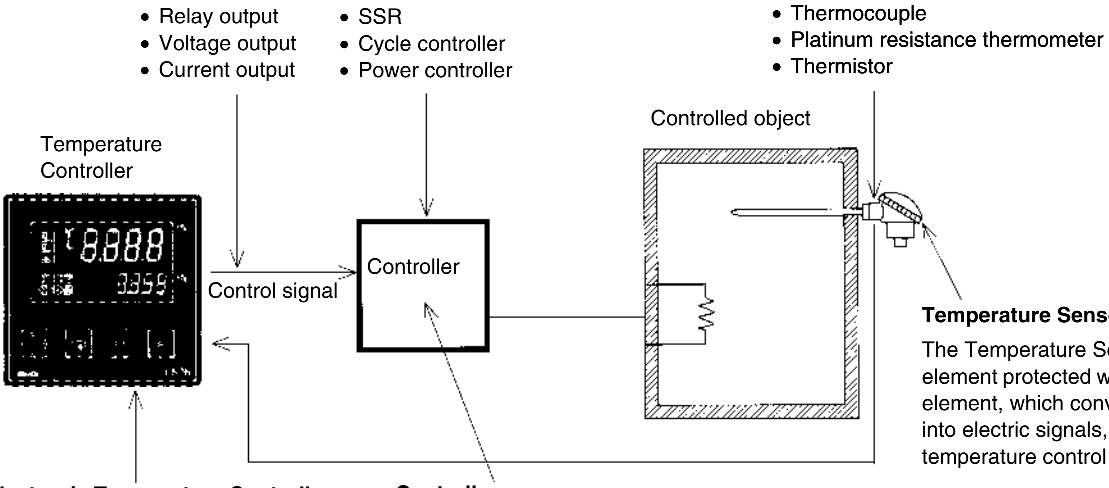
Technical Information

Configuration Example of Temperature Control

The following is an example of the configuration of temperature control.



Temperature Sensor

The Temperature Sensor consists of an element protected with a pipe. Locate the element, which converts temperatures into electric signals, in places where temperature control is required.

Electronic Temperature Controller

The Electronic Temperature Controller is a product that receives electric signal input from the temperature sensor, compares the electric signal input with the set point, and outputs adjustment signals to the Controller.

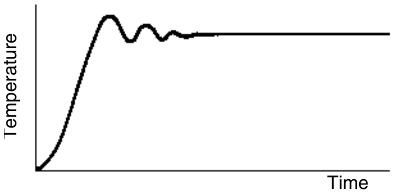
Controller

The Controller is used to heat up or cool down furnaces and tubs using a device, such as a solenoid or fuel valve, to switch electric currents supplied to heaters or coolers.

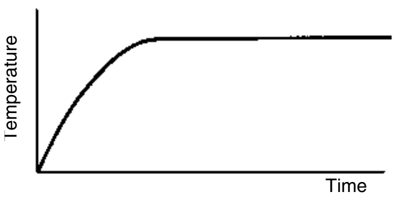
Temperature Control

The set point is input into the Temperature Controller in order to operate the Temperature Controller. The time required for stable temperature control varies with the controlled object. Attempting to shorten the response time will usually result in the overshooting or hunting of temperature. When reduce the overshooting or hunting of temperature, the response time must not be shortened. There are applications that require prompt, stable control in the waveform shown in (1) despite overshooting. There are other applications that require the suppression of overshooting in the waveform shown in (3) despite the long time required to stabilize temperature. In other words, the type of temperature control varies with the application and purpose. The waveform shown in (2) is considered to be a proper one for standard applications.

1. The temperature stabilizes after overshooting several times.



2. Proper response



3. The response is slow in reaching the set point.

Characteristics of the Controlled Object

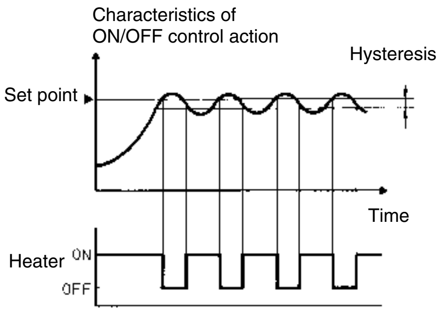
Before selecting the Temperature Controller and Temperature Sensor models, it is necessary to understand the thermal characteristics of the controlled object for proper temperature control.

Characteristics of controlled object

- **Heat capacity** — Heat capacity, which indicates the degree of ease of heating, varies with the capacity of the furnace.
- **Static characteristics** — Static characteristics, which indicate the capability of heating, vary with the capacity of the heater.
- **Dynamic characteristics** — Dynamic characteristics, which indicate the startup characteristics (i.e., excessive response) of heating, vary with the capacities of the heater and furnace that affect each other in a complex way.
- **External disturbances** — External disturbances are causes of temperature change. For example, the opening or closing of the door of a constant temperature oven will be a cause of external disturbance thus creating a temperature change.

