High temperature, high density plasmas in a pulsed DC arc

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HIGH TEMPERATURE, HIGH DENSITY PLASMAS IN A PULSED DC ARC

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INTRODUCTION. Atmospheric cascaded arcs are widely used for the investigation of high density plasmas with temperatures in the eV range. These plasmas are close to local thermodynamic equilibrium (LTE), and the small deviations from LTE are well studied.
With cooled cascade-plates one can permit current densities of $10^7 \mathrm{Am}^{-2}$, which yield at 1 atm, in Argon electron densities, n_e, up to $2.10^{23}\mathrm{m}^{-3}$ and temperatures, T_e, up to 16000 K [1].
At higher current densities serious cooling problems can appear and high power supplies are required. An alternative is applying a current pulse to a DC arc. In this way we have increased considerably the current density in a ϕ 8 mm arc, and reached significantly higher densities and temperatures. Before presenting these results, we describe the parameters of the stationary, 8 mm bore, atmospheric cascaded arc in argon.

PARAMETERS IN THE STATIONARY STATE. Values for n_e and T_e have been determined by the "Source Function Method" [1]. The intensity, $J_1(\lambda)$, of a partially absorbed line is measured as a function of wavelength. By allowing a hollow mirror to image the arc in itself, a different intensity, $J_2(\lambda)$, apparantly from an arc with twice the original length, is obtained.
$J_1(\lambda)$ and $J_2(\lambda)$ contain information about the absorption, $K(\lambda)$, and emission, ε_λ, of the observed line.
Now we assume Voigt profiles for $K(\lambda)$ and ε_λ, superimposed on a continuum. Then we generate, according to the formal expressions, theoretical predictions $\overline{J}_1(\lambda)$ and $\overline{J}_2(\lambda)$ for respectively $J_1(\lambda)$ and $J_2(\lambda)$. These are then convoluted with the measured apparatus profile $A(\lambda)$, and the result is compared with $J_1(\lambda)$ and $J_2(\lambda)$. The differences between the two profiles are then minimized with a "least-square" method. From the best fit, profile parameters such as Lorentzian and Gaussian widths, line shift, ε_λ, $S = \varepsilon_\lambda / K(\lambda)$ and information about the continuum is obtained. The electron temperature follows from :

$$S = \frac{2hc^2}{\lambda^5} \{\exp[\frac{hc}{\lambda k T_e}] - 1\}^{-1}$$

n_e can be calculated from the partial Saha equation. For a ϕ 8 mm atmosphere argon arc, we obtain the results shown in figure 1, together with previous results on a ϕ 5 mm atmospheric argon arc [1].

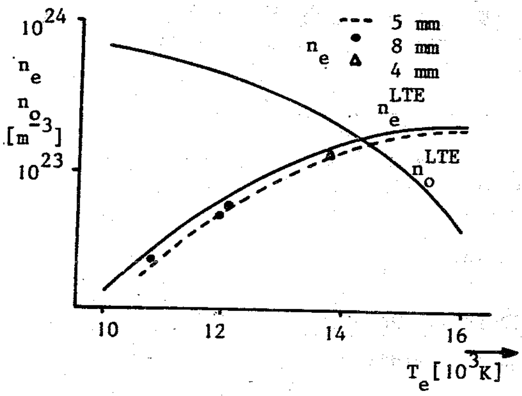

Fig. 1 Particle densities as function of temperature

Also indicated is a result of a ϕ 4 mm argon arc at 1 atm. of an experiment performed at the University of Kiel and worked out by our method.
We note that for the determination of T_e an absolute calibration with e.g. a tungsten ribbon lamp is needed, but that the transition probability A of the considered line (here 696.5 nm) is not needed. For the determination of n_e from PLTE, one does need A and also an expression for the lowering of the ionisation energy.
We note here, that an error in the calibration has also a consequence for n_e. It turns out, that a calibration error moves the (n_e, T_e) point roughly along the PLTE-curve. Se we can conclude, that a small but finite deviation from LTE has been found. Proceeding from the assumption of PLTE, we obtain for the neutral density n_o, $n_o = p/kT_e - 2n_e$ (see also fig. 1). At low current densities (low values of n_e) the assumption that $T_e = T_o$ is not completely correct. But then $n_e \ll n_o$ and $n_o \approx p/kT_e$.

