

Determination of External Stabilizing Resistor Value in the Glow Discharge Power Supply While Welding

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Abstract – The article considers the possibility of increasing stability of glow discharge in the diffusion bonding processes at discharge currents 1 ... 30 A and the gas pressure 1.33 ... 13.3 kPa by external active resistance, turned on sequentially in the discharge gap. It is shown that the absence of such resistor in the glow discharge gap causes its transition to an electric arc, as a more stable form of gas discharges, with the violation of welding technological process through external disturbances. The methodology of the calculation of an external stabilizing resistor optimum value is offered in this work. The divergence of calculation data with the similar, obtained experimentally is 15 ... 20%.

Keywords – glow discharge; diffusion bonding; disturbances; external stabilizing resistor.

I. INTRODUCTION

The main way of obtaining undetachable high precision joints of dissimilar materials is a diffusion bonding, carried out at relatively low temperatures without melting. As an energy source for diffusion bonding a normal medium pressure glow discharge burning in the active or inert gas (argon, helium, nitrogen, hydrogen) is widely used. Considerable advantage of a dc glow discharge is its high thermal efficiency - 70 ... 80%, which significantly exceeds similar parameter of other sources of heat for diffusion bonding (induction heating, radiation heating, electrical resistance heating) [1].

A distinctive feature of glow discharge as a welding heat source is the simplicity and cheapness of equipment because there is not necessary to use the high-vacuum complex system, which is compulsory at other sources.

The glow discharge power supply is also quite simple. Its circuit consists of a step-up transformer, voltage regulator, included in the primary circuit as autotransformer or thyristor contactor and full-wave rectifier (Fig. 1).

At the same time, the burning of a glow discharge is carried out at relatively high voltages (300 ... 1000 V) and, accordingly, at high electric field strength in the discharge gap. In this regard, the effect of external disturbances may cause the transition of a glow discharge to a more stable form of a gas discharge - an electric arc. The exposure of concentrated arc discharge on the welded workpieces leads to the melting and destruction of the latter [2].

II. SUSTAINABLE EXISTENCE OF GLOW DISCHARGE

Since the normal glow discharge has a hard static current-voltage characteristic (CVC), stability of the system "glow discharge - power supply" is guaranteed only if the external characteristic of power supply is falling (Fig.2). One way to obtain of power supply's falling characteristics is the inclusion of the ballast resistor on its output. A ballast resistor in such type of power supply has the following functions: it generates

