# TEMPERATURE MEASUREMENTS WITH RESISTANCE THERMOMETERS

## 1 PHYSICAL FUNDAMENTALS OF TEMPERATURE MEASUREMENT WITH RESISTANCE THERMOMETERS

All naturally occurring bodies can be classified by their electrical conductivity properties into three groups: metals, semiconductors and dielectrics. Bodies belonging to each group have the different range of the value of resistivity, which is approximate:

| | |
|---|---|
| - metals | $\rho = 10^{-8}$ to $10^{-6}$ [Ωm] |
| - semiconductors | $\rho = 10^{-5}$ to $10^{8}$ [Ωm] |
| - dielectrics | $\rho = 10^{8}$ to $10^{12}$ [Ωm] |

Metals and semiconductors, the first two groups of bodies are used for the construction of resistance thermometers. Semiconductors have particularly great potential, as they cover the widest range of resistance value variations, varying by 13 orders of magnitude.

The principle of resistance thermometers is to take advantage of the phenomenon of changes in the resistance of metals or semiconductors with a change in temperature.

For metals with electron conductivity, this function can be represented, with a sufficient approximation, in the form

$$R = R_0\,[1 + \alpha\,(T - T_0) + \beta\,(T - T_0)^2 + \gamma\,(T - T_0)^3 + \cdots] \tag{1}$$

The resistivity of most metals increases with increasing temperature, and then the temperature coefficient of resistance α is positive. This phenomenon is explained as follows: conduction of electric current in metals is carried out by the movement of electrons. The number of electric current carriers is constant, independent of temperature. With increasing temperature, the amplitude of vibration of hot atoms in the crystal lattice increases and the speed of free electrons increases. The probability of collisions of free electrons with vibrating atoms in a crystal lattice increases. This causes inhibition of the motion of free electrons and an increase in the resistance of the conductor.

For semiconductors with hole-electron conductivity the relationship is exponential

$$R = A * e^{\frac{B}{T}} \tag{2}$$

where A and B are constant quantities and T is the absolute temperature.

To present the changes in resistance resulting from the equations (1) and (2), which is equivalent to the change in the resistivity of these materials, Figure 1 shows the curves of the characteristics ρ = f(T) for metallic and semiconductor sensors.

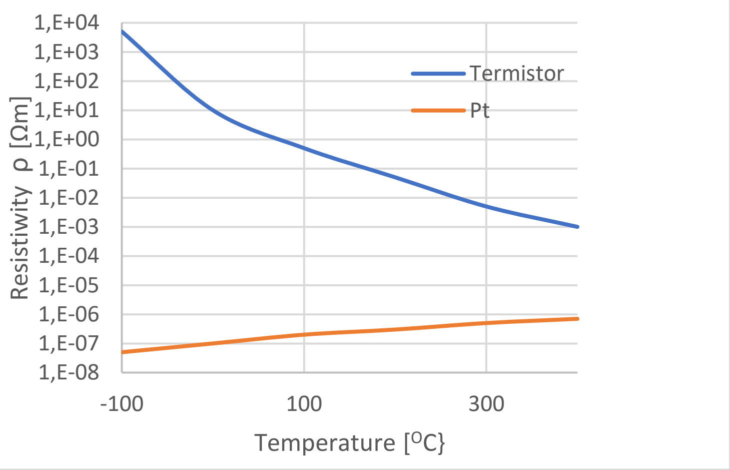


Fig. 3.1 The characteristics ρ = f(T) for metallic and semiconductor sensors

The change in the resistivity of a given material is determined to a first approximation by its temperature coefficient of resistance:

$$\alpha = \frac{1}{R}\left(\frac{dR}{dT}\right)_T \tag{3}$$

where: R is the resistance of the material at temperature T.

The value of α is usually given in the literature in relative magnitudes or as a percentage of the change in resistance per degree Kelvin. It is also very common in practice to use the average temperature coefficient of resistance, which is defined in the form

$$\alpha = \frac{1}{100}\left(\frac{R_{100}}{R_0}\right) \tag{4}$$

Where: $R_{100}$ - resistance of the material at 100°C;

$R_0$ - resistance of the material at 0°C.

## 2 RESISTIVE METAL DETECTORS

Resistive metal detectors are usually made of pure platinum, nickel or copper. Characteristic data are given in Table 1. Other metals and alloys (such as nickel and iron) are used rather uniquely.

