CONCEPTION OF ELECTRON LINAC WITH REGULATION OF MAIN PARAMETERS FOR RADIATION TECHNOLOGIES

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Abstract

The conception of the electron linac with variation of main parameters is presented. This accelerator has next main regulated parameters: kinetic energy is 1.0 -10.0 MeV; average power is 1.0 - 5.0 kW. The accelerator consists of some independently driven 700 MHz one-gap accelerating cavities. The opportunity of any change of accelerating RF field along system length can be realized by means of the regulation of field phase and RF power simultaneously in every cavity. This accelerator can find applications in the many radiation technologies, for example: environmental applications, technology of materials, food irradiation.

1 INTRODUCTION

The electron accelerators are widely used for solving of various applied problems in industry and medicine. The most widely used radiation complexes are based on electron accelerators with energy from 1 up to 10 MeV [1-3]. As a rule, the accelerator is designed for a constant beam energy, or energy tuning can be available in the narrow range (no more than several tens percent). Various methods of particle energy adjustment in low energy electron accelerators are known. The energy adjustment can be done by means of current loading of the accelerating structure [4]. The other solution of the problem is applying of two-section accelerator [5]. The disadvantage of the first method is the impossibility to change particle energy more than by 40-50%. The second method of energy adjustment gives the possibility to decrease energy by two and more times with respect to minimum value, which results in significant reduction of beam current. It is due to electron outcome from a relativism at its decelerating and, as a result, there appears particle loss on accelerating structure walls.

There is a possibility of creating universal radiation complexes with smooth and deep adjustment of accelerating particle energy and with high efficiency of RF power use [1,6]. In this case linear accelerator consists of a large number of independently controlled cavities. The problem of the given work is the calculation and development of the electron accelerator with deep and smooth tuning of particle energy - from 1 up to 10 MeV and average beam power from 1 up to 5 kW.

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2 MAIN CHARACTERISTICS OF THE ACCELERATOR

Beam energy – 1 to 10 MeV
Injection energy - 50 keV
Pulse beam current - not less than 250 mA
Average power of beam - 5 kW
Maximum total power of microwave sources - 5 MW
Duty factor - 0.002
Amount of bunching cavities - 2
Amount of accelerating cavities - 18

3 SYSTEMS AND COMPONENTS OF THE ACCELERATOR

3.1 Accelerating Cavities

The comparison of various geometry of accelerating cavities was conducted. The preference should be given to a cavity of the cylindrical form. It is simple in manufacturing, has rather high shunt impedance. The magnitude of electrical field over-strengthening on edges of gap is insignificant, that ensures good electrical strength of the cavity.

The choice of operational frequency of cavities is determined by characteristics of generators used. Because of executed comparative analysis of various types of generating and amplifying valves the operational frequency is selected equal to 700 MHz.

The geometric sizes of a cavity are selected from a condition of deriving an acceptable shunt impedance on the main frequency and possibility of reducing a coupling impedance on maximum frequencies at the expense of a diminishing the transient time factor. For selected frequency the diameter of a cavity is about 33 cm, the cavity length was selected equal to 11 cm. Its shunt impedance makes 3.2 MΩ, and its own Q-factor $2.6 \cdot 10^4$. When the length of a cavity is increased shunt impedance can be enlarged up to 4.0 MΩ. In an construction of a cavity offered the power input is carried out through an inductive loop from a feeding coaxial waveguide.

The executed evaluations of amplitudes of high order modes excited by beam in resonator, have shown, that their influence over beam dynamics can become noticeable if currents exceed 400 mA, that is higher than design parameters of the accelerator.

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3.2 RF Generator

Cost of the RF generator largely determines cost of the accelerator as a whole. It is known, that in frequency band of 400-700 MHz it is most expedient to use generating valves with electrostatic control - triodes. At higher frequencies (700-900 MHz) klystrons have some advantages. Each cavity should be fed by power about 0.5 MW. The accelerator consists of 18 identical blocks, each of them including accelerating cavity and feeding generator. The accelerator can also consist of 9 blocks, each containing two accelerating cavities. This variant allows to accommodate the generator and high-Q load (cavity). The economical and technological comparison of the different variants has shown, that the set of valve generators of an average power has smaller cost, than that of high-power generator. The comparison of the production of serially valves has shown, that it is expedient to stop the choice on self-oscillating and amplifying triodes ensuring work at frequencies up to 750-800 MHz. Later, as it was specified above, the choice was made for the benefit of operational frequency of 700 MHz.

