STATUS OF ILU-14 ELECTRON ACCELERATOR

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Abstract

A new high power (up to 100 kW) industrial linear electron accelerator ILU-14 for energy of 7.5–10 MeV is under construction at Budker INP. The accelerator operates at 176 MHz with total efficiency of 26 %, its modular structure allows the electron energy and beam current to be varied within certain limits by changing the modular arrangement. The 5 MeV prototype of the accelerator was created and successfully tested in 2009. The designed average beam current of 600 mA with pulsed power of 2.5 MW and accelerating structure electron efficiency of 68 % were obtained during experiments. Applying an additional RF voltage to the electron gun cathode-grid gap allowed a beam current passing of 96 % with minor beam energy spread. The paper presents results of the numerical and experimental study of the accelerator systems together with the latest tests on the accelerator prototype.

INTRODUCTION

A new powerful (up to 100 kW) industrial electron accelerator with energy range from 7.5 to 10 MeV was designed in BINP SB RAS [1-3]. This model was named ILU-14 and can be used in electron and bremsstrahlung modes. This accelerator has all basic features of ILU-type accelerators like internal injection type and using of autogenerator for RF power feeding, but has also some its own features. On the base of ILU-14 it planned to produce a line of simple and effective accelerators, which can compete with existent industrial accelerators in this energy range.

IDEA OF ILU-14 ACCELERATOR

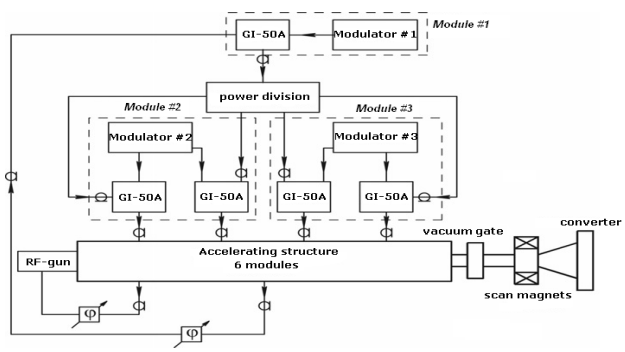

Fig.1. Block scheme of ILU-14

The main elements of the accelerator are: accelerating structure, triode RF-gun, two-cascade autogenerator, feeder system, RF power inputs, modulators, scan magnets system and converter (in the case of bremsstrahlung mode operating) (Fig.1).

In ILU-14 (in comparison with other powerful impulse linear accelerators) some features were realized.

The first feature of it is using of low-frequency many-resonator structure on standing wave with coupling resonators on the axis. The accelerating structure is assembled from separate modules with using of indium vacuum seals. The module consists of one coupling resonator and two half accelerating resonators (Fig. 2-A). Accelerating structure, used for electron accelerating to the energy up to 10 MeV, consists of 6 such modules (Fig.2-B).

The structure is excited by autogenerator, based on powerful pulse triodes GI-50A, which provide competitive efficiency to the accelerator.

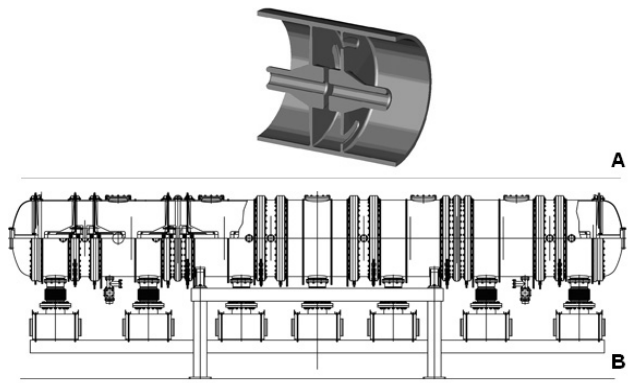

Fig.2. ILU-14 units. A-The module of accelerating structure. B-General view of accelerating structure

The second feature of the low-frequency accelerator is the using of triode RF-gun with specially designed for it grid with high transmissivity as an injector. RF-gun is placed directly in the first accelerating gap. Narrow energy spectrum of electron beam, which is necessary for effective conversion its power to bremsstrahlung and beam conducting through the structure with small losses are provided by feeding of grid-cathode unit of the RF-gun by additional RF-voltage.

The third feature is using of two-cascade autogenerator with feedback through accelerating structure. This feature allows operating of the accelerator without frequency stabilization system of structure or generator. As a result, the generator and accelerator control system are simple enough.