Tab. 1

Properties of metals used to build metallic resistance thermometers

| Metal | P * $10^8$ [Ωm] w 0 $^{O}$C | α * $10^3$ [$K^{-1}$] in the range $0^{O}$C do $100^{O}$C | Temperature range [K] | Calculation formula |
|---|---|---|---|---|
| Pt | 9,83 | 3,91 | 70 - 670 | RT = R) [1+A(T*) +B(T*)$^2$]<br>where T* = T-273 |
| Ni | 6,38 | 5,40 | 220 - 420 | RT = R) [1+A(T*) +B(T*)$^2$+C(T*-100)(T*)$^3$]<br>where T* = T-273 |
| Cu | 1,56 | 4,31 | 70 - 320 | RT = R) [1+A(T*) +B(T*)$^2$]<br>where T* = T-273 |

A platinum resistance thermometer has been selected in the range from the oxygen point to 903.9 K as an MPST interpolation tool. By using appropriate means of measurement (compensation methods, special bridging circuits), the measurement uncertainty of less than 0.001 K is achieved. In technical applications the platinum resistance thermometer also makes it possible to achieve high accuracy. A necessary condition is high purity of platinum.

Platinum used in resistance thermometry should satisfy the condition

$$\frac{R_{100}}{R_0} \geq 1.385$$

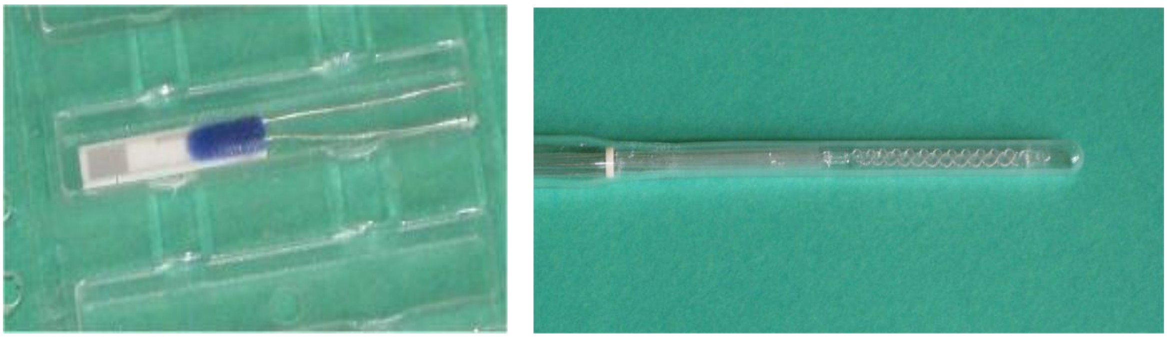
and for precision thermometry this condition should be greater then 1.391,

The precondition for obtaining high measurement accuracy is protection against contamination of platinum (metal vapors are especially harmful - at higher temperatures), aging (it is recommended to anneal for 24 hours at a temperature of about 700 °C) and appropriate design of the sensor ( no mechanical stress).

The characteristic R(T) = f(T) for copper in the range from - 40°C to 200°C deviates from linearity by less than 0.1°C, for platinum in the range from 0 °C to 100 °C by 0.36°C, while for nickel it already deviates by 2.96°C. In addition, obtaining strictly repeatable characteristics for nickel from different melts is practically impossible due to the significant dependence of the characteristics on even negligible impurities.

Platinum thermometer sensors are the most commonly used. Sensors made of nickel are increasingly losing their importance, mainly in view of their inability to meet the increasing accuracy requirements. The nonlinearity of the temperature dependence of platinum resistance requires linearization in the case of analog-to-digital processing. In cases use of analog outputs, linearization is usually unnecessary.

The design solutions of typical resistance sensors PT100 are shown in Figure 2.



a) Platinum sprayed on a ceramic plate b) A spiral of platinum wire wound on a glass carcass

Fig.2 The design solutions of typical resistance sensors PT100

## 3 THERMISTOR SENSORS

Semiconductor resistors, commonly known as thermistors, are made from mixtures of oxides of various metals, for example Fe, Ni, Ti, Zn, Mn, Sc, V, Co, Cu. They are properly formed and then sintered together with supply electrodes. The most common wire used for electrodes is platinum wire with a diameter of 50 um.

Resistances of thermistors can be approximated in the form of formula (2)

$$R = A\,e^{\frac{B}{T}}$$

where A [Ω] is a constant, theoretically corresponding to the resistance of the thermistor at $T \rightarrow \infty$, while B [K] is a constant that depends on the thermistor material. The value of the thermistor's temperature resistance coefficient is derived from equation (2)

$$\alpha = \frac{1}{R}\left(\frac{dR}{dT}\right)_T = -\frac{B}{T^2} \quad [K]^{-1} \tag{5}$$

The value of the coefficient α is inversely proportional to the temperature T. The values of B are contained between 3200 and 4200 K.

Thermistors are divided, depending on the nature of the function a = f(T), into three main groups:

I. **NTC thermistors**. They have a negative temperature coefficient of resistance, mostly contained in the range of $-2.5*10^{-2}\,K^{-1}$ to $-6*10^{-2} K^{-1}$ and resistivity in the range of 104 Ωm to 107 Ωm.

II. **PTE thermistors**. In a certain temperature range they have a large positive temperature coefficient of resistance, reaching up to $0.7K^{-1}$,

III. **CTR thermistors**. These are thermistors whose temperature coefficient of resistance has in a certain narrow temperature range a sharply defined minimum, the value of which can even reach $-0{,}7K^{-1}$.

