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Thermocouples, RTD's and Other Methods of Temperature Measurement

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UChicago Argonne LLC

Office of Science
U.S. DEPARTMENT OF ENERGY

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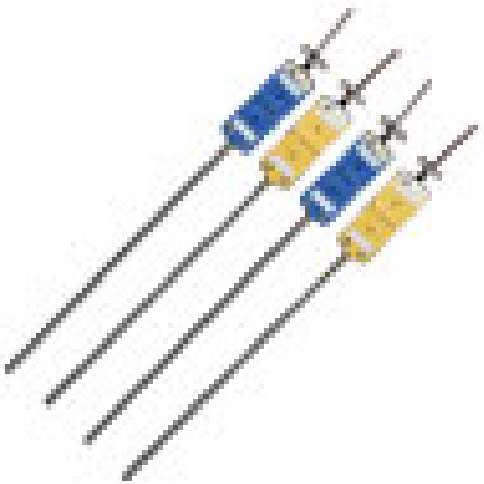
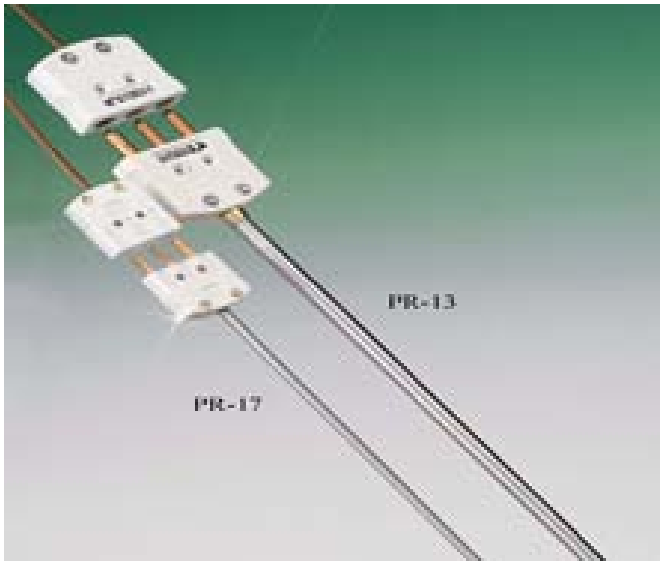
Outline

This presentation will focus mainly on thermocouples and RTD's but will also touch on:

- Common Temperature Measurement Devices
- Device Pros and Cons
- Theory of Operation
- Types and Installation
- Troubleshooting





Common Temperature Measurement Devices

- Thermocouples
- Resistance Temperature Devices (RTD’s)
- Temperature Indicating Tapes, Crayons and Paints
- Infrared Thermometers
- Infrared Imagers

Device Pros and Cons - Thermocouples

PROs

- Inexpensive
- Wide temperature range
- Various types, sizes and application methods
- Remote read back
- Read back electronics can be simple
- Usable in virtually any environment

CONs

- Requires cold junction compensation
- Slow response time
- Not as accurate as many other devices without good CJC and calibration
- Susceptible to noise
- Connection cable/wire is expensive compared to copper conductors
- Cable/wire length is limited

Device Pros and Cons - RTD's

PROs

- More linear than thermocouples
- Cold junction not an issue
- Special cable/wire not needed
- Cable/wire length can be much longer than TC's
- Better noise immunity
- More stable over time than thermocouples
- Remote read back
- Usable in virtually any environment

CONs

- More expensive than thermocouples
- More delicate than thermocouples unless encased
- Not as wide of temperature range as thermocouples
- Requires more conductors per device
- Read back electronics more complex

Device Pros and Cons - Temperature Indicating Tapes, Crayons and Paints

PROs

- Inexpensive
- Variety of ranges and application media

CONs

- No remote read back
- Most are not reversible (one time use)
- May not be suitable for some environments

Device Pros and Cons – Infrared Thermometers

PROs

- Portable
- Accurate (when the emissivity of the material being measured is known and reflected radiation is not an issue.)
- Inexpensive when used to read many temperatures on a daily basis (equipment rounds)
- Remote read back (sometimes)

CONs

- Expensive
- Complex electronics
- Susceptible to noise when used with remote read back
- Emissivity of material required for accurate measurement
- Reflected radiation an issue
- Some devices not equipped with an adjustable emissivity setting
- May not be suitable for some environments

Device Pros and Cons – Infrared Imagers

PROs

- Very accurate (when the emissivity of the material being measured is known)
- Ability to measure many temperatures in a wide area
- Sometimes range limited within the image (Delta T)
- Somewhat portable
- Remote read back possible

CONs

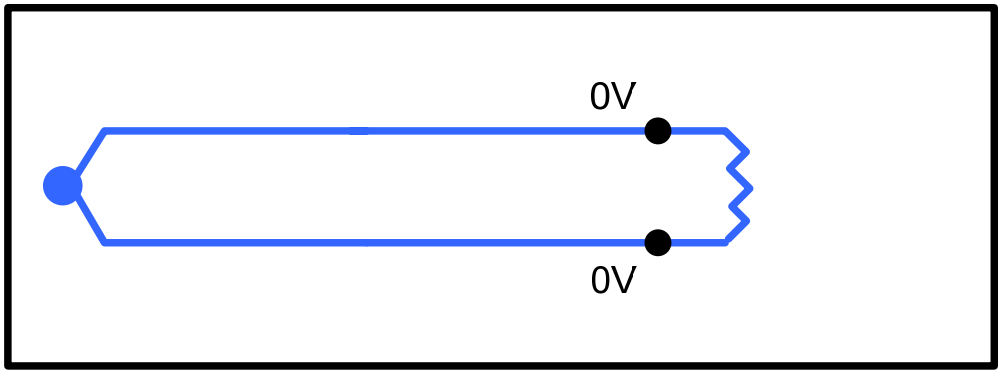
- Very expensive
- Very complex electronics
- Some require a small internal cryo-cooler for element reference
- May not be suitable for MANY environments

Theory of Operation – Thermocouples

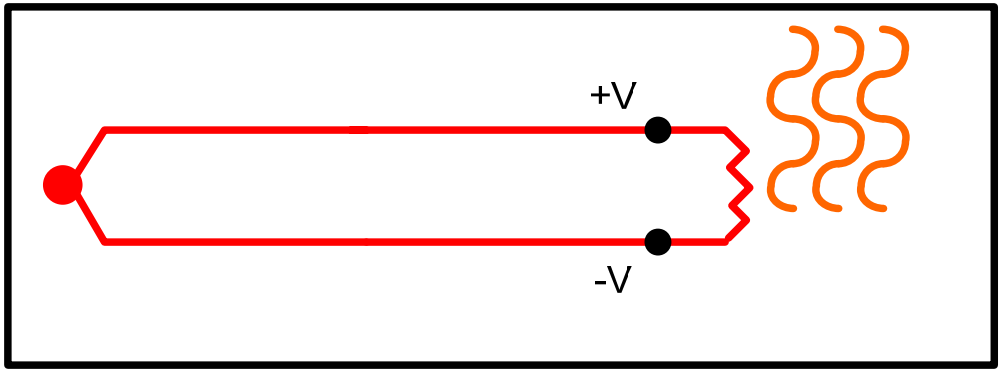
- A thermocouple is a simple temperature measurement device consisting of a junction of two dissimilar metals
- Contrary to popular belief, the voltage measured (and converted to a temperature) is not a function of the junction alone. Rather it is the temperature difference (or gradient) between the junction (or hot), end and the reference (or cold), end.
- A thermocouple circuit whose junction and reference are the same temperature will measure no temperature (0V).
- If this were not true, we could create a self-sustaining voltage generator using a thermocouple, a resistive load and an oven, that would require energy only at start-up.

Thermocouple Self-Sustained Voltage Generator

Oven Off



Oven Momentarily On

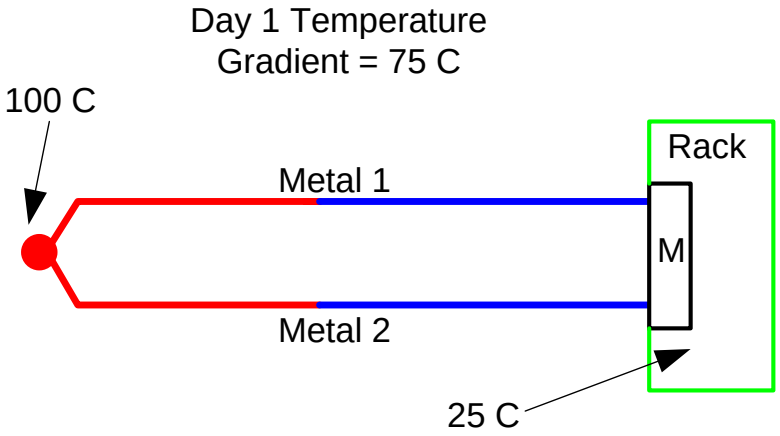


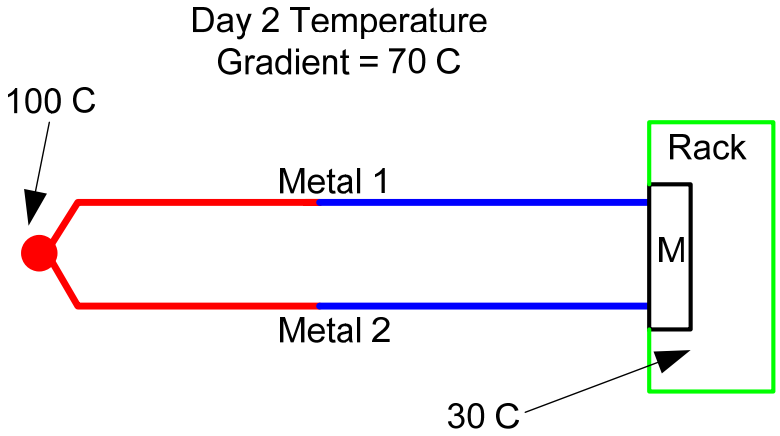
Thermocouples

- The larger the gradient, the larger the voltage value, and the larger the temperature value.
- Since the temperature of the reference end affects the gradient temperature value, it is essential that the reference temperature be known.

Thermocouples

- As an example, think of having a temperature process that on the measurement (or junction), end is extremely stable from day to day, yet the reference end (e.g. a meter in an equipment rack), has no means of temperature control.
- Even though the junction remains the same from day to day, fluctuating rack temperatures would cause a different gradient from day to day, and a different temperature read back.





