MECHANISMS OF THE CONTRACTION OF AN ARC DISCHARGE. 1. PECULIARITIES OF THERMAL CONTRACTION

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The influence of properties of a gaseous medium on the processes of contraction (self-constriction) of an arc discharge in the atmosphere of inert gases is theoretically considered. The calculations are carried out, and it is shown that the degree of constriction of an arc discharge is determined by both the thermophysical characteristics of the gaseous medium and the characteristics of electron-atom collisions. It is revealed that the Ramsauer effect has an influence on a character of the contraction of an arc discharge.

Introduction

Electric arc discharge occurs in a gaseous channel that has an electrical conductivity. The conductivity of the arc plasma is a result of thermal ionization at temperatures relatively high as compared to that of electrodes. Also, there is a balance between both the heat generation in plasma due to the electric current and the heat flux towards electrodes and the external gas.

The contraction (self-constriction) of a discharge takes place if the following conditions are met [1—4] : (1) bulk neutralization of charged particles dominates their diffusion drift to walls of a discharge chamber; (2) frequency of the formation of charged particles sharply decreases from the axis to the chamber walls. Thus, the degree of contraction of a discharge depends upon the nonuniformity of the temperature across its section. In particular, thermal contraction is caused by the fact that temperature at the periphery of the discharge falls and the gas density (under constant pressure) rises. 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.

As a rule, the thermal contraction of an arc discharge takes place under high pressure or middle one. On the other side, for a low-pressure arc discharge and glow discharge, when the processes of heat transport are negligible, the concentration contraction is typical, which is mainly due to a nonlinear dependence of the ionization coefficient on the concentration of plasma components [2, 3].

The amount of energy that is transferred to heavy particles from electrons, has a strong dependence on a type of the particles (atoms, ions, molecules, clusters, etc.). Because of that, the process of contraction has an essentially different character in various gaseous media.

As a rule, in the calculation of both the transport coefficients and the temperature of plasma components, the frequency or the cross-sections of electron-atom collisions are assumed to be independent of the electron energy to simplify calculations [4—7]. However, the cross-sections of electron-atom collisions may be characterized by a nonmonotonous dependence on electron energy. Especially, the deep minimum is observed for certain noble gases and alkaline metals. This phenomenon is called the Ramsauer effect that has an influence on the plasma properties.

In this paper, the real cross-sections are taken into account, and the influence of characteristics of the gaseous medium on the process of thermal contraction in the atmosphere of various inert gases is studied.

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 [8].

1. Local Thermodynamic Equilibrium

The state of the plasma of an arc discharge at a normal or high pressure is described as a state of local thermodynamic equilibrium (LTE) [7, 9]. Because of the high concentrations of atoms and electrons, the collision processes play a significant role in that plasma. In this case, the diffusion of particles due to a space inhomogeneity is negligible, and the state close to equilibrium is supported at each point of the discharge. The two-temperature model of plasma is considered in the case where a state is described by both the certain gaseous temperature T and the electron one T_e, which corresponds to a Maxwellian function of distribution of atoms and electrons over velocities. There is the ionization equilibrium relative to T_e.

The temperatures are established due to the interactions of electrons with external fields, the collisions of electrons with atoms and heat transfer in the cross-section of the discharge. But, the interrelation between both the gaseous temperature and electron one is only determined by collision processes and the interaction of electrons with an electric field. In the case where a gas-discharge plasma is in a constant electric field of intensity E, an equation which determines the interrelation between both the gaseous temperature and electron one has the form [1, 7, 10]

$$[T_e - T = \frac{m_a}{3k}\left(\frac{eE}{m_e}\right)^2 \frac{\langle u^2/\nu_{ea}\rangle}{\langle u^2\nu_{ea}\rangle}, \tag{1.1}$$

where m_a is the atomic mass, k is the Boltzmann constant, e is the electron charge, m_e is the electron mass; u is the electron velocity, v_{ea} is the frequency of electron-atom collisions; the angular brackets denote the averaging with the Maxwellian distribution function of electrons over velocities.

Consider a gas at low ionization, when

$$kT_e << E_I. \tag{1.2}$$

Here, E_I is the effective energy of ionization of a gaseous medium.

For the regime of discharge, when 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 neutral atoms n_a by the Saha formula [7, 11]

$$\frac{n_e n_i}{n_a} = \frac{2g_i}{g_a}\left(\frac{2\pi m_e kT_e}{h^2}\right)^{\frac{3}{2}} \exp\left(-\frac{E_I}{kT_e}\right), \tag{1.3}$$

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

It should be pointed that, because of condition (1.2), the density of excited atoms in plasma is small in comparison to the density of atoms in the ground state.

