PROTON ACCELERATION IN RESONANCE STRUCTURES EXCITED BY ELECTRON BEAMS

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Abstract

Experimental results on proton acceleration in resonant RF structures excited by the modulated electron beam are presented. The electron beam moving in z-direction is used for proton focusing as well. Two versions of the proposed proton accelerator with different power levels of electron and proton beams are considered.

Introduction

The first works devoted to Electron Beam Focused Ion (EBFI) Linac - a new field of accelerator physics - were published in the fifties-sixties [1,2]. The idea of EBFI-Linac is the following one. A space charge of the electron beam, moving in z-direction in the ion linac, compensates the defocusing strength of the accelerating field and the ion space charge. The electron beam is hold by longitudinal magnetic field. The necessary value of this magnetic field is much less (20-30 times) as compared with the ion focusing without electron beam. On the one hand, electron beam creates the symmetrical transverse focusing forces which are especially important in the low ion velocity range. On the other hand, there is not any limits on autophasing in the EBFI-Linac. These attractive features defined the advantages of the EBFI-Linac at the first stage. At the second stage of the EBFI-Linac development it has been realized the excitation of the accelerating structure (AS) by the focusing electron beam [3,4]. Generator function of the electron beam permits to get rid of RF generator, feeders and tuning systems.

Two versions of the EBFI-Linac with different power levels of electron and ion beams have been developed. The first version was proposed and designed in the Moscow Engineering Physics Institute and the second one with the higher energy parameters - in the Moscow Radiotechnic Institute.

The Accelerating Structure Excitation

The most complicated problem is providing for an effective interaction of the electron beam with AS at the necessary RF mode. First, for this purpose it was proposed to use non-modulated electron beam, but, as experiments showed, it is insoluble because of the great number of RF modes in AS.

In the first version the preliminary bunching of the electron beam has been realized by means of the two gaps spiral resonator [5]. The buncher design has possibility to bring up negative high potential to the resonator, that permits to reduce the necessary drift space and to raise maximum current of the modulated electron beam. The buncher can operate with the feeding from RF generator or without it on the self-excited mode.

In both versions as AS for the EBFI-Linac it has been chosen the kind of interdigital structure, which was invented in the Moscow Engineering Physics Institute [6] (Fig. 1a).

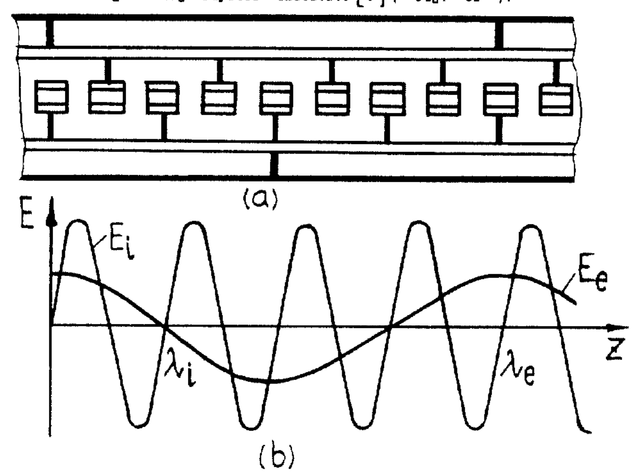

Fig. 1. Accelerating structure (a) and electric field harmonics (b).

An important feature of this structure is polyharmonical distribution of the electric field in it. Besides the slow harmonic of the electric field which is responsible for the ion acceleration and defined by the drift tubes arrangement period, there is the fast harmonic arising due to the grounding supports of the longitudinal vibrators. The fast harmonic can be used for AS excitation. Both harmonics are shown in Fig. 1b.

The First Version of Linac

Design

The first version of EBFI-Linac is illustrated in Fig. 2.

