

# Temperature Dependencies of Thin-wire Platinum Bolometer of High Power Laser Radiation

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## ABSTRACT

The resistance of platinum filament on heating to different temperatures has been measured. Measurements showed platinum wire resistivity matching to tabulated values, and therefore can be used to obtain the temperature dependence of conductors used in bolometric measurers of radiation. The results obtained make it possible to create absolute bolometric measurer of continuous power and pulse energy of laser radiation.

**Keywords:** Temperature Dependencies; Thin-wire Platinum Bolometer; High Power Laser Radiation

## 1. Introduction

The material used in the measuring transducer in the form of thin filaments with a resistance that changes under the influence of laser radiation, must meet some fundamental requirements: 1) weak sensitivity to small impurities generated in production and operation process; 2) the ease of obtaining and manufacturing technology; 3) resistance to high temperatures; 4) high corrosion resistance. Such conditions are satisfied platinum filaments which resistance are normalized for temperature changes up to 1100 °C<sup>[1]</sup>.

Pure platinum is one of the best material for sensitive components of resistive temperature transducers manufacturing<sup>[2]</sup>. Their advantages are high chemical inertness up to the melting point, high melting temperature, high resistivity (9.85 μΩ·cm under normal conditions).

It is necessary to know the basic physical parameters of platinum filaments to use them as sensitive temperature transducers.

High radiation intensity leads to significant heating of bolometer, nonlinearity of its conversion response and as consequence to systematic errors of measured radiation parameters<sup>[3]</sup>. The nonlinearity of bolometer conversion response caused by temperature dependence of its basic physical parameters

(temperature resistance coefficient, specific heat capacity, absorption efficiency factor, heat exchange with the environment coefficient) and amplified by irregularity in length distribution of the incident radiation intensity. In this case, it is necessary to take into account temperature dependences of the basic physical parameters of platinum filaments and non-uniformity of intensity distribution on the lattice area to exclude the dominant errors due to conversion response non-linearity<sup>[4]</sup>.

Relative resistance temperature dependence for platinum obeys equations, which are regulated by International Practical Temperature scale ITS-90<sup>[5,6]</sup>. Sensitive components of resistive temperature transducers are made of free of tension, baked, pure platinum filament with ratio of resistances at 100 °C and at 0 °C  $W_{100} \geq 1.3925$ . For used in temperature measurement platinum, there are three classes  $W_{100}$  A-from 1.3845 to 1.3905 (nominal value 1.3850 to 1.3845); B-from 1.3840 to 1.3900 (nominal value 1.3850 to 1.3910); C-from 1.3835 to 1.3595.

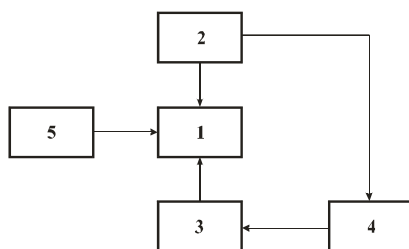
Thus, the investigation of the temperature dependence of the resistance of platinum can occur in two ways:

1) Measure resistance at  $T_1 = 0$  °C and  $T_2 = 100$  °C and according to  $W_{100}$  ratio choose the course of characteristic, using the state standard table (GOST 6651-84);

2) Direct measurement platinum filament resistance in the range of temperature changes from 0 to 1000 °C.

## 2. Measuring instrument

To measure the resistance temperature dependence of platinum filaments was used device which block diagram is shown in **Figure 1**. Electric muffle oven is a device that consists of pipe-shaped chamber made of fused quartz with diameter of 20 mm and length of 900 mm, heating element of the ceramic frame tube diameter of 60 mm, the thermocouple to establish and maintain the temperature inside the chamber automatically. During manufacturing quartz pipe was wrapped with one layer of asbestos tape, which was saturated with a suspension of 60 weight parts of finely dispersed aluminum oxide and 40 weight parts of liquid glass. After drying the tape, heater coil made of nichrome wire with diameter of 1 mm was wrapped with a uniform step over the tape. To fix the coil and to improve spatial temperature uniformity along the chamber, heating element was covered with thermo-conductive paste made of aluminum oxide and liquid glass taken in equal volume parts. The thickness of paste layer was about 3 mm. Quartz chamber with a heating element was covered in three asbestos tape layers and one asbestos cord layer. The whole structure was inserted into the tube made of pyroceramics. Pyroceramics pipe was wrapped with three asbestos cord layers. Aluminum foil was wrapped above the cord layers. The ends of the chamber were isolated from the ambient asbestos corks with thickness of 50 mm.



