INVESTIGATION OF PLASMA OF ARC DISCHARGE BETWEEN MELTING Cu- AND Ni-ELECTRODES

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Plasma of electric arc between asymmetric one-component Cu and Ni electrodes was investigated by optical emission spectroscopy. Radial distributions of temperature and electron density were determined in the average cross section of arc column. Plasma composition was calculated on the base of experimentally obtained temperatures and electron densities as initial data in the assumption of local thermodynamic equilibrium. It was found that a cathode surface plays predominated role as a erosion source of metal vapors in arc discharge plasma. The proposed technique can be used for estimation of the erosion properties of different contact materials.

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INTRODUCTION

It is well known, from one hand, that composite materials are proposed to be used in fabrication of electrodes or contacts of switching devices nowadays [1]. The advantage of such materials is a combination of high erosion resistance, high thermal conductivity and electrical conductivity.

From another hand, the single-component wires or cables from different materials sometimes are used in modern electric networks. A breakdown of isolation occurs between such conductors in emergencies during overvoltage in the power system. As a result, the arc discharge take place between conductors. So, it is a reason that the surface of the wires or cables is damaged and the lifespan of the electric circuits can be reduced. The study of the erosive stability of asymmetric materials is an actual and unresolved problem still today. The development of new manufacturing technologies and optimization of the component content of electric wire and cables will increase their electric and mechanical strength.

The main aim of this paper is the investigation of behaviour of asymmetric electrodes from copper and nickel under the influence of discharge plasma of free-burning electric arc in air atmosphere. The content of metal vapour admixtures, which are evaporated from electrodes, is determined by optical emission spectroscopy. So, the erosion intensity of contact materials can be determined.

1. EXPERIMENTAL INVESTIGATIONS

The free burning electric arc was ignited in air between the end surfaces of the non-cooled electrodes [2]. The diameter of the rod electrodes was 6 mm and arc currents was 3.5 A. The discharge gap was 8 mm. Electrodes were positioned vertically: asymmetric discharge was realized. Namely, copper and nickel are used as materials of one-component electrodes. The polarity of upper and bottom electrodes of DC arc in different experiments can be able to reverse. So, both materials, i.e. Cu and Ni were used as a cathode or an anode in upper and bottom position.

The one-pass tomographic recording of the spatial distribution of spectral line intensities was used in the first techniques [3]. Monochromator MDR-12 with 3000-pixels CCD linear image sensor (B/W) Sony ILX526A accomplished fast scanning of spatial distribution of radial intensity. Due to the instability of the discharge, statistical averaging of the recorded spatial distributions of the radiation characteristics was carried out.

2. RESULTS AND DISCUSSION

The radial distributions of plasma temperature were determined in the middle section of discharge gap (Fig. 1). The techniques of Boltzmann plot in the assumption of local thermodynamic equilibrium (LTE) was used. In this study spectral lines Cu I 427.5, 465.1, 510.5, 515.3, 521.8, 578.2, 793.3, 809.3 nm were used [2]. Radial distributions of plasma temperature coincide within the measurement error for all investigated modes of arc discharge. One can see, that nor the position or polarity of electrodes are not the determining parameters, which define the temperature of electric arc at current 3.5 A.

The plasma temperature at the axis and its radial profile are very similar to those, which take place in the free burning electric arc in air between copper electrodes [3].

The electron density is obtained from electric conductivity, which can be calculated by solution of energy balance equation (Elenbaas-Heller) in assumption of LTE in plasma [3]. Previously, the measurement of electric field has been carried out in positive plasma column of arc discharge. As an example, the radial profile of electron density of electric arc discharge between one-component Cu and Ni electrodes at current 3.5 A arc shown in Fig. 2. As one can see, the calculated electron density profiles have also the same values within the adequate accuracy for all positions and polarities of asymmetric electrodes.

The composition of air-copper-nickel plasma mixture can be calculated on the base of experimentally measured temperature and obtained electron density in the LTE assumption [4]. Such approach provides the quantitative determination of radial profiles of metal vapours in the discharge gap.

