5 Keys to Effective Temperature Control

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Following these five design principles can help ensure success in process temperature control.

The world of heat transfer is a battle of moderation. Too much or too little heat can be a real problem. One thing is for sure: Controlling the means of heating and cooling in a process is both an art and a science. Because each thermal cooling and heating system is unique, following good design principles will allow success in the control of process temperatures.

“Success” in process temperature control is an uncertain term. Some processes can accept wide fluctuations in process temperature control while other processes demand extremely tight temperature tolerances. Obviously, the more exacting the control requirements, the more exacting the system design must be. When developing a process control system, the following five design variables should be considered: sensor type, sensor location, cooling and heating capacity, process variable consistency, and proportional controller capabilities. No one variable is more important than any other. The goal of a temperature control system is to maintain balance with all the process inputs to achieve the proper temperature control.

1. Select the Right Sensor

Selection of a temperature sensor often is the last decision made in system design. The decision typically is driven by the compatibility of the system process controller and often comes down to cost and availability. Unfortunately, critical selection criteria such as operating temperature, sensor mass, reading sensitivity, signal strength (interference potential) and operating ambient frequently are overlooked.

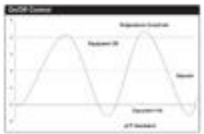

Figure 1. On/off control activates the full capacity of the heating or cooling system at a predetermined temperature either above or below the setpoint.

Three types of sensors typically used in commercial temperature control are resistive thermal devices (RTDs), thermocouples and Thermistor. Each sensor type has its own characteristics, and different styles within each type are designed for specific temperature ranges, output signals and process compatibility (based on the materials of construction). The sensor should be chosen to match the specific system design application parameters.

Sensor mass also is an important characteristic that should be considered when making a final selection. Heavier sensor bodies provide a slower, dampened response to process changes while a light sensor mass will provide a quicker response to process temperature changes. Typically, the more exacting the process temperature control, the lighter and faster-responding the sensor should be.

2. Install the Sensor in the Correct Location

It might be obvious, but the location of the system temperature sensor is crucial. In some cases, field installation of a temperature sensor is influenced by physical obstacles that cause the initial design location to be modified. When it is difficult to place the sensor in the correct location, compromises and alternative locations might be considered. However, the position of the sensor is the key to the success of all the other parts of the system. System efficiency should never be compromised for ease of sensor installation.

The following are a few tips to avoid common pitfalls:

- Make sure the sensing location is at the entry point of the critical temperature position.
- Make sure the process fluid is mixed and there are no hot or cold currents that can “fool” the sensor.
- Make sure the sensor location is not negatively affected by changes in fluid velocity.
- Make sure that no outside heating or cooling sources will affect the process fluid. (For example, an un-insulated section of piping after the sensor but prior to the critical temperature point of the process can affect the delivered temperature to the critical point).

3. Balance the Cooling and Heating Capacity

Balancing the cooling and heating capabilities of the system is the goal of any temperature control system. Mismanaging the energy balance will result in temperature instability.

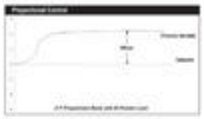

Figure 2. A proportional controller operates based on a linear calculation in which a change in a given deviation will result in a linear change in output.

Two basic types of controls are on/off output control and proportional output control. On/off control is the easiest control type to understand. It bases its decision making on a temperature deviation from the system temperature set point. At a predetermined temperature, either above or below the set point, the system activates the full capacity of the heating or cooling systems (figure 1). The only means to stop further heating or cooling is to turn off the conditioning equipment.

If the process mass is large compared to the cooling or heating capacity and the allowed temperature fluctuation is wide, on/off control can be an acceptable and cost-effective control method. However, it does have some practical limitations. Because a system’s capabilities often are significantly higher than the load during different situations, merely turning the heating or cooling equipment on and off is generally impractical.

One approach to enhance the capacity control of on/off control systems is to add differing levels or stages of capacity to the heating or cooling system. Newer mechanical equipment has been built with stages of capacity that can be turned on and off to balance varying loads and improve energy management. Instead of a 0 or 100 percent output, some systems now have 0 percent, 25 percent, 50 percent or 100 percent output options. These systems can minimize energy peaks and valleys and allow for improved process temperature management while still using a variation of on/off control.

By contrast, proportional output control is staged control. Instead of 0 or 100 percent capacity, these systems provide a variable 0 to 100 percent output capacity. Proportionally controlled systems are standard in the industry when fine process control is required. System components generally include proportioning control valves, variable-frequency drive motors and variable-output gas valves. Typically, the more complex the proportioning system, the higher is the initial system cost. However, the improved process temperature control provided by these systems along with the potential for energy savings over the life of the equipment often justifies the higher initial cost. In some cases, the energy savings can offset the cost of the equipment.

4. Keep Process Variables Consistent

Figure 3. The integral gain of PI controllers compensates for any error in the proportional signal and adjusts the control signal to achieve the set point.

