MULTI-BEAM ELECTRON ACCELERATOR FOR INDUSTRIAL APPLICATION

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Abstract

This report describes a design of the multi-beam accelerator optimized for e-beam processing. Parameters of the accelerator are: 600-700 kV accelerating voltage, 300-350 kW average output power, 5 A peak current, 10-20 μs pulse duration and 10-20 kHz repetition rate. A coaxial spiral-line resonator serves as a high voltage supply. Electron beams are generated by a mosaic cold cathode with threshold emission characteristic and accelerated in a vacuum diode. Each electron beam is delivered into the air via individual output window. Such a multi-cathode, multi-window design allows one to reduce the energy loss in the beam extraction system and increases the reliability of the accelerator.

1 INTRODUCTION

High-tonnage industry existing today in chemistry, oil refining, production of fertilizer and paper etc. are based mostly on the scientific basic of previous and beginning of the last centuries. The above industries are low efficiency in a case of energy and raw material consumption and also harmful for environment. The recent industrial revolution which included the electronics, computation technique etc. didn't almost touch the basic industries supplying our civilization with the metal, energy carriers, various chemical products [1].

Up to present the basic forms of energy in this high-tonnage industries were a heat, various chemical reactions and low-voltage electricity. In these days the above forms start to be replaced step by step with plasma-chemical initiation of many processes where due to the non-equilibrium vibration and rotational molecular degrees of freedom a much more high efficiency that at traditional equilibrium form is reached [1, 2].

One of the most promising and principally new tools for initiation and conducting various physical and chemical processes in the future industry is high power beams of the fast charged particles power 100 kW and higher, especially electron beams. From technological point of view the electron beam is nothing else the ideal flux of ”clear” energy in well controllable form. Such beam can be easy modulated in time and space. One can also control the fluxes of secondary electron etc. As a result of the this extraordinary flexibility the working regime of electron gun can be chosen in the optimal agreement with technological demands. Therefore unique technological possibilities of electron beams attract a great attention and lead to fast development of studies in radiation physics and chemistry, radiation modification of polymers and other materials etc. Below we present some very promising e-beam accelerator construction developed recently at JINR, Dubna.

2 ACCELERATOR DESIGN

The accelerator have four main design-technical features:

- using a cold cathode with a threshold emission characteristic permits to employ a sinusoidal voltage for forming the current pulses of the electron beam;

- a multi-beam multi-window variant of accelerator allows to design an electron beam extraction system having very large total area of the extraction windows by means of increasing the number of the small windows;

- a small dimension of the extraction windows allows one to increase a thickness of the extraction foil and reduce the energy loss in the foil;

- using a high voltage source based on a coaxial vacuum resonator enhance significantly an efficiency of the energy conversion from power line to the electron beam.

To verify the above new design-technical solutions we have manufactured a scaled model of the accelerator. Parameters of the model are following: electron beam energy - 200 keV, beam peak current - 1 A, pulse duration of the beam current - 10 micros, repetition rate of the current pulses - 18 kHz, average beam power - 20 kW [3, 4].

The experimental experience obtained with 200 keV accelerator model gave us the base for the construction of a full scale multi-beam accelerator with energy 600-700 keV and output power 300-350 kW and extremely low cost. Electron beam parameters of the accelerator are following: total peak beam current – 5 A, pulse duration – 10-20 μs, repetition rate – 10-20 kHz.

2.1 High Voltage Source

Scheme of the full scale 700 keV accelerator is shown on Fig. 1. The outer dimensions of the machine are 1.1 x 2.5 m. A coaxial resonator of a high voltage source is excited by a magnetic flux of a primary winding located outside the accelerator. The exciting winding is powered by an electronic inverter.

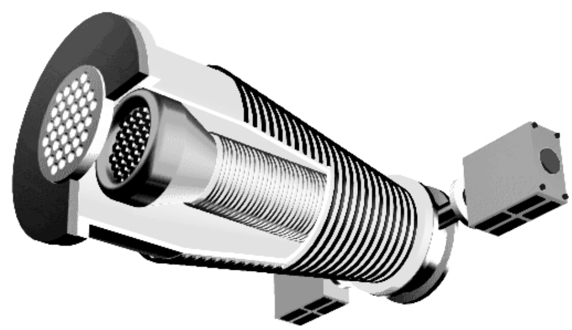

Figure 1: Layout of the multi-beam accelerator.