Thermocouple Voltage Equations

$$E = \int_{0}^{L} \mathcal{E}_A \frac{dT}{dx} dx + \int_{L}^{0} \mathcal{E}_B \frac{dT}{dx} dx \qquad \text{Equation 1}$$

If the wires are both homogeneous, then

$$E = \int_{T_{Ref}}^{T_{Jct}} \mathcal{E}_A \, dT + \int_{T_{Jct}}^{T_{Ref}} \mathcal{E}_B dT \qquad \text{Equation 2}$$

If both wires begin at T_{Ref} and end at T_{Jct}, then

$$E = \int_{T_{Ref}}^{T_{Jct}} (\mathcal{E}_A - \mathcal{E}_B) dT \qquad \text{Equation 3}$$

For small temperature differences, we can use the average calibrations:

$$E = (\mathcal{E}_A - \mathcal{E}_B)(T_{Jct} - T_{Ref}) = \mathcal{E}_{AB}(T_{Jct} - T_{Ref}) \qquad \text{Equation 4}$$

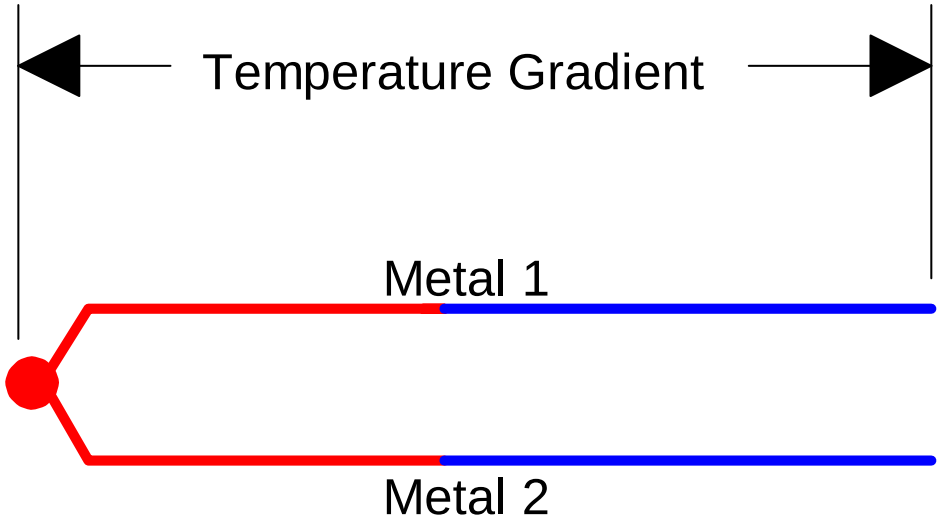
Thermocouples

- The temperature equation for the simplest of thermocouple circuits shown at right is:

$$T = T_{junc} - T_{ref}$$

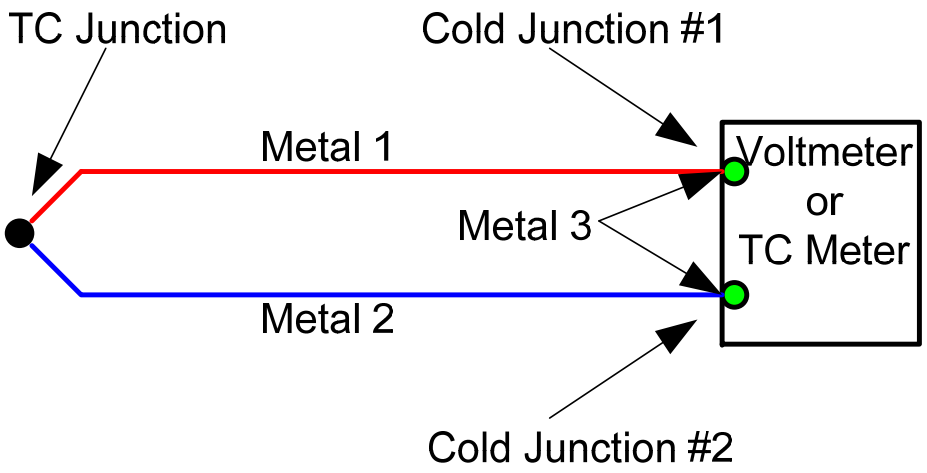
Where T is the desired measurement, T_{junc} is the hot junction temperature and T_{ref} is the reference temperature, or cold end.

For simplicity's sake I use T, T_{junc} and T_{ref} here, but in reality these are voltages that are later converted to a temperature.



Cold Junctions

- A fundamental problem when using thermocouples is the fact the when connected to a measurement device (voltmeter or TC meter), a third metal is introduced (the connecting terminals), and two more thermocouple junctions are created. These adversely affect the temperature being measured. The new, (and unwanted), junctions are referred to as “cold junctions” and need some type of “cold junction compensation” in order to make accurate measurements.



The temperature equation for this diagram is:

$$T = T_{junc} - T_{cj1} - T_{cj2}$$

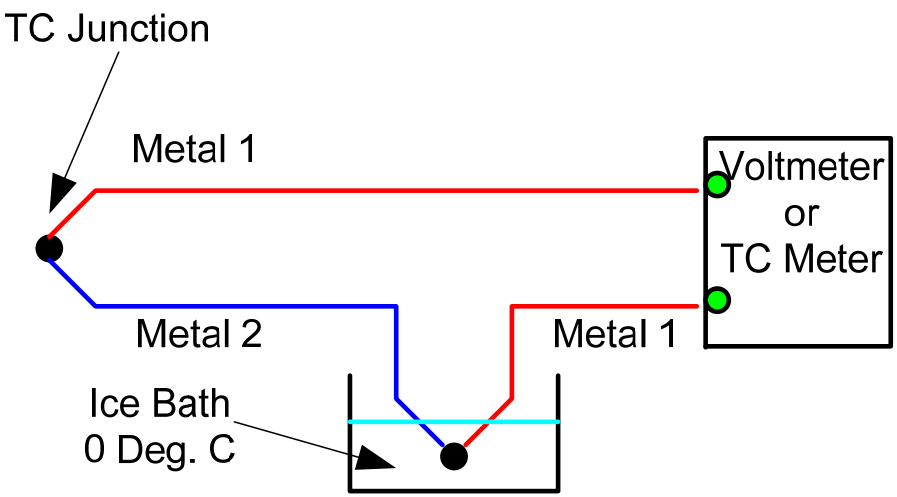
- In addition to the added variables in the previous equation, the temperature of the cold junctions (reference end), is still not known. The following rule helps things out a bit:

  If both TC connections to the meter are of the same metal or alloy, they cancel each other and have no affect on the measurement, as long both connections are at the same temperature (which can be assumed).

- Since the definition of a thermocouple states that it must be of dissimilar metals, a second thermocouple must be introduced to the circuit to achieve this. This was the first of what is commonly called “cold junction compensation”

- By adding a second series thermocouple suspended in an ice bath, the cold junctions at the meter are of identical metals and cancel each other. In addition, the temperature of the ice bath is known to be 0 Deg. C and becomes the reference end of the thermocouple.
- The temperature equation is now simplified and once again becomes:

$$T = T_{junc} - T_{ref}$$



- While the ice bath reference junction eliminates errors, it is clearly impractical for most, if not all applications.
- It’s only practical use in the modern world is in the generation of thermocouple reference tables.
- These tables can be helpful when troubleshooting thermocouples, but keep in mind that the voltage published has a 0 Deg. C reference, (i.e. 4.096mV does not mean 100 Deg. C in the field).

ISE, Inc.

ITS-90 Table for Type K Thermocouple (Ref Junction 0°C) http://iseinc.com

K

Thermoelectric Voltage in mV

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468	4.509
110	4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879	4.920
120	4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288	5.328
130	5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694	5.735
140	5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098	6.138
150	6.138	6.179	6.219	6.259	6.299	6.339	6.380	6.420	6.460	6.500	6.540
160	6.540	6.580	6.620	6.660	6.701	6.741	6.781	6.821	6.861	6.901	6.941
170	6.941	6.981	7.021	7.060	7.100	7.140	7.180	7.220	7.260	7.300	7.340
180	7.340	7.380	7.420	7.460	7.500	7.540	7.579	7.619	7.659	7.699	7.739
190	7.739	7.779	7.819	7.859	7.899	7.939	7.979	8.019	8.059	8.099	8.138
200	8.138	8.178	8.218	8.258	8.298	8.338	8.378	8.418	8.458	8.499	8.539
210	8.539	8.579	8.619	8.659	8.699	8.739	8.779	8.819	8.860	8.900	8.940
220	8.940	8.980	9.020	9.061	9.101	9.141	9.181	9.222	9.262	9.302	9.343
230	9.343	9.383	9.423	9.464	9.504	9.545	9.585	9.626	9.666	9.707	9.747
240	9.747	9.788	9.828	9.869	9.909	9.950	9.991	10.031	10.072	10.113	10.153
250	10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520	10.561
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	10.971
270	10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341	11.382
280	11.382	11.423	11.465	11.506	11.547	11.588	11.630	11.671	11.712	11.753	11.795
290	11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167	12.209
300	12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582	12.624
310	12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998	13.040
320	13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415	13.457
330	13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833	13.874
340	13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251	14.293
350	14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671	14.713
360	14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091	15.133
370	15.133	15.175	15.217	15.259	15.301	15.343	15.385	15.427	15.469	15.511	15.554
380	15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933	15.975
390	15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355	16.397
400	16.397	16.439	16.482	16.524	16.566	16.608	16.651	16.693	16.735	16.778	16.820
410	16.820	16.862	16.904	16.947	16.989	17.031	17.074	17.116	17.158	17.201	17.243
420	17.243	17.285	17.328	17.370	17.413	17.455	17.497	17.540	17.582	17.624	17.667
430	17.667	17.709	17.752	17.794	17.837	17.879	17.921	17.964	18.006	18.049	18.091
440	18.091	18.134	18.176	18.218	18.261	18.303	18.346	18.388	18.431	18.473	18.516
°C	0	1	2	3	4	5	6	7	8	9	10

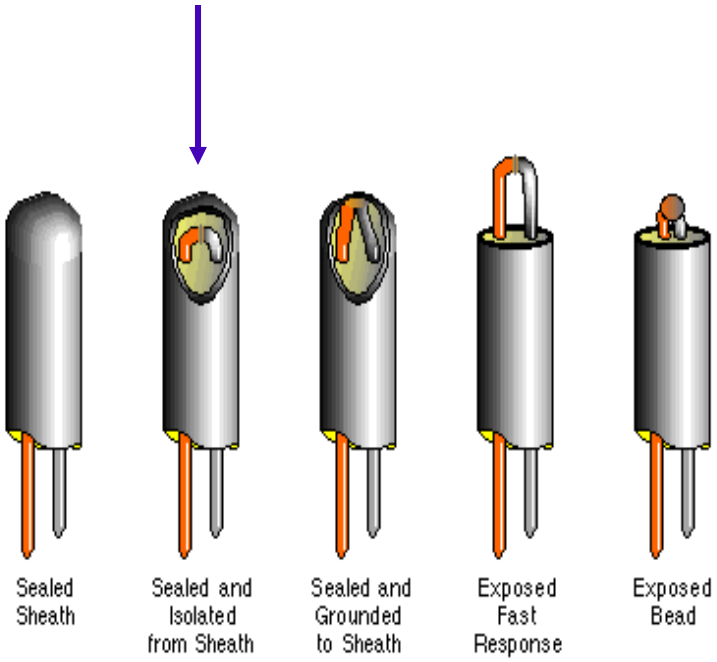
- Most (if not all), of today's thermocouple read back options (meters, chart recorders, PLCs, etc.), come equipped with cold junction compensation, usually a thermistor and associated circuitry and software. By taking the cold junction worries out of the picture, the thermocouple remains one of the simplest , most robust and widely used temperature measurement devices around.

Types and Installation

- Thermocouples are manufactured in a wide variety of ways and calibrations, to suit almost any application. They can be taped, glued, clamped, tack welded or held in a liquid or gas stream with the use of compression fittings (probably the most common method at Argonne).

