COMPACT ELECTRON LINEAR ACCELERATOR RELUS-5 FOR RADIATION TECHNOLOGY APPLICATION

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Abstract

Electron linear accelerator for radiation technology application is designed to meet the following main requirements: 3-5 MeV energy, 3-6 microsecond pulse width, 1 kW average beam power. The accelerating system is 0.5 m long S-band standing wave on-axis coupled biperiodic structure. 35-40 kV electron gun with spherical cathode is used as the injector. RF generator is 2.5 MW peak power 4 kW average power magnetron. Generated frequency is stabilized by high Q-factor accelerating system connected into feed-back of the magnetron. The magnetron is fed by compact 45-55 kV IGBT based modulator. The accelerator is controlled through PLC based control system.

REQUIREMENTS

The compact linear electron accelerator is developed for the use in the investigation program of radiation material modification.

Main required parameters of the accelerated electron beam are:

- electron energy 3-5 MeV;
- average power of the electron beam 1 kW;
- electron beam pulse length 3-5 µsec;
- accelerated electron beam should be directed to the target located in the atmosphere;
- accelerated beam diameter at the target is to be 2-3 cm.

The second requirement for the accelerator development is to use module type of the accelerator design to use this design results in another accelerator systems with different parameters.

MAIN SCHEME

The accelerator includes following main systems: accelerator unit, RF power supply, pulse power supply, service systems and control system.

Accelerator unit consists of electron injector, accelerating section and beam extraction system.

RF power supply is to feed the accelerating section by RF power. It consists of magnetron, ferrite circulator, phaseshifter, reflector, load, waveguide ceramic window and waveguide vacuum unit.

Pulse power supply includes modulator for magnetron anode high voltage power supply, magnetron filament power supply unit and injector power supply unit.

Service systems are vacuum system, water cooling system, SF6 unit and main power supply.

ACCELERATOR UNIT

Electron Injector

Electron injector is two electrode electron gun with spherical cathode. The calculated injected beam trajectories are shown in Fig.1.

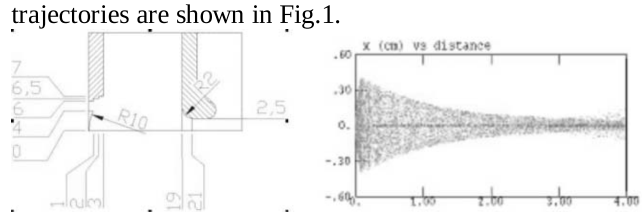


Figure 1: Calculated injector geometry (mm) and beam trajectory (cm).

The anode wall is the wall of first cell of the accelerating section so that the injected beam cross-over is located in the first accelerating cell of the accelerating section .

Accelerating section

The accelerating section is built on base of on-axis coupled biperiodic structure [1]. The section includes two bunching cells and 9 regular accelerating cells. Shunt impedance of the structure is 73 MOm/m. Section length is 0.5 m.

The section will be used in two modes shown in Table 1.

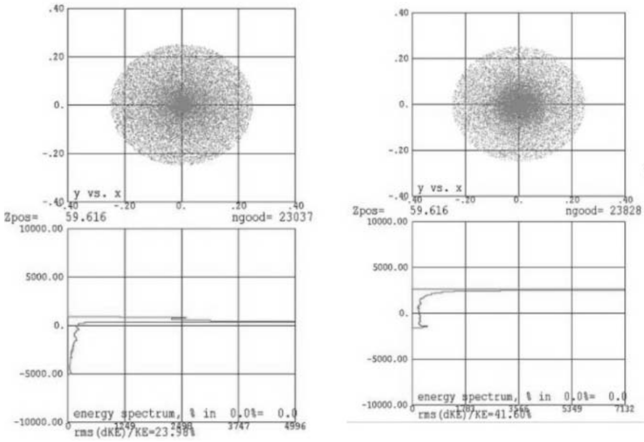
Table 1: Two operating modes of the accelerator.

Mode	**1**	**2**
Average energy, MeV	5	3
Max energy, MeV	5.9	4.2
Injected current, A	0.74	1.18
Peak beam current, A	0.17	0.28
Peak magnetron RF power, MW	2.0	1.5
Pulse length, µsec	5	5
Frequency repetition rate, Hz	300	300
Average beam power, kW	1.2	1.2

The beam cross-section distributions and energy spectra are presented in Fig.2.

Beam extraction system

Beam extraction system includes 50 µ thick titan foil for electron beam extraction from vacuum to atmosphere, beam current transformer for measurement the beam current and adjustable two Al plate electron energy measurement unit. Calibration chart of energy measurement unit is presented in Fig.3. I1 and I2 are the current from first Al plate (4.8 mm thick) and from second Al plate (10 mm thick).