■ ON/OFF Control Action

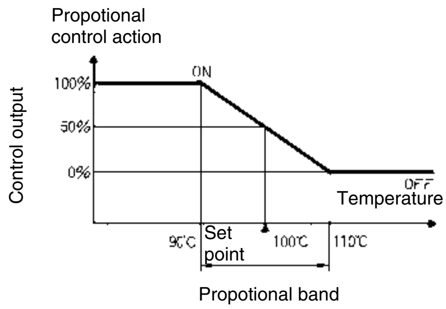
As shown in the graph below, if the process value is lower than the set point, the output will be turned ON and power will be supplied to the heater. If the process value is higher than the set point, the output will be turned OFF with power to the heater shut off. This control method is called ON/OFF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



■ P Action

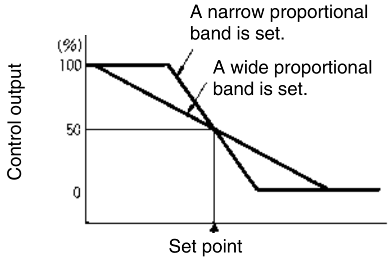
P action (or proportional control action) is used for obtaining the output in proportion to the input.

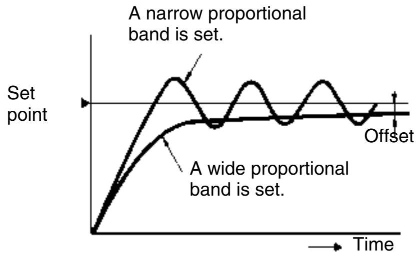
The Temperature Controller in P action has a proportional band with the set point in the proportional band. The control output varies in proportion to the deviation in the proportional band. In normal operation, a 100% control output will be ON if the process value is lower than the proportional band. The control output will be decreased gradually in proportion to the deviation if the process value is within the proportional band, and a 50% control output will be ON if the set point coincides with the process value (i.e., there is no deviation). This means P action ensures smooth control with minimal hunting compared with the ON/OFF control action.



Example:

If a Temperature Controller with a temperature range of 0° 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, provided that the set point is 100°C, 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. 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 with the same interval).

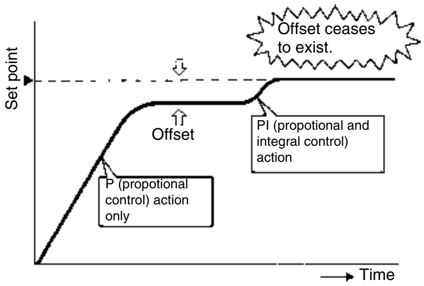


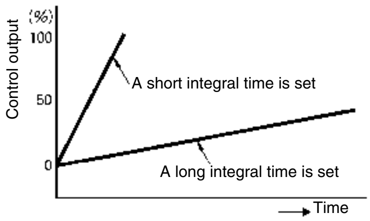


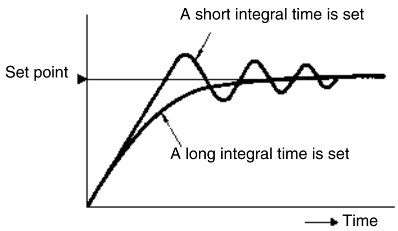
■ P Action

I action (or integral control action) is used for obtaining the output in proportion to the time integral value of the input.

P action causes an offset. Therefore, if proportional control action and integral control action are used in combination, the offset will be reduced as the time goes by until finally the control temperature will coincide with the set point and the offset will cease to exist.



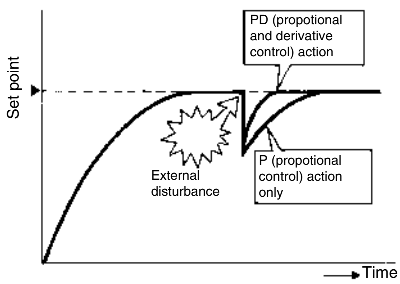


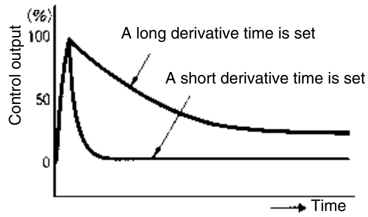


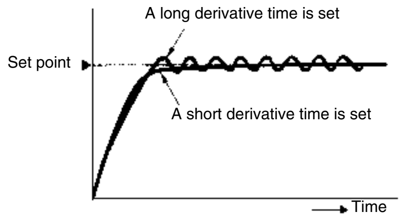
■ D Action

D action (or derivative control action) is used for obtaining the output in proportion to the time derivative value of the input.

Proportional control action corrects the result of control and so does integral control action. Therefore, proportional control action and integral control action respond slowly to temperature change, which is why derivative control action is required. Derivative control action corrects the result of control by adding the control output in proportion to the slope of temperature change. A large quantity of control output is added for a radical external disturbance so that the temperature can be quickly in control.

