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We find that today with fast advancing technology, unless you are in an environment where you continually work with issues such as temperature control, it is easy to forget the very basics and we have to re-learn everything each time we visit the topic. Many applications where stand-alone temperature controllers are used are in plants that generally do not have specialised instrumentation personnel on hand and as a result the relatively simple task of temperature control can become a time consuming matter that may not give the results you were expecting. The intention of this article is to briefly touch on some basic aspects of the topic that will be of interest to those who find themselves in this kind of situation and will be able to use the information to ensure they are not being incorrectly advised of over-sold for their particular application.

BASICS OF TEMPERATURE CONTROLLERS

Stand-alone electronic temperature controllers are devices used to control the temperature of processes such as baking ovens, furnaces, in the plastic industry etc. They come in varying sizes and housings, but in the main can be broken into two groups:

Simple ON/OFF or proportional controllers and

More advanced PID controllers.

Both of these two groups have the same main components from a control loop point of view:

The input We measure the process temperature using a probe, typically a thermocouple (type J or K etc) or PT100 and then connect that signal back to the controller. This signal is referred to as the input to the controller.

The controller This is the device that monitors the input signal and decides by comparing it with the "set-point" or desired temperature setting, whether to increase the temperature by applying heat.

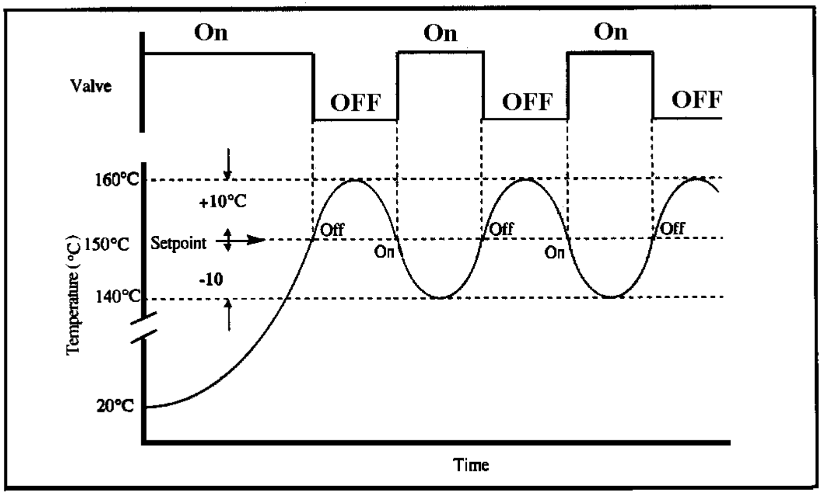
The output. This is the part of the controller that is used in turning the heating elements on or off to make the temperature hotter or cooler. This is typically a relay out-put or a solid state relay output. (We can also have an analog such as a 4~20 milliamp or 1~5 Vdc signal. Generally used with some sort of thyristor controller to regulate the heat.)

Let's first discuss the two main types of control:

1. Simple ON/OFF or proportional controllers and
2. More advanced PID controllers.

1. ON/OFF CONTROL

On/off control is the simplest type of control. Whenever the temperature you are measuring is below the set point, the output relay will be switched on. Whenever it is above the setpoint the output will be switched off. It is as simple as that. You can easily imagine though that once a temperature has reached the setpoint, it is possible that as the measurement changes by 0.1 of a deg C around the setpoint, causing the output to switch on and off a lot. We do not want the contactor switching unnecessarily, so we have built in a deadband, which prevents this relay chatter. In most simple on/off controllers, this is factory set and could be a degree or two around the setpoint