A typical course of changes in the temperature coefficient of resistance α of NTC, PTC and CTR thermistors is shown in Figure 3. In the case of thermistors, a particularly important issue is the self-heating effect of the sensor caused by Joule heat from the measurement current, which is harmful to the accuracy of the measurement result. The value of the flowing measurement current should be small so that the influence of Joule heat is negligible.

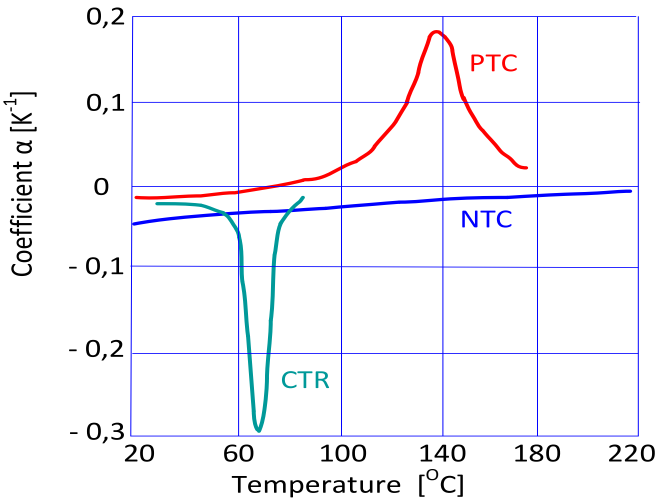


Fig.3 A typical course of changes in the temperature coefficient of resistance α of NTC, PTC and CTR thermistors

The basic material from which PTC thermistors are made is barium titanate (BaTiO). The addition of suitable oxides makes it possible to reduce BaTiO resistivity and allows shifting the temperature range of the PTC effect in the thermistor. CTR thermistors are mainly made of appropriately doped vanadium oxides. For the production of refractory thermistors for applications up to 1000°C are used such materials as ZrO with the addition of rare-earth oxides or TiO and SnO with the addition of Sb, Ta and Zn oxides.

Thermistors of any type can come in a variety of shapes and dimensions. They can be shaped like sticks, beads, plates or lozenges. The examples of their shapes are shown in Figure 4.

Fig.4 The examples of thermistors

The high absolute value of the temperature coefficient of resistance of thermistors, the possibility of making thermistors of very small dimensions (in the form of pearls with diameters of $0{,}3 \div 1mm$) and their high resistance values mean that they will be used to an increasing extent as temperature sensors. This is all the more true as their manufacturing technology continues to improve and their parameters are becoming more and more repeatable, and the non-linear temperature dependence of their resistance is no longer a problem in this era of widespread use of microprocessors.

The semiconductor sensors are currently used as temperature sensors for the very accurate measurement of small temperature differences and also to compensate for the effects of a change in ambient temperature.

## 4 MEASURING THE RESISTANCE OF RESISTANCE THERMOMETRIC SENSORS

To measure the change in resistance of thermometric sensors in industrial conditions bridges are used, primarily unbalanced and balanced bridges, powered by stabilized voltage or current. For less accurate measurements, ratio meters are also used in a narrow temperature range. For the most accurate measurements, balanced bridges are used, also for alternating current, with inductive balancing and voltage dividers. They are often the input module of a digital meter - ohmmeter.

Figure 5 shows a diagram of an unbalanced Wheatstone bridge with a three-wire RT thermometer sensor connection. Compensating for changes in the resistance of the sensor-bridge connections requires full electrical and thermal symmetry of the connecting cables.

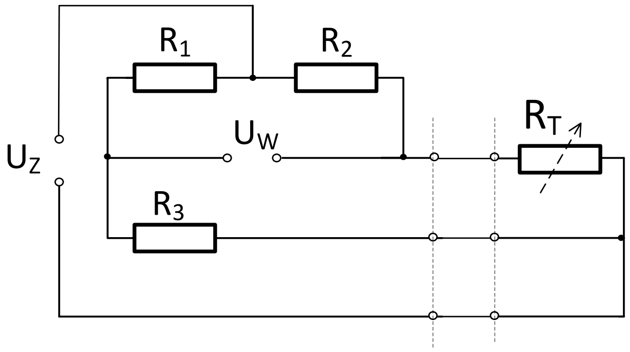


Fig.5 A diagram of an unbalanced Wheatstone bridge with a three-wire RT thermometer sensor connection

The primary output signal of an unbalanced resistive bridge with a temperature sensor in standard industrial devices has a value in the range of 0.2 to 1 mV/K. Its dependence on temperature is non-linear due to the non-linear dependence of the sensor resistance on temperature and due to the non-linearity of the output voltage of a symmetrical bridge with one active branch.

