MINCO

APPLICATION AID #25
940615-1 Minco 10-2001

Prototyping Techniques for Thermofoil™ Heaters

Thermofoil heaters provide excellent temperature control and uniformity in a broad range of applications. Their thin profile and foil elements contribute to fast warmup, consistent heat distribution, and extended heater life.

To achieve ideal performance, however, the heater must be properly configured to the thermal demands of the application. The complex physics of heat transfer makes it difficult to predict all aspects of system performance in the early design stages. Therefore, applications requiring tightly regulated temperature may require extensive prototype work.

This Application Aid presents some tools and techniques to assist in thermal prototyping, which seeks to optimize the heater for desired:

- Initial warmup and cycle recovery time.
- Temperature uniformity or distribution.
- Control accuracy.

Factors influencing performance may include:

- Total heater wattage.
- Heater and sensor positioning.
- Profiled and multiple heater elements.
- Insulation.
- Controller type.

In addition to this Application Aid see Bulletin HS-201, “Thermofoil Heaters,” Bulletin TS-102, “Temperature Sensors,” and data sheets for the various Minco controllers.

Analytical Methods

Numerical analysis can eliminate part of the cost and leadtime of repeated bench trials with actual equipment. Two analytical methods are:

Thermal Calc

Minco’s Thermal Calc program, offered free for PC’s, uses simplified heat transfer equations to provide initial estimates of total wattage requirements. It considers warmup and process heat requirements, plus losses due to convection, and radiation. The companion Application Aid #21 explains the heat transfer equations underlying Thermal Calc.

Thermal Calc can yield a good starting value for heater wattage but falls short of an exhaustive analysis. It necessarily oversimplifies both the description of the heater/heat sink and the heat loss formulas. Still, a wattage estimation on Thermal Calc should often be your first design step.

Typical heater test and prototyping setup: Heater (with multiple elements), variable power sources, digital temperature indicator, and infrared thermal imager.

Finite Elements Analysis (FEA)

Computerized FEA, available as a design service from Minco, more accurately simulates thermal systems. It subdivides the heater and hardware into discrete elements and calculates the thermal profile of each element. It can model both steady state and transient conditions, in two or three dimensions. Advantages of FEA include:

- Simulation of temperature changes too rapid for ordinary sensors to handle, or determination of temperature in inaccessible locations.
- The ability to fine-tune the model by comparing predictions with observed data, and derive solutions with fewer hardware iterations.
- Experimental variations on a defined model.
- Assistance in laying out profiled heater patterns. Profiling is the addition of extra wattage in high-loss areas to equalize temperature. Higher wattage around the perimeter of a plate, for instance, will compensate for edge losses. One approach which employs FEA is to measure gradients produced by a non-profiled heater, then work backward from this data to develop a model for profiling (see the flowchart on page 3).

FEA does have some limitations:

- Even the best model cannot account for all factors operating on and in the system.
- Depending on design complexity, FEA can be more expensive and time consuming than experimentation.

- FEA never fully replaces bench testing of heaters. You may still need to make more than one hardware iteration for ideal profiled patterns.

Experimentation

The most accurate approach to heater design is the most direct: mount heaters to the heat sink, power them, and test operating parameters until the system behaves as desired. A typical test setup will include:

- The heated device
- Temperature measurement instruments
- Heater(s)
- Power supply (AC or DC)
- Controller

Temperature monitoring

Experiments must produce data, and you will need some means to observe and/or record temperatures in your system. Minco model TI142 (Bulletin TI142) with a small flexible Thermal-Ribbon™ (S651, page J-2, Bulletin TS-102) makes an economical and accurate system.

But in many instances you must measure temperature gradients across whole surfaces, not single points. Infrared imaging answers this need. A thermal video system like that used at Minco can vividly reveal temperature gradients in both static and dynamic situations (see pages 3-4). It can resolve temperature differentials within a fraction of a degree and provides video output for taping of test results in addition to live display. Furthermore, the imager's isothermal maps can furnish solid empirical data to verify or improve FEA models.

Thermal imaging does require line-of-sight access to the heated area. Because heater mounting hardware and housings will affect heat loss, heaters must operate in the actual equipment for reliable observations. Where thermal imaging cannot "see" the heater, you may want to monitor temperature with an array of thermocouples connected to a multichannel recorder or data acquisition system.

