5 MeV 300 kW ELECTRON ACCELERATOR PROJECT*

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Abstract

The paper presents a project of high power linear accelerator for industrial applications. The accelerator has a modular structure and consists of the chain of accelerating cavities, connected by the axis-located coupling cavities with coupling slots in the common walls. Main parameters of the accelerator are: operating frequency of 176 MHz, electron energy of up to 5 MeV, average beam power of 300 kW. The required RF pulse power can be supplied by TH628 diacrode.

INTRODUCTION

Currently some interest has been aroused in X-ray radiation technologies because of the high penetration ability of X-rays. This is of particular importance for pasteurization of wide spectrum of food products, disinfection of mail deliveries, and some other applications. However, because of low efficiency of X-ray conversion for electrons with energy below 5 MeV, the intensity of X-rays required for some industrial applications can be achieved only when the beam power exceeds 300 kW.

The goal of a project is to develop an efficient electron accelerator with sufficiently high average beam power. Design parameters of the accelerator are listed in Table 1.

Table 1: Accelerator design parameters

Energy, MeV	5
Average Electron Beam Power, kW	300
Nominal RF Power Efficiency	>70%
Maximum Duty Cycle	0.15

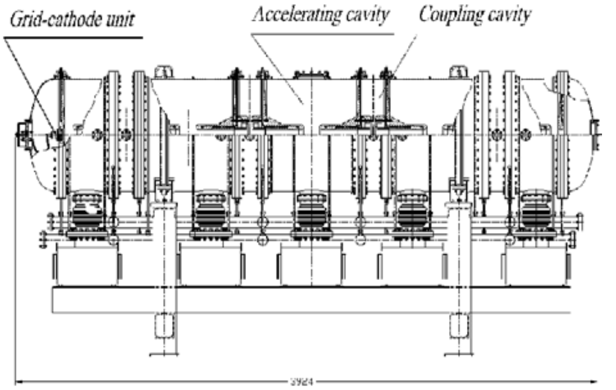

Figure 1: General view of accelerator.

Figure 1 represents the general view of a new efficient electron accelerator for industrial applications. The electrons are accelerated in the low frequency multi-resonator standing wave on-axis coupled structure. This design makes it possible to decrease power losses in each resonator comparing with the single-resonator accelerator (at the same average beam power level) and to increase the electron efficiency of the accelerator [1]. The electron beam is injected by triode RF gun formed by a grid-cathode unit and the first accelerating gap. Such design allows us to sufficiently simplify the beam injection system.

To realize this concept one has to perform the following:

- To achieve the required value of the pulse beam current at relatively low electric field strength in the accelerating gaps comparing with the single-resonator accelerator;
- To obtain the relatively narrow energy spectrum of accelerated electrons;
- To transport without losses the powerful electron beam through the accelerating structure without usage of electro- and magnetostatic lenses;
- To efficiently cool the accelerating structure's resonators;
- To suppress the multipactor excitation.

The report briefly describes possible ways to do these and that will allow us to sufficiently simplify the design and reduce the cost of accelerator, as well as to improve its reliability and reduce the maintenance charges.

GRID-CATHODE UNIT

The beam injection system of the accelerator must provide the pulse electron current of up to 7 A. The amplitude of electric field strength in the grid plane will be up to 80 kV/cm. The cathode with diameter of 20 mm and area of 3 cm^2 is made of LaB$_6$.

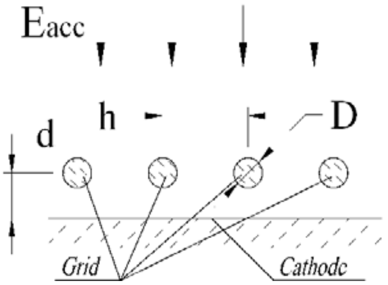

Figure 2: Scheme of grid-cathode unit.

Figure 2 represents the scheme of the accelerator's cathode-grid unit. The main geometric parameters of the unit are: the cathode-grid gap *d*, step of the grid *h*, and diameter of wires *D*. The computer optimization of these parameters was carried out by SAM program package [2].

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The results given below were obtained using these optimal values.

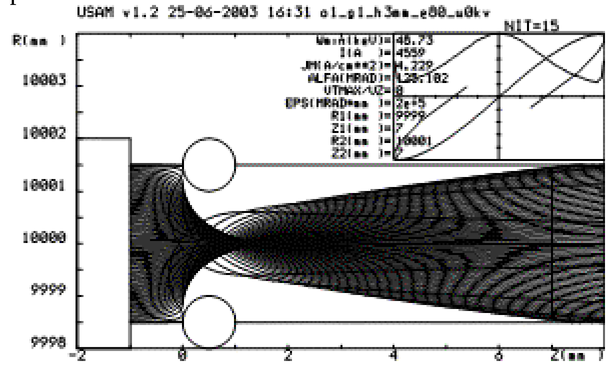

Figure 3: One cell of grid-cathode unit.

