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VACUUM-ARC EQUIPMENT FOR ION-PLASMA DEPOSITION OF COATINGS

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A brief overview of NSC KIPT developments intended for creating the process equipment for vacuum-arc deposition of coatings is presented. The equipment devised is to be adapted to large-scale manufacture conditions and to be most suitable for commercial production. Consideration is given to the developments of high-efficiency butt-end plasma sources, vacuum-arc evaporators with extended (cylindrical and planar) cathodes, magnetic filters for removal of macroparticles from plasma, and also a number of devices to form various-purpose coatings.

1. INTRODUCTION

The coating formation by condensation of ion-plasma streams resulting from the electric arc discharge in vacuum or in rarefied atmosphere (10^{-3} Pa...10^{2} Pa) of reaction gases has gained for the last two decades wide recognition as one of most promising directions in material surface modification for tool production, surface decoration of consumer goods and some fields of mechanical engineering. The results of studies performed here and abroad [1...4] indicate that the advantages of the method under consideration might be realized in a significantly wider range of applications. Until recently, the main, if not the only, reason for this was the absence of such technical solutions that could provide the commercial utility and competitiveness of new production methods and equipment in the applicability range much wider than mentioned above. Thus, for example, for the absence of sufficiently efficient plasma filtering devices, the vacuum-arc method has not been introduced in such industries of importance as electronics, optics, precision mechanics, where this method would make much for an essential progress. The absence of efficient techniques of reducing heat load on the object under treatment during coating deposition significantly restricts the use of the vacuum-arc method for surface strengthening of machine components (friction units), giving no way of treating by this method the overwhelming majority of components manufactured from steels and alloys with a low temperature of strength degradation.

The first systematic investigations and developments of the vacuum-arc method and associated equipment to adapt them to the commercial production were started at KIPT as early as in late sixties [3] and are continued up to the present [4]. The work has been done in the last decade to solve the above-mentioned problems of creating the process equipment suitable for commercial use. The present communication gives a brief overview of just these developments.

2. PLASMA SOURCES

The key unit that determines the basic possibilities of any vacuum-arc setup is the plasma source. Therefore, the main efforts were focused on the development and studies of just these devices. The so-called butt-end-type sources have found the widest application. The designs and principles of operation of these sources devised at the Institute have been described in refs. [3,4]. The principles presented there

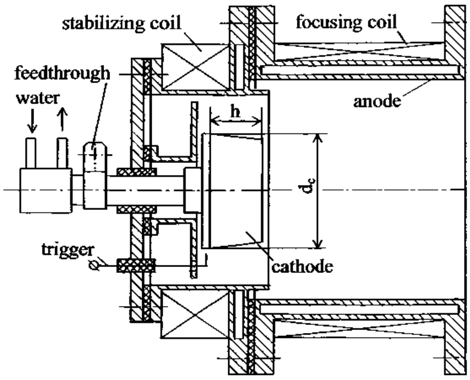

Fig. 1. Butt-end evaporator

were used in more recent developments completed with due regard for accumulated experience and industrial demands. Thus, the plasma source

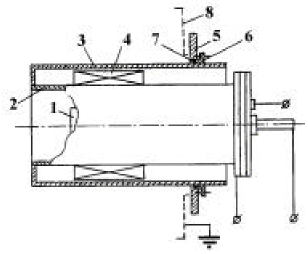

Fig. 2. Plasma source with a movable sealing unit. 1 - cathode; 2 - anode; 3 - case, 3 - magnetic coil; 5,6,7 - sealing unit components; 8 - chamber

model was created, providing for the use of butt-end-type cathodes of any diameter (d) within the 60 to 110 mm range at a consumable length (h) of up to 60 mm (fig. 1).

Designed are also the sources providing for the possibility of adjusting the outlet hole position with respect to the item under treatment by means of a movable sealing unit (fig. 2).

Fig. 3 shows the three-cathode plasma source devised for formation of multilayer coatings based on two or three metals or alloys. The cathode displacement is effected by the electrically/mechanically-operated revolving device.

