THERMAL PLASMA OF A FREE BURNING ELECTRIC ARC BETWEEN MELTING ELECTRODES

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Abstract

In this paper the parameters of plasma of free burning electric arc in air between Cu-Mo and Cu-W electrodes were studied. By methods of optical spectroscopy with using of spectral lines of copper atom 510.5 and 521.8 nm radial profiles of plasma temperature are determined at discharge current 3.5 and 30 A. With the use of a laser mass analyser the structure change of an electrode material being effected by arc was studied. It was found that the structure of a material varies during arc burning.

1. Introduction

A problem of developing of reliable interrupting devices, where ignition of electric arc often is realised, can not be resolved without careful analysis of processes which take place in the arc and its electrodes. Furthermore, an electric arc, being generated at contact disconnection, results in considerable material erosion of contacts. This causes the decrease of device efficiency and limits reliability of its activity.

In this paper the processes occurred in a free burning electric arc in air between electrodes from Cu-Mo and Cu-W composite materials were studied. Such arc is model of arcs arising between contacts of current disconnectors of electric circuits.

2. Experimental Set-up

Methods of plasma diagnostics of electric arcs between copper electrodes with usage of copper spectral lines were developed earlier [1, 2]. Therefore at the first stage the applicability of these methods for plasma diagnostics of an electric arc between composite electrodes was studied.

It was found, that the diagnostics copper lines in radiation spectrums of investigated plasma are not overlapped with lines of other elements. Therefore, the developed spectroscopic techniques can be applicable for diagnostics in this case.

The arc was ignited between the end surfaces of the non-cooled electrodes. The diameter of the rod electrodes was of 6 mm. To avoid the metal droplets appearing a pulsing mode was used: the current pulse up to 30 A was put on the "duty" weak-current discharge. The pulse interval ranged up to 30 ms. The quasi-steady mode was investigated.
Because of the discharge spatial and temporal instability the method of the single
tomographic recording of the spectral line emission was used. A 3000-pixel CCD linear
image sensor (B/W) Sony ILX526A accomplished fast scanning of spatial distributions of
radiation intensity. It allows recording the radial distributions of nonstationary arc radiation
intensity in arbitrary spatial sections simultaneously.

Just as previously spectrometer [1], the using of the monochromator MDR-12 with the
significant astigmatism allowed excluding additional focusing optics from the optical path of
given spectrometer. The CCD linear image sensor is directly aligned with sagittal focal plane
of monochromator behind its exit slit. This slit is located in the meridional focal plane. Such
technical decision enables to increase aperture ratio of the device and to register spatial
distribution of radiation intensities along an entrance spectral slit of monochromator in a
given spectral range. In a combination with a Fabry-Perot interferometer the spectrometer
provides simultaneous registration of spatial and spectral distribution of radiation intensities.
Thus, the spectrometer allows measuring contours of spectral lines in different spatial points
of plasma volume.

Dynamic range of ILX526A equals 320 typically at the clock frequency \( F = 500 \text{ kHz} \).
The exposure time \( t_{\text{exp}} \) of the CCD linear image sensor is determined by product of
quantity of effective pixels \( N \) on clock period \( T \) (see Fig 1):\[
   t_{\text{exp}} = N \cdot T
\]
where \( T = 1/F \).

It is possible to change a clock frequency \( F \) in a range from 100kHz (Min) up
to 1 MHz (Max). Thus it provides the variations of an exposure time. This results in
the extension of a dynamic range.

Moreover this range can be changed using an electrical shutter function at fixed
clock frequency \( F \). It is possible to change the exposure time \( t_{\text{exp}} \) by changing delay time of
the shutter \( t \) as well (see Fig 1):

\[
   t_{\text{exp}} = N \cdot t.
\]

The step change of the shutter delay time \( t \) in an interval from \( t = T/2 \) up to \( t = T/(2\cdot32) \)
in this case is stipulated.

For the data storage of two reading cycles the buffer memory by a volume 8 KB
is stipulated. The synchronization of operation of the CCD linear image sensor with
the external electrical circuit is stipulated also.

The ISA interface slot of IBM PC in a control and data exchange is used. The hardware
and software was especially designed for laboratory and industry plasma investigations.

As an illustration the radiation radial distributions of copper spectral lines 521.8
nm in the average cross section of a free burning electric arc between electrodes from
Cu-W composite materials are shown in Fig 2-3 (small and vast scale accordingly).
The discharge gap \( l_{\text{arc}} \) was 4 mm at arc current 30 A.

