Understanding Vacuum Furnace Temperature Measurement Issues

Presented By: William R Jones, CEO
Solar Atmospheres Inc., www.solaratm.com

Technical Contributors:
Virginia M Osterman, Ph.D. Senior Scientist, Solar Atmospheres Inc.
Rèal Fradette, MSME, Senior Consultant, Solar Manufacturing Inc.
Overview

- Thermocouple construction
- Types of thermocouples
- Control thermocouple placement
- Temperature uniformity in a furnace
- Use and placement of work thermocouples
- How work material properties affect heating rate
  - Emissivity, surface finish, mass, surface area
- Dummy blocks selection and placement
- Non-electrical temperature monitoring devices
Temperature Measurement
Optical Pyrometer
Temperature Measurement Sensors

Convert an EMF electrical signal to °C or °F

Thermistor
(thermal resistor)

RTD
(resistance temperature detector)

Thermocouples
(thermoelectric couple- Seebeck Effect)
Sheath Thermocouple Construction

- **Exposed Wire:**
  - Rapid response time
  - Affected by contamination

- **Ungrounded:**
  - Longer response time
  - Shielded from contamination

- **Grounded:**
  - Faster response
  - Shielded from contamination
  - Longer life at high temperatures

TC Construction
Advantages/Disadvantages

Wire Size
• Smaller diameter wires
  – Faster response times
  – More fragile
  – Low/moderate temperature applications

• Larger diameter wires
  – Longer life
  – High temperature applications
### Types of Thermocouple Wire

<table>
<thead>
<tr>
<th>ANSI Type Symbol</th>
<th>Wire Alloys</th>
<th>Temperature Range °C</th>
<th>Temperature Range °F</th>
<th>Calibration Tolerance %</th>
<th>Application Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Chromel*(+)/Alumel* (-) (Nickel-Chromium/Nickel-Aluminum)</td>
<td>0 to 1250</td>
<td>32 to 2300</td>
<td>+/-0.4</td>
<td>Work TC, all atmospheres Accurate to high temperatures, limits on reuse</td>
</tr>
<tr>
<td>N</td>
<td>Nicrosil (+)/Nisil (-) (Nickel-Chromium-Silicon/Nickel-Silicon)</td>
<td>0 to 1250</td>
<td>32 to 2300</td>
<td>+/-0.2</td>
<td>Work TC, all atmospheres Greater accuracy and reuse at high temperatures</td>
</tr>
<tr>
<td>S</td>
<td>Pt – 10% Rh (+)/Pt (-) (Pt- Platinum and Rh – Rhodium)</td>
<td>0 to 1450</td>
<td>32 to 2800</td>
<td>+/-0.1</td>
<td>Furnace control TC Expensive, fragile sheath High accuracy at high temperature</td>
</tr>
<tr>
<td>W3</td>
<td>W-3% Re (+)/W - 25% Re (-) (W- Tungsten, Pt-Platinum and Re-Rhenium)</td>
<td>400 to 2300</td>
<td>800 to 3800</td>
<td>+/-0.25</td>
<td>Furnace Control TC Expensive Very high temperatures Wire becomes brittle after one cycle</td>
</tr>
</tbody>
</table>
Furnace Control and Over-temperature TCs

Alumina (Mullite) Sheath: Fragile
Furnace: Type S - up to 2800°F (Pt – 10% Rh) (+) /Pt (-)
Higher Temperature: Type B – 3200°F (Pt/Rh 70%/30%) (+) – Pt/Rh 94%/6%(-)
External View of Furnace Control TCs
Placement of Control TCs

Proper placement of control TCs relative to the heating elements is critical!!
Location of Furnace TCs in the Hot-Zone
Proper Thermocouple Placement for Temperature Survey (TUS)

- This is a typical box configuration with heat sink blocks located at the corners and center position.
- Design limitations for conforming to AMS 2750E
- Not universal for multiple sized furnaces
## Universal Thermocouple Survey Rack
Meets all TUS Certification Requirements