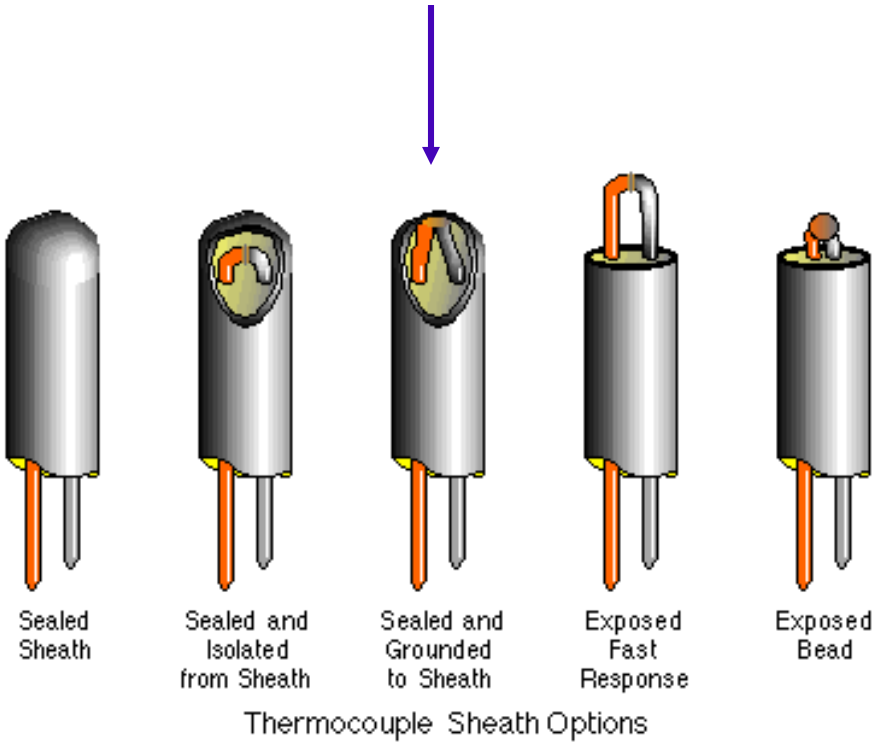
Sheathed Thermocouples

- A number of sheathing options exists.
- <u>Sealed and Isolated from Sheath:</u> Good relatively trouble-free arrangement. The principal reason for not using this arrangement for all applications is its sluggish response time - the typical time constant is 75 seconds (Depending on who is publishing the data. Omega claims a 2.25 second response time for a .25" dia. sheathed, ungrounded thermocouple)
- If fast response is not an issue (used for trending), and the sheath can be dealt with application-wise, sheathed, ungrounded junctions are the way to go.

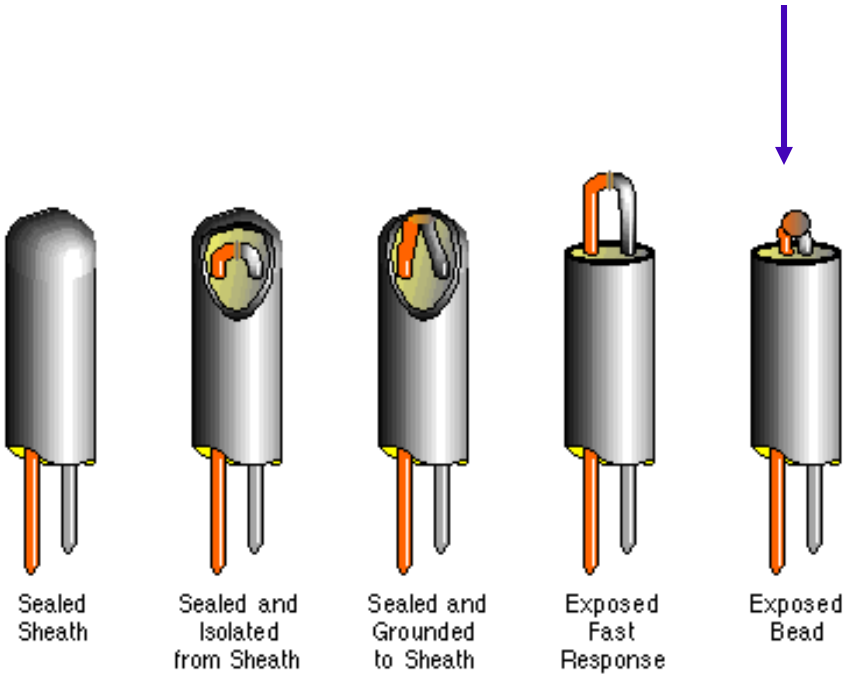


Thermocouple Sheath Options

- <u>Sealed and Grounded to Sheath:</u> Can cause ground loops and other noise injection, but provides a reasonable time constant (40 seconds), and retains the sealed enclosure.

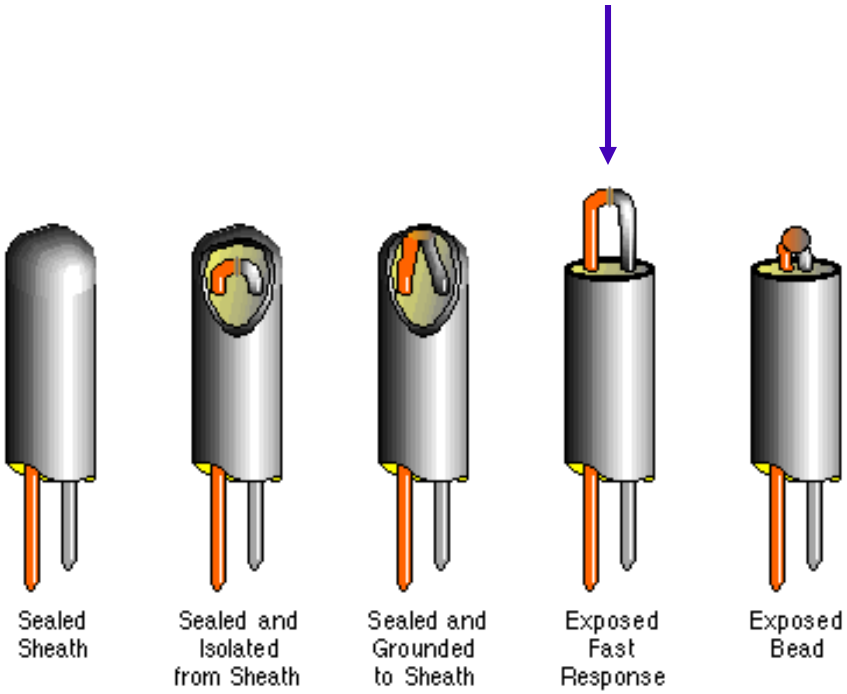


- <u>Exposed Bead:</u> Faster response time constant (typically 15 seconds), but lacks mechanical and chemical protection, and electrical isolation from material being measured.
- The porous insulating mineral oxides must be sealed.
- Faster response comes at the expense of mechanical integrity and robustness.



Thermocouple Sheath Options

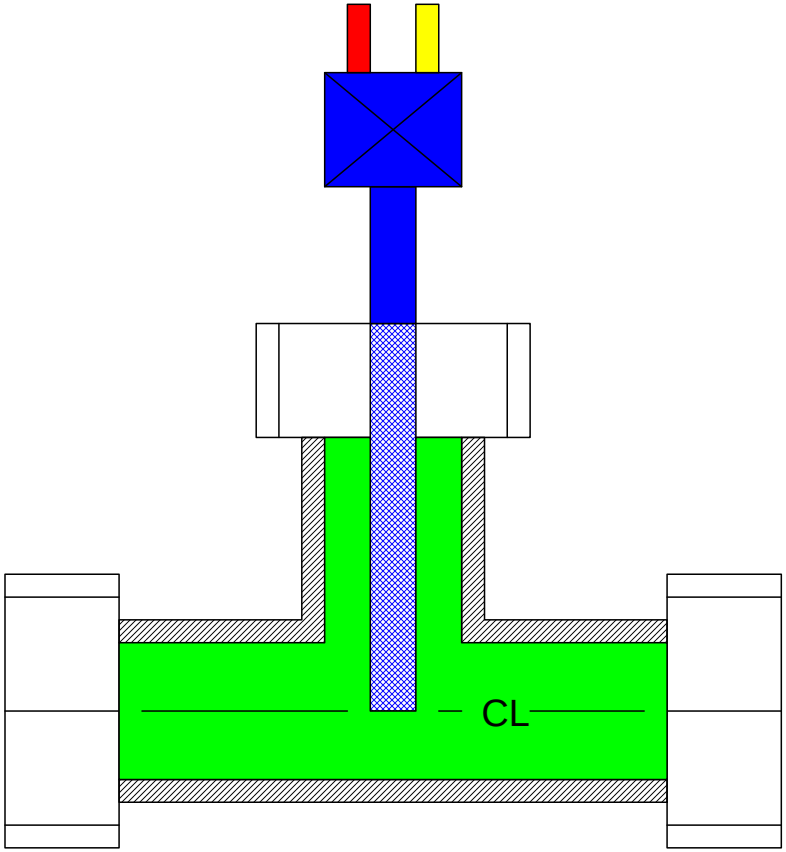
- <u>Exposed Fast Response:</u> Fastest response time constant (typically 2 seconds), depending on the gauge of junction wire.
- In addition to problems of the exposed bead type, the protruding and light construction makes this thermocouple even more prone to physical damage.



Thermocouple Sheath Options

Sheathed Thermocouples & Compression Fittings

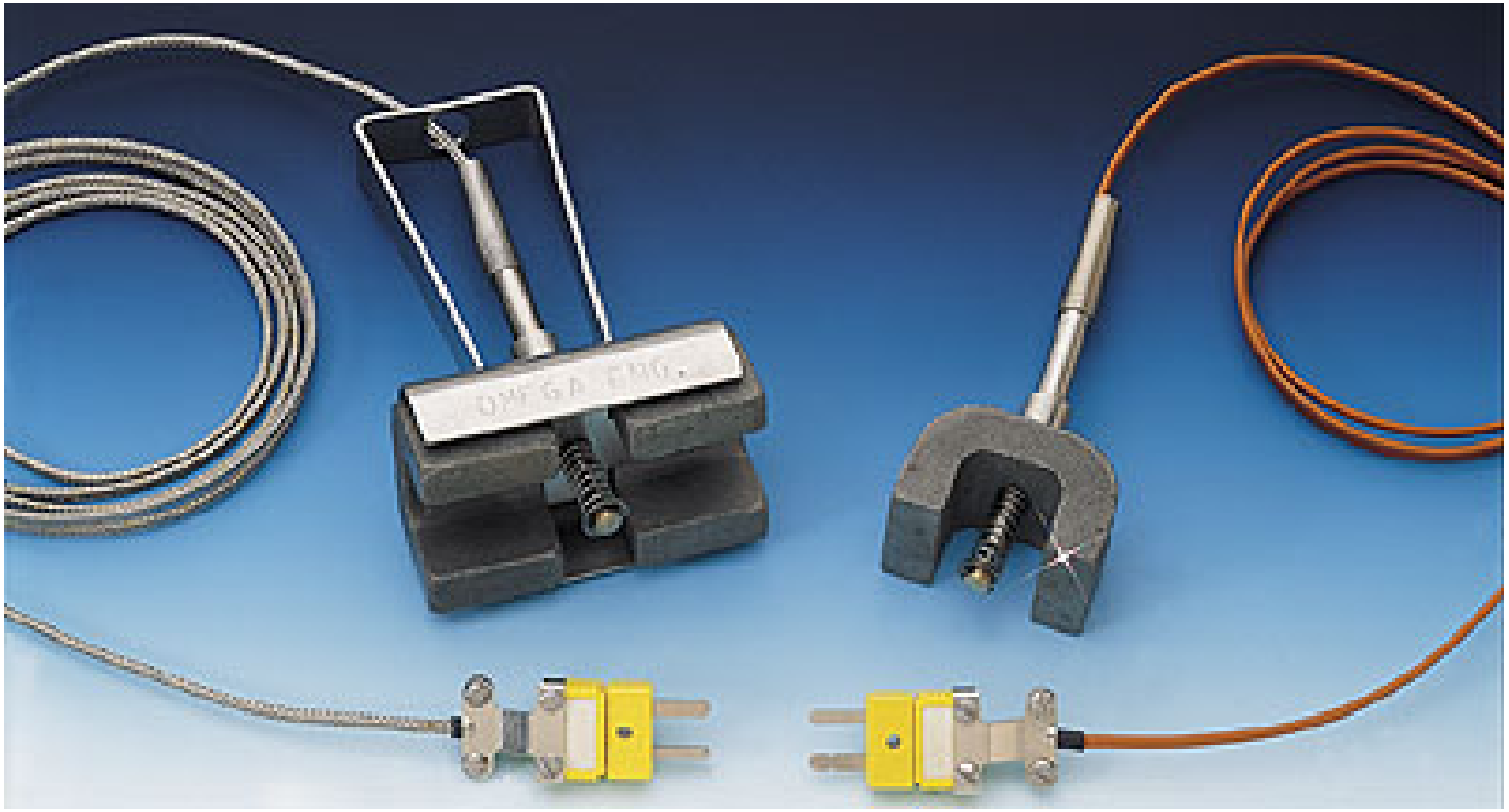
- When used with a compression fitting, care must be taken to ensure that the tip of the thermocouple is in the center of the liquid or gas stream to be measured.
- Over-tightening of the compression fitting can cause the ferrule to cut into the sheath too deeply, causing erroneous read back or failure.