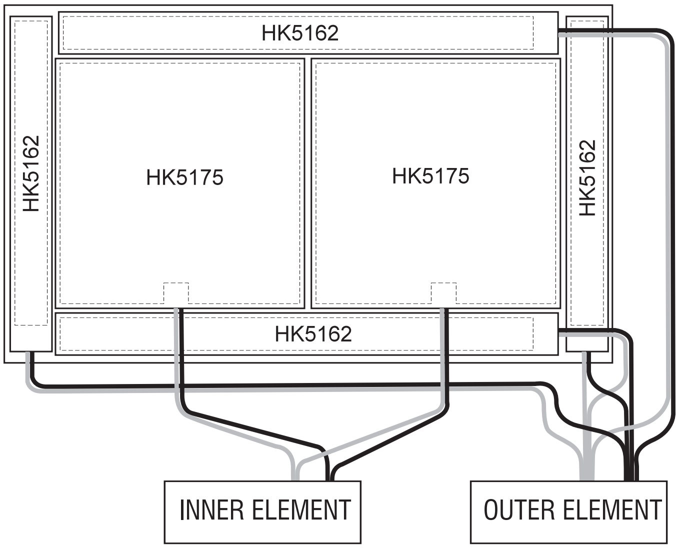
Heaters

Minco's Bulletin HS-201 lists over 2000 standard sizes and resistances of heaters. Catalog heaters alone will suffice for many applications, but you can also use them to prototype custom designs.

If the size or shape of your heat sink precludes using a single standard heater, you can often construct a mosaic to cover the surface.

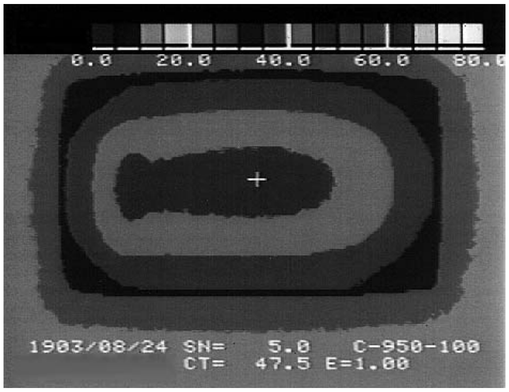
One technique is to use the stock heaters listed in bulletin HS-201. Models HK5160 through HK5165 will produce uniform watt densities when powered in parallel, regardless of size. The same holds true for HK5166 through HK5185. (The first series dissipates 5 W/in^2 at 28 V, the second 5 W/in^2 at 115V. You can use other voltages as long as heaters operate within rated watt densities.)

Ganged catalog heaters can also mimic profiled designs. You increase power to certain heaters until temperature stabilizes in the desired pattern. The resulting power settings tell you how to profile the watt density zones in a custom design.



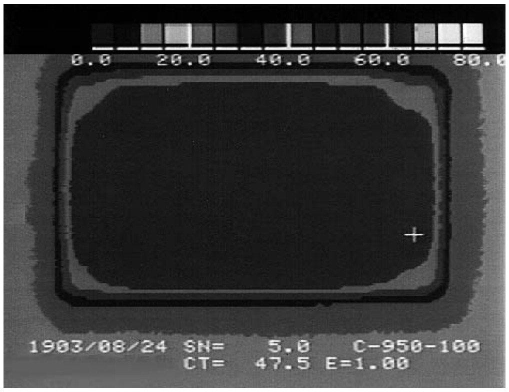
Test setup for heater profiling analysis.

In the setup shown above, the first variable AC power supply (e.g. "Variac") drives the inner elements, while the second separately powers the outer elements. Adjusting the power to give uniform watt density produces the thermal profile below. Notice the cooler edges.



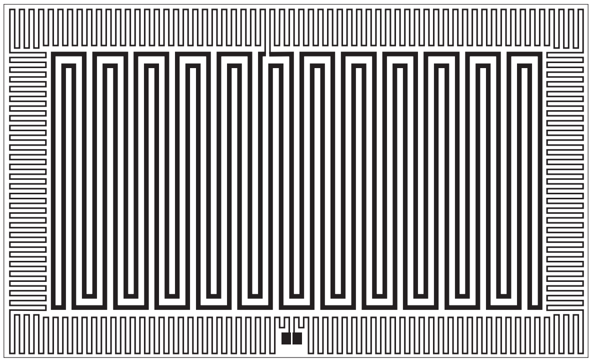
Temperature map, uniform wattage.

Operating the outer heaters at a higher watt density (higher watts per unit area, not necessarily higher total wattage) cancels the edge losses for more uniform temperature:



Temperature map, profiled wattage.

