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SELECTION OF THE MOST EFFICIENT TEMPERATURE MEASUREMENT METHOD BASED ON DESIRED RESPONSE TIME AND EXPERIMENTAL RESULTS

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Abstract: *This paper aims to present how temperature can be measured in the fastest and most accurate way using different types of sensors. It closely describes the use of simplistic temperature measurement via thermometer liquids and bimetallic thermometers, as well as the advanced measurements using thermocouples, NTC resistors, etc. Semiconductor materials which behave as ideal isolators at very low temperatures are depicted as the most slow rate response sensors, because of the time it takes for them to heat up. Whilst in most cases thermocouples type K have the quickest response time, and the most effective, due to the fact that their junction, when heated, generates thermoelectric voltage; this allows the measuring of the temperature. Also, the temperature measurement with thermistors resistance is very much explained using 2, 3, 4 -conductor connection. Furthermore, explained in detail is the main purpose which is to enable the documenting of characteristic curves via a 3 channel line recorder using measured values from the electrical temperature sensors and providing a response time through readings. In the finale stage of the paper experimental readings, calculations and measurement are shown and compered with one another according to the use of non protection tubes, tubes of high-grade steel and immersion tubes made of brass.*

Key words: *Temperature measurement, NTC thermistor, Pt100 sensor, Thermocouple, Response time.*

1. INTRODUCTION

One can state that the temperature is a measure of a material's internal molecular activity. Whilst the level of molecular activity increases, the temperature of the material upsurges. Hot and cold are qualitative descriptions of a change in molecular activity. The necessity of more accurate ways to describe temperature led to the development of temperature-measuring devices otherwise known as sensors. They use standard, universally recognized temperature scales, because not only do these scales rely on fixed points in nature (for example freezing point of water), they also provide a way to describe temperature objectively and quantitatively [1].

The four temperature scales which are used today are Fahrenheit, Celsius, Kelvin, and Rankine. Fahrenheit based his research on the Romer scale, which was formerly introduced in using simple association; normal temperature was known as 24°C, and zero degrees was the coldest day. Fahrenheit described the mercury-in-glass thermometer, introducing three temperature fixed points: a mixture of ice, ammonium chloride and water was the zero point, mixture od water and ice was 32°C and the human body temperature was taken as 96°C. Furthermore, the development on the thermodynamic temperature scale was made by astronomer and physicist Celsius; he assigned 100°C to the temperature of boiling water.

So in conclusion, the aim of any scale of temperature, especially the thermodynamic scale, is the representation of hotness and hotness relations between objects and events in the real physical world by real numbers [2].

Though there are many forms of temperature measurement, some are quite simple do not require units or special equipment. For example, when there is a use of a glass thermometer, the relative expansion of a liquid is measured in a vessel. Liquid expands at a regular, measureable rate when it is heated. This is the main reason for the use of liquid in a narrow glass tube. Practically any liquid can be used as the thermometer filling. A distinction is made here between wetting and non-wetting liquids. Mercury, a non-wetting liquid, is one of the most familiar materials used in liquid thermometers; other liquids, such as kerosene or ethanol, may also be used in these types of thermometers.

However, wetting liquids can cause additional errors when the temperature drops. Organic liquids are dyed in order to be better visible and more easily readable in the capillary. The main portion of the liquid is contained in a spherical or cylindrical vessel which acts as the sensor component of the thermometer. The change in volume of thermometer liquids is governed by the following law [3]:

$$V_t = V_0 \cdot (1 + \gamma \cdot \Delta t) \tag{1}$$

On the other hand, bimetallic thermometers make use of the differential expansion of two different materials in order to indicate changes in temperature. Two or more layers of different materials are rolled on top of each other, making it possible to achieve different shapes depending on the intended application. The length of individual metals changes in accordance with the following formula [3]:

$$L_t = L_0 \cdot (1 + \alpha \cdot \Delta t) \tag{2}$$

2. TEMPERATURE MEASUREMENT

A temperature sensor is the initial part of a temperature measurement, therefore an instrumentation chain is depicted in the following photo.

