MODERN PYROMETRY

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FOREWORD

This book was developed from a lecture prepared for the Cleveland Chapter of the American Society for Metals, that was given in the 1947 Spring Educational Series.

The lecture was designed to illustrate the relatively common as well as the new techniques in pyrometric practice and equipment in order to help those men who returned to industry recently as well as to acquaint newcomers in metallurgy with the principles of and new developments in pyrometry. No criticism of any particular pyrometric system was intended and, although all types and makes are not discussed, the selected group was deemed sufficient to give a fairly accurate picture of the available methods of temperature measurement and control.

I wish to acknowledge the assistance received, particularly from Gordon Spare who did the photographic work. My thanks are also due to the various authorities who have granted permission to publish this book.

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CHAPTER 1

TYPES AND USES OF THERMOCOUPLES, LEAD WIRE, AND PROTECTION TUBES

The improvements in the heat treatment of steel within the past few years require close temperature control on a large production basis. This is especially true of the isothermal spheroidization of high-carbon steel, which converts the iron carbide into spheroids or balls within the soft ferrite matrix. Such a structure yields a soft steel. Uniform temperatures must be maintained throughout the entire charge in this type of box-annealing cycle to produce a strip that will satisfactorily withstand a severe flat bend. If any portion of the charge overshoots the required temperature by 20 or 30°F., the resulting steel microstructure will contain some small brittle spots which produce breakage during a bending formation. Proper temperature control is also a prerequisite in the modern continuous annealing and patenting lines for the development of special properties in steels. The patenting treatment is used for wire to produce a microstructure of very fine pearlite. This structure has maximum ductility for wire drawing. For uniform nondirectional properties in deep drawing steels, for maximum decarburization and strain relief in electrical steels, for uniform patented structures in spring wire, for best physical properties in quenched and tempered products, close control of both temperature and time is required.

Concurrent with the improvements in metallurgical processes has been the development of more accurate means of indicating and controlling temperatures. Various types of instruments now being used will be described with regard to their mode of operation to illustrate to those engaged in pyrometry the new methods and techniques of securing accurate control.

Thermoelectric Effects

Before describing some of the recent developments in the technique of accurately measuring and controlling temperatures in the metallurgical field, it might be justified to briefly recount some of the fundamental concepts upon which pyrometry is based.

The basic discovery of pyrometry was made by Seebeck in 1821. He noted that if the ends of a copper and an iron wire were fused together and one of the junctions was heated, a current flowed from the copper to the iron wire at the hot end and from the iron to copper at the cold end. Peltier later observed a thermoelectric effect which was the reverse of the Seebeck discovery. This effect is observed when an electromotive force is applied to two dissimilar metals connected together. When copper and iron wires are used, a current flow from copper to iron produces a cooling of that junction while at the iron-copper junction, heating occurs. This heating effect at the iron-copper junction is distinct from that produced by the resistance of the wire. The extent of heating and cooling effect is dependent on the metals used and on the amount of current. A supplement to the Seebeck effect is that discovered by Thompson. This effect is illustrated by heating the end of a uniform copper wire. An electromotive force is developed between the hot and cold ends of the wire the magnitude of which depends on the metal and on the differences in temperature at the wire ends.

Considering these thermoelectric effects, a thermocouple may be defined as a pair of dissimilar conductors joined so as to produce an electromotive force when the junctions are at different temperatures. If one junction is maintained at room temperature or at the temperature of melting ice, the temperature of the other junction can be determined by measuring the electromotive force developed in the circuit. The electromotive force values developed by thermocouples are small, usually a few thousandths of a volt.

A simple circuit illustrating the thermoelectric principle is shown in Figure 1. Two dissimilar materials A and B are connected together at hot junction T_1 and cold (reference) junction T_2. A millivoltmeter placed in the circuit measures the electromotive force produced when there is a temperature difference between T_1 and T_2. The current flow must be very small in order to secure maximum voltage in the pyrometer circuit. When the null-balance potentiometer method is used, the current flow is zero at the point of balance. Therefore, the voltage measured is a maximum. This generated millivoltage is dependent on the kind of material used in the circuit and the temperature differential. Neither the diameter of the thermocouple wires nor variations in the temperature gradient along the wires have any effect on the output of a uniform couple. For example, a Chromel-Alumel couple will generate a definite amount of electromotive force for a given temperature differential whether the

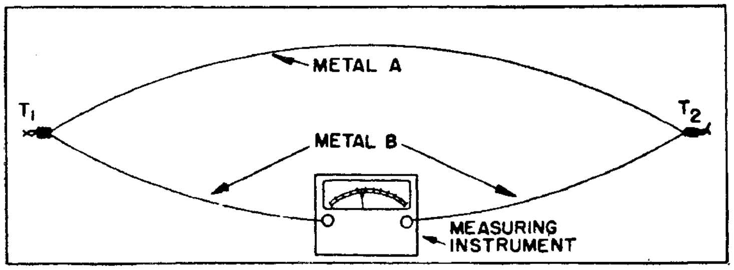

FIGURE 1. *The Fundamental Thermoelectric Pyrometer Circuit*

wire size is 12 or 20 gage. The heavier wire withstands rough handling and severe oxidation to a greater degree and is used on equipment not requiring rapid temperature response. However, if the wires are chemically or mechanically (degree of cold work) heterogenous over a given thermal gradient, the output of the couple will be distorted because of the establishment of secondary hot and cold junctions. The normal arrangement for a thermocouple circuit is to have the cold junction of the thermocouple connected to the compensated lead wires which go to the recording instrument. The cold-junction compensation is made at the instrument.