Figure 3 shows the results of computer simulation of a single cell of the grid-cathode unit in the case when the grid and the cathode have equal potentials, the transverse current density distribution and phase curve of the beam at 6 mm from the grid are shown in the upper right corner of the Figure 3. Figure 4 represents the calculated curves of average density of current emitted from the grid-cathode unit, relative transverse velocity of electrons in the grid's plane, and relative current falling on grid versus potential difference between the grid and the cathode.

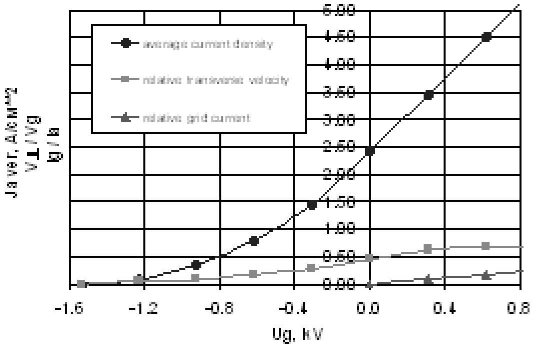

Figure 4: Dependence of average current density, relative transverse velocities, and relative grid current on grid-cathode potential for accelerating field strength 80 kV/cm.

BEAM DYNAMICS

Computer simulation of the beam dynamics from the grid to the accelerator output was performed in long-wave approximation using SAM code.

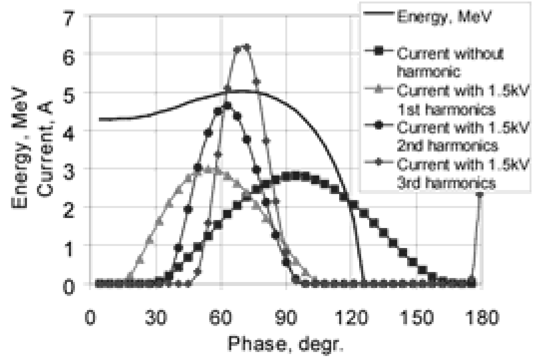

Figure 5: Results of transit effect simulation for four-gaps accelerator and its compensation by applying the additional harmonic voltage.

Figure 5 shows the calculated initial acceleration phase (in the grid plane) dependence of final electron energy at the accelerator output and the resulting micropulse form on the grid outer surface. To improve the electron energy spectrum, one can apply a constant biasing voltage and an additional bias RF voltage of either basic, second or third harmonics with appropriate phase shift to the cathode-grid gap.

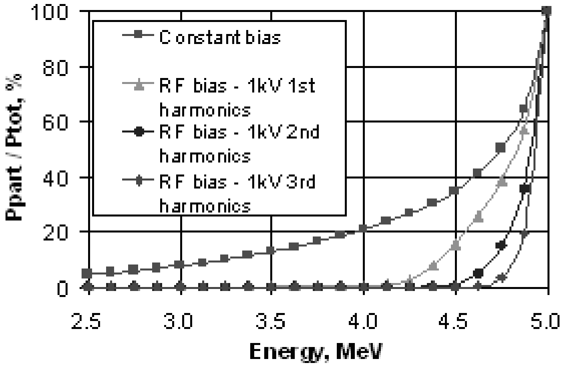

Figure 6: Electron energy spectrum without and with RF biasing voltage.

Figure 6 represents the calculated energy spectrum of electrons after acceleration using constant grid-cathode bias and with additional RF bias of first, second, and third harmonics. The partial power of beam P_{part} is determined according to the following formula:

$$P_{part}(W) = \int_{0}^{W} \frac{\partial P}{\partial E}\, dE\,, \qquad (1)$$

where $\partial P/\partial E$ is differential power density of electron beam. The partial power is normalized on the total beam power $P_{tot}=P_{part}(W_{max})$, where W_{max} is the maximal beam energy. One can notice that the additional RF biasing voltage can sufficiently reduce the lower energy part of the spectrum.

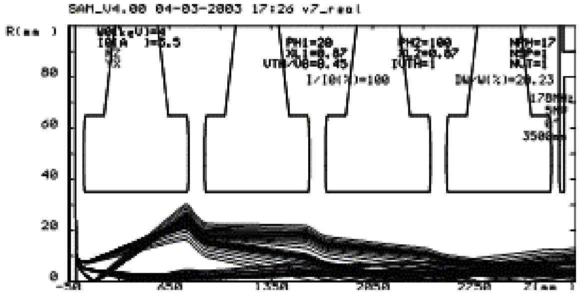

Figure 7: Results of beam dynamics simulation for 5 MeV accelerating structure.