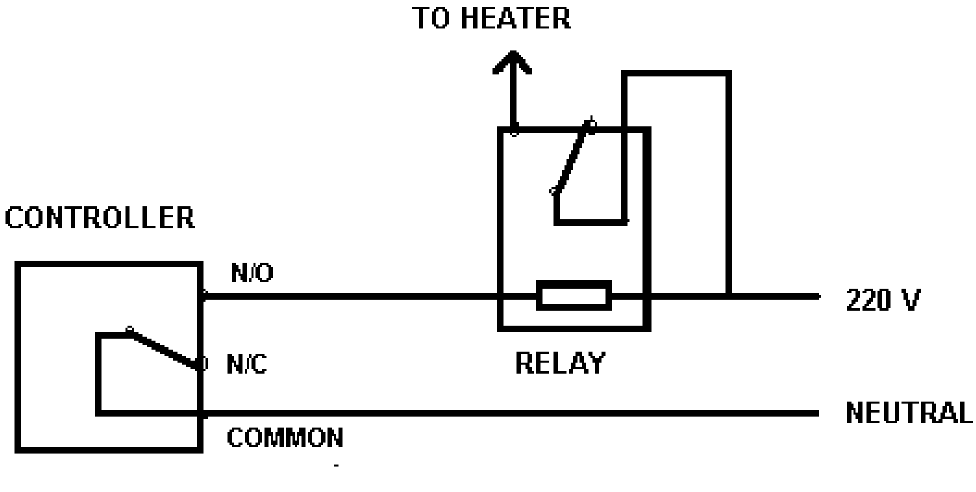


This type of controller although widely used in most applications is best-suited in applications where precise control is not the criteria, and the process is such that the energy inflow into the system is small relative to the energy already in the system. This would typically be oven or furnace control where the elements have carefully selected so as not to inject excessive amounts of heat into the system, in relation to the oven size. It should also be chosen where the frequency of output switching is to be kept to a minimum (in applications where the contacts of the switching contactor will fail as a result of more frequent switching)

INTERPOSING RELAYS

The output relay of our product range (and most others) is rated at 5 amp 220v resistive load and to avoid any problems in the external circuit damaging the controller, that would result in unnecessary expenses, an interposing relay should be designed into the system to switch the load. When the output relay is used on inductive loads such as contactor coils the current rating should be limited to that of contactors rated at 10kw or less that typically have coils drawing inrush currents of 70va and sealed currents of 6 or 7 va's.

If the elements are connected directly to the controller output contact, in the event of element failure it would blow the out-put relay due to overload. Take a 1000 w element that at 220 v would draw only 4.5 amps or there about. This will work fine connected directly to the controller out-put relay until the element fails. Let's say it fails and shorts to earth halfway down the element. This would in effect double the load to 9 or more amps and blow the out-put relay causing considerable damage to the controller. For the price of an inexpensive interposing relay this can be avoided. You could use a simple 8 or 11 pin type relay, or a contactor depending on the load switching requirements of the elements. This is typically how you should connect this up.

