EXPERIMENTAL MEASUREMENTS OF HIGH TEMPERATURE OBJECTS IN CONTACT WITH AN ELECTRIC ARC

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Abstract: The paper is focused on the measurements of high temperatures related to electric low voltage apparatuses switching off process. An optical emission spectroscopy was used for these measurements, because the optical emission spectroscopy is one of best methods for obtaining a temperature of high temperature objects. Experimental measurement of radiation spectra of electrodes among which an arc was burning is presented. Electrodes was made of carbon with stabilisation core with potassium and sodium admixture. Radiation spectrum of electrodes was close to the black body radiation spectrum. The problems connected with the measurements are discussed. The main part of the paper deals with a calculation of the electrode temperature using Planck function.

Keywords: DC arc, high temperature measurement, optical emission spectroscopy, Planck law

1 INTRODUCTION

The optical emission spectroscopy is a powerful tool for a wide range of diagnostics. For example, obtaining composition or temperature of hot gases, temperature measurements of solids and metal melts, analysing of light sources, gathering data for calculation of velocity and atmosphere properties of stars in the space, investigating of daylight properties during the day etc. The main advantage of this method is that the measured object is not affected by the measuring devices. Basic block diagram of measurement chain is shown in the Figure 1.

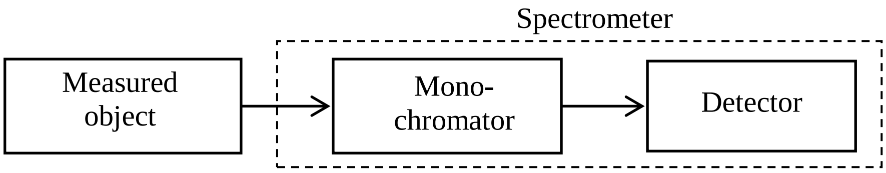

Figure 1: Block diagram of optical emission spectroscopy.

Investigated object radiates energy into a spectrometer assembly. A monochromator is one of the important parts of the spectrometer assembly. A monochromator contains input and output slits, two mirrors and diffraction grating. The configuration of those parts could be various, the most common configuration is Czerny-Turner. A basic function of the monochromator is the isolation of a narrow band of whole spectrum and reduce the radiation intensity to required value [1]. The second important part of the spectrometer is a detector. CCD, EMCCD or CMOS chips are usually used as a detector of radiation intensity. All those detectors have a high sensitivity, because a lot of investigated objects radiates small amount of energy or they are so far from the measuring place. There is the problem with the white noise because of high sensitivity [2]. Possible solution of white noise reduction is cooling of the detector. Thermoelectric coolers based on Peltier effect are balanced choice for this purpose because of small dimensions and low price. Next improvement of the cooling power could be cooling of thermoelectric cooler's hot side by the circulating air or liquid. The most commonly used system is the airflow cooling systems for its low price and easy maintenance. For example, this system can cool the detector of Newton 940 CCD camera up to -100 °C.

If the investigated high temperature object contains free atoms/ions, then its radiation spectrum contains narrow intensive peaks called spectral lines. It is possible to identify relative chemical composition of the volume because each chemical element has a specific energy levels. Specific wavelengths of a lot of lines for chemical elements are listed in databases such as NIST [3]. The theory is based on the quantum mechanical atom model. Movement of electrons from the higher energy level to lower one causes radiation on specific wavelength which is given by the equation (1).

$$\Delta E = \frac{hc}{\lambda} \tag{1}$$

where h is Planck constant, c speed of light and λ is wavelength.

This situation is common for gases, plasma, etc., see Figure 2.

