GENERAL - PRINCIPLE OF MEASURING TEMPERATURE WITH RESISTANCE THERMOMETER

Resistance thermometer

Temperature measuring instruments with resistance thermometers are used for more accurate temperature measurements, but in narrower ranges and with slightly more expensive components.

Resistance thermometers work on the principle of dependence of electrical resistance of material on temperature. For their production, pure metals or semiconductors are used, whose temperature resistance functions have been determined experimentally with relatively high accuracy.

The following belong to the group of metal-based resistance thermometers:

Type of resistance thermometer	Accuracy class	Measuring range (C°)	Limits of permissible errors (C°)
Platinum resistance thermometer	A B	-200 to 650 -200 to 850	$\pm(0,15 + 2,0 \cdot 10^{-3} \lvert t \rvert)$ $\pm(0,30 + 5,0 \cdot 10^{-3} \lvert t \rvert)$
Copper resistance thermometer	B C	-50 to 180 -50 to 180	$\pm(0,25 + 3.5 \cdot 10^{-3} \lvert t \rvert)$ $\pm(0,50 + 6,0 \cdot 10^{-3} \lvert t \rvert)$
Nickel resistance thermometer	C C	0 to 180 -60 to 0	$\pm(0,20 + 8,0 \cdot 10^{-3} \lvert t \rvert)$ $\pm(0,20 + 16,5 \cdot 10^{-3} \lvert t \rvert)$

In terms of their distribution and accuracy, platinum resistance thermometers are the most widely used, since their sensor is made of high-purity platinum, so their resistance-temperature function is quite well defined, and thermometers are very stable even after long-term measurements at the highest temperatures of their measuring range. They are used in all types of measurements where the requirements regarding accuracy and stability are high.

Relationship between temperature and electrical resistance is not directly proportional but can be expressed as a polynomial multiple:

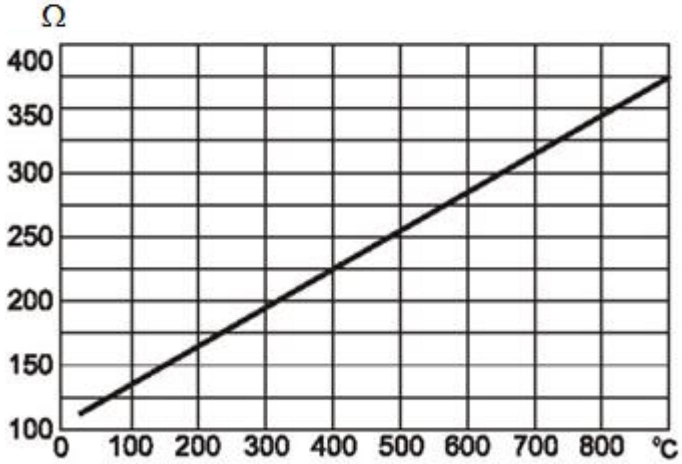
$$R(t) = R_0(1 + At + Bt^2 + Ct^2 + \ldots)$$

R_0 - represents nominal resistance and is determined by specific temperature
$t^2, t^3 \ldots$ - may include dependence on measurement accuracy

Coefficients A, B, etc., depend on the resistance of material and the shape of comprehensive definition of temperature-resistance relationship.

Platinum resistance thermometers IEC 60751

In industrial measuring technology, platinum as a resistant material has found general application. Its advantages include chemical stability, relatively easy fabrication (primarily wire fabrication), possibility of achieving the highest purity form and good reproduction of electrical properties. These characteristics are fully given in the international standard IEC 60751, so platinum resistance sensors have found the widest application. IEC 60751 standard also shows change in resistance with temperature, (shown in the reference table), nominal value depending on the reference temperature and tolerance allowed. Temperature range is also specified in the standard, in the range from -200 to 850°C. Series of reference values is divided into two parts: from -200 to 0°C and from 0 to 850°C.



Characteristics of Pt 100

The first temperature range from -200 to 0°C is covered by a third-degree polynomial:

$$R(t) = R_0(1 + At + Bt^2 + C[t - 100C]t^3)$$

For the range from 0 to 850°C, a second-degree polynomial is used:

$$R(t) = R_0(1 + At + Bt^2)$$

Coefficients used in the forms have the following values:

$$A = 3{,}90802 * 10 - 3 * C^{-1}$$
$$B = -5{,}802 * 10 - 7 * C^{-2}$$
$$C = -4{,}2735 * 10 - 12 * C^{-3}$$

R0 value is determined as nominal value or nominal resistance and it is the resistance at 0°C. According to the provisions of the IEC 60751 standard, the nominal value is 100.00 Ω and therefore the common name is Pt 100 measuring resistor.

