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MEASUREMENTS OF TEMPERATURES IN A PULSED ARC

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Abstract: Measurements of the intensities of copper spectral lines emitted by a pulsed arc and observed with time resolution, revealed two sets of distribution temperatures. The pattern of temperatures for currents from 3 to 9 amps was found to correspond to a pattern previously found in a d. c. arc.

1. Experimental

In low current discharges there are deviations from the local thermal equilibrium. For a d. c. arc freely burning between copper electrodes, a study of distribution temperatures of low- and high-lying atomic levels revealed a conspicuous behaviour of these temperatures[1]. Here, we describe the results of a similar study carried out on a pulsed arc in the open air. The arc was strongly fluctuating and its time resolved spectrum was obtained by means of an electronic gate which used the sampling principle. The current pulses used are shown in Fig. 1. (The current generator was Russian make DG-2.) The current pulses through the arc lasted approximately 3 ms, the interval between the individual pulses 7 ms, the repetition rate of the pulses being 100 s^{-1}. The experimental set-up is sketched in Fig. 2. The assembly (described in detail in Ref.[2]) can operate in three modes: in the wavelength scanning mode, in the time-scanning mode (»time microscope«), and at fixed time instant t_0 and wavelength λ_0. The duration of the test pulse which determines the time resolution amounted to 5 μs. The time interval scanned extends to 5000 μs. The assembly has the important property that the succession of signals need not be regular since the triggering is done by the signals themselves. A low-frequency limit of the assembly was set at 10 s^{-1}.

A recording instrument shows a mean value of $I(\lambda, t)$ of light intensity during the time constant of the recording instrument; in our case this was equal to 1 s. In our experiment with 100 pulses per second, the number of pulses during the averaging time was equal to 100. The recording instru-

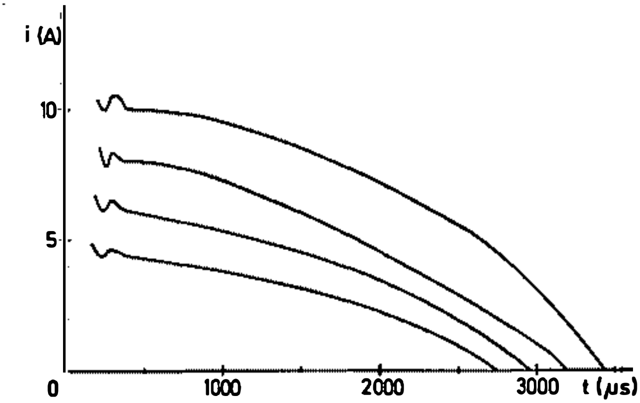

Fig. 1. Current pulses generated by a pulse generator (Russian make, DG-2) and observed at several chosen time instants.

ment of the assembly gave signals reproducible within 5 %, while an independent observation of the light pulses with an oscilloscope found fluctuations of about 30 %. A graphical averaging of the oscilloscope traces would be time consuming and laborious.

2. *Results*

The temperatures were obtained by using the relative intensities of the copper spectral lines 5105 Å (the initial transition level 4p), 5153 Å (4d), and 4530 Å (6s). The light of a 1 mm high central portion of the discharge (the electrodes made of electrolytic copper were spaced 6—7 mm) was dispersed by means of a three-prism glass spectroscope (Russian make ISP-51) equipped with a photomultiplier (photomultiplier attachment FEP-1, photomultiplier RCA 1P21). The straight entrance slit had a width of 20 μm, and the

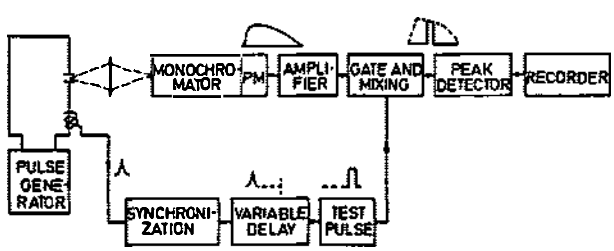

Fig. 2. Time resolving assembly.

curved exit slit 100 μm thus introducing a wavelength interval of 3 Å at 4700 Å. The spectral response of the photoelectric assembly was calibrated by means of a tungsten strip lamp (Osram Wi 17/G). The relative populations of copper atoms for the 4p, 4d and 6s levels were obtained by using the transition probabilities of Ref.[3]. The population lines for any measured current connecting the 4p and 4d levels, were not colinear with the population lines connecting the 4d and 6s levels; the same phenomenon appeared as in the case of a d. c. copper arc (Fig. 2 of Ref.[1]). Using pairs of lines (or pairs of levels), we defined the distribution temperature of the lower levels