Once the system behaves as desired, note the power settings for each element. Minco can then reproduce the watt pattern in a custom single-element heater (narrower strands produce higher watt density):

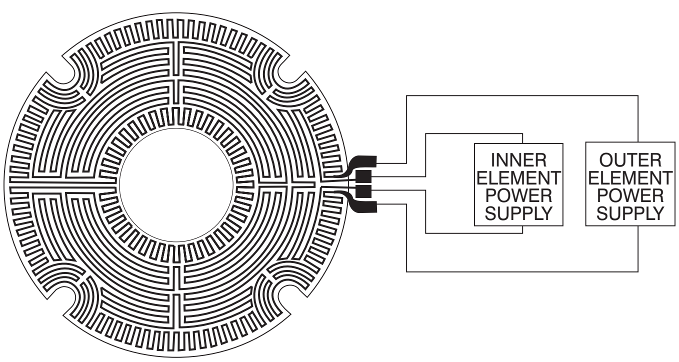


Heater profiled for higher wattage at edges

Note that you can change the wiring to place Variacs between controllers and heaters for simultaneous testing of wattage and control methods provided that the controller furnishes AC power, not DC, to the heater. Power resistors or rheostats in series with the heater can be used to scale DC (or AC) voltage.

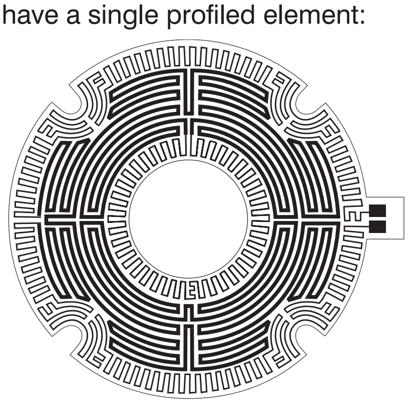
Odd-shaped heat sinks may require custom heaters for profile testing. Although this approach incurs the setup cost of a custom heater, the overall price tag may be less than consulting fees for Finite Element Analysis.

The custom heater below has a guard element running along both the inner and outer edges in addition to the central heating element. Each element operates from its own power supply:

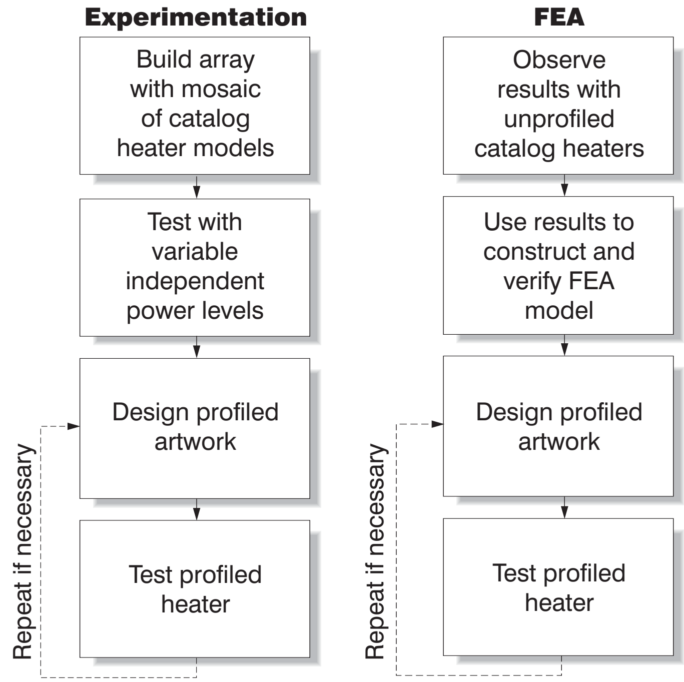


Custom dual-element heater for profile testing

As with the simple rectangular heater, the finished design will have a single profiled element:



Resulting profiled design



Alternative approaches to profiling heaters

Controller

A comparison of control methods, both mechanical and electronic, is too broad a topic for this application aid. Two tools for prototyping deserve mention:

Minco model CT15 controller offers proportional control and digital display of setpoint and process temperature. Adjustable proportional band and cycle time let you simulate many types of control action, including on/off.

The CT198 Heaterstat™ sensorless controller directly regulates heater temperature by sensing resistance as it supplies power. It operates on DC and works with special heater models having high Temperature Coefficient of Resistance. Multiple heaters can be individually connected to CT198's for economical multizone control.