Adhesive Backed Thermocouples

Bolt On Thermocouple

Magnet Mount Thermocouples



Fine Gauge Wire Thermocouples

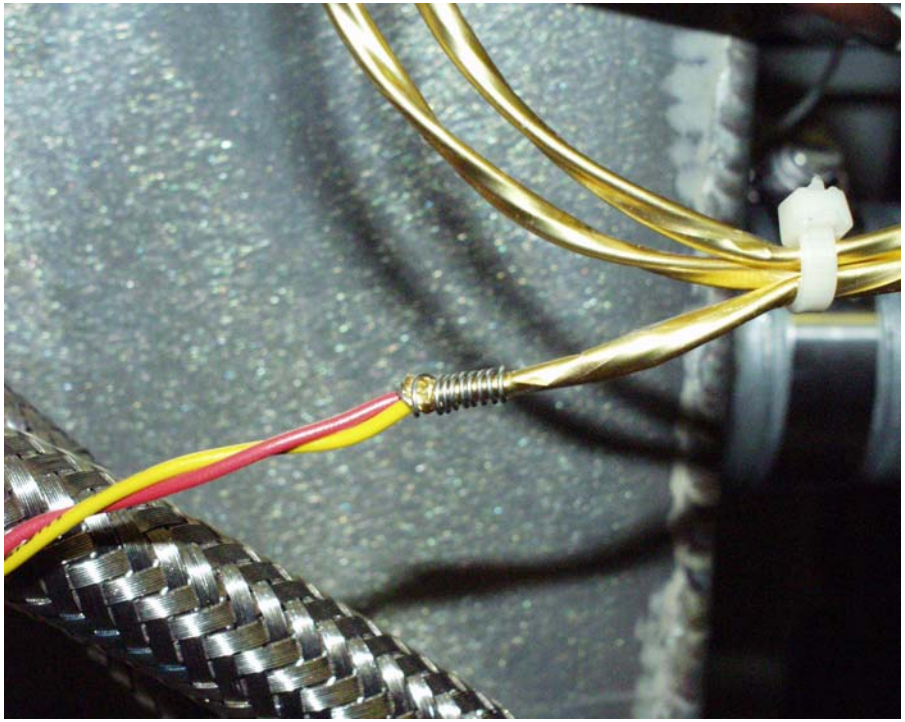
- For better sensitivity and response, fine gauge wire thermocouples should be used, if the application permits.
- Keep in mind that these are delicate and susceptible to vibration if not properly affixed.

Installation Suggestions

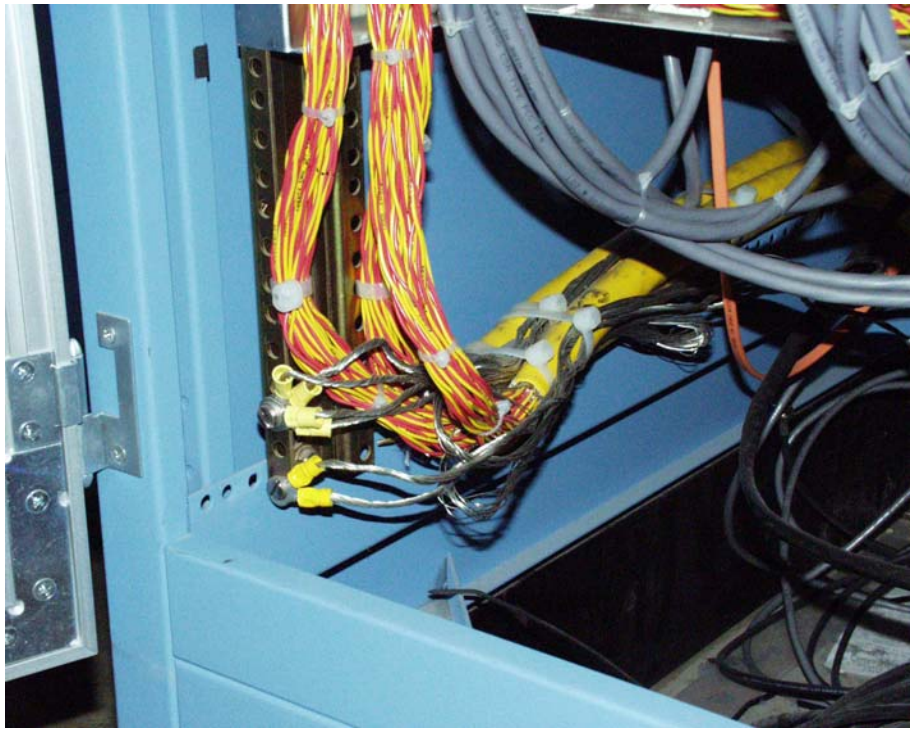
- Because thermocouples operate in the uV-mV range, they are susceptible to noise. ALWAYS use twisted/shielded pairs with the shield grounded at the meter end of the cable, and floating at the other.
- This is a good rule of thumb for ALL signal cables, not just thermocouples.
- Between the Booster/SR RF cavities, the SR pinger and kicker chambers and the S25 bellows liner tests, I have been involved in the installation of over 550 thermocouples in an incredibly noisy environment. Other than a few special case exceptions, none have experienced noise issues using this wiring technique.

Proper Shield Grounding Technique:

Thermocouple End



Meter End

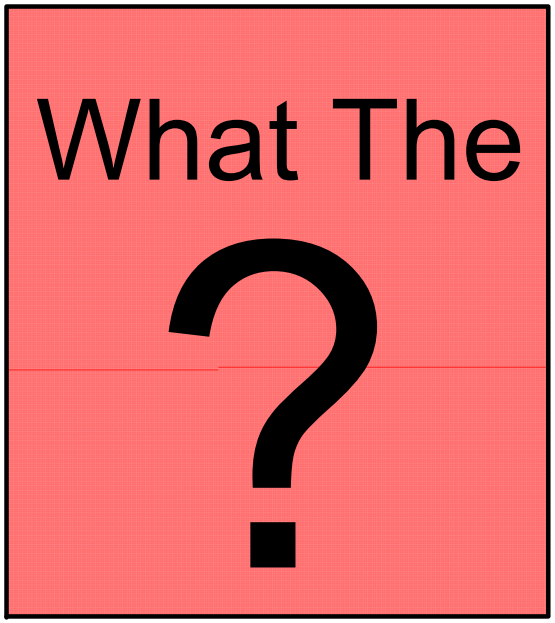


Installation Suggestions

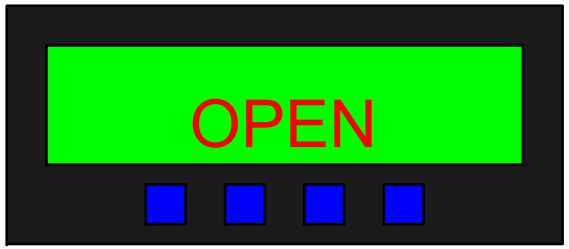
- Whenever possible, run the wires away from noise and heat sources (motors, transformers, heating ducts, etc.).
- Cable length has a major effect. 20 AWG type K extension wire is only good for ~ 170’. Consult manufacturer’s recommendations for long runs.
- In order to minimize noise and ground loop problems, use ungrounded, sheathed thermocouples whenever possible.

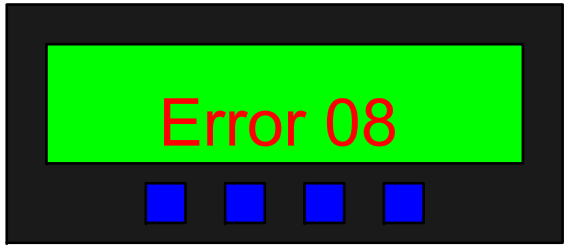
Thermocouple Troubleshooting – Common Issues

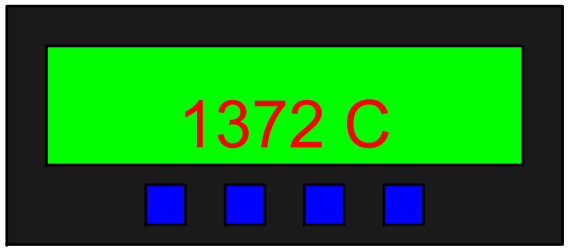
- Open thermocouple
- Flakey read back
- Read back opposite of what you would expect
- Sudden changes that may or may not be real
- Read back known not to be accurate (e.g. at rest or ambient temperature is incorrect)



- Open Thermocouple – Many modern day meters are capable of detecting an open and displaying this in some form of user interface, “OPEN”, an error code, or a high end-of-scale temperature.
- Checking can also be done with an ohm meter after first disconnecting the TC from the meter. A good thermocouple should read a very low (almost dead short), resistance. Connecting wire will add to this value.
- An open indication can also be caused by a blown component or an open trace on the meter’s circuit board.

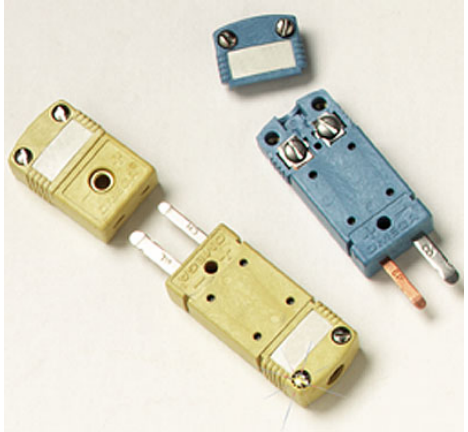






- Flakey Read Backs
  - Can be caused by a ground loop.
  - Noise issues
  - Broken Sheath – Particularly when used in a water application with a compression fitting. The ferrule scores the sheath and over time it weakens, and eventually water is able to penetrate and compromise the mineral oxide insulation.

