MULTI-BEAM PULSED ACCELERATOR FOR ELECTRON BEAM PROCESSING SYSTEM

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Abstract

This report describes the design and experimental study of the accelerator for electron beam processing. The accelerator produces an electron beam with the energy up to 200 keV, the peak current up to 1 A, the pulse duration about 10 μs and the repetition rate of 18 kHz. The electron pulses are produced by a cold pyrolitic carbon mosaic cathode with a threshold volt-ampere characteristic. The experimental experience obtained with 200 keV accelerator module gave us the base for starting the construction of a full scale, low cost accelerator with the energy of about 1 MeV and output power of about 30, 300 and 1000 kW.

1 INTRODUCTION

Electron Beam Processing is widely used in a variety of applications: modification of material properties, surface treatment, sterilization, environment protection, etc. It is recognized that the electron beam technology is an effective method for removing toxic components from flue gases [1]. Sulphur dioxide (SO_2) and nitrogen oxides (NO_2), main pollutants of the thermal plants, could be removed effectively by irradiation with powerful electron beam. The injection of ammonia during the irradiation process converts SO_2 and NO_2 into agricultural fertilizers. Electron beam technology is also used for removal of NO_x exhaust gases produced by cars in highway tunnels. Another important area of EB-technology applications could be found in municipal waste incinerators. Usually they are situated near urbanized areas, so they are dangerous for human health due to the emission of pollutants, such as SO_2, NO_x and HCL. Pilot experiments have shown that EB-cleaning is more economical that the conventional process [2].

The electron accelerators for radiation processing are based on different principles of the electron beam generation and accelerating voltage generation [3]. An "ideal" accelerator for EB-technologies should meet the following requirements:

- high reliability during a long time of operation;
- high conversion efficiency of the net power to the electron beam power;
- minimum losses in extraction window system;
- high beam current;
- low cost.

This report describes a compact and low cost electron accelerator optimized for the irradiation of a large volume of flue gases with a high power beam. Realization of multi-window and multi-beam optical system allows one to reduce the foil thickness and the electron energy loss.

2 DESIGN FEATURE

The accelerator is designed as a vacuum diode with a special cathode under sinusoidal high frequency potential. The cathode voltage is formed by a high frequency resonance transformer with secondary high voltage winding mounted into the cathode insulator (Fig. 1).

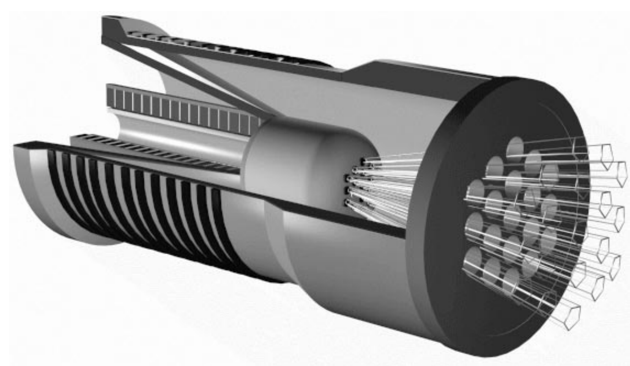

Figure 1: Layout of the multi-beam electron accelerator.

2.1 High Voltage Transformer

The ground self-capacitance of the secondary winding is much larger than cathode-anode capacitance, so the high frequency transformer operates as $\lambda/4$ coaxial resonator. The coaxial line of the resonator is designed as a spiral delay-line. The spiral coaxial resonator is excited by a magnetic flux of a primary winding located outside the accelerator. Using of the vacuum insulation allows one to increase significantly the resonator quality.

2.2 Cold Cathode

The cathode material is a cold pyrolitic carbon with a threshold volt-ampere characteristic. 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 vacuum diode. 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 (see Fig. 2). The volt-ampere characteristic of the cold pyrolitic carbon material is shown in Fig. 3.

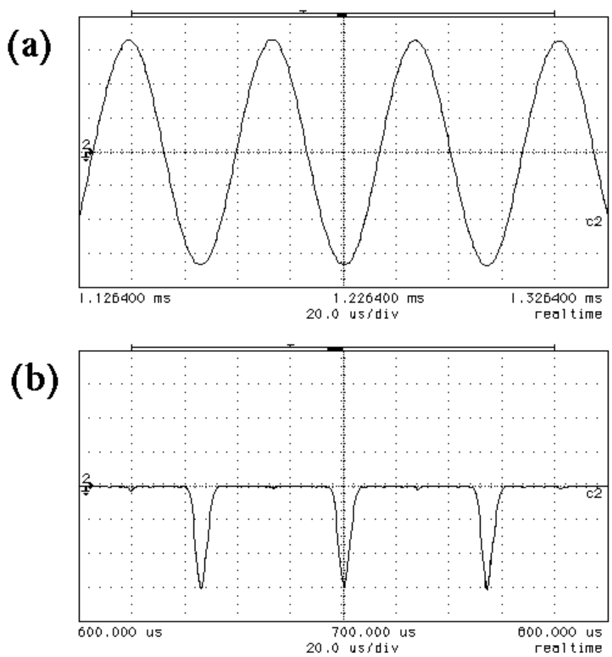

Figure 2: Oscillograms of the accelerating voltage (a) and the electron beam current (b).

