ON THE INFLUENCE OF METAL IMPURITIES ON THE THERMAL CONTRACTION OF A NITROGEN ARC

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The influence of metal impurities on the process of contraction (self-constriction) of an arc discharge is considered in the ambient atmosphere of nitrogen. The calculations are carried out, and it is shown that the degree of constriction of an arc discharge is determined by both the thermal characteristics of the gaseous medium and the characteristics of electron-atom collisions. It is revealed that the shape resonance effect under electron-atom collisions has an influence on a character of the contraction of an arc.

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1. INTRODUCTION

Thermal contraction (self-constriction) of an arc discharge is caused by the fact that temperature at the periphery of the discharge falls and the gas density (under constant pressure) rises [1-4]. Therefore, electrons at the periphery give up a larger amount of energy to neutral particles and their temperature falls, which leads, in turn, to a decrease in the concentration of electrons because of the intensification of the recombination processes.

The contraction of an arc in one-component gas media is studied in papers [2-4]. Unfortunately, the obtained results can not be apply to the case of an arc discharge in gaseous mixtures due to the fact that the properties of the mixtures and multicomponent plasmas are known to be not additive relatively to the concentration of components [5,6].

In this paper, it is studied the thermal contraction of an arc in the various mixtures of nitrogen with some metals on the base of formalism of papers [7,8].

It should be mentioned that the contraction is usually considered as a negative phenomenon that restricts an application of arc discharges [1]. However, on the other hand, in certain cases, namely the contraction can be a base in applications of arc discharges in technology [3].

2. MODEL OF AN ARC DISCHARGE

Consider the plasma of the column of a cylindrical arc discharge, in which a local thermodynamic equilibrium (LTE) is maintained. Assuming that the heat release is proportional to the local current density and ignoring the radiant transfer, the heat transfer equation (the Elenbaas-Heller equation) can be written as

$$\frac{1}{r}\cdot\frac{d}{dr}\left\{r\left[\begin{array}{l}\left(\kappa_g(T)+\kappa_{rd}(T)\right)\dfrac{dT}{dr}\\ +\left(\kappa_e(T_e)+\kappa_{ri}(T_e)\right)\dfrac{dT_e}{dr}\end{array}\right]\right\}+q(r)=0 \qquad (1)$$

.

Here, r is the distance from the discharge axis, T is gaseous temperature, T_e is electron temperature, $\kappa_g(T),\kappa_{rd}(T),\kappa_e(T_e),\kappa_{ri}(T_e)$ are the coefficients of gaseous, dissociate, electron, ionization heat conductivities, respectively; $q(r)=j(r)E$ is the power of heat release per unit volume; $j(r)=\sigma E$ is the electric current density; E is electric field strength, σ is electric conductivity.

Consider a gas at low ionization, when $kT_e \ll U_I$, where U_I is the effective energy of ionization of a gaseous medium. If LTE occurs, the number density of electrons n_e at the point of discharge is connected with the number densities of ions n_i and neutrals n_a by the well-known Saha formula

$$\frac{n_e n_i}{n_a}=\frac{2g_i}{g_a}\left(\frac{2\pi m_e kT_e}{h^2}\right)^{\frac{3}{2}}\exp\left(-\frac{U_I}{kT_e}\right), \qquad (2)$$

where m_e is electron mass, h is the Planck constant, g_i, g_a are the effective statistical weights of ion and atom, respectively.

Since LTE occurs in the plasma region, which is determined by its heat balance, the temperatures of electrons and gas are varied weakly. That fact allows to obtain an approximate solution of Eq.(1) by using the method stated in [2,4,7,8]. Accordingly to this method, we assume that the dependences of the current density, power of heat release, and corresponding quantities on the temperature in the cross-section of a discharge are given, and the coefficients in Eq.(1) are constant, and their values are set on the discharge axis. In this way we obtain the following system of equations that is described an arc discharge:

$$T_e-T=\frac{M}{3k}\left(\frac{eE}{m_e}\right)^2\frac{\left\langle u_e^2/\nu_{ea}\right\rangle}{\left\langle u_e^2\nu_{ea}^*\right\rangle}\quad , \qquad (3.1)$$