- Read Back Opposite What You Would Expect. - (i.e. You know it's getting hotter but the read back shows it's getting cooler)
  - Polarity is incorrect. Unlike other DC circuits, the red wire on a thermocouple is <u>ALWAYS</u> negative *(in the U.S.)*.
- If the wire color cannot be determined a small magnet can be used. The + lead is non-magnetic while the – lead is magnetic.
- Many, but not all manufacturers also trim the negative lead shorter.
- The larger pin on a connector is also the negative lead.

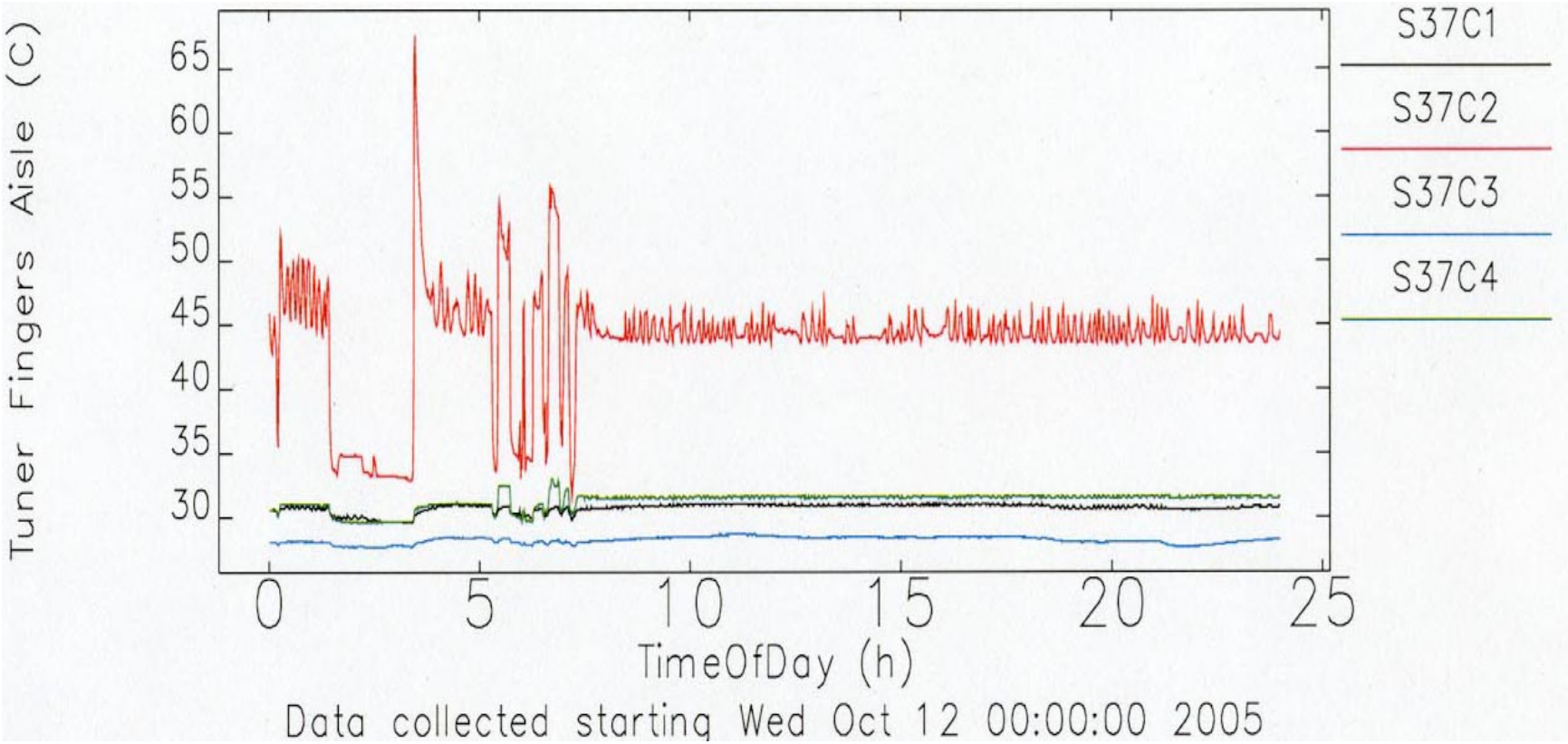


- Sudden Changes That May Or May Not Be Real – This is a problem that can be more difficult to troubleshoot. Sudden changes can be caused by noise, but also by vibration, movement of the wires or probe, or unrelated equipment turning on or off (also a noise issue).

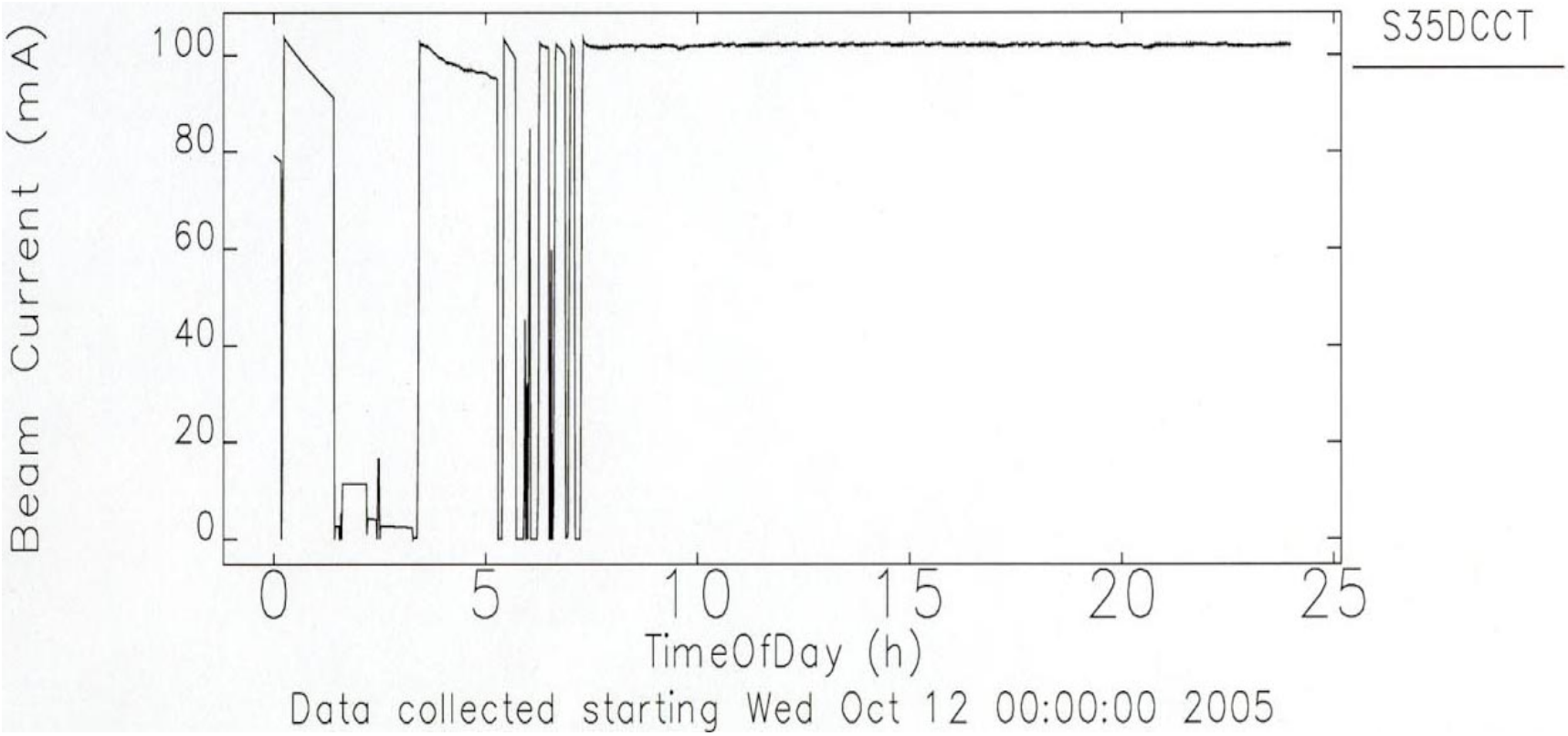
  Or…it can be real. Ask questions. Did something in the environment change? Is something external to the item of interest, affecting it's temperature (e.g. loss of beam, change in power, supply water temperature)?

  Redundancy and data logging are good things and a luxury we often take for granted. Check other data sources if available, and start here before tearing into hardware.

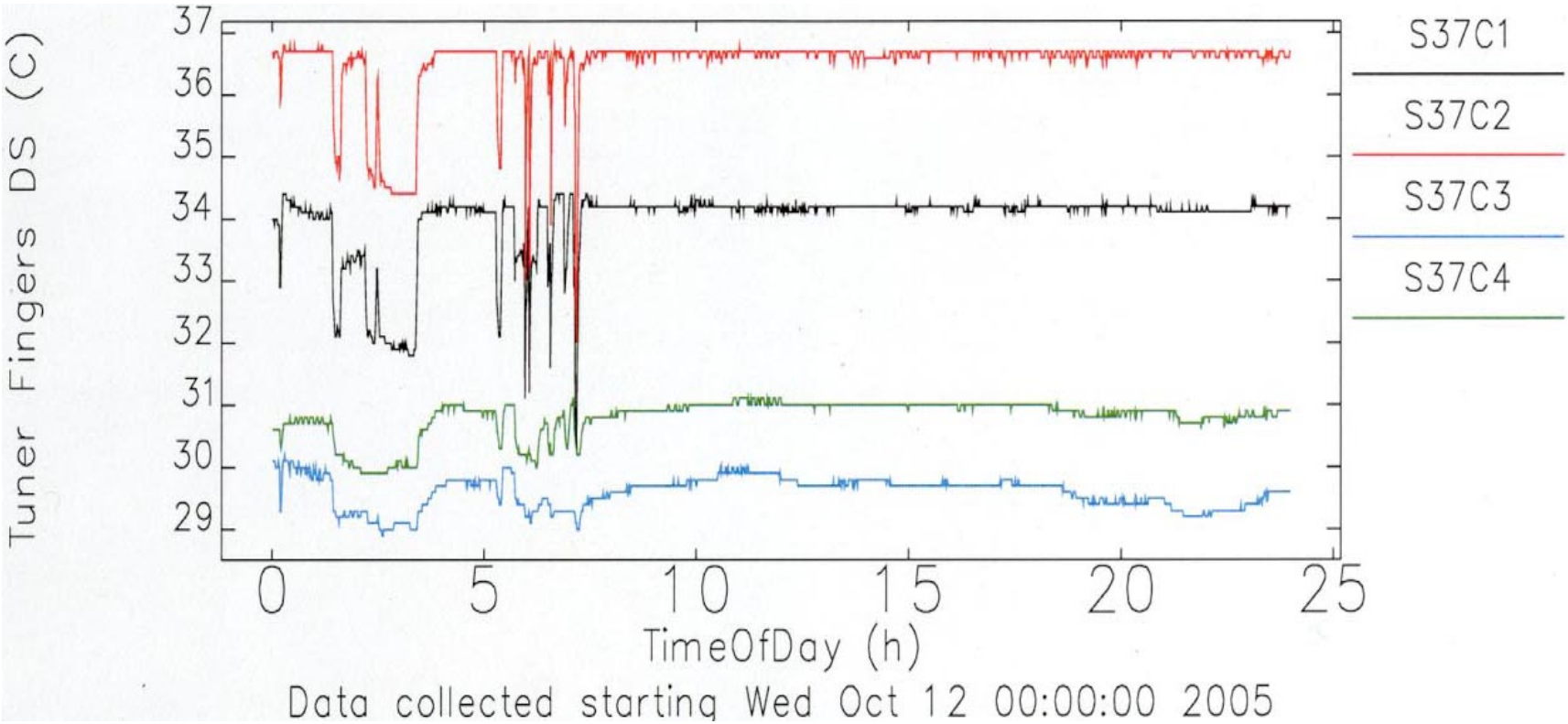
- Notice cavity 2's aisle finger temperature compared to the other three cavities. Is it real? Why the sudden change?