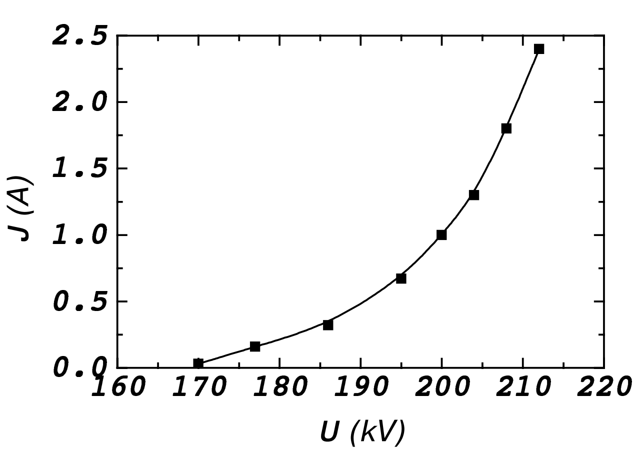

Figure 3: Volt-ampere characteristic of the cold cathode electron gun.

2.3 Extraction System

To reduce the energy loss in the electron beam extraction device we use a multi-beam, multi-window system. The electrons emitted by each small cathode are directed to its own output window (see Fig.1). The multi-beam, multi-window system has evident advantages. 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 foil. As a results, the heat load and the electron energy loss in the output window is reduced significantly with respect to a standard design with single powerful beam, one large output window and scanning system [4]. Also, total beam current (and 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.

2.4 Uniformity of the Cathode Emission

The threshold behavior of the cathode emission (see Fig. 2) 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 (see Fig. 4).

3 EXPERIMENTAL VERIFICATION

To verify main technical solutions we have manufactured a scaled model of a 1 MeV, 1 MW multi-beam high repetition accelerator for EB-technology and have performed the experimental study of this model [5]. The project parameters of scaled model are following: beam energy – 200 keV, average power – 20 kW, operating frequency – 18 kHz.

The coaxial high voltage resonator is manufactured as a spiral delay-line with distributed inductance 6 H/m and wiring capacitance 80 pF/m. The cathode–anode capacitance is equal to 10 pF. The quality of unloaded coaxial resonator is equal to 140. The outer dimensions of the device are 0.3 m$\times$ 0.8 m.

To improve the uniformity of the electrical field on the surface of the mosaic cathode we have performed optimization of the cathode electrode configuration. The form of the cathode electrode and the distribution of the electrical field are shown on Fig. 4. Such distribution of the field provides the uniformity of the emission of the mosaic cathode tablets of about $\pm 5\%$. The dark current in cathode-anode system is detected at a voltage exceeding 300 kV (without cold cathode). The operating voltage of a mosaic cathode is equal to 200 kV (see Figs. 2 and 3).

The primary exciting winding is located outside the accelerator and is powered by voltage pulses of a rectangular form produced by an electronic inverter. The high frequency inverter has the following parameters: output voltage 500 V, average power 30 kW, operating frequency 15 –

25 kHz.

The accelerator produces an electron beam with the peak current up to 1 A, pulse duration about 10 μs and repetition rate of 18 kHz (see Fig. 2). The average beam current is equal to 0.1 A. Dispersion of the electron energy is less than 15 % which is sufficient for such applications as the radiation processing and technology.

The high frequency resonator (resonance transformer) provides high conversion efficiency (about 97 – 98 %) of the electrical power from the inverter to the electron beam power. The beam energy loss in the output window foil is reduced significantly, because the diameter of the small window is equal to 40 mm which allows to install titanium foil of 10 μm thickness.

Experiment has shown that parameters of the electron optical system have been chosen correctly and design parameters of the accelerator have been achieved. Moreover, an interesting effect has been observed – after training of the mosaic cathode the uniformity of the emission became to be significantly better. Photography of the experimental setup is shown on Fig. 5.

Experimental experience obtained with 200 keV accelerator model gave us the base for the construction of a full scale accelerator with energy of about 1 MeV, and output power of about 30 – 1000 kW and extremely low cost.

4 REFERENCES

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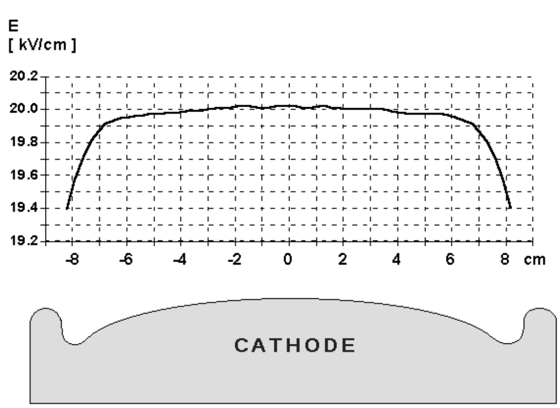

Figure 4: Configuration of the cathode electrode and distribution of the electric field.

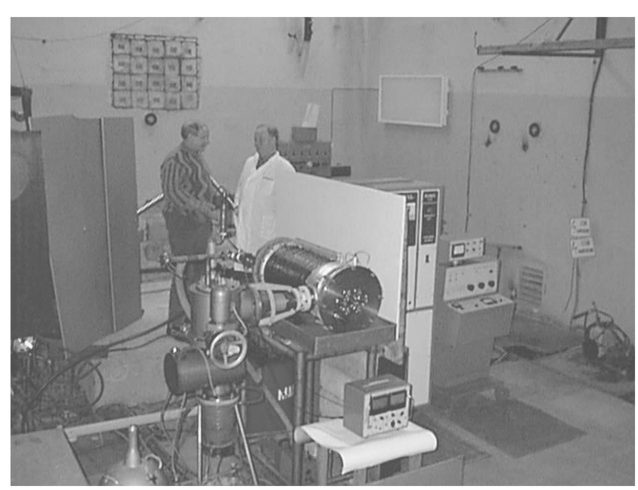

Figure 5: Experimental setup.