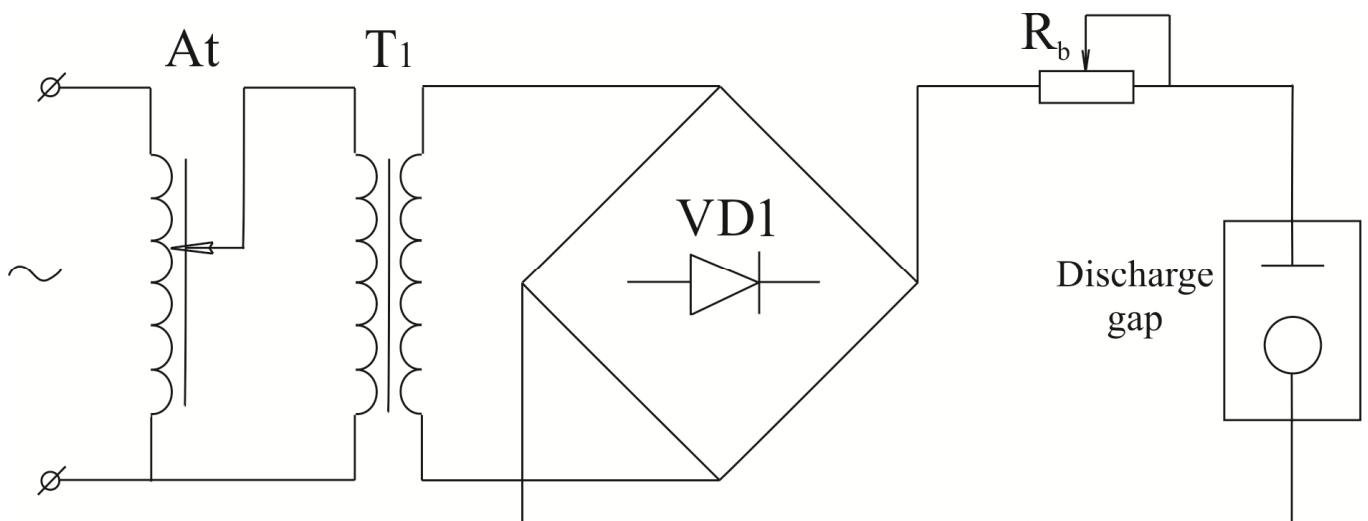


Fig.1. The glow discharge power supply circuit.

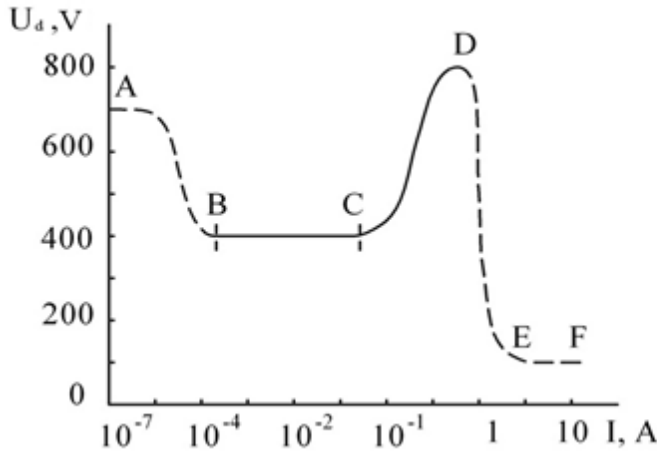


Fig. 2. The current-voltage characteristics (CVC) of gas discharges (BC - normal glow discharge, CD - abnormal glow discharge, EF - arc discharge).

a falling external characteristic, current regulation and the glow discharge stabilization (Fig.3).

In this regard, in a number of research papers [3, 4], dedicated to the study of problem of glow discharge stability, the issue of determining the optimal value of this resistor is under consideration. This is because the excessively high value of this resistor, increasing discharge stability leads to lower energy performance of heating process due to the increase of power losses on it. Low value resistor does not provide the discharge stability in a given mode.

However, the results of these studies cannot be uniquely useful for welding processes in the gas discharge, since they are obtained for significantly other conditions of the glow discharge, in particular for laser plasma, and are semi-quantitative in nature.

Therefore it is advisable to develop a method of determining the external ballast resistor value for glow discharge stabilization in the welding process on the discharge currents over 1 A and gas pressure above 1.33 kPa.

III. DETERMINATION OF STABILIZING RESISTOR VALUE

The stabilizing effect of the external ballast resistor, as shown in [4], is that the any increase in the discharge current from a steady state value including at the transition of glow discharge to arc, increases the voltage drop across this resistor. Such deviation will inevitably lead to a voltage drop decrease across the interelectrode gap and electric field intensity in the positive discharge column at a constant power supply voltage. All these accompanied by a decrease in the electron temperature and ionization rate. The rate of electrons formation becomes lower than the rate of their extinction due to recombination and the electron density starts to decrease, thereby reducing the discharge current to the initial steady state value.