The ion beam is produced in the duoplasmatron 1. The focus of the electrostatic lens 2 is situated in the plane of the electron gun annular cathode 3, made of lanthanum hexaborid. A weak magnetic field in the cathode region is used to ensure the adiabatic focusing of the electron-ion beam in the compressive section [7], where the beam diameter decreases from 30 mm to 8 mm. Then the electron - ion beam enters the electron buncher 6 operating on the self-excited mode. In the accelerating structure 7 the modulated electron beam interacts with the fast harmonic of the

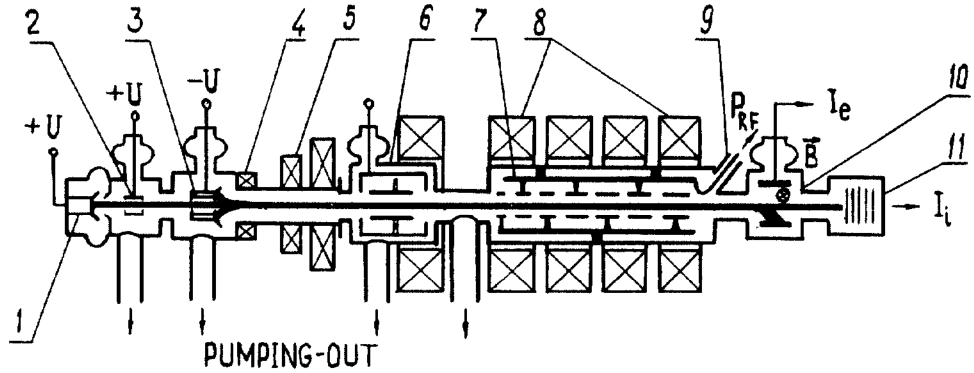

Fig. 2. Schematic drawing of the first version of EBFI-Linac.

electric field and excites RF oscillations which are accelerating for the ions. The frequency of the electron beam modulation is chosen close to the resonant frequency of AS at the necessary RF mode. The electron beam is focused by the pulse magnetic coils 8. RF field amplitude is controlled by the coupling element 9. Deflector 10 with the magnetic field applied along X-direction separates the ions and electrons. The electron beam is deflected in Y-direction to hollow cylindrical collector and, at the same time, the ions move along Z-direction toward the foil spectrometer 11.

The EBFI-Linac main parameters are given in the Table 1.

Experimental Results

Fig. 3 shows the energy distribution of the protons accelerated in EBFI-Linac with electron beam excitation (solid) and with only external RF power supply (dashed).

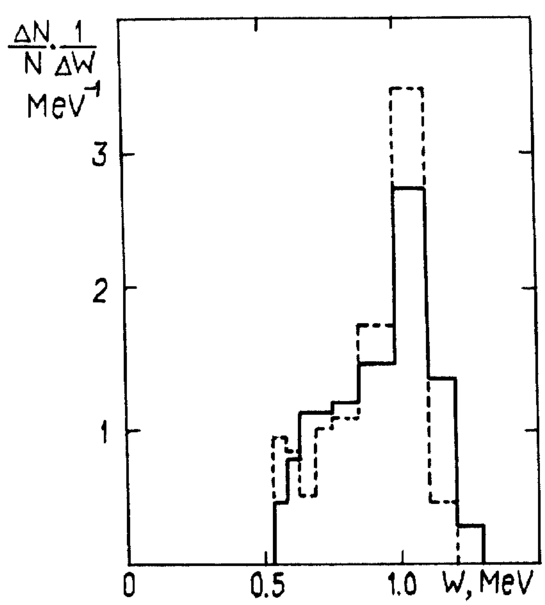

Fig. 3. Energy distribution of protons accelerated in the first version of linac with electron beam excitation (solid) and with only external RF power supply (dashed).

It should be noted, that both distributions are in a good coincidence.

Table 1. The EBFI-Linac main parameters.

Parameter	Version 1	Version 2
Proton beam		
injection energy, keV	70 - 80	220 - 240
final energy, MeV	1.05	0.8 - 1.3
current, mA	5 - 10	8 - 60
diameter, mm	15	-
Pulse length, μs	50	1
Repetition frequency, Hz	1	-
Electron beam		
energy, keV	60 - 80	170 - 200
current, A	20	200 - 800
Magnetic field, T	0.15 - 0.25	0.25 - 1.5
Accelerating resonator		
resonant frequency, MHz	148.2	185
Q-factor	1450	1000
shunt impedance, $M\Omega/m$	42	-
RF power level, kW	50	1000
diameter, m	0.2	0.3
length, m	0.74	0.8
aperture, mm	15	30

The Second Version of Linac

Design

The second version of EBFI-Linac was developed to verify the possibility of the accelerated proton beam current increasing. The ion source, electron gun and electron buncher were done as shown in Fig. 4. The explosive cathode 1 is produced in form of graphit tube with the sharp edge. Magnetic field isolation of the cathode-anode gap is provided by the pulse magnetic coils 2,3. The magnetic field is grown from 0.25 T on cathode to 1.5 T on anode. Accelerating voltage applied to the cathode is 170 - 200 keV, the electron beam current is 200 - 800 A, the electron beam pulse length is 2 - 3μs. The electron beam diameter decreases from 37 mm on the cathode to 15 mm in the anode hole.