$$IE=\frac{\pi kT_e^2}{E_I}\left[16\kappa_h^*\zeta_T\left(1+\left(\frac{r_g}{R}\right)^2\right)^{-1}+5\kappa_e^*\right]\quad , \qquad (3.2)$$

$$S=0.215q_0r_0{}^2\ln\left(\frac{R}{r_0}\right)\quad , \qquad (3.3)$$

$$p+\Delta p=NkT+n_ekT_e\quad , \qquad (3.4)$$

$$I = \sigma E \cdot \pi r_0^2 \quad . \qquad (3.5)$$

Here e is an electron charge, M is an effective mass of atom in gaseous mixtures ($M^{-1} = \sum\limits_{\alpha} x_\alpha m_{a\alpha}^{-1}$, where the subscript α indicates the type of species, $m_{a\alpha}$ is an atom mass, x_α is the molar concentration of α -species), $\nu_{ea} = \sum\limits_{\alpha} \nu_{e\alpha}$, $\nu_{ea}^* = \sum\limits_{\alpha} (M/m_{a\alpha}) \nu_{e\alpha}$, where $\nu_{e\alpha}$ is the frequency of electron-atom collisions for the α -species in mixture, u_e is the electron velocity, and the bracket $\langle \ \rangle$ denotes the averaging over the Maxwellian distribution of electron velocities; $\kappa_h^* = \kappa_g + \kappa_{rd}$, $\kappa_e^* = \kappa_e + \kappa_{ri}$, I is the arc current, R is the radius of the chamber wall, S is the heat function, $q_0 = \sigma E^2$, $\zeta_T = dT/dT_e$, Δp is the diminution of pressure in plasma, and r_0 is a characteristic radius of plasma (radius of contraction), which is determined from the relation $r_0^2 \approx 1.32 r_g^2 + r_J^2$, where r_g and r_J are determined as

$$r_g^2 = \frac{16 k T_e^2 \kappa_h^* \zeta_T}{q_0 E_I}, \qquad r_J^2 = \frac{11.6 k T_e^2 \kappa_e^*}{q_0 E_I} \ .$$

The heat function S is determined as

$$S = \int_0^{T_e} \kappa_e^* (T_e') \, dT_e' + \int_0^{T} \kappa_h^* (T') \, dT' \cdot$$

For gaseous conductivity of inert gas mixtures it is used the Wassiljeva's formula with coefficients calculated by the Mason-Saxena method [5]. To calculate electric conductivities of the complex arc plasma it is used the first order approximations from [6]. Under calculations the cross-section data are used from [9-13]. Upon increasing the ionization degree it is essential to consider the Coulomb collisions because it should be respectively modified the above frequencies.

Also, it should be took into account the following conditions: the quasineutrality of plasma $n_e = n_i$, the electric field strength and the ambient atmosphere pressure are constant ($E = const$, $p = const$).

The system (3) with the Saha formula (2) allows us to obtain the values of $E, T_e, T, n_e, n_a, N, r_0$ under the desired values of the arc current I and pressure p and vice versa.

3. RESULTS AND DISCUSSION

The above-presented model of an arc discharge describes the discharge where the released heat is transferred by means of conductivity into the wall of the discharge tube. This situation corresponds to the idealization of a long arc (see [4]).

The characteristics of an arc without radiation transfer are known to describe in unified variables r/R, ER and I/R. The arc temperatures are calculated for some mixtures (Fig.1). In experiment the atmospheric air arc discharge is studied between melting *Ag-CdO* electrodes under 3.5 A. Thus, we can see that the measurements using Ag I lines are in good agreement with calculation.

