USING THERMOCOUPLES

This simple device generates voltage that is used to measure heat, cold, pressure, flow, and directly creates cold from electricity!

By Walter W. Schopp

Simply twist the ends of one copper and one steel wire together and you have created an amazing device called a *thermocouple*. If you apply heat to the twisted junction, a voltage is produced across the open wire ends. Reverse the situation and run current through the junction and the temperature of the junction will go up or down depending on the direction of the current.

That *thermoelectric* effect of direct temperature-to-electricity or electricity-to-temperature conversion was discovered over a century ago. Simple thermocouple devices that directly convert heat to electricity, are extensively used for measurements of temperature, flow, and pressure. Thermoelectric cooling devices are found in applications that make use of the electricity-to-temperature conversion abilities of the thermocouple.

Actual Thermocouples

The simple copper and steel thermocouple leaves a lot to be desired because the output voltage from that configuration is very low. Years of research have produced a variety of metals and alloys that produce more output.

A common material used for thermocouples is *copper constantan*. Copper constantan is an alloy of 60% copper and 40% nickel. A thermocouple junction made from that material combined with another alloy can produce about one and a half millivolts at 100°F.

Other combinations of materials used in thermocouples are iron and iron constantan, chromel and alumel, and various alloys of platinum and rhodium. The last two materials are quite expensive and are used mostly for extending the temperature range above 3000°F. That is usually of little interest to the home experimenter.

The output of the thermocouple is rated in millivolts per degree and is always *non-linear*. That means that as the temperature changes, the millivolts per degree will not always be the same. By plotting the output against the temperature, tables for various materials have been compiled. The tables are available from many sources. One of the prime sources for them, and all the materials needed to experiment with is Omega Engineering Inc., Box 4047, Stamford, CT 06907.

Series Connections

The output from a single thermocouple junction can directly drive a pivot-and-jewel type millivolt meter. By using an op-amp, a thermocouple's output can be amplified and unloaded. That is useful if the thermocouple is to be used as a sensing and control device.

The thermocouple junction can be compared to a small battery whose voltage increases or decreases with temperature changes. But unlike batteries, since each material in the junction assumes a fixed polarity, the connections that are made between the thermocouples produce voltage equal and opposite to that of the thermocouples themselves. That effectively cancels out any voltage produced by the thermocouples (see Fig. 1). It is comparable to connecting batteries in series with every other battery connected backwards. Series connections of thermocouple joints can be accomplished by making certain that only every-other joint sees heat, while the reverse connected joints are not heated (see Fig. 2.)

A circuit showing how a lot of thermocouples can be connected together to produce a usable voltage with every other junction kept cool is shown in Fig. 3. One ring of junctions is shown, but many rings can be made around a heat source. Enough thermocouples can be arranged in a circular pattern to power a small radio. The ring of thermocouples can be heated with a candle in the center, or slipped over the chimney glass of a lantern.

Hook Up

You can connect thermocouples in parallel, or use larger wire size to increase their current generating capability. The size of the wire has little to do with the output voltage from the junction. Small-diameter wires heat and cool quicker,

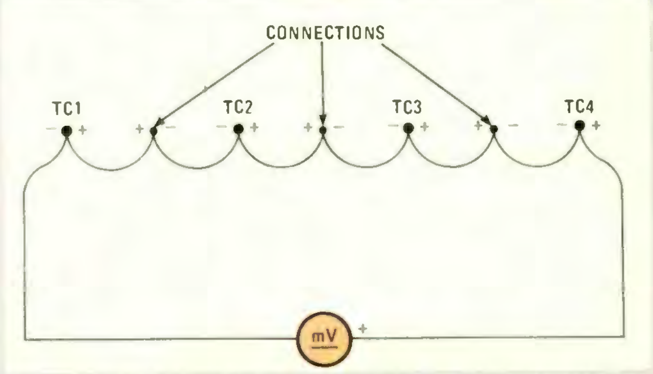

Fig. 1—Connections between thermocouples are themselves thermocouples of opposing polarity and equal magnitude.

