Your Heater Material and Design Dictate how you Control it

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If you are designing a control system for a resistance-heated process you can't ignore the properties of the heater. This article focuses only on features of the heater that affect how you deliver power.

These are:

- Resistance change with material temperature and service life.
- Connection arrangement for multi-element heaters.
- Speed of response to power changes.
- Effect of thermal cycling on life.

We will consider four of the most commonly used materials; **the nickel-chrome alloys**, **silicon carbide**, **molybdenum disilicide** and **tungsten.**

Figure 1 shows how resistance varies for nickel-chrome and silicon carbide. Note that this is element not process temperature.

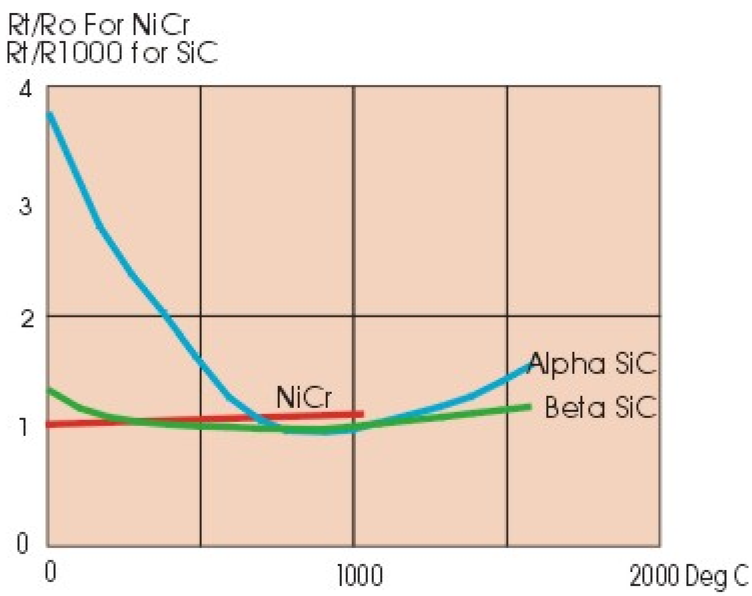

Fig 1 Resistance change with temperature

Nickel-chromium alloys. These are the most common, and for control, the most docile class of resistance heater materials. Various formulations, which can include iron, aluminum and silicon, show useable element temperatures up to some 1400 º C. Change in resistance from room temperature over the working range is only some 4 – 6%. It also changes very little during service life, which also makes it easy to detect and

warn of **partial heater failure** by monitoring the combined resistance of several parallel branches.
Control is usually by low-cost electromagnetic or solid state contactors working in the time-proportioning mode.
Speed of response. For heaters such as cartridge, band and metal sheathed magnesium oxide (MgO) insulated types with thermal time constants more that one or two minutes, cycle times around 10 or 20s are acceptable.
Because of their fast response, low-mass spiral wound radiant heaters in quartz tubes or refractory panels and open-coil heaters in air streams need fast cycling or phase angle control. Slow cycling could give process temperature variations in sympathy with the cycle time. With air heaters a flow-failure power-cut-off switch is advisable, to avoid wire overheating and burnout. This is done in hair dryers by a bimetal thermostat near to the heater coil.

Silicon carbide. This class of materials has a permissible element temperature close to 1600 ^{o} C. The control system has to cope with resistance changes of some 4:1 over the useful life of the element and up to about 3:1 over the working temperature range.
Resistance change with life. A new element may need for example 60V, so a string of four in series would suit a 230V ac supply. Power modulation by a magnetic is a common but not a good choice. Thermal fatigue caused by slow cycling magnetic contactor control can severely limit the working life of the elements. Though many such systems are still in service, fast **solid state contactors** (SSCs) are replacing them.
Over the service life, silicon carbide's resistance can increase gradually up to fourfold. To maintain the power you may have to reconnect the elements into two parallel paths and/or find a higher voltage supply. You could use a multi-tap transformer and adjust it periodically. These arrangements while still widely used are tedious to monitor and adjust. Another disadvantage with a series string is, the higher resistance elements dissipate proportionally more power and show accelerated aging relative to their partners. Whereas in a parallel group, the higher resistance elements take lower than their share of power which retards their aging.
Resistance change with temperature. From the SiC curves in Fig.1 here again you have to cope with resistance change. But this time the variation is by the minute, not by the month as you run up to working temperature.

Conclusions so far:

- All elements in parallel make the best self-compensating arrangement since the higher resistance elements take proportionally less power and age more slowly than their partners.
- If you must connect elements in series, use the least possible number and select them so that their resistances match to 5% or less
- Though you will never need both at the same time, your power supply or transformer has to be sized to provide enough voltage for maximum resistance and enough current for minimum resistance.

