

Technical Note No. 102-B

THERMOCOUPLES AND THERMOCOUPLE SLIP RING CIRCUITS

A simple thermocouple circuit is shown in Figure 1.

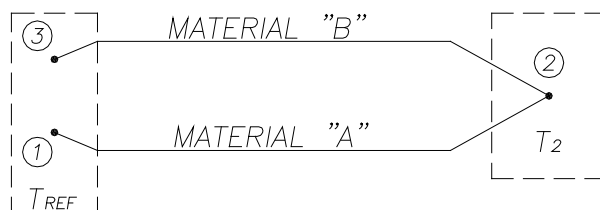


Figure 1. Simple thermocouple circuit.

Let points **1** and **3** be thermally integrated i.e. the temperature at point **1** always equals the temperature at point **3** and let this temperature equal T_{ref} . If the temperature at point **2** does not equal the reference temperature ($T_2 \neq T_{ref}$), there is an end-to-end voltage or electromotive force (EMF) generated along the length of material "A" wire and another end-to-end EMF generated along the length of material "B" wire. The magnitude of the end-to-end EMF generated is a function of the temperature difference between the ends of the wire, or stated another way, is a function of the integrated temperature gradient along the entire length of wire. EMFs are not generated at wire junctions; they are generated along the lengths of the wires.

By algebraically summing voltages, the EMF between **1** and **3** is equal to the EMF from **1** to **2** plus the EMF from **2** to **3**. Therefore the magnitude of the EMF developed between points **1** and **3** is a function of the temperature at point **2**. Hence, the connection or junction of the two thermocouple wires at point **2** defines a location of where temperature can be sensed as well as serving to complete the electrical circuit.

Figure 2 shows the EMF versus temperature behavior of several common thermocouple materials with reference to platinum. Note that the two materials used to make a thermocouple type (e.g. K-type, J-type, etc.) are those that exhibit a "large" mutual divergence.

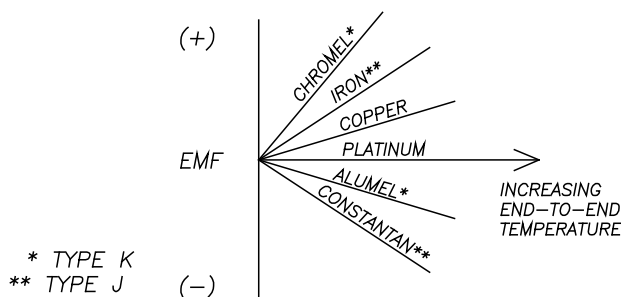


Figure 2. EMF vs. temperature for various materials.

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The EMF versus temperature plot of the circuit depicted in Figure 1 for a K-type thermocouple is shown in Figure 3.

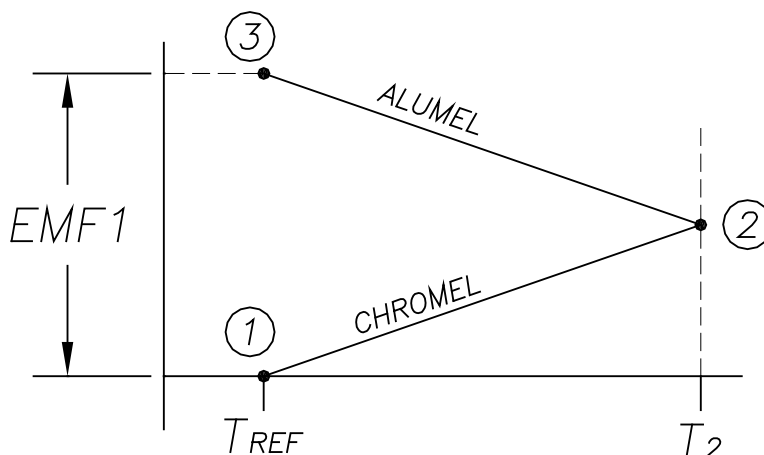


Figure 3. EMF vs. temperature for K-type T/C circuit of Figure 1.

