA) SUS310S	K (CA) SUS316	J (IC) SUS316
10 dia.	750°C	750°C	450°C
12 dia.	850°C	850°C	500°C
15 dia.	900°C	850°C	550°C
22 dia.	1,000°C	900°C	600°C

Permissible Temperature in Dry Air

Element M / D	R PT0	R PT1
15 dia.	1,400°C	

JIS symbol	Type
PT0	Protective tubing: Special ceramic
PT1	Protective tubing: Ceramic Cat. 1

Further Information

Thermocouple Standard Potential Difference

Thermocouples generate voltage according to the temperature difference. The potential difference is prescribed by Japanese Industrial Standards (JIS).
The following chart gives the potential difference for R, S, K, and J thermocouples when the temperature of the reference junction is 0°C.
(Standards Published in 2015)

JIS C 1602-2015 (Unit: µV)

Category	Temperature (°C)	0	10	20	30	40	50	60	70	80	90
R standard potential difference	0	0	54	111	171	232	296	363	431	501	573
	100	647	723	800	879	959	1,041	1,124	1,208	1,294	1,381
	200	1,469	1,558	1,648	1,739	1,831	1,923	2,017	2,112	2,207	2,304
	300	2,401	2,498	2,597	2,696	2,796	2,896	2,997	3,099	3,201	3,304
	400	3,408	3,512	3,616	3,721	3,827	3,933	4,040	4,147	4,255	4,363
	500	4,471	4,580	4,690	4,800	4,910	5,021	5,133	5,245	5,357	5,470
	600	5,583	5,697	5,812	5,926	6,041	6,157	6,273	6,390	6,507	6,625
	700	6,743	6,861	6,980	7,100	7,220	7,340	7,461	7,583	7,705	7,827
	800	7,950	8,073	8,197	8,321	8,446	8,571	8,697	8,823	8,950	9,077
	900	9,205	9,333	9,461	9,590	9,720	9,850	9,980	10,111	10,242	10,374
	1,000	10,506	10,638	10,771	10,905	11,039	11,173	11,307	11,442	11,578	11,714
	1,100	11,850	11,986	12,123	12,260	12,397	12,535	12,673	12,812	12,950	13,089
	1,200	13,228	13,367	13,507	13,646	13,786	13,926	14,066	14,207	14,347	14,488
	1,300	14,629	14,770	14,911	15,052	15,193	15,334	15,475	15,616	15,758	15,899
	1,400	16,040	16,181	16,323	16,464	16,605	16,746	16,887	17,028	17,169	17,310
	1,500	17,451	17,591	17,732	17,872	18,012	18,152	18,292	18,431	18,571	18,710
	1,600	18,849	18,988	19,126	19,264	19,402	19,540	19,677	19,814	19,951	20,087
	1,700	20,222	20,356	20,488	20,620	20,749	20,877	21,003	---	---	---
S standard potential difference	0	0	55	113	173	235	299	365	433	502	573
	100	646	720	795	872	950	1,029	1,110	1,191	1,273	1,357
	200	1,441	1,526	1,612	1,698	1,786	1,874	1,962	2,052	2,141	2,232
	300	2,323	2,415	2,507	2,599	2,692	2,786	2,880	2,974	3,069	3,164
	400	3,259	3,355	3,451	3,548	3,645	3,742	3,840	3,938	4,036	4,134
	500	4,233	4,332	4,432	4,532	4,632	4,732	4,833	4,934	5,035	5,137
	600	5,239	5,341	5,443	5,546	5,649	5,753	5,857	5,961	6,065	6,170
	700	6,275	6,381	6,486	6,593	6,699	6,806	6,913	7,020	7,128	7,236
	800	7,345	7,454	7,563	7,673	7,783	7,893	8,003	8,114	8,226	8,337
	900	8,449	8,562	8,674	8,787	8,900	9,014	9,128	9,242	9,357	9,472