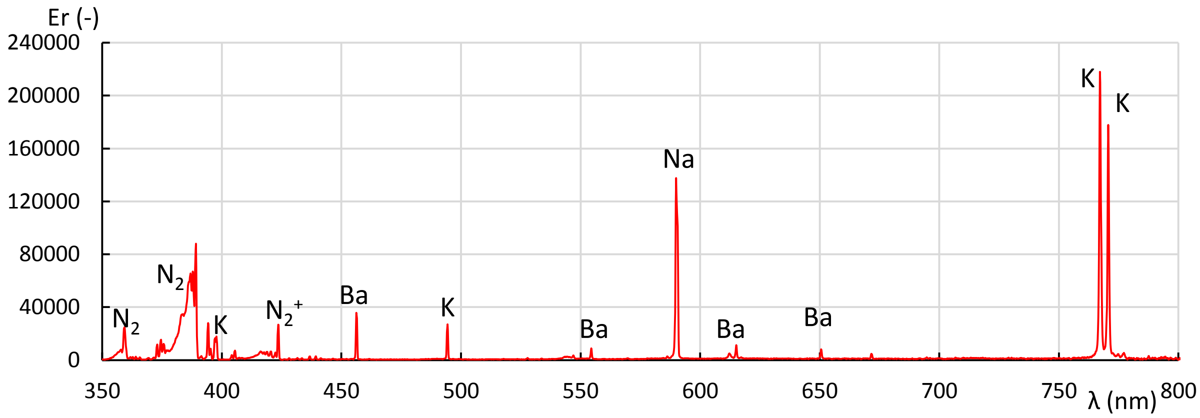

Figure 2: Emission spectrum of DC arc plasma contains free atoms of copper, carbon, sodium, and molecules of nitrogen.

Atoms are affected by each other or by external fields. Broadening of spectral lines increases with increasing pressure, see Figure 3.

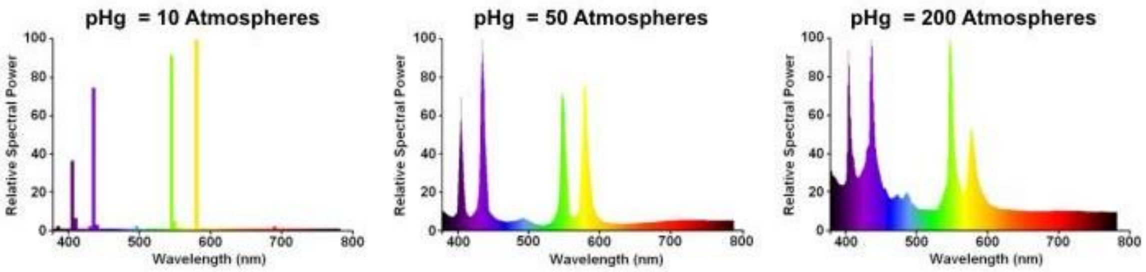

Figure 3: Effects of mercury vapour pressure on the spectral power distribution [4].

Thus the spectral power distribution goes to be a flatter with change of gases to liquids or solids. Radiation function of solids may be described by black body radiation with emissivity[1] lower than 1. Radiation function of the black body was described by Max Planck in 1900:

$$H_\lambda = \frac{2\pi hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda kT}} - 1\right)} \tag{2}$$

where h is Planck constant, c speed of light, κ Boltzmann constant, λ wavelength and T is temperature.

[1] Emissivity is a coefficient of radiation effectiveness of the object surface.

2 EXPERIMENTAL SETUP

Experiments were performed in a high current laboratory at BUT. A dynamo was used as a DC power supply. Series stabilization resistor was used for the current control. Electrodes were cylindrical rods with diameter of 13 mm and length of 100 mm. The cathode and the anode were originally arc lamp carbon electrodes with stabilisation core with sodium and potassium admixture. The arc was projected through the lens to the screen. Optical fibre was used for transmission of light from a specific position to the input slit of the spectrometer. Avantes Avaspec ULS-3648TEC was used as a spectrometer. Data were stored and processed in laptop using AvaSoft 8 software.

The arc was burning under atmospheric pressure without any external ionisation source. Current and voltage between electrodes were measured and maintained constant. Current was of 5 A. Voltage between electrodes was of 55 V.

3 MEASUREMENT PROCEDURE

a) Top electrode was connected as a cathode and free burning arc was generated with current of 5 A and voltage of 55 V between electrodes.
b) Optical fibre was adjusted to the centre of cathode nearest to the arc.
c) Two minutes after the arc ignition a radiation spectrum was taken.
d) Optical fibre was shifted to the anode position and spectrum was recorded.
e) Electrodes position was switched (cathode – bottom, anode – top).
f) Procedure from b) to e) was repeated.
g) Calibration coefficient of spectrometer assembly was applied to measured data.
h) Measured spectra were fitted using Planck function.

4 RESULTS AND DISCUSSION

Data measured at 650 nm and more are not presented due to the low sensitivity of the spectrometer in this range and overlap with the second order.