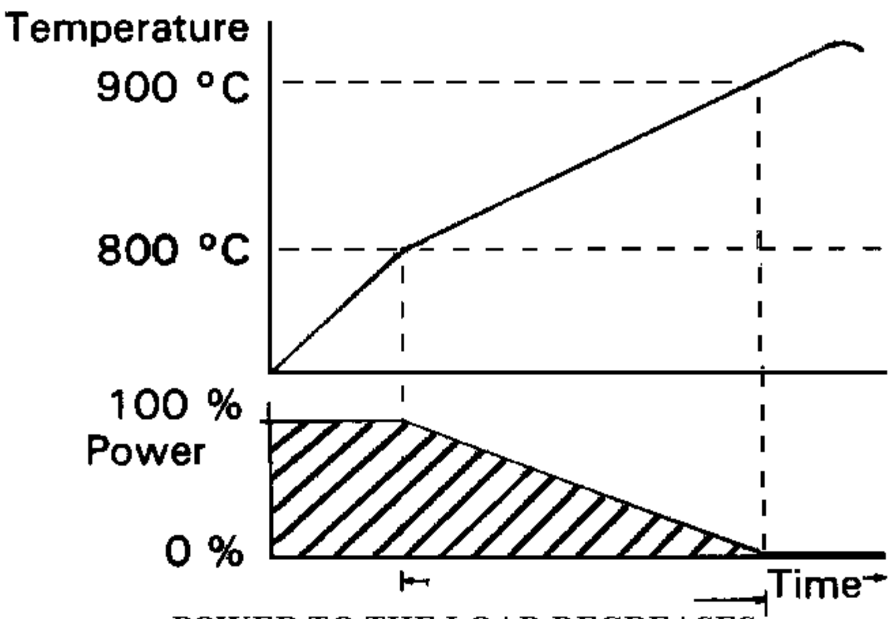


PROPORTIONAL

Proportional only control is a term usually applied to any type of control where the output is determined by the **relationship** (or size of gap) between the measured variable (temperature) and the reference point (set point). This means that the relay will switch on and off "more" or "less" as the gap between the setpoint and the actual temperature varies. (Gets bigger or smaller) The frequency of switching of the output relay is proportional to the deviation between the measured variable (actual temperature) and the desired set point. The further the temperature drops away from the set-point, the more the controller will increase the on pulses of the out-put relay, and as the temperature nears the set-point, it will tend to reduce the number of on pulses, thereby reducing the heat entering the system.

Taking an oven as an example, if we had a proportional band of 100% it would mean that when the oven temperature is at ambient when we first switch the oven on, and our setpoint is say at 200 deg C, the heating elements would be fully turned on. Now as the temperature tends to increase, going up towards 200 deg C, the relationship between the duration of the "on" and "off" periods would be changing all the time. As the temperature gets up to 200 deg C the heating elements would be fully off. If we now narrowed the proportional band to say 50%, for a 50% variation in the temperature of the oven (say from 150 deg C up to 200 deg C) the heating elements would change from being fully on at 150 deg C to fully off, at 200 deg C. If we narrowed the proportional band still further to say 10%, it would mean that for a 10% variation in the temperature (say from 190 deg C to 200 deg C) the elements would change from being fully on at 190 deg C to fully off at 200 deg C.

You can see from this that the smaller the proportional band setting, the more radical the response to smaller changes taking place in the gap between the setpoint and the measured temperature. The extreme extrapolation of this would be when you reduce the proportional band down to say 1%, for a very small change in the gap between the setpoint and the measured temperature, the elements would change from being fully on to fully off. In fact with a proportional band of 0% when the temperature in at the setpoint, the elements would be fully off and in theory as soon as the temperature drops by as little as 0.1 deg C the elements would be fully on. This is now on/off control.



POWER TO THE LOAD DECREASES AS THE MEASURED TEMPERATURE TENDS TOWARDS THE SETPOINT

Proportional control in relay output controllers is normally achieved by varying the relay on/off time relationship. For example if the controller was calling for a 50% power output and the cycle time of the controller was 20 seconds the relay would be on for 10 seconds and off for 10 seconds. The cycle time of the Caho on/off controllers is approximately 15 seconds.

You can see from this that due to the operation of proportional control, you will get much less overshoot as the temperature of the process reaches the setpoint. Why ? Well in the case of an on/off controller, as the temperature is rising, and lets say is 0.5 deg C from the setpoint, the heating elements are fully on and stay on delivering maximum power to the system. They only turn off once the temperature has reached the setpoint.

In the case of proportional control, because the amount of heat required for the system is dependent on the gap between the setpoint and the actual measured temperature, when the measured temperature is 0.5 deg C away from the setpoint, the output will be virtually off. They will be delivering significantly less heat to the system. This in turn means that there will be considerably less “latent heat” left in the elements at the point just before the temperature reaches the setpoint, resulting is little or no overshoot.