	1,000	9,587	9,703	9,819	9,935	10,051	10,168	10,285	10,403	10,520	10,638
	1,100	10,757	10,875	10,994	11,113	11,232	11,351	11,471	11,590	11,710	11,830
	1,200	11,951	12,071	12,191	12,312	12,433	12,554	12,675	12,796	12,917	13,038
	1,300	13,159	13,280	13,402	13,523	13,644	13,766	13,887	14,009	14,130	14,251
	1,400	14,373	14,494	14,615	14,736	14,857	14,978	15,099	15,220	15,341	15,461
	1,500	15,582	15,702	15,822	15,942	16,062	16,182	16,301	16,420	16,539	16,658
	1,600	16,777	16,895	17,013	17,131	17,249	17,366	17,483	17,600	17,717	17,832
	1,700	17,947	18,061	18,174	18,285	18,395	18,503	18,609	---	---	---
K standard potential difference	0	0	397	798	1,203	1,612	2,023	2,436	2,851	3,267	3,682
	100	4,096	4,509	4,920	5,328	5,735	6,138	6,540	6,941	7,340	7,739
	200	8,138	8,539	8,940	9,343	9,747	10,153	10,561	10,971	11,382	11,795
	300	12,209	12,624	13,040	13,457	13,874	14,293	14,713	15,133	15,554	15,975
	400	16,397	16,820	17,243	17,667	18,091	18,516	18,941	19,366	19,792	20,218
	500	20,644	21,071	21,497	21,924	22,350	22,776	23,203	23,629	24,055	24,480
	600	24,905	25,330	25,755	26,179	26,602	27,025	27,447	27,869	28,289	28,710
	700	29,129	29,548	29,965	30,382	30,798	31,213	31,628	32,041	32,453	32,865
	800	33,275	33,685	34,093	34,501	34,908	35,313	35,718	36,121	36,524	36,925
	900	37,326	37,725	38,124	38,522	38,918	39,314	39,708	40,101	40,494	40,885
	1,000	41,276	41,665	42,053	42,440	42,826	43,211	43,595	43,978	44,359	44,740
	1,100	45,119	45,497	45,873	46,249	46,623	46,995	47,367	47,737	48,105	48,473
	1,200	48,838	49,202	49,565	49,926	50,286	50,644	51,000	51,355	51,708	52,060
	1,300	52,410	52,759	53,106	53,451	53,795	54,138	54,479	54,819	---	---
J standard potential difference	0	0	507	1,019	1,537	2,059	2,585	3,116	3,650	4,187	4,726
	100	5,269	5,814	6,360	6,909	7,459	8,010	8,562	9,115	9,669	10,224
	200	10,779	11,334	11,889	12,445	13,000	13,555	14,110	14,665	15,219	15,773
	300	16,327	16,881	17,434	17,986	18,538	19,090	19,642	20,194	20,745	21,297
	400	21,848	22,400	22,952	23,504	24,057	24,610	25,164	25,720	26,276	26,834
	500	27,393	27,953	28,516	29,080	29,647	30,216	30,788	31,362	31,939	32,519
	600	33,102	33,689	34,279	34,873	35,470	36,071	36,675	37,284	37,896	38,512
	700	39,132	39,755	40,382	41,012	41,645	42,281	42,919	43,559	44,203	44,848
	800	45,494	46,141	46,786	47,431	48,074	48,715	49,353	49,989	50,622	51,251
	900	51,877	52,500	53,119	53,735	54,347	54,956	55,561	56,164	56,763	57,360
	1,000	57,953	58,545	59,134	59,721	60,307	60,890	61,473	62,054	62,634	63,214
	1,100	63,792	64,370	64,948	65,525	66,102	66,679	67,255	67,831	68,406	68,980
	1,200	69,553	---	---	---	---	---	---	---	---	---

Reference Temperature Characteristics for Platinum Resistance Thermometers (Ω)