Moreover, aforementioned experimentally obtained data of temperature and calculated electron densities can be plotted on the diagram in the coordinates N_e and T, (Figs. 3, 5, 7, and 9). Additionally, the profiles of electron density in air plasma with different contents of metal vapours as a function of temperature can be plotted as well in these figures. The contents of metal vapours are defined as follows:

– the content of copper vapours X_{Cu} in plasma X_{Cu}, % = (N_{Cu} + N_{Cu+})·100/$\sum N_k$ and

– the content of nickel vapours X_{Ni} in plasma X_{Ni}, % = (N_{Ni} + N_{Ni+})·100/$\sum N_k$,

where N_{Cu}, N_{Cu+}, N_{Ni}, and N_{Ni+} are the concentrations of copper and nickel atoms and ions, and $\sum N_k$ is the total amount of particles in plasma.

As one can see, that all experimental data are in region between curve of pure air plasma (air/Cu/Ni(100/0/0)) and curve of air-metal vapours plasma mixture (air/Cu/Ni(99/1/0) and (air/Cu/Ni(99/0/1)). It means, that content of metal vapours in plasma does not exceed 1%. It should be noted, the plasma is mostly in equilibrium along the entire width of the arc channel.

The content of the impurities of metal vapours of different elements in plasma varies depending on the polarity of the applied voltage to the electrodes (Figs. 4, 6, 8, and 10). As we can see, the most intensive metal erosion take place from the electrode that is used as a cathode. Nevertheless, the total content of vapours of copper and nickel in plasma of the arc discharge at current 3.5 A is 0.2 – 0.5%. We can conclude, that just this parameter plays a key role in processes which provide necessary temperature and electron density in the arc channel plasma.

The additional study of the surface of working layers of electrodes, treated by plasma of electric arc, was performed. The images of electrodes surface, obtained by the digital camera, are shown in Figs. 11-14.

It was found, that the erosion zones on the surface of the nickel cathode are formed predominantly as a point focus (see Figs. 11 and 14). Moreover, the formation of erosion zones of the electrode material does not depend on the location of the nickel cathode in this case (i.e. independently on position: upper or bottom its arrangement).

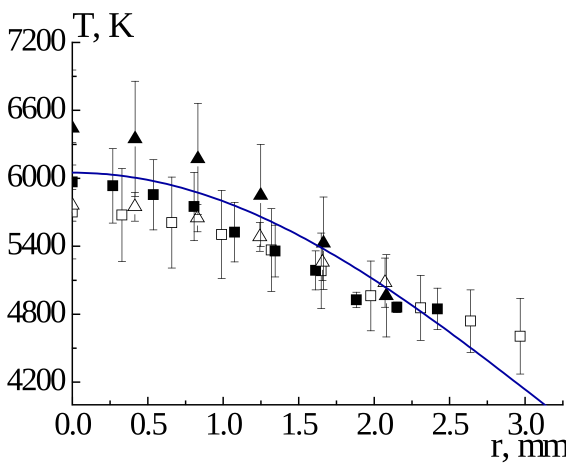

Fig. 1. Radial distributions of plasma temperature of arc discharge between one-component Cu & Ni electrodes (□ and ■ – Cu in upper position; Δ and ▲ – Ni in upper position; open symbol – cathode in upper position; close symbol –cathode in bottom position)

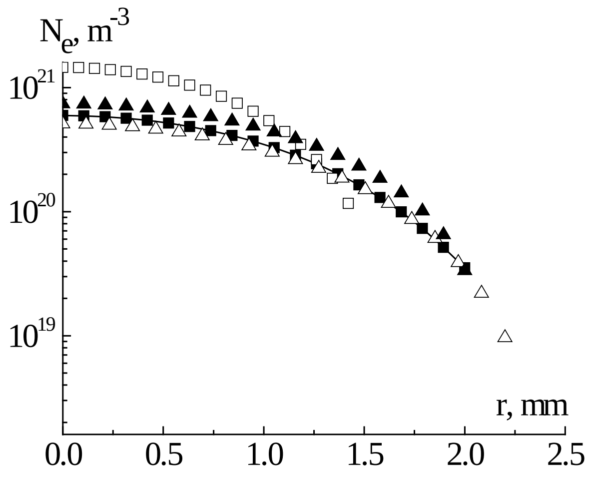

Fig. 2. Radial distributions of electron density of plasma of electric arc discharges between one-component Cu & Ni electrodes (□ and ■ – Cu in upper position; Δ and ▲ – Ni in upper position; open symbol – cathode in upper position; close symbol –cathode in bottom position)

