

Modernization of electron accelerator with a large cross section beam for radiation effects on materials

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Abstract. The results of the work on the creation of an automated wide-aperture electron accelerator with a grid plasma cathode based on the low-pressure arc discharge and outputting of a large section beam (750×150 mm) in the atmosphere through a outlet foil window. The distinctive feature of such electron accelerator is a weak correlation of beam parameters, as well as a high current beam extraction efficiency to air, reaching $\approx (80 \div 90)\%$ of the current in the accelerating gap at an accelerating voltage of 200 kV, beam current amplitude in the atmosphere up to 30A, frequency and pulse duration up to 50 s^{-1} and 100 μs , respectively. The electron source provides a stable continuous operation for tens of hours in a repetitively pulsed modes at the maximum average beam power in the atmosphere is $\approx 5 \text{ kW}$. Examples of applications of such accelerator in the radiation-stimulated technology are given, showing the prospects of its using in scientific and technological purposes.

1. Introduction

Modern electron accelerators with beam in an atmosphere characterize by the principle of action, have a very wide range of the generated beam parameters, as well as its different configurations, etc. A wide variety of such accelerators due to the application prospect of such accelerators in the scientific and technological purposes [1–7]. Reliable and durable electron accelerators with stable parameters are required for the solution of existing problems still. Among the electron accelerators are accelerators based on a grid plasma cathode [1, 6–10]. This type of accelerators offers a series of advantages over those based on thermionic cathodes (longer service life, wider range of vacuum conditions, higher energy efficiency) and over accelerators based on explosive emission cathodes (longer service life, longer pulse duration, higher pulse repetition frequency, more uniform current density distribution). In view of the above advantages, we studied the possibilities of modification of an electron accelerator based on a grid plasma cathode for its automation and increasing its energy efficiency.

2. Experimental procedure

The electron accelerator scheme is shown in Fig.1. A plasma cathode (2) is located in a vacuum chamber (1). The plasma cathode (2) of the accelerator is a hollow stainless-steel half-cylinder with two low-pressure-arc cathode units (3,4) fixed on the cylinder ends [11]. A stainless-steel mask (6) of

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thickness 200 μm is put on the emission grid (5) of dimensions 750 mm \times 150 mm, which serves as the anode for the arc discharge. There are 344 round holes of diameter 8–12 mm in the mask, which are individual emission units of the plasma emitter, and the wide electron beam produced is a superposition of beamlets formed by individual emission units with the plasma boundary stabilized by the fine metal grid. The hollow anode (7) is electrically connected via a resistor to the emission grid (5), which is necessary to facilitate the discharge ignition, switching, and operation in the region of the emission grid. Electrons are extracted from the plasma surface of the emission units under the action of a dc accelerating voltage of up to 200 kV applied to the 120-mm gap between the plasma cathode (2) and the extraction foil window (8,9). The aligned holes in support grid (8), having a total geometric transparency of 56%, are of the same number as those in mask (6), but of larger diameter (15 mm). Alignment of the holes in mask (6) and in support grid (8), and thereby attainment of a coaxial plane-parallel geometry of the acceleration gap, minimizes the beam losses in the support grid of the extraction foil window. Support grid (8) is covered with 30- μm -thick foil (9) made of AlMg–2n alloy [10].

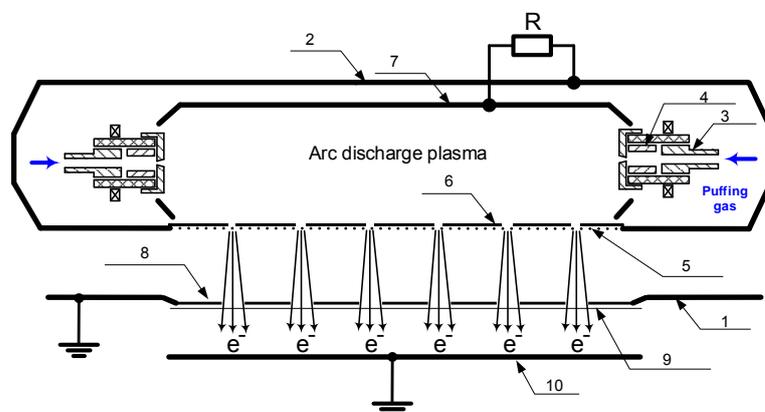


Figure 1. Scheme electron source with wide-aperture plasma emitter: 1 – vacuum chamber; 2 – plasma cathode; 3 – igniter; 4 – cathode; 5 – metallic mesh; 6 – metallic mask; 7 – hollow anode; 8 – support grid outlet foil windows; 9 – output foil; 10 – substrate.