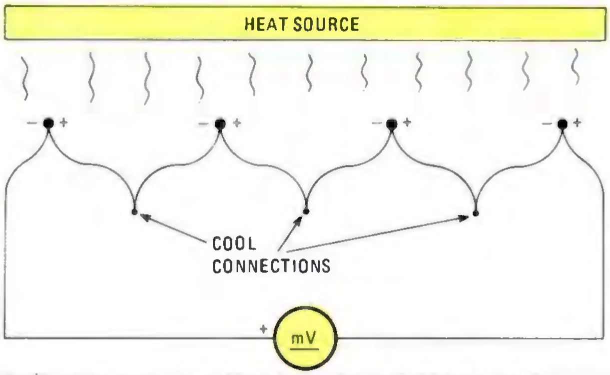

Fig. 2—Since connections between thermocouples are thermocouples of opposing polarity, to connect thermocouples in series requires that we keep the connections between the thermocouples cool.

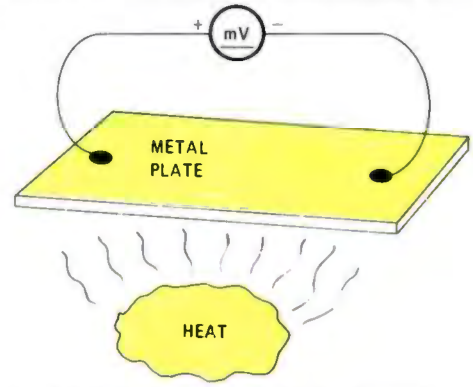

Fig. 4—Average temperature measurements can be obtained by connecting to more than one point on the surface of a metal plate. Here the two connections act as a single junction.

and so respond to changes in temperature faster. The size of wire that is chosen will entirely depend on the intended use. In a series configuration, the distance between joints is limited only by the ability to keep every-other joint away from the direct heat.

Long runs between the output device (a readout or op-amp stage) and the junction are limited by the IR drop of the wire, but since the voltage and current are quite low, wire resistance in fairly long runs is not usually a problem. The voltage drop in a long wire will reduce the rated output of the junction, but that can be remedied by recalibration. The connecting wire between the junction and the output device can be common hook-up wire as long as you remember that the joints you have made for the extension are also junctions and will also change your calibration. If an equal amount of junctions are made in each leg, they will cancel each other's voltage output.

Variations in Connection

Thermocouples are often used for sensing temperature in harsh environments that preclude ordinary methods of measurement. Selected materials can be used to make junctions that can measure temperatures inside furnaces or the temperature at different points in a flame.

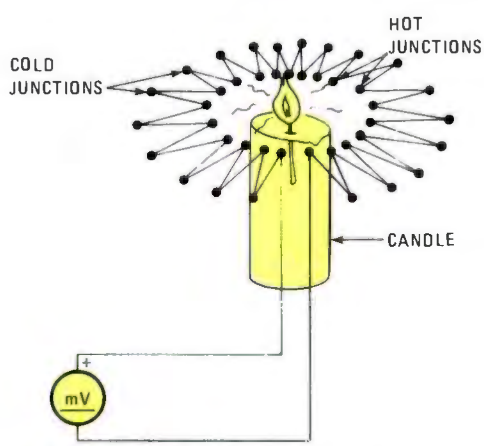

Fig. 3—Here's a circuit showing how a lot of thermocouples can be connected together to produce usable voltage with every other junction kept cool.

An interesting variation of the standard junction is to make two junctions by spot welding the wires at different points on a metal panel (see Fig. 4). Each of the junctions will put out a portion of the total output. The outputs of the two junctions will output the same voltage as one junction of the selected thermocouple material. The output produced from that configuration will be determined by the average temperature between the two junctions.

