Cryogenic Heat Treatment Control

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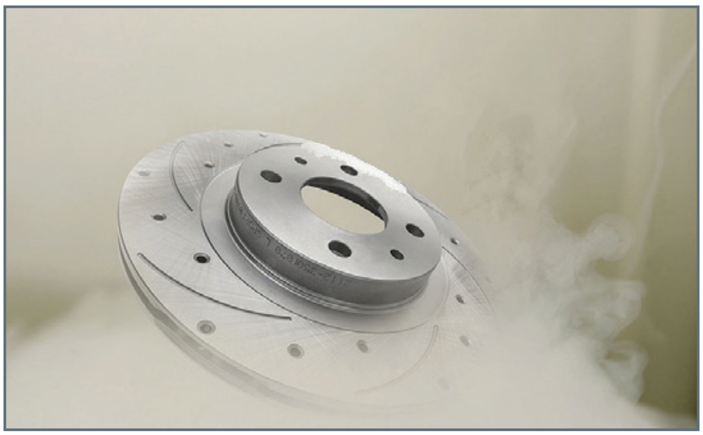
The basic concepts of metals heat treatment date back to the earliest blacksmiths. In the process of making tools and weapons, they learned:

- How to control temperature with a mix of fuels and air.
- How to evaluate the amount of heat through the color of the metal.
- How quenching with water changed hardness characteristics.



With the arrival of the industrial revolution, processes evolved with many advances in metallurgy. A higher level of control through more precise temperature measurement and process quantification allowed repeatability in ways previously not possible. Then, in the latter half of the 19th century, newly developed refrigeration and cryogenic processes allowed products to be cooled to levels far below traditional winter experiences regardless of the location or season.

As it relates to metals heat treatment, manufacturing histories note that 19th-century Swiss watchmakers left parts outdoors through the winter. When assembled into a timepiece, these components allowed the watch to run more accurately over the long term. By the 1930s, the practice of freezing tool steel became common, primarily because it allowed the metal to hold an edge better. Those makers probably did not understand what was happening, but they realized the result.

Many manufacturing advances were developed during World War II, but the uses of cryogenics in metal treatment were still largely in their infancy. While metals frozen to low temperatures showed greater wear resistance, the processes were not well characterized. Just as users realized heat treatment required more care than simply throwing the parts to be heated into a furnace, they also noticed that cryogenic processes required careful calibration and control.

Controlling Time and Temperature for Heat Treatment

Many basic heat-treatment processes are simple. Others — such as when parts are loaded into a furnace following a series of ramp-and-soak cycles — are far more sophisticated. In such applications, the furnace heats up slowly and evenly, moving to perhaps 1500°F (815°C) over 40 hours. Then, it is left at the final temperature for 80 hours and cooled slowly over another 20 hours. The controller manages the furnace temperature, accurately and deliberately, through the ramping cycles and holds it steady at whichever level is selected.

Because the quantity of parts in a load and their combined mass can vary, the amount of heat they absorb also can vary. This means the controller must be able to compensate to keep the furnace at the optimal temperature regardless of the load size.

Some processes involve just a heating cycle or just a cryogenic cooling cycle, but many involve both. To get the maximum temperature spread and the most optimum metal treatment, parts often are cooled and then heated following a carefully designed program. In some processes, a controller may have to cool and then heat parts, moving from -300 to 400°F (-184 to 204°C) over a 10-hour period in a linear fashion.

When a heat-treatment process demands both low and high temperatures, it provides complex challenges for the controller. Controlling a cold process — whether in a cryogenic furnace or a chest-type freezer — has some critical differences compared to controlling a standard heat-treat furnace at temperatures well above 1000°F (537°C). These critical factors affect a temperature controller's performance when subzero temperatures are involved. They must be considered when applying the same controller to perform both heating and cooling steps. While the technology may look and feel similar to heating, the process characteristics are quite different.

Manufacturers of cryogenic furnaces and environmental chambers often use the least expensive method of removing heat from the process and individual parts. When starting from a typical ambient temperature, using a liquid cryogen is costly and not always necessary. A basic mechanical freezer may provide the first stage of cooling to reduce the amount of cryogen used. Naturally, this means the controller must be able to handle multiple stages of cooling in the process. In situations where the lowest temperatures are needed, multiple cryogens might be involved.

