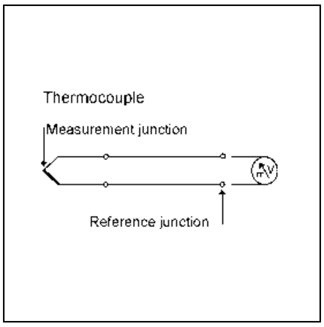
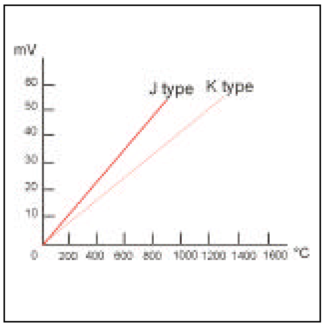
Temperature controllers

TEMPERATURE MEASUREMENT

The Seebeck effect and the thermocouple





Joining both the ends of two different metal wires and creating a temperature difference between the two junctions, a thermoelectric circuit with a continuous current flow across the conductors is obtained. Thus, opening one of the two junctions, an electromotive force proportional to the temperature difference with the other junction is measurable.

This physical effect draws its name from Thomas Seebeck, the scientist who discovered it in 1821. In the thermocouple the Seebeck effect is used for the temperature measurement, supplying a voltage proportional to the temperature difference between the measurement junction and the reference junction. The voltage/temperature characteristic is denominated Seebeck coefficient and varies according to the different metals, generally alloys, used in thermocouples. The Seebeck coefficient is expressed in µV/°C and is not linear.

Reference junction compensation

The thermocouple provides a voltage proportional to the temperature difference between the measurement junction and the reference junction (also called hot and cold junction). Thus, if the temperature of the reference junction is unknown, the correct value of the process temperature cannot be obtained. In order to provide the correct process temperature, a reference junction compensation (also called cold junction or ambient temperature compensation) is automatically added to the measurement made by the thermocouple. The reference junction temperature is measured by means of a semiconductor placed in thermal contact with the point where the thermocouple is connected to the electronic thermometer. The semiconductor can be a diode, exploiting the thermal drift of the forward voltage.

Compensated extension cables

If a thermocouple is connected to an electronic thermometer using a common copper cable, a possible error equal to the difference between the temperature of the connection points 'thermocouple-to-cable' and 'cable-to-thermometer' can occur. This effect occurs as the thermocouple provides a voltage equal to the temperature difference between its measurement junction and its terminals; while the electronic thermometer compensates only the temperature of its connecting point to the copper cable.

Compensated extension cables, made of alloys with the same thermoelectric characteristic of those used in the thermocouples, are used to avoid this measurement error. In this way the thermoelectric circuit is actually extended to the thermometer's connecting point. The compensated extension cables are polarised and vary according to the thermocouple type.

Types of thermocouples

The different thermocouple types are distinguished by an ANSI standard letter, according to the alloys used in the junction. The E type, Iron+/Constantan- (Fe/Cu-Ni), is suitable for low and medium temperatures and has the highest Seebeck µV/°C coefficient. The J type, Iron+/Constantan- (Fe/Cu-Ni), is the most diffused in processes that reach medium-high temperatures. The K type, Chromel+/Alumel- (Ni-Cr/Ni-Al) is also very diffused and is suitable from low to high temperatures. The L type has the same characteristics of the J thermocouple, but presents a different calibration with a higher µV/°C coefficient. The R and S types, both Platinium-Rhodium+/Platinium- (Pt-Rh/Pt), are similar and are suitable only for high temperatures due to the very bad linearity at medium-low values. The T type, Copper+/Constantan- (Cu/Cu-Ni), is not very common and is mainly used in low temperatures.

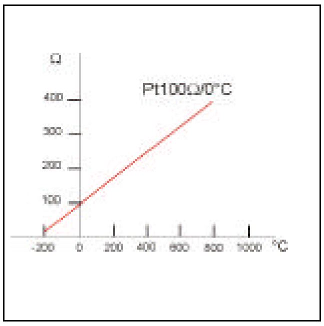
The same type of thermocouple can have different assemblings and dimensions according to the installation requirements.

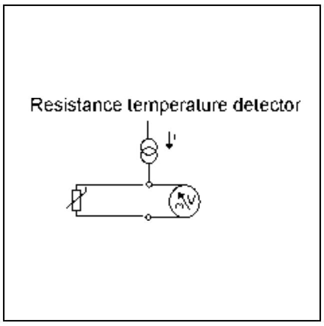
Thermocouple assemblings

The thermocouple is generally assembled inside a tubular stainless steel housing, where the most important specifications are the length and diameter of the useful measurement element.