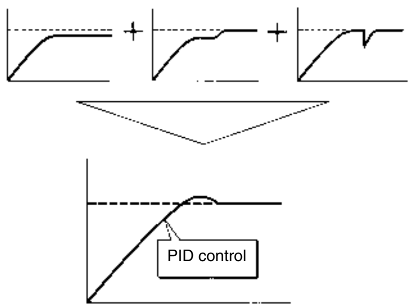






■ PID Control

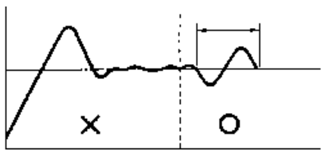
PID control is a combination of proportional, integral, and derivative control actions, in which the temperature is controlled smoothly by proportional control action without hunting, automatic offset adjustment is made by integral control action, and quick response to an external disturbance is made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



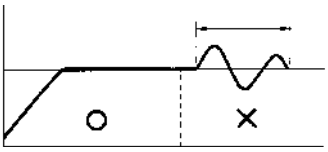
■ 2-PID Control

Conventional PID control uses a single control block to control the responses of the Temperature Controller to a target value and external disturbances. Therefore, the response to the target value will oscillate due to overshooting if importance is attached to the response 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, if importance is attached to the response to the target value (i.e., the P and I parameters are set to large values), the Temperature Controller will not be able to respond to external disturbances quickly. It will be impossible to satisfy both the types of responses in this case.
2–PID control eliminates this weakness while retaining the strengths of PID control, thus making it possible to improve both types of responses.

PID-Control

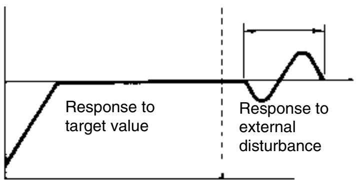


Response to the target value will become slow if response to the external disturbance is improved.



Response to the external disturbance will become slow if response to the target value is improved.

2-PID-Control

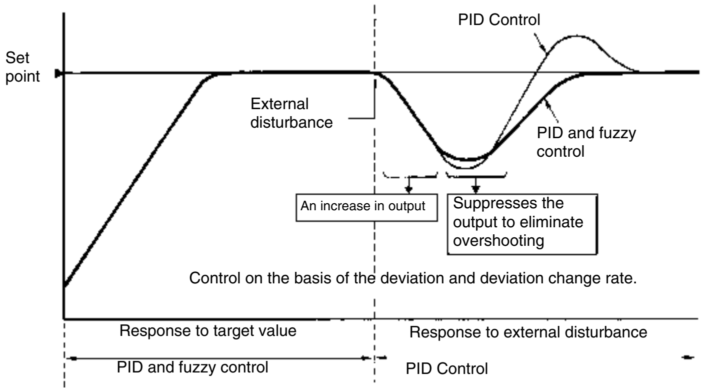


Controls both the target value response and external disturbance response.

■ PID with Fuzzy Control

By adding fuzzy control to PID control, further improvement in response to external distur bances is possible. PID and fuzzy control usually operate as PID control. If there is external disturbance, fuzzy control will operate in combination with PID control.

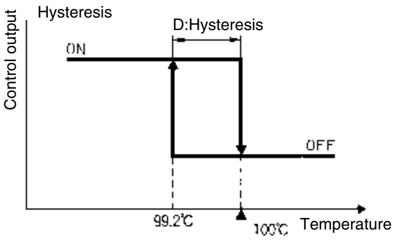
OMRON's fuzzy control estimates tempera ture change from the difference between the deviation (i.e., the difference between the set point and process value) and deviation change rate, and then makes the delicate adjustment of the control output.



Control

Hysteresis

ON/OFF control action turns the output ON or OFF on the basis of the set point. This means the output frequently changes according to minute temperature changes, which shortens the life of the output relay or unfavorably affects some devices connected to the Temperature Controller. Therefore, a margin is prepared between the ON and OFF operations. This margin is called hysteresis.

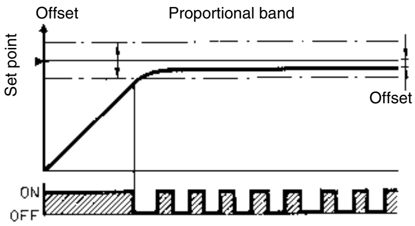


Example:

If the Temperature Controller with a temperature range of 0°C to 400°C has a 0.2% hysteresis, D will be 0.8°C. Therefore if the set point is 100°C, the output will turn OFF at a process value of 100°C and will turn ON at a process value of 99.2°C.

Offset

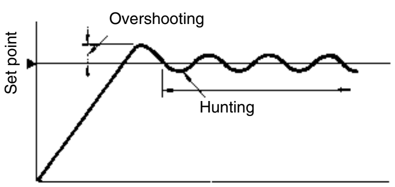
Proportional control action causes an error in the process value due to the heat capacity of the controlled object and the capacity of the heater, which results in a small discrepancy between the process value and set point in stable operation. This error is called offset. Offset may exist above or below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



Hunting and Overshooting

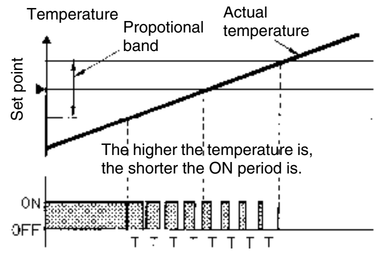
ON/OFF control action often involves the waveform shown in the following graph. A temperature rise in excess of the set point after temperature control starts is called overshooting. Temperature oscillation near the set point is called hunting. Improved temperature control is to be expected if the degrees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

Hunting and Overshooting in ON/OFF Control Action



Control Cycle and Time-proportioning Control Action

The control output will be turned ON intermittently according to a preset cycle if P action is used with a relay or SSR. This preset cycle is called control cycle and this control method is called time–proportioning control action.



