THE PROTON AND ION LINEAR ACCELERATOR ILU-9

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Abstract

The pulse RF ion linear accelerator of ILU-9-type is described. The accelerator is intended to use for various radiation-technological processes and investigations. The parameters of the accelerator and the ion beam measured during the tuning are given.

INTRODUCTION

The proton and ion linear accelerator ILU-9 was designed basing on experience gained in BINP SB RAS, Novosibirsk, during development, production and operation of single-resonator pulse radio frequency linear accelerators of ILU series. This machine is purposed for work as an injector for accelerating complexes for research, technological and medical application. The pulse duration required for synchrotron injection is 5 mks, energy – more than 2 MeV.

Figure 1: View of the vacuum tank and resonator inside it, RF generator is removed

Views of the ILU-9 vacuum tank and resonator inside it and RF generator with power input loop are shown in Fig.1 and Fig.2. Distinctive features of this machine are simplicity of design, convenience of operation and reliability at long work. The machine is designed to accelerate ion beams with Z/A = ½ up to energy 5.8 MeV per charge unit in the main channel, the other options are the possibility of proton beams acceleration up to energy 2.9 MэB and ion beams with Z/A = 1/3 acceleration up to energy 8,7 MeV per charge unit at injection energy of 70 keV. After passage of magnetic turning system and acceleration in the additional channel the particles energy makes: 9.8 MeV per charge unit for ions with Z/A = ½, 14.7 MeV per charge unit for ions with Z/A = 1/3 and 4.9 MeV for protons.

Figure 2: RF generator with power input loop

ACCELERATING STRUCTURE

The design of the accelerator is shown in Fig.3. The machine is based on radio frequency (RF) resonator performed as an antiphase excited quarter wave asymmetrical shielded pair line. The upper sides of the double lines 1 are shortened by a disk 5, the other ends of the lines are loaded by capacity of drift tube 2. The main accelerating channel contains eight accelerating gaps and six drift tubes having the lengths determined by acceleration rate.

Lengths of accelerating gaps in the initial part of acceleration path are calculated so that the first gap transit angle is close to π at the given electric field tension. The drift tubes' lengths are growing along the beam line due to increase in particles' speed as passing the accelerating gaps with the acceleration period of $\beta\lambda/2$ (β=v/c, λ – length of a wave of the resonator) so the accelerating rate is decreasing. To keep the constant accelerating rate with the same accelerating electric field tension in all accelerating gaps it is necessary to increase the voltage on the last accelerating gaps by increasing their length. This problem is solved by a proper choice of double line design values.

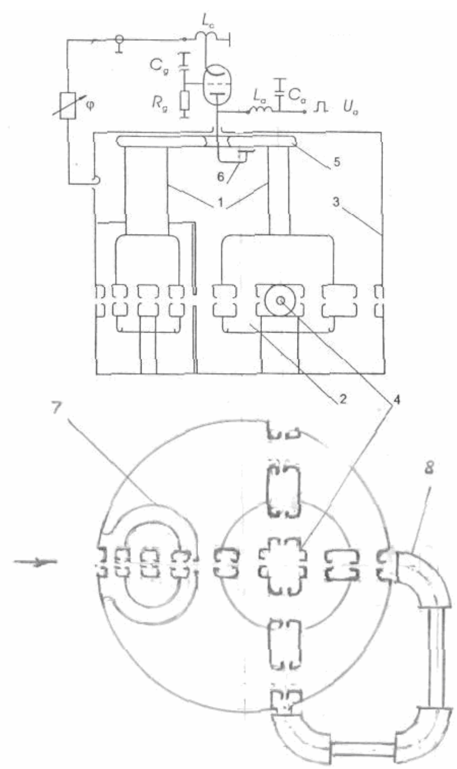

Figure 3: The basic circuit of the ILU-9 accelerator:1 - double lines; 2 – drift tube; 3 – outer drum of the resonator; 4 – drift tube; 5 – shortening disk; 6 – RF power input; 7 – screen; 8 – turning magnets.

Diameter of the resonator 3 is 1100 mm, height - 920 mm. The first conductor of a line having diameter of 156 mm is shifted from resonator's axis on 345 mm, the second having diameter of 75 mm is shifted on 153 mm in the opposite side. Length of accelerating gaps in the initial part of beam line is 40 mm, the last accelerating gaps have length of 73 mm. The beam channel aperture is 20 mm, diameter of drift tubes is 120 mm.

