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Thermal Conditions of Technological Plasma Sources Cathodes

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Were determined thermal conditions of vacuum-arc plasma sources cathodes.Stationary thermal field of the cathode with refrigeration was researched along both later a landend surfaces having different geometry of cathodes and thermal flows onto the operating surfaces.Was detected non uniformity of cathode operational surface temperature distribution along its radius. This non uniformity is greater for the cathode with refrigeration along the side surface and it can be minimized to several degrees range by changing the geometry of the cathode.Weredetermined time periods for cathodes with different refrigeration types reaching stationary thermal regime depending on cathodes' geometry and arc current.

Keywords: Vacuum-arc plasma source cathode, Plasma flow composition, Cathode operating surface temperature, Cathode stationary thermal field, Time to reach stationary thermal regime.

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1. INTRODUCTION

While analyzing the market of vacuum devices and technologies used top roduce wear proof, strengthening and other coatings, made in [1] in tensive growth (10-15 % peryear) was noticed. It is also noticed, that a peculiarity of such technologies is low cost of raw materials and high cost of the technology itself for the final product. Commercial value of final product 1 kg done using beam technologies is around 10-30 thousand USD, which is 1000 times more than in mechanical engineering and one rate more than for microelectronics.

At the same time analyzing the progress of leading companies producing coatings, machinery and technologies of their creation in developed countries(Balzers, Cemicon, Metaplas, Leybold, Platit and etc.) that use physical vapor deposition (PVD) and also products of CIS scientific centers done by specialists from SPA "Saturn" showed that by now in Russia and abroad there were actually not created processes and technologies to form widely spread nanostructured multileveled composite coatings for industrial devices and specifically for cutting and stamping tools.

One of the reasons for such circumstances is presence of great microparticles amount in the plasma flow generated by vacuum-arc plasma sources. Main parameter defining the number of microparticles in plasma is temperature of cathode operation surface.

Research of vacuum-arc plasma sources cathodes thermal conditions and time to reach stationary thermal regime (with refrigeration along both lateral and end surfaces, having different cathodes geometry and thermal flow intensities onto the operation surfaces) is the goal of the work.

2. ISSUE UP TO DATE STATE

Experimental data obtained for an arc with titanium cathode [3] show that there is major influence of integral temperature on erosion velocity and character. Insuchawayhaving unsatisfactoryheat dissipation from the non-operation end of rod cathode (there is powder graphite between the cathode and adapter) erosion velocity increases more than 5 times comparing to the cathode with direct refrigeration. Unfortunately data about cathode temperature and referring erosion velocities is absent in sources [3,4 and etc.]

In [5] were studied possibilities and peculiarities of cathode with refrigeration along both lateral and end surfaces operation surface temperature regulation and stabilization. Were developed cathode nodes constructions in which temperature of operation surface can be controlled by changing the temperature of the refrigerated end of the cathode, changing current of vacuum-arc discharge and changing the distance between the operation surface and its refrigeration zone by moving the cathode. Still the temperature of operation surface and time period to reach stationary thermal regime of the cathode with different refrigeration types are not researched depending on the geometry and vacuum-arc discharge current in [5].

Vacuum-arc plasma source developed in [6] is characterized by low micro particles content in the created plasma flow. Such peculiarity was reached by using disk cathode with initial ratio of diameter D and length L $D / L = 4$. Temperature of cathode operation surface doesn't exceed 500 K. During operation of a plasma source with such cathode geometry D / L ratio permanently increases that leads to lowering the temperature of cathode operation surface and changes the composition of plasma flow generated.

To obtain coatings with reproducible composition in [7] decreasing gorge in the rod cathode close to its operation surface takes place between sputtering cycles. Main imperfection of the method is a need to perform a complicated process of decomposing – composing of plasma source cathode node after each processing cycle that decreases the productivity of the process. A more rational way to keep the temperature of cathode operation surface constant in a separate sputtering cycle is a method of changing refrigerating liquid flow suggested in [5].

There is a noticeable increase of cathode plasma forming substance provided in constructions of vacuum-arc plasma sources with refrigeration of the cathode along the lateral surface [8]. Such composition allows to move the cathode with respect to its depletion. This take saway the limitation of cathode material. Also stabilization of cathode operation surface temperature takes place due to absence of distance change between it and the refrigeration zone.