T: Control cycle

$$\text{Control output} = \frac{T_{ON}}{T_{ON} + T_{OFF}} \times 100\ (\%)$$

T_{ON}: ON period

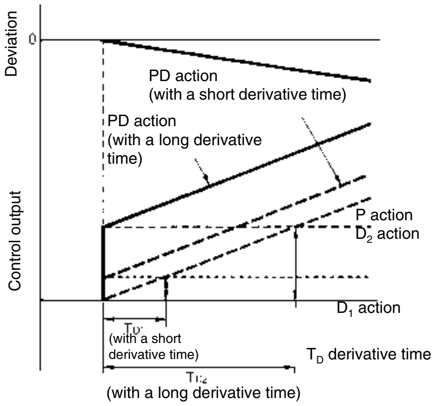
T_{OFF}: OFF period

Example;
If the control cycle is 10 s with an 80% control output, the ON and OFF periods will be the following values.
T_{ON}: 8 s
T_{OFF}: 2 s

Derivative Time

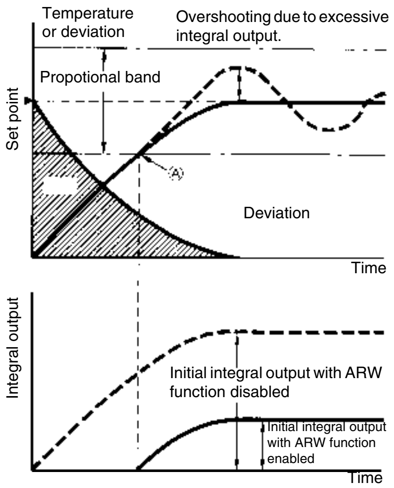
Derivative time is the period required for a ramp-type deviation in derivative control (e.g., the deviation shown in the following graph) to coincide with the control output in proportional control action. The longer the derivative time is, the stronger the derivative control action is.

PD Action and Derivative Time



ARW Function

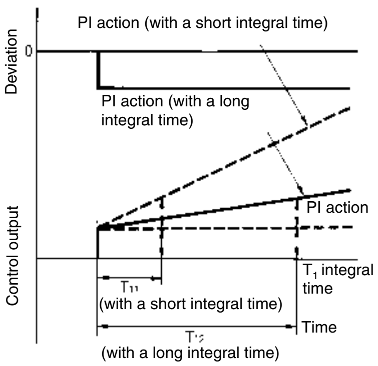
ARW stands for anti–reset windup.
There is usually a large deviation (i.e., a large difference between the process value and set point) when the Temperature Controller starts operating. Integral control action in PID control is repeated until the temperature reaches the set point. As a result, an excessive integral output causing overshooting is output. To prevent this, the ARW function sets a limit to restrict the output rise in integral control action. In normal control operation, the integral output is eliminated until the process value reaches the proportional band.



Integral Time

Integral time is the period required for a step-type deviation in integral control (e.g., the deviation shown in the following graph) to coincide with the control output in proportional control action. The shorter the integral time is, the stronger the integral control action is. If the integral time is too short, however, hunting may result.

PI Action and Integral Time

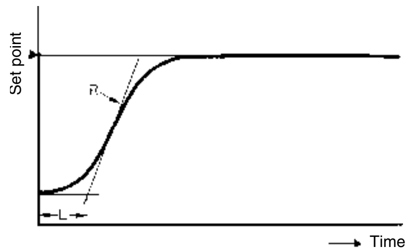


■ Auto-tuning

PID constants for temperature control vary in value and combination according to the characteristics of the controlled object. There has been a variety of conventional methods suggested and implemented to obtain PID constants from the waveforms of temperatures to be controlled by the Temperature Controller in actual operation. Among them, auto–tuning methods make it possible to obtain PID constants suitable to a variety of objects. Auto-tuning methods include the step response, marginal sensitivity, and limit cycle methods.

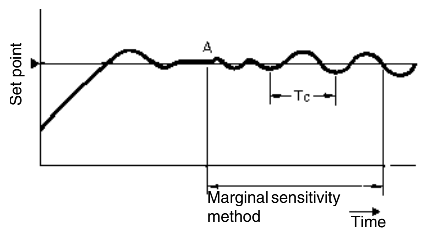
Step Response Method

The value most frequently used must be the set point in this method. Calculate the maximum temperature ramp R and the dead time L from a 100% step-type control output. Then obtain the PID constants from R and L.



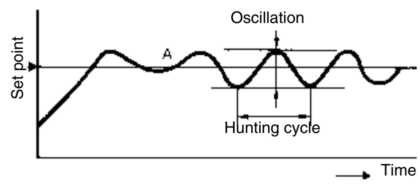
Marginal Sensitivity Method

Proportional control action starts from the start point A in this method. Narrow the width of the proportional band until the temperature starts to oscillate. Then obtain the PID constants from the value of the proportional band and the oscillation cycle T at that time.



Limit Cycle Method

ON/OFF control action starts from the start point A in this method. Then obtain the PID constants from the hunting cycle T and oscillation D.

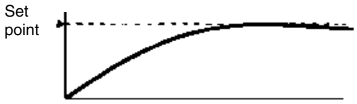


Readjustment of PID Constants

PID constants calculated in auto–tuning operation normally do not cause problems <u>except for some particular applications</u>, in which case, refer to the following to readjust the PID constants.

