Narrow Focusing Electron Beam Production by Plasma Cathode Gun at Fore-Pump Pressure Range

V. Burdovitsin, Y. Burachevsky, I. Zhirkov, M. Fedorov, E. Oks

Tomsk State University of Control Systems and Radioelectronics,40 Lenin Ave.,Tomsk,634050,Russia, +7-3822-413369,Fax +7-3822-513262, burdov@fet.tusur.ru

Abstract – It was designed plasma electron gun which produces narrow focusing beam with diameter not more 1 mm, energy 12 kV and current 0,1 A at pressure range 2.0–2.5 Pa. These parameters are result of investigations as on optimization discharge and accelerating gap geometry so physics of plasma boundary stabilization in emission channel. The gun may be used for metal melting and welding in installations with only mechanical pumps. In its turn it simplifies all the equipment and makes the process more fast and cheap.

1. Introduction

Plasma electron guns are used for metal welding more than twenty years [1]. These guns are based on reflective discharge with hollow cathode. They show excellent results but require high vacuum (pressure lower 10 mPa) for their operation. At the same time there are some tasks which need in electron guns able to work in bad vacuum (10 Pa and more) and in active gas media. These tasks are, for example, surface melting, powder baking, special welding and others. The only way to produce electron beam in shown pressure range is electron emission from gas discharge plasma. Several years ago fore vacuum plasma electron gun based on hollow cathode discharge was designed in our laboratory [2] for wide cylindrical beam production. Problem was to produce narrow beam. The problem was decided by using emission electrode with one hole instead of grid or mesh. Small (about 1 mm diameter) emission hole led to small emission current. Investigations show strong current dependence on discharge gap geometry. Present gun produces 0.1 A, 12 keV electron beam with diameter less 1 mm.

2. Experimental Set-up

Scheme of installation is shown at Fig. 1. It consists of electron gun 1, focusing system 2, collector 3. There are also two power supplies 4 for discharge and accelerating systems. Beam (5) diameter was measured by rotating probe 6. Details of electron gun construction are presented in Fig. 2. Main elements are the same as for wide beam gun: hollow cathode 1 plane anode 2, accelerating electrode 3. All electrodes are electrically separated by insulators (not shown). At the same time there are some differences. Anode 2 has only one emission hole 4. Hollow cathode 1 contains insertion 5, which inner diameter is less than hollow one. There was possibility to change distance *l* between the insertion 5 and anode 2. In our experiments we investigated beam current as function of insertion diameter *D*, distance *l* between insertion and anode, emission hole diameter *d*, anode thickness *h*. Another experimental series were provided to measure electron beam diameter as function of gas pressure in beam propagation area.

