EAA602 Log Book

Adirondack Chapter Newsletter

December 2011

From The Presidents Desk

by Tim Devine

It can't believe its December already. It seems like I was just writing about the start of the 2011 flying season and now it is already winding down. This years weather has certainly made it interesting and unpredictable. My personal goal of getting some longer trips in went unfulfilled, except for the flight down to Sky Acres in Dutchess County. Coordination this year seemed like the biggest problem. Weekends that everyone could fly were halted by bad weather. Many nice weekends found people with other activities planned. With jobs, families, homes and lives to live sometimes it's just hard to find time to fly.

Next week we will be having our annual Christmas party and at that time I will be touching on some of the chapters accomplishments from the past year and looking forward to where the chapter is headed. Next year will take on a new look with some new board members and a new vice president. Look for small changes on how the chapter is evolving in a positive manner. Stay tuned for more to come, and make time to go flying.

Tim D.

NEW 2012 EAA602 Officers

President	Tim Devine
V-President	Larry Saupe
Secretary	Pat Morris
Treasurer	Darryl White
Editor	Doug Sterling
Y.E. Coord.	Judy Sterling

Board Members:

Fred Blowers
Don Fleischut
Kevin Bartholoma
John Pashley
Doug Sterling

Editors Note:

The new slate takes charge at the December Christmas Dinner/ Meeting on Dec. 11th @ 2pm at C&R Restaurant. Hope to see you all there, it will be fun as usual.

If you haven't contacted Judy with your reservation please do so by Wednesday the 7th as they need to make sure there are enough setups. Remember you can order off of the menu at our dinner.

Our Annual Christmas Dinner Will Be At:

C&R Resturant

Sun. Dec. 11th

@ 2:00 pm

Don't Be Late!!

Making the Measurement – Theory and Operation of Thermocouples

Earlier in the year I gave a short demonstration on thermocouples at one of the club meetings and mentioned at that time I would write an article to better articulate some of the topics.

Some of the most important instruments on our aircraft are what could be termed “non-powered”. What is meant by “non-powered” is that they derive their source of energy needed for operation from the medium that the instrument is trying to measure (no external power required for successful operation). A few examples include our air speed indicators, altimeters, fuel sight gages and various temperature measurement devices (such as outside air temperature, cylinder head temperature and exhaust gas temperature).

One of the most common methods to measure temperature (especially for those measurements with temperatures in the 100’s and 1,000’s of degrees) is the thermocouple. This device is very common in the aviation community, however the actual principles of operation are often misunderstood. These misunderstandings can sometimes lead to erroneous measurements and/or failure of the system altogether.

So… how does the cylinder head temperature (CHT) instrument on your dash actually know the cylinder head is at 357 °F? One of the paradigms out there is that somehow the junction of two dissimilar metals (the sensing head) actually generates voltage when it gets hot. This junction actually does not create any voltage at all, but only serves to allow two materials (in this case wires) to be connected at the same electrical potential (voltage). The junction (sensing point) just connects two wires electrically, nothing more.

To get an indication in your cockpit, we need to look at the instrument & thermocouple components as a “system”. The system consists of some device that will turn a difference in temperature into voltage (thermal energy into electrical energy – the thermocouple wires) and then a device to measure this voltage (the instrument in your cockpit – which is basically just a very sensitive volt meter).

Let’s first look at how thermal energy is changed into electrical energy in a thermocouple system. The key component is what is referred to as the *Seebeck* effect. The German Physicist, Thomas Seebeck, discovered in the early 1820’s that most metals (and some other materials) will generate a small voltage when one end of the material is held at one temperature and the other end is held at another temperature. The actual physics of what causes this is a bit complicated and revolves around electron interactions at the Fermi level (a reference is provided at the end of this article with some good explanation of this effect). For some materials the hot end is at a higher voltage than the cold end. For others, the hot end is at a *lower* voltage than the cold end. For many materials, especially metals, we can find values for this Seebeck effect, known as a Seebeck coefficient, to determine how it will behave when subjected to a temperature gradient (Table 1 provides values for several common metals).