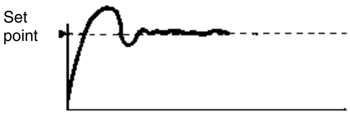
Response to Change in Proportional Band

Wider



It is possible to suppress overshooting although a comparatively long startup time and set time will be required.

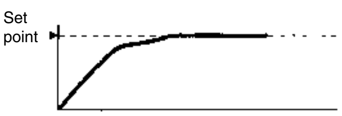
Narrower



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



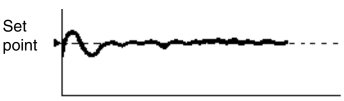
It is possible to reduce hunting, overshooting, and undershooting although a comparatively long startup time and set time will be required.

Narrower

The process temperature reaches the set point within a comparatively short time although overshooting, undershooting, and hunting will result.

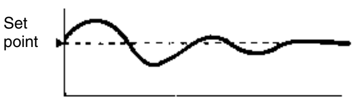
Response to Change in Derivative Time

Wider



The process value reaches the set point within a comparatively short time with comparatively small amounts of overshooting and undershooting although fine–cycle hunting will result due to the change in process value.

Narrower



It will take a comparatively long time for the process value to reach the set point with heavy overshooting and undershooting.

■ Fuzzy Self-tuning

PID constants must be determined according to the controlled object for proper temperature control. The conventional Temperature Controller incorporates an auto-tuning function to calculate PID constants, in which case, it will be necessary to give instructions to the Temperature Controller to trigger the auto-tuning function. Furthermore, if the limit cycle method is adopted, temperature disturbance may result. The Temperature Controller in fuzzy self-tuning operation determines the start of tuning and ensures smooth tuning without disturbing temperature control. In other words, the fuzzy self-tuning function makes it possible to adjust PID constants according to the characteristics of the controlled object.

Fuzzy Self-tuning in 3 Modes

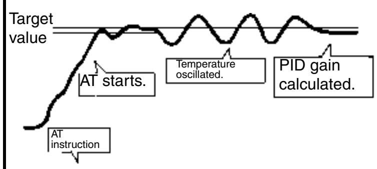
- PID constants are calculated by tuning at the time of change in the set point.
- When an external disturbance affects the process value, the PID constants will be adjusted and kept in a specified range.
- If hunting results, the PID constants will be adjusted to suppress the hunting.

Auto-tuning Method of a Conventional Temperature Controller

Auto-tuning Function: Automatically calculates the appropriate PID constant for controlling objects.

Features:

1. Tuning will be performed when the AT instruction is given.
2. The limit cycle signal is generated to oscillate the temperature before tuning.

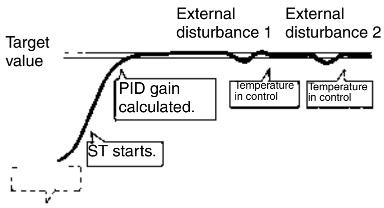


Self-tuning Function

Self-tuning (ST) Function: A function to automatically calculate optimum PID constants for controlled objects.

Features:

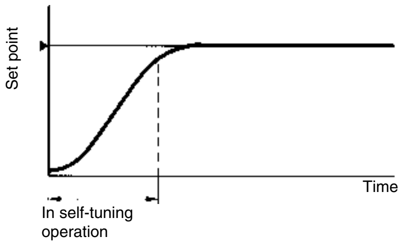
1. Whether to perform tuning or not is determined by the Temperature Controller.
2. No signal disturbing the process value is generated.



■ Self–tuning Function

(Applicable Model: E5CS)

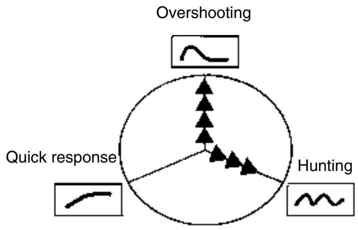
The self–tuning function is incorporated by E5CS Digital Temperature Controller. The function makes it possible to calculate and use an optimum proportional band automatically according to change in the temperature.



■ Fine–tuning Function

(Applicable Models: ES100X, ES100P)

The fine–tuning function is incorporated by the ES100 Digital Controller. Tuning is a delicate and troublesome job. The fine–tuning function performs fuzzy logic calculations to adjust the PID constants after the degrees of requirements for suppressing overshooting and hunting and improvements in response are set.