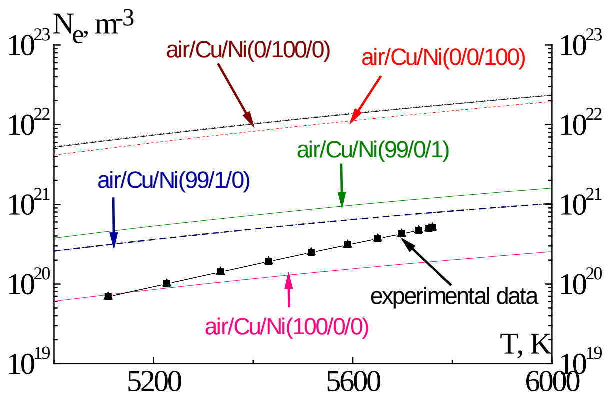

Fig. 3. The dependence of electron density from temperature for plasma of electric arc discharge between one-component Ni (cathode in upper position) and Cu (anode in bottom position) electrodes

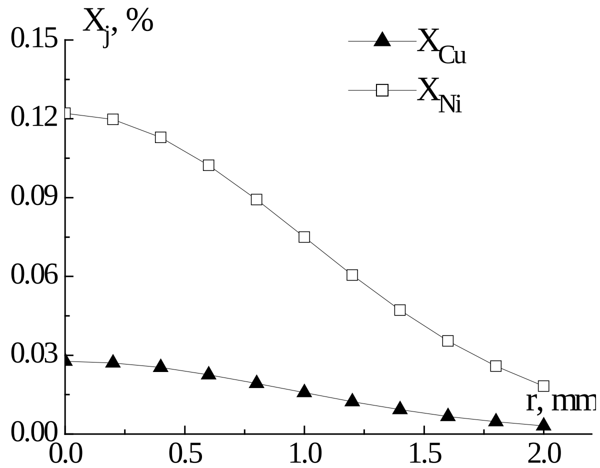

Fig. 4. The radial distributions of copper and nickel vapours contents in plasma of electric arc discharge between Ni (cathode in upper position) and Cu (anode in bottom position)

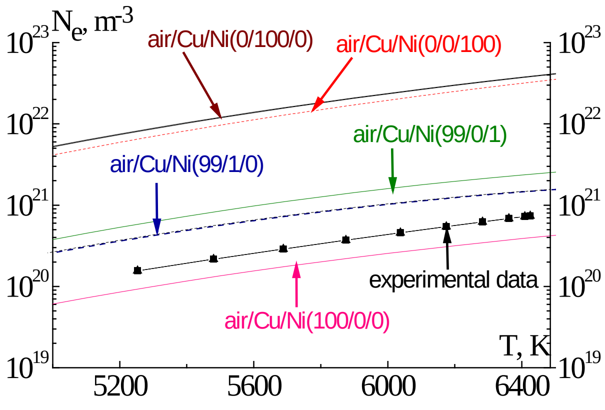

Fig. 5. The dependence of electron density from temperature for plasma of electric arc discharge between one-component Ni (anode in upper position) and Cu (cathode in bottom position) electrodes

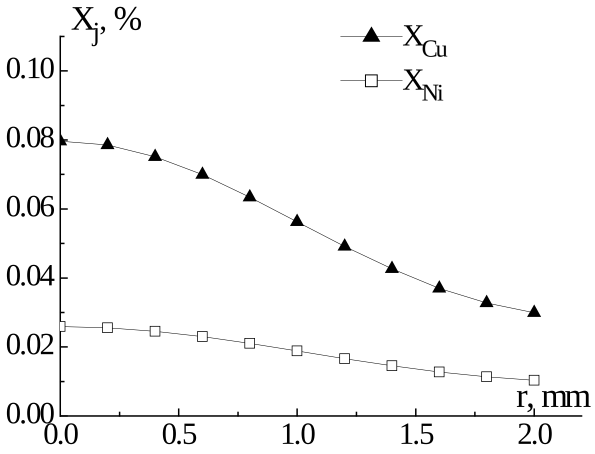

Fig. 6. The radial distributions of copper and nickel vapours contents in plasma of electric arc discharge between Ni (anode in upper position) and Cu (cathode in bottom position)