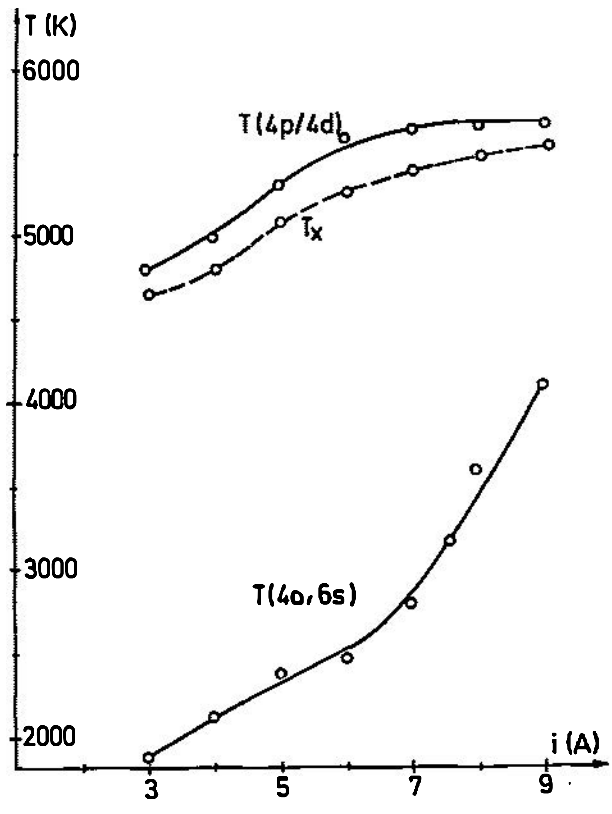

Fig. 3. The distribution temperature of the lower levels T (4p/4d), the distribution temperature of the higher levels T (4d/6s), and the excitation temperature T_x, shown as functions of the current. The excitation temperature was defined with the help of a population line fitting the populations of three levels: 4p, 4d and 6s.

T (4p/4d) and the distribution temperature of higher levels T (4d/6s). The distribution temperature is, according to Kolesnikov[4,5] temperature which is obtained from populations in a limited interval of excitation energies; e. g. distribution temperature T (4p/4d) is obtained by using the slope of line connecting in the Boltzmann plot the populations of 4p and 4d levels. The dependence of these temperatures on the current is shown in Fig. 3. The excitation temperature, defined by the population line best fitting the populations of all three levels (4p, 4d and 6s), runs between the distribution temperature of lower and that of higher levels. (The excitation temperature, as well as distribution temperatures, has the meaning of an average parameter and is used whenever detailed knowledge of population is missing.) This behaviour should be compared with the behaviour of temperatures in a d. c. arc, shown in Fig. 4 of Ref.[1]. In the case of Ref.[1], the excitation temperature was defined by the use of all levels (including a large proportion of very high levels) and exceeded both distribution temperatures. Generally, the behaviour of temperatures in a pulsed arc appears to be of the same kind as in a d. c. arc. The distribution temperature of lower levels is always higher than that of higher levels, although the difference decreases with increasing current. For the highest recorded current of 9 amps, no equilibrium was observed, and cannot be expected even for the current of 10 amps. The difference between temperatures of lower and higher levels is a sign of departures from the local thermal equilibrium.

Observations of average properties give useful insight into the state of affairs. Inhomogeneous sources are in a widespread use since the average parameters obtained refer to a localized layer within the source, which has the most dominant radiative contribution. Radiated energy is a strong function of temperature and intensity deviations of 10 % give rise to the temperature deviations as little as 1 % (for temperature of 5000 K).

The difference between the pulsed and the d. c. arcs may be due to differences in observations, and due to genuine differences inherent in the plasma structure. In the present study, the spectral line 5105 Å was used for measuring the population of the 4p level. (The same line was used in Ref.[6] for measuring the distribution temperature T (4p/4d), and for a 6 amp d. c. stabilized arc a temperature of 5800 K was found.) The distribution temperature of lower levels were not greatly different in two sources, pulsed and d. c. The distribution temperatures of higher levels, however, acquired much lower values in the pulsed arc than in the d. c. arc for currents below 8 amps. For 3 amps, the difference amounted to 1000 K. The physical conditions in the pulsed and the d. c. arcs were certainly not the same, but they could not be ascertained without a more detailed analysis using space and time resolution. We suggest that the causes of the differences may lie in the temporal behaviour of the copper vapour clouds encircling the core of the pulsed arc and having a characteristic life time of the order of milliseconds.

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MJERENJE TEMPERATURA U PULSNOM LUKU

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Sadržaj

Opisan je eksperimentalni uređaj kojim se na principu uzoraka nalaze srednje vrijednosti vremenski razlučenog spektralnog intenziteta. Uređaj je registrirao zračenje pulsnog izboja čiji su pulsevi trajali oko 3 ms i bili učestanosti od 100 s^{-1}.

Mjereni su relativni intenziteti spektralnih linija bakra u zavisnosti o struji, u intervalu od 3 do 9 ampera, te su određene temperature raspodjele donjih nivoa, temperature raspodjele gornjih nivoa i temperature ekscitacije. Nađeno je da je temperatura raspodjele donjih nivoa T (4p/4d) uvijek viša od temperature raspodjele gornjih nivoa T (4d/6s), sl. 3, što je analogno vladanju temperatura u istosmjernom luku u području struja u kojemu ne postoji lokalna termička ravnoteža. Uzrok razlika vrijednosti temperatura mjerenih u pulsnom luku prema onima u istosmjernom, nastoji se naći u vremenskom vladanju pulsnog izboja.