Minco Thermal Video Imaging Service

Minco Offers thermal imaging as a paid consulting service to help you optimize heater designs. You can send us your heat sink and associated hardware for testing, or we can bring the imager to your plant if necessary. Results can be output on videotape or as color printouts. Listed below are specifications, principles of operation, and potential applications of thermal video imaging.

Specifications

System Type: Solid state infrared.

Observable Temperature Range: -20 C to 920 C (-4 to 1688 F).

Sensitivity: 0.1 C to 100 C per color level.

Display Level: 16 color levels, 1 color per temperature level.

Focus Range: 12" to infinity (other ranges available). At 12" the field of view is 4" wide by 3.25" high.

Emissivity Setting: 0.1 to 1.0 in 0.01 increments.

Spectral Range: 2.0 to 5.6 microns.

Cooling: Cryostat with pressurized argon gas, 4000 psi.

Operating Time: 4 hours with camera mount argon gas tank, 8 hours with 2 tanks.

Ambient operating Temperature: -10 C to 45 C.

Power: 120/240 VAC, 50/60 HZ, 100 watts.

Features

Portable: Requires line voltage and argon to operate. Unit can be shipped to destination with argon tanks sufficient for 8 hours of operation.

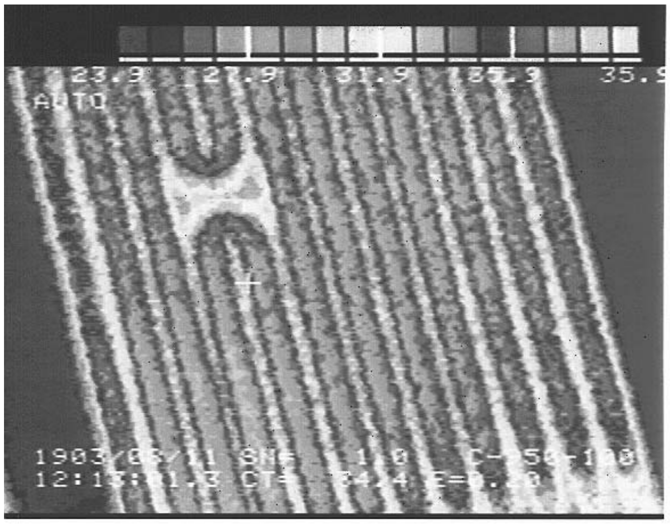
Outputs: Live video image, with VHS recording via VCR or hard copy output via color image printer.

Operating options include:

- Adjustable emissivity correction
- Automatic temperature ranging
- Can be programmed to show a single isotherm
- Freeze frame
- Remote control and remote focus

Partial Applications List

- Help to determine ideal location of sensors or thermostats on heater assemblies.
- Reduce the number of design iterations for multi-zoned or profiled heaters.
- Perform real time measurement of heat sink temperatures, temperature distribution, and warmup time. Answer questions such as: is there enough wattage to do the job?
- Test heater mounting methods
- Monitor heat loss through insulation.
- Determine radiant loss from heat sinks.
- Measure true surface temperatures—no heat sinking by sensors. This is especially critical for small heater/heat sink assemblies.



Thermogram of heater element strands

Basics of Thermography

Thermal imagers operate by detecting infrared radiation at wavelengths from 2 to 5.6 micrometers. They convert the radiation to patterns of color corresponding to temperature. The device performing the conversion, called a “quantum detector,” must operate at cryogenic temperatures. Minco’s imager cools the detector with argon gas.

Understanding the concept of “emissivity” is essential for accurate thermal imaging. Maximum infrared radiation is emitted from an ideal material called a blackbody. All other materials emit less radiation at the same temperature. A material’s emissivity is the ratio of its thermal radiation to that of a blackbody. As a rule of thumb, electrical insulators (like plastics and paint) have high emissivity values, around 0.9. Metals range from 0.05 to 0.4 for shiny surfaces, 0.3 to 0.9 for anodized or oxidized surfaces. Practical implications of emissivity are:

- Absolute temperature measurement requires emissivity correction. The thermal imager allows such correction if you know the emissivity of the measured surface or the actual temperature of a reference point.
- Measurement of relative temperatures across a single material requires no emissivity correction.
- Shiny surfaces will reflect the thermal radiation of surrounding objects. (It may be necessary to coat the shiny surface with flat black paint to eliminate the reflectance and increase the emissivity.)
- Some optically transparent materials (e.g. window glass) are actually opaque to infrared radiation.

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