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TEMPERATURE CONTROLLERS

Marian BLEJAN[1], Ioana ILIE[1]

[1] INOE 2000 – IHP, Bucharest, blejan.ihp@fluidas.ro

Abstract: *To accurately control process temperature without extensive operator involvement, a temperature control system relies upon a controller, which accepts a temperature sensor such as a thermocouple or RTD as input. It compares the actual temperature to the desired control temperature, or setpoint, and provides an output to a control element. The controller is one part of the entire control system, and the whole system should be analyzed in selecting the proper controller.*

Keywords*: Temperature, controller*

1. Introduction

The following items should be considered when selecting a controller:

1. Type of input sensor (thermocouple, RTD) and temperature range

2. Type of output required (electromechanical relay, SSR, analog output)

3. Control algorithm needed (on/off, proportional, PID)

4. Number and type of outputs (heat, cool, alarm, limit)

There are three basic types of controllers: on-off, proportional and PID. Depending upon the system to be controlled, the operator will be able to use one type or another to control the process.[1][2]

2. On/Off Controllers

An on-off controller is the simplest form of temperature control device. The output from the device is either on or off, with no middle state. An on-off controller will switch the output only when the temperature crosses the setpoint. For heating control, the output is on when the temperature is below the setpoint, and off above setpoint. Since the temperature crosses the setpoint to change the output state, the process temperature will be cycling continually, going from below setpoint to above, and back below. In cases where this cycling occurs rapidly, and to prevent damage to contactors and valves, an on-off differential, or "hysteresis" is added to the controller operations. This differential requires that the temperature exceed setpoint by a certain amount before the output will turn off or on again. On-off differential prevents the output from "chattering" (that is, engaging in fast, continual switching if the temperature's cycling above and below the setpoint occurs very rapidly). On-off control is usually used where a precise control is not necessary, in systems which cannot handle the energy's being turned on and off frequently, where the mass of the system is so great that temperatures change extremely slowly, or for a temperature alarm. One special type of on-off control used for alarm is a limit controller. This controller uses a latching relay, which must be manually reset, and is used to shut down a process when a certain temperature is reached.

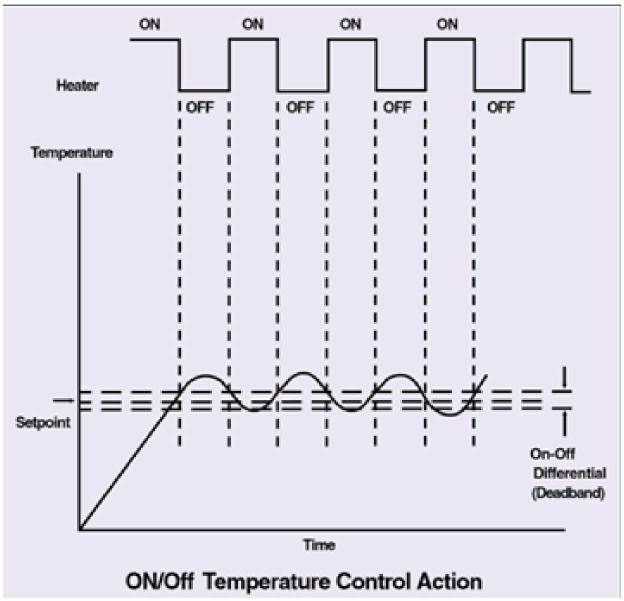

Fig. 1. On/off temperature control action

3. Proportional Controllers

Proportional controls are designed to eliminate the cycling associated with on-off control. A proportional controller decreases the average power being supplied to the heater as the temperature approaches setpoint. This has the effect of slowing down the heater, so that it will not overshoot the setpoint but will approach the setpoint and maintain a stable temperature. This proportioning action can be accomplished by turning the output on and off for short intervals. This “time proportioning” varies the ratio of ‘on’ time to ‘off’ time to control the temperature. The proportioning action occurs within a “proportional band” around the setpoint temperature. Outside this band, the controller functions as an on-off unit, with the output either fully on (below the band) or fully off (above the band). However, within the band, the output is turned on and off in the ratio of the measurement difference from the setpoint. At the setpoint (the midpoint of the proportional band), the output on:off ratio is 1:1; that is, the on-time and off-time are equal. If the temperature is further from the setpoint, the on- and off-times vary in proportion to the temperature difference. If the temperature is below setpoint, the output will be on longer; if the temperature is too high, the output will be off longer. The proportional band is usually expressed as a percent of full scale, or degrees. It may also be referred to as gain, which is the reciprocal of the band. Note, that in time proportioning control, full power is applied to the heater, but is cycled on and off, so the average time is varied. In most units, the cycle time and/or proportional band are adjustable, so that the controller may better match a particular process. In addition to electromechanical and solid state relay outputs, proportional controllers are also available with proportional analog outputs, such as 4 to 20 mA or 0 to 5 V DC. With these outputs, the actual output level is varied, rather than the on and off times, as with a relay output controller. One of the advantages of proportional control is simplicity of operation. It may require an operator to make a small adjustment (manual reset) to bring the temperature to setpoint on initial startup, or if the process conditions change significantly.
Systems that are subject to wide temperature cycling will also need proportional controllers. Depending upon the process and the precision required, either a simple proportional control or one with PID may be required. Processes with long time lags and large maximum rate of rise (e.g., a heat exchanger), require wide proportional bands to eliminate oscillation. The wide band can result in large offsets with changes in the load. To eliminate these offsets, automatic reset (integral) can be used. Derivative (rate) action can be used on processes with long time delays, to speed recovery after a process disturbance.