Pt100

JIS C 1604-2013

Temperature (°C)	–100	–0	Temperature (°C)	0	100	200	300	400	500	600	700	800
0	60.26	100.00	0	100.00	138.51	175.86	212.05	247.09	280.98	313.71	345.28	375.70
–10	56.19	96.09	10	103.90	142.29	179.53	215.61	250.53	284.30	316.92	348.38	378.68
–20	52.11	92.16	20	107.79	146.07	183.19	219.15	253.96	287.62	320.12	351.46	381.65
–30	48.00	88.22	30	111.67	149.83	186.84	222.68	257.38	290.92	323.30	354.53	384.60
–40	43.88	84.27	40	115.54	153.58	190.47	226.21	260.78	294.21	326.48	357.59	387.55
–50	39.72	80.31	50	119.40	157.33	194.10	229.72	264.18	297.49	329.64	360.64	390.48
–60	35.54	76.33	60	123.24	161.05	197.71	233.21	267.56	300.75	332.79	363.67	---
–70	31.34	72.33	70	127.08	164.77	201.31	236.70	270.93	304.01	335.93	366.70	---
–80	27.10	68.33	80	130.90	168.48	204.90	240.18	274.29	307.25	339.06	369.71	---
–90	22.83	64.30	90	134.71	172.17	208.48	243.64	277.64	310.49	342.18	372.71	---
–100	18.52	60.26	100	138.51	175.86	212.05	247.09	280.98	313.71	345.28	375.70	---

JPt100

JIS C 1604-1997

Temperature (°C)	–100	–0	Temperature (°C)	0	100	200	300	400	500
0	59.57	100.00	0	100.00	139.16	177.13	213.93	249.56	284.02
–10	55.44	96.02	10	103.97	143.01	180.86	217.54	253.06	---
–20	51.29	92.02	20	107.93	146.85	184.58	221.15	256.55	---
–30	47.11	88.01	30	111.88	150.67	188.29	224.74	260.02	---
–40	42.91	83.99	40	115.81	154.49	191.99	228.32	263.49	---
–50	38.68	79.96	50	119.73	158.29	195.67	231.89	266.94	---
–60	34.42	75.91	60	123.64	162.08	199.35	235.45	270.38	---
–70	30.12	71.85	70	127.54	165.86	203.01	238.99	273.80	---
–80	25.80	67.77	80	131.42	169.63	206.66	242.53	277.22	---
–90	21.46	63.68	90	135.30	173.38	210.30	246.05	280.63	---
–100	17.14	59.57	100	139.16	177.13	213.93	249.56	284.02	---

Standard Temperature Characteristics for Element-interchangeable Thermistors

The following chart gives the temperature characteristics for low-cost thermistors used in the E5C2, E5L, and E5CS. JIS C 1611-1995