Table 1 (Sample Seebeck Coefficients)

Symbol	Nomenclature	microvolts/°C
Na	Sodium	-5.00
K	Pottassium	-12.50
Al	Aluminum	-1.80
Mg	Magnesium	-1.30
Pb	Lead	-1.30
Pd	Palladium	-9.90
Pt	Platinum	-5.28
Li	Lithium	14.00
Cu	Copper	1.84
Ag	Silver	1.51
Au	Gold	1.94

It turns out that the plot of voltage vs. temperature for most metals is pretty linear (see Figure 1). That is, if you generate X volts for a 20F temperature difference you would generate 2X volts for a 40F temperature difference and so on. So… if you could measure the voltage generated by a wire, you would then be able to determine what the “difference” in temperature is between the cold end and the hot end (by going backwards through the graph).

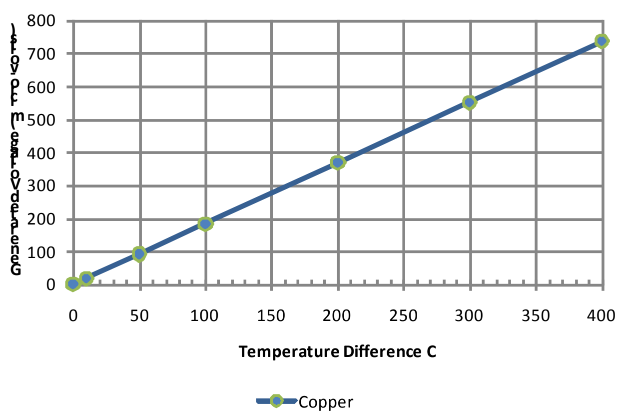
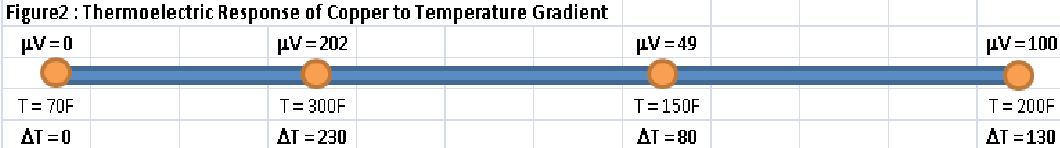


Figure 1

It is important to remember that we are only interested in the voltage at some particular point along the wire (and this voltage will vary with position and temperature). If one end was at 70F, a section in the middle was at 300F, another location at 150F, and the far end (where we wish to take our measurement) is at 200F, the end result voltage would be the same as if we only had one end at 70F and the other at 200F. Within certain limits, intermediate temperatures would have no effect (see Figure 2).

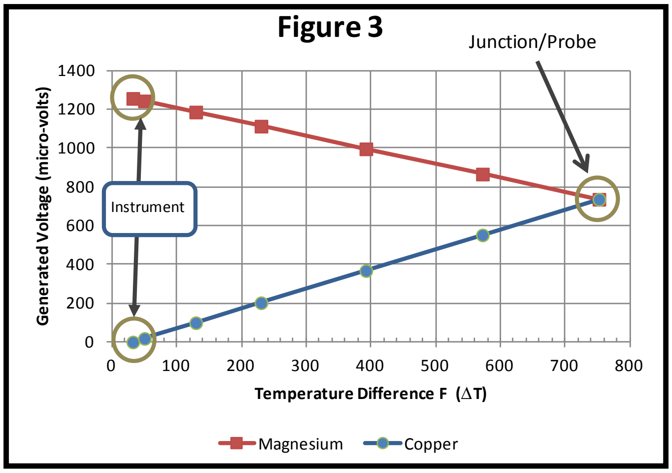
Figure2 : Thermoelectric Response of Copper to Temperature Gradient



However, it appears we still have some missing information. We can reasonably find the temperature difference along a wire (well, if we can find a way to measure its voltage). To find the temperature of interest (the thermocouple junction) we also need to know at what temperature the cold end of the wire is. This is called the “reference” temperature. If we know the reference temperature (either by assuming this value (maybe 70F), or by using some other type of temperature indicating device), we can then add the temperature increase that is indicated by our Seebeck voltage and arrive at the real temperature. One of the problems here, however, is finding a simple reliable way to measure the voltage at the hot end. As this measurement would most likely involve using a wire, it too would generate its own Seebeck voltage (due to the temperature at the measuring tip) and cause an error in the reading.