The cost of monitoring a number of separate junctions can also be kept to a minimum by using a common-leg switching circuit as shown in Fig. 5. To avoid confusion remember that the meter is common to all junctions. To get meter readings that make sense, the junctions should be made from the same materials. The same rules apply if accuracy is required: calibrate the final circuit to compensate for all the extra junctions.

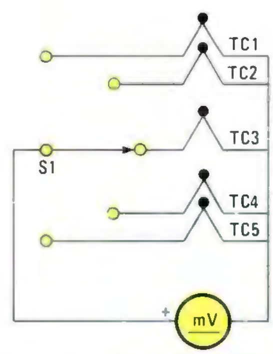

Fig. 5—Reduced lead length can be achieved by switching between various thermocouples at the reading station.

Air Flow Measurements

Thermocouples are often used in applications other than temperature sensing. One such application is air-flow sensing. Since the junction produces no heat when used as a temperature sensor, it would have the same temperature as that of the air flowing around it, and so flow conditions could not be detected. That is remedied by pre-heating the junction.

The junction can be heated by twisting four wires together instead of two. Two of the wires are used for the thermocouple while the other two wires are connected to a variable

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voltage source and used for heating the junction, (see Fig. 6). The two circuits are completely independent and will not interfere with each other. The heating voltage is increased until the desired output from the thermocouple is obtained. The pre-heated junction is placed directly in the air flow (as shown in Fig. 7). As more air flows by the junction and cools it, less output voltage is read on the meter.

A small-gauge wire junction will respond quite rapidly to minute changes of air flowing around it.

Remember that different gases have different cooling abilities, so if you are measuring the flow rate of a gas other than air, and accuracy is required, the thermocouple unit will have to be calibrated for the gas used. The output of the junction can be directly calibrated in air-flow units.

Junctions can be pre-heated without making a special junction by using an oscillator and a power amplifier generating a radio frequency as shown in Figs. 7 and 8. The RF is induced across the joint on the same two lines as the DC output. The radio frequency is high enough so that the meter will not respond to it, but it will still provide heating to the junction. That method is used in many commercial units.

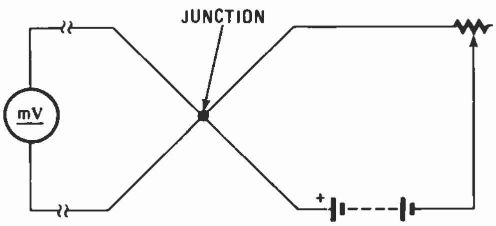

Fig. 6—Thermocouples can be better used to detect certain changing conditions if they are heated while in operation. Ganging two of them together allows one of them to act as a sensor and the other as the needed heating element.

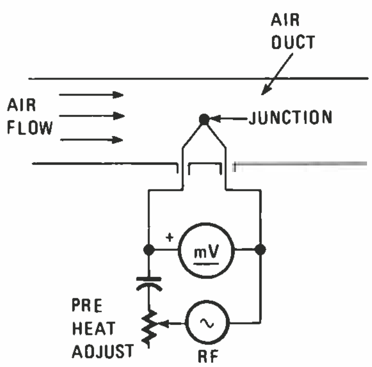

Fig. 7—A thermocouple can be used to detect gas flow if it is heated. Sending it RF signals that the meter cannot respond to is one way to heat a thermocouple.

Vacuum and Cold Measurements

Another use of the pre-heated thermocouple sensor is to measure vacuum, or rather the absence of air. Placing the thermocouple junction in a vacuum inhibits its ability to cool itself with surrounding air. That makes the output of the junction produce a voltage that is proportional to the available air inside the chamber. The output voltage will increase as the air left in the chamber is exhausted. By calibrating the pressure against the output produced by the thermocouple, pressure in the hundredths of an atmosphere can be measured. See Fig. 8.

Another interesting fact about thermocouples is that they also work in reverse. That is to say, that they are able to measure cold as well as heat. When the thermocouple junction is cooled beyond the point where it produces a positive voltage, the thermocouple junction crosses zero volts and starts producing a reverse or negative voltage that can be calibrated to hundreds of degrees below zero.

