MAGNETIC FIELD INFLUENCE ON THE SHAPE OF ERODING SURFACE OF GRAPHITE CATHODES

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1. INTRODUCTION

The vacuum - arc method of synthesis of amorphous carbon a-C allows to shape films of this unique material with the highest physical-mechanical performances [1]. As fields of practical application of this method widen more and more actual become questions of productivity of the process equipment, clearing of macroparticles from plasma, and, in the first instance, also problems of reliability and lifetime of a plasma source as basic instrument for realization of the method. The success in the solution of the problems, in turn, will be defined, as far as effectively will be eliminated difficulties in discharged an ignition and stability in the vacuum - arc carbon plasma source stipulated by specificity of a cathode spot (CS) behavior on the graphite cathode. The velocity of the CS motion on graphite is essentially (on 2-3 orders of magnitude) less, than on metal; the averaged lifetime of CS strongly depends on the sort of graphite. In practice it results in strongly nonuniform erosion of the working surface of the cathode, that in turn is the reason of unpredictable changes of plasma stream parameters, raise of an arc exiting frequency and loss of serviceability of the device.

In the present work the influence of a magnetic field on the shape of the graphite cathode eroding surface, at different pressures and arc currents was investigated.

2. EXPERIMENTAL

The schema of the experimental plasma source is submitted in Fig. 1. The replaceable water-cooled cathode (1) had the shape of the cylinder of 60 mm in diameter and of 20 to 60 mm in height. The cathode end (2) oriented to the anode (3) served as a working surface. The anode was made from stainless steel as a cylinder with water-cooled walls. Inner diameter of the anode was 210 mm, its length was 300 mm. The housing of the cathode unit (4) was embraced by the cathode coil (5) (2300 turns). The additional coil (6) (100 turns) there was disposed. At the anode disposed is the anode coil (7) (4 sections, 600 turns per section). The igniter (8) here was located at the working end of the cathode and forms a spark plasma injector in a couple with the auxiliary anode (9) [2]. On this electrode the demountable ring from steel (10) was disposed. Being ferromagnetic, this ring served as the concentrator of a magnetic field. The cathode coil (5) was enclosed with demountable magnetic screen (11). At presence of the concentrator the system ensured ignition with probability not less than 90 %.

The exit end of the source was overlapped by a flat collector (12) for imitation of a substrate under negative potential (-70 V) and for measuring ion component of a plasma stream. The cathode was made of graphite of several marks. Argon was used as a working gas.

The arc stability was defined as 1/n, where n is a number of the arc excitations per hour. The ignition probability was defined as the relation of the arc ignition number to the number of all triggering impulses which have arrived per unit of time on the electrode 8.

At the starting stage of our experiments the cathodes from titanium were used. It was done for simplification of procedure of a choice of optimum condition ensuring maintenance of the flat shape of the cathode working surface during its "burnup". At those velocities of CS motion, which is characteristic for Ti (hundreds m/sec), the area of the most probable existence of CS is easily identified visually as a part of the working surface, filled with brightly flashing twisting lines – the CS trajectories. Selecting an appropriate arcing mode (arc current, magnetic field, gas pressure, etc.) so that the area of the CS existence takes up all working surface of the cathode, one could expect that under these condition the uniform erosion of this surface will be supplied, and hence a plane form of it will be maintained.

3. RESULTS AND DISCUSSION

3.1. EXPERIMENTS WITH Ti CATHODES

The experiments have shown, that the most effective passage of plasma along the anode, which takes place in case of adding magnetic fields of the anode coil sections (Fig. 1 (b)), can't be realized at presence of the negative collector due to a strong arc instability. Therefore all experiments were carried out at the opposing fields of those sections, when the rather free sink of magnetized electrons along magnetic lines crossing the anode (Fig. 1 (c)) was ensured. Though such operation mode of the source yielded to variant with adding fields, nevertheless, it ensured rather high ion current on exit (Fig. 2).

In presence of the concentrator 10 ignition remained stable at lowering pressure up to 4·10-3 Pa. In its absence the pressure could be reduced without disadvantage for ignition reliability only up to 1,3·10-2 Pa. The positive influence of the concentrator on ignition is stipulated by that at its presence the course of magnetic lines is more favorable for CS transition from a lateral surface of the cathode to its working end: the acute angle between the lines and this surface enlarged (Fig. 3). The similar effect, basically, could be reached with the help of the screen 11. However in our condition the expected effect has appeared inappreciable owing to a small thickness and large distance of the screen from the cathode.

