EXPERIMENTAL MEASUREMENT OF RADIAL TEMPERATURE DISTRIBUTION OF DC ARC

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Abstract: The paper is focused on an electric arc spectroscopy diagnostics related to electric low voltage apparatuses. Measurement of radiation spectra of the electric arc burning between carbon electrodes with cooper admixture is presented. Cooper has a lot of suitable atomic spectra lines for calculation purposes. The problems connected with the measurements are discussed. The main part of the paper deals with a calculation of radial temperature distribution of the arc. Abel inversion was used to extracts the radial (2D) distribution from a one-dimensional projection measurement. Atomic lines database of National Institute of Standards and Technology was used as a spectral data source for the calculations.

Keywords: DC arc, temperature measurement, atomic emission spectroscopy

1 INTRODUCTION

Atomic emission spectroscopy is a powerful tool for plasma diagnostic. Hot plasma between electrodes radiates a lot of energy. If the plasma contains free atoms/ions, then its radiation spectrum consists of narrow energy peaks. These peaks are called spectral lines. If the atom/ion accepts amount of energy which is given by the difference between two neighbouring energy levels, then the electron can jump to the higher one. This phenomenon is called excitation. Excited state is unstable. If there is lower energy income than necessary to stay excited, electron moves spontaneously back to the lower energy level while irradiates energy specific to the radiation transfer between two energy levels. This radiation energy can be measured by spectrometer. Two main methods of the spectra measurement are commonly used. The first method based on self-radiation of plasma is called emission spectroscopy. On the other hand the second method which needs supplementary source of radiation is called absorption spectroscopy. The radiation of this source is measured after passing through measured object. Output data from spectrometer is emission or absorption spectrum, see Figure 1.

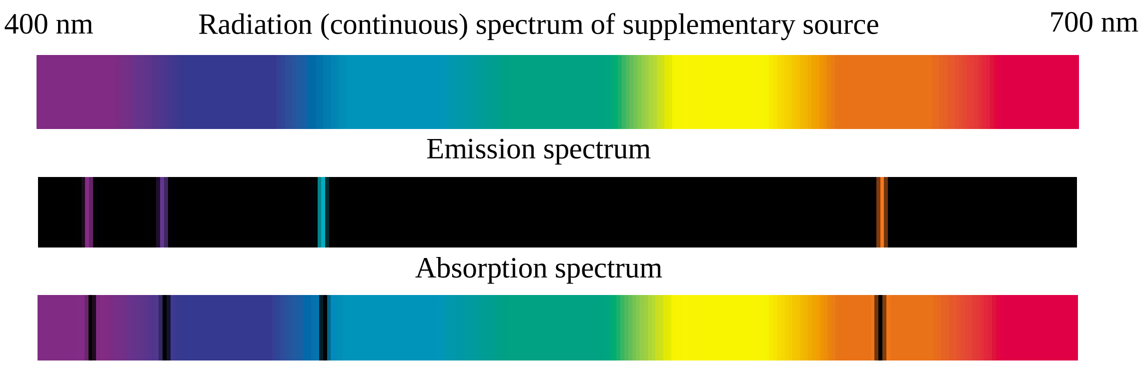

Figure 1: Absorption and emission spectra of hydrogen [1].

Atomic spectra can be described by the Bohr model of atom and wave mechanics. Bohr used classic laws of motion and quantum conditions for his theory. Basic idea was placed by equation (1).

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

where	h	is Planck constant,
	c	speed of light
and	λ	wavelength [1, 2].

Atomic emission spectroscopy is more suitable for electric arc spectra measurements. It allows calculation of a plasma composition, temperature and other important physical properties. An advantage of this method is that the measured object is not affected by the measuring devices. Block diagram of measuring circuit is shown in Figure 2.

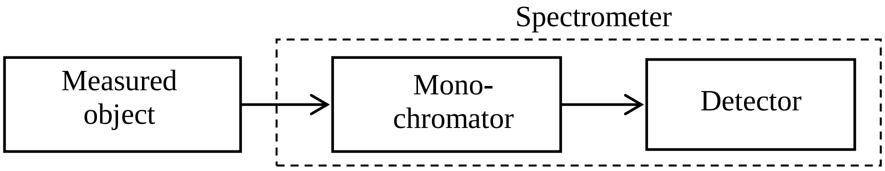

Figure 2: Block diagram of emission spectra measurement.

Spectrometer was used as measuring instrument. CCD chip is commonly used as a detector. Output from this measurement is a line spectrum which contains peaks of specific wavelengths. Peaks look like lines in global view. Shape of a spectral line is shown in Figure 3. In the Figure 3 there are labelled important properties of spectral line: maximum relative intensity of line (I_{max}), full width at half maximum ($\Delta\lambda$) and characteristic wavelength of line (λ_0).