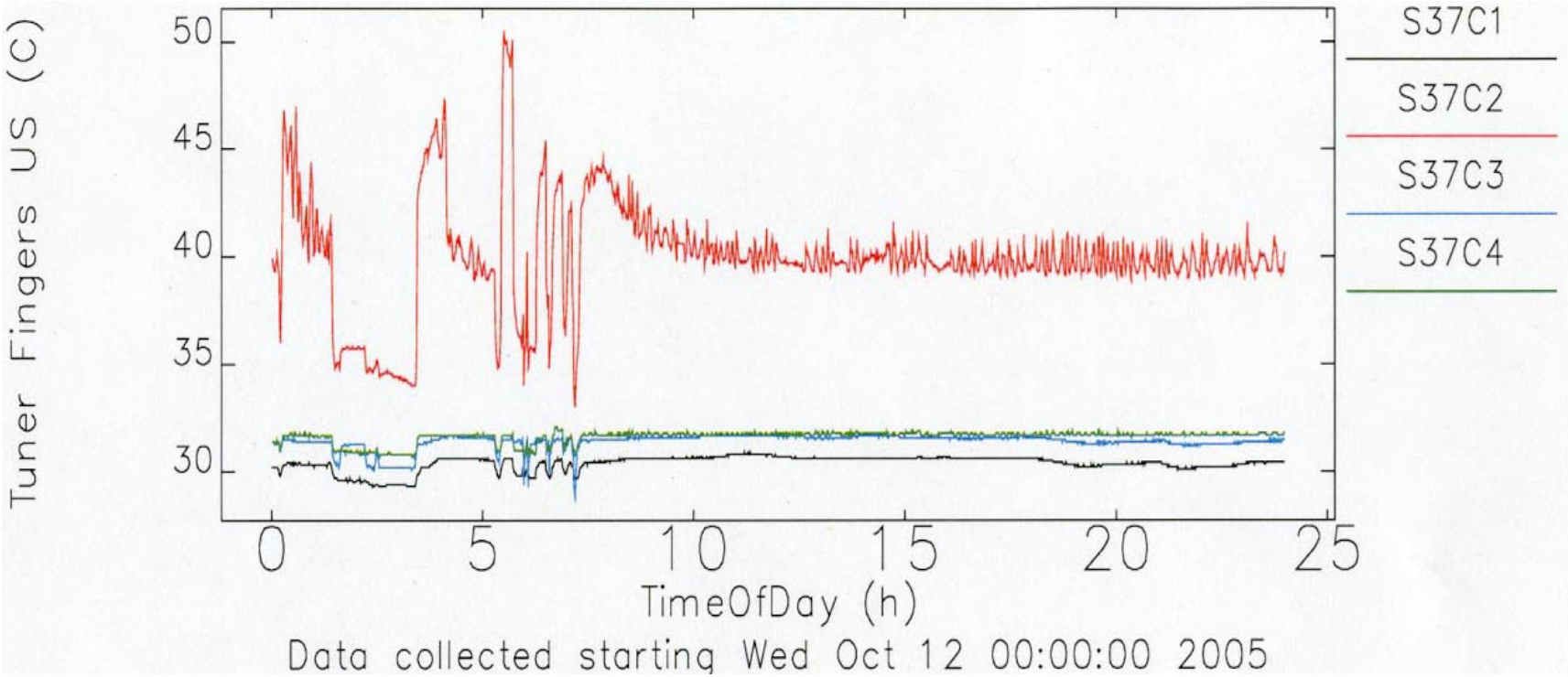
- Introduction of beam at the same time. But why is cavity 2 so different from the other cavities? Again, is it real?



- Cavity 2 downstream fingers are hotter than the others but not nearly as hot as the aisle temperatures (>65C). Might be real.



- Cavity 3 upstream fingers also show some elevated heating. One would have to conclude that this is real. What about the little spikes?



- Many times the best place to start troubleshooting a thermocouple problem is to use a portable thermocouple calibrator, which reads thermocouples and also simulates a thermocouple output voltage.
- This can sometimes determine whether it is the TC or the meter that is defective, but beware…
- Virtually all modern meters, whether rack mounted or hand-held, do some type of signal processing (averaging, filtering, etc.). Noise seen by your rack meter may not have an effect on your hand-held and vice-versa.

- Read Back Known Not To Be Accurate (e.g. at rest or ambient temperature is incorrect) – This is most likely one of three things.

  1). The thermocouple circuit is not calibrated.

  2). The cold junction compensation is defective.

  3). The connecting wires have degraded to a point where they no longer conform to the NBS polynomial standard used to convert the thermocouple voltage to a temperature. This can be caused by high temperatures or cold-working of the metal.

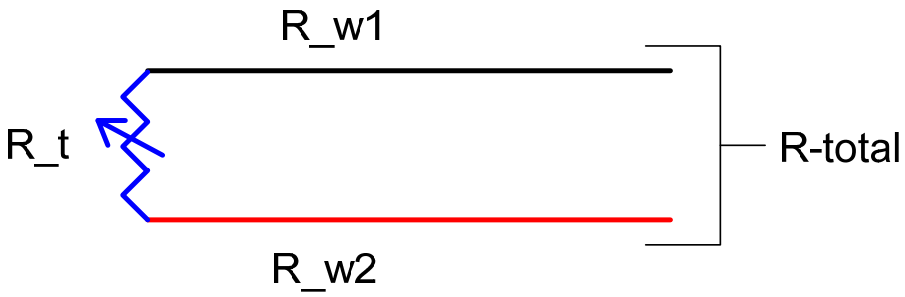
- There is no sure-fire way to determine #'s 2 & 3. Start with the calibration then replace either the meter or the wiring, whichever is easier or less expensive.

Thermocouple Circuit Calibration

- There are two basic ways to calibrate your thermocouple circuit. Using an ice bath or using a mercury thermometer. Both work well. The ice bath is probably slightly more accurate but not practical/suitable for most applications. I prefer the mercury thermometer with some heat conductive goop.
- Place the thermometer as close as possible to the thermocouple and wait for the temperature to level out.
- Use the temperature read from the thermometer to calibrate the thermocouple circuit. This may be an adjustment to the meter's CJC, the entry of the temperature in a calibration mode, the entry of an offset (not the best way), etc., depending on the meter being used. Check the manufacturer's product manual.

Theory of Operation – RTD's

- An RTD is a temperature measuring device that changes resistance with temperature change, rather than changing voltage, as with a thermocouple.
- Most commonly used is the platinum 100 ohm RTD because of it's stability in air and linearity. It's resistance is 100 ohms @ 0 Deg.C and increases with temperature.



RTD Resistance Equation

R_t = R_total – R_w1 – R_w2

- Common terms associated with RTD's are temperature coefficient or alpha, and tolerance class.
- Alpha is ohms per ohm per Deg.C.

  The average resistance change per unit of temperature from boiling point to ice point of water

  R_boiling – R_ice point/100deg/100ohms

  138.5 – 100.0/100/100 = .00385
- Tolerance class is the amount an RTD will differ from the standard resistance curve per Deg.C.

  Class A (+/- .15 + .002*t)

  @ temp of 100DegC = +/- .35DegC

Standard	Alpha ohms/ohm/°C	R_0 ohms	Polynomial Coefficients	Countries
IEC751 (Pt100)	0.00385055	100	**200°C < t < 0°C** a = 3.90830×10^{-3} b = -5.77500×10^{-7} c = -4.18301×10^{-12} **0°C < t < 850°C** a & b as above, but c = 0.0	Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Czech Rep, Denmark, Egypt, Finland, France, Germany, Israel, Italy, Japan, Poland, Rumania, Sth. Africa, Turkey, Russia, UK, USA
SAMA RC-4	0.0039200	98.129	a = 3.97869×10^{-3} b = -5.86863×10^{-7} c = -4.16696×10^{-12}	USA

Tolerance Class	Tolerance Equation (°C)
Class A	± (0.15 + 0.002.| t |)
Class B	± (0.30 + 0.005. | t |)
Class C	± (0.40 + 0.009. | t |)
Class D	± (0.60 + 0.0018. | t |)

- My meter does the calculations, why tell me about alpha and tolerance class?
- Your meter needs to either:

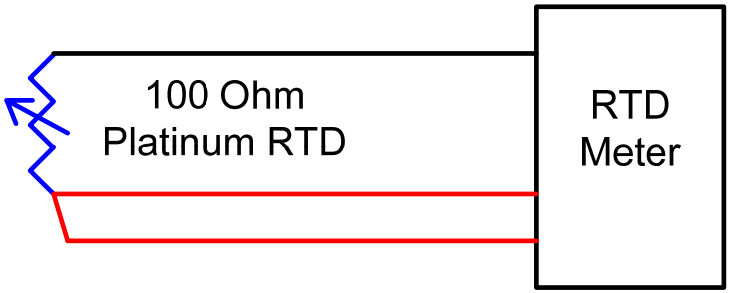
  Be ordered with the correct alpha calibration.

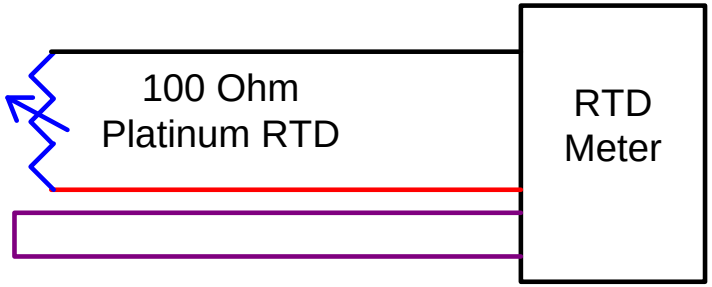
  Have a programmable alpha option.
- When ordering an RTD, a tolerance class will be part of the order, dependant on the application. IEC 751 stipulates that the RTD be marked with it's nominal R0 value, it's tolerance class, the wiring configuration and the temperature range.

Pt100 / A / 3 / -100/+200

Platinum 100 Ohm / Class A / 3-Wire / -100 to +200 Deg.C

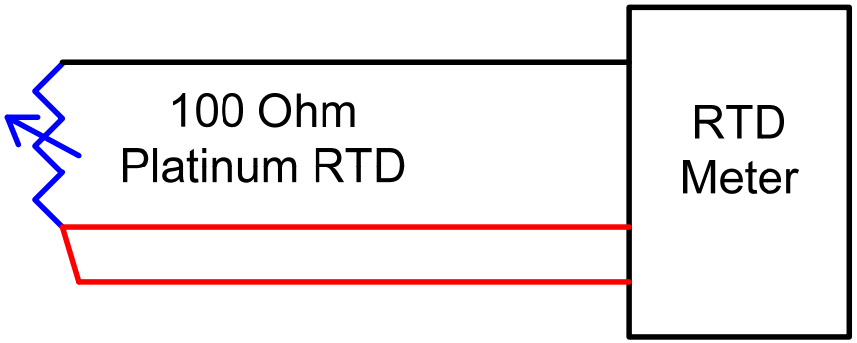
- The most common RTD configuration is the three-wire type. This configuration is more than adequate for 99.9% of applications. If absolute accuracy is needed, a fourth wire can be introduced, but rarely is it worth the added cost.
- Another configuration is a two wire RTD with a stand-alone loop. (Probably rarely used today).