As has been shown by theoretical and experimental studies [10, 12], the use of a multi-aperture two-electrode system in the source enhances the operation stability of the plasma cathode and the electric strength of the acceleration gap. Moreover, the system allows one to extend the range of electron beam parameters – namely, to enhance the beam extraction efficiency β , to increase the beam current density, and to narrow the beam energy spectrum within a pulse (through decreasing the capacitor bank voltage per pulse).

The electron current from the plasma is controlled by varying the plasma density for which the discharge current is varied, as clearly seen from the dependence in Fig. 2 a. From Fig. 2 b it follows that the accelerating voltage U_0 little affects the current in the acceleration gap I_0 , and this, as noted, is one of the advantages of electron sources based a grid plasma cathode.

Reasoning from the previous study [10], we modified the wide-aperture electron accelerator with plasma cathode to increase its efficiency and its automation. Power and control block diagram of the modified electron accelerator is shown in Fig. 3. The modification has made possible an automated wide-aperture plasma cathode electron source capable of providing Main beam parameters, that the modified accelerator can provide, are presented in Table 1. It is important to note, that at a maximum average beam power in the atmosphere of ≈ 5 kW the maximum average power of the plasma cathode power supply is no greater than 100 W. This greatly simplifies the design of the accelerator.

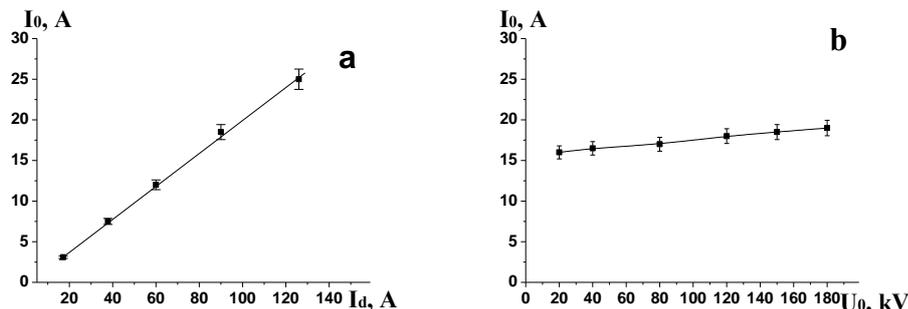


Figure 2. Current in the acceleration gap I_0 vs discharge current I_d at $U_0=150$ kV (a) and accelerating voltage U_0 at $I_d=90$ A (b)

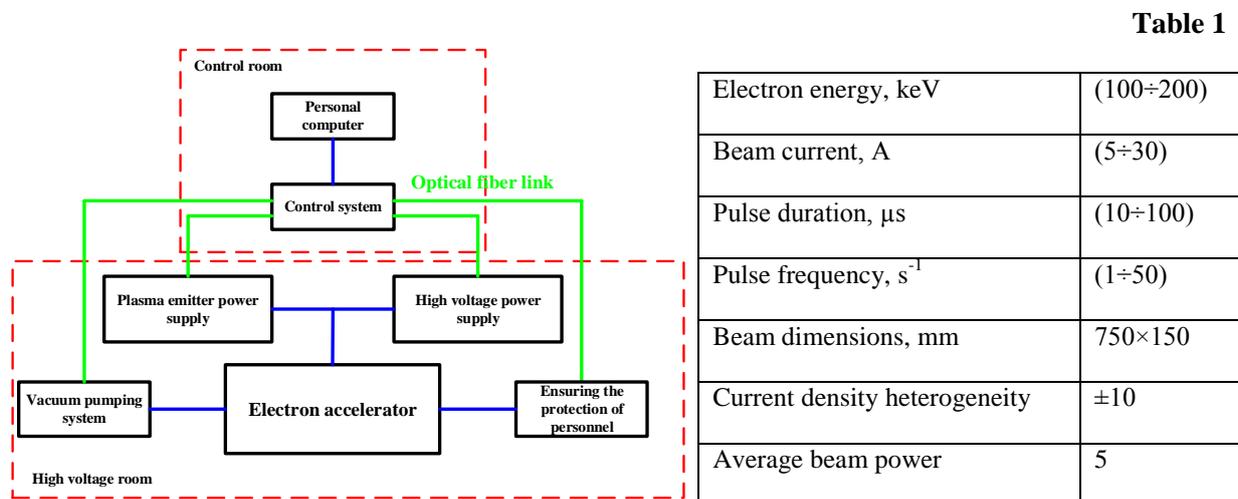


Figure 3. Power and control block diagram of the modified electron accelerator.