Still when practically realizing plasma sources of such type there stays the question about cathode geometry (its radius) cause while increasing the radius of the cathode there might increase temperature nonuniform distribution along the operation surface.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Thermal Regime of Cathode Refrigerated Along and Surface

Modelling temperature of cathode with refrigerated end surface was based on the developed mathematic model that takes counts heat losses due to radiation using finite element method. Results of thermal fields on cathode operation surface having different cathode length *L*, radius *R*, arc currents Iд are given in Fig. 1-3.

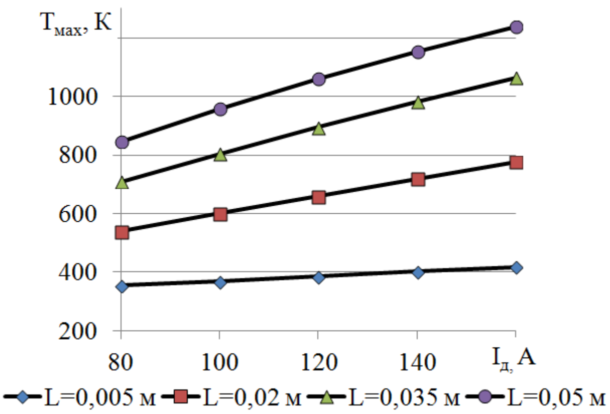

Fig. 1 – Cathode operation surface maximum temperature with refrigeration along thee and with respect to arccurrent:$R = 0.03$ m

Increasing arccurrent $I_д$ effects to in crease of power $P_к$ that executes on the cathode that leads to raise of operation surface maximum temperature (Fig. 1). In this case temperature is linear, growth velocity is in proportion to cathode length *L* and in inverse proportion to radius *R*. Having valuable cathode length increase катода ($R = 0.03$ m and $L > 0.035$ m)radiation energy losses from the operation surface start to valuably effect that leads to temperature growth slowdown (Fig. 2). When $L = 0.30$ m energy losses are equal to the energy delivered to the cathode and operation surface temperature stabilizes and the value of 1695 K. When the radius of the cathode is greater temperature stabilization takes place at greater cathode lengths.

Increasing cathode radius leads to lowering operation surface temperature (the greater is the length of the cathode the faster) that happens due to decreasing specific power delivered to the surface of the cathode.

Radiation energy losses from cathode lateral surface lead to temperature non uniform distribution along the

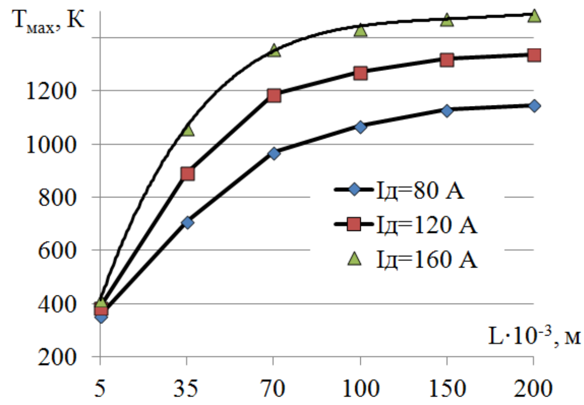

Fig. 2 – Cathode operation surface maximum temperature with refrigeration along thee and with respect to its length:$R = 0.03$ m

radius of cathode operation surface: maximum value in the center and minimum on the distance equal to the radius of the cathode. This temperature gradient ΔT is insignificant (several hundredths of degree at $L = 5$ mm and not exceeding 0.65 at $L = 10$ mm – Fig. 3). Still this gradient increases when *L* increases and can reach up to several tens degrees, though gradient value decreases with cathode radius increase.

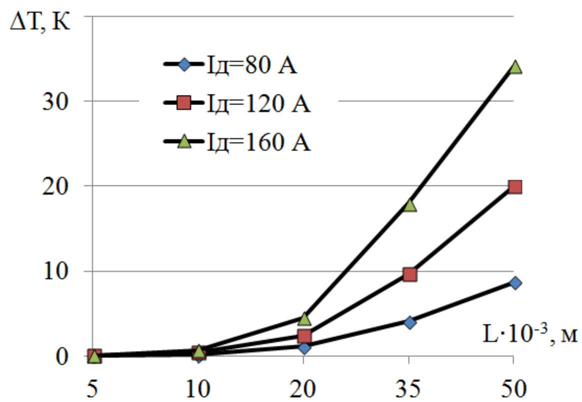

Fig. 3 – Temperature gradient on cathode operation surface with refrigeration along thee and with respect to its length at different arccurrents: $R = 0.03$ m

Time to reach stabilization of cathode operation surface is an important parameter because it allows to define the time after which plasma source will be generating plasma flow of constant composition. In the newest ion-plasma devices it will allow to define the time opening the cap that separates plasma flow from the processed surface after plasma source is on [9].

