Basics of the Thermoelectric Effect with Magnetic Readout

by Johann H. Hinken and Yury Tavrin

Excerpt from: J. H. Hinken and Y. Tavrin, THERMOELECTRIC SQUID METHOD FOR THE DETECTION OF SEGREGATIONS, to be published in Review of Progress in Quantitive Non-destructive Evaluation
edited by D. O. Thompson and D. E. Chimenti, Vol. 19 (Plenum, New York)

A new NDT method, which we call the Thermoelectric SQUID Method, is being developed. It makes use of the thermoelectric effect, especially the Seebeck effect, with magnetic, non-contacting readout. Here the basic physics are sketched.

The Seebeck effect predominantly is known from thermocouples to measure temperatures and temperature differences.

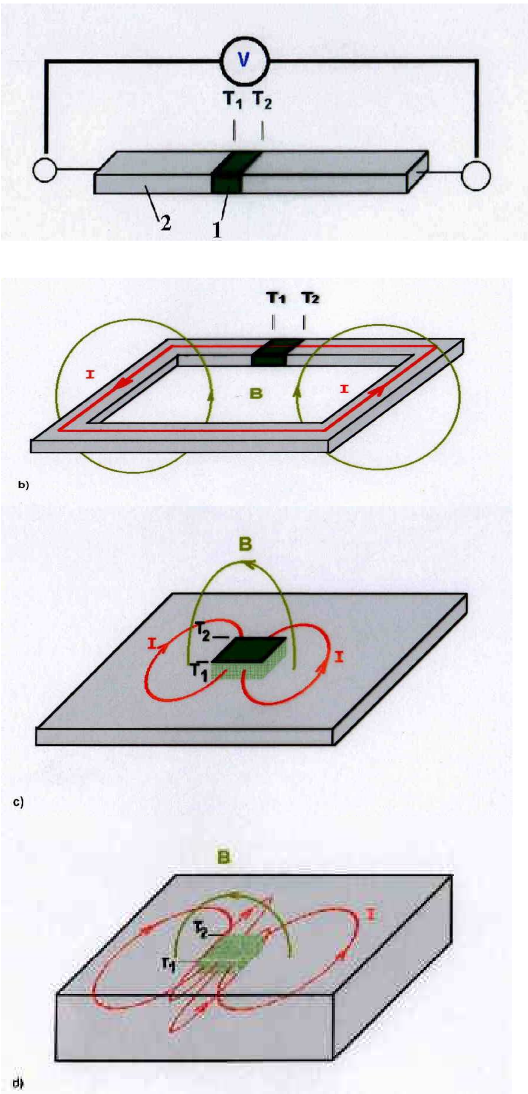

Figure 1: Different geometries containing metal 1 and metal 2 with temperatures T_1 and T_2 at their interfaces. According to the Seebeck effect a voltage V, currents I and magnetic fields, here depicted as magnetic flux density B, are generated.

a) One dimensional straight wire configuration
b) One dimensional closed loop configuration

c) Two dimensional sheet configuration
d) Three dimensional configuration

Figure 1a) shows the principle geometry: A wire consists of sections of two different materials 1 and 2. The interfaces between them are on different temperatures T_1 and T_2.

Then a thermoelectric voltage is generated and can be measured. If this wire is formed into a closed loop, see Figure 1b), a current I is generated which in turn produces a magnetic field with flux density B. These magnetic field lines to a large extent are outside the wire.
Figure 1c) shows a metal sheet with an inclusion as a two dimensional geometry in which the Seebeck effect can occur. The inclusion 1 extends through the full height of the sheet 2. If a temperature gradient is realized such that the temperatures T_1 and T_2 occur as shown in Figure 1c), current distribution I and magnetic field distribution B are obvious. Therefore when realizing a temperature gradient in such a sample and measuring a magnetic field signal as a consequence, then a material inhomogeneity must be the reason.
When coming to the three dimensional case according to Figure 1d) where the inclusion does not extend to the surface but is buried completely within the host material, then to a small extent additional currents will also flow between the inclusion and the surface of the host material. Although this will lead to a small reduction of magnetic field strength outside the sample the principle of the test procedure can be made equal to that described for the two dimensional case under Figure 1c).

In all the above cases it is required that the magnetic field strengths that occur are large enough that they are accessible for measurements. In order to have an idea on the magnitude of voltage, current, and magnetic field strength in these situations these values are given for a simple example for the material combination Copper (Cu) and Konstantan (54%Cu, 45%Ni, 11% Mn). The thermoelectric voltage U_o is approximately 40 µV per ^{o}C. [1, p.64]

For the two dimensional case according to Figure 1b) the equivalent circuit consists of the open voltage source U_o, the resistance R_1 for the section of metal 1 and the resistance R_2 for the section of metal 2. Assuming wire cross sections of 1mm ^{2} and section lengths L_1 = 10 mm and L_2 = 20 mm as well as conductivities of s_{Cu} = 56 MS/m and s_{Konst} = 2 MS/m from [1, p.19] we obtain resistances R_1 = 5 mW and R_2 0.4 mW. The current I results as 7 mA/ ^{o}C.

Of special interest is the magnetic field generated by this current loop. From [2] follows that the axial magnetic field strength on the axis of the current loop is about 20 pT in the plane of the loop and about 10 pT at a distance of 10 mm above this plane.
This example can give only a very rough idea on the order of magnitudes which can be expected in practical NDT situations. Because then the material differences may be not such pronounced as between Copper and Konstantan, the geometry may be quite different, and the temperature differences which can be realized between the metal interfaces may be different from one degree. However, this numerical example shows that only the most sensitive magnetometers have a significant chance to detect the expected magnetic field values at a proper signal to noise ratio.

REFERENCES

1. F. Moeller, *Grundlagen der Elektrotechnik* (B. G. Teubner, Stuttgart, 1997)
2. G. Lautz, *Elektromagnetische Felder* (B. G. Teubner, Stuttgart, 1969), p. 119