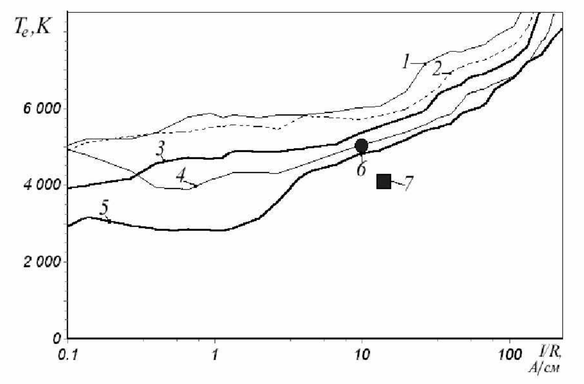

Fig.1.The calculated values of the electron temperature on the axis of the arc (p =1 atm). Calculation: the equimolar mixtures of nitrogen (90%) with metals (10%), curves 1-N_2-Hg, 2- N_2-Zn, 3- N_2-Cd, 4- N_2-Ag, 5- N_2-Mo. Experiment: the arc in Ag-Cd vapours (present work), 6 - from Ag I lines (520.9 nm, 827.3 nm), 7 - from Cd I lines (479.9 nm, 508.5 nm, 643.8 nm)

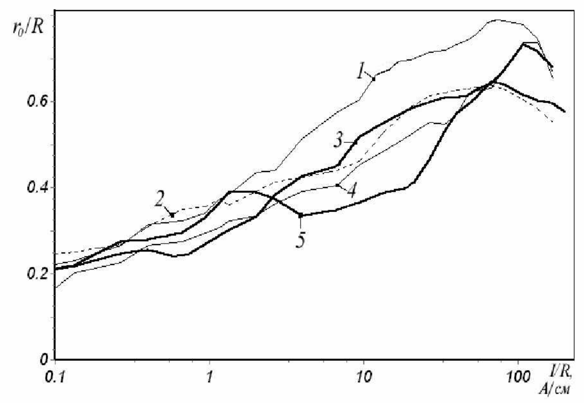

Fig.2. The calculated values of the reduced radius r_0/R of contraction via reduced current I/R (p =1 atm) for the equimolar mixtures of nitrogen (90%) with metals (10%), curves 1-N_2-Hg, 2- N_2-Zn, 3- N_2-Cd, 4- N_2-Ag, 5-N_2-Mo

The calculation of a reduced radius of contraction r_0/R in various regimes allows us to depict the following discharge contraction pattern (Fig.2). At a relatively low current the extremely strong constriction of an arc occurs under dominating the gaseous heat conductivity. At increasing of current the electron heat conductivity is raised to a leading hand. If the electron-atom collisions are still dominated than the value of reduced radius of contraction is stabilized i.e. $r \propto R$. At the follow-up increasing of current the Coulomb collision is prevailed and the discharge field is diminished.

The most important influence on the properties of an arc plasmas have the discrepancy between gaseous and electron temperatures that depends on the peculiarities of electron-atom cross-sections. It should be noted that under scattering of electrons on molybdenum the shape resonance takes place. That causes the strong constriction of an arc under low current (Fig.2).

4. CONCLUSIONS

The degree of thermal contraction of an arc discharge is determined by the heat transfer characteristics of the gaseous mixture and by the characteristics of electron-atom collisions.

The contraction of a discharge in a certain mixture is more pronounced in the case where the gaseous thermal conductivity dominates in the heat transfer processes.

The presence of the shape resonance effect for a gas medium where an arc is burning has an essential influence on the process of contraction under low current.

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О ВЛИЯНИИ МЕТАЛЛИЧЕСКИХ ПРИМЕСЕЙ НА ТЕПЛОВУЮ КОНТРАКЦИЮ АЗОТНОЙ ДУГИ

П.В. Порицкий, А.Н. Веклич

Рассмотрено влияние характеристик газовой среды на процесс контракции (сжатия) дугового разряда в смесях азота с парами металлов. Проведены расчеты и показано, что степень сжатия дугового разряда определяется теплофизическими характеристиками газовой среды и характеристиками столкновений электронов с атомами и ионами. Выявлено влияние эффекта резонанса формы на характер контракции дугового разряда.

ПРО ВПЛИВ МЕТАЛЕВИХ ДОМІШОК НА ТЕПЛОВУ КОНТРАКЦІЮ АЗОТНОЇ ДУГИ

П.В. Порицький, А.М. Веклич

Розглянуто вплив характеристик газового середовища на процес контракції (стягування) дугового розряду в суміші азоту з парами металів. Проведені розрахунки і показано, що ступінь стягування дугового розряду визначається теплофізичними характеристиками газового середовища і характеристиками зіткнень електронів з атомами та іонами. Висвітлено вплив ефекту резонансу форми на характер контракції дугового розряду.