Thus, we can say that to glow discharge stabilizing in the positive moments of the discharge current fluctuations is necessary to provide such energy conditions at which the electron recombination rate will exceed the rate of ionization, i.e.:

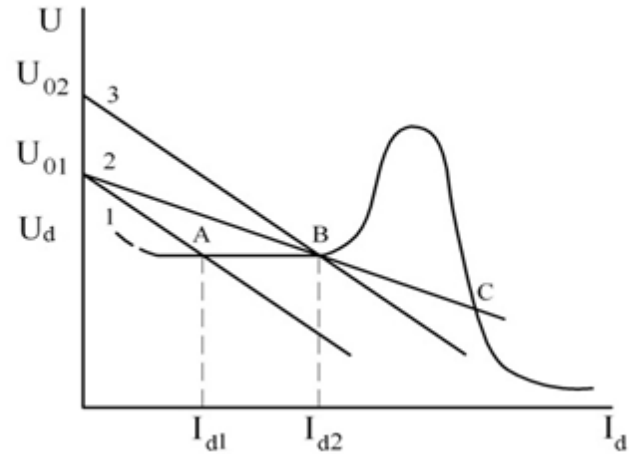


Fig. 3. Formation of falling CVC of glow discharge power supply.

$$\left(\frac{dn_e}{dt}\right)_i \leq \left(\frac{dn_e}{dt}\right)_{rec}, \quad (1)$$

where n_e - number of electrons per unit volume of the discharge plasma.

Assuming that the ionization develops in homogeneous conditions, i.e. at a constant rate, the rate of electron production or ionization rate is defined as [5]:

$$\left(\frac{dn_e}{dt}\right)_i = K_i \cdot N \cdot n_e, \quad (2)$$

where K_i - constant of ionization rate; N - bulk density of neutral particles (atoms) of gas.

The recombination rate is characterized by a number of recombination acts per unit volume per unit time is proportional to the density of recombining particles:

$$\left(\frac{dn_e}{dt}\right)_{rec} = -\beta \cdot n_e \cdot n_i, \quad (3)$$

where β - the recombination coefficient; n_i - the number of positively charged particles per unit volume of plasma.

Thus, for a glow discharge steady state, using (2) and (3) can be written:

$$K_i \cdot N \cdot n_e = |\beta \cdot n_e|, \quad (4)$$

Since, in the electrically neutral plasma positive column of a glow discharge the number of electrons equals the number of ions $n_e = n_i$ the expression (4) takes the form:

$$K_i \cdot N = |\beta \cdot n_e|, \quad (5)$$

The rate constant of ionization is a function of the parameter E/N (Fig. 4) [6], where E - the electric field intensity in the positive column of glow discharge.

Bulk density of plasma particle (N) can be determined from the expression [7]:

$$p = N \cdot k \cdot T, \quad (6)$$

where p - gas pressure; T - absolute temperature.

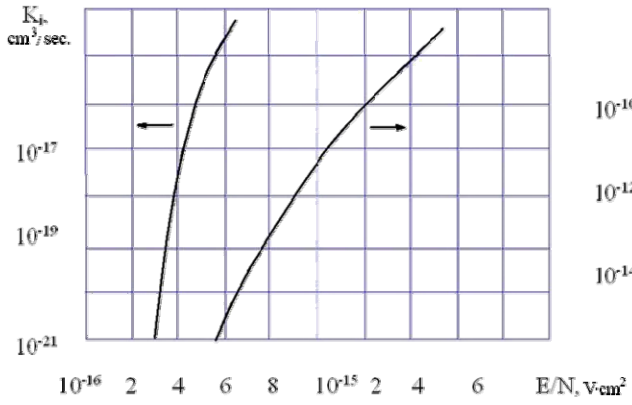


Fig. 4. The rate constant of ionization (K_i) in nitrogen [8].

The electric field intensity values (E) in the discharge column can be determined in accordance with (Fig. 5) which shows dependence of the voltage drop in the positive column on discharge current, gas pressure and interelectrode distance for the most widely used gas mediums. Therefore, for the welding glow discharge modes the value of the specified parameter is $E/N=6 \cdot 10^{-16} \dots 4 \cdot 10^{-15} \text{ cm}^3/\text{sec}$. The mathematical processing of curve functions $K_i=f(E/N)$ shown in Fig. 4 in the specified range allowed to obtain the empirical expression of this dependence in the form of:

$$K_i \approx A \cdot \frac{E}{N}, \quad (7)$$

where $A \approx 10^{2.4}$ for the above variation range of the parameter E/N .