RESET SCREW

Proportional control attempts to return a measurement to the set point after a change has occurred. For dynamic reasons, it is possible that a proportional controller may not be able to return the measurement exactly to the set point and in order to accommodate this inherent offset, most controllers are fitted with a manual reset adjustment screw. In most applications once the controller has been installed and commissioned one needs to adjust this reset adjust only once for a given set of dynamics and the system will remain stable. In fact in most practical applications it may not be necessary to adjust this at all.

- When using proportional only control, the effect of this offset can be reduced by narrowing the proportional band, bearing in mind that when the proportional setting is zero the controller will behave as an on/off controller and will by definition get back up to the setpoint.. This trade off introduces an element of instability in the control function because by its very nature an on/off introduces process swings around the set point. Narrow band proportional only controllers are generally used in simple temperature applications having longish time constants. The proportional band setting on the Caho range is factory set at 2.5% of full scale.

2. MORE ADVANCED PID CONTROLLERS.

PROPORTIONAL AND DERIVATIVE

So far only proportional action has been discussed so it is worth considering the benefits of introducing the derivative term to the controller. The derivative term is used to enable a controller to react actively to rates of change of the process (e.g. rate of change of temperature). For example, if someone opens a furnace door while the furnace is at a high temperature the derivative term will react to the rate of change of temperature (sudden dropping as the door is opened) this will increase the output power to compensate for the drop prior to the system generating a steady state error to which proportional only would react and by so anticipating changes reduces unwanted oscillation in the system. In addition to this by the same action it also tends to prevent over shoot that may be encountered in a proportional controller. In simple terms derivative action is a term that responds to the rate of change while proportional action is based on a fixed relationship between the measured variable and setpoint.

PROPORTIONAL INTEGRAL AND DERIVATIVE

The most sophisticated type of control action is the PID controller. This is used in any application where dynamic changes are large or fast and where precise control is required. While the derivative term discussed above tends to eliminate any offset between the measured variable and set point it is still based on a fixed relationship formula. The integral term has the effect of continually repeating the proportional output change until the measured variable has returned to the set point. The integral rate is generally measured in repeats per minute. This means that for example if a change between the measured variable and the set point was say 5% every minute the integral action would change the output by 5% until the offset was zero.

The VERTEX range of PID controllers incorporate an enormously helpful function that assists in the tuning of the PID parameters, namely the self tuning function. This allows the operator to simply activate this function, and the controller will by way of simple tests, tune the PID parameters itself.

- This is either the "adaptive" self-tuning function in the VT10 series, or the "fuzzy logic" self-tuning function in the VT20 series. You must remember that the PID terms are in fact mathematical functions and will vary between one set of dynamic parameters and another. In most applications self tuning is recommended, particularly where the operating staff are not fully conversant with tuning three term controllers.
- Self tuning should be done only once the control loop has been allowed to more or less stabilise using the factory PID settings, and them using the self tuning feature to fine tune the controller.

THE INPUT

Types of probes

In the main there are three popular types of probes used. These are PT100 resistance bulbs, Type J and Type K thermocouples. Type R is also common at temperatures above 1000 deg C.

A thermocouple is a sensor device designed to measure temperature. It consists of two dissimilar metals joined together at one end that produces a small voltage (milli-volt) signal that changes with temperature. As a result of this it is imperative that the correct type of connecting cable is used. This cable is referred to as compensating cable and is made of material that displays the same thermal characteristics as the actual thermocouple metals used.

A PT100 is similar in construction but uses a platinum resistance as the measuring element. This means that in stead of the device generating a milli-volt signal in the case of PT100's we measure changing resistance with temperature. This resistance in the case of a PT100 is 100 ohm's at 0 deg C. In this case because the measurement is resistance ordinary copper cable can be used as the material will have no effect on the signal from a dissimilar metals point of view but the length of the connecting wires will introduce additional resistance into the loop. To overcome this designers of controllers use either a three or four wire system. In essence this calls for the inclusion of an additional wire between the probe and the controller the resistance of which is then measured and subtracted from the actual measurement resistance to eliminate the effect of the lead wire resistance. This means that when PT100's are used ordinary copper cabtyre of any reasonable length can be used.