In the Laboratory, digital ohmmeters with an input resistance of $10^9\Omega$ are used to measure resistance, allowing for measurement of resistance in the entire range of sensor resistance changes. The KEITHLEY 2000 universal digital meter is used, which allows, among others: for two-wire and accurate, four-wire resistance measurement with a resolution of 0.0001Ω.

## 5. MEASUREMENT OF PISTON TEMPERATURE DURING ENGINE OPERATION

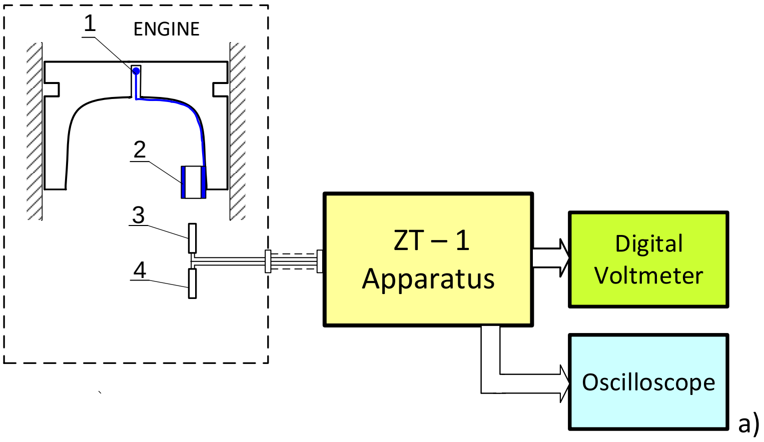
The piston of an internal combustion engine is subjected simultaneously to mechanical loads from gas-mass forces and to thermal loads caused by the periodic absorption of heat by the piston crown from the exhaust gas contained in the combustion chamber. The magnitude of the thermal load on the piston is dependent on the engine operating and cooling conditions. The highest temperatures occur at the piston crown and the lowest at the lower edges of the piston shell.

A direct measure of the heat load on the piston is its temperature, which is dependent on the amount of heat taken up by the piston crown from the combustion chamber gases and the the heat resistance encountered by the heat flow from the piston crown through the annular zone to the cylinder walls and to the coolant.

There are two main purposes of measuring piston temperature. In the first case, we are interested in the maximum temperature values in specific areas of the piston, which during engine operation cannot exceed the limit values permitted due to the piston material used or the coking temperature of the oil used in the piston ring grooves. In the second case, measuring the temperature at specific points in the piston allows for specifying the boundary conditions of heat transfer necessary to carry out numerical simulations of the temperature field in the piston and to determine the thermal stresses caused by uneven heating of the piston material.

ZT-1 apparatus for measuring piston temperature

In the exercise, a specialized apparatus for measuring the temperature in the ZT-1 piston was used to measure the piston temperature, with an input circuit adapted to measure temperature using semiconductor resistance sensors (thermistors) and non-contact transmission of the measurement signal using inductive coupling. The block diagram of the ZT-1 apparatus and its use in measuring piston temperature is shown in Figure 6.



a)

b)

Fig. 6 Block diagram (a) and view (b) of the ZT-1 Apparatus.

The input measurement circuit is made in the form of a symmetrical inductive bridge. One half (active half-bridge) together with the secondary coupling circuit is located in the engine crankcase, and the other half (regulating half-bridge) is located outside the engine in the ZT-1 measuring device. The active half-bridge is made of two identical core coils (active and compensating). . Both half-bridges are connected with a two-wire signal cable.

The thermistor (1), mounted at the measuring point in the piston, is connected by wires to a cylindrical secondary coil (2), mounted on a bracket to the lower inner wall of the piston. The thermistor and coil constitute the secondary measuring circuit. When the engine is running, this circuit moves with the piston in a reciprocating motion, and in the internal piston reversing position it engages with the stationary coil (3) of the active half-bridge, attached to the lower edge of the cylinder liner on a bracket. The primary active coil (3) and the compensation coil (4) are mounted on the axis of movement of the secondary coil. Primary coils (3) and (4) constitute the measuring half-bridge, which is connected by a cable to the regulation half-bridge located in the ZT-1 measuring apparatus.

Figure 7 shows pistons of internal combustion engines prepared for temperature measurements. The feedback coils attached to the piston side surface and the set of compensation coils along with the connecting cables to the ZT-1 apparatus are visible.

Fig. 7 Pistons of 8C22, PF 125p, Leyland SW680 and Wola H6 engines
prepared for temperature measurements

## Method of measuring the piston temperature

Before measurement, the bridge is balanced and the output voltage is zero. When the engine is running and the piston is positioned close to the internal rotation, the secondary coil (2 – fig.6) is coupled with the active primary coil (3). This changes the total impedance of the active arm of the bridge due to the impedance contributed from the secondary circuit to the primary circuit. The value of the instantaneous impedance from the secondary circuit introduced into the primary circuit at the moment of maximum coupling is a function of the thermistor resistance, which in turn is a function of the temperature of the thermistor and the piston in the place of mounting the thermistor. The bridge imbalance voltage at the moment of coupling of coils (2) and (3) is fed to further elements of the measuring system. By selecting the mutual position of the coupling coils, a measurement signal in the form of a two-hump curve is obtained at the output of the strain gauge bridge. The two-hump shape of the measurement signal proves the correctness of the measurement. Changes of this voltage can be observed on the oscilloscope attached to the ZT-1 device. Figure 8 shows an example oscillogram of the signal from one measurement point.

