COLLECTIVE ION ACCELERATION BY THE SPACE-CHARGE WAVES IN INTENSE ELECTRON BEAMS

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Abstract: Two collective methods of ion acceleration are investigated in the experiments with 0,2 - 0,5 MeV, 0,5-1,5 kA, 4 - 10 mcs intense relativistic electron beams (IREB). The first method is based on using electromagnetic fields excited in goffered structure by modulated electron beam. IREB modulation is carried out by means of two quarter-wave coaxial cavities. The other method is based on an application of slow cyclotron waves, which are excited in the beam by passive H-cavity. Ions are injected towards electron beams and are accelerated up to the energy of 0,2-1,5 MeV. Collector plasma is used as an ion source.

Introduction

It has been shown that collective ion accelerators may be based on different methods utilizing IREB [1]. There are many experimental results on collective ion acceleration. The best results have been obtained in the experiments with nanosecond IREB [2,3,4], but for many applications it is needed to accelerate ion beams having microsecond or more duration. Two collective methods are proposed to obtain such beams. One method is based on invention by Belikov, Khijnyak and Lymar and was realized experimentally [5]. But this experiment was performed with the low current electron beam. Another method was proposed by Sloan and Drummond [6], but there is no publication about an experimental realization of such collective ion accelerator.

The present report describes the experimental installation and first results of experiments on the collective ion acceleration by microsecond IREB. Two methods were investigated. According to the first method ions were accelerated by electromagnetic fields, excited in a goffered structure by modulated IREB. The other method was based on utilizing of slow cyclotron waves [6], which were excited in the IREB by a passive H-cavity.

The Experimental Installation

The experiments were carried out on the installation [7] which is shown schematically in Fig.1. The istallation consists of the main systems as follows: a Marx - Arkadyev generator; a high intensity electron diode (6); a magnetic system (5); a vacuum chamber (3) containing removable structures (2,4); an electron beam collector (an ion source) (1) ; a diagnostic chamber (7) with a Faraday cup (8). The installation has the following parameteres: diode voltage up to 0,9 MeV; diode current of 1 - 5 kA; pulse duration of 6 - 10 mcs; maximum magnetic field induction up to 2T.

Acceleration of ions by a modulated electron beam propagating in a goffered structure

The modulated IREB propagating in a goffered structure excites an electromagnetic wave train. The wave phase velocity is given by

$$V = f * l ,$$

where f is the modulation frequency and l is the goffered structure period.

These waves have an attractive feature for an ion acceleration that the phase velocity can be made very small.

Experiments were carried out with 1 - 2 kA electron beams. The electron energy was varied from 0,2 to 0,6 MeV. The beam modulation was performed by means of two quarter-wave passive coaxial cavities having the length of 0,4 m.

The IREB produced in the diode was guided into a drift tube containing two cavities and the goffered accelerating structure (see Fig.1). The last one had 43 periods with the total length of 1 m. The cavities were excited at the natural frequency of (190 ± 3) MHz. The field in the second cavity reached an amplitude of 120 kV.The beam current RF oscillations

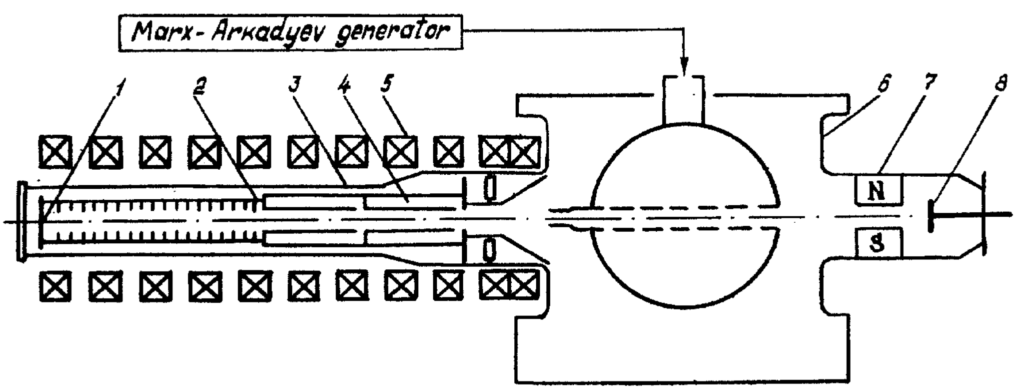

Fig.1 Scheme of the experimental installation with two passive cavities (4) and a goffered structure (2) .

appeared 0,5 mcs after the pulse beginning and lasted for 0.5 – 4 mcs. The disappearence of oscillations may be explained by an RF breakdown occured in the cavity. The beam current modulation up to 100% was a result of the interaction between the IREB and RF cavity fields.