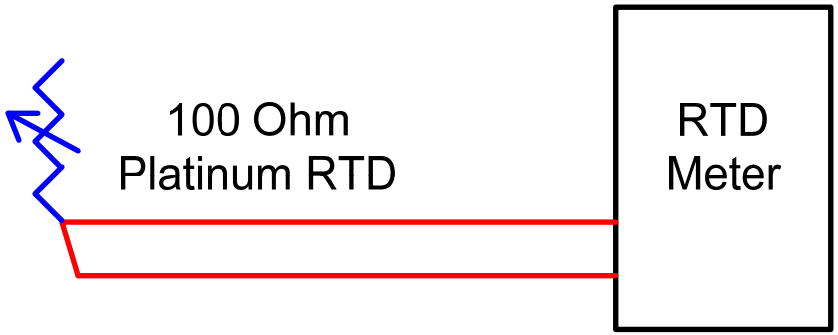




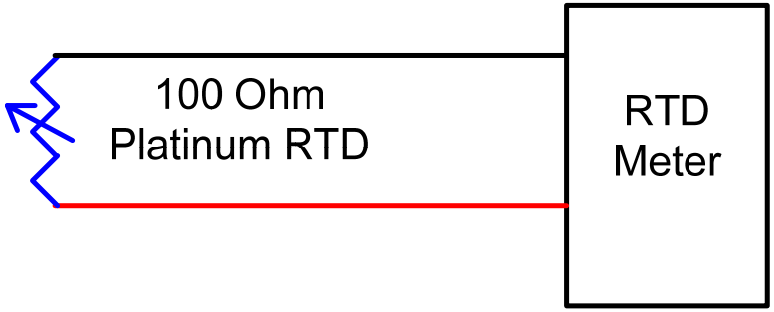
Theory of Operation – RTD's

- Since the RTD is a resistance device, the resistance of the wires used to connect the RTD to the measurement meter introduces errors and must be known. This is the reason a third (or fourth), wire is used.
- First the meter reads the resistance of the two common wires to determine the value of R_{wire}. For a three wire RTD, it is assumed that this resistance is the same as that of one common and one non-common wire.





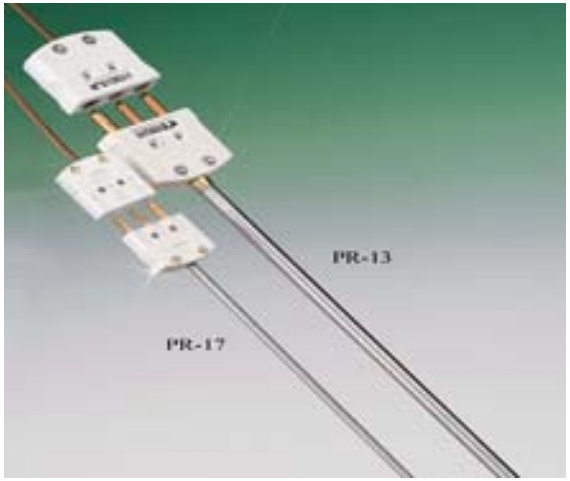
- Then the meter reads the resistance of one of the common wires, the RTD, and the non-common wire to determine R_{total}
- Meter electronics and software then subtract R_{wire} from R_{total} to get R_t which is then converted to a temperature.



$$R_t = R_{total} - R_{wire}$$

RTD Types and Installation

- Many configurations available, similar to thermocouples. Sheathed, bolt-on, flexible, surface mount, etc.
- Keep in mind that the RTD element is very fragile, use a sheathed configuration if possible



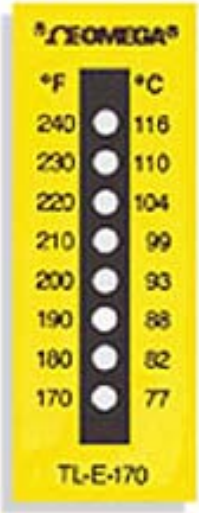
RTD Troubleshooting Common Issues

- Troubleshooting RTD's can be done using the same methods as with thermocouples – using an ohm meter or handheld calibrator.
- Noise is normally not an issue, but don't overlook it.
- If the temperature is known, use an ohm meter to perform the Rt = Rtotal-Rwire calculation.
  - May be a software problem with the meter
  - May have the wrong alpha setting
  - Shorted/grounded wires
  - 4-20mA "Hockey Puck" defective, wrong alpha or not calibrated (Water Group likes to use this configuration)
  - Sheath compromised if this is the configuration

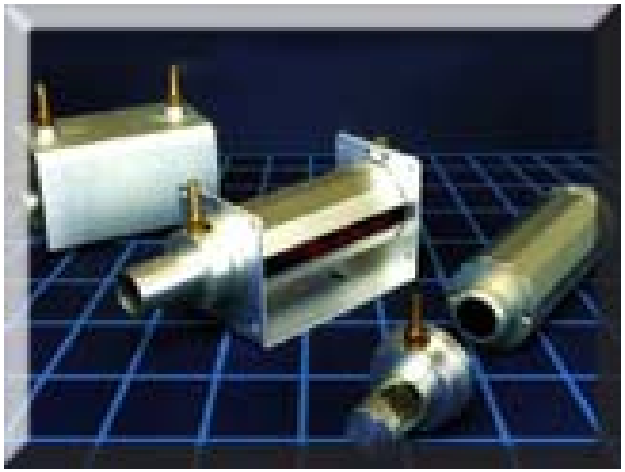
Other Temperature Measurement Devices

- Temperature Indicating Tapes, Crayons and Paints
- Infrared Thermometers
- Infrared Imagers

Temperature Indicating Tapes, Crayons and Paints

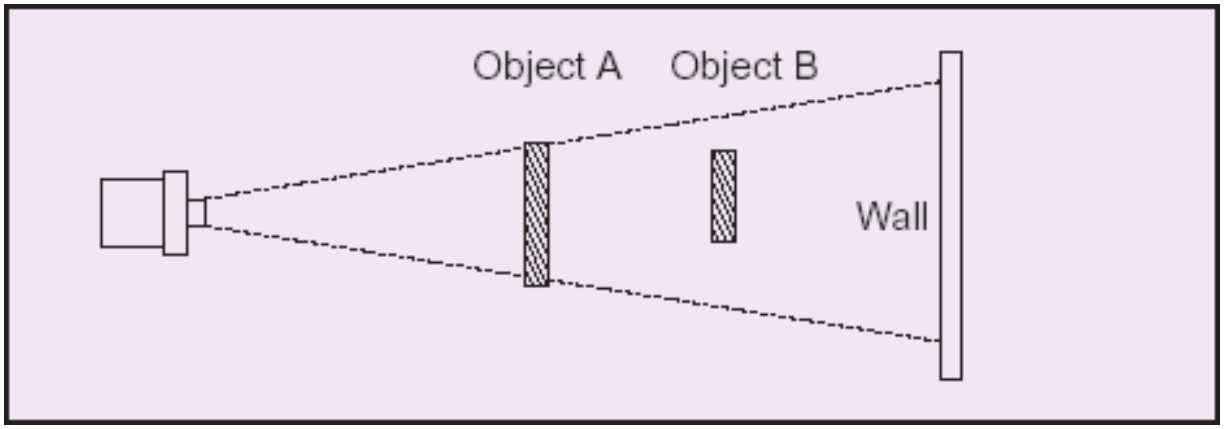


Infrared Thermometers



Infrared Thermometers – Terms and Definitions

- Field of View
  - The angle of vision at which the instrument operates
  - Infrared thermometers determine the average temperature of all surfaces within the field of view
    - *For accurate measurement, the object being measured should completely fill the field of view.*



Infrared Thermometers – Terms and Definitions

- Emissivity, Transmissivity & Reflectivity
  - Emissivity
    - *The ratio of the energy radiated by an object at a given temperature to the energy emitted by a perfect radiator, or blackbody, at the same temperature*
    - *Range 0.0 to 1.0*
    - *Blackbody emissivity = 1.0*
    - *The higher the emissivity, the easier it is to obtain accurate measurements*
  - Transmissivity
    - *A measure of an object's ability to pass or transmit infrared energy*
  - Reflectivity
    - *A measure of an objects ability to reflect infrared energy*
- E + T + R = 1.0

Ways to Determine Emissivity

- Heat a sample of the object to a known temperature, then adjust the emissivity to obtain the correct value.
- For lower temperatures, place a piece of electrical tape (E=0.95) on the object, then adjust the emissivity until the object material reads the same.
- For higher temperatures, drill a hole in the object (depth = diameter x 6). The hole acts like a blackbody with an emissivity of 1.0. Measure the temperature of the hole, then adjust the emissivity to obtain the correct temperature of the object material.
  - Not always practical due to field of view considerations
- Dull black paint has an emissivity of ~1.0. Paint a section of the object then adjust the emissivity of the unpainted area to obtain the same temperature.
- Consult an emissivity table. Values for most materials are documented, but other factors such as amount of oxidation can affect the emissivity. Using one of the methods above will produce a more accurate reading.

Emissivity Table

Table of Total Emissivity

These tables are presented for use as a guide when making infrared temperature measurements with the OMEGASCOPE® or other infrared pyrometers. The total emissivity (ε) for Metals, Non-metals and Common Building Materials are given.

Since the emissivity of a material will vary as a function of temperature and surface finish, the values in these tables should be used only as a guide for relative or delta measurements. The exact emissivity of a material should be determined when absolute measurements are required.