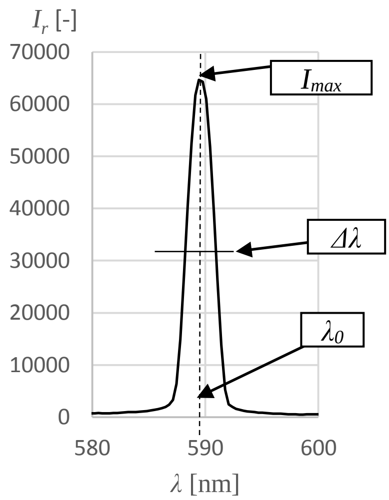

Figure 3: Shape of spectral line [2].

2 EXPERIMENTAL SETUP

Measurement chain was arranged according to Figure 4. Dynamo was used as 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. Cathode was an arc lamp carbon electrode with cooper admixture. Anode was an arc lamp carbon electrode without cooper admixture. The arc was projected through the lens to the screen. Optical fibre was used for necessary separation of measurement devices from the power circuit and transmission of light from a specific position to the input slit of the spectrometer. Avantes Avaspec ULS-3648TEC was used as spectrometer. Data were stored and processed in laptop using AvaSoft 7.7 software.

The arc was burning under atmospheric pressure without any external ionisation source, it is called free burning arc. Both current and voltage between electrodes were measured and maintained constant. Current was of 5 A. Voltage between electrodes was of 52 V.

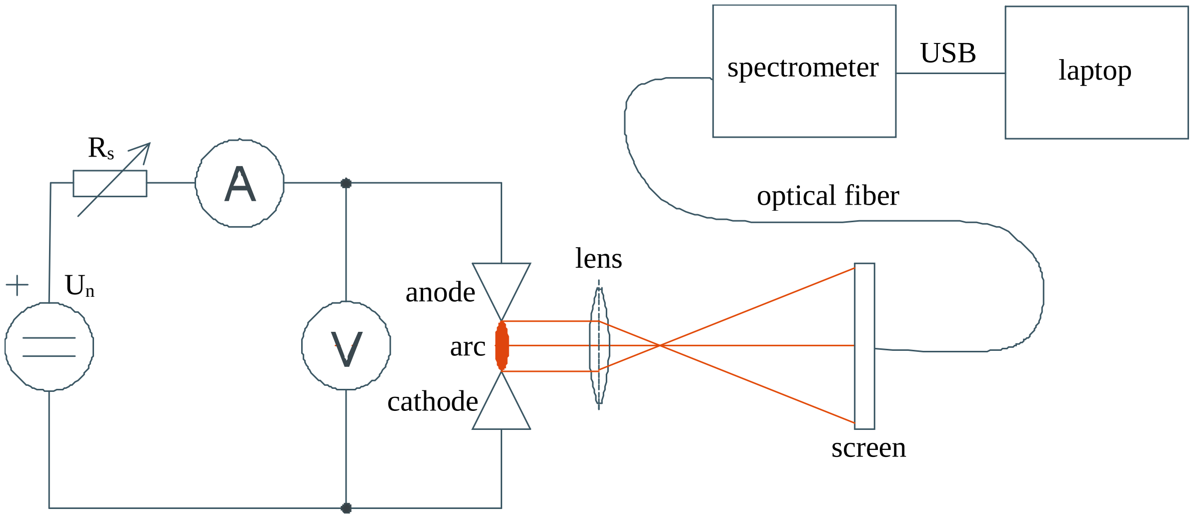

Figure 4: Simplified scheme of measurement chain.

3 MEASUREMENT PROCEDURE

a) The free burning arc was generated with current of 5 A and voltage of 52 V.
b) Optical fiber was adjusted to center of an arc image on the screen.
c) Radiation spectrum was saved into laptop.
d) Optical fiber was shifted to next position and spectrum was saved. Eleven spectra were measured in eleven different positions.
e) Relative radiation intensities of all lines were calculated.
f) Relative radiation intensities of all lines were plotted into graph in dependence on position of optical fiber and points were fitted by polynomial.
g) Abel inversion was applied to all curves to extract the radial (2D) distribution from a one-dimensional projection measurement.
h) Boltzmann plot was plotted for each point and temperature was calculated from slope of the Boltzmann plot.
i) The temperatures were plotted into graph in dependence on distance from the arc axis.

4 RESULTS AND DISCUSSION

Example of radiation spectrum can be seen in the Figure 5. Admixture of cooper is suitable for calculation purposes, because its spectrum contains appropriate lines. The spectral lines are intensive and have appropriate distance between each other.