The fourth feature is the module construction of ILU-14. Separate modules are assembled by using of serial units, designed in the experimental plant of BINP.

This conception allows simplify the construction, decrease the cost of the accelerator, raises its safety and diminishes the operating costs.

ACCELERATING STRUCTURE AND DYNAMICS OF ELECTRON BEAM

Accelerating structure operates on frequency of 176 MHz on standing wave mode (quality factor is equal to 22000, shunt resistance – to 27.3 MΩ). Magnetic field coupling is provided through coupling slots (coupling coefficient is equal to 0,078). Every resonator side has two coupling slots. The slots on opposite sides of resonator are located from each other at the angle of 90^0 for prevention of slot-through-slot coupling.

On Fig. 3 the forms of electron trajectories in ILU-14 are presented [5].

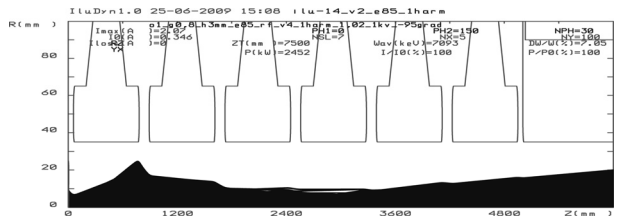

Fig.3.Typical electrons trajectories in the accelerating structure.

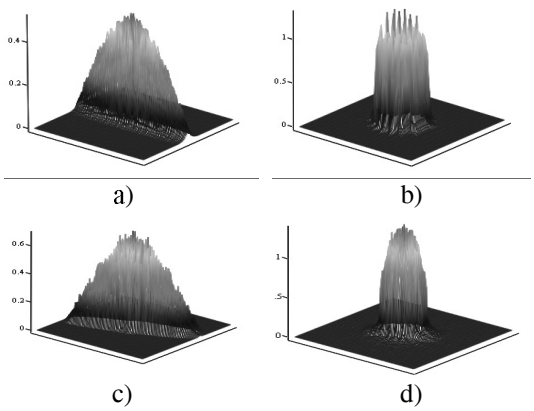

Fig.4. Profiles of average beam current density: a) – on the input to the second accelerating gap; b) – on the distance of 3000 mm from cathode; c) – on the output of accelerating gap; d) – after magnet lens focusing.

Electrons, which fly out from slot center in the grid perpendicularly to the cathode, form beam core. Around the core there is a visible halo, formed by electrons, flown out from slots borders under the angle to the perpendicular. Calculations showed a possibility of beam conduction through accelerator at the expense of aperture increase and RF focusing effect only [4-5].

On Fig. 4 calculated profiles of average current density during the macroimpulse width are presented.

Because of spread of injection transverse velocities across grid slots density profile of beam current obtains elliptic form on the input to the second accelerating gap (Fig. 4a). RF focusing gradually diminishes this effect (Fig. 4b), but at the same time overfocuses the extreme particles (Fig. 4c). This effect can be removed by additional magnet lens focusing of the beam in magnet scan system on the output of accelerator (Fig. 4d).

ACCELERATOR PROTOTYPE

In radiation protected bunker the 5 MeV electron energy accelerator prototype was assembled for main elements tests. RF system of the prototype includes 4 module accelerating structure (Fig.2), triode RF-gun and two-cascade autogenerator on the pulse triodes GI-50A.

Fig. 5. ILU-14 prototype. A - two-cascade RF feeding system with coaxial feeders. B - accelerating structure with scan system.

For positive feedback of the autogenerator the part of RF power is withdrawn from accelerating structure by feedback loop, goes through coaxial phase-shifting line to the input of first cascade cathode circuit and, two parts divided, is delivered to the inputs of second cascades (Fig.5-A). Cascades power is delivered by two 2λ feeders to the power inputs and summarized in the structure (Fig.5-B). The amplitude of 30 kV anode voltage pulse of 450 μs width is provided by ILU-10M modulator [2]. Repetition rate is up to 50 Hz.

TEST OF PROTOTYPE STRUCTURE

Experimentally frequencies of structure coupling and Q-factor of working mode were measured by RF circuits analyzer (Fig.6). Also measurements of working mode

fields amplitudes relative values were carried out by method of dielectric ball small perturbation. Measurements results were in good agreement with results of 3D calculations by Microwave Studio program [6].

