VACUUM-ARC PLASMA SOURCE WITH STEERED CATHODE SPOT

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The improved version of a vacuum arc plasma source with magnetic control of a cathode spot and focusing of plasma stream is described. The advanced structure of the cathode unit, the shortened anode and their swing joint with each other allowed reducing overall dimensions of a source, lowering its material capacity, increasing weight of the consumable cathode material, simplifying procedure of replacement of the cathode, improving design and raising performance data of the source. On operational characteristics of the new plasma source exceeds the best modern plasma sources of similar designation.

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1. INTRODUCTION

The cathode vacuum arc is the basic tool in vacuum-arc coating deposition techniques. A number of plasma sources on the basis of the discharge of this type is developed. These sources are intended for the decision of various technological problems: from deposition of thin and superthin (2 − 3 nm) wear resistant antifrictional and optical coatings – to growing thick and superthick (up to 1.5 − 2.0 mm) multi-layered structures [1]. Vacuum arc plasma sources with magnetic steering of a cathode spot (CS) and magnetic focusing of plasma stream are widely used. However big longitudinal size, high material cost and inconvenient consumable cathode replacement, should be considered as drawbacks of this source. Deposition of thick and superthick condensate layers needs long operation time of the plasma source without process stopping and without working chamber opening for cathode replacement. In this case the indispensable requirement to the plasma source is the increased reserve of consumable cathode material on the basis of which the coating is formed. Such requirement is satisfied with sources which have extended cylindrical cathode [2]. They have possibility of cathode shifting inside the source when it shortens due to erosion. However such ability of displacement of the cathode is reached by considerable complication of the source construction. The relatively big longitudinal size of the source reduces ergonomic qualities and appearance of installation as a whole.

This work describes the new model of the plasma source which design provides the said problems solution.

2. THE PLASMA SOURCE STRUCTURE. EXPERIMENTAL DETAILS

The design of the source implements the principle of cathode spot existence zone stabilization on the electrode working surface by "bottle necked" type magnetic field located behind rear cathode face.. Magnetic field in the anode cavity is generated by focusing coils. Correction of magnetic field, which provides stable arc burning in the source during cathode consumption process, is realized by selection of magnitude and direction of focusing coils currents. Thus mechanical cathode moving becomes unnecessary, what leads to cathode unit design simplification and the source length reducing.

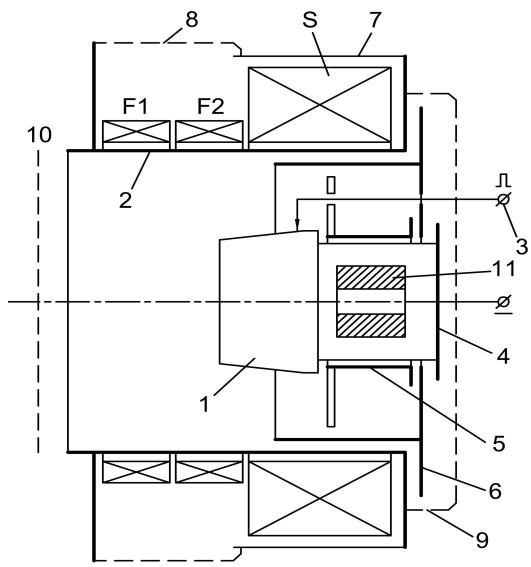

Fig. 1. Scheme of the vacuum-arc source under investigation

The scheme of the new source is shown in Fig. 1. Its cathode 1 has the form of the truncated cone with the basis of 80 − 100 mm and initial height 50 mm, so the reserve of consumable cathode material is two or three times higher than for a standard prototype source having cathode with 60 mm basis and height of 40 mm. In our experiment titanium was used as a cathode material. Anode 2 is made of nonmagnetic stainless steel and arranged coaxially with the cathode. Internal diameter of the anode is 160 mm, the length of a current-collecting part of the anode is about 150 mm. The anode walls and the back end face of the cathode are water-cooled (not shown). The spark triggering device 3 of contactless type is located opposite to the lateral surface of the cathode close to its basis. The cathode holder with elements of bayonet-type mount, a supply of cooling water to the cathode and sealing of all connections on the scheme is designated by numeral 4. The cylindrical part of auxiliary anode 5 shields the lateral walls of the cathode holder 4, and its face part in the form of a flat ring adjoins the basis of the cathode with a gap of 1.5 − 2.0 mm. On the auxiliary anode which is also an element of the triggering device [1], "spark-plug" of this device is fixed. The cathode unit, the auxiliary anode and the triggering device are fixed on flange 6. The swing joint of the flange 6 with the anode 2 considerably facilitates access to all elements mounted on the flange. Such design in a combination with bayonet-type mount of the cathode considerably simplifies procedure of replacement of the cathode.