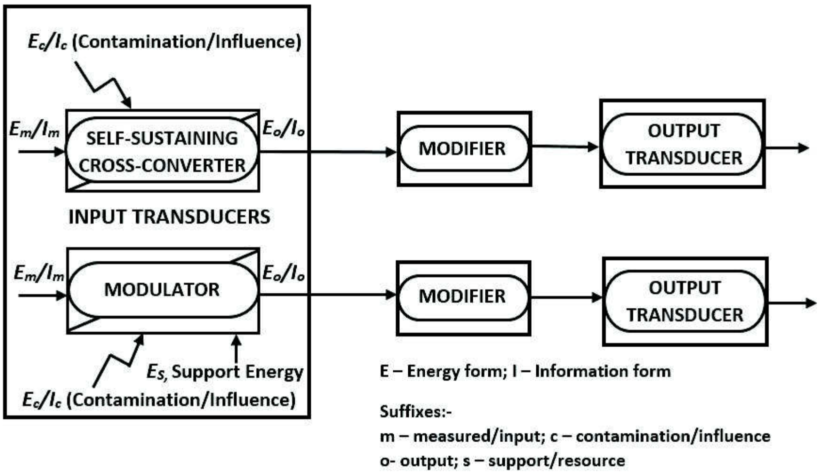


Figure 1: Block diagram of temperature measuring chains [2]

These sensors may be either self-supporting cross-convertors or modulators. Self-sustaining cross-converter types of temperature sensors extract energy from the system under measurement during the conversion of an information bearing signal in the thermal energy domain into an information bearing signal in another, different, energy form. Modulating temperature sensors require the supply by an external power source to support the acquisition and flow of the temperature information. The sensor, which is also called and initial transducer, is the thermometer. In temperature sensors, which are the front end elements in temperature instrumentation, the main output is an information output. This quantity, known as the measuring signal, is subjected to further transformation in a modifier, such as data converter, an amplifier, a filter or other kind of conditioner, into the desired output signal [2].

2.1. Temperature measurement with thermistors

These special resistance elements are made of semiconductor materials. There are two different types: NTC resistors (NTC thermistors) and PTC resistors (PTC thermistors). All semiconductor elements act as ideal isolators at very low temperatures. Their conductivity increase is described approximately by the following law [3]:

$$R_T = R_0 \cdot e^{b \cdot \left(\frac{1}{T} - \frac{1}{T_0}\right)} \tag{3}$$

Here, *R0* and *RT* are the sensor resistances at the absolute temperature *T* and a reference temperature T0 [K]. “ *b*” is a material constant, whose numerical value lies between 2000 and 6000 K [3].

The common forms of thermistor thermometer measuring circuit are deflection type bridge circuits [2].

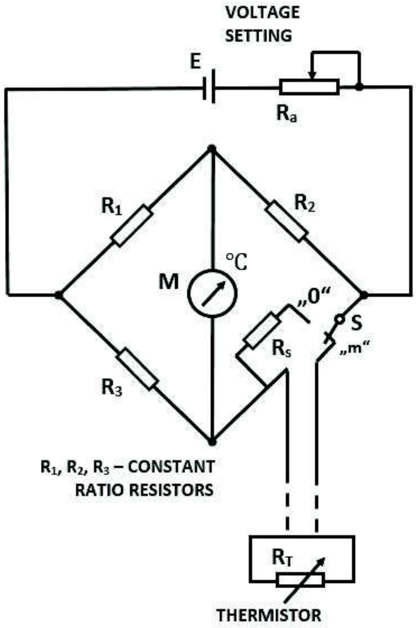


Figure 2: Deflection type bridge circuit for a thermistor thermometer

The bridge energy source may be a battery cell or a rectified supply voltage. To ensure that the supplying voltage remains constant, a standardizing resistor, *Rs*, is provided. In the position ‘O’ of the switch, S, where *Rs* temporarily replaces the thermistor, *Rt*, the value of *Ra* is adjusted in such a way that the readings of the meter, M, are brought to a marked scale position. This is not necessary when a stabilised voltage source is used. Measuring temperatures ranges of 30 to 50°C may easily be achieved. The whole measuring range is divided into several selectable sub-ranges. Most producers now supply thermistor thermometers in deflection type bridge circuits with an IC output amplifier guaranteeing a precision of 0.5 to 1.0°C [2].

2.2. Temperature measurement with thermocouples

The thermoelectric effect was first technically utilized by Seebeck and Peltier for the purpose of temperature measurement [3].

The combination of two dissimilar conductors, which may be metals, alloys or non-metals, connected at one end is known as a thermocouple. The point of connection is called the measuring junction and their free ends are referred to as the reference junction [2].