METALS

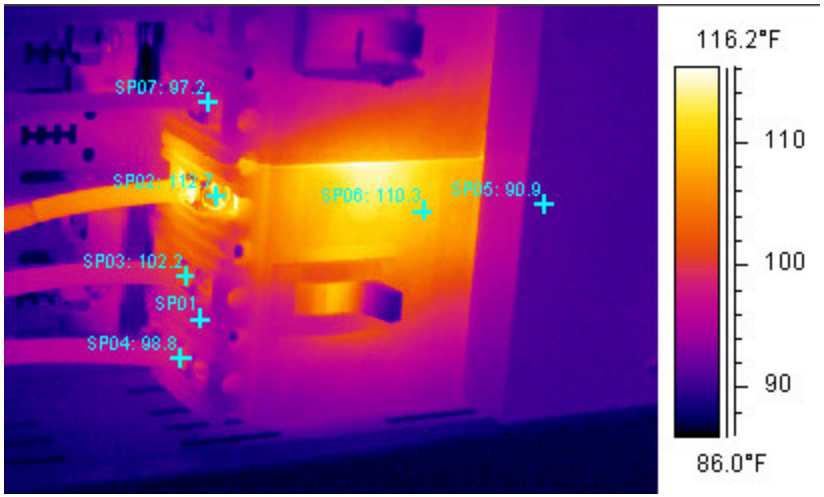
Material	Temp °F (°C)	ε-Emissivity
Alloys		
20-Ni, 24-CR, 55-FE, Oxid.	392 (200)	.90
20-Ni, 24-CR, 55-FE, Oxid.	932 (500)	.97
60-Ni , 12-CR, 28-FE, Oxid.	518 (270)	.89
60-Ni , 12-CR, 28-FE, Oxid.	1040 (560)	.82
80-Ni, 20-CR, Oxidized	212 (100)	.87
80-Ni, 20-CR, Oxidized	1112 (600)	.87
80-Ni, 20-CR, Oxidized	2372 (1300)	.89
Aluminium		
Unoxidized	77 (25)	.02
Unoxidized	212 (100)	.03
Unoxidized	932 (500)	.06
Oxidized	390 (199)	.11
Oxidized	1110 (599)	.19
Oxidized at 599°C (1110°F)	390 (199)	.11
Oxidized at 599°C (1110°F)	1110 (599)	.19
Heavily Oxidized	200 (93)	.20
Heavily Oxidized	940 (504)	.31
Highly Polished	212 (100)	.09
Roughly Polished	212 (100)	.18
Commercial Sheet	212 (100)	.09
Highly Polished Plate	440 (227)	.04
Highly Polished Plate	1070 (577)	.06
Bright Rolled Plate	338 (170)	.04
Bright Rolled Plate	932 (500)	.05
Alloy A3003, Oxidized	600 (316)	.40
Alloy A3003, Oxidized	900 (482)	.40
Alloy 1100-0	200-800 (93-427)	.05
Alloy 24ST	75 (24)	.09
Alloy 24ST, Polished	75 (24)	.09
Alloy 75ST	75 (24)	.11
Alloy 75ST, Polished	75 (24)	.08
Bismuth, Bright	176 (80)	.34
Bismuth, Unoxidized	77 (25)	.05
Bismuth, Unoxidized	212 (100)	.06
Brass		
73% Cu, 27% Zn, Polished	476 (247)	.03
73% Cu, 27% Zn, Polished	674 (357)	.03
62% Cu, 37% Zn, Polished	494 (257)	.03
62% Cu, 37% Zn, Polished	710 (377)	.04
83% Cu, 17% Zn, Polished	530 (277)	.03
Matte	68 (20)	.07
Burnished to Brown Colour	68 (20)	.40
Cu-Zn, Brass Oxidized	392 (200)	.61
Cu-Zn, Brass Oxidized	752 (400)	.60
Cu-Zn, Brass Oxidized	1112 (600)	.61
Unoxidized	77 (25)	.04
Unoxidized	212 (100)	.04
Cadmium	77 (25)	.02
Carbon		
Lampblack	77 (25)	.95
Unoxidized	77 (25)	.81
Unoxidized	212 (100)	.81
Unoxidized	932 (500)	.79
Candle Soot	250 (121)	.95
Filament	500 (260)	.95
Graphitized	212 (100)	.76
Graphitized	572 (300)	.75
Graphitized	932 (500)	.71
Chromium	100 (38)	.08
Chromium	1000 (538)	.26
Chromium, Polished	302 (150)	.06
Cobalt, Unoxidized	932 (500)	.13
Cobalt, Unoxidized	1832 (1000)	.23
Columbium, Unoxidized	1500 (816)	.19
Columbium, Unoxidized	2000 (1093)	.24
Copper		
Cuprous Oxide	100 (38)	.87
Cuprous Oxide	500 (260)	.83
Cuprous Oxide	1000 (538)	.77
Black, Oxidized	100 (38)	.78
Etched	100 (38)	.09
Matte	100 (38)	.22
Roughly Polished	100 (38)	.07
Polished	100 (38)	.03
Highly Polished	100 (38)	.02
Rolled	100 (38)	.64
Rough	100 (38)	.74
Molten	1000 (538)	.15
Molten	1970 (1077)	.16
Molten	2230 (1221)	.13
Nickel Plated	100-500 (38-260)	.37
Dow Metal	0.4-600 (-18-316)	.15
Gold		
Enamel	212 (100)	.37
Plate (.0001)		
Plate on .0005 Silver	200-750 (93-399)	.11-.14
Plate on .0005 Nickel	200-750 (93-399)	.07-.09
Polished	100-500 (38-260)	.02
Polished	1000-2000 (538-1093)	.03
Haynes Alloy C, Oxidized	600-2000 (316-1093)	.90-.96
Haynes Alloy 25, Oxidized	600-2000 (316-1093)	.86-.89
Haynes Alloy X, Oxidized	600-2000 (316-1093)	.85-.88
Inconel Sheet	1000 (538)	.28
Inconel Sheet	1200 (649)	.42
Inconel Sheet	1400 (760)	.58
Inconel X, Polished	75 (24)	.19
Inconel B, Polished	75 (24)	.21
Iron		
Oxidized	212 (100)	.74
Oxidized	930 (499)	.84
Oxidized	2190 (1199)	.89
Unoxidized	212 (100)	.05
Red Rust	77 (25)	.70
Rusted	77 (25)	.65
Liquid	2760-3220 (1516-1771)	.42-.45
Cast Iron		
Oxidized	390 (199)	.64
Oxidized	1110 (599)	.78
Unoxidized	212 (100)	.21
Strong Oxidation	40 (104)	.95
Strong Oxidation	482 (250)	.95
Liquid	2795 (1535)	.29
Wrought Iron		
Dull	77 (25)	.94
Dull	660 (349)	.94
Smooth	100 (38)	.35
Polished	100 (38)	.28
Lead		
Polished	100-500 (38-260)	.06-.08
Rough	100 (38)	.43
Oxidized	100 (38)	.43
Oxidized at 1100°F	100 (38)	.63
Gray Oxidized	100 (38)	.28
Magnesium	100-500 (38-260)	.07-.13
Magnesium Oxide	1880-3140 (1027-1727)	.16-.20
Mercury	32 (0)	.09
"	77 (25)	.10
"	100 (38)	.10
"	212 (100)	.12
Molybdenum	100 (38)	.06
"	500 (260)	.08
"	1000 (538)	.11
"	2000 (1093)	.18
" Oxidized at 1000°F	600 (316)	.80
" Oxidized at 1000°F	700 (371)	.84
" Oxidized at 1000°F	800 (427)	.84
" Oxidized at 1000°F	900 (482)	.83
" Oxidized at 1000°F	1000 (538)	.82
Monel, Ni-Cu	392 (200)	.41
Monel, Ni-Cu	752 (400)	.44
Monel, Ni-Cu	1112 (600)	.46
Monel, Ni-Cu Oxidized	68 (20)	.43
Monel, Ni-Cu Oxid. at 1110°F	1110 (599)	.46
Nickel		
Polished	100 (38)	.05
Oxidized	100-500 (38-260)	.31-.46
Unoxidized	77 (25)	.05
Unoxidized	212 (100)	.06
Unoxidized	932 (500)	.12
Unoxidized	1832 (1000)	.19
Electrolytic	100 (38)	.04
Electrolytic	500 (260)	.06
Electrolytic	1000 (538)	.10
Electrolytic	2000 (1093)	.16
Nickel Oxide	1000-2000 (538-1093)	.59-.86
Palladium Plate (.00005 on .0005 silver)	200-750 (93-399)	.16-.17
Platinum	100 (38)	.05
"	500 (260)	.05
"	1000 (538)	.10
Platinum, Black	100 (38)	.93
"	500 (260)	.96
"	2000 (1093)	.97
" Oxidized at 1100°F	500 (260)	.07
"	1000 (538)	.11
Rhodium Flash (0.0002 on 0.0005 Ni)	200-700 (93-371)	.10-.18
Silver		
Plate (0.0005 on Ni)	200-700 (93-371)	.06-.07
Polished	100 (38)	.01
"	500 (260)	.02
"	1000 (538)	.03
"	2000 (1093)	.03
Steel		
Cold Rolled	200 (93)	.75-.85
Ground Sheet	1720-2010 (938-1099)	.55-.61
Polished Sheet	100 (38)	.07
"	500 (260)	.10
"	1000 (538)	.14
Mild Steel, Polished	75 (24)	.10
Mild Steel, Smooth	75 (24)	.12
Mild Steel, Liquid	2910-3270 (1599-1793)	.28
Steel, Unoxidized	212 (100)	.08
Steel, Oxidized	77 (25)	.80
Steel Alloys		
Type 301, Polished	75 (24)	.27
Type 301, Polished	450 (232)	.57
Type 301, Polished	1740 (949)	.55
Type 303, Oxidized	600-2000 (316-1093)	.74-.87
Type 310, Rolled	1500-2100 (816-1149)	.56-.81
Type 316, Polished	75 (24)	.28
Type 316, Polished	450 (232)	.57
Type 316, Polished	1740 (949)	.66
Type 321	200-800 (93-427)	.27-.32
Type 321 Polished	300-1500 (149-815)	.18-.49
Type 321 w/BK Oxide	200-800 (93-427)	.66-.76
Type 347, Oxidized	600-2000 (316-1093)	.87-.91
Type 350	200-800 (93-427)	.18-.27
Type 350 Polished	300-1800 (149-982)	.11-.35
Type 446, Polished	300-1500 (149-815)	.15-.37
Type 17-7 PH	200-600 (93-316)	.44-.51
Type 17-7 PH Polished	300-1500 (149-815)	.09-.16
Type C1020, Oxidized	600-2000 (316-1093)	.87-.91
Type PH-15-7 MO	300-1200 (149-649)	.07-.19
Stellite, Polished	68 (20)	.18
Tantalum, Unoxidized	1340 (727)	.14
"	2000 (1093)	.19
"	3600 (1982)	.26
"	5306 (2930)	.30
Tin, Unoxidized	77 (25)	.04
"	212 (100)	.05
Tinned Iron, Bright	76 (24)	.05
"	212 (100)	.08

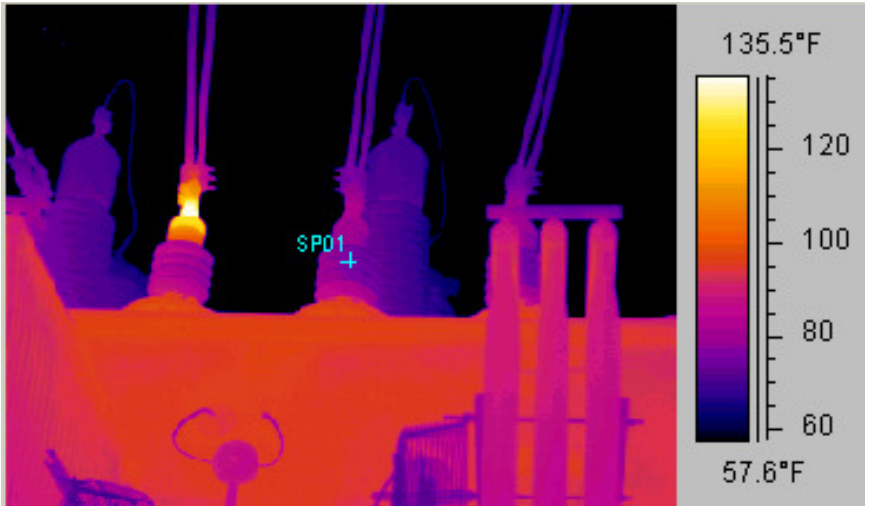
Argonne NATIONAL LABORATORY

Infrared Imagers

- Very expensive
  $30k to $60k
- Very useful diagnostic tool as it gives you visual feedback
- Cursor “spots” can be moved within the image to obtain temperature data, even with a saved image

Infrared Images





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