INDUSTRIAL HIGH POWER ELECTRON ACCELERATOR FOR THE ENERGY 5-10 MEV

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This paper presents the project of an industrial accelerator of the modular structure. Accelerating structure consists of the chain of coaxial ILU cavities, connected by the coupling cavities. Two designs of accelerating structure, differing by a version of coupling cavities, are presented. Main parameters of the accelerator are: energy of electrons 5-10 MeV, average beam power up to 150 kW, operating frequency 176 MHz, duty factor 10%.
PACS numbers: 29.17.+w

1 INTRODUCTION

Experience in development and maintenance of ILU-type accelerators has shown that the single-cavity system with one accelerating gap can be effectively used for the industrial accelerators with the energy up to 5 MeV and beam power up to 50 kW [1, 2]. Increasing the electron energy beyond 5 MeV evidently requires the system with several accelerating gaps, connected in sequence. ILU-11 with two accelerating gaps was the first accelerator of such a type [3]. Its RF power source, modulator and control system were similar to those of the other ILU-type machines. ILU-11 was designed as a basic unit for the further development of new accelerators with a higher energy and power of electron beam. The main parameters of ILU-11:

Energy – 2.5-5 MeV
Average beam power – up to 60 kW
Operating frequency – 176 MHz
Shunt impedance of the accelerating structure – 13.4 MOhm/m
Duty factor – 2.5%

2 ACCELERATING STRUCTURE

There are two possible variants of accelerating structure design. First variant is based on the ILU-11 accelerating structure. It is a three-circuit cavity, in which the coaxial line with length λ/2 plays the role of coupling cavity. In the accelerating quarter-wave cavities with operational mode π/2, the oscillations with phase shift π is formed, thus providing the electron acceleration.

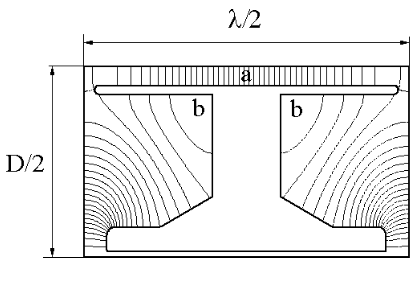

Fig. 1. ILU-11 accelerating structure unit: (a) - coupling cavity, (b) - accelerating cavity.

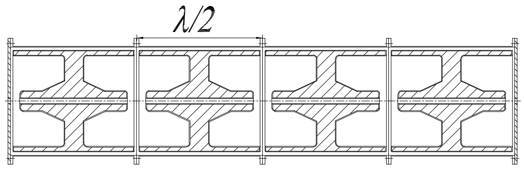

Fig. 2. Drawing of the accelerating structure, consisted of four ILU-11 units.

Fig. 1 shows the unit of accelerating structure ILU-11 with electric field lines distribution. At the optimal dimensions of the cavities the coupling could reach 15%. Such units, consisted of 2 quarter-wave cavities and half-wave coupling cavity, could be combined into extensive accelerating structure. Increasing the number of these units we can either increase the energy gain of the accelerator or decrease the RF power, spent on accelerating field creation. Fig. 2 presents a drawing of accelerating structure, which consists of four units. The DC voltage for the multipactor suppression can be created at the isolated inner parts of cavities with alternating polarity. However, such design makes difficulties with the cavity inner parts cooling.

Another variant of the accelerating structure assumes that coupling cavity appears on the axis in between the neighboring quarter-wave accelerating cavities. Its resonant frequency is provided by the intrinsic capacity, while coupling – by two slots in the walls. With length of the slots about 80° of circumference, the coupling is about 10%. Fig. 3 presents the accelerating structure unit with electric field lines at the operating mode π/2.

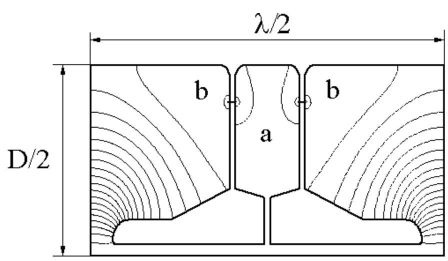

Fig. 3. Accelerating structure unit with an axis situated on the coupling cavity: (a) - coupling cavity, (b) - accelerating cavity.