The emf versus temperature values of the more commonly used thermocouples are shown in the following photo.

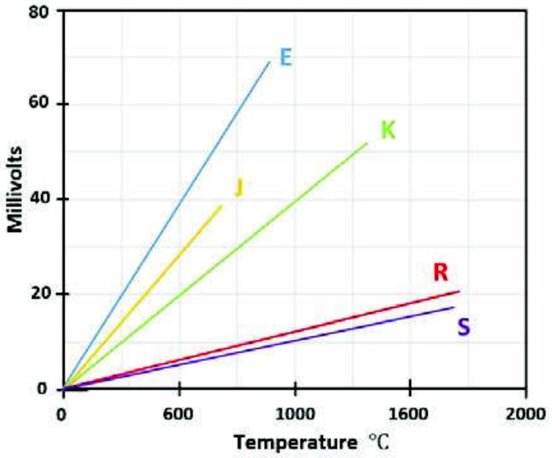


Figure 3: MilliVolts generated by various thermocouple types [1]

The sensitivity of a thermocouple is the algebraic sum of the thermoelectric voltages of both conductors. The greater the difference between the two thermoelectric voltages, the higher the sensitivity. If two different materials are welded to form a thermocouple and their junction is subsequently heated, an electromotive force - or thermoelectric voltage - is generated. The thermoelectric voltage permits temperature to be treated as a measurement variable.

Due to their high long-term stability, type K thermocouples are usually employed in practice. This type of thermocouple is 10 times more stable than the Fe-CuNi element and 100 times more stable than the Cu-CuNi element [3].

2.3. Temperature measurement with thermistors resistance thermometers

The dependence of the resistance of metallic conductors on temperature can be expressed very precisely using cubic equations. However, quadratic or even linear functions are considered sufficient for normal precision requirements [1]:

$$\Delta R = \alpha \cdot R \cdot \Delta t \quad \text{or} \quad R_t = R_0 \cdot (1 + \alpha \cdot t) \tag{4}$$

R, *R0* and *Rt* [Ω] are resistances in the original state, at 0°C and at *t*[°C]. [1/K] is the linear temperature coefficient of the resistor. As the linear equation does not apply precisely for most materials, i.e. is not constant, a mean relative change in resistance per degree between 0 and 100°C is defined [1]:

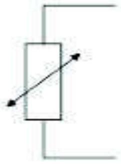
$$\alpha_{0,100} = \frac{1}{R_0} \cdot \frac{\Delta R}{\Delta t} = \frac{1}{R_0} \cdot \frac{R_{100} \cdot R_0}{100} \qquad [K^{-1}] \tag{5}$$

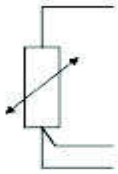
R100 and *R0* are measured at the boiling and freezing points of water. There are several possibilities of connecting resistance thermometers.

A two-conductor connection (displayed on Figure 4) does not take into account the influences of the line resistances generated by temperature fluctuations or high currents. Every change in line resistance misleadingly indicates a change in temperature on the sensor.

In the case of a three-conductor connection (displayed on Figure 5), one end of the shunt is connected via a measurement cable isolated from the supply. This makes it possible to reduce the influence of temperature on the lines. Here too, however, line balancing by means of adjustable resistors is necessary.

In the case of four-conductor connection (displayed on Figure 6) used for compensation measurements, two lines serve for current supply and two lines for voltage tapping via the shunt. In this case, the supply lines do not need to be balanced even if they are long [3].





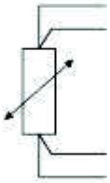


Figure 4 [3] **Figure 5** [3] **Figure 6** [3]

3. EXPERIMENTS AND RESPONSE TIME

The response of a heat sensor, the time taken by the sensor to indicate the actual temperature of a medium, depends essentially on its thermal resistance and heat storage capacity. The higher the thermal resistance, the more time the sensor takes to warm up.

Figure 7: WL920: advanced temperature measurement trainer consists of the ability to obtain a wide range of temperature measurements and record them simultaneously.

Short response times are achieved by using small sensors made of materials with a high heat conductivity. Response times are lengthened, in particular, by insulating air gaps between the measuring element and the protective tube, and between the sensor and any fitted immersion tube.

Protective tubes and immersion tubes of large diameters also result in long response times. Information on a response time can be obtained from the corresponding transient function, which indicates measurement values as a function of stepped changes in sensor temperature. It can be determined by placing a thermometer in a stream of water or air.

