MEASUREMENTS OF THERMAL VOLTAGES AND RESISTANCES

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Annotation

Thermal voltages and resistances are important parameters in industrial and scientific measurement systems. Accurate measurement of these quantities is essential for monitoring temperature-dependent processes and ensuring system efficiency and safety. Thermal voltage is mainly generated in thermocouples due to the Seebeck effect, while thermal resistance is widely used in resistance temperature detectors (RTDs) and thermistors. These measurement methods provide reliable data for process control, automation, and energy management. This work focuses on the principles, methods, and practical applications of measuring thermal voltages and resistances in modern industrial systems.

Key words: Thermal Voltage, Seebeck effect, thermocouple, reference junction, platinum resistance, two-wire circuit, three-wire circuit.

Introduction

Nowadays, accurate temperature measurement and control play an important role in industrial processes and scientific research. The efficiency of technological systems, product quality, and operational safety largely depend on the correct determination of temperature parameters. Especially in industrial environments with high temperature, high pressure, and strong vibrations, reliable measurement systems are essential.

The measurement of thermal voltages and resistances is one of the fundamental methods of temperature monitoring. Thermal voltage is generated in thermocouples based on the Seebeck effect, where a temperature difference is converted into an electrical voltage. Resistance measurement, on the other hand, is based on the change in resistance of materials, particularly platinum, under the influence of temperature. This principle is widely applied in resistance temperature detectors (RTDs) and thermistors.

Today, thermocouples and resistance thermometers are among the most commonly used temperature sensors in industry. Their main advantages include high accuracy, stability, and long-term reliability. Therefore, understanding their working principles, circuit configurations, and factors affecting measurement accuracy is of great importance.

The main objective of this work is to analyze the methods of measuring thermal voltages and resistances, to study the operating principles of thermocouples and resistance thermometers, and to examine their practical applications in modern industrial systems.

The thermal voltage resulting from the Seebeck-Effect is utilized in a thermocouple as the measuring principle. Measuring the temperature from the thermal voltage is actually a difference measurement between the hot end of the thermo-couple and the reference junction temperature. For correct measurements, the electrical connection to the reference junction

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must always be made of the same material as the thermocouple leg or suitable compensation cables must be used.

Copper can be used for the remaining wiring. Because U_M = U1 - (U2+U3) an exact determination of the measurement voltage U1 can only be made if the reference junction voltage U_V = (U2+U3) is known. To measure absolute temperatures, the temperature at the reference junction T_R must always be known.

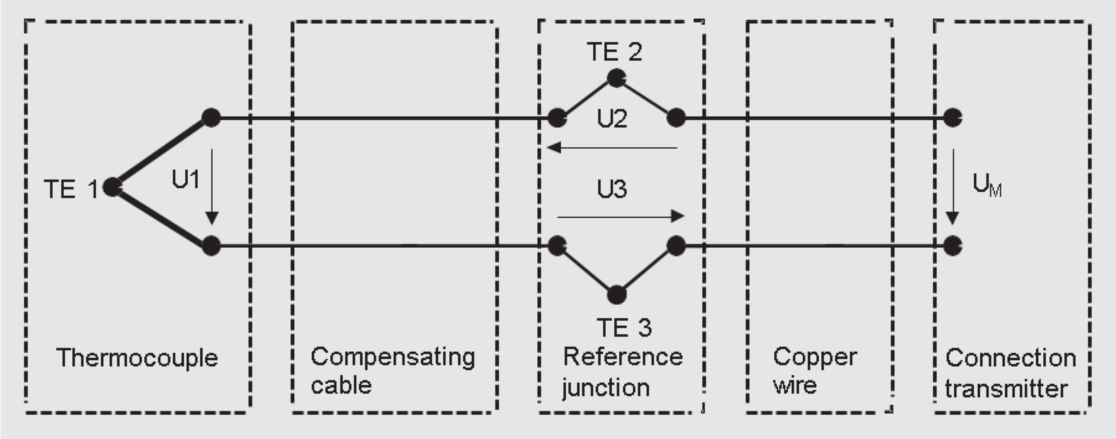

Figure 1. Thermal voltage measurement.