As we have seen, the EMFs generated are dependent upon the *differences* of temperature, so we need to know the temperature of points 1 and 3 in order to measure the temperature at point 2. Furthermore, we need a means of connecting points 1 and 3 to a readout device (e.g. a voltmeter) and the leadwires to this device will introduce another material (e.g. copper) that is subject to thermal EMF generation.

Figure 4 shows the circuit of Figure 1 using K-type thermocouple materials but now includes a readout device with copper leadwires and a reference temperature zone held at T_{ref} . The EMF versus temperature plot for this arrangement is shown in figure 5.

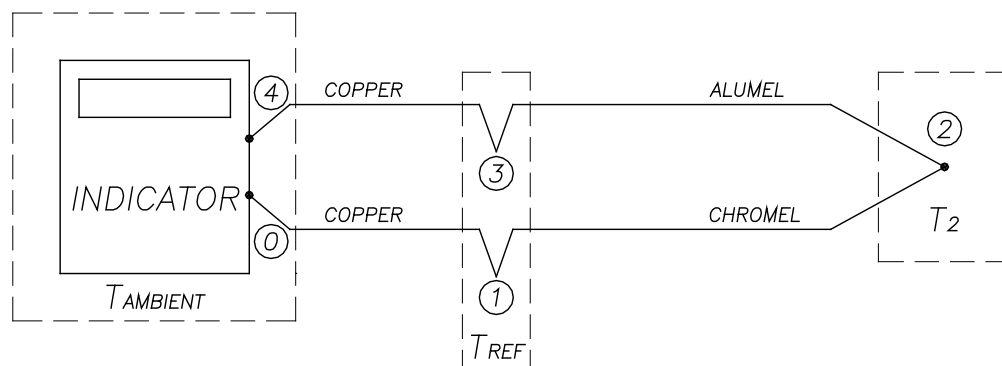


Figure 4. Simple K-type thermocouple circuit with indicator and temperature reference.

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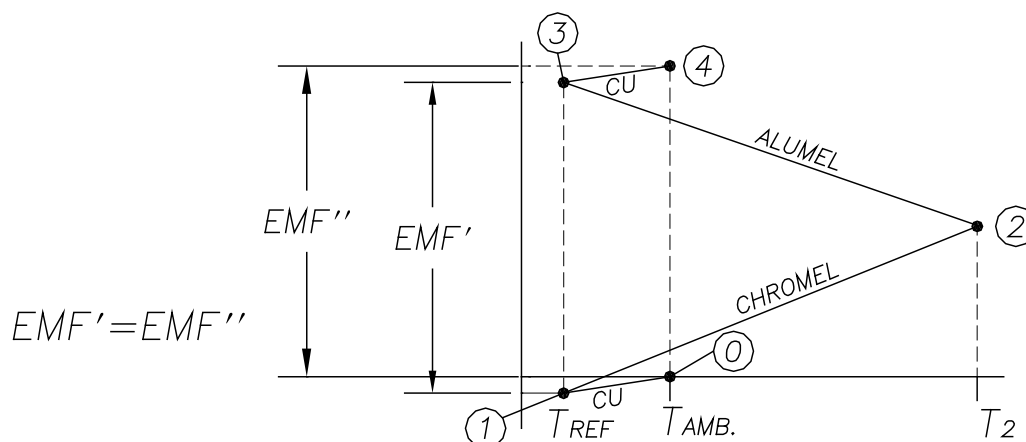


Figure 5. EMF vs temperature plot of circuit shown in figure 4.

Examination of figure 5 reveals that the introduction of the copper leadwires has no effect upon the output EMF as long as points **0** and **4** are at the same temperature.

We still however need a means of holding both points **1** and **3** at some *known* temperature, T_{ref} . Historically, this has been achieved through the use of an ice water bath. (Consequently, published thermocouple tables provide output voltage with respect to a reference junction temperature of 0° C.)

Since ice baths are not usually practical to implement, other methods to obtain or emulate a reference junction have been developed. One method utilizes an electrical resistance bridge circuit that contains a temperature sensitive resistor element. This bridge circuit is placed in series with the thermocouple circuit and is thermally integrated with the reference junction (points **1** and **3**). With the reference junction at 0° C, the bridge does not introduce any voltage. However, when the reference junction deviates from 0° C (say for example to the ambient temperature of the indicator), the bridge will automatically introduce a voltage equal and opposite to the thermocouple-EMF change that also results from this reference junction temperature deviation. Thus an equivalent 0° C reference junction temperature is effectively maintained.