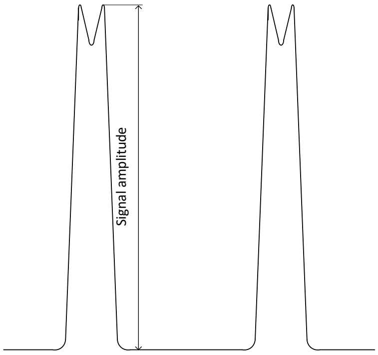


Fig.8 Sample oscillogram of the measured signal

The line separating the two-hump pulses, visible in the oscillogram, corresponds to the state without coupling (zero line). Both maxima of the two-hump pulse correspond to maximum couplings. After detection and amplification, the two-hump signal is fed to the device output as an analog DC signal. The value of the output voltage amplitude depends on the thermistor resistance and is a measure of the piston temperature at the place where the thermistor is mounted.

The piston temperature measurement using the described method can be performed provided that the reference characteristics are previously determined for each measurement point: temperature characteristic of the thermistor and voltage characteristic of the ZT-1 measuring circuit. Such characteristics should be made in conditions similar to real ones. Since it is difficult to create real, dynamic measurement conditions, the reference characteristics of the measurement system are determined outside the engine in static conditions on a laboratory stand. In this procedure, it is assumed that for the tested engine:

- in the measuring system, there is no disturbing influence of metal masses and moving engine components (piston, crankshaft, connecting rod) on the own magnetic field of the primary and secondary coupling coils;

- the measurement system self-compensates the impact of temperature changes in the engine crankcase on changes in the parameters of the measurement signal transmission elements (measuring and secondary coils);

- measurement results do not depend on engine speed.

If the measurement system meets the conditions presented above, the determination of the reference characteristics can be performed outside the engine in two stages:

a) determining the thermometric characteristics of the thermistor resistance changes as a function of temperature $R_T = f(T)$ for all thermistors used for measurement;

b) determining the reference characteristics of the measuring system - the dependence of the output voltage value on the thermistor resistance for each measuring circuit of the apparatus.

Determination of the thermometric characteristics of the thermistor

Heat-resistant bead thermistors used to measure the piston temperature have a measurement range of up to 450°C and a bead diameter of 0.3 to 1.2 mm. They are well suited for spot temperature measurement throughout the entire volume of the piston material. The influence of mounting the thermistor on the change of the temperature field in its surroundings is negligible. This happens even in thin piston skirt walls due to the small dimensions of the thermistor in relation to the cross-sectional areas through which heat flows. In the manufacturing process, during heat treatment of thermistors, shape changes occur, resulting in changes in their physical properties - including resistance. This results in the need to experimentally determine the thermometric characteristics for each thermistor used to measure temperature.

Determining the thermometric characteristics of a thermistor comes down to measuring its nominal resistance at various temperatures of the environment in which the thermistor is placed. The block diagram of the system for determining the thermometric characteristics of thermistors is shown in Figure 9.

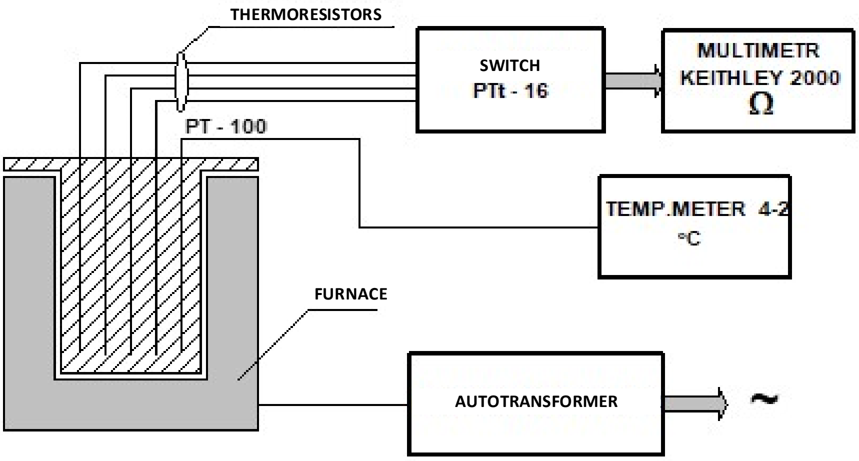


Fig. 9. Diagram of the thermistor calibration system

The thermistors are placed in the holes of the aluminum block placed in the silite furnace. The thermistor wires are insulated from the hole walls using two-channel ceramic sleeves. The furnace temperature is regulated manually by changing the supply voltage to the furnace heater using an autotransformer. The temperature of the aluminum block is measured using a Type K thermocouple attached to the RS-41 temperature meter. The value of the measured temperature is displayed on the digital display of the meter with a resolution of 0.1$^{O}$C. The sensor resistance is measured at a slowly increasing furnace temperature, with readings at constant steps, e.g. 10°C.

