PLASMA CHEMICAL PROCESSES IN THE NEAR ELECTRODE AREAS IN CASE OF ELECTRICAL CONTACT ARC HANDLING OF METALS.

Dresvin S.V., Frolov V.Y., Smirnov E.E., Krylov A.V.
Saint Petersburg State Technical University, dept. of Electrical Engineering and Electrical Technology, Polytechnic st. 29, Saint Petersburg, 195251, Russia.

Abstract
Feature of heat exchange of electrodes with plasma of the discharge in a fluid is mechanism of formation of an electric arc in conditions of electrical contact arc cutting (ECAC) of metals.
It is appear at intensification of mechanisms of heat and mass transfer on boundary of environments at intensive physicochemical reacting of components of plasma gas with a solid heated body at incremental velocity of flowing reactions.
For formulation of boundary conditions at the boundary of plasma and electrodes is necessary to obtain the information about relations linking the arc current and sizes of electrode spots, influence of processes of interaction of plasma and electrodes on oscillation of plasma. Also determination of parameters of electrode and above electrode areas and their sizes is necessary.
At the presented paper formulated basis of the theory of processes in the near electrode areas in case of interaction of a steam-gaseous cavity with electrodes sublimating vapors of metal.

1. Introduction

The magnification of efficiency, reliability and stability of installations of ECAC is connected with a fundamental problem of interaction of plasma with electrodes. The solutions of practical problems appears in the making and improvement of ECAC installations rather strong depends from depth of understanding of the processes in the technological module, i.e. in the areas of arc contact with electrodes. Among these problems the main is magnification of efficiency \( \eta \) of the technological module and installation as a whole, magnification of a resource of disk instrument, and also extension the technological applications with this method.
Input dates describing processes at electrode spots and at electrode areas are:
- The mechanism of formation of an electric arc;
- Requirements of a thermionic emission from the cathode;
- Shaping of an anode spot;
- The conditions of interaction of electrodes and extremely short electrical arc;
- The conditions of heat and mass transfer in the short arcs.
- The purpose of the present work is the ascertaining of an opportunity of applicability of the classical theories of electrode processes to the analysing of ECAC process.

2. The analysis of the electrode processes at ECAC.

The discharge in the ECAC conditions exists at intensive evaporation of a material of electrodes. Therefore, for the analysis of the electrode processes is necessary to take into
account the presence of metal vapor. As the discharge arises in water, the necessity of the account of processes of a dissociation of molecules of water, oxygen and hydrogen is obvious. As follows from dependence at the fig. 1 at the temperature above 4500 the molecule of hydrogen and oxygen, formed as a result of the dissociation of water molecule, practically completely is dissociated. Should be noted that in conditions of ECAC process there is a division of atoms of hydrogen and oxygen between the cathode and anode. So as result of thermochemical reactions the hydrogen is allocated at the cathode region and the oxygen at the anode. These facts allow us to analyse the cathode processes with model multicomponent plasma consisting of atoms of hydrogen and vapors of metal.

![Graph showing dissociation degree of water depending on temperature](image)

**Fig.1** The dissociation degree of water depending on temperature

In conditions of ECAC there is a saturation of a material of electrodes by atoms of hydrogen. In this case the thermion emission of the electrons from cathode is featured by the following equation:

$$j = CT^{5/4} \exp \left[ - \frac{1/2q_i + W_F}{kT} \right]$$  \hspace{1cm} (1)

where $C$ - empirical coefficient, $q_i$ - an ionization energy of atoms, which saturate the surface layer of metal of the cathode. Evidently, that the temperature of plasma at an initial stage of development of discharge will not exceed 7000. It is stipulated by that the partial pressure vapors of metal considerably exceeds a partial pressure of atoms of hydrogen and ionization energy of atoms of metal approximately twice less ionization energy of atoms of hydrogen, i.e. sufficient amount of charged particles will be formed under more low temperature, than in other gas ambiences. Besides in the conditions of ECAC the discharge is exist at high pressure which can reach $4 \times 10^5$ N/m$^2$. This circumstance renders essential influence to the parameters of cathode area.

### 3. Estimation of parameters of the cathode area in conditions of ECAC

For the estimation of parameters of the cathode area the two-layer model was used. This
mode was developed in [1] and adapted to conditions of ECAC.

The model include follows equation: the equations for calculation the plasma composition, the Maceown equation, the equations of energy balance for each layer (ionization an space charge sheath), the equations for calculation of ion flux and back diffusing electron flux, Bohm criterion, the equation for calculation the flux of electrons of thermionic emission (eq. 1).

As a result of calculations for set values of temperature of plasma and the temperature of the cathode were obtained the base characteristics of the cathode area: near electrode voltage drop $U_e(T_c, T)$, the heat flux to the cathode $q(T_c, T)$, fractions of ionic and electronic currents (fig. 2), current density in the cathode area $j(T_c, T)$.