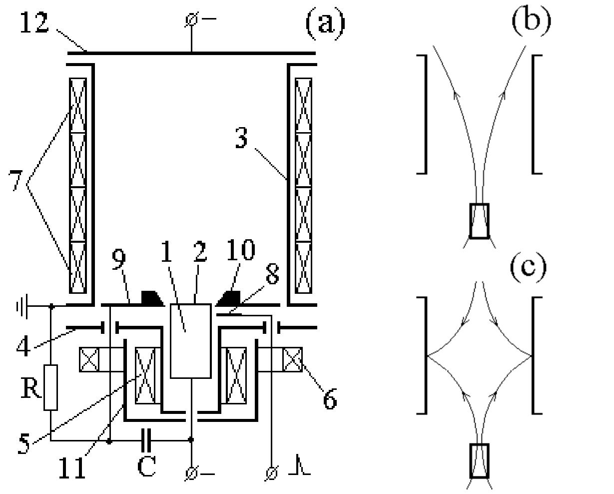

Fig. 1. Schematic of the experimental plasma source (a); lines of adding (b) and opposing (c) magnetic fields (arrows)

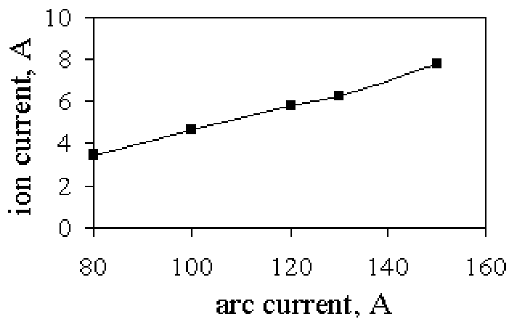

Fig. 2. Output ion current dependence on the arc current

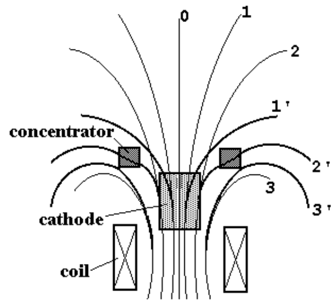

Fig. 3. Magnetic field lines in the source without concentrator (thin lines) and with concentrator (bold lines)

The character of "burnup" of the cathode owing to erosion under action of the CS is defined by low of the spot motion on the cathode surface. In turn, the CS behavior on the cathode of source of the explored type is defined by balance of magnetic fields: external fields created by the coils, and so-called internal fields generated by currents through the CS. In absence of external fields the zone of CS random travel is restricted to a central part of the working surface of the cathode. In this place a concave [3] is formed. With occurrence of an exterior axisymmetric magnetic field, which lines are canted from centre to periphery of the working end of the cathode, the CS rotation around the cathode centre ("retrograde" motion under action of the magnetic field radial component H_r) is superimposed on its random motion. According to "the rule of an acute angle" the CS shifts on such distance r, at which the action of an external field on the spot is balanced by action of internal fields. At some magnetic field strength the equilibrium circular trajectory of CS shifts to the periphery of the working surface. Its edges erode most intensively. CS frequently runs on the lateral surface of the cathode and dies away. The device, practically, is disabled. At some intermediate value of a magnetic field intensity the CS, making motions on a circle with $r \approx R/2$ and being deviated from it chaotically on distance $\approx \pm R/2$, "visits" all points of the effective area with equal probability and equal frequency. (R is radius of the cathode). Thus the erosion of the surface is uniform, and its shape remains flat up to complete "burnup" of the cathode (see Fig. 4a). As the cathode was expended owing to erosion it gradually was moved in the source so that it's working end was in the auxiliary anode vicinity.

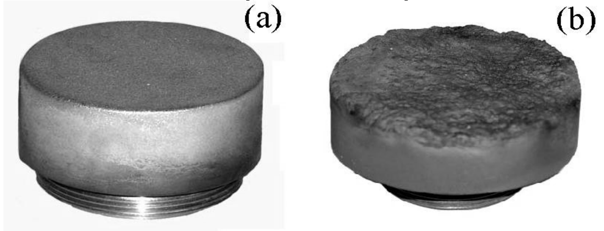

Fig. 4. Titanium cathode exposed during 360 min., I_d = 110A, I_5 = 0.7A, I_6 = 7A (a); graphite cathode exposed during 510 min., I_d = 110A, I_5 = 0.65A, I_6 = 9A (b)

The data on influence of the magnetic field of the coils 5 and 6 on the arc stability and shape of the eroding surface of the cathode are given in the Table. Here I_6 is the coil 6 current, H_r and H_z are the radial and axial components of the magnetic field measured at the surface of the working end of the cathode at radius r when the current in the coil 5 was I_5 = 0.7 A.

Table. Influence of magnetic fields on the arc stability and the shape of the cathode eroding surface

I_6, A	H_r, Oe / H_z, Oe			n, hour $^{-1}$	The cathode end shape
	r =0	r =15 mm	r =30 mm		
0	0/57	5/54	8/40	~1	concave
6	0/67	6/64	12/49	6 ÷ 7	flat
9	0/73	8/70	12/59	~30	convex

3. 2. EXPERIMENTS WITH GRAPHITE CATHODES

The experiments have shown, that in case of a vacuum arc with graphite as well as with metal (Ti) cathode the CS reaction on an exterior magnetic field is qualitatively the same. In both cases the spot rotates around the centre of the electrode under actions of radial component of the magnetic field H_r, being simultaneously displaced from centre to the periphery against the gradient of axial component ∇H_z. Last circumstance is in accordance to the conclusion of ref. [4], which could be interpreted as follows: in an oblique nonuniform magnetic field the CS moves athwart tangential component of the magnetic field in retrograde direction and also drifts along this component against the gradient of the normal component. A special case of this rule is the known rule of an acute angle.