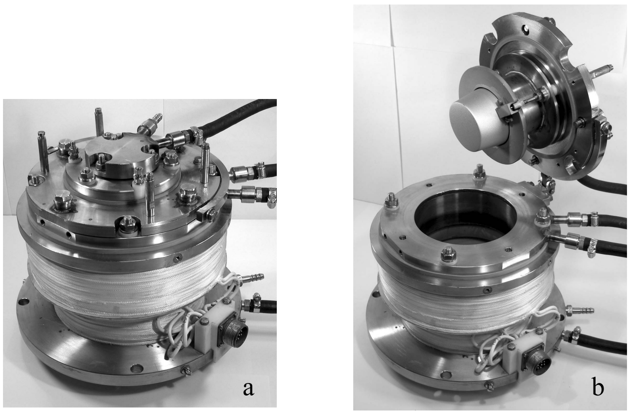

Fig. 2. Photograph of the vacuum-arc plasma source without protective casing (a); cathode unit is in the opened state (b)

The new design of the cathode unit and the shortened anode have introduced a possibility to reduce length of the source in two times (256 mm) in comparison with the prototype source (560 mm). On the anode the stabilizing coil S and two focusing coils, F1 and F2, are placed. The stabilizing coil consists of 2100 turns, each focusing coil contains 380 turns. Coils copper expenses are 30% less than in a prototype source. Numerals 7, 8 and 9 designate parts of protective casing. The dashed line 10 designates a site of the substrate holder. In a cavity of the cathode holder the cylindrical core 11 is placed. It is made of magnetic steel and serves as magnetic concentrator for correction of geometry of magnetic field distribution near to a lateral surface of the cathode [3]. The photograph of the plasma source described is shown in Fig. 2.

Titanium coatings were deposited on stainless steel samples of (20×10×1.5) mm in size. The samples were mounted on the flat substrate holder on distance of 120 mm from the end face of the anode. The coating deposition rate was defined as thickness or weight of the condensate deposited during a time unit onto a unit of area. Thickness of coating was measured by means of interference microscope as a height of a step between the coating surface and the substrate surface covered by a mask before deposition. Operation stability of the plasma source was estimated by arc spontaneous decay frequency, triggering efficiency – by quantity of the triggering pulses which preceded ignition of the arc discharge.

3. RESULTS AND DISCUSSION

In conditions of high vacuum (~ $2\cdot10^{-5}$ Torr) rather stable work of the investigated plasma source takes place in wide ranges of key parameters describing an operating mode of the source: arc current (I_a) – from 80 up to 160 A, stabilizing coil current (I_s) – from 0.5 up to 1.4 A, focusing coil current (I_f) – from 0 up to 2.5 A.

Fig. 3 illustrates influence of the arc current and focusing coils current on stability of arc burning in the source. The presented dependences are typical for vacuum arc plasma sources with axisymmetrical focusing magnetic fields in the anode cavity.

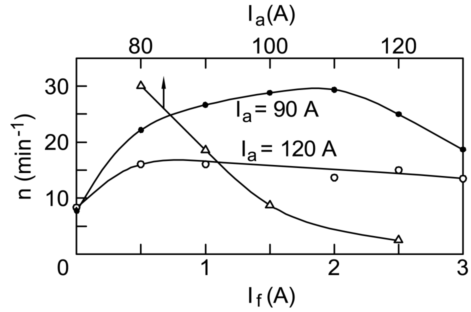

Fig. 3. Influence of the focusing coil current (I_f) and the arc current (I_a) on the frequency of spontaneous decay of the arc (n). $I = 1.4$ A; $p = 2\cdot10^{-5}$ Torr

The arc is most stable when magnetic field of coils F1 and F2 is absent ($I_f = 0$). The arc decay frequency *n* thus is minimal, and arc ignition is most facilitated – the arc is ignited commonly from the first starting pulse. It is caused by favorable geometry of magnetic fields in the source (Fig. 4): the angle of crossing of magnetic lines of force with a surface of the cathode in a point of initiation of the arc is great enough [4] for pushing the cathode spot off the lateral surface of the cathode to its working end face at the stage of ignition and in case of spontaneous runaway of the spot onto the lateral surface of the cathode. Component of the magnetic field tangential to the anode surface hinders current transfer between the cathode and the anode.

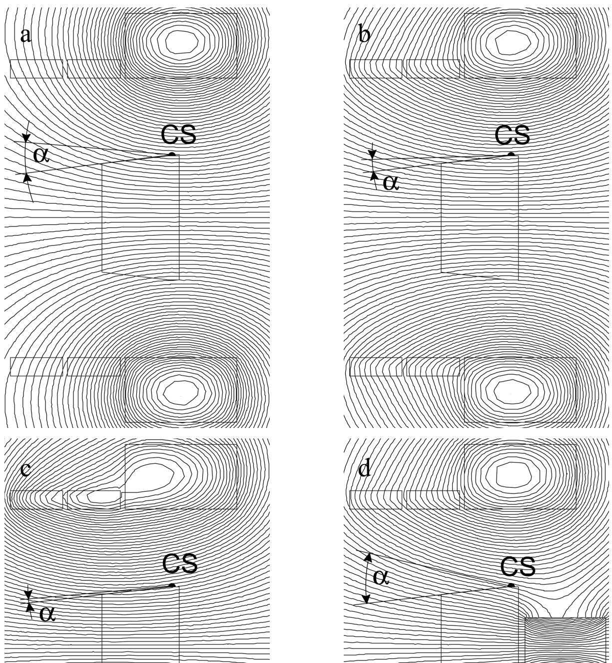

Fig. 4. Distributions of magnetic fields. (a) $I_s = 1.4$ A, $I = 0$; (b) $I_f = 1.5$ A; (c) $I_f = 3$ A; (d) $I_f = 1.5$ A