Multiplying these values is also allowed, so Pt 500 Ω and Pt 1000 Ω measuring resistors are also used. Their advantage is increased sensitivity, i.e. greater change in resistance with temperature. IEC 60751 standard also treats the Pt 10 measuring resistor, which is very rarely used due to its low (weak) sensitivity, if applied above 600°C.

Change in resistance is approximately:

0,4 Ω/°C for Pt 100

2,0 Ω/°C for Pt 500
4,0 Ω/°C for Pt 1000

Additional parameter defined by IEC 60751 standard is the mean (average) value of temperature coefficient between 0 and 100°C. It represents mean resistance change defined for nominal resistance at 0°C and is:

$$\alpha = \frac{R_{100} - R_0}{R_0 * \Delta t} = 3,850 * 10^{-13} * C^{-1}$$

R_{100} is resistance at 100°C; R_0 resistance at 0°C; Δt temperature difference.

Connecting resistance thermometers

In resistance thermometer, electrical resistance varies with temperature. In order to ensure change of output signal depending on the measured temperature, it is necessary to provide constant current through measuring resistor. According to Ohm's law this signal (voltage drop on measuring resistor) is given in the form of a formula:

V= R * I

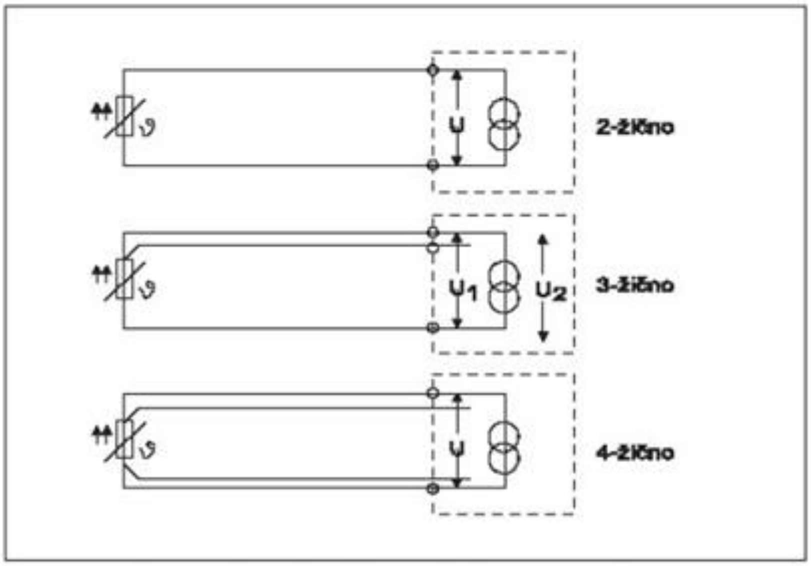
V – output signal - voltage drop on measuring resistor Pt 100 in the function of temperature.
R – temperature-dependent resistance of Pt 100
I – current.

Current should be as low as possible to avoid heating the Pt 100 sensor. It is considered that 1 mA current does not cause heating that significantly affects accuracy of measuring and achieves a voltage drop of 0.1 V on Pt 100 measuring resistor at 0°C. This voltage signal must be transmitted through connecting (signal) wires to indicator with minimal signal attenuation.

Four types of connection between the Pt 100 measuring resistor and the temperature indicator are in use, namely:

- 2-wire connection
- 3- wire connection
- 4- wire connection

Connection types are shown in the following figure:



Connecting resistance thermometers

2-wire connection

In a two-wire connection, the connection between Pt 100 measuring resistor and temperature indicator is made with a 2-wire cable. Like every electrical conductor, this cable has its own electrical resistance, which is directly related to the resistance of Pt 100 measuring resistor. The two resistances add up, which is manifested on the indicator as increased temperature.

At longer distances, longitudinal resistance can amount to several ohms, which causes a significant change - increase in the indicated value.

Example:

Cross section of cable: 0,5 mm^2
Resistance: 0,0017 Ω mm^2 po m
Cable length: 100 m
Cable material: copper

$$R = 0.0017\ \Omega\ \text{mm}^2 / \text{m} \cdot \frac{2 \cdot 100\ \text{m}}{0.5\ \text{mm}^2} = 6{,}8\ \Omega$$

Resistance of 6.8 Ω for Pt 100 corresponds to temperature change of up to 17°C. In order to avoid this error, longitudinal resistance is electrically compensated. Indicator is designed to tolerate longitudinal resistances of 10 Ω. When the resistance thermometer is connected, calibration resistor is connected to the measuring circuit and the sensor is momentarily replaced by a 100 Ω resistor. The calibration resistor is then being adjusted until the instrument reads 0°C.