5 MeV 3 MeV

Figure 2: beam cross-section distribution and energy spectrum.

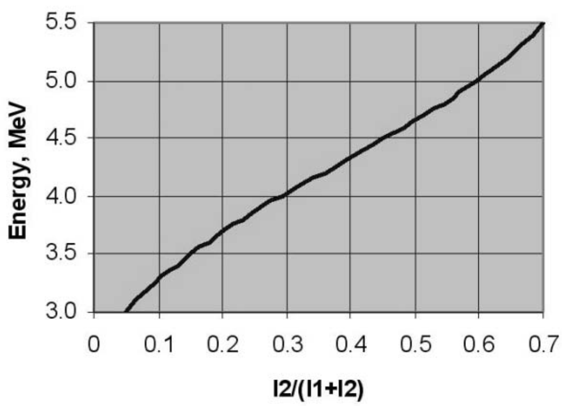


Figure 3: Calibration chart of energy measurement unit.

RF POWER SUPPLY

RF power supply includes magnetron, ferrite Y-circulator, waveguide ceramic window to isolate vacuum and gas-filled waveguide parts, waveguide vacuum unit, waveguide 90 degree E-bend phase shifter, reflector, reflected wave antenna and waveguide load.

RF power supply operates with feed-back self-oscillating loop scheme. Feed-back loop includes forward wave in the waveguide running from the magnetron through circulator, window, vacuum unit to the accelerating section and wave reflected from the accelerating section running through vacuum unit, window, circulator, phaseshifter, reflector and magnetron. The adjustable phaseshifter allows to keep the phase shift on the whole feed-back loop being a multiple of 360 degree at the oscillating frequency equaled to the resonant frequency of the accelerating section. High Q-factor (16000) of the accelerator section in the feed-back loop increases magnetron frequency stability 10-times. This scheme allows automatic frequency control (AFC). The oscillating frequency follows accelerating section resonant frequency. The magnetron parameters are

- frequency 2797 MHz
- peak power 2.5 MW
- average power 4.5 kW
- pulse length 6 μsec
- anode voltage 45-55 kV
- peak anode current 100 A max.

Ferrite Y-circulator is used for isolation the magnetron and the resonant accelerating cavity.

Reflector, phaseshifter, and reflected wave pin-antenna are combined in one waveguide unit located between third port of the Y-circulator and the waveguide load. Reflector is a 8 mm diameter metal rod. The length of this rod is 12 mm, which corresponds to needed reflection value VSWR=1.2. There are 8 possible positions of this rod, located in 10 mm along waveguide axis. This allows step-adjustment of the wave phase in feed-back loop at following values 0, 45, 90, 135, 180, 225, 270 and 315 degree.

Phaseshifter includes moved Teflon plate (see Fig.4).

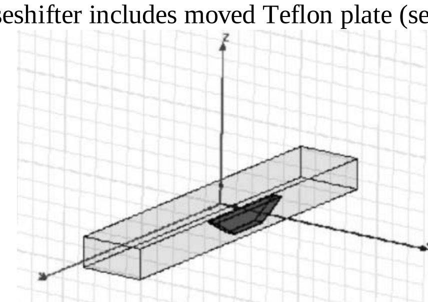


Figure 4: Teflon plate phaseshifter.

The phase shift depending on Teflon plate position for one wave pass through the phaseshifter (phase of S12) is shown in Fig.5.

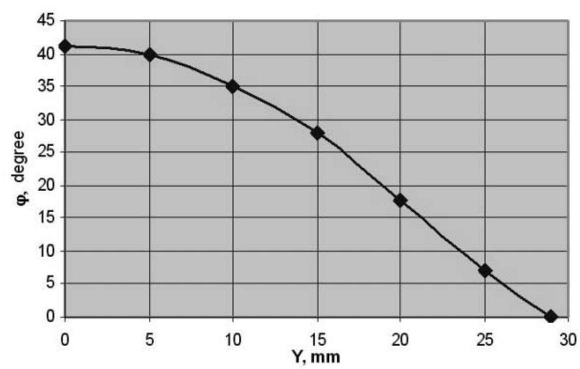


Figure 5: The phase shift depending on Teflon plate position for one wave pass through the phaseshifter.

The wave goes two times through the phaseshifter in the feed-back loop. Therefore the phase shift in feed-back loop is 2φ (phase of S11 at short condition in port 2).

The shape of this plate is optimized for minimization of the reflection at any position in the waveguide. The reflection VSWR is less then 1.07 in the whole control range.

So reflector and phaseshifter allow to control continuously in the range from 0 to 360 degree.

Waveguide vacuum unit consists of waveguide with slots in the waveguide height walls, vacuum case and vacuum flanges for connection to vacuum valve, ion pump and vacuum gauge.