Time to reach static thermal regime of the cathode considerably depends on the mass of the cathode and arc current, it increases with increase of cathode mass and decreases with arc current increase (Fig. 4). To provide acceptable timing for cathode with refrigeration along end surface ($t_в < 100$ s) it is required to use cathodes with length *L* not exceeding 0.02 m and radius *R* not exceeding 0.05 m. With such geometrical parameters maximum temperature of cathode operation surface doesn't exceed 600 K that leads to respectively low content of drop fraction in plasma flow.

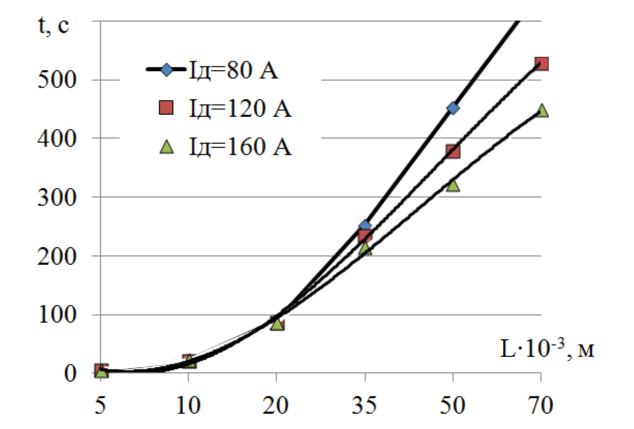

Fig. 4 –Time to reach stationary thermal regime for cathode with refrigeration along then on operation surface with respect the length of the cathode at different arccurrents: $R = 0.03$ m

3.2 Thermal Regime of Cathode with Refrigeration Along Lateral Surface

Comparing maximum temperature cathode refrigerated along the nonoperation end operation surface (Fig. 1) with that of the cathode refrigerated along the lateral surface (Fig. 5) shows that the least value of this parameter is detected for the cathode refrigerated along the end surface (309 Кat $R = 0.06$ m and $L = 0.005$ m for the cathode refrigerated along the end versus 423 К at $R = 0.05$ m and $l_3 = 0.005$ m for the cathode refrigerated along the lateral surface).

It is remarkable high temperature of cathode refrigerated along the lateral surface operation surface at low cathode radiuses that can be explained with inverse square dependence of thermal flow density onto the cathode depending on its radius (at $R = 0.01$ m thermal flow density onto the surface of the cathode is one digit greater than that when $R = 0.03$ m).

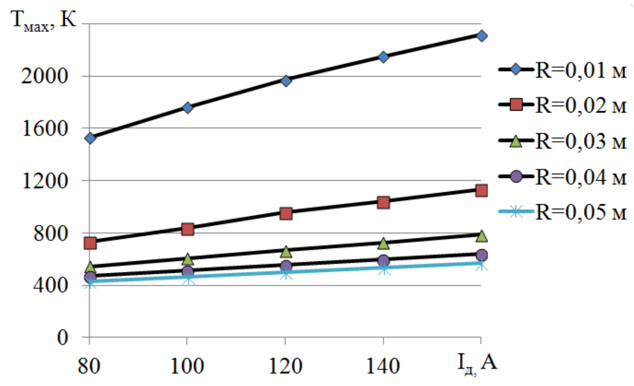

Fig. 5 – Maximum temperature of cathode refrigerated along lateral surface operation surface with respect to arccurrent: $L = 0.01$ m

In the case of refrigeration along lateral surface unlike refrigeration along the end there is detected a more expressed cathode operation surface temperature increase with arc current increase and there is no its stabilization. Also there can be noticed a more expressed decrease of cathode operation surface maximum temperature with increase of cathode radius (Fig. 6).

