

# Testing EGTs and CHTs

Here's a primer on these important engine gauges.

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KITPLANES, October 1995

Engine temperature gauge sensors generally rely on one of two well-known phenomena: a change of *resistance* with temperature or a generation of *voltage* with temperature.

In the first case, we have the low-temperature variable-resistive sensors like thermistors and semiconductor diodes in the temperature ranges below 200°F for measuring things like carburetor ice temperature, outside air temperature, and other low-temperature measurements.

## Thermocouples

However, when we get above 200°F, we rely on an ancient technology known as the thermocouple effect for generating a voltage as a function of the temperature of the thermocouple. (Resistors and diodes can't take the heat of temperatures above about of 300°F.)

A thermocouple exists when any two wires made out of different metals are twisted together and heated. Copper-steel, aluminum-nickel, and gold-silver twisted wires all make thermocouples and generate a voltage when heated. However, some combinations are more useful than others because most combinations will only produce a very small voltage just barely detectable with sensitive instruments.

This same effect, by the way, produces an unwanted effect known as galvanic corrosion when, for example, a steel screw is used in an aluminum sheet. That one-turn steel-aluminum thermocouple sits there year after year generating a voltage that further heats the junction that generates more voltage that further heats the junction. And then, of course, the problem resolves itself when the steel screw eventually drops out of the hole corroded in the aluminum plate.



A 12-volt battery and a resistance substitution box makes testing CHT and EGT meters easy. Don't use too little resistance!

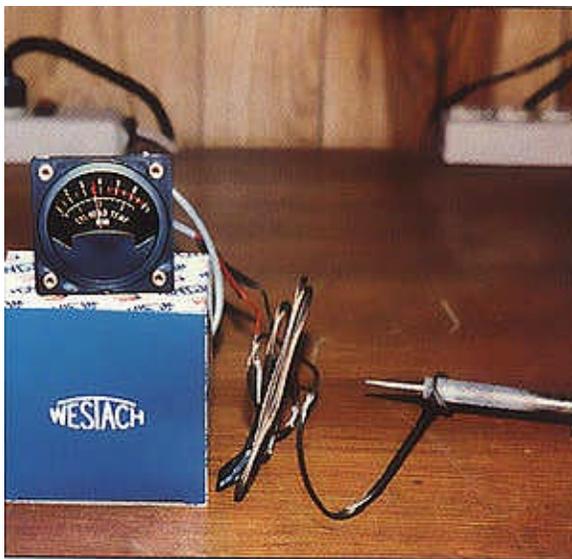


Over the years, we have found that a thermocouple made of a *copper* wire and a *constantan* wire (CU-CN) twisted together makes a dandy

thermocouple, as does a thermocouple made out of iron and constantan (FE-CN). (Constantan is an alloy of copper and nickel.) Both have a fairly high output measured in millivolts in the temperature range of 200-1000°F and are fairly resistant to temperature and to corrosion.

The iron/constantan couple is so widely used that it has been nicknamed the J-type thermocouple. The J-couple has a relatively high output voltage for a given temperature change, but it will melt and become useless above about 1000°F.

Another wire pair that works well as a thermocouple is a chrome alloy and an aluminum alloy called *chromel-alumel*. This wire pair can take much higher temperatures than the iron-constantan pair. It, too, has been given a nickname. It is called a K-couple. It has a fairly *low* output voltage for a given temperature change, but it is useful past 2000°F.



A soldering iron provides enough heat to check a CHT probe.

### Engine Gauges

In particular, a J thermocouple may be welded to a spark plug gasket to sense cylinder head temperature (CHT) and a K thermocouple can be welded into a stainless steel probe for exhaust gas temperature (EGT) measurements.

While an article about the design of CHTs and EGTs might be informative to a few, my sense is that most of us would prefer to go out and buy an off-the-shelf gauge but would like to know how to test or repair that gauge when the

airplane takes its inevitable toll on the innards of the thing...and to do it without the special test equipment you might find in the average rocket scientist's lab.

I'm not going to distinguish right now between CHT and EGT because in essence they are the same gauge calibrated for two different temperature ranges. Basically, they perform quite similar functions with the CHT sensor usually welded onto a spark plug gasket and the EGT sensor welded into a nail-shaped stainless steel probe that goes into a hole that you drill in your exhaust stack.

The gauge is really comprised of two parts: a meter and a sensor. There isn't much whoop-tee-doo electronics involved; the sensor puts out a voltage that the meter reads. Either part can go bad, and either part can be tested separately.

The sensor is pretty much an all or nothing device. Rarely, if ever, have I seen a sensor "lose sensitivity" or "go out of calibration." They are what is called a "pregnant" device; they either am or they ain't. There's no in between.