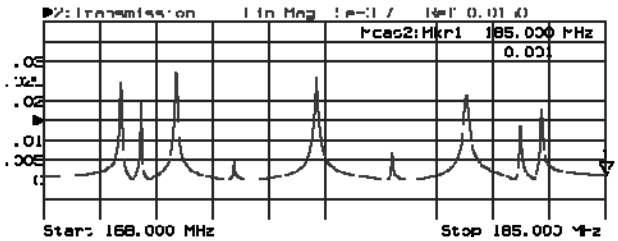

Fig.6. Spectrum of working mode oscillation.

After structure assembling it was needed 6 hours for obtaining of vacuum of 10^{-7} torr. On the repetition rate from 1 to 25 Hz it was needed about 3 hours of structure training for multipactor suppression. On the 4-module structure accelerating voltage level of 7.5 MV was obtained during 2 hours. So, 6-module accelerating structure will be possessed of enough electric strength to accelerate electron beam up to 10 MeV.

Current transmission of electron beam through accelerating structure without RF voltage feeding of gun cathode is equal to 80%. After the feeding of cathode-grid gap with optimal by amplitude and phase RF voltage cathode pulse current with current transmission coefficient of 96% was obtained.

Average power of electron beam was estimated:

a) as multiplying of average energy (which was defined after results of beam spectrum measurements) to average current of collector;

b) by calorimetric method.

At the energy of accelerated electrons of 5 MeV, impulse amplitude of accelerated current on the collector of 480 mA (injection current from gun cathode was equal to 500 mA), pulse duration of 420 μs, repetition rate of 33 Hz, power, measured by calorimetric method, was equal to 33±2 kW. Power, measured as multiplying of average energy and average current, was equal to 34.2±1 kW. This agreement is satisfactory.

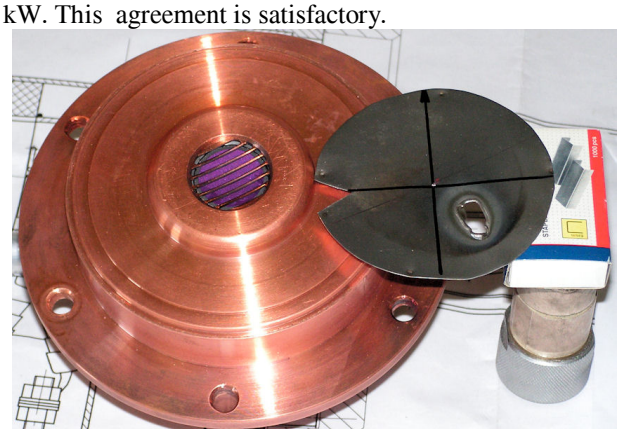

Fig.7. Cathode-grid unit and the burned foil (grid diameter is 20 mm).

Measurement of accelerated electrons energy was carried out by magnet spectrograph with inhomogeneous magnet field (n=0.5), turn angle, equal to 148°, and turn radius, equal to 200 mm. Beam current was fixed on the Faraday cup, placed after spectrograph.

Measurement of beam size on the output of accelerating structure was carried out by the method of spot burning in 0.25 mm-wide foil (Fig.7).

CONCLUSION

In the BINP SB RAS prototype of the powerful industrial electron accelerator passed the development tests in impulse regime successfully. Achieved parameters are presented in the Table 1.

Table 1: Achieved parameters of the prototype

Maximum accelerating voltage, MV	7,5
Maximum impulse beam current, mA	600
Beam current transmission coefficient, %	96
Impulse beam power at the 5 MeV electron energy, MW	2,5
Impulse duration, μs	420
Average beam power (at the repetition rate of 33 Hz), kW	33

At the impulses repetition rate of 50 Hz, average power of the beam will be 50 kW. Also impulse of accelerated current, equal to 300 mA, at the electron energy, equal to 6.7 MeV, was obtained.

Tests results confirm a possibility of ILU-14 accelerator at the energy up to 10 MeV and the power up to 100 kW on the base of designed modules creation. Accelerated structure in that case must be formed from 6 modules. Necessary RF power is provided by summation of 4 output cascades on the GI-50A triodes power.

Narrow energy spectrum of accelerated electrons allows use ILU-14 in the electron regime and the regime of bremsstrahlung. This fact increases application field of the accelerator in the industry.

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