

EFFECT OF SELF-REVERSED SPECTRAL LINES AND THE TEMPERATURE OF THE SWITCHING ARC PLASMA

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1. Introduction

For determining the temperature and its radial distribution in the plasma of an electric arc can be used a method based on the existence of the self-reversal of the spectral lines emanating from the plasma. The method has been theoretically derived by Hans Bartels and has not yet been applied for an AC current fed arc. Even though the theoretical derivation of the mathematical relationships is relatively complicated, the practical application is on the contrary very simple. The application of this method requires the knowledge of the excitation voltages of the lower and upper term of the spectral line employed for the measurement, furthermore a knowledge of the ionization voltage of the chemical element which is emitting this spectral line and it obviously requires the existence of a measurable self-reversal of the employed spectral line. Apart from the determination of the intensity on one beam starting out from the peak of the self-reversal, this method does not require the knowledge and the measurement of further physical quantities. However this method requires the fulfilment four very general assumptions:

- a requirement is that the plasma is axially symmetrical;
- it is assumed that the intensity of the spontaneous plasma radiation decreases monotonously from the axis of the plasma to its fringes;
- it is further assumed that in the frequency range of the considered spectral line the intensity of the spontaneous plasma radiation is constant;
- in the frequency range of the considered spectral line the value of the absorption coefficient must decrease monotonously from maximum in the centre of the line to minimum on its fringe.

These are conditions that can be satisfied relatively easily. As regards the plasma it is assumed that plasma is in a local thermic equilibrium. The maximum temperature of the plasma is determined according to Bartels by the relationship :

$$T_{max} = T(r)_{r=v} = \frac{T_w(v)}{1 + \frac{kT_w(v)}{hf} \ln[M_\infty(v)Y_{max}(p_\infty(v))]},$$

where r is the radial spacing of the monitored location from the plasma axis, y is the perpendicular distance of the monitored ray from the axis, f is the frequency of the monitored spectral line, k and h are the Boltzmann and Planck constants, respectively, and T_w is so-called the Wien temperature, since it is determined with the aid of the Wien law by measuring the radiation intensity emanating from the peaks that surround the self-reversal. The quantities M and p are parameters determined by relatively complicated relationships and are given in the original paper by Bartels. The values of these parameters depend on the frequency interval measured from the frequency value of the self-reversal centre of the spectral line to the frequency value of the peak. With a growing frequency interval the values of these parameters approach the constant limiting values which were denoted as M_∞ and p_∞ . As the expressions for these limiting values are extensive, they are therefore not presented here.

The function $Y_{max}(p_\infty(\nu))$ has also been derived by Bartels and represents a solution of a transcendental equation. Its explicit expression is also considerably complicated. For practical purposes it can be, however, replaced by the approximation

$$Y_{max} = 0.736 + 0.264 p^2$$

which has also been introduced by Bartels.

2. Experimental

This method has been applied to the plasma of an electric arc fed by an AC current with an RMS value of 25A and a frequency of 50Hz. One copper and one carbon electrode was used. The arc burned freely in air in a vertical direction and was displayed by a quartz lens in a 1:1 ratio onto the spectrograph slot. There have been observed the spectral lines of copper with the wavelengths 324.8 nm and 327.4 nm, which exhibited a pronounced self-reversal. The stroboscopic equipment allowed the observation of the spectral line for an arbitrarily long time at always the same value of the AC current phase. That allowed a special stroboscopic device. Upon photographing the spectra pictures were taken with exposures of several seconds up to several tens of seconds, depending upon whether spectra of the arc in the vicinity of current zero or is the vicinity of the maximum were involved.

The photographs of the spectra were photometered with the aid of the CCD camera. During the determination of the absolute radiation intensity of the monitored spectral line, the intensity of this line was compared with the radiation intensity of a standard arc which was implemented by an anode from spectrally pure carbon and a cathode which can be formed by another arbitrary type of carbon. Reproducible radiation intensity values are obtained

by adjusting the AC current onto a value around 80% of the critical current. The critical value of the current can be recognized according to the unstable burring of the arc and a hissing sound which is emitted by the arc directly at the critical value of the current.

3. Discussion

In special references occurs hitherto the opinion that this method can be applied on a homogeneous and also non-homogeneous plasma but in a stationary state. But by the application of a suitable stroboscopic device it was possible to widen the application of this method also on a plasma in the non-stationary state.. In Fig.1 there is the photograph of the AC arc spectrum . On this photo in this paper we can see the self-reversal of two copper lines (324.8 nm and 327.4 nm). In Fig.2 there are digitalized values of blackening of these two spectral lines. The next figure (Fig.3) shows a curve of blackening in one row of the digitalized values table.

The AC arc spectrum was photometered at various locations of the cross section of an axially symmetrical plasma and from the results of the individual evaluations was determined the radial waveform of the plasma temperature at a certain phase value of the AC current. In the form of diagrams (Fig. 4) are displayed the radial temperature waveforms, each for a different phase value. On the horizontal axis is plotted the radial spacing r from the plasma axis, on the vertical axis the local temperature value. From the waveforms in the diagrams can readily be seen the delayed development of the instantaneous plasma temperature values behind the instantaneous values of the electric current, since whereas the value of the current after the attainment of the maximum value (for $\varphi = 90^0$) begins to drop, the temperature still rises (for $\varphi > 90^0$). Measurements confirm that the plasma temperature is a monotonous function of the distance r from the symmetry axis of plasma. It was further proved that the copper electrode dissipates from the plasma more heat than the carbon electrode, since in those half-periods of the AC current, in which the copper electrode was the anode, there occurred a distinct temperature drop in the entire volume of the plasma.