PID Control and Tuning Methods

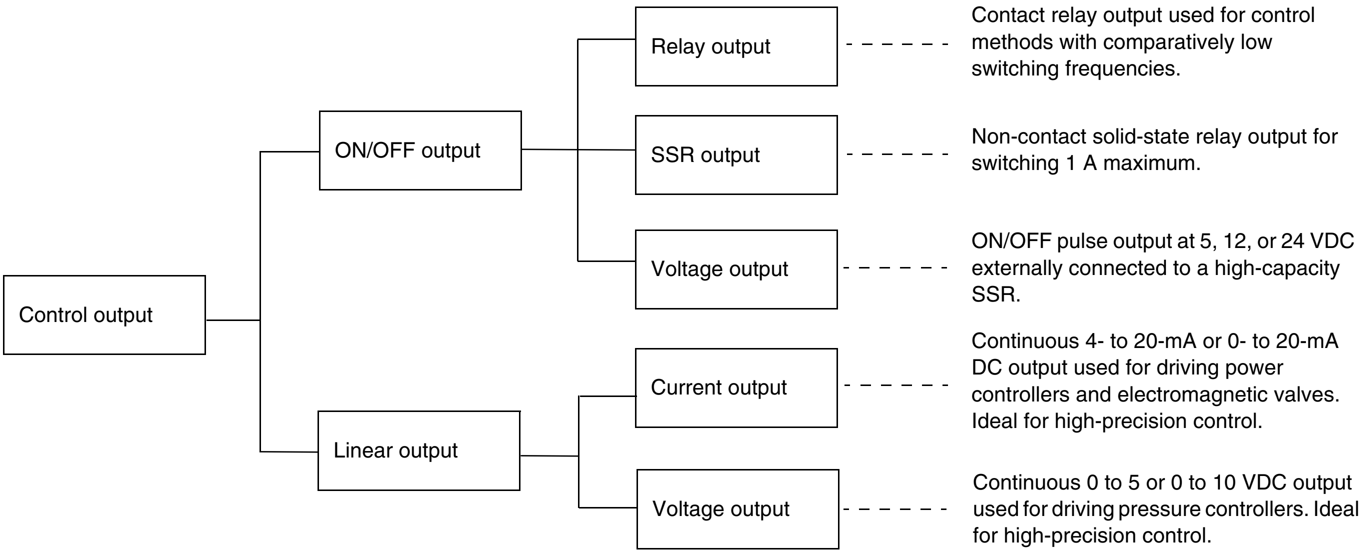
Model	Type of PID control		
	PID	2-PID	PID with fuzzy control
E5☐N		AT, ST	
E5☐K		AT, ST	
E5CS	ST*		
E5ZD		AT	AT
E5ZE			AT
ES100X			AT, FT
ES100P			AT, FT

Note: ST stands for fuzzy self-tuning function, ST* stands for self-tuning function, FT stands for fine-tuning function, and AT stands for auto-tuning function.

Auto-tuning Method

Type	Tuning method	
	Step response method	Limit cycle method
E5☐N	Not built–in	Built–in
E5ZD	Not built–in	Built–in
E5ZE	Not built–in	Built–in
E5☐K	Not built–in	Built–in
ES100X/P	Not built–in	Built–in

■ Control Output



Alarm

Alarm

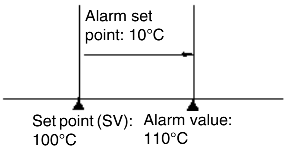
The Temperature Controller compares the process value and the preset alarm value, turns the alarm signal ON, and displays the type of alarm in the preset operation mode.

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.



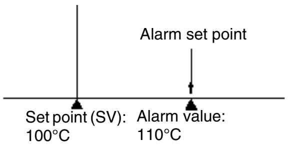
The alarm set point in the above example is set to 10°C.

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

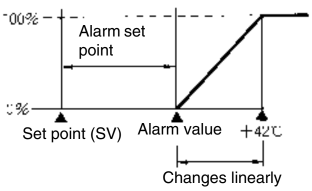
Alarm temperature is set to 110°C.



The alarm set point in the above example is set to 110°C.

Proportional Alarm

The proportional alarm enables simple heating and cooling control, in which the control output of the Temperature Controller is used for heating and the alarm output is used as cooling control output. The 0% control output is turned ON with the alarm value and the 100% control output is turned ON with the proportional upper limit, between which the control output changes linearly.

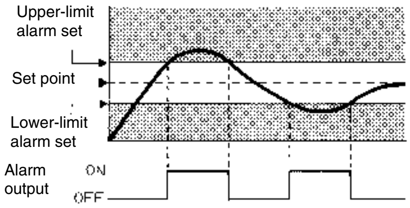


Standby Sequential Alarm

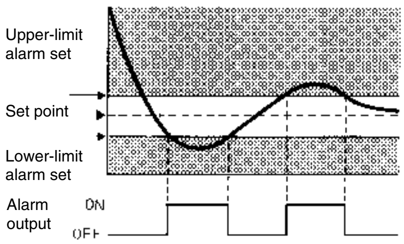
It may be difficult to keep the process value outside the specified alarm range in some cases (e.g., when starting up the Temperature Controller) and as a result the alarm turns ON abruptly. This can be prevented with the standby sequential function of the Temperature Controller. This function makes 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

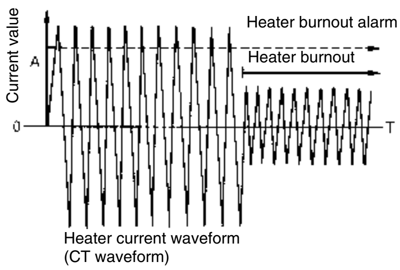


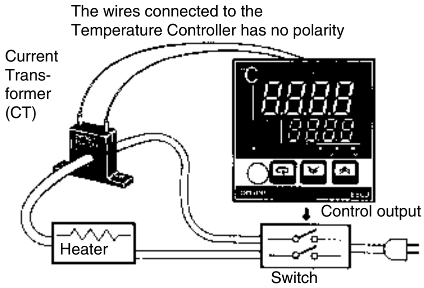
Temperature Drop



Heater Burnout Alarm (Single–phase Use Only)

Many types of heaters are used to raise the temperature of the controlled object. The CT (Current Transformer) is used by the Temperature Controller to detect the heater current. If power interruption is caused by heater burnout, the Temperature Controller will detect the heater burnout from the CT and will output the heater burnout alarm.