The observed spatial distributions of spectral line intensities can be transformed into
local distribution by Abel inversion. Our developed software provides such procedure on the
base of Bockasten technique [3].
3. Results and Discussions

The radial profiles of temperature are determined in the average cross section of the discharge gap $l_{ak} = 4$ and $8$ mm in air at arc currents $3.5$ and $30$ A. The temperature profiles are obtained from relative intensities of copper spectral lines $510.5$ and $521.8$ nm. The results of measurements are shown in Fig 4-7.

From the analysis of obtained results it is visible that in the discharge gap $l_{ak} = 4$mm (short arc) the axial temperature increases with increase of a current. Besides accordingly to the value of effective ionization potential [4] the axial temperature in a discharge between Cu-W electrodes is higher than in an arc between Cu-Mo electrodes.

In a long arc ($l_{ak} = 8$mm) the situation completely differs. The axial temperature in a discharge between Cu-W electrodes is lower than in a short arc, that is natural [5]. In plasma of electric arc between Cu-Mo electrodes the axial temperature is higher than in a short arc.
and is decreased at a current increase. Probably some secondary structure on a surface of electrodes can be realized during the discharge operation. This structure regulates the injection of metal vapors in arc plasma in a special manner. Besides the plasma of such arc probably is not in a local thermodynamic equilibrium. Such effect was observed in plasma of a short free-burning electric arc between copper electrodes [6].

![Cu-W, L_{ab} = 8mm](image)

*Fig 5.*

![Cu-Mo1, L_{ab} = 4mm](image)

*Fig 6.*

The processes occurred in the discharge gap are determined by erosion of the electrode material and condition of its surface. The mass-spectrometry and metallography technique was applied to analysis of change of surface composition and structure of studied contacts. The surfaces of electrodes were investigated pre- and post-arc operation. The laser mass-
spectrometry technique is based on the evaporation and ionisation of investigated material by the laser beam of the thin cross section (1 μm). Then, in such way formed plasma is analysed by an ordinary mass-spectrometry method [7]. It was shown that the element composition of a material is changed during the arc operation.

Fig 7.

The metallographic analysis of working layers of a Cu-W composition has shown that under influencing of a heat flow of the arc discharge in a working layer the secondary structure is formed. It represents a layer of a variable composition with high-melting peel in the vicinity of a surface. Such peel is formed as a result of depletion of the initial material in copper. The melting point for copper is much lower, than for tungsten. There is a vaporisation, spraying, sweating of copper and as result friability of a high-melting framework, formation of porosity and open channels (see Fig 8). The volatile oxide of W and their complexes (trimers, pentamers etc.) will be formed at such modify structure of a composite material in a working layer. This working layer at abrupt change of temperatures becomes friable and is failed.

Such point of view is confirmed also by mass-spectrometry analysis. The composition material consists of copper (58 %) and tungsten (41 %). The dark and light areas are observed on the electrode surface after the arc operation. The content of tungsten decreases in such areas and the content of oxygen increases almost a ten times. It is interesting to note that such changes take place only on a surface of the electrode. At a depth of 2 μm the content of a material is the same pre- and post-arc operation. The electrode fast burns in the arc operation mode. It becomes friable and crumbles. The large deficiency of a tungsten is observed in the fallen off part. Such structure change of the composition material essentially modifies its mechanical and electrical properties and should influence its performance.

The analysis of Cu-Mo electrode surface yields some another results. The composition material consists of copper (56 %) and molybdenum (35 %). There are visually distinguished from each other areas on an electrode surface probably due to the arc chaotic motion. In these areas the copper percentage decreases by 5 + 10 % and essentially the oxygen content increases. The metallographic analysis implies the other nature of interaction in a Cu-Mo-system in comparison with Cu-W one. The copper wets the molybdenum fragments at the
melt. In the arc operation mode it makes for localised sintering and formation of dense aggregates of a high-melting phase in a working layer with a film of an oxides melt on an electrode surface (see Fig 9). Petrographical and roentgenphase analysis of such working layer has confirmed formation in it not only MoO_3_, but Cu_6Mo_4O_15_ and Cu_3MoO_5_ as well. The formation of fusible molybdates on the electrode operation in air causes irreversible structural changes in a working layer and therefore, nature of erosion. Nevertheless despite of an essential decrease of melting point of fusible component of the Cu-Mo composition material the electroerosive wearing of such electrodes on the operation in air is comparable with electroerosive wearing of electrode from the Cu-W composition material. Probably it is due to the heat absorption at phase changes in the Cu-Mo- system. It makes for dissipation of energy and decrease of electroerosive wearing.

Fig 8.

The spectroscopy techniques yield results, which are not at variance with another technique results.

The further complex investigations of composition materials will allow to optimise the contact and electrode content.

4. Conclusions

The obtained results allow to make some conclusions concerning of processes of the electrode material erosion in arc.

References