Figure 2 shows how voltage might vary for a copper wire when subjected to the various temperatures along its length. Note that the local voltage goes up and down relative to the local temperature. If you could tap in and measure the voltage at any of these points, you would see the values indicated and then be able to infer the temperature at each point (I.e. multiple temperature measurements using only one wire, this is known as a common leg thermocouple arrangement).

The concept seems straight forward enough. We have a temperature gauge in the cockpit (which is basically just a sensitive volt meter) and a wire that is making voltage for us, now we just need to figure out how to connect the wires to make a reading. We can attach our first thermocouple wire directly to the instrument. We next need to connect a wire from the remaining pole on the instrument to the location on the first wire where we would like to make the temperature measurement. Where these two wires meet is called a thermocouple *junction*. Quite often the junction is the thermocouple “probe” that we use in our aircraft. If we look at the circuit of the thermocouple (TC) system we see that we generate a positive voltage along the wire as it increases temperature. If we were to use the same type of wire on the return leg (or one with the same Seebeck coefficient) we would see that we would loose all that voltage as we move back towards the cold/reference end were we are making our measurement. To get around this problem we could use a return wire that has very low or non-existent Seebeck coefficient (i.e. does not generate a voltage in a temperature gradient), or we could use a wire with a negative Seebeck coefficient and amplify the signal. The later, is what is typically done when designing a thermocouple system. This is why you see a thermocouple often referred to as a combination of two wires of dissimilar metals. Figure 3 shows how a system might respond for a thermocouple constructed of copper (Seebeck +1.84) and magnesium (Seebeck -1.30).



Practical Stuff:

What materials should I use for my particular application? Fortunately the measurement community has standardized these pairings into off the shelf items with known characteristics. Table 2 below is reference of typical combinations and normal usages. One of the pairings with the highest temperature range and voltage output is that of the "E" type thermocouple. This thermocouple is often found employed for CHT and EGT measurements on light aircraft, boats, snowmobiles etc.

Table 2 (ref Omega.com)

ANSI Code	ANSI/ASTM E-230 Color Coding: Thermocouple Grade	Extension Grade	Alloy Combination: + Lead	– Lead	Comments Environment Bare Wire	Maximum T/C Grade Temp. Range
J			IRON Fe (magnetic)	CONSTANTAN COPPER-NICKEL Cu-Ni	Reducing, Vacuum, Inert. Limited Use in Oxidizing at High Temperatures. Not Recommended for Low Temperatures.	-210 to 1200°C -346 to 2193°F
K			CHROMEGA® NICKEL-CHROMIUM Ni-Cr	ALOMEGA® NICKEL-ALUMINUM Ni-Al (magnetic)	Clean Oxidizing and Inert. Limited Use in Vacuum or Reducing. Wide Temperature Range, Most Popular Calibration	-270 to 1372°C -454 to 2501°F
T			COPPER Cu	CONSTANTAN COPPER-NICKEL Cu-Ni	Mild Oxidizing, Reducing Vacuum or Inert. Good Where Moisture Is Present. Low Temperature & Cryogenic Applications	-270 to 400°C -454 to 752°F
E			CHROMEGA® NICKEL-CHROMIUM Ni-Cr	CONSTANTAN COPPER-NICKEL Cu-Ni	Oxidizing or Inert. Limited Use in Vacuum or Reducing. Highest EMF Change Per Degree	-270 to 1000°C -454 to 1832°F

Note that each thermocouple material and/or pairing has specific codes for quick identification.

How does my cockpit instrument know what the reference temperature is? Typically this is handled one of two ways. Either a constant value is assumed (which is referred to as an *uncompensated* instrument), or a local cockpit temperature measurement is made internally (referred to as a *compensated* instrument). One quick way to determine if you have a compensated gage or not is to look at the temperature reading when it is cold outside (say 30° F). If it reads close to 30° F then most likely you have a compensated gage. If it reads 70° F, chances are it is uncompensated. Always refer to your particular instrument literate to verify. Below is a sample from a Westach EGT gage *uncompensated*:

CAT. # 2C2-1
SINGLE INSTRUMENT

EXHAUST GAS TEMPERATURE GAUGE.
RANGE 100-1900 F. and 100-1000 C.
USE WITH 4 FOOT TYPE K
THERMOCOUPLE SENDER.