Substituting the K_i expression in (5) we obtain an electric field intensity expression in the positive discharge column:

$$E = \left| -\frac{\beta \cdot n_e}{A} \right|, \quad (8)$$

At the same time, the electric field intensity in the positive column can be determined based on the electrical characteristics of the discharge circuit:

$$E = \frac{U_c}{l} = \frac{U_s - U_r - U_{a-c}}{l} = \frac{U_s - I_d \cdot R_r - U_{a-c}}{l}, \quad (9)$$

where U_s - voltage on the power supply output terminals; U_c , U_r , U_{a-c} - voltage drop in the discharge positive column, on the ballast resistor, at the cathode-anode discharge region respectively, I_d - discharge current; l - the interelectrode distance.

From Eqs. (8) - (9) the minimum required value of the external resistance, sufficient to stabilize of glow discharge under given conditions can be determined:

$$R_{ex} \geq \frac{l}{I_d} \left[\frac{U_s - U_{a-c}}{l} - \frac{\beta \cdot n_e}{A} \right], \quad (10)$$

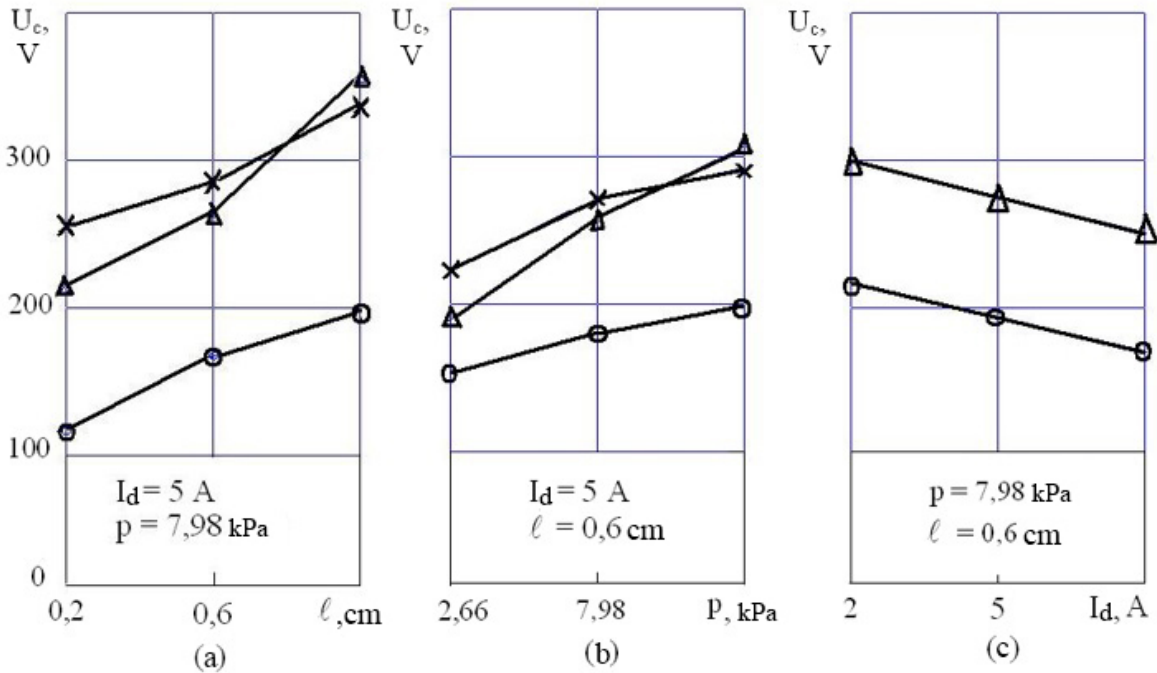
The diffusion processes of charged particles in the discharge column are negligible in comparison with the processes of bulk recombination for the considered gas pressure. In this case, the balance equation for the electron concentration, achievable as a result of electron impact ionization in an electric field [4] looks like this:

$$\left(\frac{dn_e}{dt} \right)_i = \nu_i \cdot n_e - \beta \cdot n_e = 0, \quad (11)$$

The probability of the gas thermal ionization, determined by Saha equation, due to low temperatures in the glow discharge plasma is negligible therefore, also not taken into consideration.