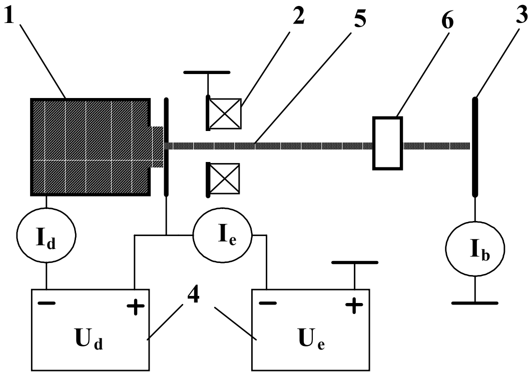

Fig. 1. Scheme of installation

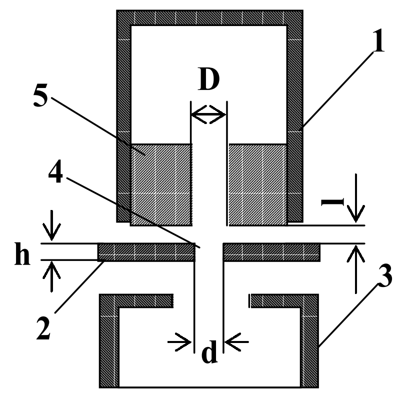

Fig. 2. Scheme of electron gun

3. Results and Discussion

It is clear, emission current depends on plasma emission surface area. Therefore we needed to decide two contradictory problems. One is to fulfill as small emission hole as possible to be able to make sharply focused electron beam. The other is to provide beam current as much as possible to have possibility for metal melting, welding and so on. In its turn emission current density is as much as more plasma density. The first task was to determine conditions for maintaining maximum plasma density near emission surface. Two ways were used for it. First, insertion of bush with small inner diameter in hollow cathode and second, variation of distance between hollow cathode and anode. The first way showed positive results. As lower inner bush diameter as beam current more. However it is not possible to decrease diameter less than 8 mm because of difficulties in discharge support. We suppose discharge does not penetrate into hollow, and hollow cathode discharge does not take place. Distance l between cathode bush and anode also influences at beam current. Beam current is as more as distance l is lower. Therefore l is limited only by cathode and anode electrical connection. Important parameters are also anode plate thickness h and emission hole diameter d. It is obviously as more hole diameter as beam current more. At the same time this connection is not so simple. If hole diameter is large enough it is impossible to provide electron acceleration. Turning on of accelerating power supply leads to discharge appearance in accelerating gap. It is due to plasma penetration throw emission hole from discharge region to accelerating one [3]. As it was stated earlier [4], plasma boundary stabilization may be achieved if emission hole in anode plate is long enough. In this case we say about “emission channel”. To make clearness in this question we investigated beam current as function of hole diameter d and anode plate thickness h. Results are presented at Fig. 3. It may be seen, short channel with small diameter showed more beam current than long channel with large diameter. This fact finds its explanation in frames of model, formulated in [4]. According [4], plasma density falls quickly if plasma penetrates into emission channel. Main reason of it is

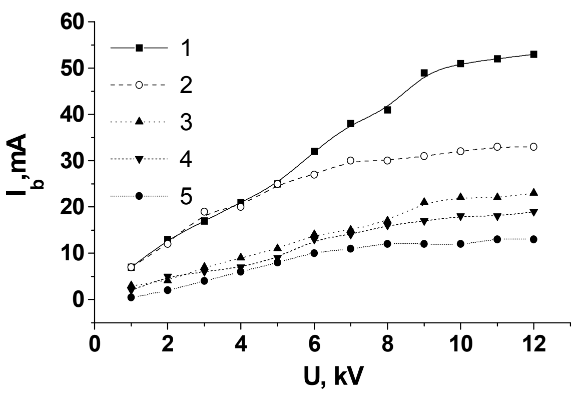

Fig. 3. Beam current I_b as a function of accelerating voltage U_a for different thicknesses of anode plate: 1 – 0.2 mm, 2 – 0.5 mm, 3 – 1 mm, 4 – 1.5 mm, 5 – 2 mm (I_d = 500 mA, d = 0.8 mm)

particles losses on walls of channel. Achieved amount of beam current about 100 mA is enough for maintaining of installation for purposes, formulated at the beginning of present article.

Together with beam current another important parameter is beam diameter. Appropriate measurements were provided using rotating probe [5]. This probe was placed at the distance 25 cm from gun accelerating electrode. Fig. 4 shows electron beam diameter as function of gas pressure in beam propagation area.

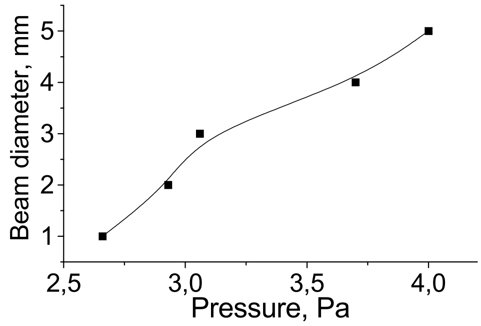

Fig. 4. Beam diameter as function of gas pressure (accelerating voltage 12 kV)

As anybody can see, gas pressure growth leads to beam diameter increasing, if beam current and energy are unchanged. Our estimations show, the most probable reason of it is electron scattering at gas molecules. Beam space charge has no remarkable role because of its neutralization by ions positive charge. Also it is necessary to take into account possibility of non self sustaining discharge in accelerating gap. In this case beam diameter is determined by size of accelerating electrode window. Preliminary experiments with this electron beam showed, steel about 10 mm depth may be melted. It allows to say about real possibility of electron gun application for metal welding in special cases.

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