For the analyze the near electrode phenomena the fraction of an ionic current is the most essential characteristics, since the base mechanism of heating of the cathode is the flux of ions ‘bombarding’ the cathode.

![Fig. 2 The dependence of fractions of ionic current (solid curves) and electronic current (dotted curves) on temperatures of plasma and cathode. Combinations of material cathode - anode: Cu - Cu, Fe - Fe.](image)

As shows the investigations of the near cathode voltage drops [3], the relaxation of energy of electrons in the ionization layer occurs in base at the expense of elastic collisions, in this case the ionic fraction of a current can be calculated as:

$$f = \frac{1}{2 + \xi}$$  \hspace{1cm} (2)

Where $\xi$ - fraction of ions recombining on a surface of the cathode. If to accept, that all ions recombine on a surface than $f = 0.5$.

In [3] change of a fraction of an ionic current in time (ascertaining of an electric arc) also was considered. Here was shown, that in the ionization layer a quasistationary condition is fixed after certain time, and the ionic fraction of a current go to 0.5. From here it is necessary to consider, that in requirements of collision ionization this value of an ionic fraction of a current is limiting.

However, this fact bases at the assumption that the electrons do not lose the energy at excitation of the vapor atoms. Such assumption is valid for metals of the first group, but is not
admissible for the majority of metals. At excitation of atoms of metal to the resonance levels the electron loses a lot of energy and further practically does not participate during ionization. This circumstance reduces that only part of electrons participates in ionization of metal vapors and not all atoms of metal vapor are ionized. In work [2] the estimation of ionic current fraction by the following relation is given:

$$ f \approx \frac{Q_i(U_e)}{Q_{\beta}(U_e)} $$

(3)

where $Q_i, Q_{\beta}$ – section of ionization and section of excitation on a resonance level accordingly.

The relation (3) in the greater degree falls into low melting metals and metals of a medial melting temperature. For refractory metals of the cathode, in particular of tungsten or at presence of a gradient of temperatures at a stage of development of an electric arc, as it takes place in requirements of preliminary contact at ECAC the amount of evaporating metal it is not enough. It can considerably decrease the ionic fraction of a current not because of losses of energy by electron to excitation of atom, and because of a deficiency of metal vapor. If to consider, that all atoms which are taking off from the cathode as vapor are ionized than ionic fraction of current is

$$ f = \frac{w_i e}{m_{\beta} j} $$

(4)

where $w_i$ – the evaporation rate of cathode metal.

In this case in the near cathode area the electron current density $j_e$ is rather higher than relation $w_i e / m_{\beta}$, then the fraction of ionic current will be much less limiting value $f << 0.5$ as the deficiency of evaporating atoms of metal of the cathode is exist.

The requirements (2) and (4) are physical criterion allowing to estimate limiting values of a fraction of the ionic current at the near cathode area from above and from below accordingly. These criterion are necessary for an ascertaining of actual conditions of existence the near cathode area, which can be obtained from a mathematical model.

At the fig. 3 and fig. 4 the dependencies of the fraction of an ionic current on the arc current and power to the cathode on the fraction of the ionic current graphing by results of experiments (oscillogram at the fig. 5) are presented.

As follows from dependence (fig. 3) with growth of the arc current the ionic component is increase and can reach values 0.5 and above. Such character of dependence is stipulated by fact that the magnification of arc current there is a growth of temperature of plasma and at the current $I=1400A$ temperature of plasma can reach $T=10 - 12$ kK (depending on a combination of materials the cathode - anode).
Fig. 3 The dependence of function of ionic current on arc current.

Fig. 4 The dependence of power to the cathode on fraction of ionic.

Fig. 5 The oscillogram of arc current (500 / point) and voltage (20 V/point). The values of power calculated (104 W/point). Fe-Fe.

At such temperatures the atoms of vaporous of metal are completely single-ionized and there is a necessity to take into account the double ionized atoms. The dependence (fig. 4) illustrates values of the fraction of ionic component of current for definition of optimum technological modes of operations of settings ECAC. It is obvious, that with growth of the fraction of ionic component of current the power to the cathode is rapidly increase that reduces to the intensive cathode erosion. In requirements of experiment the cathode the steel disk is intensively worn-out at considerable growth of the arc current.

Conclusions.

The explorations the near electrode area of the electric arc at ECAC conditions are carried out. As a result of explorations is fixed:

1. The electric arc in conditions of ECAC exists at high pressure in the vapors of metal and
oxygen-hydrogen ambience;
2. At the initiation of the discharge as result of thermochemical reactions the hydrogen
ambience near the cathode and oxygen ambience near the anode is formed;
3. With magnification of the arc current there is magnification of the fraction of ionic
current up to limiting values, that essentially accelerates process of decay of the instrument -
cathode.

References.

[1]. Benilov M.S., Marotta A. A model of the cathode region of atmospheric pressure arcs. //