- Individual corner pipes
- Adjusts vertically to accommodate furnace size
- Positioned at extremes of the working zone
- Top and bottom T/C heat sinks welded to the inner surface
- 8 corner TCs
- 1 Center TC

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Furnace Set-Up for TUS

Tolerance by Furnace Class

• Class 1 is +/- 5°F
• Class 2 is +/- 10°F
• Class 3 is +/- 15°F
• Class 4 is +/- 20°F
• Class 5 is +/- 25°F
• Class 6 is +/- 50°F
Why Use Workload Thermocouples?

Measure heat transfer from heating elements to the “work.”

Factors Affecting Heat Transfer

1. Thermal conductivity of part
2. Emissivity/absorptivity of part
3. Mass of the work load
4. Surface area of parts
Typical Work TC Materials

- Refrasil®-Bare Wire
- SS Mesh-Bare wire
- Alumina Sleeve
- Approx. ½” Hard Twist
- Inconel® Sheathed 1/16” O.D.

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Thermocouple Sheath Materials and Advantages

1) Refrasil®: Hygroscopic, can react with parts at high temperatures or with atmosphere; temperature limitation 2250°F

2) SS Mesh: More rugged, less friable; temperature limitation 2250°F

3) Inconel® Sheath: Non-hygroscopic, resists oxidation. Maximum operating temperature: 2250°F

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Thermocouple Characteristics

- Type K – is used protected or exposed in oxidizing, inert or dry reducing atmospheres; exposure to vacuum limited to short time periods; reliable and accurate at high temperatures

- Type N – is used protected or exposed in oxidizing, inert or dry reducing atmospheres; very reliable and accurate at high temperatures

- Type S – Normally used as control and over-temperature thermocouples with alumina protection tubes; very reliable and accurate at high temperatures

- Type W3 – Normally used for control of very high temperature applications; offer the advantage of ductility over pure tungsten thermocouples; Accurate at extremely high temperatures
Typical Work TCs

1) Type K – most common TC, accurate, must recalibrate, losing favor
2) Type N – improved accuracy and extended life and re-use
3) When operating above 2150°F re-use is discouraged owing to temperature drift
4) Aerospace requires new Type K TCs for each run
Thermocouple Jack Panels

- Source of error: dirty jack panel
- Clean regularly
- Dummy jack plugs for unused slots

High Temperature TC Plug
Up to 1000°F – Do not use the Yellow plug (400 °F)
Thermocouple Feed-through - OLD
Thermocouple Feed-through - Modern
Correct Work TC Placement

• Place the load thermocouples in existing holes or crevices with the tip, or hot junction, in contact with the metal
• Work TC must be inserted deep into the center of the workload
• Consider the area most shielded from the radiation or the thickest cross-sectioned part (slowest portion to reach equilibrium)
Proper placement of load thermocouples is critical!!

Correct T/C placement = High quality results
Direct Contact Between Layers

Brass Tubing Annealing
Why Load Thermocouples?

Poor Conductors of Heat:
• Loosely coiled and stacked sheet
• Loosely rolled screen
• Loosely coiled wire
• Small fasteners/ ball bearings
• Powders
TC Placement – In the Load
When Surface Contact is Not the Best Option

What to Do:
• Use a dummy block
• Mimics the heating profile of the part
# Dummy Block Material Selection and TC Placement

1. Drill TC holes into center
2. Match cross-section to largest part
3. Match the mass of the work
4. Match thermal conductivity
5. Match surface condition
6. Match emissivity

**Ti part – Ti Block**
Ti heats slower than steel

**Cu part – Cu block**
Carbon Steel Dummy Blocks with Various Surface Conditions

1. Oxidized
2. Grit Blast
3. Copper
4. Nickel
5. Polished
6. Chrome
Emissivity and Surface Condition Affect Heat Rate

- Emissivity - The ability of a surface to emit radiation
- Absorptivity - ability of a surface to absorb radiation
- At thermal equilibrium, the emissivity of a body (or surface) equals its absorptivity
- A perfect black body (absorbs 100% radiation)
- Test study – same sized dummy blocks, various surface conditions subject to same heat treat cycle and record heat profiles
Surface Condition Effect on Heating

Test Block Time vs Temperature

- Control
- Oxidized
- Grit Blasted
- Copper
- Nickel
- Polished
- Chrome

Temperature (°F)

Time (min.)