The main stages of the accelerator modernization are to automate the vacuum pumping system, to create of automated high-voltage and plasma cathode power supply systems, providing including additional safety system for staff operating with the electron source. Control of the vacuum and the high-voltage systems, as well as of the plasma cathode power supply system is carried out from the control room from a PC, using fiber optic communication channels.

The automated vacuum pumping system is based on a WAGO–750–312 industrial controller. This system allows to remotely manage and control the pressure in the vacuum chamber, and perform of emergency shutdown of the electron source in the event of a foil breakthrough.

Since a new high-voltage power supply was created by a new one built around modern high-frequency elements, this made it possible to decrease the overall dimensions and mass of the high-voltage source, to ensure a more stable retention of accelerating voltage, which is extremely important for operation at high average power, using which a smooth transition to the setting of the accelerating voltage was organized at 30 kV/s (the speed is chosen empirically). That is necessary to restore of the stable work of the electron accelerator at first accelerator starting or after electrical breakdown of accelerating gap.

Using this electron accelerator with a grid plasma cathode has been shown experimentally a principle possibility of silicon tetrafluoride molecules decomposition under the influence of low-energy (200 keV) electron beam to form a silicon film and fluorine free [5]. In addition, a possibility of efficient using of a wide-pulsed electron beam during the pre-radiation cross-linking of natural

rubber latex without adding substances, accelerating the curing process, is demonstrated [7]. Also the paper [14] demonstrates the fundamental possibility of forming carbon structures in polyvinyl chloride films without additives and in polyvinyl chloride films added with 5 wt% of ferrocene by this electron accelerator, that produces the output response amorphous carbon material.

3. Conclusion

The automated plasma cathode electron source with its modern power supply system provides remote control of the beam parameters and their independent adjustment, stability of operation and personnel safety. The parameter range, reliability, and service life of the source meet the requirements that allow its successful use in electron beam technologies and small-scale industrial production.

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References

- [1] Bugaev S P, Kreindel Yu E and Schanin P M 1984 *Large section electron beams* (Moscow: EAI)
- [2] Chmielewski A G, Zimek Z, Iller E, Tyminski B and Licki J 2000 *J. Tech. Phys. Spec. Iss.* **41(1)** 551
- [3] Ershov B G 2013 *Herald of the Russian Academy of Sciences* **83(5)** 437
- [4] Sokovnin S Yu 2007 *Nanosecond electron accelerators and radiation technologies based on them* (Yekaterinburg: UD RAS)
- [5] Koval N N, Shugurov V V, Suslov A I, Denisov V V, Yakovlev V V, Vorobyov M S, Khandorin G P, Ledovskikh A K, Galata A A, Murlyshev A P and Volchkov V S 2010 *Proc. 16th Int. Symp. on High Current Electronics* 545.
- [6] Bugaev A S, Koval N N, Lomaev M I, Mel'chenko S V, Ryzhov V V, Tarasenko V F, Turchanovsky I Yu, Fedenev A V and Shanin P M 1994 *Laser Part. Beams* **12(4)** 633
- [7] Vorob'ev M S, Denisov V V, Koval' N N, Shugurov V V, Yakovlev V V, Uemura K and Raharjo P 2015 *High Energy Chem.* **49(3)** 143
- [8] Bayless J R 1975 *Rev. Sci. Instrum.* **46(9)** 1158
- [9] Gielkens S W A, Peters P J M, Witteman W J, Borovikov P V, Stepanov A V, Tskhai V N, Zavjalov M A, Gushenets V I and Koval N N 1996 *Rev. Sci. Instrum.* **67(7)** 2449
- [10] Vorobyov M S, Koval N N and Sulakshin S A 2015 *Instrum. Exp. Tech.* **58(5)** 687
- [11] Vorobyov M S, Devyatkov V N, Koval N N and Shugurov V V 2015 *J. Phys.: Conf. Ser.* **652** 012066 (1-6).
- [12] Nguen Bao Hyng, Koval T V, Vorobyov M S and Koval N N *Izv. 2015 Vys. Ucheb. Zaved. Fizika.* **58(9/2)** 213
- [13] Kryazhev Yu G, Koval N N, Vorobyov M S, Solodovnichenko V S, Trenihin M V, Sulakshin S A and Liholobov V A 2016 *Proc. 10 Intern. Conf.on Carbon in Moscow* 233