### Checking Thermocouples

Testing a sensor, then, involves nothing more than heating up the sensor and measuring its output with a sensitive voltmeter. How sensitive a voltmeter? Well, at room temperature, the average J and K thermocouples will both read a little less than half a millivolt (0.0005 volt). When heated to about 400°F with a soldering iron, the CHT J sensor will put out about 8 millivolts (0.008 volt). And when an EGT-type K probe is heated to 1400°F with a propane torch, the sensor puts out around 25 millivolts. Now, your average multimeter is going to have a hard time reading fractions of millivolts, but both references (1) and (2) at the end of this article sell fairly inexpensive multi-purpose meters that have sensitivities down in this range.

The (+) plus and (-) wires depend on the type and style of sensor you have. On a yellow/red type K couple, the yellow wire is plus and the red wire is minus. On a red/black type J couple, the black wire is plus and the red wire is minus. Note that the easiest way to think you have a dead box on a new installation is to accidentally reverse the plus and minus wires. You aren't

going to harm the gauge, but you aren't going to get any indication, either. Since these gauges don't need ship's power to run, you can test them in place by heating up the sensor with any handy hangar heat source (heat gun, soldering iron or gun, torch on low flame, or if desperate a [shudder] cigarette lighter) and watching for an indication on the meter.

### Checking the Meter

Testing the meter is just a little more complicated than testing the sensor, but not a whole bunch. Most instruments today are nothing more than a milliamperemeter with a known coil resistance. Given that we know resistance and the voltage of our thermocouple, the current through the meter is given by Ohm's law as  $I=E/R$ , and this is the basis on which the meter is calibrated.

However, meters are almost always "pregnant" devices also. Oh, yes, every now and again you will get one with a cracked pivot jewel or a fly speck in the air gap, but for the most part, meters such as this are pretty rugged instruments and either work or don't.

Testing them involves nothing more than running a known current through them and watching the needle move. How much current? Well, for the popular Westach line of CHTs and EGTs, the basic movement is one milliamperemeter for full-scale movement. If that were all there were, it would be child's play to test them. However, there is a *diddle constant* that has to be taken into account.

The *diddle constant* (or *finagle factor*—your choice of terms) comes from the fact that the zero line on the meter isn't zero current. That is, the meter zero has been "suppressed" so that the scale can be spread out over the gauge's temperature band of interest.

For example, look at the EGT in the second photo. Note that "zero" on the meter is actually 700°F. You and I know cotton-picking' well enough that the bench isn't at 700°F. The engineer who designed this system said to herself something like this:

"I know darned good and well that nobody with an engine bigger than a go-kart cares about exhaust temperatures below 700°. What the customer *really* wants is to spread the usual temperature range of 700-1700° out over the

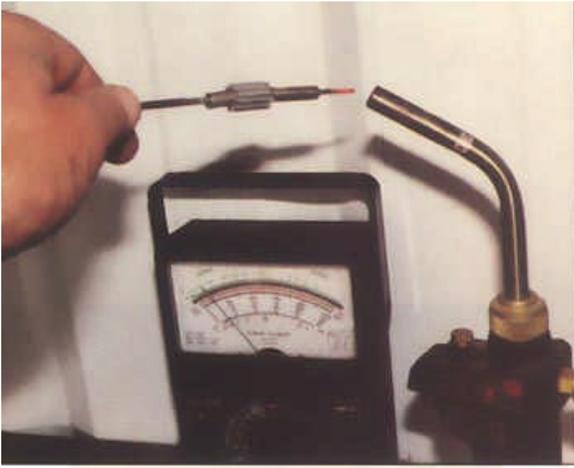
swing of the needle. If I get into the meter and spring-load the needle against the peg so that it takes the sensor 700° of voltage to push against that spring to bring the needle to zero, then I have effectively suppressed the first 700° of needle swing. Now I have a full needle swing of one milliamperemeter to spread over my desired range of 700-1700° and the calibration marks on the meter can be almost double what they would have been had I not suppressed the meter zero."

Does all this rigmarole mean we can't test the meter? Not a bit of it. All it means is that we will have to run a little bit more current through the meter than we might have done had the zero not been suppressed.

How about a little rough-cut calculation? What to use for a voltage source? How about the airplane battery? Why not? The battery voltage is almost always available when the master switch is on in both the instrument panel area and the engine compartment area. Let's presume a 12-volt battery. If the meter zero weren't suppressed, we might think that a 12K ohm resistor would give us full-scale deflection on the one milliamperemeter. However, since we have roughly doubled the meter sensitivity (full scale is 2 milliamperes or so), it should take something on the order of 6K ohms for full-scale deflection of the EGT gauge. Since 6.8K ohms is the nearest standard value, let's use that.

Sure enough, using the circuit of Figure 1, we find that 6.8K ohms for R1 gives us a reading of about 1200° on the meter. Using separate resistors or a resistor switching box allows us to vary the current through the meter and watch the needle move.

How about the CHT? No problem. Here the meter zero isn't quite so far suppressed (zero on the meter is 100°F) and a 10K ohm resistor in series with the battery and the meter gives us a very nice deflection.