The criterion of local ionization equilibrium has the form [7, 12]

$$\tau_{\rm rec} << \tau_{\rm dif}, \tag{1.4}$$

where $\tau_{\rm rec} \sim \left(Kn_e^2\right)^{-1}$ is the characteristic recombination time for electrons, and $\tau_{\rm dif} = \frac{r_{\rm PS}^2}{a_g D_{\rm amb}}$ is the characteristic diffusion time of electrons from the plasma region. Here, K is the three-body recombination rate constant which is equal to $K = 6.4\cdot 10^{-22(1000/T_e)^{9/2}}$ cm^6/c [3—5], where temperature is expressed in K; $r_{\rm PS}$ is the plasma region radius, a_g is a geometric factor (for the cylindrical form, $a_g = 5.78$) .

Thus, the local ionization equilibrium takes place if

$$\eta = \frac{\tau_{\rm dif}}{\tau_{\rm rec}} = \frac{Kn_e^2 r_{\rm PS}^2}{a_g D_{\rm amb}} >> 1 \tag{1.5}$$

2. Model of an Arc Discharge

Consider the plasma of the column of a cylindrical arc discharge, in which a local thermodynamic equilibrium 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 [4, 13]) can be written as

$$\frac{1}{r}\frac{d}{dr}\left\{r\left[\kappa(T)\frac{dT}{dr}+\right.\right.$$

$$\left.\left.+(\kappa_e(T_e)+\kappa_p(T_e))\frac{dT_e}{dr}\right]\right\} + q(r) = 0. \tag{2.1}$$

Here, r is the distance from the discharge axis, $\kappa(T), \kappa_e(T_e), \kappa_p(T_e)$ are the coefficients of gaseous, electron heat conductivity and that due to the ionization-recombination process, respectively; $q(r) = j(r)E$ is the power of heat release per unit volume; $j(r) = \sigma E$ is the electric current density, and σ is the electric conductivity of plasma.

Equation (2.1) describes the heat transfer in a cross-section of an arc discharge. The temperature field is obtained from the solution of this equation. The boundary conditions may be taken in the following manner: the temperature at the center $T(0) = T_0$, and the temperature at the wall of a discharge tube ($r = R$) $T(R) = T_R = \text{const}$.

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. (2.1) by using the method stated in [4—6]. Accordingly to this method, we assume that the dependences of the current density, power of heat release, and correspondent quantities on the temperature in the cross-section of a discharge are given. The coefficients in Eq. (2.1) are assumed to be constant, and their values are set on the discharge axis. In this way, we can transform Eq. (2.1) to an ordinary differential equation. An analytical solution of

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this equation gives the distributions of temperatures, current density, and other values over the discharge cross-section.

The analytical solution of Eq. (2.1) is important despite its approximate nature because this allows us to analyze the influence of various physical mechanisms on the distributions of temperatures and other values over the cross-section of the discharge.

By introducing a new variable $\theta = \frac{[T_e(0)-T_e(r)]E_I}{2kT_e^2(0)}$, we obtain $n_e(r) = n_e(0)\exp(-\theta)$. Respectively, the current density and the power of heat release varied over a cross-section as $j(r) = j_0 \exp(-\theta)$ and $q(r) = q_0 \exp(-\theta)$, where $j_0 = j(0)$, $q_0 = q(0)$. Moreover, $\kappa_e \sim n_e \sim \exp(-\theta)$ and $\kappa_p \sim n_e \sim \exp(-\theta)$. Then, by introducing the dimensionless variable $x = \left(\frac{r}{R}\right)^2$, we reduce the equation of heat balance (2.1) to

$$\frac{d}{dx}\left(x\left[\exp(-\theta)+\xi\right]\frac{d\theta}{dx}\right) - A\exp(-\theta) = 0 \qquad (2.2)$$

where the parameters are as follows:

$$\xi = \zeta_T \frac{\kappa(T)}{\kappa_e(T_e)+\kappa_p(T_e)},$$

$$A = \frac{q_0 R^2 E_I}{8kT_e^2\left(\kappa_e(T_e)+\kappa_p(T_e)\right)}, \quad \zeta_T = \frac{dT(r)}{dT_e(r)}.$$

The first term in Eq. (2.2) corresponds to the heat flux due to heat conductivity, and the second characterizes the heat flux connected to the current through plasma.

