OPTICAL DIAGNOSTICS OF HIGH CURRENT PULSED ARC IN HIGH DENSITY GAS.

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ABSTRACT

The energy losses mechanism of high current pulsed discharge at high pressure was investigated experimentally. Using the information obtained from emission spectra of the arc column it was shown that the thickness of layer between the arc column and surrounding gas is very small. The temperature gradient existent at this layer can cause the significant heat flux comparable with radiant loss of the arc. The pulsed discharge simulation to be used must take into acount conductive heat transfer from the arc column to the surrounding gas.

NOMENCLATURE

e,	Charge of electron,
m_o	Mass of electron
c	Light velocity.
f_{ik}	Oscillator force
$\varkappa_\nu$	Absorption coefficient
$\varkappa_o$	Absorption coefficient at the line center.
$\Delta\nu$	Half−width of the line
ν_o	Frequency at the line center
n_i	Atom concentration of Cu in the state of energy E_i and statistical weight g_i,
n_o, g_o	Atom concentration and statistical weight of Cu in normal state.
l	Thickness of the absorbing layer
λ	Thermal conductivity
q	Heat flux

INTRODUCTION

A detailed investigation of the physical characteristics of high pressure discharge is conditioned by the technological progress in the area of the dense plasma employment, such as for example, thrusters, electrothermal launchers.

Despite of the achievements made in the field of pulsed discharge study and simulation a number of physical problems still need to be resolved. One of the most important problems in the pulsed discharges is the problem of the energy exchange mechanism from the arc to the surrounding gas. Revealing of this mechanism could enable to evaluate and to predict important discharge parameters as the pulsed pressure, temperature, the electric field strength, etc.

EXPERIMENTAL RESULTS

We present the results of measurements, carried out at a model device described in detail in Ref.[1]. In a closed vessel of volume V_o=30cc, which was filled with helium at the initial pressure P_o<13MPa the discharge (τ~120μs, I_{max}~70kA) was carried out by means of the copper wire of d=0.021cm diameter explosion.

The dynamics of the arc expansion and the spectrum of the discharge column was observed through the optical port by means of the high speed camera. In the course of the energy input into the discharge the pressure value increased up to P~(50−70)MPa.

The spectrum of the radiation of the discharge shows, that it is continuous with broadened absorption lines of the metals of the fuse and the electrodes (copper and sodium). By means of NaI absorption lines broadening the temperature of absorbing atoms of Na was evaluated by authors[2] as T_{ab}~8 10^3K. In that work there also was shown, that the atoms of

metal are not distributed homogeneously in the volume of the discharge vessel. They are concentrated mostly in the expanding arc column.

DISCUSSION

The absorption atoms temperature T_g and the size of absorption zone l can be evaluated from measurements of relative intensity of absorption lines to different excited levels of Cu−atoms. For any contour the relation between the absorbing atoms concentration n_i, the oscillator force f_{ik} and the absorption coefficient $\varkappa_\nu$ is valid, according to[3]:

$$\int_o^\infty \kappa_\nu d\nu = \frac{\pi e^2}{m_o c} f_{ik} n_i \qquad (1)$$

Substituting in (1) the expression of Lorentz contour[3]:

$$\kappa(\nu) = \frac{\Delta\nu^2}{4(\nu - \nu_o)^2 + \Delta\nu^2} \qquad (2)$$

and integrating, we get (if $\Delta\nu \ll \nu_o$) the following:

$$\frac{\pi}{2} \kappa_o \Delta\nu = \frac{\pi e^2}{m_o c} f_{ik} n_i \qquad (3)$$

We assume the excited states distribution of copper atoms as Boltzman's one:

$$n_i = n_o \frac{g_i}{g_o} e^{-\frac{E_i}{kT_g}} \qquad (4)$$

Multiplying both sides of (3) by l−length, at which the absorption takes place, we get:

$$\ln\left(\frac{\kappa_o l\ \Delta\nu\ m_o c\ g_o}{2e^2 f_{ik}\ g_i}\right) = \ln(l\ n_o) - \frac{E_i}{kT_g} \qquad (5)$$

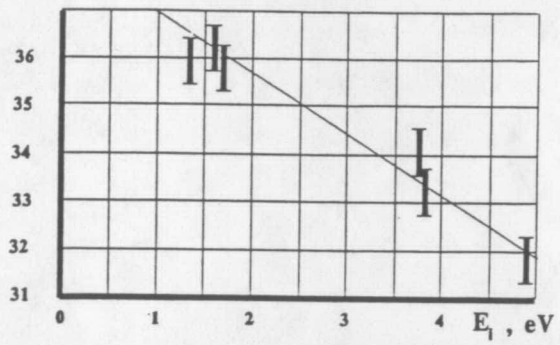

Fig.1. The graphic presentation of equation (5)

where $\varkappa_o l$ is the optical thickness, evaluated by contours of absorption lines. It was taken into account, that the apparent $\Delta\nu_{ob}$ and the true $\Delta\nu$ half−width of absorption line dispersion contour are related by the expression:

$$\Delta\nu_{ob} = \sqrt{\frac{\kappa_o l}{\ln 2 - \ln(e^{-\kappa_o l} + 1)} - 1}\ \Delta\nu \qquad (6)$$

The graphic presentation of E_i as function of the left side of (5) (see Fig. 1) enables to define the excitation temperature by the line inclination angle tangent (assuming the linear approximation) and the value of $n_o l$. It is evident, that the population of excited states is close to the Boltzman's one and the excitation temperature is $T_g \sim 9.4\ 10^3$K. This temperature is close enough to the gas temperature value $T_{ab} \sim 8\ 10^3$K obtained from the NaI D−line of broadening, that proves the existence of equilibrium at the absorption area. Indeed, the frequency of collisions at given temperatures and gas kinetics section areas $\sigma \sim 10^{-15}$cm^2 is about 10^{11}s^{-1}. The value of T_g is some greater than of T_{ab}, evaluated by the NaI absorption line half−width. However, such a discrepancy can be explained by the temperature gradient in the absorption area neglect and by the measured values experimental errors.

This plot allows to determine the value of $n_o l$, which equals to $n_o l \sim 2.4\ 10^{16}$cm^{-2}. The total number of copper atoms in the fuse $N_{Cu} \sim 7\ 10^{19}$. Using the results of the discharge radius measurements[4,5] and correspondingly its volume one can exactly enough estimate the

copper atoms concentration in the discharge. In the case of P_o=11MPa it equals $n_o \sim 10^{19} cm^{-3}$, for the given $n_o l$ one can evaluate the absorbing layer thickness l, which equals $l \sim 3\ 10^{-3} cm$.

The temperature gradient existence at the layer of $l \sim 10^{-3} cm$ thickness (the temperature difference between the discharge and the surrounding gas is $\delta T \sim 2\ 10^4 K$) can cause the significant heat flux q, comparable with other energy losses, radiant $W_r = \sigma_r T^4$, for instance. Let us evaluate the heat flux q

$$q = \lambda \nabla T \approx \lambda \frac{\delta T}{l} \qquad (7)$$

and compare it with the power, radiated from the discharge. Therefore at $l = 3\ 10^{-3} cm$ the heat flux is $q \sim 0.4\ 10^{13}$ erg s^{-1} cm^{-2}. The radiated power at $T \sim 2\ 10^4 K$ equals $W_r \sim 1\ 10^{13}$ erg s^{-1} cm^{-2}.

CONCLUSION

Therefore, the important result is obtained: in high current pulsed arc analysis it is essential to consider not only the radiant loss, but also the heat flux through the arc–surrounding gas layer.

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