Reference

Bartels, H.: "Eine neue Methode zur Temperaturmessung an hochtemperierte Bogensäulen I." Zeitschr. für Phys. **127** (1950), p. 243

Fig.1: Photograph of the AC Arc Spectrum

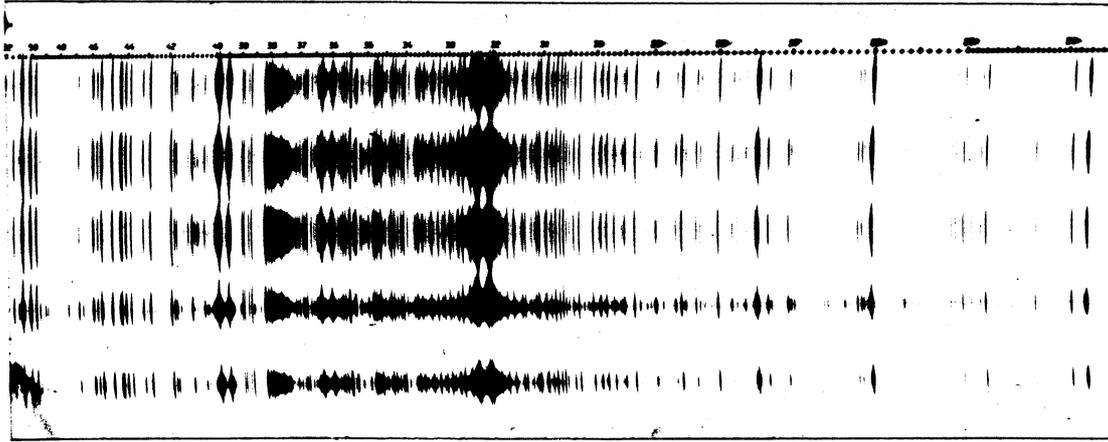


Fig.2: Digitalized Values of Blackening

1	2	3	4	5	6	7	8
2	24	25	29	29	27	27	29
3	27	29	29	29	27	27	25
4	29	27	27	29	29	25	25

Fig.3: Curve of Blackening

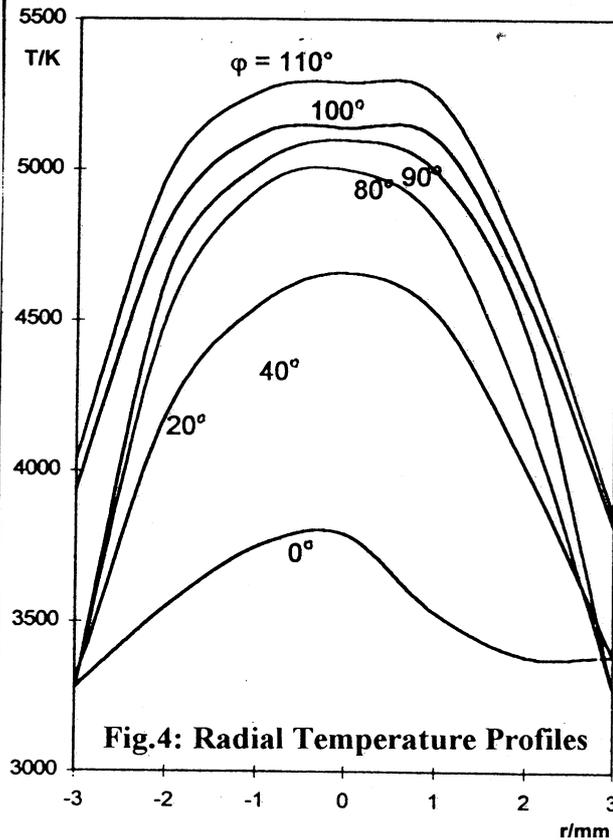
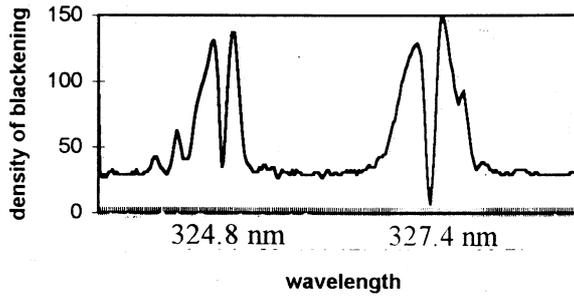


Fig.4: Radial Temperature Profiles

5	27	27	27	27
6	27	27	27	27
7	25	27	31	29
8	25	27	29	29
9	27	29	29	29
10	27	31	27	27
11	27	29	29	25
12	29	29	29	29
13	29	29	27	29
14	29	29	29	29
15	29	29	29	29
16	29	29	29	29
17	29	29	29	29
18	29	29	29	29
19	29	29	29	29
20	29	29	29	29
21	29	29	29	29
22	29	29	29	29
23	29	29	29	29
24	29	29	29	29
25	29	29	29	29
26	27	27	27	27
27	27	31	31	27
28	29	29	29	29
29	29	29	29	29
30	27	29	27	27