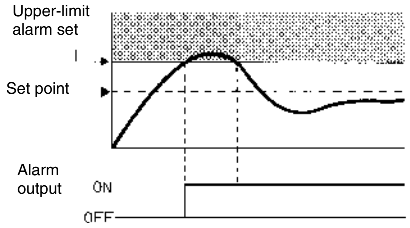




Latch Alarm

Applicable Models: E5☐N

An alarm will usually turn OFF if the process value is not within the specified alarm range. The latch alarm function makes it possible to keep the alarm output turned ON once the alarm is triggered.



LBA

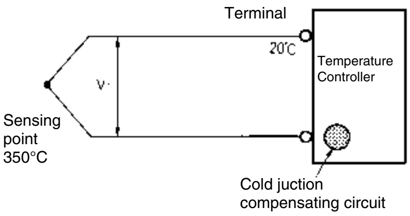
Applicable Models: E5☐K

The LBA (loop burnout alarm) is a function to turn the alarm signal ON by assuming the occurrence of control loop failure if there is no input change with the control output set to the highest or lowest value. Therefore, this function can be used to detect control loop errors.

Temperature Sensor

Cold Junction Compensating Circuit

The thermocouple generates a thermo–electromotive force according to the difference in temperature between the hot junction and cold junction. The temperature sensor data will change if there is any change in the temperature of the cold junction regardless of whether there is any change in the temperature of the hot junction. Therefore, another temperature sensor is employed to detect the temperature of the cold junction connected to the thermocouple and make an electrical compensation so that the temperature of the cold junction will be always 0°C. This compensation is called cold junction compensation.



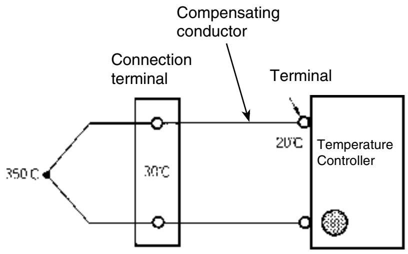
The thermo–electromotive force VT is calculated from the following formula: VT = K (350 - 20)

Condition:
The terminal temperature is 20°C.
VT = K (350 - 20) + K • 20 = K • 350

K (350 - 20): Thermo-electromotive force of thermocouple
K • 20: Thermo-electromotive force generated by cold junction compensating circuit

Compensating Conductor

An actual application has a sensing point that may be located far away from the Temperature Controller. Special–conductor thermocouples are expensive. Therefore, the compensating conductor is connected to the thermocouple in such a case. The compensating conductor must be in conformity with the characteristics of the thermocouple, otherwise precise temperature sensing will not be possible.



Example of Compensating Conductor Use

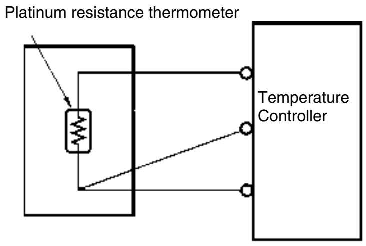
K (350 - 30) + K (30 - 20) + K • 20 + K • 350

K (350 - 30): Thermo-electromotive force of thermocouple
K (30 - 20): Thermo-electromotive force through compensating conductor
K • 20: Thermo-electromotive force generated by cold junction compensating circuit

Three-wire Resistance Thermometer

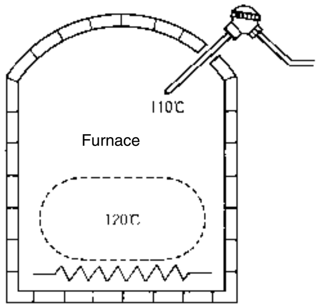
The three-wire platinum resistance thermometer is used by OMRON's Temperature Controller. One of the resistance conductors of the three-wire resistance thermometer is connected to two wires and the other resistance conductor is connected to another wire, the wiring of which eliminates the influence of the resistance of the extended lead wires.

Connection of Three-wire Platinum Resistance Thermometer



Input Compensation

A preset point is added to or subtracted from the temperature detected by the temperature sensor of the Temperature Controller to display the process value. The difference between the detected temperature and displayed temperature is set as an input compensation value.



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

Platinum Resistance Thermometer

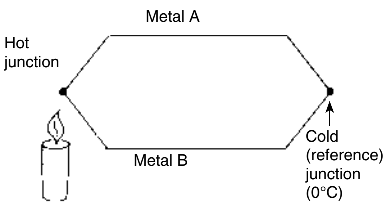
The resistance of a metal will increase if the temperature of the metal increases. This is especially true if the metal is platinum. The platinum resistance thermometer makes use of the nature of platinum (e.g., its resistance increases with the temperature rise) by incorporating a fine platinum wire wound around a mica or ceramic plate.

Thermocouple

A thermocouple consists of two different metal wires with the ends connected together. If the two contacts are different in temperature, the thermocouple will generate a voltage called thermo-electromotive force. The power of thermo-electromotive force depends on the metals. The temperature sensor making use of this voltage as input to the Temperature Controller is called a thermocouple.