Two periods characterize the transient function: The half-life indicates the time taken for the measurement value to attain 50% of the final value; and the nine-tenths time indicates the time taken for the measurement value to attain 90% of the final value [3].

3.1. Response time without a protective tube

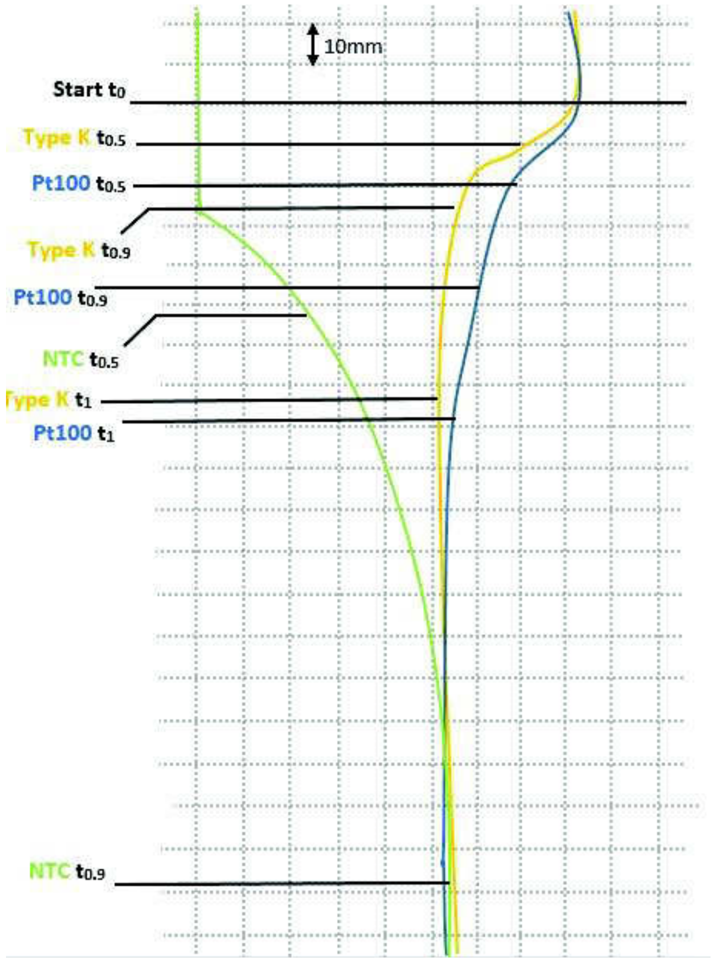


Figure 8: Transient response of an NTC, Pt 100 and type K thermocouple

Pt 100; Initial temperature t0=17.1 °C. Half-life t0.5=10.3 s (at 30.2 °C). Nine-tenths life t0.9=19.4 s (at 42.5 °C) Final temperature t1=46.1 °C (after 39 s)
Type K thermocouple; Initial temperature t0=16.0 °C Half-life t0.5=5.1 s (at 33.2 °C) Nine-tenths life t0.9=11.2 s (at 44.1 °C) Final temperature t1=42.6 °C (after 33.4 s)
Thermistor NTC; Initial temperature t0=outside the measuring range, Half-life t0.5=25.2 s (at 30.0 °C). Nine-tenths life t0.9=87.1 s (at 41.0 °C) Final temperature t1=45.5 °C (after 209 s)