Three different thermocouple assemblings are possible. The "grounded junction" is the most diffused assembling, where the thermocouple is completely protected inside the housing at thermal and electric contact, in order to offer a short response time. In the "ungrounded junction" the thermocouple is still completely protected, but an electrical insulation is present to avoid the effect of eddy currents. Lastly, in the "exposed junction" the thermocouple's measurement junction is outside the protective housing for very fast detection, limited to laboratory use. In any case, the metal housing is connected to the ground of the machinery.

Resistance temperature detectors





Resistance temperature detectors (RTD) exploit the characteristic of metal's electric resistance to increase proportionally to the temperature.
Platinum is the metal with the best resistance/temperature characteristic. A RTD consists of a Platinum wire coiled and sealed in a ceramic or glass element, which is generally protected inside a metal housing, as for thermocouples, but always electrically insulated. The Pt100Ω/0°C is a Platinum RTD which offers a 100Ω resistance at 0°C, with a r coefficient of 0,00385 Ω according to the DIN-43760 standard, thus its resistance at 100°C becomes 138,5 Ω. The resistance variation is not linear and slightly decreases with temperature increase; nevertheless, the RTD offers more precision compared to thermocouples and are used at medium-low temperatures, including negative values.

Two and three wires resistance temperature detectors

To connect a RTD to an electronic thermometer the resistance value must be converted into a voltage value by means of a constant current generator. If the RTD is placed far from the thermometer, the line resistance is added to the sensor's resistance and consequently the measurement is conditioned. For instance, the measurement of a RTD's resistance increases by about 1°C every 10 metres of 1mm² wires line, also changing with ambient temperature. A third 'compensation' wire, connected between a RTD terminal and an apposite thermometer input, is used to compensate the line resistance. A current, equal to the one flowing through the RTD, is injected across the compensation wire and comes back along one RTD wire. In this way a voltage equivalent to the two wire's resistance is obtained and subtracted from the total value.

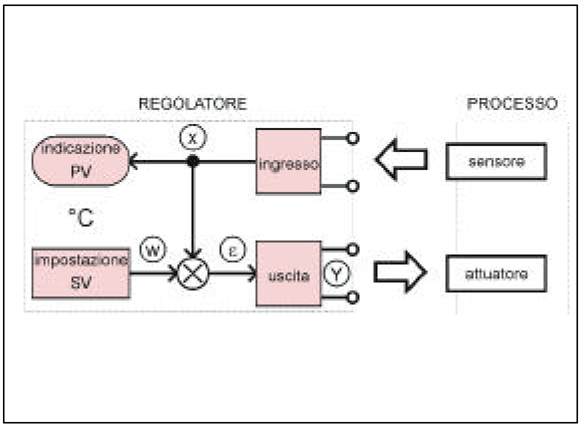
A comparison between thermocouple (TC) and resistance temperature detector (RTD)

Thermocouple advantages: the TC directly supplies a voltage, while the RTD requires a constant current generator inside the thermometer; the TC is sturdy and presents a simple construction, while the RTD is more fragile and needs sophisticated technologies and materials; a TC costs nearly four times less than a RTD, with equal dimensions and assembling; the TC can measure higher temperatures than the double of RTD.
Resistance temperature detector advantages: the RTD gives an absolute value, while the TC produces a relative value requiring the reference junction compensation; the RTD can provide a mV/°C gain, while the TC has a low µV/°C gain; the RTD has a good linearity, while the TC is characterised by very irregular curves with difficult linearization; the RTD can offer a precision of ± 0,1°C, while the best tolerance of the TC, due to the alloys' impurities, is ± 1,1°C.

TEMPERATURE REGULATION

Maximum and minimum control action

The [x] process value temperature measured is compared with the [w] set value and the [ε] resulting error is elaborated by the controller to supply the necessary [Y] control output. In the simplest control action ON/OFF the [Y] output drive the actuator's power to zero or to 100% according to the [ε] error's sign. A 'maximum' ON/OFF control action can be used to control a heating process: the output is 100% when the [x] process value is lower than the [w] set value and the [ε] error is negative; the output becomes zero when the measured value is higher than the set value. A 'minimum' ON/OFF control action can be used to control a cooling process: the output is 100% when the [x] process value is higher than the [w] set value and the [ε] error is positive; the output becomes zero when the measured value is lower than the set value.