4.1. CONFIGURATION 1 – CATHODE IN THE TOP POSITION

Radiation spectrum of cathode in the top position can be seen in the Figure 4. The spectrum contains spectral lines because of a high concentration of ions in the cathode area. Moreover the spectrum contains three molecular bands of nitrogen, because an arc was burning in the atmosphere.

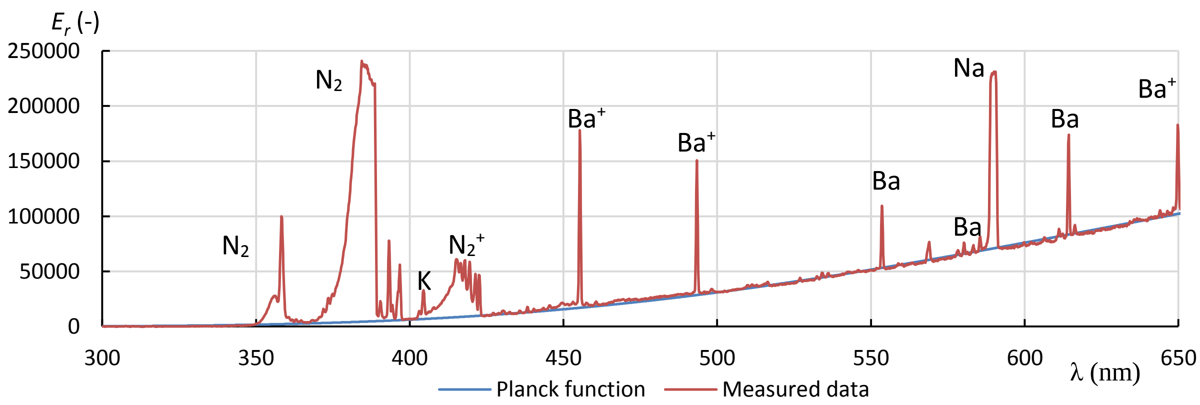

Figure 4: Radiation spectrum of cathode in the top position.

The continuous radiation of cathode in the top position was fitted by the Planck function. The temperature was estimated at 2650 K.

The second investigated object was anode in the bottom position for this configuration, see Figure 5. Radiation spectrum contains Planck function and three molecular bands of nitrogen. Reason of appearance of molecular band in the spectrum is the same as in the cathode area.

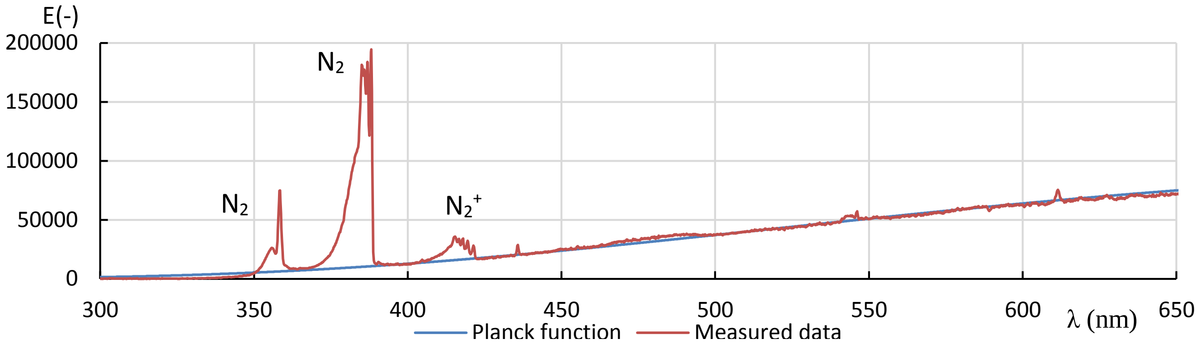

Figure 5: Radiation spectrum of anode in the bottom position.

Temperature of anode was evaluated of 3300 K.

4.2. CONFIGURATION 2 – CATHODE IN THE BOTTOM POSITION

Radiation spectrum of cathode in the bottom position was measured, see Figure 6. The spectrum contains spectral lines and molecular bands of nitrogen in the cathode area, but intensity is lower than in case of measurement in the top position because of lower temperature.