Figure 7 shows the results of 5MeV beam dynamics simulation in the accelerating structure considering the transverse velocity spread of electrons due to scattering on the microlenses formed by the grid mesh (see Figs. 3 & 4) and the space charge influence on the transverse beam dynamics. The trajectories of electrons started from the cathode edge at different starting phases are shown considering the initial spread of transverse velocities, which results in the accelerator's aperture increase comparing with a single-gap variant. The simulation proved a possibility to avoid the usage of magnetic focusing elements for the beam successful transportation.

ACCELERATING STRUCTURE

Let us consider the design of the accelerating structure that is presented in Fig.1 in more details. It is assembled of four identical units (biperiodic structure periods) and two end-walls. This structure advantages are: simple design, convenient cooling and high resistance to the thermal deformation. It is supposed to coat the inner cavity surfaces by titanium nitride for the multipactor suppression.

Figure 8 represents a 1:5 scale model of accelerating structure operating at $\pi/2$ mode. The measured coupling coefficient is about 8% and this value is in good agreement with computer simulation results.

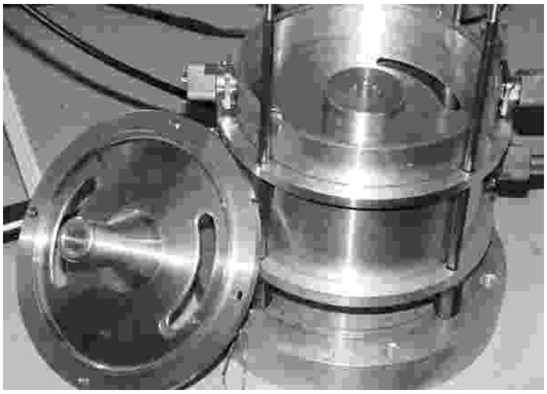

Figure 8: Accelerating structure (1:5 scale model).

In order to create the required accelerating gradient to reach 5 MeV electron energy in the accelerating structure we need about 0.8 MW of RF pulse power. With power supply of 2.8 MW, we can transfer about 2 MW to the beam and can reach electron efficiency of more than 70%.

Accepting 300 kW as an average beam power, we can set duty factor to 15%. In this case, the power losses in every unit of accelerating structure will be about 30 kW of average power. The heating of resonators is the main factor that causes the shift of the eigen frequencies of the structure's resonators, so the efficient cooling of resonators is a must. Simulations carried out by SAM program have shown that cooling the disks only is not enough for heat transfer from the coaxial part, so the additional water pipes should be soldered to the central part of the resonator to efficiently cool this system.

ACCELERATOR DESIGN

Figure 9 presents a block diagram of the accelerator.

The accelerator version for the 5 MeV electron beam is assembled by four modules. It corresponds to an assembly, which consists from three whole cavities, two half-cavities, and four coupling cavities. RF power input (a loop) is settled in the center of the accelerating structure.

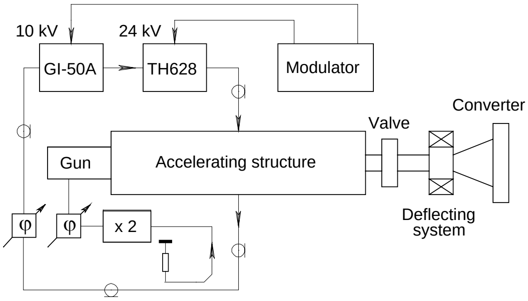

Figure 9: Accelerator block diagram.

The two-stage amplifier operates as RF power source and is excited by a signal from the accelerating structure via phase shifter, which provides the proper phase shift in the feedback circuit. A two-stage scheme has been chosen to increase the output power, to optimally adjust the output cascade, and to lighten the phase shifter operating in the feedback circuit. TH628 diacrode should be used in the output cascade to obtain the pulse power of 3 MW and average power of about 450 kW. The diacrode has been tested by “Thomson” firm in 3 MW pulse power, 600 kW average power operating regime [4]. TH116 or GI-50A triode may be used in the prime cascade.

The amplifier is powered by the modulator with the pulse power of about 6 MW at the average power level of 1 MW. The voltages are 24 kV and 10 kV for the prime and output cascades correspondingly.

The electron gun is triode-type with the second harmonic voltage applied to its grid-cathode circuit. It allows us to decrease the electron beam energy spread. The phase shift of that voltage is adjusted by the phase shifting line.

The converter is located at the accelerator output and serves for X-ray conversion of the electron beam power.

RF power source with GI-50A triode designed for ILU-8 electron accelerator is supposed to be used for accelerator prototype testing at 3 MW of pulse power and 20-30 kW of average beam power level operation conditions. It will be also used as the prime cascade for unification purposes.

CONCLUSION

The results obtained proved the possibility to solve the main problems and so to create the efficient and powerful electron accelerator for energy of up to 5 MeV and beam power of 300 kW.

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