**Figure 1.** Block diagram of a device for measuring the platinum filament resistance in the temperature range 25 °C, 1100. 1. Electric muffle oven with platinum filament; 2. Thermometer; 3. Heating element; 4. Electronic circuit of temperature control device; 5. Resistance measurer.

To establish and maintain preselected temperature value the junction of chromel-alumel thermo-

couple was fixed inside the quartz chamber. Conclusions thermocouple through the layers of insulation produced outside and mounted on massive copper plate, which is at room temperature. Thermocouple calibration was done using standard thermometer that was provided by the National Scientific Center “Institute of metrology”. The value of thermal electromotive force after differential-input amplifier with gain factor  $K_U = 22$  was measured by SHCH68003-type digital device.

Automatic temperature control circuit includes amplifier of thermal electromotive force, comparator unit and output amplifier with electromagnetic relay switch. Proportional to the difference between room temperature and the temperature of the chamber signal, received from the thermocouple located on the wall of muffle oven chamber, was amplified by single-chip differential amplifier and fed to the voltage comparator unit. Operational-amplifier comparator unit with an open feedback loop allows us to compare the signals that were received at its inverting noninverting inputs from thermocouple and regulating reference voltage. At positive voltage at the comparator unit output, KT805A-type transistor output amplifier with MKU-48-type relay, connected to the collector circuit, drops into state of saturation, relay contacts are closed and power-supply voltage is applied to the heating element. After reaching the target temperature, output comparator unit voltage changes its sign step like, output amplifier becomes locked, and relay contacts becomes opened, switching the heating element off. After reducing the temperature in the muffle oven, comparator unit again feeds a driving signal to heating and so on. Measurements showed that at the steady state temperature excursion in the center of muffle oven channel does not exceed  $\pm 0.5$  °C.

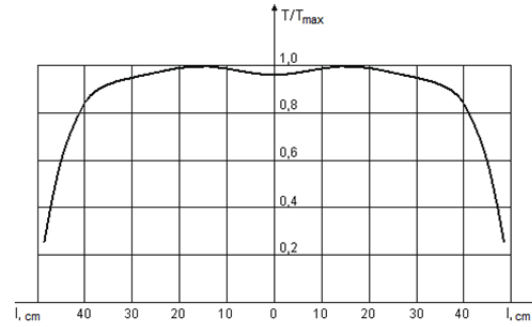
## 3. Experiment and results

Temperature distribution along the oven chamber was measured using chromel-alumel thermocouple, which could move within the chamber. For the specified purpose thermocouple was introduced into the chamber and its junction was placed in the center of the chamber using an external counting device. Reference voltage correspond-

ing to the target temperature was set and automatic temperature control circuit was switched on. After steady state reaching, readings were taken. Then thermocouple junction was shifted from the center to one of ends of chamber by a target distance, and after steady state reaching temperature readings were taken again. Thus, readings were taken until the thermocouple junction does not reach the end of the chamber. A similar series of measurements performed also towards another end of the muffle oven chamber.

On **Figure 2** is given distinctive relative distribution of temperature along the channel of the oven at temperature in the middle of the channel of 607 °C. The figure shows that because of heat losses the chamber temperature decreases from the center to the ends. Relative temperature minimum at the center of the chamber caused by irreparable quartz pipe bend under its own weight while warming up to 1,200 °C and, as a result of increase heat loss for massive ceramic frame heating. To improve the accuracy of measurements it is necessary to confine that part of the channel where temperature differences are minimal. According to the graph, we can determine that, if we limit the working part of the chamber channel to the length of the

conductor, the mean temperature in this part will be 617.6 °C with a relative root-mean-square deviation of 0.37%.