In fig. 5 the dependences $n(\nabla H_z)$ and $U_d(\nabla H_z)$ are shown. The character of dependences is explained as follows. The higher ∇H_z value corresponds to greater H_z absolute values. H_z amplification, in turn, leads, on the one hand, to diminution of electron-type conduction of plasma in direction to the anode and therefore U_d raises. On the other hand, it lead's to greater CS shift toward the working end edges, and also to increasing probability of it's moving off from the end surface and, hence, to it's extinction (Fig. 6). The strong correlation between n and U_d can be used for self-acting correction of an arc stability, and, consequently, of the cathode erosion character by means of a magnetic field control device with a back coupling on U_d.

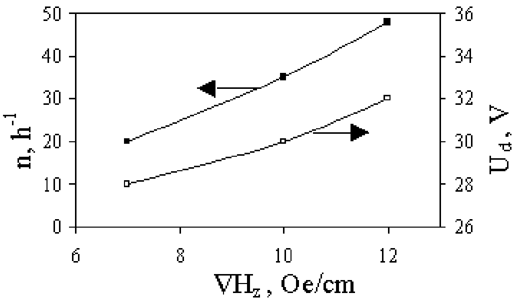

Fig. 5. Extinction frequency (n) and arc voltage (U_d) as functions of ∇H_z. (H_z – axial component of the magnetic field)

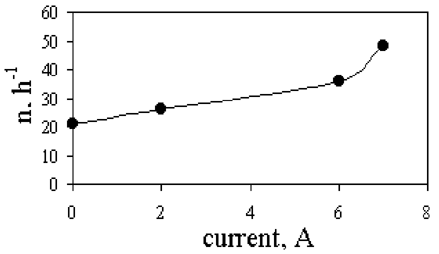

Fig. 6. Extinction frequency (n) as a function of the coil 6 current

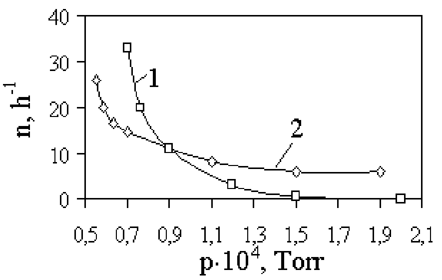

Fig. 7. Extinction frequency as a function of pressure: $I_6 = 0$; $I_5 = 0.65A$ (1), $I_5 = 0.2A$ (2)

Fig. 7 illustrates the influence of pressure of argon on the arc stability. It follows from the figure, that in presence of Ar in moderate magnetic fields, close to optimum, the arc stability rises with growth of pressure, and at $p \geq 1{,}5$ mTorr the arc burns almost without extinctions (curve 1). But in feeble magnetic fields at the same character of dependence n (p) the n quantity remains different from zero in all explored range of pressure and does not fall below ~ 6 hour $^{-1}$.

Dependence of the shape of the graphite cathode eroding end on the magnetic field, as a whole, is the same, as for the metal cathode. The photo of the cathode from MG graphite, saturated with pyrocarbon, is show in Fig. 4(b). The cathode was subject to undergone an arc action during 510 minutes at I_d = 110A, I_5 = 0,65A and I_6 = 0,9A. One can see, that in operation mode, close to optimum for the Ti cathode, the end of the graphite cathode till the test finishing has maintained the flat shape. It must be noted, that the uniform burnup of the graphite cathode was achieved only at high arc stability, when the CS average lifetime essentially exceeded the CS circular motion period on the equilibrium trajectory. Otherwise cathode burned off nonuniformly: an electrode eroded, in basic, near to the igniter. As a result the ignition rather soon became impossible. The alignment of erosion in such case is achieved by means of application of several triggering electrodes disposed around the cathode on perimeter of its working end. The igniting impulses are supplied to the electrodes alternately. Such method of ignition is especially expedient in case of use of graphite characterized by lowered arc stability [5].

4. CONCLUSION

It is established experimentally, that in an end-type vacuum-arc plasma source with magnetic steering of the cathode spot the uniform erosion of the graphite cathode end can be ensured by selection of an appropriate intensity of an axisymmetric magnetic field with gradient of axial component.

At the presence of argon the arc stability essentially rises; in an optimum mode at $p \cong 1{,}5$ mTorr the arc burns practically without extinctions.

At use of graphites characterized by low arc stability, the using of the multielectrode triggering device is recommended.

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