Nominal resistance	6 kΩ (0°C)		30 kΩ (0°C)		3 kΩ (100°C)		0.55 kΩ (200°C)		4 kΩ (200°C)		8 kΩ (200°C)	
Ambient operating temperature	–50 to 100°C		0 to 150°C		50 to 200°C		100 to 250°C		250 to 300°C		200 to 350°C	
Temperature (°C) / Deviation in characteristics and resistance	Resistance	Resistance deviation	Resistance	Resistance deviation	Resistance	Resistance deviation	Resistance	Resistance deviation	Resistance	Resistance deviation	Resistance	Resistance deviation
–50	75.36 kΩ	±4.28 kΩ										
–40	42.90	±2.28										
–30	25.23	±1.26										
–20	15.21	±0.72	77.07 kΩ									
–10	9.414	±0.422	47.41									
0	6.000	±0.261	30.00	±1.35 kΩ								
10	3.934	±0.158	19.49	±0.80								
20	2.637	±0.100	12.97	±0.50								
30	1.812	±0.065	8.828	±0.323	28.05 kΩ							
40	1.266	±0.043	6.140	±0.212	19.31							
50	904.2 Ω	±29.0 Ω	4.356	±0.144	13.57	±0.47 kΩ						
60	657.7	±20.0	3.147	±0.098	9.717	±0.310						
70	487.0	±14.0	2.317	±0.068	7.081	±0.214						
80	365.7	±10.0	1.734	±0.048	5.243	±0.151	12.66 kΩ					
90	278.9	±7.2	1.318	±0.035	3.939	±0.108	8.626					
100	215.6	±5.5	1.017	±0.026	3.000	±0.080	6.281	±0.194 kΩ				
110	168.4		794.0 Ω	±18.9 Ω	2.314	±0.058	4.649	±0.134				
120	133.3		627.7	±14.2	1.805	±0.043	3.495	±0.096				
130			501.7	±10.8	1.424	±0.033	2.664	±0.069	23.06 kΩ			
140			405.2	±8.3	1.134	±0.025	2.056	±0.051	17.44			
150			330.5	±5.6	912.1 Ω	±9.5 Ω	1.610	±0.039	13.33	±0.35 kΩ		
160			272.0		734.9	±15.4	1.273	±0.029	10.29	±0.26		
170			225.8		596.1	±12.1	1.017	±0.022	8.027	±0.194		
180					486.7	±9.6	823.6 Ω	±17.0 Ω	6.312	±0.147	13.39 kΩ	
190					400.0	±7.7	669.3	±13.2	5.006	±0.113	10.29	
200					330.6	±6.2	550.0	±10.5	4.000	±0.087	8.000	±0.190 kΩ
210							455.4	±8.3	3.221	±0.068	6.305	±0.146
220							380.6	±6.7	2.611	±0.053	5.015	±0.111
230							319.2	±5.4	2.131	±0.042	4.014	±0.086
240							269.9	±4.4	1.751	±0.034	3.240	±0.076
250							230.0	±3.5	1.445	±0.027	2.634	±0.054
260							196.8		1.202	±0.022	2.156	±0.042
270							169.5		1.004	±0.018	1.779	±0.033
280									842.5 Ω	±14.4 Ω	1.474	±0.027
290									710.8	±11.8	1.228	±0.022
300									602.4	±9.7	1.030	±0.018
310									512.8		868.1 Ω	±14.3 Ω
320									438.3		738.2	±11.7
330											631.0	±9.6
340											542.2	±7.9
350											468.0	±6.8
Thermistor constant B	3,390 K		3,450 K		3,894 K		4,300 K		5,133 K		5,559 K	

Note: Amount of change in resistance per degree C in the resistance deviation and specified temperature.

FAQs

What precautions should be taken when extending the temperature sensor lead wires?

Platinum Resistance Thermometer: Pt and JPt

Make sure the three lead wires to be used for extension have the same resistance and are the same length.

Extending the lead wires will cause their resistance to influence the displayed temperature. Therefore, use wire with a thick conductor. (Extension lead wires are not available from OMRON. Use commercially available lead wires.)

Thermocouple: K, J, and R

Always use compensating lead wires for extension. Use a compensating conductor designed for the connected thermocouple.

If you use a different type of compensating conductor from the thermocouple or if you use normal copper wires to extend, correct temperature measurement will not be possible.

Also, do not connect positive and negative incorrectly.

Thermistor

Use wire with a thick conductor for the lead-wire extensions. There is no polarity.

Common Precautions

The lead wires will be easily influenced by noise when they are extended. Be careful when performing wiring.

How much of an insertion length does the temperature sensor require?

Make sure the protective tube has sufficient length to touch the object to be measured, or to insert it into the object.

A length of at least 20 times the diameter of the protective tube is required for metal protective tubes. A length of at least 15 times the diameter of the protective tube is required for non-metal protective tubes.

Can the temperature sensor be used when it is bent?

Sheathed temperature sensors can be bent. The following precautions, however, should be taken.

- The minimum permissible bend radius of a sheathed temperature sensor is five times the diameter of the protective tube. Do not bend the temperature sensor repeatedly in the same place.
- Internal wiring may become disconnected or warped if the temperature sensor is bent to an acute angle and then stretched out again. Also, do not bend the welded section.
- The protective tube is brittle when low temperatures are being measured. Do not bend the tube when it is cold.
- To protect the measuring part of the sheathed temperature sensor, do not bend the sensor within 100 mm of the tip.