**Figure 2.** Temperature distribution along the channel of the oven.

In the experiment, the platinum filament with length of 54 cm and a diameter of 0.05 mm was fastened to nickel wire lead terminals with diameter of 2.5 mm. Lead terminals were passed through asbestos cork. The conductor was placed symmetrically with respect to the ends of the chamber. Filament was baked in the chamber in temperature range from 25 °C to 1,030 °C with exposure at the maximum temperature for 30 minutes. Filament then slowly cooled in oven to room temperature.

**Table 1.** Approximation of resistivity

$T_i, ^\circ\text{C}$	$\rho_i \times 10^6, \Omega\cdot\text{cm}$	$\sigma_i \times 10^4, \text{S/cm}$	$\frac{\Delta\rho(T)}{\rho_0}$	$\frac{\Delta\rho(T)}{\rho_0 \text{ approx}}$
1	2	3	4	5
0	9.81	10.19	0.0000	0.0000
100	13.65	7.326	0.3914	0.3919
200	17.38	5.754	0.7717	0.7721
300	21.00	4.762	1.1407	1.1405
400	24.50	4.082	1.4975	1.4972
500	27.88	3.587	1.8420	1.8421
600	31.15	3.210	2.1753	2.1753
700	34.30	2.915	2.4964	2.4967
800	37.34	2.678	2.8063	2.8064
900	40.27	2.483	3.1050	3.1043
1000	43.07	2.322	3.3904	3.3905
1100	45.76	2.185	3.6646	3.6649
1200	48.34	2.069	3.9276	3.9276
1300	50.80	1.969	4.1784	4.1786
1400	53.15	1.881	4.4179	4.4178
1500	55.38	1.806	4.6453	4.6452

The resistance of thus baked filament was 34.12  $\Omega$  at an initial temperature of 25 °C. When the filament was heated in oven chamber to temperature of 1000 °C its resistance increased to 140.18  $\Omega$ . Approximation of the obtained temperature dependence of resistance gives us values

$R_0 = 31.034\Omega$ ,  $R_{100} = 43.05\Omega$  and, respectively,  $W_{100} = 1.3872$ . Comparison of received data with the tabular data<sup>[7]</sup> and wire ratings for  $W_{100}$  indicates the applicability of tables data for platinum class-B thermometers to estimate the heating of a conductor to temperatures of the order of

1000 °C.

We obtained analytical temperature dependence of platinum resistance temperature coefficient  $\alpha(T)$  in **Table 1**. In the first column the values of temperature  $T$  in Celsius degrees are shown, and in the second column the corresponding values of resistivity of platinum are shown<sup>[8]</sup>. At the fourth column are shown the relative increments of resistivity  $\Delta\rho_i(T)/\rho_0$ , which were approximated by the least-squares technique according to expression:

$$\frac{\rho(T) - \rho_0}{\rho_0} = \frac{\Delta\rho(T)}{\rho_0} = \alpha_0 T + \alpha_1 T^2 = (\alpha_0 + \alpha_1 T) T$$

Where  $\rho_0$  is resistivity of platinum at 0 °C;  $\alpha_0 + \alpha_1 T = \alpha(T)$  is the temperature dependence of the temperature coefficient of resistance (TCR);  $\alpha_0$  is TCR of platinum at 0 °C;  $\alpha_1$  is the factor that determines the linear dependence of  $\alpha(T)$ . In the temperature range under consideration, these factors are important and their RMS deviations determined according to the method<sup>[9]</sup> are  $\sigma_{\alpha_0} = 9 \times 10^{-5}$ , and  $\sigma_{\alpha_1} = 5 \times 10^{-4}$ .

$$\alpha_0 = 3.978 \times 10^{-3} \frac{1}{\text{deg}}; \quad \alpha_1 = 5.87 \times 10^{-7} \frac{1}{\text{deg}^2}$$

In the fifth column of the **Table 1** are shown approximated values of the relative increment of the resistivity of platinum, which are in very good agreement with the values of column 4 that were approximated.

## Conclusions

(1) Measured the resistance of platinum filament (thin-wire) on heating to different temperatures. Meas-

urements showed platinum wire resistivity matching to tabulated values, and therefore can be used to obtain the temperature dependence of conductors used in bolometric measurers of radiation.

(2) The results obtained make it possible to create absolute bolometric measurer of continuous power and pulse energy of laser radiation.

## Conflict of interest

The authors declared no conflict of interest.

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