Examples of calibration characteristics of a bead thermistor are shown in Figure 10.

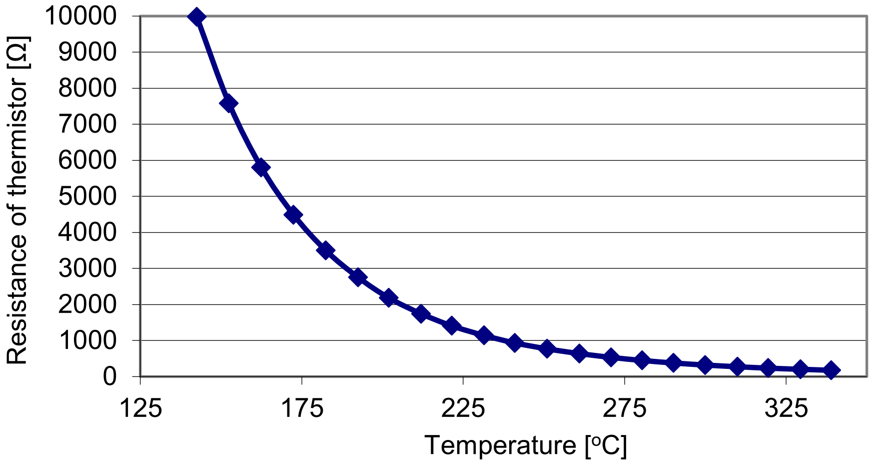


Fig.10 Example of calibration characteristics of a bead thermistor

During measurements of the piston temperature in various engines, a large dependence of the determined (measured) temperature value at the measurement point on the temperature of the coupling coils in the crankcase was found. A new ZT-2 apparatus was developed, which is a modification of the ZT-1 apparatus. It takes into account the influence of changes in the temperature of the compensation coils located in the crankcase on the parameters of the measuring bridge and thus on the output voltage values from the equipment. For this purpose, an algorithm was used to calculate the corrected temperature value at the measurement point based on three characteristics of the measurement path obtained with three compensation coil temperature values. The assumed coil temperature values corresponded to the minimum, maximum and average values of the oil mist temperature in the crankcase of the running engine. Oil mist temperature values are specific to a given engine and must be measured before the calibration process. The compensation coils of the measurement path were placed in a laboratory dryer with an adjustable heating temperature. This made it possible to determine three characteristics of the measurement path at previously determined values of the temperature of the coupling coils. The compensation coils in the crankcase are equipped with a thermocouple that allows determining the current, actual temperature of the coils. The algorithm calculates the actual temperature value at the measurement point based on three calibration characteristics and the measured coil temperature. The ZT-2 equipment includes a microcomputer that calculates the temperature.

## Determining the reference characteristics of the measurement system

Determining the reference characteristics of the ZT-1 measuring system itself should include all components, i.e. coupling coils, connecting cables and the ZT-1 apparatus. Determining the reference characteristics of a full measurement system differs from measuring the piston temperature on a running engine in that:

- the thermistor resistance values are simulated with the appropriate resistance values set on the decade resistor.

- calibration takes place with maximum coupling of (active) coils, not dynamically but statically.

Elements of a laboratory stand to simulate the reciprocating movement of a piston were built. They are shown in Figure 11.

Fig.11 Elements of a laboratory stand to simulate the reciprocating movement of a piston

The movement of the bolt carrier is achieved by a disc mounted on the axis of the DC motor. Changing the motor supply voltage causes a change in the disc rotation speed. This simulates the change in engine speed in real measurements. A cylindrical coil connected to a decade resistor is attached to the bolt carrier. At the turning point of the bolt carrier movement, the cylindrical coil engages a stationary cylindrical coil attached to the bracket. The fixed coil is the input element of the ZT-1 device bridge. A view of the complete laboratory stand for determining the reference characteristics of the measurement system is shown in Figure 12.

Fig. 3.12. Laboratory stand with ZT-1 apparatus

Determination of the characteristics of the measurement circuit U= f($R_T$) takes place in stages:

1) On the calibration device (slide with a driving motor), set the bolt coil in a position without coupling with the primary coil on the bracket – Figure 13.a. Using the measurement channel knobs on the front panel of the ZT-1 device, we bring the input bridge to a balanced state - the meter readings equal to 0V.