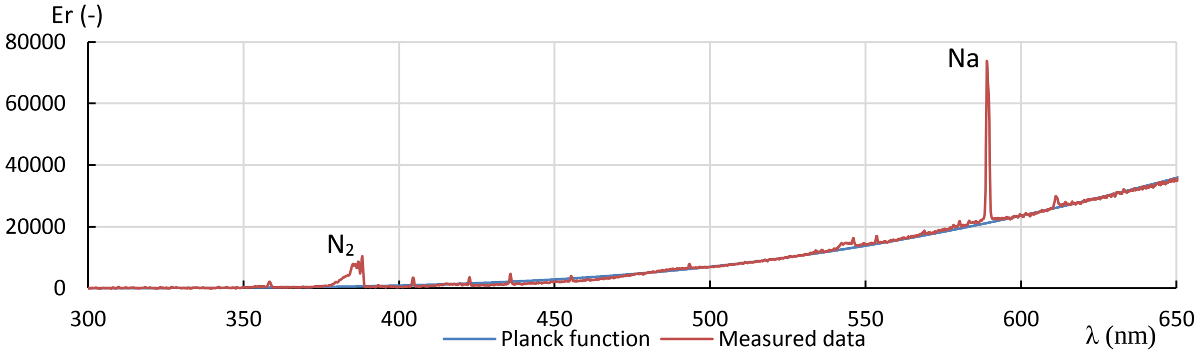

Figure 6: Radiation spectrum of cathode in the bottom position.

Temperature of cathode in the bottom position was calculated at 2250 K.

The second measured object in this configuration was anode. Spectrum can be seen in the Figure 7.

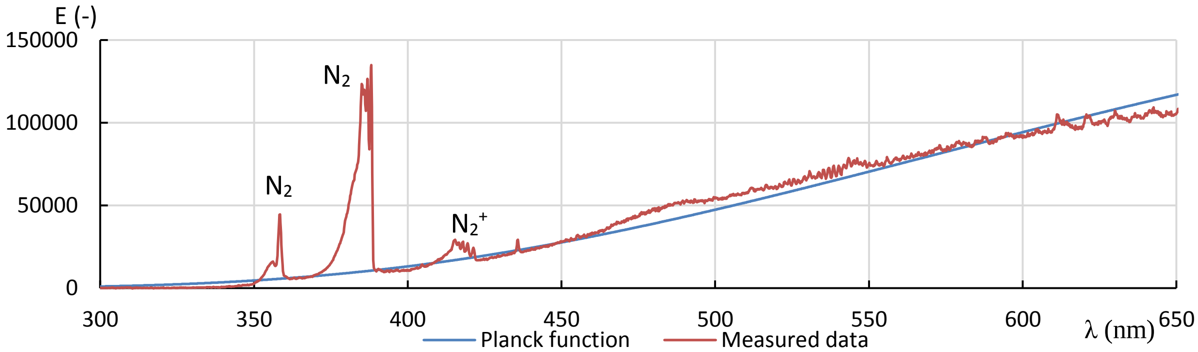

Figure 7: Radiation spectrum of anode in the top position.

Temperature of anode in the top position was of 3000 K. Three molecular bands of nitrogen were observed.

Temperature of both electrodes is higher in case of configuration 1. Temperature of anode is higher for both configuration. This effect may be due to the wider diameter of plasma in the anode area and heating of outside electrode surface.

Investigated object	**Temperature (K)**
Cathode in the top position	2650
Anode in the bottom position	3300
Cathode in the bottom position	2250
Anode in the top position	3000

Table 1: Overview of obtained temperatures

It is important to mention that the result may be affected by a few factors. The first one is a deviation of the measured function due to spectral lines and molecular bands. This deviation was partially eliminated during the fitting by deleting these lines and bands from the solver inputs.

The second problem is due to the emissivity dependence on the wavelength. Interpretation assumes constant emissivity across the used spectrum. Spectral emissivity in the used range of spectrum is almost constant according to Shurer [5].

The third complication is related to the focus. The optical fibre may focus to another point close to the expected measurement area, but it is not exactly the one.

5 CONCLUSION

The aim of the measurement was to find out the DC arc electrodes temperature and its dependence on the electrodes configuration. Temperatures of electrodes were found out for two different configurations. Results will be used for the better description of the DC arc behaviour both in education and research.

Atomic emission spectroscopy was used for spectra measurement. Temperature was obtained using Planck function. Calculated values correspond to the realistic assumptions, although the calculation contains simplifying assumptions.

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