The vacuum-arc deposition of coatings on long-in-size products (shafts, tubes, broaches, etc.), and also on rolled products (metal foils, polymer films) is generally carried out by means of vacuum-arc plasma sources (evaporators) having an extended cathode of planar type (i) or as a cylinder with a working lateral surface (ii). The practical utility of this equipment was restricted by the absence of any cardinal solution of the

Fig. 3. Three-cathode plasma source

problem of reliable control over the CS displacement along the working surface of cathode. To eliminate this difficulty, the planar plasma source [5] and the evaporator with an extended cylindrical cathode were designed.

The degree, to which the areas of practical use of the vacuum-arc method can be extended, much depends on how successfully the problem of removing the cathode macroparticles from plasma flows will be solved. In principle, the problem of filtering the vacuum-arc plasma was solved by creating curvilinear magnetic filters. However, in spite of a great number of patented versions of such filters, their complexity, low productivity and insufficient efficiency of filtering the plasma, inherent in the majority of them, prevent from a wide use of these devices in practice. In view of this, consideration should be given to the recent modifications of filters (separators) developed by KIPT specialists. In this case, the efforts were mainly focused on simplifying the design (and hence, on reducing the cost) of new filters, on improving the efficiency of cleaning the plasma, and on decreasing the losses of plasma flow as it is transported from the CS to the item under treatment. The computations of magnetic fields and trajectories of macroparticles in filtering systems have made the procedure of their optimization in all three criteria much easier. As a result, a few versions of filtering systems were created. They can arbitrarily be classified into three groups: (i) rectilinear filters with a labyrinth set of intercepting screens [6...8]; (ii) systems with axial-to-radial flow transformation [9]; (iii) systems with a curvilinear plasma-guiding duct and an improved set of absorbing screens.

3. VACUUM-ARC FACILITIES

The equipment for vacuum-arc deposition of coatings onto industrially produced items must ensure the highest possible efficiency of the production process and a high accuracy of control over its parameters, and therefore, a high degree of reproducibility of the properties of the resulting coatings. For this purpose, the present-day vacuum-arc facilities are fitted with high-performance equipment for evacuating the chamber, with reliable evaporators that provide the needed rate of deposition, and with the computer-aided control of the process. And yet, the productivity of the vacuum-arc process of coating deposition with the use of even the most recent refined equipment is far from being always to meet the requirements of large-scale production. This is due to the fact that all the above-mentioned advantages of present-day facilities can influence the duration of only two stages of the operating cycle of deposition; these are, first of all, the duration of working chamber evacuation, and secondly, the duration of the process of ion-plasma treatment itself, including the coating condensation. However, aside from these two stages, the duration of the whole technological cycle associated with the facility is also determined by such stages as (I) loading the chamber with products to be treated, (II) hermetic sealing the chamber, (III) cooling the products after treatment, (IV) opening the chamber and (V) its unloading. While the duration of evacuation and ion-plasma treatment ranges between 20 and 60 minutes in present-day setups (depending on the particular process), the total duration of all other stages (I... V) is several times longer. Besides, the duration of the evacuation stage in existing designs corresponds to the claimed values mostly at the start of setup service, only. In time, the duration of evacuation considerably increases because of the atmospheric moisture accumulation on the chamber walls during rather prolonged

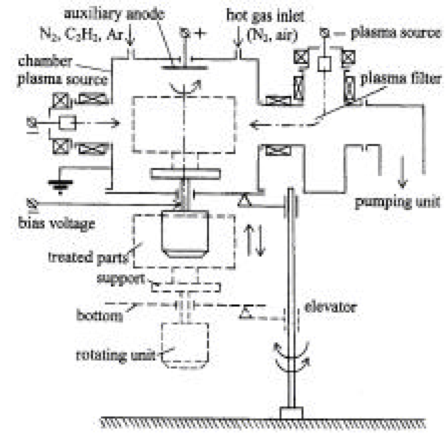

Fig. 4. Scheme of the vacuum-arc setup “Bulat-9”

stages (I) and (V) when the chamber is fully open.