The IREB bombarded the collector and produced a plasma which was a source of counterstreaming ion beam in these experiments. The ions were preaccelerated by a negative potential of the IREB and had initial energy of 40 – 60 keV. Then the ions were accelerated in the goffered structure due to an interaction with the fields excited by the modulated IREB. The accelerated ions were collected in the diagnostic chamber after passing through the cavities and the diode region.

A typical oscillogram of an ion current signal is shown in Fig.2. The first peak was detected only in experiments with the goffered structure. It was absent if the goffered structure was replaced with a smooth drift tube.

The velocity and energy of ions were determined by means of the time-of-flight method. The calculation was based upon a suggestion that accelerated ions were protons. Indeed the first peak (see Fig.2) was much greater (about 0.1 A) if the collector material was polyethylene and was much smaller if the collector was graphite or stainless steel. The accelerated protons had energy of approximately 200 keV.

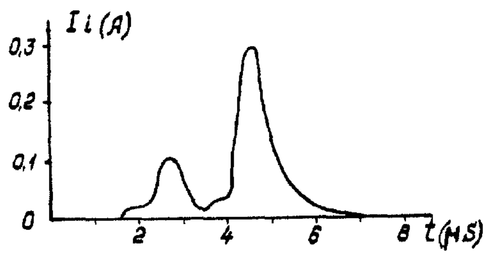

Fig.2 Ion current measured by the Faraday cup.

The second peak was much greater than the first one and occured at that time when the cathode and collector plasmas began to fill the vacuum channel. These ions were accelerated to much lower energy and it was difficult to identify the accelerating mechanism.

Collective acceleration of ions by the cyclotron waves in a counterstreaming electron beam

The autoresonant method for controlled acceleration of protons [6] is based on utilizing slow cyclotron waves with negative energy grown on an electron beam propagating in a vacuum and confined by an axial magnetic field. A preliminary experiment was carried out at Austin [8]. The procedure was to pass the IREB through a double-helical resonant excitation section driven by a powerful RF generator. The cyclotron waves were excited but an acceleration of ions was not performed. We also carried out experiments on exciting cyclotron waves in an IREB but our experimental installation contained neither helical resonant structure nor an RF generator. The cyclotron waves were excited by a passive H-cavity and had an amplitude of 10 MV/m [9].

The present experiments were carried out on the same installation described in the previous section (see Fig.1) with the novel structures installed in the vacuum chamber as it is shown in Fig.3.

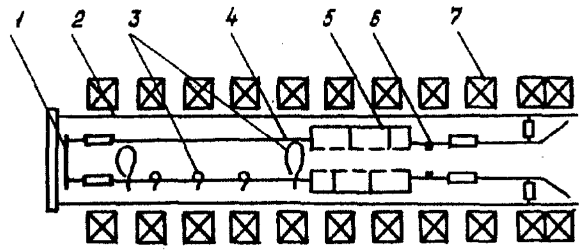

Fig.3 Scheme of experimental structure for a collective ion acceleration: 1-IREB collector, 2-vacuum chamber, 3-magnetic loops, 4-collective acceleration section, 5-H-cavity, 6-diaphragm, 7-coils of the magnetic system.

The H-cavity had a length of 0,34 m and was loaded by drift tubes which were installed with period of 2 cm and an aperture of 4 cm. The collective acceleration section had the length of 0,78 m and inner diameter of 0,1 m and was immersed in an axial magnetic field varied adiabatically from a maximum level of 2 T at the collector (ion source) location down to 0,5 – 1 T at the end of the H-cavity. The spatial variation of the guide-magnetic field provided the synchronism between the cyclotron wave phase velocity and the velocity of accelerated ions.

The next results were obtained in the experiments. The IREB propagating through the cavity excited powerful RF oscillations. The frequency of RF oscillations was 667 MHz and corresponded to a natural one of the cavity. The active losses power reached a level of 0,5 MW. Cyclotron waves were generated on the IREB as a result of interaction between the IREB and RF cavity fields. The ions emitted from the collector plasma were accelerated by cyclotron waves. Fig.4 shows the oscillograms of a diode voltage (a), an IREB current (b), a detected signal (c) from a magnetic loop located in the acceleration section (see Fig.3), ion beam currents on the first foil of a stopping range spectrometer (d) and on the second foil (e).

The first peak of a loop signal (see Fis.4,c) appeared at the front of IREB current and corresponded to a generation of cyclotron waves on the IREB. The generation process lasted for about 0,5 mcs. The second signal from the magnetic loop appeared after 4 – 6 mcs and probably was a result of interaction between the IREB and a plasma filling the structure by that time.