2) Set the piston coil to the position of maximum coupling with the primary coil - Figure 13.b. We successively set the resistance value on the decade resistor corresponding to the thermistor resistance values in the entire range of its resistance changes and read the voltage value on the voltmeter.

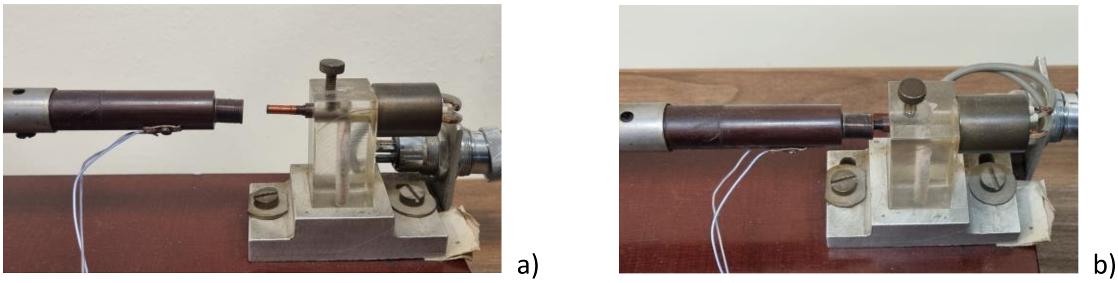


Fig.13. Mutual position of the coils on the laboratory stand: a) no coupling, b) maximum coupling.

The measurement results should always be recorded in an appropriate table. An example of the characteristics of the measurement track is shown in Figure 14.

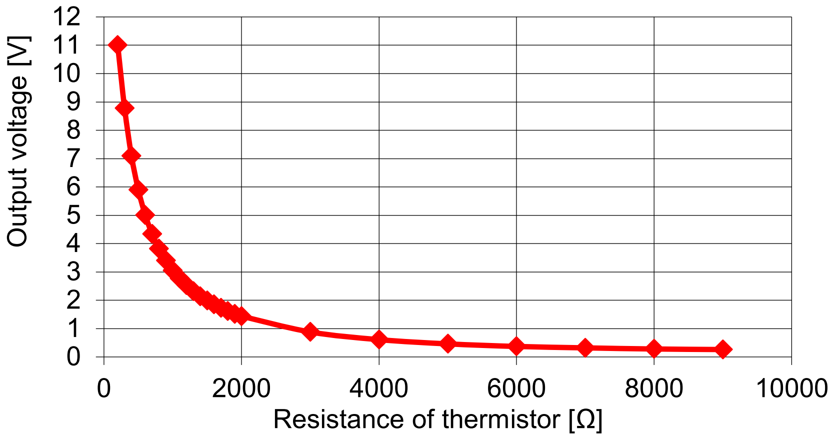


Fig.14 Characteristics of the measurement path $U_{output} = f(R_T)$

The temperature characteristics of the thermistor $R_T$=f(T) and the measuring circuit U=f($R_T$) should be compared on a common graph T=f($U_{output}$) with two scales on the y axis. The horizontal axis of the graph concerns the resistance of the thermistor and has a logarithmic scale of resistance values. Example results for common characteristics are shown in Figure 15.

Using this graph, you can directly read the temperature value at the measuring point knowing the value of the measured voltage. An example reading is shown in Figure 15 with a green line starting at 5,9V on the U voltage axis. The temperature value read from the chart is 275$^{O}$C.

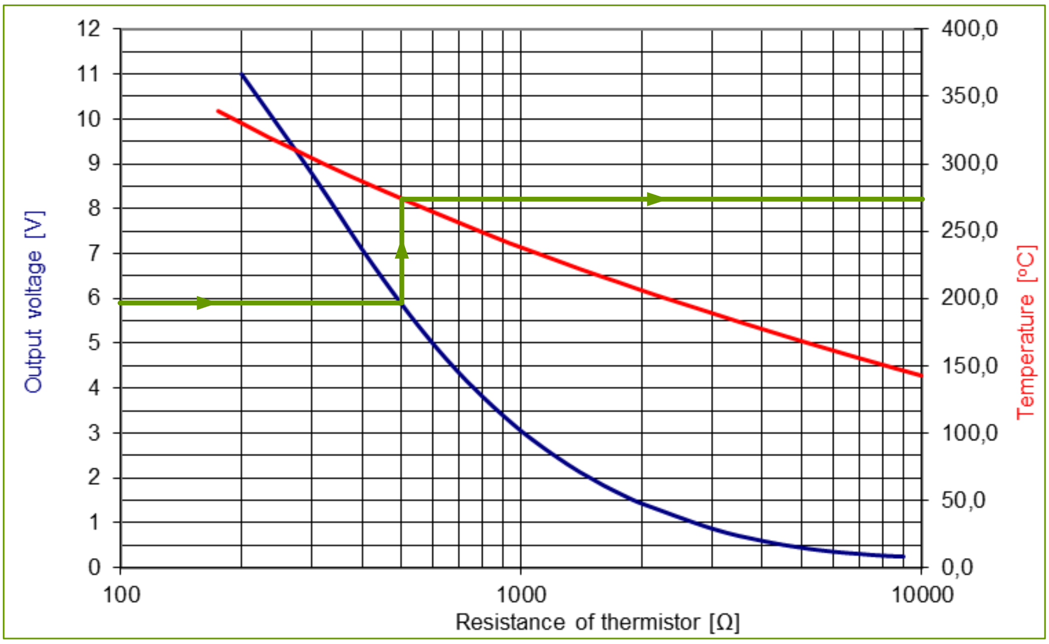


Fig.15 Common graph of the thermistor's temperature characteristics and measurement path calibration