For the case when cathode is refrigerated along the

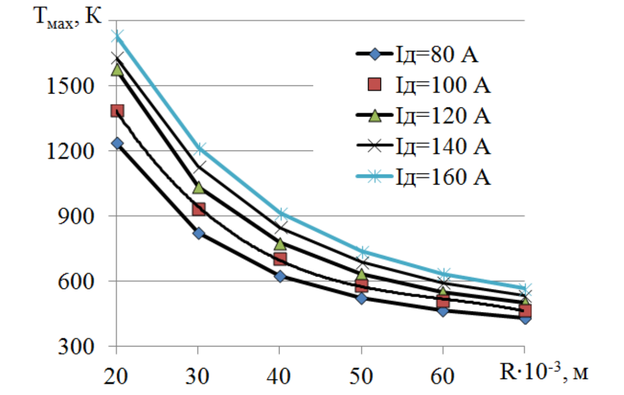

Fig. 6 – Maximum temperature of cathode refrigerated along lateral surface operation surface with respect to arccurrent: $L = 0.04$ m

later al surface is representative higher operation surface temperature gradientt hat reaches 100 degrees. This temperature gradient can be minimized up to several degrees by changing the length of the cathode operation part l and its radius R (Fig. 7). Them inimal temperature gradient achieved will be constant while keeping l constant, same as maximum temperature of cathode refrigerated along lateral surface operation surface.

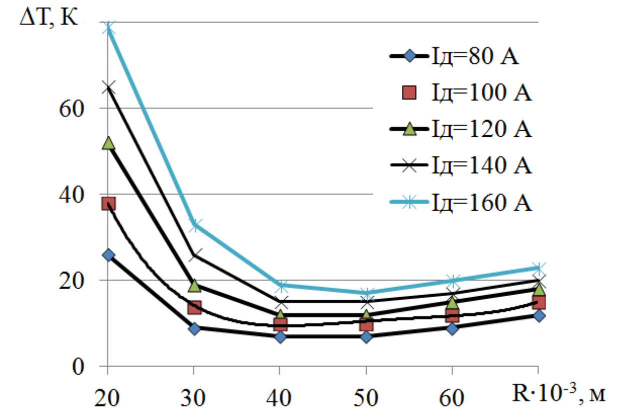

Fig. 7 – Temperature gradient on cathode refrigerated along lateral surface operation surface with respect to cathode lengt hat different arccurrents: $R = 0.04$ m

Havin glow values of cathode operation part (l = (0,005-0.01) m) time to reach stationary regime is small almost doesn't depend on arc current and is only defined by the radius of the cathode (Fig. 8). When increasing the length of cathode operation part (l = (0.02 -0.04) m) time to reach stationary temperature regime decrease is observed when increasing arc current (most significant for cathodes with$R \geq 0.03$ m).

Comparing time to reach stationary regime for cathode soft he same radius ($R = 0.03$ m) but having different refrigeration types shows that warm-up time of the cathode refrigerated along lateral surface is greater. In the case of cathode length slow values (l = (0.005-0.01) m) the difference is (6-12) times, when increasing cathode length (l = (0.02-0.04) m) warm-up time difference decreases to about 2 times or less.

Alsowhenobservinghighcathoderefrigeratedalonglateral surfacelengthvaluesdependence of time to reach stationary temperature from arc current is nonlinear (Fig. 9) meanwhile it is linear for cathode refrigerated along nonoperation end surface.

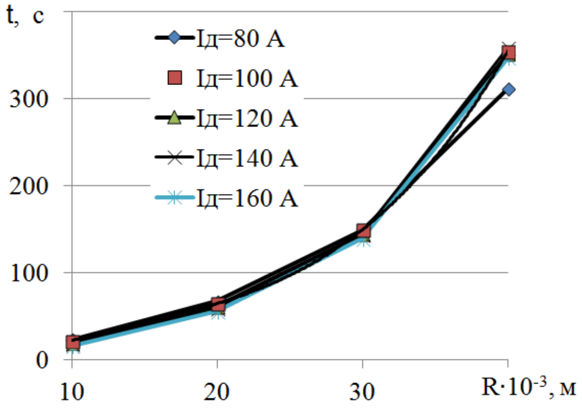

Fig. 8 – Time to reach stationary regime for cathode refrigerated alongn on operation surface with respect to cathode length at different arccurrents: $R = 0.03$