Requirements and Types of Thermocouples

Although any two dissimilar conductors may be used for a thermocouple, there are certain requirements which must be met if the couple is to be used commercially. There are five factors which should be considered in the selection of thermocouple materials.

1. Capacity for resisting corrosion, oxidation, reduction and melting.

Heat will naturally accelerate any of these reactions. We know that the requirements of temperature measurement in an ingot-soaking pit are quite different from those of a tempering furnace or of a cleaning bath. If the couple does not have the ability to withstand the respective deteriorating effects, premature failure will occur at the bead or at a localized hot spot along the wire. This type of failure can be easily detected since the thermocouple wire is broken and the circuit will be open. However, in some cases, the couple may become contaminated with metal vapors or various furnace atmospheres and still continue to operate for a considerable time. This contamination will change the calibration of the thermocouple thus giving inaccurate temperature readings. Platinum couples are prone to such contamination. The use of various metallic and nonmetallic protection tubes has lightened the burden on the thermocouple wires in this respect.

2. Development of a comparatively large electromotive force.

It is quite a task to measure low voltages accurately, therefore, a thermocouple with a high millivolt output would be preferable. According to thermoelectric tables, a couple composed of germanium and silicon would give a relatively high output, but it would be disadvantageous when other factors, such as corrosion resistance, strength and cost, were considered. The best couple will have the highest electromotive force at the desired temperature and also sufficient corrosion and oxidation resistance for the particular application.

3. Such temperature-millivoltage relationship that the millivoltage increases fairly uniformly with increasing temperature.

The importance of this point can be seen readily. Some conductors develop a maximum electromotive force at a certain temperature, but as the temperature continues to rise, the output decreases. In this case, the couple would indicate two temperatures at which the same electromotive force is generated and, therefore, trouble would be encountered in controlling or recording. If the slope of the temperature-thermoelectric potential curve for a material changes rapidly it is difficult to secure uniform accuracy in controlling temperature. A large voltage change over a small temperature range would result in close temperature control.

4. Cost.

It is obvious that noble metal couples, in spite of their high resistance to corrosion and oxidation, are not suitable for relatively low temperature work, because of their high cost. But for high temperature work, the platinum couple is the only solution.

5. Reproducibility.

The thermoelectric properties of most materials are quite difficult to control. It requires a close control of composition and physical working to reproduce a given millivolt output. This is particularly true of iron wire. They must meet definite thermoelectric specifications, and small variations in the residual aluminum, copper, or carbon content are sufficient cause for rejection. The effect of a slight composition variation on the millivoltage output of iron wire is illustrated by the following two samples.

Carbon	*Manganese*	*Phosphorus*	*Sulfur*	*Silicon*	*Copper*	*Millivoltage*
0.03	0.17	0.008	0.021	0.009	Trace	+ 0.356
0.03	0.08	0.006	0.022	0.002	0.10	− 0.190

The millivoltage values show the plus and minus deviations from the standard iron wire at 1500°F. The difference in millivoltage characteristics of these samples was due to the variation in copper content. Thus without good control each couple would first have to be given a complete calibration, and the entire controlled process would be based on this particular couple. Since there would be a wide variation between couples, only the millivolt scale could be used. The temperature conversion would then be made from the calibration curve.

The four thermocouples listed in Table 1 have been recognized as standards for normal industrial uses.

High quality and uniformity of both thermocouple and lead wires are of prime importance for industrial application. At present, standard millivolt versus temperature curves are available for platinum-platinum rhodium and Chromel - Alumel thermocouples. The iron - constantan couples have not been standardized as yet because of the difficulty in getting pure, uniform iron and constantan. However, operating curves have been established by the manufacturers to which they adhere quite closely, the allowable error for iron-constantan being ± 0.5% from 1000 to 1600°F. The Chromel-Alumel guarantee is ± 0.75% from

TABLE I

Standard Types and Limitations of Thermocouples

Type	*Kind of Wire*	*Recommended Temperature Limits and Approximate Maximum Millivoltage*	*Atmospheric Conditions for Which the Thermocouple Is Best Suited*
Iron-Constantan	**Iron—Positive** **Constantan—Negative**	1600°F.—50 mv.	Reducing or Neutral
Chromel-Alumel	**Chromel—Positive** **Alumel—Negative**	2000°F. Continuous Duty—45 mv. 2300°F. Intermittent Duty—51 mv.	Oxidizng or Neutral
Platinum-Rhodium	Pure Platinum—Negative 10% **Rhodium** } —Positive 90% **Platinum** }	2700°F. Continuous Duty—15 mv. 2850°F. Intermittent Duty—16 mv.	Requires Protection from All Atmospheres; Do Not Use Bare
Platinum-Rhodium	**Pure Platinum—Negative** 13% **Rhodium** } —Positive 87% Platinum }	2700°F. Continuous Duty—17 mv. 2850°F. Intermittent Duty—18.4 mv.	Requires Protection from All Atmospheres

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