From Eq. (11) can be obtained:

$$n_e = \frac{\nu_i}{\beta(T_e)}, \quad (12)$$



o - Argon; Δ - Nitrogen; x - Hydrogen

Fig. 5. Dependence of the voltage drop in the positive column of a glow discharge on the electrode gap (a), the gas pressure (b), discharge current (c).

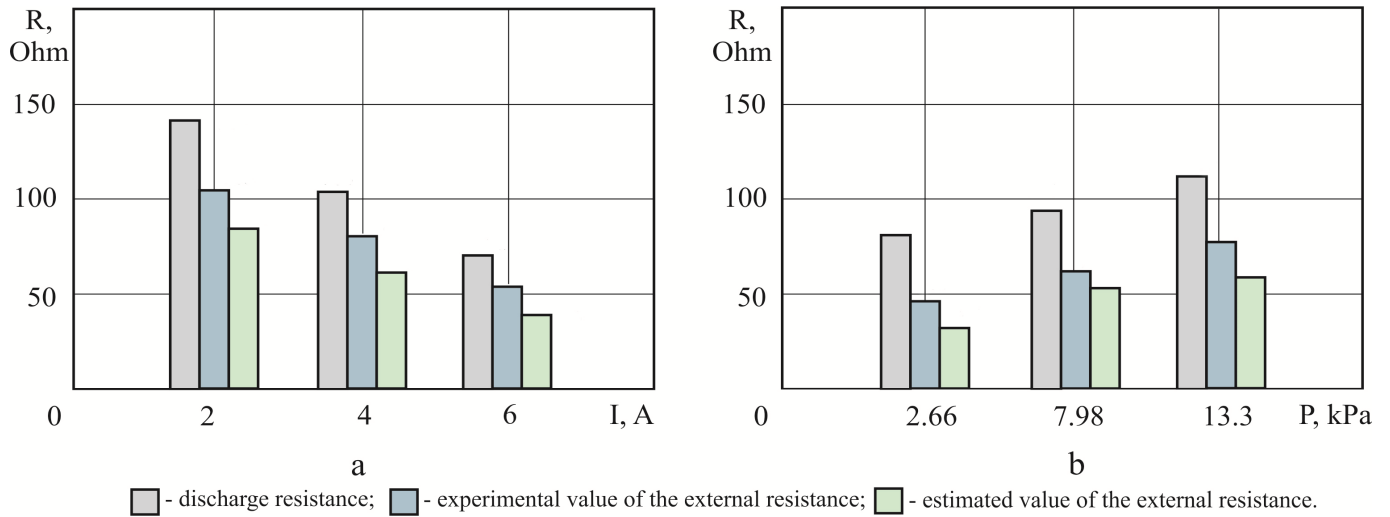


Fig. 6. The results of external resistance value calculation depending on the discharge current (a) and gas pressure (b).

where ν_i - ionization frequency, $\nu_i = K_i \cdot N$.

At low gas temperatures, the recombination takes place mainly dissociatively. The constant of dissociative recombination depends on the electron temperature (T_e) [5]. The recombination coefficient values for some ions are given in table 1.

TABLE I. THE CONSTANTS OF DISSOCIATIVE RECOMBINATION

Ion	β^* , 10^{-7} cm ³ /sec.	References
Ne ⁺ ₂	1.1...2.3	[9]
He ⁺ ₂	0.13...0.25	[10]
H ⁺ ₂	0.3...0.52	[10]
N ⁺ ₂	1,3...2.2	[9]
Ar ⁺ ₂	2.2...3.6	[9]

The lower β coefficient values corresponds to the $T_e \approx 1 \dots 2$ eV, top values – $T_e \approx 0.2 \dots 0.5$ eV.