Keeping all of the equipment subsystem functions predictable can make the process control more manageable. With the advent of energy-management improvements, some energy-saving schemes can actually have a destabilizing effect on process temperature control. As loads change, many new systems automatically will compensate several variables in response to this change. Some of the variables that are commonly adjusted are process fluid volume, supply fluid temperature, and cooling or heating capacities. The adjustment of several subsystems like fluid flow, supply temperatures and process pressures will change the characteristics of the system, and these changes can create temperature instability and cause control problems.

For example, consider a plant chiller system in which the fluid flow rate of the process is changed. The reduced flow rate can exponentially change heat-transfer characteristics in some system components and heat exchangers. The loss of heat transfer can cause temperature instability at the critical point and can cause the compressor or other components to malfunction.

If the fluid flow falls below the minimum air entrainment velocity, air pockets can form within the piping system. Sensors will then sense the air pockets rather than the fluid. Reduced flow rates also could cause poor fluid distribution in piping and cause inaccurate temperature measurement due to stratification in the piping. Another potential problem is that fluid control valves sized for full flow might be required to operate closer to their “turned down” position. Valves operating at their extremes will tend to “hunt” for the proper position, causing increases and decreases in flow rates that can affect temperature stability. Additionally, reduced mass flow rates can disrupt the system reaction time and require the system’s control parameters to be adjusted for proper temperature control.

This example demonstrates how changing one system variable can impact other subsystems by requiring a significant counter action. Understanding the relationship of subsystems is key to temperature control success. The more consistent the subsystem variables remain, the more stable the processes become.

5. Use the Correct Proportional Controller

Most proportional controllers fall into three design types or actions: proportional only (P), proportional plus integral (PI), and proportional plus integral and derivative (PID). Technical advances in small process controllers have provided engineers with more flexibility in their designs. Controllers have improved to such a degree that they often can compensate for system design flaws and unruly characteristics.

Figure 4. PID controllers use the advantages of integral gain to bring the process variable closer to the set point and to negate the proportional offset while also using a derivative function that compares the rate of change in time to the required set point.

Proportional controllers are the simplest controllers and are the basis for most small electronic control devices. A proportional controller works off a deviation of temperature and applies an output signal based on a linear calculation in which a change in a given deviation will result in a linear change in output (figure 2). An example of a linear proportional control scheme is in a cooling process where a 5°F (2.8°C) change in the temperature from the set point will result in 100-percent output in cooling. Acting linearly, a 1°F (0.6°C) deviation in temperature would equal a 20-percent cooling output, and a 2.5°F (1.4°C) deviation in cooling would equate to a 50-percent cooling output. Not until the 5°F differential occurs will the 100-percent output be provided. The proportional controllers offer a means of variable control but, by design, they do not hold a consistent temperature. They are designed to provide a “range” of temperature control.

Proportional controllers with integral adjustment use the standard concept of a proportional controller, which provides a linear change in output based on a linear change in temperature deviation. In the example above, a 5°F deviation from setpoint would provide a 100-percent output in cooling. In addition, the PI controller allows an additional mathematical calculation: The integral gain of the controller will compensate and adjust the control signal to achieve the set point (figure 3). The integral gain will work to reduce the error of the proportional signal and will allow a tighter control to set point. It is often possible to reduce the error-to-set point level to zero if the system is operating at steady-state conditions. Unfortunately, the addition of integral gain also can cause instability in a dynamic system. Although the process temperature might be unstable, the combination of proportional and integral adjustment should keep process temperature close to the set point.

Proportional controllers with integral and derivative adjustment also are based on the standard proportional control. These systems use the advantages of integral gain to bring the process variable closer to the set point and to negate the proportional offset. The derivative function in the PID controllers adds an additional mathematical operator that compares the rate of change in time to the required set point (figure 4). The result is that the derivative function adds to the integral gain function with the effect of stabilizing the process temperature at set point. The controller anticipates over-compensation due to integral gain.

Most controllers allow for the manual selection of P, I and D parameters. This approach can be effective, but achieving the best control results requires time, effort and a lot of patience. Intelligent trial and error is the only way to determine the proper selection of the parameter values. Because the value of each parameter affects the controller's operation and all three parameters can be independently selected, the potential combinations of parameter changes are infinite.

To resolve this problem, some controllers are now built with auto tune features. These controllers can be programmed to suggest acceptable parameters for the P, I and D values that best fit the application conditions. The auto tune feature requires the controller to "learn" the characteristics of the system. It must measure the response time of the system and compare heating and cooling capacities against given loads. The controller judges the reaction of the process to the change in capacity. Once it has determined the characteristics of the process, it stores the variables for the P, I and D parameters to be used in the mathematical formula that best controls the process. These parameters can be tested for effect at various conditions and can be modified if desired. However, the auto tune feature certainly can save time and help adjust for unplanned system variables. It is not uncommon for the auto tune function to be used at various times during the year to help compensate for changes in ambient or operating conditions.

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