The calibration resistance added to the longitudinal resistance is then exactly 10 Ω. The equalizing resistance always takes resistance value of the coiled wire, so the equalization consists of the coiled wire resistance. Due to the relatively complicated procedure of calibrating the measuring circuit and the fact that the compensation of the temperature effect is not performed at the point of temperature measurement, the use of 2-wire type of connection becomes extremely rarely applicable, especially in cases where increased measurement accuracy is required.

3-wire connection

In order to eliminate the influence of longitudinal resistance and its change depending on temperature, 3-wire connection is used, instead of the 2-wire connection described above. From one end (output) of the Pt 100 measuring resistor, two conductors (working and auxiliary) are lead. In this way, two measuring circuits are formed, with one of them being used as a reference. The 3-wire connection allows compensation for the change in longitudinal resistance depending on the distance and depending on the temperature. It is required for all three conductors to have identical characteristics and to be exposed to identical temperatures. Considering that additional equalization (calibration) of the measuring circuit is not necessary, this type of connection is most often used today.

4-wire connection

Optimal connection form for the Pt 100 measuring resistor is a 4-wire connection. The accuracy of measurement is independent of both the magnitude of the longitudinal resistance and its change depending on the temperature. Furthermore, no additional equalization (calibration) of the measuring circuit is required.

Pt 100 measuring resistor is supplied with current by "special circuit" through the power connections (joints). Voltage drop on Pt 100 measuring resistor (output signal) is transmitted by measuring circuit to the indicator. Since input resistance of the indicator is many times higher than longitudinal resistance of the measuring circuit, the measuring error is negligible.

Voltage drop on the resistor is independent of the characteristics of the connecting conductors (length, ambient temperature).

With both 3-wire and 4-wire connections, it should be remembered that all conductors of measuring circuit are not always directly connected to Pt 100 sensor, but the connection between connection head and sensor is usually in a 2-wire connection. This causes the same measurement accuracy problems as a 2-wire connection, only to a lesser extent. Total resistance is the sum of the resistance of internal connections and the resistance of sensor and is defined by DIN 16 160 as **the resistance of thermometer (resistance of complete measuring device).**

Problems of 2-wire connection can be avoided without using multi-wire connection, by using 2-wire transmitter. Transmitter converts sensor signal into current signal in the range of 4 to 20 mA which is proportional to the temperature. Powering the transmitter is also done through the same two connections using the remaining current of 4 mA.

Since the amplified signal significantly reduces the effects of external influences, two-wire transmitters offer additional advantages. There are two ways to install the transmitter. Since the distance for the unamplified signal should be as short as possible, the transmitter can be mounted directly on the thermometer inside the connection head. This optimal solution is sometimes impossible for structural reasons because the transmitter cannot be built into the head housing. In such situations, the transmitter is mounted inside the measuring control cabinet (on the rail). Both solutions have their advantages, and the choice depends on the distance the unamplified signal has to travel. For measurements in hazardous - explosive environments, equipment according to EN 50 014 and EN 50 020 should be used, which is designed in such a manner that there is no possibility of electric arc occurring on the device used. If the transmitter is mounted in that hazardous area, it must be in Ex design.

The following table shows resistance values depending on the temperature value for the temperature interval from -250°C to 850°C:

Resistance in Ω

	Otpor u Ω									
°C	0	10	20	30	40	50	60	70	80	90
- 200	18,49	14,45	10,49	6,99	4,26	2,51	-	-	-	-
- 100	60,25	56,19	52,11	48,00	43,87	39,71	35,53	31,32	27,08	22,80
- 0	100,00	96,09	92,16	88,22	84,27	80,31	76,33	72,33	68,33	64,30
0	100,00	103,90	107,79	111,67	115,54	119,40	123,24	127,07	130,89	134,70
100	138,50	142,29	146,06	149,82	153,58	157,31	161,04	164,76	168,46	172,16
200	175,84	179,51	183,17	186,82	190,45	194,07	197,69	201,29	204,88	208,45
300	212,02	215,57	219,12	222,65	226,17	229,67	233,17	236,65	240,13	243,59
400	247,04	250,48	253,90	257,32	260,72	264,11	267,49	270,86	274,22	277,56
500	280,90	284,22	287,53	290,83	294,11	297,39	300,65	303,91	307,15	310,38
600	313,59	316,80	319,99	323,18	326,35	329,51	332,66	335,79	338,92	342,03
700	345,13	348,22	351,30	354,37	357,42	360,47	363,50	366,52	369,53	372,52
800	375,51	378,48	381,45	384,40	387,34	390,26				