HIGH POWER ELECTRON ACCELERATOR FOR ENERGY 5-10 MeV

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Abstract

This paper presents the project of 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%.

1 INTRODUCTION

Experience in development and maintainance of ILU-type accelerators has shown that the single-cavity system with one accelerating gap can be effectively used for the industrial accelerators with energy up to 5 MeV and beam power up to 50 kW [1,2]. The 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 type [3]. Its RF power source, modulator and control system was 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 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 $\lambda/2$ plays the role of coupling cavity. In the accelerating quarter-wave cavities with operational mode $\pi/2$, the oscillations with phase shift π is formed, thus providing the electron acceleration.
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%.
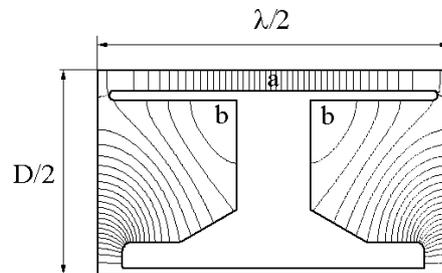

Figure 1: ILU-11 accelerating structure unit.

a) coupling cavity
b) accelerating cavity

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.
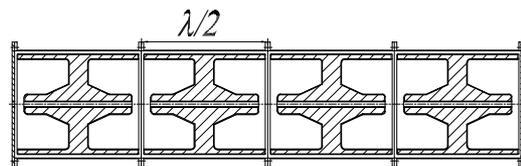

Figure 2: Drawing of the accelerating structure, consisted of four ILU-11 units.

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 $\pi/2$.

Fig.4 presents a design of accelerator with structure, combined from four units described above. The advantage of this scheme is simplicity of single-wall
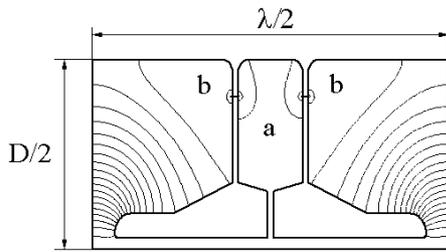
Figure 3: Accelerating structure unit with on axis situated coupling cavity.

a) coupling cavity
b) accelerating cavity

design, convenient cooling (through wall tubes), and high resistance to the thermal deformation. The disadvantage is, obviously, the necessity of covering of 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 on axis situated coupling cavities. The design, described below is based on this variant.

3 OPERATION OF THE ACCELERATOR

The accelerator operates in pulsed mode at the frequency 176 MHz. In order to create necessary accelerating gradient for gaining 5 MeV by electrons at 4-units accelerating structure, we need about 0.6 MW of RF power. Table 1 presents values of RF power, dissipated in accelerating structure in dependence of 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
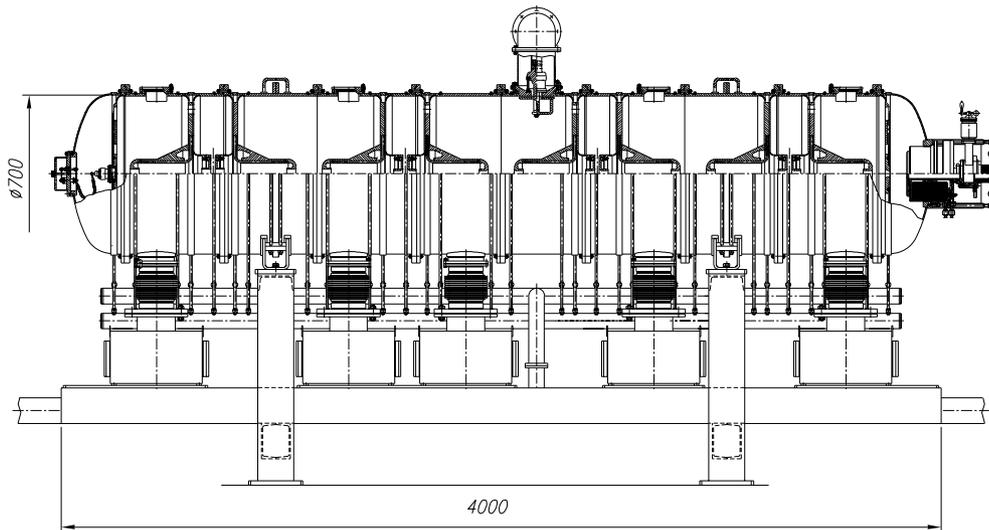
Limiting the power level for creation of the accelerating gradient by 1 MW, with power supply output 2.5 MW, we can transfer about 1.5 MW to the beam. Accepting 150 kW as an average beam power we can set duty factor to 10%. Such power output could be obtained from tetrode EIMAC 4CM2500KG or diacrode TH628.