Fig.4 presents a design of accelerator with structure, combined from four units described above. The advantage of this scheme is simplicity of the single-wall design, convenient cooling (through wall tubes), and high resistance to the thermal deformation. The disadvantage is, obviously, the necessity of covering the copper surfaces by titanium nitride for the multipactor suppression. Nevertheless, due to relative simplicity of the construction, we have chosen the variant of the accelerating structure with an axis situated on the coupling cavities. The design, described below is based on this variant.

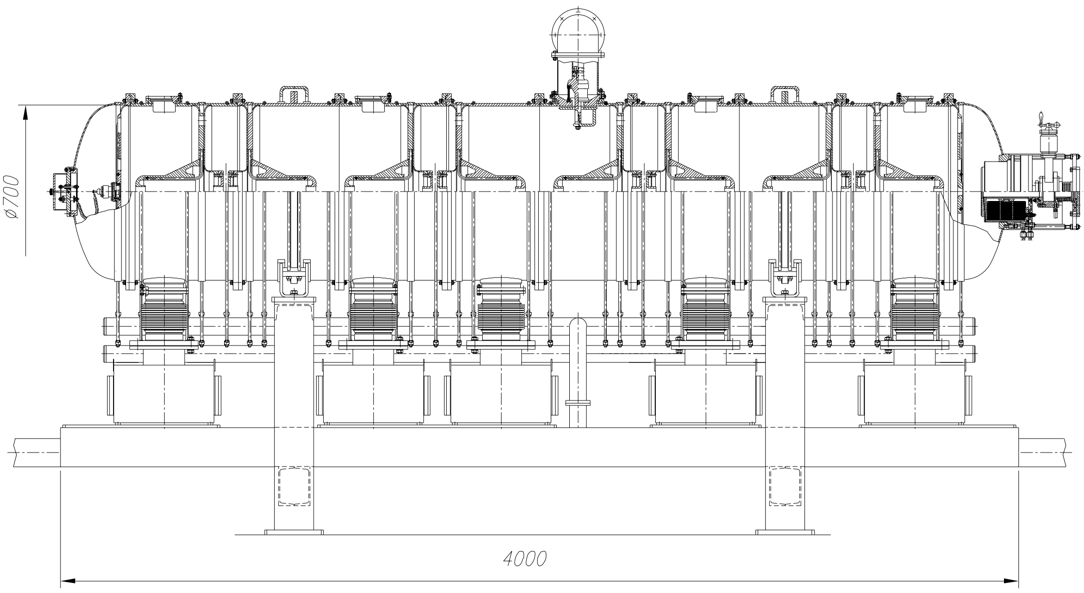

Fig. 4. Accelerator design with an axis situated on the coupling cavities.

3 OPERATION OF THE ACCELERATOR

The accelerator operates in pulsed mode at a frequency of 176 MHz. In order to create a necessary accelerating gradient for gaining 5 MeV by electrons at 4-units accelerating structure, we need the RF power of about 0.6 MW. Table 1 presents values of the RF power, dissipated in the accelerating structure in dependence on the electron energy and quantity of units (in parentheses).

Table 1

E, MeV	5(4)	7(4)	7(6)	10(8)	10(10)
P_c MW	0.625	1.22	0.8	1.25	1.0

Limiting the power level for creation of the accelerating gradient by 1 MW, with a power supply output of 2.5 MW, we can transfer about 1.5 MW to the beam. Accepting 150 kW as an average beam power we can set the duty factor to 10%. Such a power output could be obtained from the tetrode EIMAC 4CM2500KG or diacrode TH628.

4 RF POWER SOURCE

Fig. 5 presents the design of the generator based on the EIMAC 4CM2500 KG tetrode at a frequency of 176 MHz. Anode and cathode circuits are situated at the opposite sides of the tetrode. High frequency blocking of the shielding grid is performed using a structural capacity. The driving grid is solidly grounded, while the cathode is under positive potential due to the voltage drop on the bias resistor. The electric length of the anode circuit is equal to the wavelength λ [4]. This design allows one to make cooling water input and DC anode voltage supply inlet at the second minimum of voltage in the anode circuit. Moving of external tube bottom of the anode circuit performs fine tuning of the frequency. Diameters of the tubes are 600 and 300 mm correspondingly. Coupling with the anode circuit is inductive. Feeders cross-sections is 160x70 mm. Diameters of the cathode circuit tubes are 280 and 216 mm. High frequency blocking is performed by the ring capacitor KVK, circuit placed at the minimum of the central conductor current. The circuit is tuned by a short-circuiting plunger. The cathode circuit has a conductive coupling. The electric length of the circuit is about 1 m.