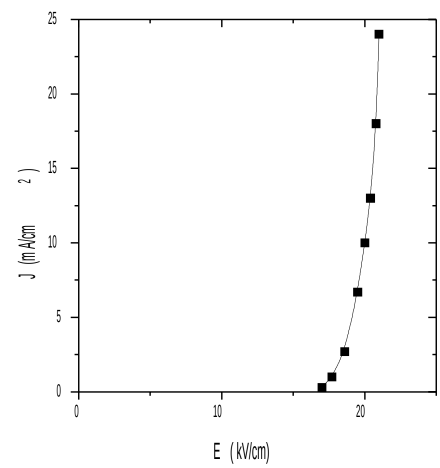

Figure 2: Emission characteristic of the pyrolitic carbon cathode

The high frequency inverter has the following parameters: output voltage 500 V, average power up to 350 kW, operating frequency 10-20 kHz.

To decrease the resonance frequency down to 10-20 kHz the coaxial resonator is design as a spiral delay-line. The design value of the quality factor of the resonator is equal to 250-500. At such quality factor the efficiency of the energy conversion from the electronic inverter to the electron beam will be equal to 98-99%.

2.2 Electron Gun

The electron gun is a vacuum diode with mosaic cold cathode. Electrons emitted by each small cathode tablet are directed to its own output window. The cathode tablet material is a pyrolitic fiber carbon with threshold emission characteristic. The emission characteristic of the pyrolitic carbon is shown on Fig. 2. Maximum density of the emission current is limited by a second threshold which corresponds an appearance of an explosive emission of electrons. The explosive emission regime is used for an electrical polish of a cathode surface to improve a uniformity of the cathode emission. After training in this regime we reduce the current density and operate in the regime of a field emission. The field emission regime is the operating regime, in which an evaporation of the cathode material is absent.

The threshold behavior of the cathode emission allows one to give up from a rectifier circuit and a sinusoidal voltage can be directly applied to the electron gun (See Fig. 2 and Fig. 3). The electron emission starts at a high negative voltage close to the maximum voltage. As a result, the dispersion of the electron energy may be reduced to the value required by application (Fig. 3).

The threshold field emission regime requires a highly uniform distribution of the electric field on a surface of the mosaic cathode. To attain the required uniformity of the emission, the nonuniformity of the electric field should be reduced down to the value of a few per cent. The experimental experience with the 200 keV scaled model of the accelerator have shown that after training of the mosaic cathode the uniformity of the emission became to be significantly better.

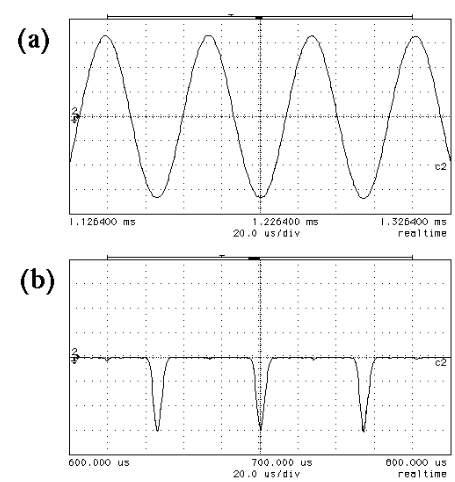

Figure 3: Oscillograms of the accelerating voltage (a) and the electron beam current (b)

2.3 Electron Beam Extraction System

The multi-beam, multi-window extraction system has evident advantages with respect to a standard design with single powerful beam, one large output window and scanning system [5, 6]. The size of the output windows of the multi-beam extraction device is relatively small which reveals the possibility to manufacture them of very thin metallic or metal-polymer foil. As a results, the heat load and the electron energy loss in the output window is reduced significantly. Also, total beam power can be increased in a simple way by increasing the number of cathodes and output windows. Another advantage consists in an easy recovering of defective windows of a small size instead of replacing a large foil as it takes place in the case of a standard design.

Now we are carrying an optimization of the small window design to reduce the electron energy loss and have a possibility to replace the defective windows in some minutes.

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