The KIPT specialists have created the setup Bulat-9, where all the associated technological cycle is automated, starting from loading the chamber with product-containing cassettes and ending with unloading the chamber. This degree of automation together with the use of a variety of additional design and technological measures (e.g., use of a dome-type chamber and filling the chamber with heated dry nitrogen or argon before its opening) have stabilized the time needed for evacuation (about 8 to 10 minutes), have reduced the time (down to 1.5 minute) required for loading and unloading the chamber, and have practically excluded time losses for cooling the processed products before unloading. The productivity of the facility has increased 2.5...3 times as compared to the productivity of conventional setups having a similar chamber volume (≅ 0.2 m^3). The setup schematic (without power supply and control systems) are given in fig. 4. The setup permits the conduction of a number of technological processes, unfeasible with serial facilities, in addition to usual ("standard") processes. These processes include the deposition of wear-resistant nitride coatings onto small-size tools (~∅1 drills, dental drills, etc.); coating deposition onto internal surfaces of such tools as dies, threading dies; deposition of wear-resistant coatings on machine components made from steel (KhVG, 40Kh) with a low (250...280)°C tempering temperature; deposition of "droplet-free" metal and nitride coatings, nitriding of surfaces for a depth of 30 to 50 μm at temperatures up to 500°C.

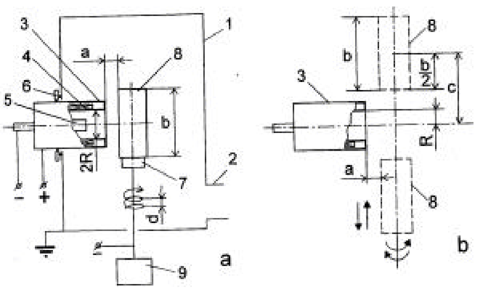

Fig. 5. A setup for forming thick films
1- chamber; 2 - pump connection pipe; 3 - anode; 4 - solenoid; 5 - cathode; 6 - sealing unit; 7 - substrate holder; 8 - substrate; 9 - device for substrate holder rotation.

The special features of the setup allow its use as a constituent of production lines in the manufacture of tools, machine components, products (or their elements) of everyday use.

In the vacuum-arc deposition of coatings the formation of the assigned (e.g., uniform) distribution of their properties (most often, thickness) over the particular object surface with simultaneously ensuring a high efficiency in the use of plasma-creating (cathode) material presents a rather complicated problem. This is due to a high nonuniformity in the space distribution of plasma characteristics (first of all, plasma density) in the flow generated by the cathode spot of the arc, that occupies practically all the half-space over the cathode working surface. Therefore, it has been considered until recently that the vacuum-arc method is unsuitable for solving the problem. However, recent experimental studies, performed at KIPT, have proved the practicality the of the vacuum-arc method for thick film formation. A setup was developed to form coatings from one or more refractory metals at a deposition rate of up to 40 μm/hour with the efficiency in the use of cathode material k≅ 0.3. (The coefficient k is determined by the m_c/m_Σ value, where m_c is the material mass being directly the coating mass, m_Σ is the total mass of material that has left the cathode during coating formation). The schematic illustrating the method of uniformly thick film deposition onto a cylindrically shaped object is shown in fig. 5. In the formation of a multilayer film from two (or more) metals, two (or more) evaporators with cathodes made from the corresponding metals are used (fig. 2). Developed is the process providing formation of refractory metals condensates about 2 mm in thickness.

The "Bulat-6" facility has been used as a basic model to develop its three modified versions.

Version 1. The facility is equipped with two vacuum-arc sources having rectilinear [8] filtering devices. It is intended for depositing protective coatings from one or two metals and their nitrides. Its main purpose is to form wear-resistant coatings on precision friction unit components in precision mechanics (gas-dynamic supports of gyros, fuel pump plunger, etc.).

Version 2. The facility has two vacuum-arc sources with rectilinear plasma filters [7]: one with the Ti cathode, the other with the graphite cathode. The facility is intended for depositing diamondlike carbon coatings on precision friction unit components, on special tools (for machining non-ferrous metals, measuring tools), on optics elements (lenses, mirrors, infrared windows, etc.). The facility is equipped with components to supply HF potential to the object under treatment.

Version 3 (Bulat TNP-5). The difference from the basic model lies in the chamber having a height of 850 mm and a diameter of 850 mm. The facility is intended for depositing decorative coatings onto products of everyday life.

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