An EGT probe provides voltage that shows on a sensitive voltmeter when heated by a propane torch.



Another type of probe is heated by the torch and shows the temperature on the EGT gauge.

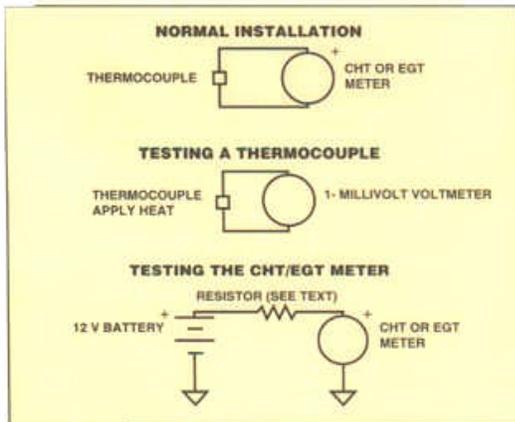


Figure 1. Circuit diagrams.

One word of caution: If you ever let the battery get directly across the meter or if you ever mistakenly put more than about 10 mA through the meter, just figure on buying a new meter. No ifs, ands, or buts. Note that the resistor values

are in kilohms (thousands of ohms). Mistakenly reading a 680ohm (blue-gray-brown-gold) resistor for a 6800 ohm (blue-gray-red-gold) resistor is going to spoil your whole day.

I know the difficulty involved when building or restoring a plane to "get the thing in the air." But if you will stop long enough to run a couple of quick tests on your SuperWhizBang EGT and CHT gauges when they are new (with notes in your permanent notebook, of course), then 20 years down the road you will be able to recreate the original tests when the unit finally wears out.

### Next Steps

So the meter checks out good and the sensor checks out good. But the system still doesn't work in the airplane. What could have gone wrong? You've made the plus/minus wire check and actually swapped them just to see, right? You've heated the thermocouple end and it doesn't move the meter one iota. Now what? About the only thing left is an unintentional ground on one of the meter wires. If you measure DC resistance from either of the thermocouple wires to the spark plug gasket (CHT) or the stainless case on the EGT probe, you will find that both wires are shorted to the gasket or probe. If you tried to use the airframe ground on the minus lead so that you only had to run one wire (the plus thermocouple lead) to the gauge and use airframe ground to carry the minus return current, you goofed. Once they leave the thermocouple, neither of the wires nor the terminals on the gauge can be grounded without making the system inoperative. One easy way to check for this is to hold the gasket or probe (plus any metal wire shielding on them) away from airframe ground while a friend checks for anything below infinity ohms to ground from either the plus or minus wires.

Another tip: You say you want to make a custom cable between the end of the sensor leads and the meter? Guess what. References 1 and 2 both sell the little pins that mate to the pins on the meter and the sensor as the *female* pins of a standard Molex or AMP 0.093-inch nylon connector. They also sell the shrink sleeving you should use on the sensor end to keep the pins from shorting to each other or to ground. And, since this is a millivolt milliam-

pere system, using small gauge wire (22 or 20) shouldn't affect the meter to any measurable extent-even if you ran the cables nose to tail and back again.

One last bit of information. Some older units used a specific resistance for their extension leads. While it is true that modern CHTs and EGTs use the meter resistance plus the thermocouple resistance for calibration, the extension wires in between the two ought to be relatively insensitive to the resistance of the extension cables. You will see some ads for 2-ohm and 8-ohm wires.

CHTs first came into Boeing (excuse me, being) during WW-II. If you think about running a pair of thermocouple wires from the No. 1 or No. 4 engine on a B-29, you have a significant resistance even if you use No. 18 wire. So the manufacturers all agreed that no matter how long the cable, it would be designed with a wire gauge that gave a known resistance.

As for me, if I had one of those old-style meters, I'd probably use plain old No. 22 for my cables and buy a 2.2-ohm or 8.2-ohm resistor (whichever system you have) and either bury it in shrink sleeving in the wire or put it on a terminal block in series with one of the wires. A dime for the wire and a nickel for the resistor beats a \$10 cable all hollow.

That pretty much wraps up everything you wanted to know about your CHT and EGT. In a future article, I will discuss the same sort of tests on things like carburetor and oil temperature gauges, oil pressure gauges, and fuel quantity gauges.

My thanks to the good folks at Westberg Mfg. for the loan of the instruments you see in the photos in this article. I'll look for you at Oshkosh.

**KP**

#### **References:**

1. Mouser Electronics. 800/346-6873. Good source for voltmeters, small parts. Free catalog. Mail order only. Fine folks to deal with.
2. Radio Shack right in your home town. Good source for voltmeters and small parts.
3. Westberg Mfg. 707/938-2121. Full line of inexpensive engine gauges. Available from all the major aviation supply mail order companies.
4. RST Engineering. My little company. I'll try to answer questions on the Internet address of: [jim@rst-engr.com](mailto:jim@rst-engr.com).