In the limit case where the heat flux is determined by the gaseous heat conductivity ($\xi >> 1$), the solution of (2.2) is

$$\theta = 2\ln\left(1+(Ax/2\xi)\right), \qquad (2.3)$$

which corresponds to the following distribution of the number density of electrons over a cross-section:

$$n_e(r) = n_e(0)\exp(-\theta) = n_e(0)F(r) \qquad (2.4)$$

where $F(r) = \frac{1}{(1+(r/r_g)^2)^2}$, $r_g = \frac{16\zeta_T kT_e^2\kappa(T)}{q_0 E_I}$. Similar formulas describe the distributions of temperatures, current density, and power of heat release.

The connection between the power of heat release per unit length Q and the temperature at the center can be obtained by the integration of $q(r)$ over the cross-section of discharge:

$$Q = IE = \int_0^R q(r)\,2\pi r dr = \frac{16\pi kT_e\kappa(T)\zeta_T}{E_I}, \qquad (2.5)$$

where all the values on the right-hand side are taken at the center of the discharge.

In the second limit case where the heat flux is determined by electron heat conduction ($\xi << 1$), we obtain

$$n_e(r) = n_e(0)\exp(-\theta) = n_e(0)J_0\left(2\sqrt{A}\frac{r}{R}\right),$$

$$0 \le r \le r_J, \quad n_e(r) = 0, \quad r > r_J. \qquad (2.6)$$

For Q, we have

$$Q = IE = \int q(r)\,2\pi r dr \approx 1.36 q_0 r_J^2 =$$

$$= \frac{15.7kT_e^2\left(\kappa_e(T_e)+\kappa_p(T_e)\right)}{E_I}. \qquad (2.7)$$

Grouping relations (2.5) and (2.7), we obtain a general expression for the power of heat release per unit length of discharge:

$$Q = IE \approx \left(16\zeta_T\kappa(T) + 5\left(\kappa_e(T_e)+\kappa_p(T_e)\right)\right)\frac{\pi kT_e^2}{E_I}. (2.8)$$

The effective radius of plasma r_0 (a contraction radius) is defined as

$$\int_0^R n_e(r)\,2\pi r dr = 1.36 n_e(0) r_0^2. \qquad (2.9)$$

Then, with regard for (1.2), (2.4), (2.7,) we obtain

$$r_0^2 = \left(37.1\zeta_T\kappa(T) + 11.6\left(\kappa_e(T_e)+\kappa_p(T_e)\right)\right)\frac{kT_e^2}{q_0 E_I}. (2.10)$$

If r_0 characterizing the discharge plasma size is small as compared to the radius of a discharge tube R, the contraction takes place. In addition, it follows from (2.10) that if the energy release is increased, then the plasma region size is decreased.

To calculate the parameters of the discharge, we need to obtain an additional relation. We introduce a heat potential function as

$$S = \int_0^{T_e}(\kappa_e(T_e^{'}) + \kappa_p(T_e^{'}))dT_e^{'} + \int_0^T \kappa(T^{'})dT^{'}. \qquad (2.11)$$

Let condition (1.2) be hold. By assuming that $\kappa(T) \sim T^\gamma$ and the gaseous and electron temperatures are equal to their values on the discharge axis, we get

$$S = \left(\kappa_e(T_e)+\kappa_p(T_e)\right)\frac{2kT_e^2}{E_I} + \kappa(T)\frac{T}{1+\gamma}. \qquad (2.12)$$

On the other hand, twice integrating (2.1), we have

$$S = 0.215 q_0 r_0^2 \ln\left(\frac{R}{r_0}\right). \tag{2.13}$$

These expressions are used to calculate the characteristics of the arc discharge.

To study the separation between both the gaseous and electron temperatures in various gases, we write (1.1) as

$$T_e - T = \left(\frac{E}{n_a}\right)^2 g\left(T_e\right), \tag{2.14}$$

where $g\left(T_e\right) = \frac{m_a}{3k}\left(\frac{e}{m_e}\right)^2 \frac{\langle u^2/k_{ea}\rangle}{\langle u^2 k_{ea}\rangle}$, $k_{ea} = \nu/n_a = u\sigma_{ea}^*(u)$ is the rate constant of electron-ion collisions, and σ_{ea}^* is the momentum-transfer cross-section of electron-ion collisions.

The function $g\left(T_e\right)$ does not depend on the electrical field strength E or the atomic number density n_a and thus is the universal characteristic of the indicated temperature separation.