The calculations made by this procedure for argon and nitrogen shows that at the gas pressure of 5.32 kPa the electron temperature is varies insignificantly in the range 1 ... 1.3 eV. The calculation results are correlated with the experimental, performed in [11] for nitrogen. This allows to determine the value of the recombination coefficient β according to table 1 and the electron density that, in accordance with (12) for the typical values $E/N = 5 \cdot 10^{-16} \dots 5 \cdot 10^{-15}$ V·cm² is $n_e \approx 10^{11} \dots 10^{12}$ cm⁻³.

The results of resistance value's (R_{ex}) determination according to the expression (10) under heating in nitrogen for the gas pressure 2.66 ... 13.3 kPa, discharge current 2 ... 6 A, the output supply voltage 470 ... 500 V and the interelectrode distance of 0.6 cm are shown in Fig. 6. The experimentally determined values of discharge resistance R_d and external resistance R_{ex} , which provide the glow discharge stability, are shown in the same figure. Comparative analysis of the results demonstrates that the proposed method of the external stabilizing resistor value calculating only by 15 ... 20% different from this resistor value is established experimentally. That allows to recommend this methodology for the preliminary determination of the external resistor value in the specific welding conditions. In this case, the calculated resistance value may be assumed as the minimum allowable for the glow discharge stabilization.

IV. CONCLUSIONS

Thus, in this paper the method of the external stabilizing resistor value calculation at the insignificant divergence with the obtained experimentally values on 15 ... 20%, which provides a sustainable glow discharge existence at diffusion bonding without transition from glow to an arc discharge, was proposed.

It should be appreciated that the glow discharge stabilization by means of the ballast resistance is insufficient if not guaranteed the necessary technological process conditions, because such a source does not provide a sufficient counteraction to avalanche-like increasing of arc current. In this case, it is necessary to use more sophisticated and effective protective devices.

V. REFERENCES

- [1] G.P. Bolotov, M.G. Bolotov, I.O. Prybytko, G.K. Kharchenko, "Diagnosis of plasma glow discharge energy parameters in the processes of treatment small diameter long tubes", in II International Young Scientists Forum on Applied Physics and Engineering (YSF), Kharkiv., IEEE. 2016, pp.116 – 119.
- [2] G.P. Bolotov, M.G. Bolotov, M.M. Rudenko, "Modification of Materials Surface Layers by Low-Energy Ion Irradiation in Glow Discharge" IEEE 36th International Conference "Electronics and Nanotechnology ELNANO'2016", pp.135-140, April 2016.
- [3] K.N. Ulyanov, "The theory of normal glow discharge medium pressure". Thermophysics of high temperature. Moscow. vol.10, №5, pp.63-67, 1972. (in Russian).
- [4] Ecker G., Kroll W., Zoller O. Thennal instability of the plasma column //Phys. Fluids.-1964.-Vol.7, N212.-P.2001-2006.
- [5] Y.P. Raizer, Gas Discharge Physics. Moscow: Science, p.449, 1987 (in Russian).
- [6] F.M. Gysin, E.E. Son, Electrophysical processes in discharges of solid and liquid electrodes. Sverdlovsk, 1989, p. 431. (in Russian).
- [7] E.I. Kazantsev, Industrial ovens. Moscow: Metallurgy, 1964, p.451. (in Russian).
- [8] Y.V. Kiselev, V.L. Cherepanov, Spark gaps. Moscow: Soviet radio, 1967. p. 70. (in Russian).
- [9] M. A. Biondi, Electron-ion Recombination in Gas Lasers. In: Applied Atomic Collision Physics, Gas Lasers (E. W. McDaniel and W. L. Nighan, ed.), Vol. 3, pp 216-234, 1982.
- [10] A.V. Eletsii, Transport phenomena in weakly ionized plasma. Moscow: Atomizdat, 1975. p. 369. (in Russian).
- [11] Frommhold, L. Zeit Phys. Vol.160, 1960, pp. 554-67.