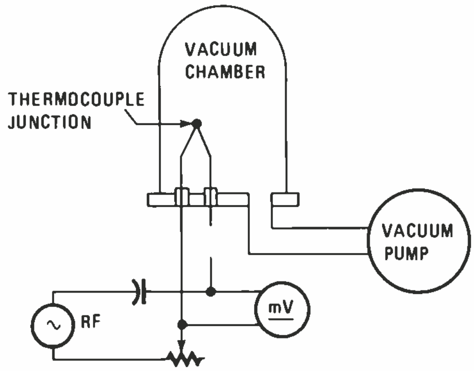

Fig. 8—Thermocouples heated with RF signals can be used to detect the presence/absence of air which would cool it.

That makes them useful in cryogenic measurements. When used to measure the temperature of cryogenic liquids like nitrogen or helium, pre-heating the junction is necessary to keep it warm in its super-cold environment. When the liquid is surrounding the junction, it is kept cold and produces a

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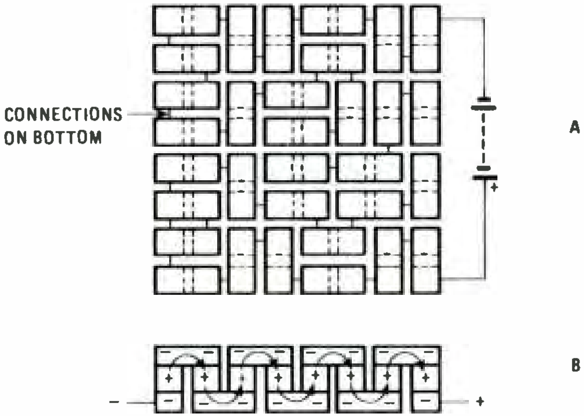

Fig. 9—Thermocouples can be joined in mass to either provide or extract heat. This is an example of one such unit with the polarities marked for clarity. The top view of the unit is shown in A; a side view is shown in B.

reverse voltage. As the junction is brought out of the liquid, the current quickly heats the junction and the reverse voltage drops to the crossover point and moves in the positive direction. By controlling the small heating current, any crossover temperatures may be selected.

Temperature Control

The other aspect of the thermocouple is its ability to directly convert electricity into heat or cold. As was mentioned earlier, inducing current into the thermocouple junction will cause the junction to get hot or cold depending on the direction of the current flowing through the junction.

That means that thermocouples have applications in heating and cooling. Let's look a little more closely at that. Thermoelectric cooling panels are composed of small cubes of the two thermocouple materials. The junctions are made by bridging the cubes with small rectangular conducting plates. Since the actual materials are not in direct contact with each other, that type of junction can be compared to the junction shown in Fig. 4. As can be seen in Fig. 9B, on the bottom side the current flow is from the plus material to the minus material, while on top side it is minus to plus. That means that with that configuration, all the heat-producing junctions are on one side of the plate, while the cold producing junctions are on the other. The cubes are arranged and bridged on the top and bottom so that they form a large number of junctions connected in series (see Figs. 9A and 9B). The panels are made in a variety of sizes by changing the number of junctions. The junctions are large and a lot of current is required to operate the units. As current flows in the device, one side of the device gets hot while the other side of the device gets cold.

Try it Yourself

When making a thermocouple junction, make certain that the junction is twisted together very tightly. Variations in output voltages from two identical thermocouples can result from bad junctions caused by oxide formations between the materials. The best method for making a junction is to twist the two wires together and fuse the wire tips with a flame. Thermocouple wires from any common metals can be fused over an open flame from the kitchen stove. Once the junction is made, you have a small energy producer that will work virtually forever.

Thermocouples are easy to make and inexpensive to experiment with. All that is needed to get started is a length of thermocouple wire and a voltmeter capable of reading millivolts. Get some wire and build yourself a micro-power supply. Who knows? You could be the one to solve the energy crisis by discovering a new thermoelectric material or technique. ■