The electron beam buncher 4 is a two-gap resonator [8] with the drift tube 5 mounted on two adjustable $\lambda/4$ co-axials 6. In the drift tube length calculating the effect of the space charge slow wave phase velocity slowing-down [9] was taken into account because of the very high value of electron gun perveance and commensurability of the electron beam current with the critical vacuum current [10].

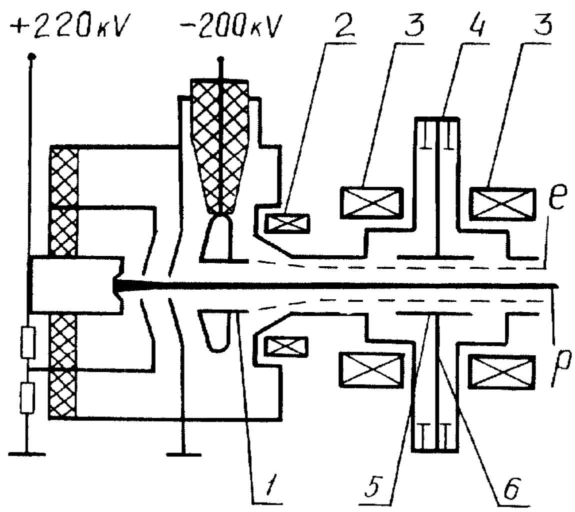

Fig. 4. The electron-ion injector and the electron buncher of the second version of linac.

The optimum drift tube length 8 is about 21 cm for frequency 185 MHz. The drift tube apperture is 32 mm.

The ion source, AS, separator and ion beam spectrometer are of the same type like in the first version of linac, but some parameters were changed (see Table 1).

Experimental Results

When the buncher operating on the self-excited mode at the frequency 185 MHz (closed to AS resonant frequency), the 20% modulation of the electron beam was achieved. The buncher self-excitation takes place when the electron beam current is in the range 300 - 500 A and the energy is near 200 keV. Dissipated in AS RF power level is up to 1 MW.

The accelerated ion current, measured by Faraday cup, screened by one or two aluminium foils with the thickness 11μm, is equal to 60 mA for energy range above 0.8 MeV and 8 - 10 mA for energy range above 1.3 MeV. The energy calculated is 1.5 MeV. The signal oscillograms are shown in Fig. 5.

Conclusions

The investigations carried out and long work done have proved the possibility of the EBFI-Linac creating with combined electron beam focusing and generator functions.

The absence of the external RF power supply permits to simplify the accelerator design, reduce the cost and make it more reliable.

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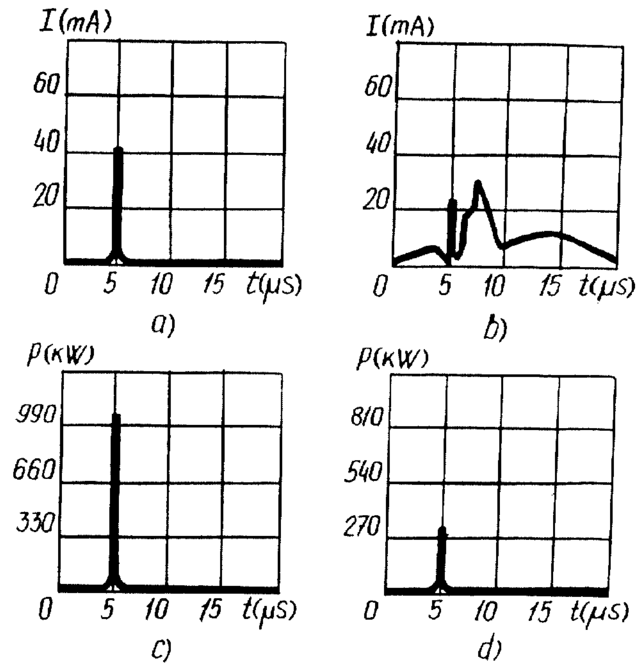

Fig. 5. The signals oscillograms showing (a) accelerated protons current on the Faraday cup screened by foil, (b) proton current on the foil, (c) accelerating resonator RF power pulse, (d) the electron buncher RF power pulse.

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