! IMPORTANT !

This system is factory calibrated at 75 deg. F. The indicator measures the temperature difference between the hot end (PROBE) and the pin terminals on the other end of the thermocouple. (COLD JUNCTION).

For COLD JUNCTION temperature of 75 deg. The indicator will read the true temperature of the PROBE end of the thermocouple.

For COLD JUNCTION temperatures HIGHER than 75 deg. The indicator will read one deg. LOW for each deg. above 75 deg.

For COLD JUNCTION temperatures LOWER than 75 deg. The indicator will read one deg. HIGH for each deg. below 75 deg.

This thermocouple "error" is a normal characteristic of self powered thermocouple systems. If possible, locate the thermocouple COLD JUNCTION connection to patch cable away from heat (or extreme cold) to minimize thermal "error".

When the COLD JUNCTION is 100 deg. and the system is calibrated at 75 deg., that means the COLD JUNCTION is 25 deg. high and the indicator will read 25 deg. low. See example in illustration.

One thing to remember when using an uncompensated instrument is that it will read off-scale high during cold weather and off scale low during warm

weather. As an example, if your uncompensated instrument is assuming the cockpit temperature remains constant at 70 deg F, when it is 30 deg F in the cockpit and the cylinder head on your engine is actually at 320 deg F, it will see the voltage generated for a change in temperature of (320F-30F) = 290F. It will now add 290F to 70F (instead of the real 30F) resulting in an indication of 360F (which is 40F high). The opposite will happen on hot days. If your cockpit was at 90 deg F and your cylinder head temperature had a true value of 320 deg F, the thermocouple would generate a voltage corresponding to (320F–90F) = 230F. The instrument then adds 230 deg F to 70 deg F and reports 300 deg F (which is 20F low).

One important item concerning the Seebeck coefficient in metals, is that its value can change depending on its state of stress & strain (such as work hardening), corrosion and exposure to excessive temperature. Values quoted are often for new, clean and annealed wires. With this knowledge, care should be taken to avoid stress and strain on the thermocouple wires and also sharp bends. A region of wire in a sharp bend or under stress/strain could itself become its own thermocouple (as that portion of the wire has a different Seebeck coefficient that the section of wire just before or after that location). This strained or bent section would then become active to changes in temperature and provide false indications to the cockpit. If unsure if your bent wire has become active, you could always test it with heat (such as a heat gun) to see if your cockpit indications respond to it (note that it could show an increase or decrease in temperature). Wires should also be routed away from regions of excessive temperature and shielded from radiation sources.

Is the length of thermocouple wire important? The answer is no, and yes! It depends on how the voltage measurement system is finding the voltage. Some systems allow a small amount of current to flow in the wires and measure a voltage drop across a high impedance resistor. In this case, the total resistance of the wire becomes a player and the calibrated system can be affected by changing the wire length. Several of the new digital systems do not induce this type of current and are independent of wire length. Always contact your system vendor (OEM) prior to making any changes (either on materials or length) to ensure measurement accuracy will not be affected.

Some thermocouple myths:

There should never be a 3rd metal in the hot junction (probe). *To create a thermocouple junction, all that is needed is to electrically short the ends together. Butting the wire ends against a metal surface will create a junction. Remember that the thermocouple signal is generated over the length of the wire. The 3rd metal must be at the same temperature as the ends of the wire to prevent errors.*

You must use special limits of error wire extension if your thermocouple is special limits. *This is not necessary "if" the extension wire is outside of the temperature gradient area. Although the signal is generated over the entire length of wire, the important area is the localized gradient between the hot and cold areas.*

Non-Thermocouple materials cannot be used in the thermocouple circuit. *It is permissible to use non-thermocouple materials as terminal blocks or splices as long as there is no temperature gradient across these devices.*

References:

Thermoelectric Effects in Metals: Thermocouples, Safa Kasap, Department of Electrical Engineering, University of Saskatchewan, Canada. http://kasap3.usask.ca/samples/Thermoelectrics-Seebeck.pdf

Omega Instrumentation Catalog.