3.2. Response time with a protective tube made of high-grade steel

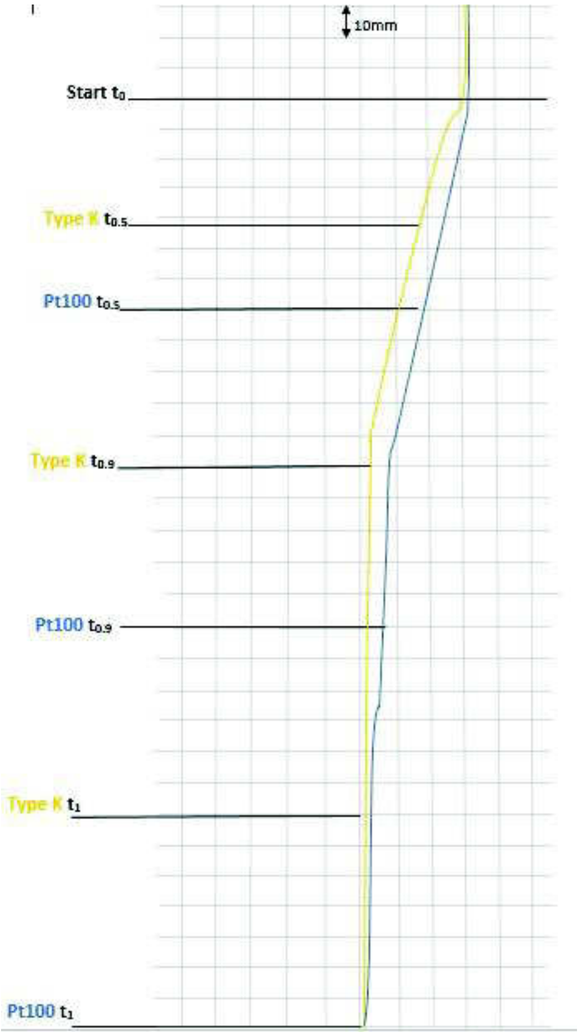


Figure 9: Transient response of a Pt 100 and type K thermocouple with protective tubes made of high-grade steel

Pt 100; Initial temperature t0=18.2 °C. Half-life t0.5=34.8 s (at 36.0 °C). Nine-tenths life t0.9=80.6 s (at 42.3 °C). Final temperature t1=47.8 °C (after 145 s)
Type K thermocouple; Initial temperature t0=18.0 °C. Half-life t0.5=26.5 s (at 34.2 °C). Nine-tenths life t0.9=59.5 s (at 46.4 °C). Final temperature t1=47.2 °C (after 118 s)

3.3. Response time of the Pt 100 with an immersion tube made of brass

Pt 100; Initial temperature t0=19.6 °C
Half-life t0.5=15.4 s (at 38.2 °C). Nine-tenths life t0.9=30.2 s (at 43.6°C). Final temperature t1=51.2 °C (after 62.0 s).
Type K thermocouple; Initial temperature t0=17.9 °C. Half-life t0.5=25.8 s (at 32.9 °C). Nine-tenths life t0.9=62.3 s (at 46.2 °C). Final temperature t1=56.2 °C (after 124 s)

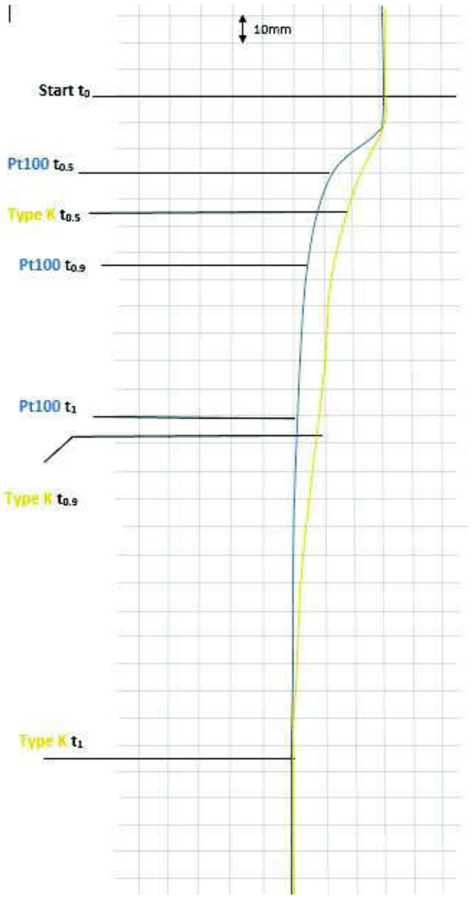


Figure 10: Transient response of a Pt 100 with a brass tube and a thermocouple with a highgrade steel immersion tube

4. CONCLUSION

Response time without a protective tube can be seen as the measurement point of the thermocouple (the point at which the two conductive materials are welded together) has a low weight and high degree of contact, it responds more quickly than the Pt 100 sensor. The NTC thermistor responds much more slowly because its design (attachment to a relatively large tube) results in a comparatively extensive heat dissipation and high heat storage capacity. In contrast, the sensor itself warms up more slowly. Simultaneously, the use of immersion tubes considerably lengthens the response time. The response of the Pt 100 is much faster than that of the thermocouple. This is because the brass immersion tube has a much better thermal conductivity than the one made of high-grade steel.

REFERENCES

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