Drift tubes of the first conductor of a line are surrounded by the additional screen 7. This design of the shielded double line provides practically the same acceleration rate along the beam line at average electric field tension of 150 kV/cm for acceleration of ions with Z/A = ½. The RF voltage amplitude is 0.6 MV on drift tubes of the first conductor and 1.1 mV on the tubes of the second conductor.

The accelerator ILU-9 has an additional acceleration line 4 with three drift tubes. It can be used after ion beam turning through an angle of 270˚ by means of turning magnets 8. The use of the additional accelerating line allows to increase the ions energy without additional expenses on accelerating system. Drift tubes of the additional acceleration line are connected to the second conductor of a line and the external screen so that their longitudinal axis is perpendicular to the axis of the main beam line.

The line with drift tubes is insulated from the external screen and the constant bias potential of -7 kV is applied to them for suppression of high-frequency resonant discharge (multipactor). The bias voltage is applied to the point of minimum RF voltage in the middle of shortening disk 5.

RF GENERATOR

The resonator has eigen frequency of 42,66 МГц, Q-factor of $7*10^3$ and effective shunt resistance about 30 MOhm/m. The pulse power of 1.2 MW is required for its excitation to the working energy level.

The resonator is excited by the single stage autogenerator on triode GI-27AM having the external feedback through the resonator. The generator is placed directly on the resonator and is connected to it by means of an inductive loop 6 without an intermediate feeder.

The cathode contour is performed as RF ferrite autotransformer (see Fig.3) with turn ratio k = 1:2 to match the triode input resistance of 150 Ohm with cable impedance of 75 Ohm. The ring ferrite core is wound by one turn coil. The middle of a coil is connected directly to the cathode input of the triode, and the whole coil is fed by the voltage from the feedback loop through the phase changer. The cathode contour is tuned by the external magnetic field imposed on the ferrite core. The magnetic field is created by an electromagnet, the cathode contour is placed between its poles. The advantages of this design are: decrease in overall dimensions of cathode contour, matching of low input resistance of triode with feedback line impedance and the contactless contour tuning to the resonator's frequency is performed.

The RF generator operates in pulse mode. Duration of anode voltage pulse is up to 600 мкс, pulse repetition rate is 0.1÷50 Hz.

BEAM ACCELERATION DYNAMICS

The accelerating electric field distribution along the axis of the main channel drift tubes was calculated using error integral approximation. This distribution was checked using the probe body method, the measurement results are shown in Fig. 4. The electric field distribution data was used to calculate the beam dynamics. For the pulse beam current up to 10 mA the ion beam energy spread makes < ±0,25 %, calculated emittance – 10^{-3} cm*rad. The longitudinal and transverse beam stability is provided by the accelerating field due to variable phase focusing.

First time the ion beam was successfully accelerated in ILU-9 in 1991 with the drift tubes made of aluminum. The plasma proton source with the cold cathode was used.The proton beam was accelerated to the energy of 2.9 MeV, pulse current was 2 мA, pulse duration was 5 mks, pulse repetition rate was up to 50 Hz. The energy spread was < ±0,25 % at an angle of bite of 40˚.

The aluminum drift tubes did not permit to further increase the accelerating voltage up to the values required for acceleration of heavier particles. The drift tubes were replaced by the ones made of copper.

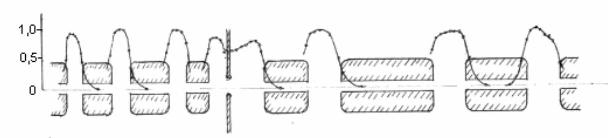

Figure 4: Accelerating field distribution along the axis of main channel drift tubes.

After replacement of the drift tubes and modernization of the feedback loop the H_2^{+1} ions beam is accelerated. The ions are generated by the plasm-arc discharge source.

The voltage on the accelerating gaps of the drift tubes was raised up to design size, practically twice exceeded the maximum voltage achieved during the acceleration of protons. The accelerated ion beam was fixed by the semiconductor detector after passage through a titanium foil having thickness of 35 micron. At last stage of experiments the accelerating voltage was raised in 1.5 times greater than the design value that allows to accelerate beams of ions with Z/A = 1/3.

CONCLUSION

For the nearest future we suppose to carry out measurement of phase volume and spectrum of the accelerated beams of protons and H_2^{+1} ions and also to study the possibility to accelerate the carbon ions C_{12}^{+4} using a carbon ion source along with the appropriate increase of voltage on the accelerating gaps of drift tubes without change of accelerating channel design.

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