Basic theory

ON/OFF and Proportional control action

The ON/OFF control sensitivity is based on the presence of a hysteresis around the set value, to avoid that the output is switched at each minimal error sign variation. For example, with a set value of 100°C and an hysteresis of ±10°C, the output goes to zero when the measured value exceeds 110°C and returns to 100% when the measured value falls below 90°C. Therefore, the ON/OFF control action effect is a periodical temperature undulation. When a more stable temperature is needed, a Proportional control action is used. In the 'P' control action, a proportional band is present around the set value and the output varies linearly between 100% and zero, settling at about 50% to keep the error at zero. For example, with a set value of 100°C and a proportional band of 40°C, the output is 100% with a measured value below 80°C and decreases linearly to zero reaching 120°C. The linear variation of a two-status ON/OFF output is obtained varying the duty cycle: Ton/(Ton+Toff).

Application and limits of the ON/OFF and Proportional actions

The ON/OFF control action follows the process thermic inertia, therefore is characterised by a large initial overshoot, followed by large and slow oscillations around the set value. The ON/OFF control action is applied in low cost systems and/or in all processes where low sensitivity and very slow cycle times are needed, for example heating with a gas burner. The proportional control action offers a remarkable reduction of the overshoot and oscillation amplitude, but requires faster cycle times. The 'P' actions fit all processes that can be controlled with major sensitivity and precision, such as heating with electrical resistances. However, the proportional control action can present a residual reset error, due to the possible difference between the power supplied and the actual power needed in the process, as well as having a slow and oscillating transient response.

PID Proportional-Integral-Derivative control action

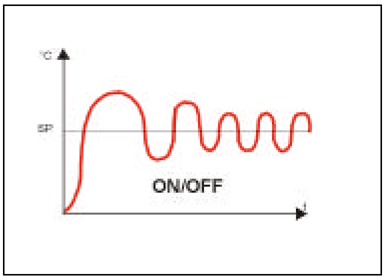
Integral 'I' and derivative 'D' actions are added in order to improve the proportional 'P' control action. The integral action intervenes progressively increasing the proportional action until the reset error becomes zero. The time needed by the integral action to double the proportional action is defined as integral time. The derivative action occurs in the presence of dynamic errors (overshoot, oscillations, transients), limiting them multiplying the proportional action according to the temperature variation speed. The time in which the derivative action acts on the proportional action is defined as derivative time. Practically the integral and derivative actions shift in the proportional band, that becomes asymmetric compared to the set value. The correct tuning of the PID parameters (proportional band, integral, derivative and cycle times) is an essential requirement for a stable temperature regulation.

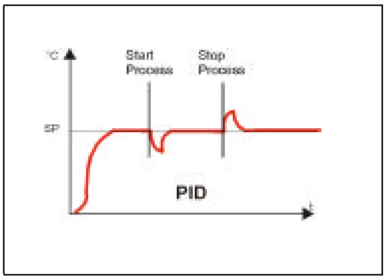
PID parameters autotuning

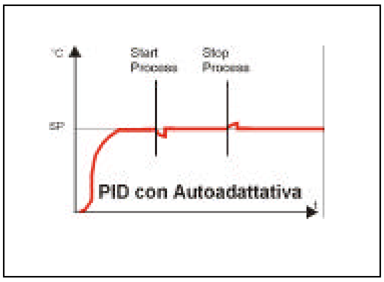
The autotuning function, available in microprocessor-based temperature controllers, allows the automatic tuning of the PID parameters. Once activated, the autotuning effects three ON/OFF cycles measuring their period (T) and amplitude (A); these values are used to tune the parameters and automatically back to the PID control action. The relations between process and PID parameters, based on the Ziegler-Nichols method, are the following: proportional band Pb=Ao1,5; integral time Ti=T/2; derivative time Td=T/8; cycle time Tc=T/20. The autotuning is suitable for stable processes; in the case the autotuning is followed by a faster and unstable process (e.g. frequent start/stop) which change the system’s dynamic, the parameters must be adjusted. The manual adjustment of the PID parameters follows some simple rules based on the temperature behaviour.

Manual PID parameters adjustment

The PID parameters can be adjusted manually according to the following rules: the proportional band must be decreased in the presence of a large initial overshoot followed by slow and wide deviations from the set value; whereas the proportional band must be increased in order to eliminate a regular and persistent oscillation of the regulated temperature; the integral, derivative and cycle time must be reduced when the temperature reaches the set value too slowly and then departs with slow deviations; whereas they must be increased in presence of a large initial overshoot followed by damped oscillations of the temperature. In the manual adjustment, it is advised to proceed with small variations, maintaining the following ratios: Ti/Td=3…5; Ti/Tc=10…20.