DESCRIPTION OF PERFORMING TASKS DURING THE LABORATORY EXERCISE.

The purpose of the measurements is to determine the temperature characteristics of selected resistance thermometers and to determine the characteristics of the measuring path of the ZT-1 apparatus for measuring internal combustion engine piston temperatures.

I. DETERMINATION OF TEMPERATURE CHARACTERISTICS OF SELECTED RESISTANCE THERMOMETERS

Due to the range of temperature changes in the piston being up to $350^{O}$C, calibrating the thermistor over the entire range of temperature changes during exercises in quasi-steady conditions would take too much time. As part of the exercise, you should calibrate two resistance sensors: a thermistor and a platinum metal resistor in the temperature range up to $150^{O}$C.

**1.** Check the connections of the thermistor calibration equipment components according to Figure 9.

**2.** Turn on the power supply of the devices and wait about 5 minutes. Set the multimeter's operating mode to resistance measurement (10MΩ range) - two-wire measurement.

**3.** Prepare a table to record the measurement results according to the formula

Tab.2

| $T_{pieca}$ [°C] | $R_{T1}$ [MΩ] | $T_{pieca}$ [°C] | $R_{T2}$ [MΩ] | $T_{pieca}$ [°C] | $R_{T3}$ [MΩ] |
|---|---|---|---|---|---|
| 25,0 | | 26,0 | | 27,0 | |
| 35,0 | | 36,0 | | 37,0 | |
| 45,0 | | 46,0 | | 47,0 | |
| . . . . | | . . . | | . . . | |
| | | | | | |

**4.** Set the desired value of the furnace supply voltage (set the autotransformer knob to the 90 mark). Using the PTt-16 switch knob, connect the thermoresistors to the multimeter one by one. Record the measured resistance values in the table. Carry out measurements in the range from $25^{O}$C to $95^{O}$C.

**NOTE: When the furnace temperature reaches $95^{O}$C - SWITCH OFF THE FURNACE POWER (set the autotransformer knob to ZERO)!!!**

Present the measurement RESULTS in the form of a graph of curves in one drawing, prepared e.g. in Excel (semi-logarithmic scale on the R axis for the thermistor resistance).

## II DETERMINATION OF THE CHARACTERISTICS OF THE MEASURING TRACK OF THE ZT-1 APPARATUS FOR TESTING THE TEMPERATURE OF THE PISTON OF AN INTERNAL COMBUSTION ENGINE.

**1.** Turn on the power supply to the devices and wait approximately 5 minutes. Set the value of 200⍰ on the decade resistor. Check and, if necessary, correct the position of the bolt carrier to obtain maximum coil coupling (obtain maximum output voltage values).

**2.** Copy the temperature characteristics of the thermistor RT=f(T) from the data provided by the teacher.

**3.** Prepare the table according to the formula (tab.3):

Tab.3

| **R**$_{T}$ [Ω] | **U** $_{wyjściowe}$ [V] |
|---|---|
| 9000 | |
| 8000 | |
| ..... | |

Read the output voltage value for the following resistance values set on the decade resistor:

from 9000Ω to 2000Ω every 1000Ω,

from 1900Ω to 200Ω every 100Ω.

**Note:** before reading the voltage on the voltmeter, always press the zero **button D** in the ZT-1 device.

Prepare a common graph of the temperature characteristics of the thermistor RT=f(T) and the characteristics of the measurement circuit Output = f(RT) using the R axis as the horizontal axis in the drawings of both characteristics( see fig. 3.15). Present the R axis as a variable on a logarithmic scale. Using both graphs prepared, read the temperature value for the output value given by the instructor.

REPORT

In the report:

- present the graphs described in points I and II
- provide the value of the output voltage given by the lecturer and the corresponding piston temperature, determined from the graph prepared in part II.

Prepare the charts, e.g. in Excel.

Review questions:

1. Construction and properties of resistive metallic temperature sensors.
2. Construction and properties of resistive semiconductor temperature sensors.
3. Explain the physics of change in resistance of metallic and semiconductor thermometer sensors.
4. Compare the temperature characteristics of metallic and semiconductor resistive sensors.
5. Discuss the operation of the system for measuring the piston temperature of an internal combustion engine.

LITERATURE

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