3.3 Devices of the Generator and Cavity Accommodating

Various kinds of insulating devices are known: ferrite insulators, hybrid junctions, etc. In selected frequency band there are no inexpensive ferrite insulators or circulators ensuring transfer of an pulse power of 1 MW and more. In this connection the authors consider the variant of hybrid junction of the generator and cavities accommodating. The connection of two identical cavities with outputs of the hybrid junction ensures compensation of waves, reflected from the cavities, and removes them into an absorbing load. In this variant the accelerating system consists of pair cavity chain, each of which feeds from the separate generator. Gradually in the long run while developing by the industry of ferrite insulators with satisfactory performances, the creation of such an accelerator is possible, in which each cavity feeds from the generator.

3.4 RF Feeder Elements

Hybrid junction is an important element of the RF feeder, therefore significant attention to the choice of its type, account and designing was given. As criteria of the comparison there were used: necessary electrical strength of the device, small dimensions, adaptability to manufacture. There are two most acceptable variants. First – magic tee in strip-coaxial performance [5], or magic tee having waveguide input arm and three output arms in coaxial performance [5]. These devices are compact enough.

The phase shifter and attenuator work at a power level which is not exceeding 10-20 W, therefore high electrical strength is not demanded to these devices. From the variants considered the preference is given to the phase shifter of trombone type, and as an attenuator the device containing a plate, covered by an absorbing material and inserted inside the coaxial feeder will be used.

3.5 Electron injector

Basic element of an injector is a three-cathode electrode element with an indirect heating (electronic bombardment of the main cathode). The broad adjustment of temperature of the main cathode is possible. Accelerating voltage is up to 50 kV. An emission current is up to 0.6 A. The duration of work up 10^4 hours without changing the spiral and if it is possible without opening to atmosphere (up to 100 openings and more). There is optics of the Pierce. The diameter of an electron beam in crossover is 2 mm.

3.6 Focusing system

The focusing system is selected from the condition of construction simplicity and possibility of posting beam with no losses through the whole accelerator at the minimum energy of 1 MeV. In the simplest case it will be periodic sequence of axial - symmetrical of magnetic lenses located in gaps between cavities. It is also possible to use a system of a reversible focussing, when the fields of adjacent lenses have an opposite direction.

4 CHOICE OF AN OPTIMUM METHOD OF BEAM ENERGY ADJUSTMENT

The increasing of beam energy is from 1 up to 10 MeV and will be realized by sequential tuning on of accelerating modules (generator +cavity) from the first to the eighteenth. At the given beam current and selected energy gain in each accelerating cavity with the help of modifications of frequency and coupling coefficient a minimum cost of the external generator power is ensured. In passive cavity (when input power is equal to zero) by appropriate choice of frequency shift fulfillment of stationary condition is achieved, when the particle energy does not change in the cavity.

5 RF COMPONENTS SYSTEM OF THE ACCELERATOR RESEARCH RESULTS

Experimental testing of the modeling results of separate components of the accelerator was conducted. The main attention was given to a research of the accelerating cavity characteristics. The breadboard model of a cavity was made of copper. The diameter of resonator was 33 cm, the length 11 cm. The following characteristics of the device are obtained: resonance frequency 702.2 MHz, own Q-factor $2.2 \cdot 10^4$, shunt impedance 2.9 MΩ. The measurements conducted in frequency band of 690 - 2400 MHz, have shown, that the amplitudes of high order modes do not exceed 2% from the main (E_{010}) mode. The coupling closed loop was used to cavity excitation, the plane of which is parallel to an cavity axes. While closed loop shifting the cavity coupling coefficient with a feeder