In the calculations of the parameters of an arc discharge, the momentum-transfer cross-sections are taken from [14, Chapter 14]. The electric conductivity of plasma and the electron heat conductivity are described by the following formulas [11, 15]:

$$\sigma = \frac{n_e e^2 \left\langle u^2\right\rangle}{m_e \left\langle u^2 \nu_{ea}\right\rangle}, \tag{2.15}$$

$$\kappa_e = \frac{5}{2}\frac{n_e k^2 T_e \left\langle u^2\right\rangle}{m_e \left\langle u^2 \nu_{ea}\right\rangle}. \tag{2.16}$$

The heat conductivity of gases does not practically depend on pressure (excepting the case of low pressure), and the coefficient of heat conductivity of noble gases is approximately described by the formula [16]

$$\lambda = \lambda_{273}\left(T/T_{273}\right)^{\gamma}, \tag{2.17}$$

where $T_{273} = 273.16$ K, $\lambda_{273} = \lambda\left(T_{273}\right)$, $0.7 < \gamma < 0.95$.

Upon increasing the ionization degree $\alpha = n_e/N$ up to $10^{-4} - 10^{-3}$, it is essential to consider the Coulomb collisions of electrons with ions. In the used formulas, we should replace the frequency of electron-atom collisions by that of collisions of electrons with heavy particles (atoms and ions) $v_e = v_{ea} + v_{ei}$, where v_{ei} is the frequency of electron-ion collisions that are expressed via the momentum-transfer cross-section of Coulomb collisions $\sigma_{ei}^*\left(u\right)$ [15]:

$$\nu_{ei}\left(u\right) = n_i u \sigma_{ei}^*\left(u\right) = \frac{1}{4\pi} n_i \left(\frac{e^2}{m_e \varepsilon_0}\right)^2 \frac{L_{ei}}{u^3}, \tag{2.18}$$

where ε_0 is the electric constant; $L_{ei} = \ln\left(\frac{12\pi\varepsilon_0 k T_e r_{\rm D}}{e^2}\right)$ is the Coulomb logarithm, $r_{\rm D} = \sqrt{\frac{\varepsilon_0 k T_e T}{n_e e^2 (T_e + T)}}$ is the Debye radius.

The coefficient of heat conductivity defined by the processes of ionization-recombination can be calculated [1, 9] as

$$\kappa_p = \frac{D_{\rm amb} n_e}{2}\left(\frac{E_I}{kT_e}\right)^2. \tag{2.19}$$

This value can be essential for the total heat conductivity due to a large value of $\left(E_I/kT_e\right)^2$.

The coefficient of ambipolar diffusion is expressed via the ion diffusion coefficient $D_{\rm ion}$ by the formula [7, 17]

$$D_{\rm amb} = D_{\rm ion}\left(1 + \frac{T_e}{T}\right) \tag{2.20}$$

In turn, the coefficient of ion diffusion is mainly determined by the resonant intercharging and may be calculated [17] as

$$D_{\rm ion} N = d_{i0}\sqrt{\frac{T}{T_{i0}}}, \tag{2.21}$$

where d_{i0} is the constant for certain types of ions and ambient gases, and T_{i0} =1000 K. In calculations, we used the data on ion diffusion [17, 18].

The above-presented relations (2.8), (2.10), (2.12), (2.13) with (1.3), (2.14)—(2.21) allow us to obtain the parameters of discharge, with taking into account the additional conditions that are the following the electric field strength and the pressure are constant (E = const and p = const) over the cross-section of discharge. We also used the equation of state $p = NkT + n_e k T_e \approx n_a k T$, where N is the number density of heavy particles, the condition of quasineutrality of plasma, and the Ohm law $I = \sigma E \pi r_0^2$. This system of equations 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.

It can be shown that the calculated characteristics of an arc discharge will be described by the unified curves in coordinates ER, and I/R, r/R that is the consequence of a general symmetry of the system of equations which describes an arc without the radiant transfer [19].