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Dummy Block - Same Diameter, Less Mass
Dummy Blocks in Contact with Parts
Dummy Block/Direct Contact
Improper Choice of Dummy Block (Mismatched Thermal Conductivity)

Part – 6” diameter plastic – non-conducting
Dummy Block – 4” diameter SS – conducting
Conclusions on Using Dummy Blocks

- Radiation heating of work is dependent on mass and surface condition
- Heat rate: Bright and polished much slower than dull and dark
- Rough surfaces heat faster than smooth, reflective surfaces
- Dummy blocks not in direct contact with parts must have similar mass and surface area to mimic the heat rate of load
- Dummy blocks should be periodically re-conditioned to maintain proper surface smoothness and appearance
- One load of material, with a particular surface condition, compared with a load of the same material with another surface condition, could take as much as twice as long to reach the desired temperature
Common Work TC Problems

- **Crossed wires**: If a thermoelectric circuit is backwards, the instrument will read backwards.
- **Loose screw**: A loose screw on the mounting plug will cause a poor connection and possibly shorting.
- **Uncompensated junction**: If materials are used that are not the same as the wires, an error will be introduced.
- **Twisted wires**: If wires touch at a point between the hot and cold junctions, a new hot junction will be produced.
- **Damaged insulation**: If the insulation is damaged, and wires touch foreign materials, an error will be introduced. In addition, this easily allows twisted wires to touch.
- **Poor hot junction**: A loosely twisted or dirty junction will introduce an error.
- **Dirty jack panel or extension wires**: A dirty jack panel is a typical source of error and must be cleaned regularly.
Easy and Cost Effective Method to Monitor Process Temperature – Orton Temp Tabs®

What are Orton Temp Tabs®?
• Ceramic disks sinter at a controlled rate over a range of temperatures.
• Shrinkage is correlated to maximum temperature in the furnace.
• Records peak temperature only.

http://www.temptab.com/
Measuring Temp Tabs

- Temp Tabs are measured after they exit the thermal process.
- Best accuracy is achieved using a Temp Tab desktop gauge.
- Place the Temp Tab in the gauge and measure the diameter.
- Other measuring devices can be used as long as they measure to .01 mm.
- Enter the diameter measured into the Temp Trakker software or look up the temperature on a printed chart.

http://www.temptab.com/

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Orton Temp Tab® Measurement vs Temperature Chart
Solar Atmospheres Technical Booklets and Articles

- Critical Melting Points and Reference Data for Vacuum Heat Treating
- Temperature Uniformity Surveying of Vacuum Furnaces
- Operating a Vacuum Furnace Under Humid Conditions
- Understanding PID Temperature Control in Operating a Vacuum Furnace
- Understanding Power Losses in a Vacuum Furnace
- Important Considerations When Purchasing a Vacuum Furnace
- Considerations When Selecting a Vacuum Furnace Water Cooling System
- Reducing Energy Consumption When Operating a Vacuum Furnace
- Explaining Vacuum and Vacuum Instrumentation
- Understanding Emissivity and the Use of Thermocouple Test Blocks in a Vacuum Furnace
- Vacuum Gauge Correction Factors
- Leak Detection and Checking of Vacuum furnaces
- Critical Areas of Preventive Maintenance
- Evaluating Pan versus Rayon Graphite Felt Insulation for Vacuum Furnaces
- The Use of a Residual Gas Analyzer (RGA) to Determine Differences in Graphite and All-metal Hot Zone Vacuum Operation (To be published)