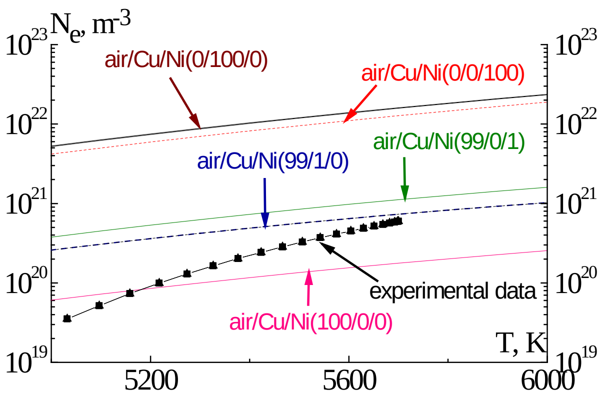

Fig. 7. The dependence of electron density from temperature for plasma of electric arc discharge between one-component Cu (cathode in upper position) and Ni (anode in bottom position) electrodes

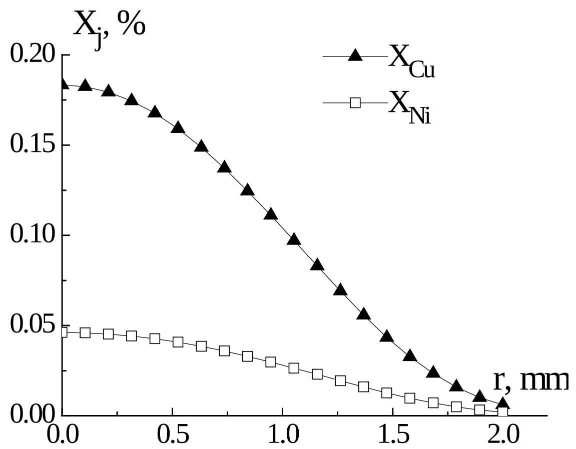

Fig. 8. The radial distributions of copper and nickel vapours contents in plasma of electric arc discharge between Cu (cathode in upper position) and Ni (anode in bottom position)

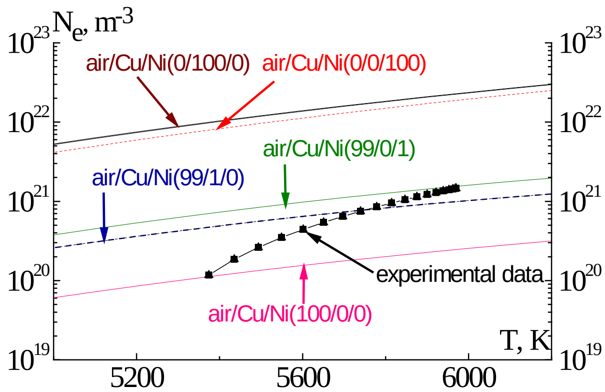

Fig. 9. The dependence of electron density from temperature for plasma of electric arc discharge between one-component Cu (anode in upper position) and Ni (cathode in bottom position) electrodes

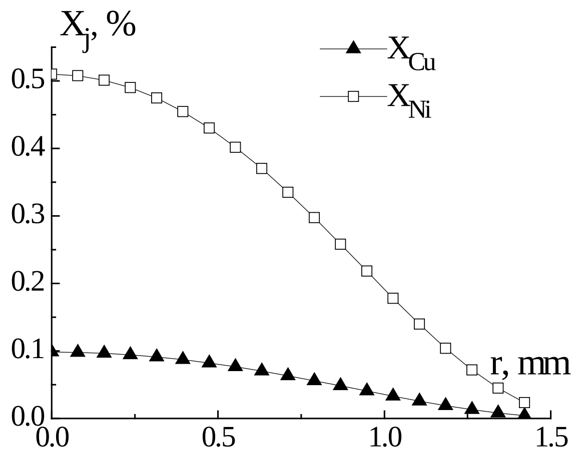

Fig. 10. The radial distributions of copper and nickel vapours contents in plasma of electric arc discharge between Cu (anode in upper position) and Ni (cathode in bottom position)

Fig. 11. Ni (cathode in upper position) and Cu (anode in bottom position)

Fig. 12. Ni (anode in upper position) and Cu (cathode in bottom position)

Fig. 13. Ni (anode in bottom position) and Cu (cathode in upper position)