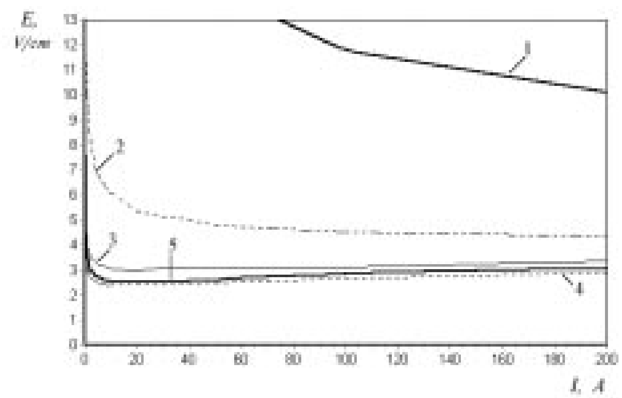

Fig. 1. Volt-ampere ($E - I$) characteristics of arc discharges (p=1 atm., R= 0.75 cm). Curve *1* is the result of calculations for He, *2* — Ne, *3* — Ar, *4* — Kr, *5* — Xe

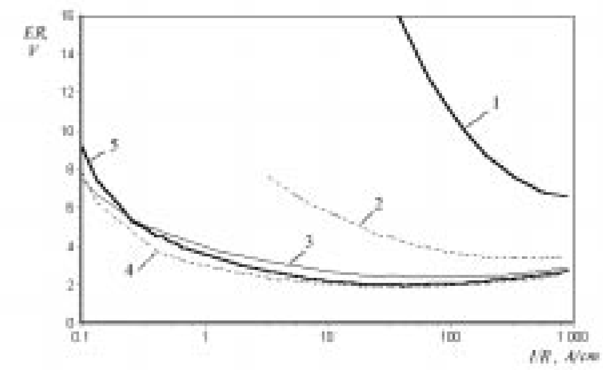

Fig. 2. Unified volt-ampere $ER - I/R$ characteristics of arc discharges (p =1 atm.). Curve *1* is the result of calculations for He, *2* — Ne, *3* — Ar, *4* — Kr, *5* — Xe

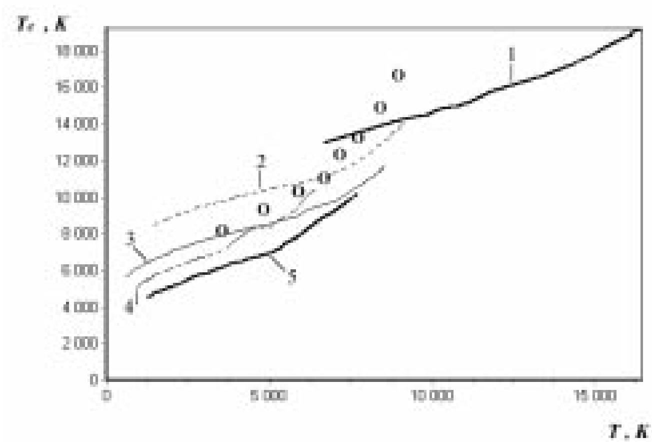

Fig. 3. Electron and gaseous temperatures in the arc (p =1 atm., R=0.75 cm). *1* — He, *2* — Ne, *3* — Ar, *4* — Kr, *5* — Xe. Points **O** correspond to the experimental data for Ar [21]

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 directly to an arc stabilized by walls. Such an arc is characterized by the increasing $E - I$ characteristics at high current contrary to a free-burning arc which has decreasing characteristics [13].

On the other hand, because of the constriction of a discharge, the plasma occupies a small region at the discharge center. It would be expected that when the radius of contraction is much smaller than the tube radius, the calculated parameters would be weakly depended on the further increasing of the tube radius. Because of that, the case of $R >> r_0$ can be considered as the case corresponding to a free-burning arc.

The stabilizing wall can be conditional. This role may be played by the gaseous streams due to convection, external fanning [9, 13, 20], or evaporation from electrodes [8, 13]. We note that, for a free-burning arc, it is recommended to take into account the glow discharge radius [21] and the influence of molecular and electronegative impurities on the temperature distributions in a discharge [8].

The considered model corresponds to the idealization of a long arc where the heat flux is transferred to the walls [13, 20]. The antipode of a long arc is a short arc where the heat flux is transferred into electrodes, and thus the near-electrode processes are important.

In Fig. 1, the calculated volt-ampere ($E - I$) characteristics of the arc discharges at atmospheric pressure are presented, and Fig. 2 shows the calculated unified volt-ampere characteristics in the coordinates $ER - I/R$. In Figs. 3 and 4, the interdependences between the electron temperatures and the gaseous temperature are presented for the arc at atmospheric pressure.