CONSEQUENCE OF INTRODUCING A SLIP RING (OR CONNECTOR) BETWEEN THE INDICATOR AND THE MEASUREMENT POINT.

Figure 6 shows the circuit of Figure 4 with a slip ring placed between the indicator and measurement point **2**, where **S1** and **S2** are slip ring stator terminals and **R1** and **R2** are the corresponding slip ring rotor terminals respectively. Note that the reference junction discussed above is physically located within the "INDICATOR".

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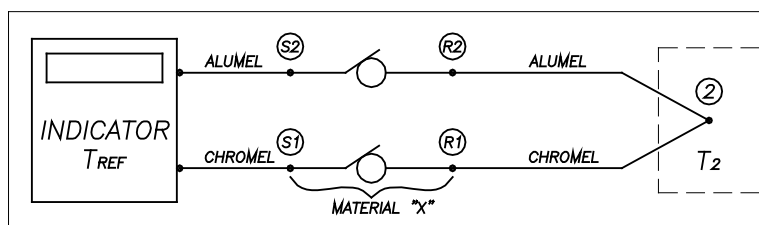


Figure 6. Thermocouple circuit with slip ring.

If there is no temperature difference between the stator and the rotor terminals, the temperature at **S1** equals the temperature at **R1** and the temperature at **S2** equals the temperature at **R2**. The EMF vs. temperature graph for this case is shown in Figure 7.

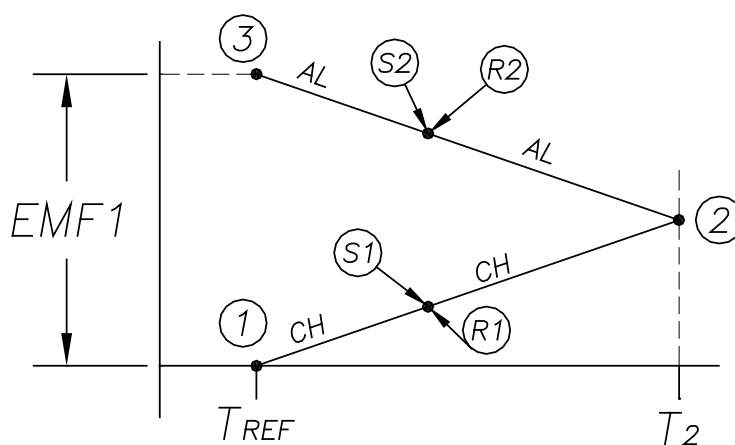


Figure 7. EMF vs. temperature for T/C with slip ring – NO temperature difference across slip ring terminals.

Since there is no temperature difference, $\Delta T=0$ across the slip ring so the stator and rotor connection points overlay each other as shown on the graph. In this case there will be no error in measurement. However, if a temperature difference does exist across the slip ring, the EMF versus temperature graph will look like that shown in Figure 8 where “X” represents the conductive path through the slip ring.

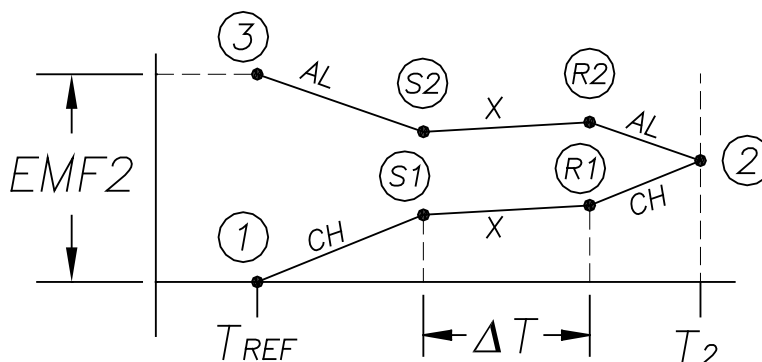


Figure 8. EMF vs. temperature for T/C with slip ring – with temperature difference ΔT across slip ring.