When using an external reference junction the connection from the thermocouple or from the compensation cable to the copper wires, is located outside of the temperature transmitter. The temperature of the reference junction T_R is controlled at a constant value e.g. by an integrated heater. This value is added to temperature value derived from the voltage U_M, to determine the temperature at the hot end of the thermocouple.

Modern temperature transmitters incorporate an internal reference junction, which greatly simplifies the measuring system for the user. The thermocouple leg or the com-pensation cables are wired directly to the transmitter. The reference junction is formed by the terminals of the transmitter. Its temperature T_R is measured by an integrated temperature sensor and utilized by the transmitter for the internal corrections. The transmitter, in this manner, can determine the temperature of the hot end of the thermocouple directly.

Resistance Measurements

The measurement principle utilized in a resistance thermometer is the temperature dependence of the resistance of Platinum. The resistance is measured by applying a constant current and measuring the voltage drop across the resistor. Ohm's Law defines the proportionality between the resistance and the voltage. Therefore the voltage is a direct measure for the resistance and thereby the tempera-ture. Three different circuit configurations are used.

In a two-wire circuit a current is applied to the temperature dependent resistor R_T from a constant current source. The voltage drop across R_T is measured by the temperature transmitter and converted. The resultant value, however, is incorrect because of the series resistances of the connection leads (R_{L1} + R_{L2}) and the contact resistances at the terminals (R_{K1} + R_{K2}).

The two-wire circuit, even for sensor head mounted transmitters is only of limited appli-cability. Connection lead lengths and terminal connections can be designed with low resistances, and utilizing statistical correction factors the measured values can be com-pensated

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in the transmitter. The temperature dependent portion of the resistance of the connection leads must always be taken into consideration. Especially for thin wires and long measuring sensors or connection leads, errors with a magnitude of a number of degrees can result.

Conclusion: The two-wire circuit is not suitable for exact temperature measurements.

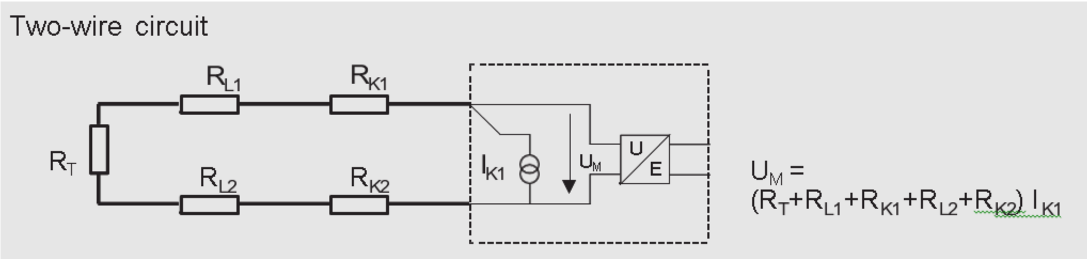

Figure 2. Circuit diagram of a two-wire circuit.

In a three-wire circuit two constant current sources are used, in order to compensate for the disadvantages described above for the two-wire circuits. Similar to the two-wire circuit the current source I_{K2} is used to measure the temperature dependent resistance R_T including the connection lead and terminal contact resistances. The additional current source I_{K1} together with a third connection lead is used to separately compensate the connection lead and terminal contact resistances. Assuming the exact same con-nection lead and terminal contact resistances for all three connection leads, the effect on the accuracy of the temperature measurements can be eliminated.

Practice has shown that this assumption is not always correct. It is not always possible to assure that the terminal contact resistances are always identical. Oxidation itself, during the course of operation, can cause the contact resistance of the individual terminals to vary by differing degrees. This can cause a non-negligible error, even in a three-wire circuit.