It should be pointed that, for Ar, Kr, and Xe, the curves increase at R = 0.75 cm, but they decrease for He and Ne (Fig. 1). The above-presented results of calculations are close to those of measurements of the electric field strength in arcs for various inert gases [13] and temperature in an argon arc [21]. Thus, at the discharge regimes corresponding to the current densities $j_0 < 8.5 \cdot 10^2$ A/cm^2, the discrepancy between the calculated results and experimental data [21] is at most

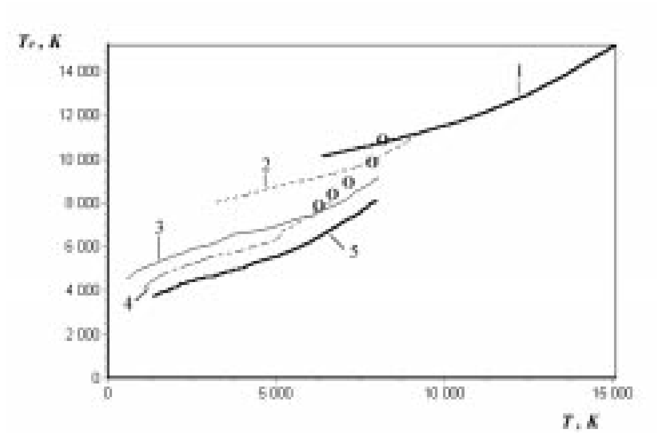

Fig. 4. Electron and gaseous temperatures in the arc (p =1 atm., R=7.5 cm). *1* — He, *2* — Ne, *3* — Ar, *4* — Kr, *5* — Xe. The points **O** correspond to the experimental data for Ar [21]

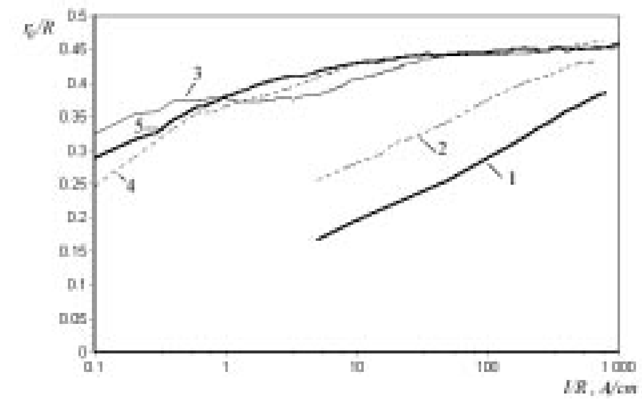

Fig. 5. Reduced radius of contraction r_0/R of an arc discharge vs the reduced current I/R (p=1 atm.). *1* — He, *2* — Ne, *3* — Ar, *4* — Kr, *5* — Xe

30% (see Figs. 3 and 4). Our results agree well with those of calculations for a xenon arc [6]. The latter were derived within a simpler model. There, the independence of the cross-sections on the electron energy was assumed, which does not allow one to calculate the region of temperatures corresponding to the Ramsauer minimum with a good precision.

From the results of calculations of the parameters of arc discharges at given I and R (see Table and Fig. 5), it may be deduced that the contraction of an arc discharge is stronger pronounced in the case where the gaseous thermal conductivity is dominated in the heat transfer processes, which corresponds to the regimes of discharge with relatively low currents and, as a rule, at low electron temperatures.

With increase in a current under the condition of constant R, which causes the increase in the electron temperature, the plasma region of the discharge is expanded. At a further increase in the current, the plasma region size is determined by the competing processes of constriction-expansion. Therefore, the contraction radius is varied weakly (Fig. 5). If we neglect this weak dependence of the contraction radius on the reduced current I/R, then it may be obtain that $\frac{r_0}{R} \approx$ const, i.e. $r_0 \sim R$ under the domination of electron heat conductivity. Here, we recall that, with regards for the conclusion in [22], a linear dependence of the contraction radius on the tube radius is a general rule for the thermal contraction.

In the case of the dominating electron heat conductivity, the more constricted discharge takes place in helium in comparison with the other inert gases for the same current.

Also, it should be noted that Ar, Kr, and Xe belong to the gases wit h a remarkably expressed Ramsauer