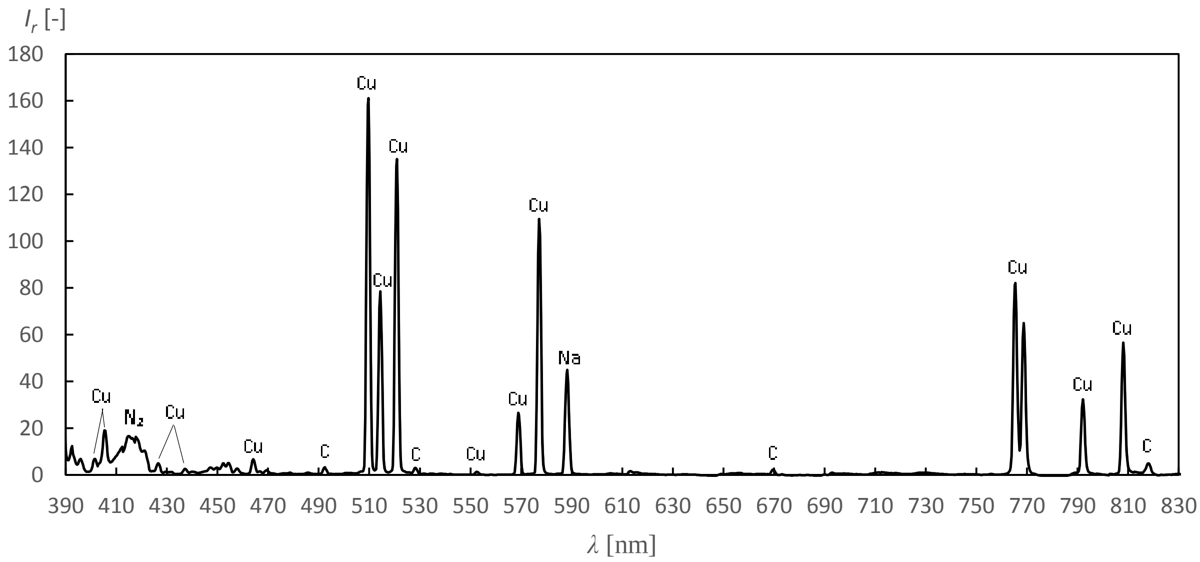

Figure 5: Spectrum measured in axis of the arc.

Radial temperature distribution is presented in the Figure 6. Interpretation assumes cylindrical symmetry of the investigated arc. Boundary points of the arc are not presented due to insufficient signal to noise ratio.

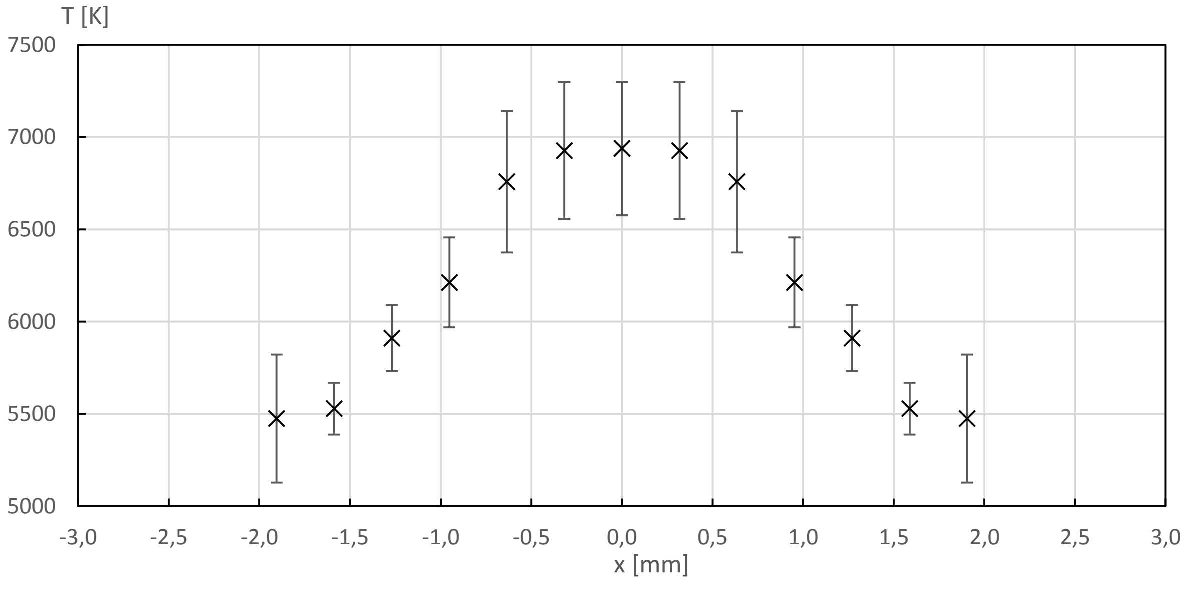

Figure 6: Radial temperature distribution of the arc.

The arc temperature was calculated about 7000 K as maximum temperature near the axis of the arc. The temperature decreases with decreasing distance from the axis.

It is important to mention that the temperature calculation may be affected by a few complications. The first one is a spectral lines shape deviation. It depends on spectrometer resolution.

The second problem corresponds with database using. The transition strength and the transition probability, or Einstein coefficient were taken from the NIST database. The NIST database states that the values used for calculations has accuracy of C+ class. That means accuracy more than 82 %.

Another problem is related to the database using again. NIST database cannot cover all experiment conditions of the spectral line measurement. That means that the database contains lines measured under different pressures, temperatures etc.

5 CONCLUSION

The aim of the measurement was to measure radial temperature distribution of DC arc between carbon electrodes with cooper admixture. Radial temperature distribution of the arc is presented in Figure 6.

Atomic emission spectroscopy was used for spectra measurement. Temperature was calculated from relative intensity of spectral lines of cooper. Calculated values correspond to realistic assumptions, although the calculation contains simplifying assumptions.

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