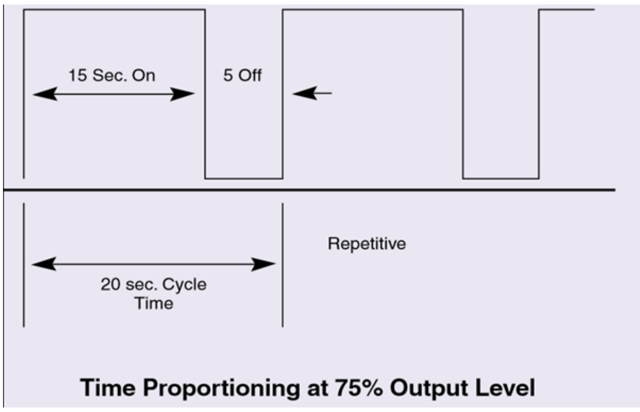

Fig. 2. Time proportioning at 75% output level

There are also other features to consider when selecting a controller. These include auto- or self tuning, where the instrument will automatically calculate the proper proportional band, rate and reset values for precise control; serial communications, where the unit can "talk" to a host computer for data storage, analysis, and tuning; alarms, that can be latching (manual reset) or non-latching (automatic reset), set to trigger on high or low process temperatures or if a deviation from setpoint is observed; timers/event indicators which can mark elapsed time or the end/beginning of an event. In addition, relay or triac output units can be used with external switches, such as SSR solid state relays or magnetic contactors, in order to switch large loads up to 75 A.

4. PID Controllers

The third controller type provides proportional with integral and derivative control, or PID. This controller combines proportional control with two additional adjustments, which helps the unit automatically compensate for changes in the system. These adjustments, integral and derivative, are expresse in time-based units; they are also referred to by their reciprocals, RESET and RATE, respectively. The proportional, integral and derivative terms must be individually adjusted or "tuned" to a particular system, using a "trial and error" method. It provides the most accurate and stable control of the three controller types, and is best used in systems which have a relatively small mass, those which react quickly to changes in energy added to the process. It is recommended in systems where the load changes often, and the controller is expected to compensate automatically due to frequent changes in setpoint, the amount of energy available, or the mass to be controlled.

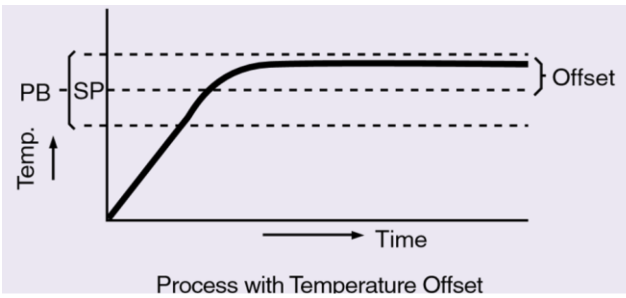

Fig. 3. Process with temperature offset

Rate and reset are methods used by controllers to compensate for offsets and shifts in temperature. When using a proportional controller, it is very rare that the heat input to maintain the setpoint temperature will be 50%; the temperature will either increase or decrease from the setpoint, until a stable temperature is obtained. The difference between this stable temperature and the setpoint is called offset. This offset can be compensated for manually or automatically.

Using manual reset, the user will shift the proportional band so that the process will stabilize at the setpoint temperature. Automatic reset, also known as integral, will integrate the deviation signal with respect to time, and the integral is summed with the deviation signal to shift the proportional band. The output power is thus automatically increased or decreased to bring the process temperature back to setpoint, The rate or derivative function provides the controller with the ability to shift the proportional band, to compensate for rapidly changing temperature. The amount of shift is proportional to the rate of temperature change. A PID, or three-mode controller, combines the proportional, integral (reset) and derivative (rate) actions, and is usually required to control difficult processes. These controllers can also be made with two proportional outputs, one for heating and another for cooling. This type of controller is required for processes which may require heat to start up, but then generate excess heat at some time during operation.

5. Controller output hardware

The output from the controller may take one of several forms. The most common forms are time proportional and analog proportional. A time proportional output applies power to the load for a percentage of a fixed cycle time. For example, with a 10 second cycle time, if the controller output were set for 60%, the relay would be energized (closed, power applied) for 6 seconds, and de-energized (open, no power applied) for 4 seconds. Time proportional outputs are available in three different forms: electromechanical relay, triac or ac solid state relay, or a dc voltage pulse (to drive an external solid state relay). The electromechanical relay is generally the most economical type, and is usually chosen on systems with cycle times greater than 10 seconds, and relatively small loads. An ac solid state relay or dc voltage pulse are chosen for reliability, since they contain no moving parts. Recommended for processes requiring short cycle times, they need an additional relay, external to the controller, to handle the typical load required by a heating element. These external solid state relays are usually used with an ac control signal for ac solid state relay output controllers, or with a dc control signal for dc voltage pulse output controllers. An analog proportional output is usually an analog voltage (0 to 5 Vdc) or current (4 to 20 mA). The output level from this output type is also set by the controller; if the output were set at 60%, the output level would be 60% of 5 V, or 3 V. With a 4 to 20 mA output (a 16 mA span), 60% is equal to (0.6 x 16) + 4, or 13.6 mA. These controllers are usually used with proportioning valves or power controllers.

6. Conclusions

When you choose a controller, the main considerations include the precision of control that is necessary, and how difficult the process is to control. For easiest tuning and lowest initial cost, the simplest controller which will produce the desired results should be selected. Simple processes with a well matched heater (not over- or undersized) and without rapid cycling can possibly use on-off controllers. For those systems subject to cycling, or with an unmatched heater (either over- or undersized), a proportional controller is needed.

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