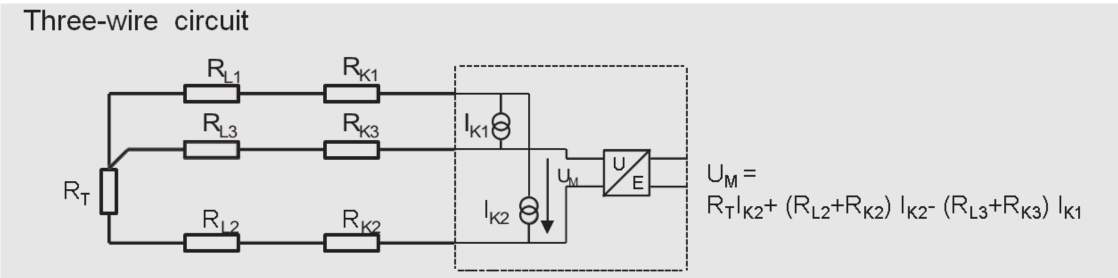

Figure 3. Circuit diagram of a three-wire circuit.

The four-wire circuit eliminates all the previously described disadvantages. In this configuration a constant current source is used to apply a current to the temperature dependent resistance R_T. The voltage drop across resistance R_T used for the temperature measurement is measured by two high resistance connection leads. In this way the voltage drop due to current flowing during the measurement is negligible and the connection lead and terminal contact resistances R_{L1}, R_{K1}, R_{L2}, R_{K2} do not impact the measurement result. The four-wire circuit is therefore always used when highly accurate temperature measurements are required.

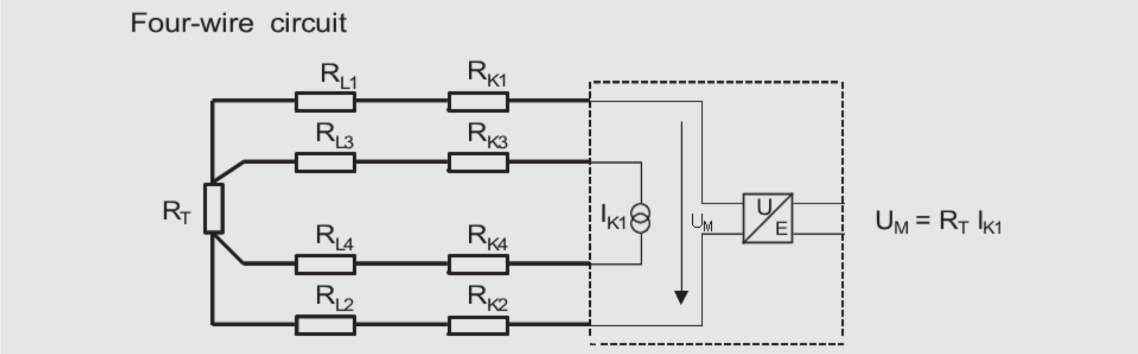

Figure 4. Circuit diagram of a four-wire circuit.

Modern transmitters support the measurement of thermal voltages and resistances using the above described circuit configurations in a single instrument. The user can select the optimal measurement configuration for his application. For thermal voltage measurements in industrial applications, the straight forward option using an internal reference junction is used almost exclusively. Use of an external reference junction makes sense when a highly precise reference junction temperature of less than 0.1 K is required. In view of the errors which could result from using the sum of a temperature measuring chain, this approach is reserved for laboratory applications. For resistance measurements, the four-wire circuit should basically be used because of its indisputable advantages. The three-wire circuit, with its disadvantages, should only come into play for resistance measurements when the use of electrical wiring configurations or system conditions are restrictive.

Conclusion

The measurement of thermal voltages and resistances plays a significant role in modern industrial and scientific applications. Accurate temperature measurement is essential for maintaining process efficiency, product quality, and operational safety. Among the various temperature measurement methods, thermocouples and resistance thermometers are the most widely used due to their reliability and effectiveness.

Thermocouples operate based on the Seebeck effect, where temperature differences generate thermal voltage. This method is especially suitable for high-temperature measurements and harsh industrial environments. On the other hand, resistance thermometers, particularly platinum-based RTDs, provide high accuracy and stability by measuring changes in electrical resistance with temperature.

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