PULSE POWER SUPPLY

Pulse power supply is to provide pulse magnetron anode voltage (modulator), magnetron filament and injector filament.

Modulator is based on the scheme of charge of capacitors, partial discharge it by means of IGBT triggering and stepping up the voltage in pulse transformer.

Pulse power supply consists of 10 power modules, pulse transformer, secondary filter, injector, filament transformer, injector filament power supply, magnetron filament power supply, injector current measuring transformer, magnetron current measuring transformer, high voltage divider, control module, oil tank, oil pump, oil-water heat-exchanger, oil flow sensor, temperature sensor.

There is eleventh module for output pulse form correction in the modulator.

The modulator with the pulse transformer inside the oil tank is shown in Fig.6.

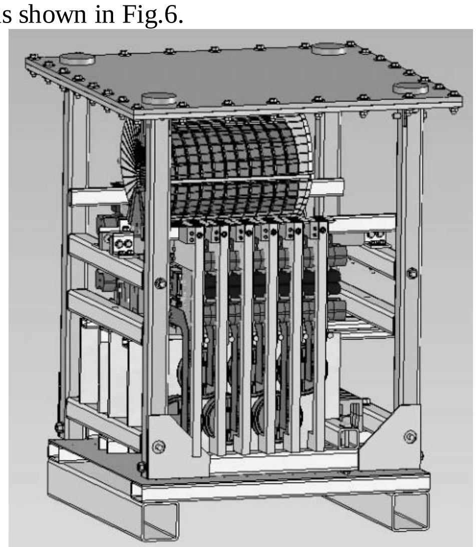


Figure 6: Modulator.

Main parameters of the modulator are:

- output voltage 45-55 kV;
- peak output current 100 A;
- pulse length 3-6 μsec;
- average output power 10 kW.

The shape of primary and secondary winding of the pulse transformer were optimized to minimize their inductance and capacitance. The model of the pulse transformer module is shown in Fig.7.

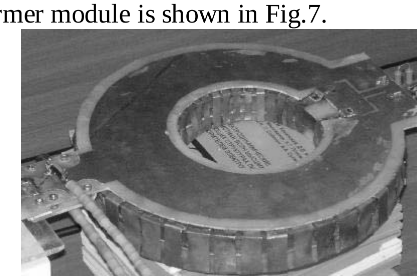


Figure 7: The model of the pulse transformer module.

The measurement shows that rise time in one module model is 300 nsec (see Fig.8).

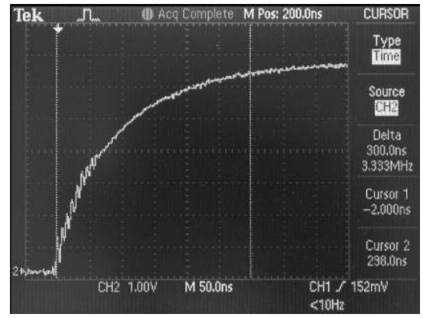


Figure 8: Measured rise time in one module model.

The whole pulse power supply is located in the oil tank with overall dimensions (LxWxH) 0.8x0.8x0.9 m and mass 350 kg.

SERVICE SYSTEMS

Vacuum system

Vacuum system includes ion pump, ion pump controller, vacuum valves, turbo pump, turbo pump controller, scroll pump, vacuum gauges and vacuum gauge controller.

Water cooling system

Water cooling system is to cool modulator, magnetron, accelerating section, circulator and load.

SF6 unit

SF6 unit is needed to fill gas part of the waveguide between the magnetron and waveguide window to improve waveguide electric strength. It includes SF6 cylinder, pressure gauge, pressure regulator and valve.

CONTROL SYSTEM

Control is PLC-based system. It controls switch on and off, keep operating regime and all needed interlock functions of the accelerator.

CONCLUSION

The presented work was done to show the module type of the building of linear electron accelerator. This approach allows to build serial design of the applied accelerators with wide range of accelerated electron beam parameters. Using accelerating section of different length with the same bunching part and RF power sources of different power we can get wide range of electron energy.

Using modular approach of the IGBT modulator building we can get wide range of the output voltage from 40 kV for the magnetron to 160 kV for klystron [2].

REFERENCES

[1] A.A.Zavadtsev, A.A.Krasnov, I.S.Kuzmin, N.P.Sobenin, A.I.Fadin. Accelerating Structure of 10 MeV Electron Linac. Proceeding of RUPAC 2004.

[2] V.T.Gavich, A.A.Zavadtsev, D.A.Zavadtsev, A.Krasnov, N.P.Sobenin. RF Power Supply System of Industry Irradiation Facility. Proceeding of RUPAC 2004.