Temperature detectors based on the phenomenon of metal resistance changes with the change of temperature are probably the most popular type of temperature sensors used in industry sector.

Most popular temperature resistors are based on platinum and nickel. Historically the first sensor made was the platinum sensor with the resistance of 100Ω and labelled PT100.

Madur company uses the platinum PT500 sensors for temperature measurements.

Principle of operation

All metals exhibit a resistance change with change of temperature. With increasing temperature increases the amplitude of vibration of the metal atoms which impedes the flow of free electrons, and in turn causes an increase in resistance.
In small temperature range, the resistance change can be considered a linear and can be described with the following formula:

$$R_t + R_0 \cdot (1 + \alpha \cdot t)$$

R0	*Resistance in 0°C*
t	*temperature [°C]*
α	*Resistance's temperature coefficient*

The temperature coefficient α is characteristic for each material (metal) that the resistor is made of. Few temperature coefficients for selected metals are displayed in the table below.

Material	**Electrical resistivity [ohm • m]**	**Linear temperature coefficient α [%/K] @ 273K**
Nickel (Ni)	$6.842 \cdot 10^{-8}$	0.5866%
Iron (Fe)	$9.579 \cdot 10^{-8}$	0.5671%
Molybdenum (Mo)	$5.225 \cdot 10^{-8}$	0.4579%
Tungsten (W)	$5.491 \cdot 10^{-8}$	0.4403%
Aluminium (Al)	$2.826 \cdot 10^{-8}$	0.4308%
Copper (Cu)	$1.664 \cdot 10^{-8}$	0.4041%
Silver (Ag)	$1.591 \cdot 10^{-8}$	0.3819%
Platinum (Pt)	$10.59 \cdot 10^{-8}$	0.3729%
Gold (Au)	$2.349 \cdot 10^{-8}$	0.3715%

Temperature coefficient for selected metals

Because the resistance as a value is very easy to measure, the phenomenon of resistance change with temperature, creates easy to produce temperature sensor with high repeatability of measurements. The most suitable materials for temperature sensors are those resistant to corrosion, that have high electrical resistivity and high α coefficient. Because of that, nickel and platinum sensors became popular and widely used.

In practice it turned out that the temperature dependence of resistance is not strictly linear. It means that the coefficient α is not constant value, but varies with temperature.

The formula describing the non-linear change of the platinum resistance with the temperature

It was possible to determine the possibly precise formula for the change of resistance of platinum resistor.
The characteristic is described with two formulas (depending on the temperature range) for higher precision.
In the temperature range 0 – 850 °C the characteristic is described with a quadratic function. For the subzero temperature range -200 °C – 0 °C, the non-linearity of the sensor is increased, and requires a more complex description of the characteristics achieved with the quartic function.
Both features are presented below:

For temperatures between 0 – 850°C

$$R_t = R_0 \cdot (1 + A \cdot t + B \cdot t^2)$$

For temperatures between -200°C – 0°C

$$R_t = R_0 \cdot (1 + A \cdot t + B \cdot t^2 + C \cdot (t - 100\,°C) \cdot t^3)$$

R0	*Resistance in 0°C*
t	*temperature [°C]*
A	*3.9083 $°C^{-1}$*
B	*$-5.775 \cdot 10^{-7}$ $°C^{-2}$*
C	*$-4.183 \cdot 10^{-12}$ $°C^{-4}$*

Inverse function for determining temperature for given R resistance

The formula below allows to determine a temperature of Pt100 sensor for a given resistance. The formula is different for two ranges of R_0 resistance: below R_0 (below 0℃) and above R_0 (above 0℃).

Formula for resistance above the nominal R_0,

$$t=\frac{-R_0\cdot A+\sqrt{R_0^2\cdot A^2-4\cdot R_0\cdot B\cdot(R_0-R)}}{2\cdot R_0\cdot B}$$

R *Sensor's resistance in [Ω]*

R_0 *Resistance in temperature 0℃*

For resistance above the nominal R0 – formula for Pt100 sensor

$$t=p\cdot R_{100}^3+q\cdot R_{100}^2+r\cdot R_{100}+s$$

For other than Pt100 sensor a substitution must be made:

$$R_{100}=\frac{R}{R_0}\cdot 100$$

R *Sensor's resistance in [Ω]*

R_{100} *Pt100 resistance in [Ω]*

R_0 *Resistance in temperature 0℃*

p *$-5.67 \cdot 10^{-6}$ ℃ • Ω^{-3}*

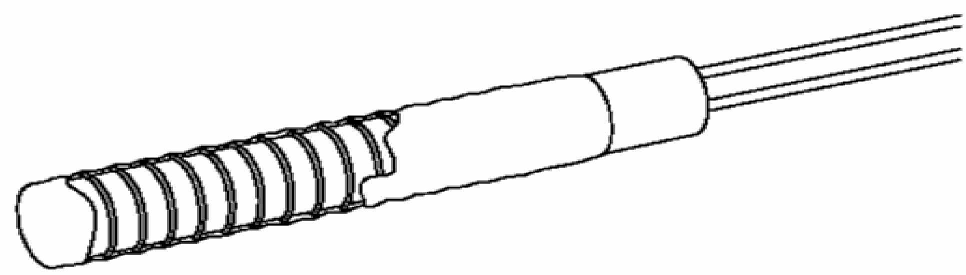
q *$2.4984 \cdot 10^{-2}$ ℃ • Ω^{-2}*

r *2.22764 ℃ • Ω^{-1}*

s *-242.078 ℃*

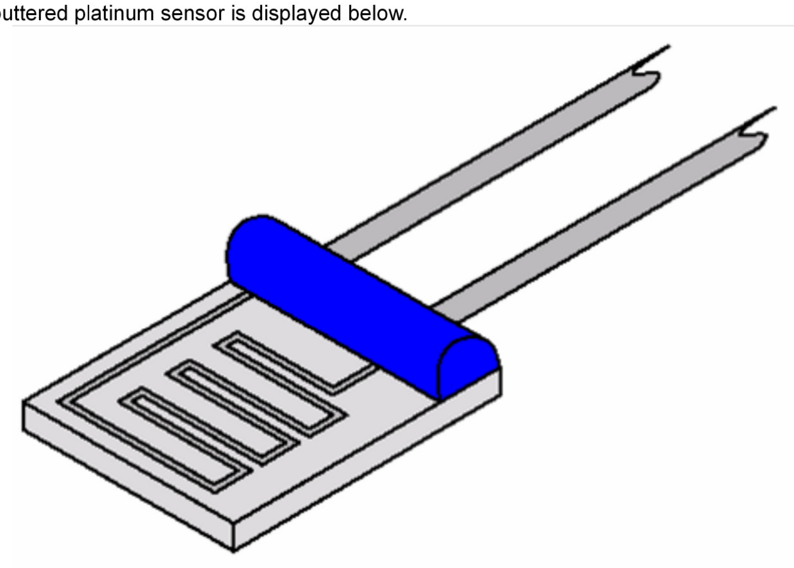
Construction of PTxx sensors

Platinum RTDs were originally manufactured as resistors rolled out very thin platinum wire. The high price of platinum at low electric resistivity allowed for mass production of sensors with low resistivity - hence the popularity of PT100.
The structure of a typical wire made resistor is shown below.



Structure of wire made resistor

Currently more popular becomes the resistor produced with sputtering technique. This allows the production of PT sensors with resistance of 500, 1000 and 2000 ohm. They are called PT500, PT1000 and PT2000. Additionally, this type of resistor require much smaller amounts of platinum.
Structure of the typical sputtered platinum sensor is displayed below.



Structure of a sensor made with sputtering technique

Types of PT sensors

PT sensors are produced in a variety of versions, differing from each other by

1. resistor's manufacturing method
2. type of sensor's casing
3. precision class
4. type of electrical connections
5. Value of R_0

1. Resistor's manufacturing method

Due to the manufacturing method, as mentioned above, we can distinguish wire sensors and sputtered sensors.

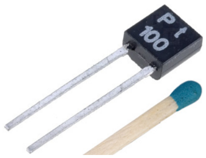
2. Type of sensor's casing

Due to the type of casing we can differ these types of sensors:

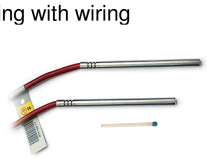
- without casing



- with electronic equipment type of casing



- Sealed in a metal casing with wiring

- with standardised factory casing with connection head

3. Precision class

Due to precision we differ classes:

- AA – most precise
- A
- B
- C – least precise

4. Type of electrical connections

Due to the built of electrical connections we can differ:

- for 2-wire connection
- for 3-wire connection
- for 3-wire connection

5. R_0 resistance

Due to the value of R_0 resistance (in the temperature of 0°C):

- PT100
- PT500
- PT1000
- PT2000

The advantages of PTxx resistive sensors

- simple construction
- high repeatability of characteristics
- wide range of temperatures measurement
- reliability and durability

Disadvantages of PTxx resistive sensors

- relatively low sensitivity (a small percentage change of resistance with temperature)
- low resistance that might force use of 3-wire or 4-wire wiring for the sensor (considering calculation the wiring resistance)
- it requires current for measurement – effect of self heating occurs
- non-linear characteristics