It is generally recommend that 3 wire PT100's be used for most applications up to 200 deg C
Use type J thermocouples for temperatures between 200 and 600 deg C
Use type K thermocouple for temperatures between 600 and 1000 deg C
Use type R thermocouple for temperatures above 1000 deg C
Other considerations that should be taken into consideration when selecting the probe type are :

- Type J (Iron-Copper Nickel or Iron-Constantantan I/C) should be used in a reducing atmosphere. Iron oxidises rapidly at high temperatures. Used commonly on plastics machines.
- Type K (Nickel Chromium-Nickel Aluminium C/A) should be used in oxidising atmospheres.

- PT100's do not require compensating cable and are used on normal 3 core copper extension cable. They are usually a little more expensive than thermocouples.
- Always bear in mind that to start with the above probes all have inherent errors before we start and when you find customers asking for accuracy's less than the controllers can deliver point out the following :

  PT100 grade 1 accuracy at 100 deg C has a measuring tolerance of ± 0.2 deg C
  PT100 grade 2 accuracy at 100 deg C has a measuring tolerance of ± 0.5 deg C (most common)
  Type J at 400 deg C has a measuring tolerance of ± 1.6 deg C
  Type K at 600 deg C has a measuring tolerance of ± 2.5 deg C

OUTPUTS

There are three main types of outputs

RELAY

SOLID STATE RELAY

ANALOG/THYRISTOR

RELAY

The most common output is relay output. This is in fact is a miniature PCB relay mounted inside the controller, that provides us with a potential free contact (switch) that we can use to switch an external contactor on or off. This external contactor then switches the heating elements on or off.

SOLID STATE RELAY

This is an output that provides a low voltage DC signal (typically 24 Vdc) to be used to switch a SOLID STATTE RELAY on or off. We have a separate simple write up about solid state relays, but in principle, a sold state relay is a high speed semiconductor device (relay) that when used with a "PID" output temperature controller, will give you the best possible control around your required setpoint. When using a solid state relay, the temperature controller is allowed to switch the heating elements on and off in much smaller bursts, but at a much higher frequency that it could with a contactor, thereby giving smaller amounts of power to the elements each time, but more frequently. The end result of this is that only the exact amount of power required for your process is applied to the elements, eliminating overshoot, and giving very good control. Using PID / SSR in most applications will give the very best control possible from a system.

ANALOG/THYRISTOR

This is in fact an analog signal, usually a milliamp signal of 4~20 milliamps, or a low voltage signal of 1~5 Vdc. This is used to regulate thyristor controller units, that are simply put, large power regulators, a bit like the simple light dimmer used in your lounge. This allows the ultimate in control, as the heating elements are never actually switched on or off, but the power is regulated to exactly the amount required to satisfy the system demands. We have a separate write up about thyristor controllers.

Note : The above information has been extracted from various articles and documents published over a period of many years and has been compiled for your convenience.

COMMONLY ASKED QUESTIONS

1. If you do not know what type of probe you have in an existing installation.
   - Check if the probe has two or three wires. If it has three it is a PT100. If only two it is a thermocouple.
2. If you do not know what type of thermocouple you have in an existing installation.

- The first thing to do is look on the old controller. It may say the thermocouple type or may say CA. “CA” is type K. “IC” is type J
- The next thing is to check is the colours of the wires. It is important to also check the outer sheath colour and colours of the two wires. Use your chart to then check the type.
- Failing this you should contact us for help or simply replace the probe together with the new controller.

3. You have installed the controller and the relay or contactor will not switch.
   - The wiring is very important and if you do not fully understand electrical circuits too well consult an electrician or contact us for assistance.
   - Consult our simplified guide to installing controllers in our web site. (qis-uk.co.uk)