NPH

Technical Letters

Miniature 1/8" OD and 4 mm OD Cartridge Heaters: Element Resistance and Its Affect on Heater Life

General

This will describe the causes and effects of resistance changes during the operation of 1/8" cartridge heaters. Their affects on heater performance and heater life are described. It also describes methods for ensuring acceptable performance and for maximizing heater life.

The type of heater being discussed is a metal-sheathed cartridge heater, electrically insulated with compacted Magnesium Oxide, with a helical resistor embedded within. The resistor is an 80 percent nickel and 20 percent chromium alloy, such as Kanthal-80 or Chromel-A.

Four causes for variable resistance are described:
- Variations in the as-manufactured resistance of the heater;
- Permanent increase on first heat up;
- Transient increase with each heat up;
- Gradual Permanent increase due to "Aging".

Except for variations due to manufacturing tolerances, all of the above affects are directly related to the operating temperature of the heater's internal resistor element. It is important to remember that the temperature of the internal resistor element the temperature can be as much as 200 degrees C higher than the system temperature.

Variations in As Manufactured Resistance
The resistance of an electric heater is typically subject to a manufacturing tolerance. Miniature cartridge heaters have a standard tolerance of minus 10 percent to plus 15 percent.

Tighter tolerances are available, depending on heater length. With special processing, 1/8" cartridge heaters may have a minimum tolerance of plus / minus 7 percent.

Where heaters are used in pairs, it is often possible to sort them by resistance to create matched pairs whose resistance varies only by one or two percent.

Permanent Resistance Increase on First Heat Up
The initial heat up of the heater (as received from the factory) results in a permanent increase in resistance, typically between 2 percent and 6 percent . This is due to

oxidation of the resistor and to the relieving of stresses created during fabrication of the heater. As a result, a 100 ohm heater (as manufactured and measured at room temperature) may return to room temperature as a 104 ohm heater. The exact increase is dependent on the temperature reached.

Subject to manufacturing variations from system to system, this increase is repeatable and can usually be determined by customer testing.

Transient Resistance Increase

With every heat up, the resistance of the heater will increase as much as 6 percent. This is due to the coefficient of resistivity of the Nichrome resistor. This increase is linear in the range between 0 degrees C and 500 degrees C, and is superimposed on the permanent increase described in 3.0 above. As a result, a 104 ohm heater at room temperature may actually have a resistance of 107 ohms at operating temperature.

The amount of change depends on the end operating temperature of the heating element within the heater. Subject to manufacturing variations from system to system, it is repeatable and may be determined by determined by customer testing.

Aging

Aging is a process of oxidation of the resistor alloy within the heater which causes an increase in the resistance of the heater. At elevated temperatures, it can be a key factor determining the service life of the heater.

Aging due to oxidation at elevated temperatures

1/8" cartridge heaters are typically insulated with Magnesium oxide which, when compacted, has a porosity of 10 to 15 percent. Oxygen which finds its way into the insulation combines preferentially with the chromium at the surface of the internal resistor wire. A dense, adherent oxide layer is created, which is designed to protect the underlying metal. The protection provided can be defeated under some operational circumstances, such as operation at temperatures above 600C, where oxidation of the resistor occurs more aggressively.

Aging due to Thermal Cycling

Thermal cycling occurs during several points of operation:

- During each heat up and cool down of system;
- During "steady state" operation, as changes in process loading occur;
- During "steady state" operation as the heater controller strives to maintain set point temperature by turning the heater on and off (however rapidly).

The rates of expansion of nickel-chromium alloy and its protective chrome oxide are not identical. As a result, with each heating / cooling cycle, cracks may open in the oxide layer, exposing the underlying metal to further cycles of oxidation. Additional chromium migrates to the exposed surface to combine with oxygen. If this continues aggressively, the alloy is locally depleted of chromium and oxygen begins to attack the remaining nickel. Operation at temperatures above 500C accelerates this affect.

Affect on Heater Serviceability

Increases in Heater Resistance During Operation

Oxidation causes heater's resistance to progressively increase. During service at extreme temperatures, heating capacity may be reduced until it reaches a point where the demands of the process can no longer be met.

Use conservative power-loadings on the surface of the heater to reduce internal element temperatures. At temperatures below 300 degrees C oxidation occurs very slowly. Additionally, the amount of thermal expansion / contraction of the element is reduced.

Minimize thermal cycling by the use of control methods that energize /de-energize the heater rapidly (typically within a 1 second period). This allows the thermal inertia of the heater to dampen temperature changes.

Customer testing is recommended. This includes accelerated, "worst-case" testing to determine the maximum rate of resistance change during service. Heater manufacturers may also perform life testing on behalf of the customer.

"Hot Spots"

Aging may occur locally, raising the resistance of the internal element in isolated segments of the heater. Areas of severe local over heating are sometimes visible as "hot spots" on the surface of the heater. In larger heaters (cartridge and tubular heaters ¼ inch diameter and up) hot spots may appear on the surface of the heater, and cause uneven heating in the system.

Local overheating can shorten heater life as effectively as overall overheating. Therefore, it is important to ensure consistent temperatures over the entire length of the heater body.

In 1/8 inch diameter cartridge heaters, the localized high temperature at a hot spot may not reach the surface of the cartridge heater. The greater thermal mass of the heater relative to that of the resistor (typically 30 : 1), dampens the local temperature difference. The mass of the system being heated enhances this effect. This is especially true for short (3/4" long) cartridge heaters, in which the designed hot zone itself may be just 1/2 inches long.

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