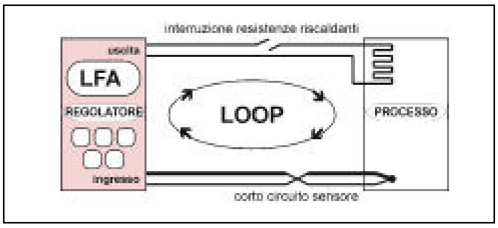




ADT Autoadaptive function

The ADT autoadaptive function, present in the **Datalogic Sensor & More** microprocessor-based temperature controllers, improves the response time and the PID control action accuracy, without the need to manually adjust the set parameters. The ADT function automatically modifies the PID algorithm according to the temperature variation derivative and is suitable for all processes characterised by frequent and fast variations, in order to prevent excessive deviations from the regulated temperature. The ADT function is particularly useful in the heat-sealing and thermoforming processes typical of automatic packaging, where start/stop phases to reload or replace the materials are necessary; in these cases the autoadaptive function significantly reduces the dead times and material wastes due to the temperature variations of the heating elements.

LFA Loop Fault Alert diagnostic function



The control 'loop' is composed of the following elements: process > sensor > controller > actuator > process. The LFA Loop Fault Alert function is used to detect any possible defects in the elements outside the controller, such as short-circuit or breaking of the sensor or actuator. The LFA function intervenes indicating a message on the display and/or deactivating the main output, if the output is at 100% and the measured temperature does not change in consequence within the integral time. This link to the integral time adapts the function to the process dynamic and is valid also with ON/OFF action. The main output deactivation is very useful in presence of a defect on the sensor or its line, as the controller could uselessly activate the output or even cause damages.

Relay and transistor outputs

Temperature controller can have a relay or transistor main output, with different advantages depending on the application. The relay output generally presents a change-over contact rated for 250 Vac, 5A max., that can be used to directly command heating resistances up to 1200 W. The transistor output is used if higher loads have to be controlled. This output, supplying a 10-30 Vdc voltage, with a 20 mA current, is suitable to drive an external solid state relay (SSR) for load currents reaching 25 or 50 A. The transistor output together with SSR allows a very low cycle time, up to 1 second. Whereas with relay output, or in the presence of external electromagnetic switch, the minimum cycle time should be limited to 10 seconds, in order not to compromise the contact's mechanical and electronic life.

Auxiliary alarm and fixed points outputs

Auxiliary outputs are often present in temperature controllers, with alarm or fixed point functions and maximum or minimum action, as well as OFF or ON dead zones. The set point of the auxiliary output is relative to the main set value in case of alarm, while it is independent and absolute in case of fixed point. A maximum action alarm with an auxiliary set point of -10°C is active below 90°C when the main set value is 100°C, or under 80°C changing the main set value to 90°C. A maximum fixed point set at 100°C is always active under 100°C, independently of the main set value. An alarm with dead zone OFF with a lower set point of -20°C and a higher set point of +10°C is activated below 80°C, or above 110°C, relative to a main set point of 100°C. A fixed point with dead zone ON with a lower set point of 80°C and a higher set point of 130°C is always active between these temperatures.

Stand-by function in auxiliary points

I punti ausiliari hanno generalmente una uscita a relè che viene utilizzata per avviare o interrompere altri processi legati alla temperatura regolata dal punto principale. Una applicazione tipica è quella di fornire il consenso macchina per una lavorazione quando la temperatura raggiunge un valore sufficiente, o al contrario un limite di sicurezza per interrompere un processo quando supera un valore di allarme. La funzione di attesa "stand-by" serve ad evitare che l'uscita ausiliaria si attivi la prima volta che si raggiunge la sua temperatura di impostazione, partendo dal momento dall'accensione del regolatore. Ad esempio, la funzione stand-by evita che un punto ausiliario di massima sia attivato durante la prima fase di raggiungimento della temperatura, oppure che un punto ausiliario di minima sia attivato alla prima sovraelongazione. Il punto ausiliario con stand-by si attiva regolarmente ad ogni successivo raggiungimento del suo valore di impostazione.

REFERENCE STANDARDS

All I.E.S. S.p.A. products with CE marking comply with the European Directives relative to Electromagnetic Compatibility (EEC 89/336 and successive 92/31 and 93/68) and Low Voltage (LVD 73/23 and successive 93/68) and corresponding European standards for industrial environment use. Temperature controllers refer to the EN 61010 Safety requirements for electrical equipment for measurement, control and laboratory use; Part 1: General requirements.