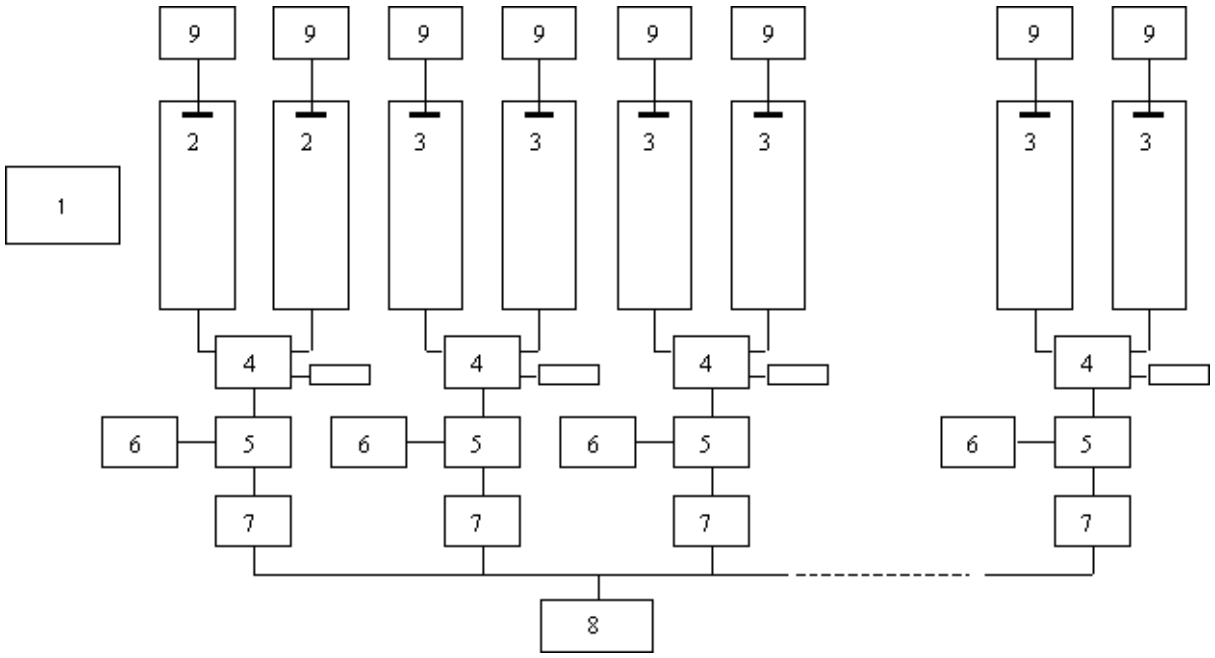

Figure 1. Block scheme of the accelerator: 1 – electron injector, 2 - one-gap cavity buncher, 3 – one-gap accelerating cavity, 4 – hybrid junction, 5 – amplifier, 6 – modulator, 7 – phase shifter, 8 – master generator, 9 – cavity resonant frequency tuning element

is changed, and in the range of the value of a coupling coefficient from 0.5 up to 4.0 resonance frequencies displaces by 6 MHz. The installation of specific operational frequency can be achieved by the master generator frequency tuning or by cavity resonance frequency tuning.

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6 THE ACCELERATOR BLOCK DIAGRAM

The conducted research of the accelerator components and account of its operation characteristics have allowed to develop its block diagram, which is represented in Fig.1. The electron source is an electron gun. The two first cavities bunch the particles and accelerate them up to 1.0 MeV. Nine identical blocks, each of which includes two cavities and power amplifier, are intended for beam acceleration up to final energy. The excitation of amplifiers is carried out from the master generator. For this purpose the coaxial feeder is laid on from the master generator, in which the adjustable closed loops of coupling with power amplifiers are fitted. At the each amplifier input there are installed the phase shifter and attenuator. Such an arrangement allows to adjust amplitudes and phases of fields in accelerating cavities independently. The focusing lenses are installed between cavities. The output equipment ensures necessary irradiation field forming for products and materials processing.

7 CONCLUSION

The conducted calculations and model tests enable to make a conclusion about the possibility of accelerator designing with deep energy adjustment, ensuring realization of radiation technological processes.

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8 REFERENCES

[1] A. Hyder, M. Rose, A. Guenter, NATO ASI Series, Series B: Physics, Vol. 178, 1988 Plenum Press, New York, p.709-715

[2] B. Bogdanovich, A. Nesterovich, Beams and Plasma at Accelerator High-Frequency Fields, Moscow, 2000 (in Russian)

[3] S. Korenev, Proc. of the XX International Linear Accelerator Conference, 2000, vol. 1, p.645-647

[4] D. Shoffstall, W. Gallagher, IEEE Trans. Nuclear Science, 1985, v. NS-32, N5, p. 3169-3171

[5] V. Vikulov et al, IEEE Trans. Nuclear Science, 1979, v. NS-26, N3, p.4292-4293

[6] A. Shalnov, B. Bogdanovich, A. Nesterovich, Proc. of the XVIII International Linear Accelerator Conference, 1996, vol. 1, p.172-174