Just as parts must be heated following a specific ramping period, in cryogenic applications, work pieces must be brought down to their final temperature at a controlled rate. Moving too fast can sabotage the desired microstructure in the metal. A control device with a good algorithm and setpoint-pattern management is necessary to maintain the specific ramping rate necessary for a successful process.

Using PID for Heating and Cooling Control During Heat Treating

One common problem with using one controller for both processes is the difference between how the heating and cooling modes work. The difference affects how the loop tuning should be set up. For many controllers, cooling is an afterthought, and they do not have full PID abilities to control the cooling side.

For many heat/cool controllers, the lowest temperature expected is 0°F (-18°C), so the cooling algorithm is a subset of the heating control. This works fine for jacketed vessels using steam and a cooling liquid such as a brew kettle in a beer brewery. For cryogenic processes, however, the controller requires a completely separate PID strategy and mechanism to control temperature near setpoint.

Typical heating loops can only move the process temperature up because the control element is a heater. If the temperature is too high, the controller shuts off the heater and waits until the temperature falls within the specified range. When both heating and cooling options are available, a poorly tuned controller may overreact when a temperature is too high during a heating cycle and turn on the cryogenic cooling. In a worst-case situation, it might even begin oscillating between heating and cooling cycles. This can cause disastrous thermal shocks to the parts being treated or become a major waste of energy and cryogen.

When the furnace reaches its setpoint — hot or cold — and the output is swinging between heat and cool, the tuning needs to be adjusted. Most automatic tuning functions do not work well unless they are sophisticated enough to realize the differences between the heating and cooling functions. Typically, they must be tuned independently.

Cryogenic Cooling Challenges During Heat Treating

The concept of latent heat is rarely considered in more conventional situations. When a liquid cryogen is used to cool parts, the changes in the latent heat remaining in the environment and parts can make it difficult to maintain a stable temperature. As the level of the latent heat changes, the dynamics of the system change. As a result, the controller must adjust how it responds to the oven even though the temperature is the same. An effective controller will minimize the amount of cryogen used by adjusting the PID variables or using a type of fuzzy logic to respond to the changing conditions. This also will produce a better product.

Measuring cryogenic temperatures can pose challenges. The temperature sensor of choice in hot and cold heat-treating processes is nearly always a thermocouple. Of course, there are various types of thermocouples, and selection merits serious consideration. Many thermocouple types are rated for subzero temperatures, but the specifications may not tell the whole story. The accuracy and sensitivity of different thermocouple types begin to diverge when trying to measure in cryogenic ranges.

If the temperature reading becomes less reliable, the ability to control accurately suffers. This is a problem because manufacturers count on repeatability from heat-treating processes to maintain consistency from batch to batch. Critical tolerances for precision-machined parts can be disrupted by processing inconsistencies.

Unfortunately, as the temperature falls, so does the sensitivity of thermocouples. The extent of the change varies according to the thermocouple type. The kinds of small millivolt signals produced at a cryogenic temperature can make an accurate reading virtually impossible. To make matters worse, the small signal from a thermocouple is more susceptible to noise than a signal generated at a higher temperature. So, noise management and proper wiring techniques are especially critical.

Moreover, many controllers and process recorders were not designed to work in cryogenic temperature ranges. Controller firmware typically converts a thermocouple signal to a temperature by using a curve or lookup table to convert the millivolt value to a temperature. So, the controller being evaluated must be able to handle such low values. The lower operating range of the thermocouples must be included in the instruments. This is particularly critical if the Type E or T curves are present. These are frequently used in cryogenic applications.

Controlling the oven environment is not always easy, depending on the desired temperature. When a liquefied gas is used as the cryogen, it can bring the environment down to the boiling point of the gas if continuously feed into the chamber until all of the latent heat is removed. The boiling point of liquid nitrogen is -320°F (-196°C).

If some higher temperature is desired — for example, -150°F (-101°C) — the controller must maintain the temperature by injecting the cryogen intermittently. For users more accustomed to heated processes, the cooling action of a cryogen is significantly faster than heating with electric heaters or natural gas, which calls for different control strategies.

In conclusion, cryogenic heat treatment, whether used alone or in conjunction with heated processes, can provide useful tools for manufacturers. The strategies for controlling such temperatures pose significant challenges for those moving into this unfamiliar territory. Suppliers can be of assistance, but they must have specific experience with cryogenics as well as products to fit these challenging applications.

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