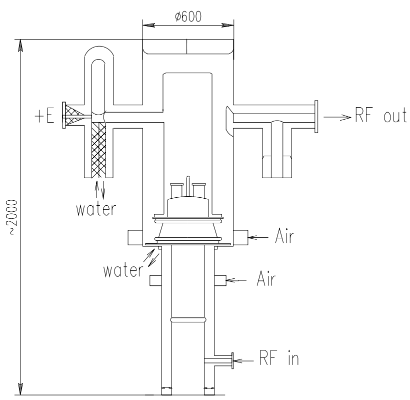

Fig. 5. Drawing of the RF power source, based on the 4CM2500KG tetrode.

Power from the anode circuit, through the feeder and the coupling loop, goes to the accelerating structure (there is also a variant of power supply through two coupling loops). Our Institute has an experience in the feeding of accelerating structures by the coupling loop (up to 200 kW of continuos power). Couplers are placed on the cowling of the central cavity that gives twice as less frequencies at the dispersion characteristic. There is also the feedback loop, from which the power goes through the feeder with a cross-section of 70x30 mm to the cathode circuit, thus creating the feedback. For the appropriate phasing the line has a phase shifter - either mechanical or ferrite. Fig. 6 shows the generator with an accelerating structure.

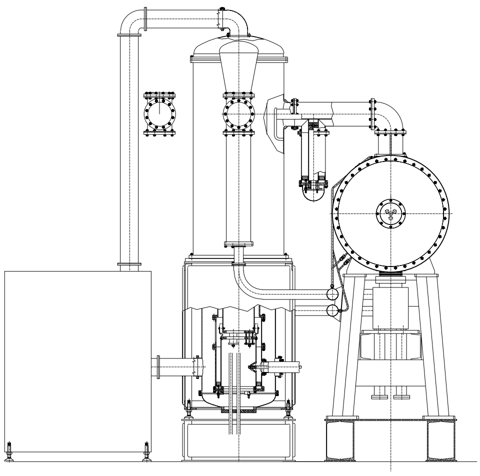

Fig. 6. RF power source with the accelerating structure.

5 BEAM DYNAMICS

As an electron source, the triode RF gun is used. It is formed by placing the cathode-grid unit directly into the first accelerating gap. The cathode is made from LaB_6 and its diameter is 20 mm. A required current magnitude is obtained by choosing the cathode-grid gap and the penetration factor of the grid. If the higher current is needed or/and we need to compensate transit effects, it is possible to put an additional voltage of either basic or second harmonic with the appropriate phase shift to the cathode-grid gap. Numerical simulation of the beam dynamics from the grid to the accelerator output was performed in a long-wave approximation using the SAM code [5, 6]. The transverse velocity spread of electrons, due to scattering on the microlenses, formed by the grid mesh, was taken into account. This led us to increasing the accelerator aperture in comparison with a single-gap variant. Fig. 7 shows the results of simulation of four-gaps accelerator on the energy 5 MeV. There are trajectories of the electrons, started from the cathode edge at different input phases. The simulations showed that there is no need in any magnetic focusing elements for the successful transportation of the beam.

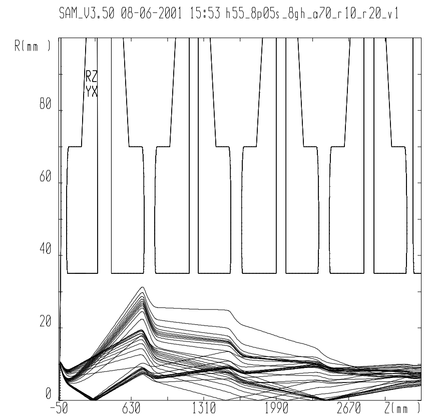

Fig. 7. Trajectories of electrons in the accelerator.

6 CONCLUSION

Here presented is the project of the industrial electron accelerator of a modular design, based on the chain of coaxial ILU cavities, connected each other by the coupling cavities. We have chosen a variant with axis-situated coupling cavities. Number of units is determined by the energy of the beam. The supposed energy range is 5-10 MeV, operational frequency is 176 MHz; average beam power is 150 kW at a duty factor of 10%.

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