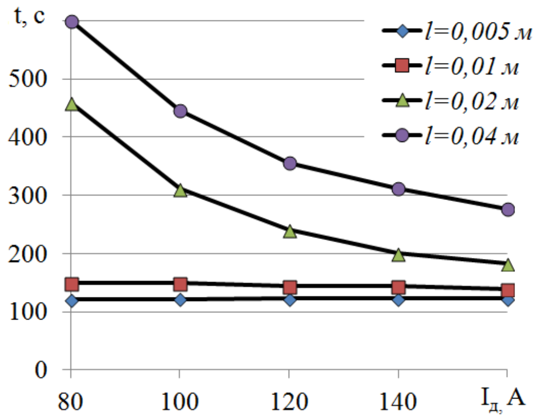

Fig. 9 – Time to reach stationary regime for cathode refrigerated alongn on operation surface with respect arccurrents: $R = 0.03$ m

4. CONCLUSION

Results, obtained in this work can be generalized in the following way:

- for cathode refrigerated along non operation and were obtained laws of operation surface temperature changing depending on the changes of geometrical parameters of the cathode and arc current: maximum temperature value is directly proportional to the length of the cathode and arc current and reverse proportional to the radius of the cathode. When valuably increasing cathode length ($R = 0.03$ mand $L > 0.035$ m) radiation energy losses from cathode operation surface start to appreciably influence. This leads to deceleration of temperature growth and its further stabilization. Obtained laws allow to define optimal temperature regime for plasma source cathode while designing;
- non uniform distribution of temperature along radius of cathode refrigerated along the end operation surface was obtained with maximum in the center of the cathode and minimum on the distance equal to the value of cathode radius, it is aligned with cathode lateral surface radiation energy losses. With low values of cathode length L temperature gradient ΔT is insignificant (when $L = 5$ mmab out hundreds digit of degree, when $L = 10$ mm doesn't exceed 0.65 K). Though this gradient increases with L increase and can reach several tens degrees, also its value decreases with increase of cathode radius;
- time to reach stationary thermal regime law was defined for cathode refrigerated on the end was defined. Top rovide accept able time storeach work regime for cathode refrigerated along and surface ($t_в < 100$ s) in the constructions of plasma sources it is required to use cathodes with length L not more than 0.02 mand radius R, not exceeding values about 0.05m;
- it was defined that maximum temperature of cathode refrigerated along nonoperation end operation surface have other conditions the same is less than that of the cathode refrigerated along lateral surface;
- it was proved that higher temperature gradient on cathode operation surface can be minimized up to values of several degrees by changing the length of cathode operation part l and its radius R.
- it was determined tat time to reach stationary thermal regime for cathodes of the same radius ($R = 0.03$ m) is less in the case of the cathode refrigerated along end surface. With low length of cathode ($l_3 = (0.005\text{-}0.01)$ m) thisdifferenceconcludes (6-12) times, increasing cathode length($l_3 = (0.02\text{-}0.04)$ m) difference in cathode warm-up times decreases up to 2 and less times.

REFERENCES

1. *Tekhnologiya i oborudovanie formirovanie vysoko-kachestvennykh uprochnyayuschikh poverkhnostnykh structur izdelii magnetronno-duhovymi plazmennymi poto-kami* [in Russian].
2. V.N. Krylov, V.A. Krylov, V.A. Poletaev, T.D. Kozhyna, – http://85.142.23.144/packages/mifi/C6886AA4-A711-4C2F-93D1-C0A9D2490CEE/1. 0.0.0/file.pdf.
3. V.M. Khoroshikh. *Phys. Surface Eng.* **2** No 14, 184 (2004).
4. J.E. Daalder, *J. Phys. D: Appl. Phys.* **8** No 14, 1647 (1975).
5. Yu. Sysoev, I. Tatarkina, *3rd Int. Conf. «Nanomaterials: Applications & Properties – 2013 (NAP-2013)»*, **2** No 3, 03AET02 (2013).
6. A.V. Kabanov, *Uprochnyayuschie tekhnologii I pokrytiya* No 3, 3 (2013) [in Russian].
7. Patent 2361014RU, Int. Cl.*C23C14/40* (2006).
8. Patent3625858 US, Int. Cl.*C23C15/00* (1971).
9. I.I. Aksenov, V.A. Belous, *VANT* No 2, 108 (2008).