Hot Junction and Cold Junction

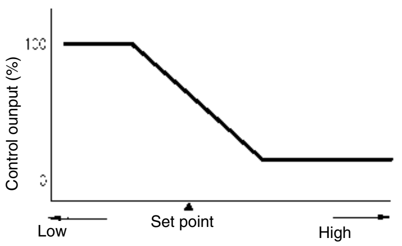
A thermocouple has hot junction and cold junction. The hot junction is for temperature sensing and the cold junction is connected to the Temperature Controller.



Output

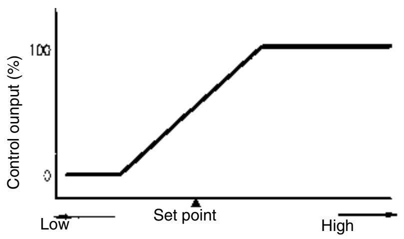
Reverse Operation

The Temperature Controller in reverse operation will increase control output if the process value is lower than the set point (i.e., if the Temperature Controller has a negative deviation).



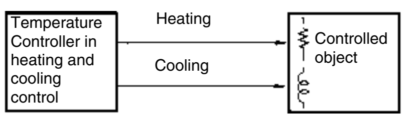
Normal Operation

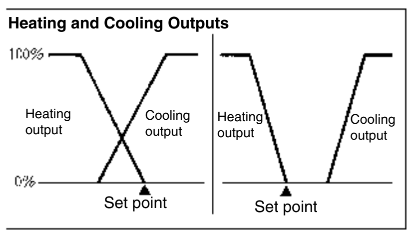
The Temperature Controller in normal operation will increase control output if the process value is higher than the set point (i.e., if the Temperature Controller has a positive deviation).



Heating and Cooling Control

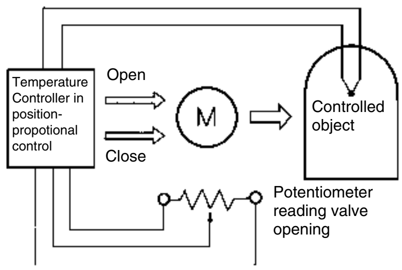
The controlled object may be in heating and cooling control if the temperature control of the controlled object is difficult with heating alone. A single Temperature Controller has heating control output and cooling control output.





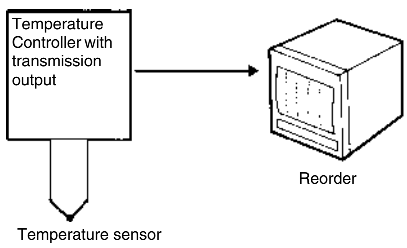
Position-proportioning Control

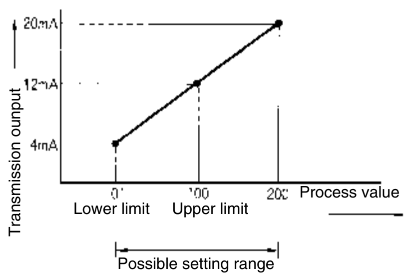
This control is also called ON/OFF servo control. If a valve with a control motor is applied to temperature control with the Temperature Controller and a potentiometer, the Temperature Controller will read the valve opening from the potentiometer and will turn the open and close signals ON along with control output for temperature control.



Transmission Output

The Temperature Controller with current output independent from control output is available. The process value or set point within the available temperature range of the Temperature Controller is converted into 4- to 20-mA linear output that can be input into recorders to keep the results of temperature control on record. The upper and lower limits can be set for transmission output in the E5CK-jF. Therefore, the transmission output between the upper and lower limits will be turned ON if the E5CK-jF is used.

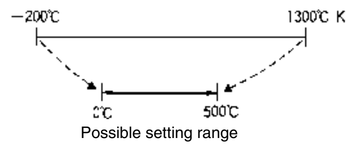




Setting

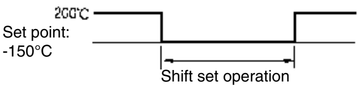
Set Limit

The set point range depends on the temperature sensor and the set limit is used to restrict the set point range. This restriction affects the transmission output of the Temperature Controller.



Shift Set Operation

The set point can be shifted to a different value to be used by the Temperature Controller in shift set operation.

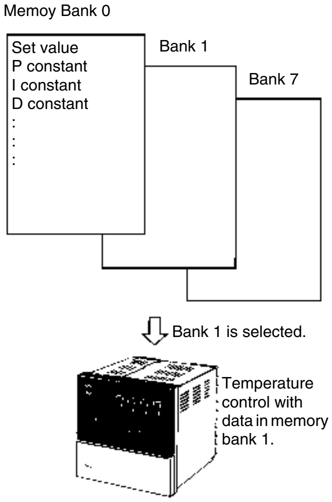


Multiple Set Points

Two or more set points independent from each other can be set in the Temperature Controller in control operation.

8 Banks

The Temperature Controller stores a maximum of eight groups of data (e.g., set value and PID constant data) in built–in memory banks for temperature control. The Temperature Controller selects one of these banks in actual control operation.



SP Ramp

The SP ramp function controls the target value change rate with the variation factor. Therefore, when the SP ramp function is enabled, some range of the target value will be controlled if the change rate exceeds the variation factor as shown below.