Protection against excessive current and power.
In the face of low element resistance you need **current-limiting** to protect wiring and transformer windings and to avoid nuisance fuse blowing and breaker tripping.
At all values of resistance you have to limit the power to a level that keeps the **watt density** of the elements below the manufacturer's recommended watts per square inch.
True Power control
Of all the power control devices tried, the most successful has been the phase-angle controlled SCR unit with true power (load voltage X load current) feedback.
With this arrangement the temperature controller puts a control signal representing demanded power into the SCR unit. The SCR then delivers power in proportion, regardless of variations in line voltage and load resistance. Ensure that you also have current and power limit features on the SCR unit that can override any excessive level of control signal.

Molybdenum Disilicide

From Fig 2 you see a resistance change of some 14:1 over the working temperature range; much more than silicon carbide but subject to only small changes with service life. This means that you have more freedom in arranging series strings of elements and less vigilance is needed in watching for signs of aging.
The SCR features recommended for silicon carbide apply equally here but the demands on current limiting are more severe. Without current limiting, cold-start load current would be some 14 times that at working temperature.

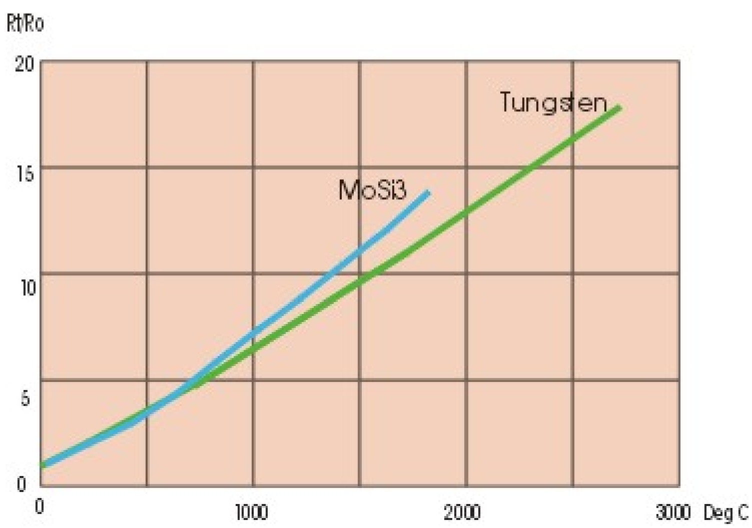

Fig 2 Resistance change with temperature

Tungsten

Here we limit the discussion to tungsten filament lamps for short wave radiant heating applications. The resistance change over the working range is about 17:1. Aging effects are negligible and the same SCR control methods apply as for molybdenum disilicide. Transformers are rarely needed. Tubular lamps are available for standard factory voltages

(115 230 400 etc) up to around 6kW rating. The high cold-inrush current can decay in a second or two because of the low filament mass and consequent fast rise to working temperature of some 2500 ºC. Current limiting is inherent in the resistance attained at working temperature. Automatic current limit is however advisable for the slower, high power lamps in order to avoid blowing the high-speed SCR fuses.
Often, with tungsten lamp heating, a temperature controller is not used and power, therefore heat flux, is manually adjusted and held stable by the SCR in true power control mode.
In many applications it is satisfactory and cheaper to adjust and hold the RMS load voltage stable by feedback of V^2 (load voltage squared) instead of true power feedback.
The common lamp dimmer switch enables you to adjust voltage for rough and ready low power applications but it will not stabilize power against line voltage variations. It will even exaggerate the variations.

Current and voltage monitoring.
RMS analog ammeters and voltmeters on your heaters can give valuable clues to heater condition and help the operator sense the heartbeat of the process. With **nickel-chrome** heaters, current will follow voltage and you can notice loss or partial loss of a heater by a drop in current. From the readings you also can calculate power and heater resistance.

With all the other heater materials dealt with here you will learn not to expect current to strictly follow voltage. Heater resistance will be going its own way according to temperature (and age in the case of silicon carbide). With aging silicon carbide you may eventually notice the SCR delivering full line-voltage yet not enough current to make the temperature you want. This is the time to move up another transformer tap and eventually change the element.
You can often omit the transformer and have the phase-angle fired SCR unit limit the load voltage initially, then raise the limit as the elements age.
False meter readings. Many meters are average-responding and give grossly low indications when handling the shark fin waveforms of SCR phase-angle control.
Your best and cost effective choice is the ac moving-iron meter. It indicates the RMS value, which represents the heating effect value of the voltage or current. Only RMS values work in the equations $W = V^2/R$ and $W = I^2R$.
Control performance. Of the foregoing materials, the wide range of element resistance with tungsten, molybdenum disilicide and silicon carbide translates to corresponding changes in proportional band that can hurt control performance. This is just one more reason with these materials to use true power control as described above.