4 RF POWER SOURCE

Fig 5. presents design of the generator based on EIMAC 4CM2500 KG tetrode at the frequency 176 MHz. Anode and cathode circuits are situated at the opposite sides of tetrode. High frequency blocking of the shielding grid is performed by structural capacity. Driving grid is solidly grounded, while the cathode is under positive potential due to voltrop on the bias resistor. Electric length of the anode circuit is equal to the wavelength λ [4]. This design lets 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 crossections is 160x70mm. Diameters of the cathode circuit tubes are 280 and 216 mm. High frequency blocking is performed by the ring capacitor KVK, placed at the minimum of the central conductor current. The circuit is tuned by short-circuiting plunger. The cathode circuit has a conductive coupling. Electric length of the circuit is about 1m.

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 loop). Our Institute has an experience in the feeding of accelerating structures by coupling loop (up to 200 kW of continuos power). Couplers are placed on the cowling of the central cavity that gives twice as less

Figure 4: Accelerator design with on axis situated coupling cavities.
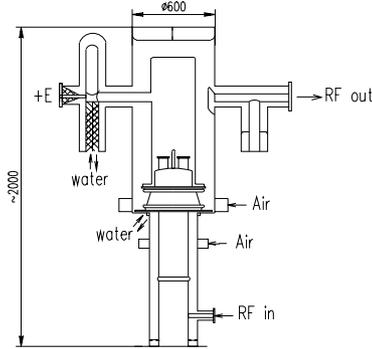
Figure 5: Drawing of the RF power source, based on 4CM2500KG tetrode.

frequencies at the dispersion characteristic. There is also the feedback loop, from which the power goes through feeder with crossection 70x30mm to the cathode circuit, thus creating the feedback. For the appropriate phasing the line has a phaseshifter - either mechanical or ferrite. Fig. 6 shows the generator with accelerating structure.
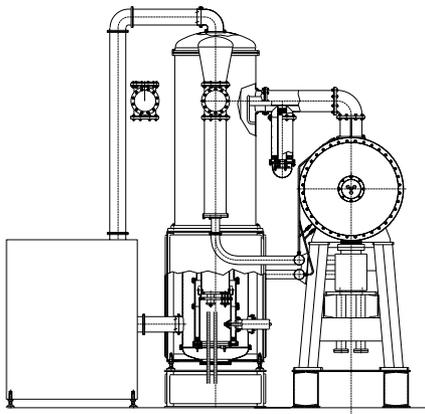

Figure 6: RF power source with the accelerating structure.

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. 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 appropriate phase shift to the cathode-grid gap. Numerical simulation of the beam dynamics from the grid to the accelerator output was performed in long-wave approximation using SAM code [5,6]. The transverse velocity spread of electrons, due to scattering on the microlenses, formed by grid mesh, was taken into account. This led us to increasing the accelerator aperture in comparison with 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.
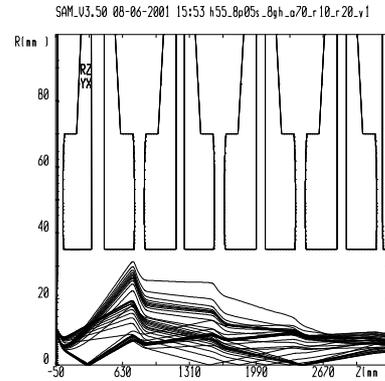

Figure 7: Trajectories of electrons in the accelerator.

6 CONCLUSION

Here is presented the project of industrial electron accelerator of modular design, based on the chain of coaxial ILU cavities, connected each other by the coupling cavities. We have chosen 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 duty factor 10%.

7 REFERENCES

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