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We have determined n_e interferometrically in the afterglow [2]. Two interferometers were used, both of the coupled cavity type (λ = 3.39 µm and 0.6328 m). The plasma is located in the external cavity, which is weakly coupled to the lasercavity [3]. A charge of the refractive index of the plasma causes an intensity variation of the laser.

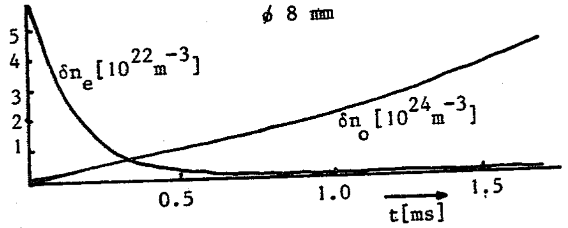

Fig. 2 Changes of n_e and n_o after short-circuit

Care has to be taken to align both interferometers, such that approximately the same plasmavolume is observed. An example of the time history of n_e and n_a is shown in fig. 2. The values of n_e in the stationary state as determined with this method are shown in fig. 3, together with those of the source function method.

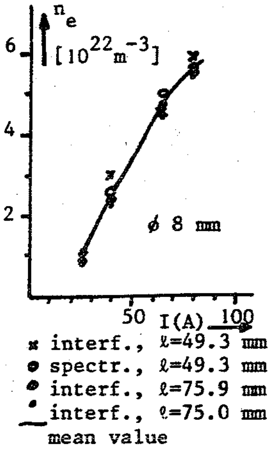

Fig. 3 Electron density as function of the current.

PARAMETERS IN THE PULSED STATE. With a current pulse generator an additional current of 275 A, during 0.5 ms, can be superimposed on the dc plasmacurrent. Again, n_e and T_e are determined by the source function method and by interferometry. The source function method has to be simplified, as there are no full line profiles available, but just the measurements at one (or a few) wavelength positions. It follows from (1) that the ratio of

$$S_{pulse}/S_{cw} = \{\exp[\beta/T_{cw}]-1\}/\{\exp[\beta/T_{pulse}]-1\}$$

If the temperature T_{cw} is known, eg. from stat. meas. the temperature in the pulse, T_{pulse} can be determined without the necessity of an additional absolute calibration. If the apparatus profile width can not be neglected, then for the DC situation a correction is needed. We have used absolute calibration to determine the departing temperature. Using the interf. set-up the electron density and, neglecting the contributions of the excited atoms, also the neutral density can be determined. Up to now only the electron density could be deduced during the whole pulse. The neutral density decreases in the beginning of the pulse, but later it is difficult to locate unambiguously possible signchanges of the phase. It is planned to solve this problem by the application of phase-quadrature [4]. Results of the measured parameters are shown in fig. 4 , for a ϕ 8 mm argon arc at 1 atm. at 65A cw pulsed to about 340 A.

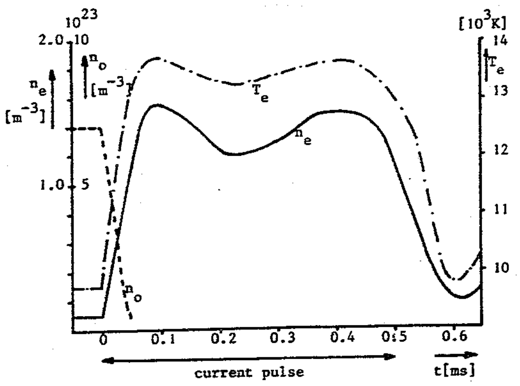

Fig. 4 Pulsed behaviour of T_e, n_e and n_o.

We conclude that with a current pulse, significantly higher temperatures and densities can be reached. By further extrapolation of this method atomic quantities can be determined at higher plasma excitations without any severe technical problems. It is planned to investigate also this system at higher pressures.

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