The ion current signal consists of two parts (Fig.4,d). The ion current corresponding to the first part reached 3 – 5 mA for a graphite collector and 5 – 10 mA for a polyethylene one. The delay time of the first peak corresponding to the

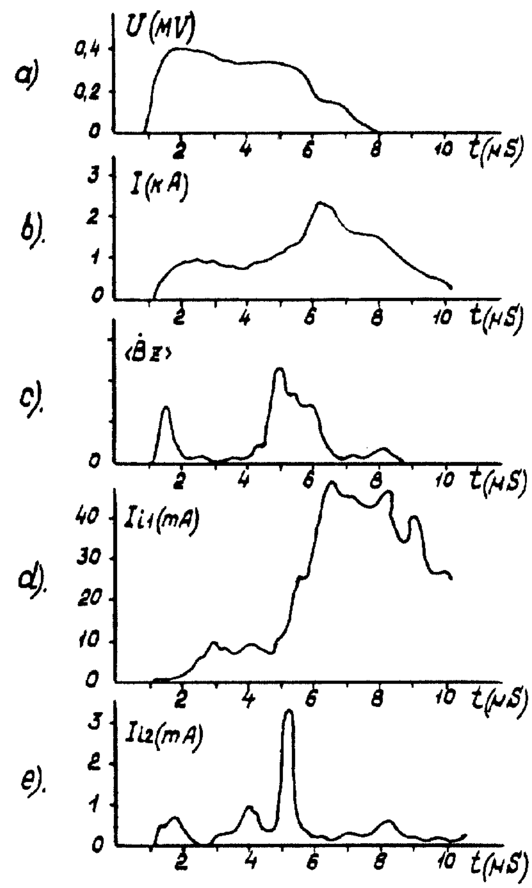

Fig.4 Typical oscillograms of a diode voltage (a), an IREB current (b), signal from magnetic loop (c) and ion beam currents (d,e).

beginning of the generation process was 0,2 - 1,5 mcs . Taking into consideration the values of the delay time, it is possible to calculate the energy of the accelerated ions. If the ions are protons the energy is about 1 Mev. The second part of the current was more intense. It was correlated with the second peak of the loop signal.

The energy of ions was also measured by the stopping range spectrometer. The ion current measured at the second spectrometer foil is shown in Fig.4,e. Thickness of the first foil was 4,8 mg/sm^2. Proton energy in this case is 1,1 - 1,4 MeV. So it was defined that the ion beam had RF structure with frequency corresponded to that of the excited fields.

Calculation of proton dynamics in the acceleration section and the cavity showed that the protons are accelerated up to 0,5 MeV in decreasing magnetic field and then are accelerated up to 1,5 MeV in the cavity gaps.

Test experiments have been carried out. The beam was thrown at the diaphragm installed upstream the cavity. In this case the first peak of the ion current corresponding to the acceleration by the cyclotron wave field disappeared. The same effect took place when a conducting tube (diameter 36 mm) was installed inside the cavity.

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References

[1] V.G.Gapanovich, and A.A.Kolomenskii "Acceleration of ions in the direct high current electron beams", Izvestia VUZ'ov, No 10, pp 59 - 82, 1979.

[2] A.A.Plutto, P.E.Belensov, E.D.Korop et al, "Acceleration of ions in the electron beams", Sov. JETP Lett, vol.6, No 6, pp 540 - 541, 1967.

[3] J.S.Luce "Neutrons and radioisotopes produced by collective acceleration", Annals of N.Y. Acad. Sci, vol.251, No 217, pp 217 - 233, 1975.

[4] C.L.Olson, C.A.Frost, E.L.Patterson, J.P.Anthes and J.W.Poukey, "IFA-2 collective ion accelerator experiments," IEEE Trans. Nucl. Sci., vol.NS -32, No 5, 1985.

[5] V.V.Belikov, A.G.Lymar and N. A. Khijnyak, "Acceleration of ions by modulated electron beam," Sov. JTP Lett., vol.1, No 13, pp 615 - 617, 1975.

[6] M.L.Sloan and W.E.Drummond "Autoresonant accelerator concept," Phys. Rev. Lett., vol. 31, No 20, pp 1234 - 1237, 1973.

[7] G.I.Batskikh, L.N.Kazanskii, A.A.Kuzmin, R.A.Meshcherov et al, "High current electron accelerators for investigations on the relativistic UHF-electronics and collective acceleration methods," in Proceedings of the IX All-Union Conference on Particle Accelerators, 1985, vol. II, pp 157 - 162.

[8] E.Cornet, H.A.Davis, T.P.Starke et al "Cyclotron wave generation and phase velocity control in intense relativistic electron beam," Phys. Fluids, vol.24, No 11, pp 2039 - 2048, 1981.

[9] A.M.Markeev, R.A.Meshcherov, P.V.Mironov, A.A.Savenko and V.D.Sajin, "Generation of accelerating fields in intense electron beams," in Proceedings of the XI All-Union Conference on Particle Accelerators, 1989, vol.II, pp 91 - 94.