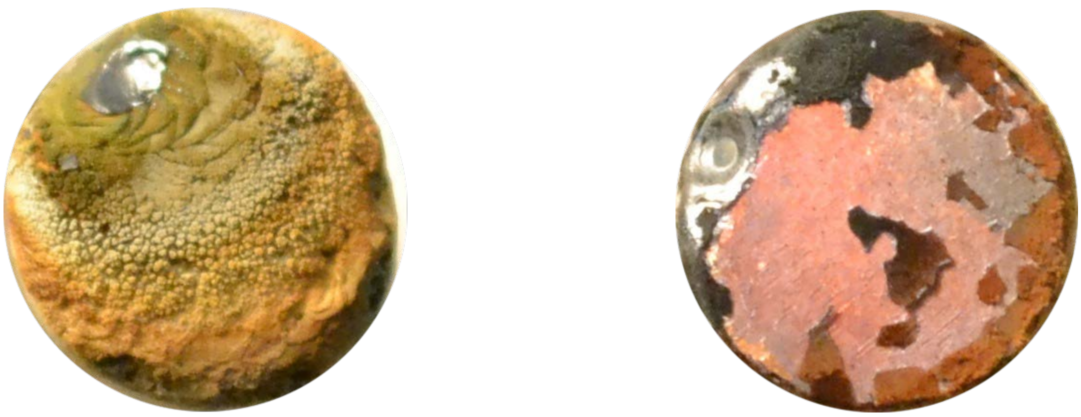

Fig. 14. Ni (cathode in bottom position) and Cu (anode in upper position)

Contrary to the cathode, the nickel anode is evaporated uniformly throughout the surface without the formation of peculiar point focuses, which are similar to the craters (see Figs. 12 and 13).

In contrast to the nickel material, both copper electrodes are evaporated more or less uniformly from the surface-distributed melted pool. There are no sharply defined craters on the surface of the copper anode or cathode, regardless of the polarity and position of the electrodes (see Figs. 11-14). Only the places of the initial arcing on the both electrodes are observed, which arise when the discharge is ignited. The lack of craters, which are characteristic for nickel cathode, can be explained by a higher thermal conductivity of copper as compared with nickel.

CONCLUSIONS

It was found in the study of plasma of electric arc between asymmetric one-component Cu and Ni electrodes at current 3.5 A by optical emission spectroscopy, that:

– the thermal plasma is mostly in local thermodynamic equilibrium along the entire width of the arc channel in the average cross section of discharge gap;
– the most intensive metal erosion take place from the electrode that is used as a cathode;
– the total content of vapours of copper and nickel in plasma of the arc discharge at current 3.5 A is 0.2…0.5%;
– the erosion of the surface of all electrodes mostly does not depend on their position; the erosion of the material of the electrodes depends on their polarity.

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ИССЛЕДОВАНИЕ ПЛАЗМЫ ЭЛЕКТРОДУГОВОГО РАЗРЯДА МЕЖДУ ПЛАВКИМИ Cu- И Ni-ЭЛЕКТРОДАМИ

М.М. Клешич, А.Н. Веклич, С.А. Фесенко, В.Ф. Борецкий, Л.А. Крячко

Методами оптической эмиссионной спектроскопии исследована плазма электродугового разряда между ассиметрическими Cu- и Ni-электродами. Радиальные распределения температуры и электронной концентрации измерены для среднего поперечного столба дуги. Экспериментально полученные температура и электронная концентрация использованы как входные данные для расчета компонентного состава плазмы. Показано, что эрозии под воздействием электрического дугового разряда в большей степени подвержены поверхности тех электродов, которые использовались в качестве катода. Предложенная методика может быть использована для оценки эрозионных свойств различных контактных материалов.

ДОСЛІДЖЕННЯ ПЛАЗМИ ЕЛЕКТРОДУГОВОГО РОЗРЯДУ МІЖ ПЛАВКИМИ Cu- ТА Ni-ЕЛЕКТРОДАМИ

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Методами оптичної емісійної спектроскопії досліджено плазму електродугового розряду між асиметричними однокомпонентними Cu- та Ni-електродами. Радіальні розподіли температури та електронної концентрації виміряні для середнього поперечного стовпа дуги. Експериментально отримані температура та електронна концентрація використані як вхідні дані для розрахунку компонентного складу плазми. Показано, що ерозія має місце під впливом електродугового розряду переважно на поверхні тих електродів, які використовувалися як катод. Запропонована методика може бути використана для оцінки ерозійних властивостей різних контактних матеріалів.