Parameters of arc discharges at atmospheric pressure

Gas	I, A	R, cm	r_0, mm	E, V/cm	T, K	T_e, K	Q, W/cm	q_0, W/cm^3	α	ξ	η
Ar	0.5	0.75	2.90	4.60	1110	6220	2.3	20	$4.7{\cdot}10^{-5}$	1.6	78
Ar	50	0.75	3.36	3.04	5380	8720	$1.5{\cdot}10^2$	$9.8{\cdot}10^2$	$9.0{\cdot}10^{-3}$	$9.9{\cdot}10^{-2}$	$8.6{\cdot}10^3$
Ar	100	1.5	6.5	15.9	6150	8680	$1.6{\cdot}10^2$	$2.7{\cdot}10^2$	$9.0{\cdot}10^{-3}$	0.11	$2.3{\cdot}10^4$
Ar	200	7.5	27.6	0.40	6810	7970	81	7.8	$3.5{\cdot}10^{-3}$	0.33	$7.0{\cdot}10^4$
Xe	0.5	0.75	2.75	4.19	1870	5100	2.1	20	$1.3{\cdot}10^{-4}$	1.7	$1.5{\cdot}10^3$
Xe	50	0.75	3.44	2.59	5690	7620	$1.3{\cdot}10^2$	$8.1{\cdot}10^2$	$2.9{\cdot}10^{-2}$	$4.9{\cdot}10^{-2}$	$6.1{\cdot}10^5$
Xe	100	1.5	6.6	13.6	6400	7600	$1.4{\cdot}10^2$	$2.3{\cdot}10^2$	$3.0{\cdot}10^{-2}$	$5.5{\cdot}10^{-2}$	$1.7{\cdot}10^6$
Xe	200	7.5	29.8	0.29	6820	6920	58	4.8	$1.2{\cdot}10^{-3}$	0.14	$7.0{\cdot}10^6$
Kr	0.5	0.75	2.65	3.44	1270	5540	1.7	18	$4.8{\cdot}10^{-5}$	0.83	$1.5{\cdot}10^2$
Kr	50	0.75	3.45	2.47	4120	7810	$1.2{\cdot}10^2$	$7.6{\cdot}10^2$	$7.9{\cdot}10^{-2}$	$4.4{\cdot}10^{-2}$	$4.3{\cdot}10^4$
Kr	100	1.5	6.6	12.6	4870	7750	$1.3{\cdot}10^2$	$2.0{\cdot}10^2$	$7.8{\cdot}10^{-3}$	$5.6{\cdot}10^{-2}$	$1.0{\cdot}10^5$
Kr	200	7.5	30.7	0.28	5640	7070	56	4.4	$2.9{\cdot}10^{-3}$	0.17	$3.0{\cdot}10^5$
He	100	0.15	0.57	42.1	12130	18410	$4.2{\cdot}10^3$	$9.7{\cdot}10^5$	0.12	$2.7{\cdot}10^{-2}$	21.4
He	200	0.75	2.53	10.1	13440	16670	$2.0{\cdot}10^3$	$2.3{\cdot}10^4$	$5.3{\cdot}10^{-2}$	0.23	99
Ne	100	0.15	0.67	22.4	5560	13590	$2.2{\cdot}10^3$	$3.7{\cdot}10^5$	$4.6{\cdot}10^{-2}$	$6.8{\cdot}10^{-3}$	$5.5{\cdot}10^2$
Ne	200	0.75	3.15	4.35	8060	12370	$8.7{\cdot}10^2$	$6.5{\cdot}10^3$	$2.1{\cdot}10^{-2}$	$4.2{\cdot}10^{-2}$	$1.4{\cdot}10^3$

effect which has a quantum nature and is revealed by the presence of a minimum in the momentum-transfer cross-section of electron-atom collisions in the energy range 0.4—1 eV. This effect causes the high transparency of a weakly ionized gas for such electrons and increases the difference between the gaseous and electron temperatures, which, in turn, causes the expansion of the discharge.In Figs. 3 and 4, the characteristic deflection corresponds to the region of the Ramsauer minimum.

But, it should be take into account that, because of the differences of values of the momentum-transfer cross-sections, the influence of the above-pointed effect on the discharge constriction has the bright distinctions for different noble gases. Thus,in the case where the gaseous heat conductivity is dominated, a xenon arc is more constricted than an argon arc at the same current. But, with increase in the current (and, consequently, in temperature), the above relation can become inverse (see Fig. 5). Therefore, an application of xenon arcs may be recommended only for the low-current processes of microplasma welding [23].

Also, it should be pointed out that, in the plasma of a low-current arc, the ionization equilibrium cannot be maintained (for example, for Ar with $I < 0.2$ A at $R = 0.75$ cm). In that plasma, the role of diffusion is increased and that of heat transfer is decreased. Under that conditions, the separation between the temperatures is determined by pecularities of the above-pointed function $g\left(T_e\right)$, because the case will be possible when a decrease in the current corresponds to an increase in the electron temperature [12, Fig. 4.1]. But this does not mean that the contraction radius is increased because, along with the thermal mechanism, the discharge constriction will be determined by the concentration mechanism.