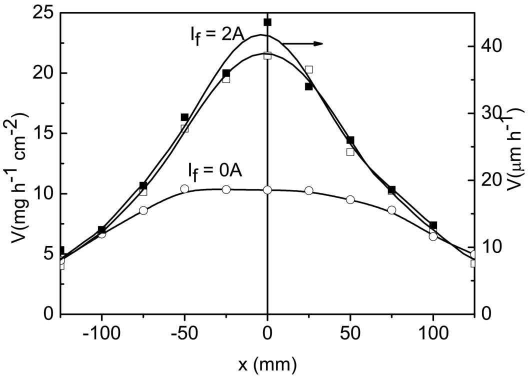

Fig. 5. Radial distribution of coating deposition rate (v) at distance of 120 mm from the anode. x – distance from the source axis in horizontal direction. All coils of have additive polarity

In considered case this component is minimal, thus the arcing conditions are optimum. With strengthening of the focusing magnetic field (Fig. 4b,c) the angle α decreases, transversal component of the magnetic field (in relation to direction of electronic current onto the anode) becomes stronger, and, hence, conditions for effective ignition and stable arcing deteriorates. This explains arc decay frequency growth with strengthening of magnetic field in the anode. Some decrease of n, observed with growth of I_f over ~ 2 A, can be explained by some stabilization of the arc by a longitudinal magnetic field when the arc begins to burn mainly onto the chamber-anode. With increase in the arc current the plasma density in the discharge gap increases resulting in decrease of electrons magnetization degree. Plasma conductivity across the magnetic field (in direction towards the anode) increases, resulting in increase of the arc stability. Creation of favorable conditions for ignition (increase in the angle α) is promoted by presence of the ferromagnetic core near the cathode rear end (Fig. 4d). It should be mentioned once again, that the data cited above relate to rather low pressure (nearby $2\cdot10^{-5}$ Torr). This pressure is the most adverse for arcing. At presence of working gases (N_2, Ar) at pressure more then $2\cdot10^{-5}$ Torr the arc burns practically without decays.

Radial distributions of the growth rate of titanium condensate are shown in Fig. 5. They were received at the lack of a current in focusing coils ($I_f = 0$) and in conditions of focusing of a plasma stream ($I_f = 2.0$ A). Currents in the coils were of the same directions. It can be seen that focusing in such conditions leads to appreciable narrowing of the directional pattern of the stream and to increasing in coating growth rate in the maximum of distribution more than twice.

4. CONCLUSIONS

The new source in comparison with a standard source-prototype is characterized twice by smaller length and the improved design, consumption of a copper wire for the coils manufacturing is lowered by 30 %, and reserve of a cathode material is increased in 2-3 times.

The cathode unit construction and its swing joint with the anode provides an easy access to all elements disposed at the flange of the unit, and considerably simplifies procedure of replacement of the cathode

The lower limit of the arc current of source investigated makes up about 80 A. At the currents more than 90 A and at presence of working gases (N_2, Ar, etc., pressure about $2\cdot10^{-4}$ Torr and more) the arc burns without decays. At distance of 120 mm from the exit of the source the deposition rate of titanium film reaches 40 microns per hour. It exceeds the level of the best modern models of plasma sources of similar designation.

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ВАКУУМНО-ДУГОВОЙ ИСТОЧНИК ПЛАЗМЫ С УПРАВЛЯЕМЫМКАТОДНЫМ ПЯТНОМ

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Описан усовершенствованный вариант вакуумно-дугового источника плазмы с магнитным управлением катодным пятном и фокусировкой выходного потока. Усовершенствованная конструкция катодного узла, укороченный анод и их шарнирное соединение друг с другом позволили сократить габаритные размеры источника, снизить его материалоёмкость, увеличить массу расходуемого катодного материала, упростить операцию замены катода, улучшить дизайн и повысить рабочие характеристики источника..

ВАКУУМНО-ДУГОВЕ ДЖЕРЕЛО ПЛАЗМИ З КЕРОВАНОЮ КАТОДНОЮ ПЛЯМОЮ

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Описаний удосконалений варіант вакуумно-дугового джерела плазми з керованою магнітним полем катодною плямою й фокусуванням вихідного плазмового потоку. Удосконалена конструкцію катодного вузла, укорочений анод та їх шарнірне з'єднання один з одним дозволили скоротити габаритні розміри джерела, знизити його матеріалоємність, збільшити масу катодного матеріалу, що витрачається, спростити операцію заміни катода, покращити дизайн і підвищити робочі характеристики джерела.