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In this case $EMF2 < EMF1$ signifying that the actual temperature of the test part at point **2** is higher than measured. Examining Figures 7 and 8 we see that the difference between $EMF2$ and $EMF1$ corresponds to ΔT . Therefore, the actual temperature at point **2** is higher than measured by an amount equal to ΔT .

In the previous example the temperature of the rotor was taken to be greater than the stator. If the stator temperature is greater than the rotor temperature the EMF vs. temperature diagram will look as shown in Figure 9.

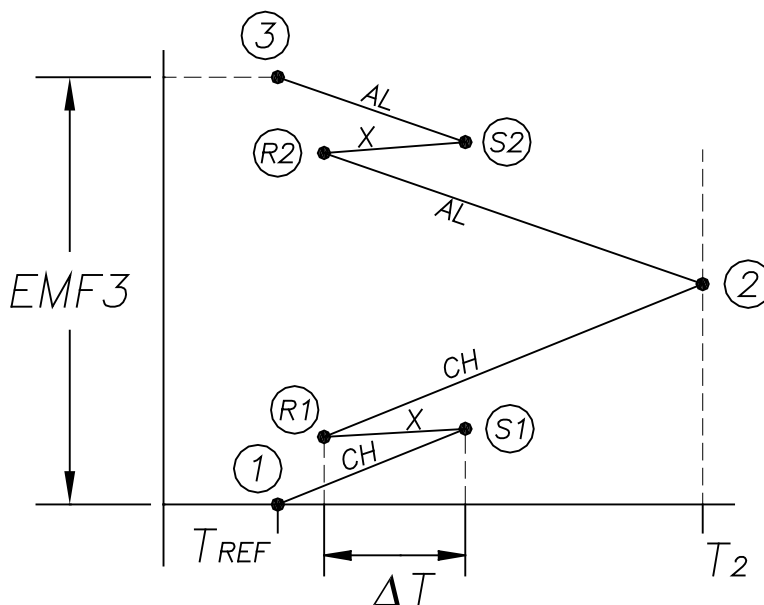


Figure 9. EMF vs. temperature for T/C with slip ring – with temperature difference ΔT across slip ring, stator terminal temperature greater than rotor terminal temperature.

Note that $EMF3 > EMF1$ signifying that the actual temperature of the test part at point **2** is lower than measured. As before, the magnitude of the error is equal to ΔT .

This discussion has been somewhat simplified in that actual slip ring assemblies can contain several connections of various materials between the stator and rotor terminals proper (i.e. conductive path “X”). All of these connected materials are subject to the kind of temperature gradient errors discussed and combine to produce a net error.

Temperature gradient errors associated with slip rings can be eliminated by placing a thermocouple amplifier (with built-in “cold junction” reference) on the spinning side of the slip ring as shown in Figure 10. Compare this figure to Figure 6. In this arrangement the slip ring is no longer in series with the thermocouple wire and therefore temperature differences across the slip ring will not manifest themselves as measurement error.

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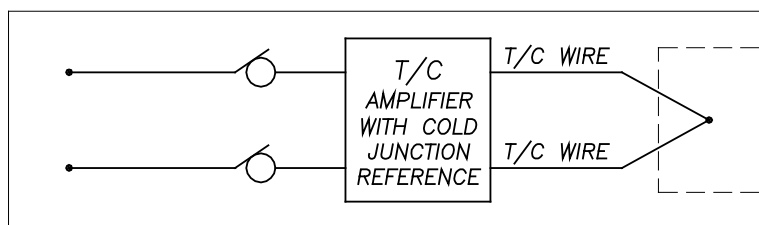


Figure 10. Slip ring with thermocouple spinning amplifier.

Michigan Scientific makes Spinning Thermocouple Amplifiers for end of shaft and tubular type slip rings. These amplifiers contain a cold junction reference and provide gain to improve the signal to noise ratio.

The temperature gradient and graphical analysis approach used to describe thermocouple behavior in this tech note is patterned after that presented by Dr. Robert J. Moffat in an article reprinted in *Applied Measurement Engineering* by Charles P. Wright, Prentice Hall, 1995. This article is suggested reading for further information about thermocouple theory and practice.