Thus, the relation between the degrees of constriction of an arc discharge in noble gases is different for the certain regimes of discharge and depends on the temperature of electrons in the plasma of discharge.

Conclusion

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

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

The presence of the Ramsauer effect for a gas where an arc is burning has an essential influence on the process of contraction, which is revealed in a decrease in the constriction of an arc discharge in the correspondent temperature range.

1. *Eletskii A.V., Palkina L.A., Smirnov B.M.* Transport Phenomena in Low-Ionized Plasma. — Moscow: Atomizdat, 1975 (in Russian).
2. *Eletskii A.V., Rakhimov A.T.* // Khim. Plazm.—1977.—**4**.— P.123 — 167.
3. *Sinkevich O.A., Stakhanov I.P.* Plasma Physics. — Moscow: Vysshaya Shkola, 1991 (in Russian).
4. *Eletskii A.V., Smirnov B.M.* //Uspekhi Fiz. Nauk.—1996.— **39**.— P.1137 — 1156.
5. *Smirnov B.M* // Teplofiz. Vys. Temper.—1997.— **35**.— P.14 — 18.
6. *Smirnov B.M., Smirnov M.B.* // Phys. scr.—1997.— **56**.— P.302 — 307.
7. *Smirnov B.M.* Physics of a Low-Ionized Gas. — Moscow: Atomizdat, 1975 (in Russian).
8. *Paton B.E., Zamkov V.N., Prilutskyy V.P., Porytskyy P.V.* // Paton Weld. Journ.—2000.— N 1.— P.5 — 12.
9. *Granovskii V.L.* Electric Current in Gases. Steady Current. — Moscow: Nauka, 1971 (in Russian).
10. *Smirnov B.M.*// Uspekhi Fiz. Nauk.— 2002.— **172**.— P.1411 — 1447.
11. *Golant V.E., Zhilinskii A.P., Sakharov I.E.* Basics of Plasma Physics. — Moscow: Atomizdat, 1977 (in Russian).
12. *Biberman L.M., Vorob'ev V.S., Yakubov I.T.* Kinetics of Nonequilibrium Low-Temperature Plasma. — Moscow: Nauka, 1982 (in Russian).
13. *Zhukov M.F., Koroteev A.S., Uryukov B.A.* Applied Dynamics of Thermal Plasma. — Novosibirsk: Nauka, 1975 (in Russian).
14. *Huxley L.G.H., Crompton R.W.* The Diffusion and Drift of Electrons in Gases. — New York: Wiley, 1974.
15. *Zhdanov V.M.* Transport Phenomena in Multicomponent Plasma. — Moscow: Energoatomizdat, 1982 (in Russian).
16. *Fastovskii V.G., Rovinskii A.E., Petrovskii Yu.V.* Noble Gases. — Moscow: Atomizdat, 1972 (in Russian).
17. *Smirnov B.M.* //Uspekhi Fiz. Nauk.—2000.— **43**.— P.453 — 491.
18. *Radtsig A.A.* // Khim. Plazm. — 1981.— **8**. — P. 230- 263.
19. *Desyatkov G.A., Engelsht V.S.* Theory of a Cylindrical Arc Discharge. — Frunze: Ilim, 1985 (in Russian).
20. *Zhovtyans'kyi V.A., Patriyuk V.M.* // Ukr. Fiz. Zh. — 2000.— **45**.— P.1059 — 1066.
21. *Batenin V.M., Minaev P.V.* // Teplofiz. Vys. Temper.— 1969.— **7**.— P.208 — 212.
22. *Rakhimov A.T., Ulinich F.R.* //Dokl. Akad. Nauk SSSR.— 1969.— **187**.— P.72 — 74.
23. *Paton B.E., Gvozdetskii V.S., Dudko D.A. et al.* Microplasma Welding. — Kyiv: Naukova Dumka, 1979 (in Russian).

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МЕХАНІЗМИ КОНТРАКЦІЇ ДУГОВОГО РОЗРЯДУ
1. ОСОБЛИВОСТІ ТЕПЛОВОЇ КОНТРАКЦІЇ

П.В. Порицький

Р е з ю м е

Теоретично розглянуто вплив характеристик газового середовища на процес контракції (стягування) дугового розряду в атмосфері інертних газів. Проведено розрахунки та показано, що ступінь стягування дугового розряду визначається теплофізичними характеристиками газового середовища та характеристиками електрон-атомних зіткнень. Висвітлено вплив ефекту Рамзауера на характер контракції дугового розряду.