LINEAR AND CIRCULAR ACCELERATION OF THE ELECTRON-ION BEAMS

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The interest to a problem of acceleration of the eletron-ion beams increases at present. Linear accelerators with such beams which energy is more than $n\times10$ MeV ($n=1\div10$) can be effectively used for nuclides transmutation by means of proton or X-rays received during electron bombarding of some target [1]. Linear accelerators with beams which energy is less than $n\times10$ MeV can be used as injectors in ion accelerators based on the collective methods [2]. Accelerators with beams which energy is less than $n\times10^{-2}$ MeV can be used for ion implantation with simultaneous neutralization of their positive charge by means of negative electron charge. It prevents microcircuits from discharge and damage [3].

The advantages of circular electron beams in proton synchrotrons were showed in the theoretical work [4] ,and the posibility of practical realization of such systems was demonstrated at the ion accelerators with electron rings [5]. These advantages consist in higher radial and vertical ion orbit stability and higher ionization by electron beam during the first acceleration stage.

In this paper various schemes of linear and circular accelerator with electron-ion beams are considered. The results reseived on accelerator with electron-ion beams, designed and performed in Moscow Engineering Physics Institute ,were used as the basis of this suggestions.

Linear accelerator may be performed as it is shown on Fig.1(a). The RF structure contain identical toroidal cavities 1 connected to RF amplifiers 2 and invertor 3. Each cavity has two RF lines connected to common generators 4 which frecuencies are f_e and f_i accordingly. These generators are united by mutual control system 5. The filters 6 and 7 (higher and lower frequencies) are included in each RF line between cavities 1 and amplifiers 2 to prevent ifluence of one generator on another. This structure can work in various regimes, that is on standing or on travelling wave with two frequencies and on standing wave with one frequency and travelling wave with the other frequency. Tipical distribution of electrical RF field strength on the axis for various frequencies at the fixed moment for standing waves are shown on Fig.1(b,c). Dotted line shows the main harmonics for these cases. Theoretical analysis showed that if the electron beam is focused by solenoids and ions are focused by negative electron charge, and if electron velosity υ_e is considerably more than ion velosity υ_i, the phase instability of electrons can arise in case if phase electron oscillation frequency is divisible to the frequency of "ion" wave.

It may be cited for example the next variant: $\upsilon_i=0.0146$ c (c-light velosity); $\upsilon_e=0.9$ c; $f_i=150\times10^6$ Hz; $f_e=50\times10^6$ Hz. Analysis showed that the stable movement of ions and electrons simultaneously is possible if the beams parameters are the next: $eE_e=eE_i=26$ MeV/m, $\varphi_{se}=\varphi_{si}=20^\circ$, where $E_{e,i}$ - the electrical harmonics amplitudes for electrons and ions accordingly; $\varphi_{se,i}$ - the synchroneous phases. The potentional gradient is defined as $dV_{e,i}/dz = E_{e,i}\sin\varphi_{se,i}$ (where e is the particle sharge).

The main difficulty in circular ion accelerator with electron beam is the turning of two beams. Authors suppose that this problem may be desided in a device shown on Fig.2. It contain two plates of the electrostatic deflector 1, placed in circular vacuum chamber on insulators 2. They are connected to high voltage sourse 3. Both ends of each plate are connected to secondary winding of transformer 4. Radial electric field created by means of sourse 3, and vertical magnet field created by means of currents I_M, provide simultaneous turning of electron and ion beams. The particle

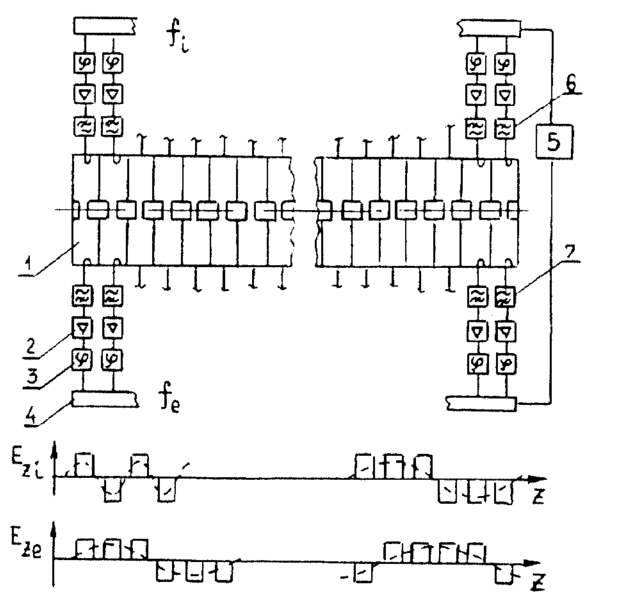

Fig.1. Scheme of the linear electron-ion acceleration structure (a) and a momentary distribution of electrical field which accelerate ions (b) and electrons (c).

movement analysis was performed by equations

$$\vec{F}_{cp\,i,e} = q_{i,e}\left\{\vec{E}+\left[\vec{v}_{i,e}\times\vec{B}_{\perp}\right]\right\}, \qquad (1)$$

$$\left|\vec{F}_{cf}\right|_{i,e} = m_{i,e}\, v_{i,e}^{2}\, R^{-1}, \qquad (2)$$

where $\vec{F}_{cp}$ and $\vec{F}_{cf}$ are the centripetal and centrifugal forces; m -particle mass; q -its charge; indexes "i" and "e" correspond to ions and electrons; R -radius of the beam axis in deflector. It turned out that if the movement directions of both beams are the same, and $v_e > v_i$ or if the directions are opposite, and $v_e < v_i$ the strength must be directed to the centre of circulation, and it is necessery to perform the next conditions:

$$E_r = \frac{v_e v_i}{R\left|v_e - v_i\right|}\left(\frac{v_i m_i}{q_i} + \frac{v_e m_e}{q_e}\right), \qquad (3)$$

$$B_{\perp} = \frac{1}{R\left|v_e - v_i\right|}\left(\frac{v_e^2 m_e}{q_e} + \frac{v_i^2 m_i}{q_i}\right). \qquad (4)$$

If the directions of the beams movement are the same and $v_e < v_i$ or if the directions are opposite and $v_e > v_i$ the strength must be directed from the centre and it is necessary to perform the conditions:

$$E_r = \frac{v_e v_i}{R(v_e + v_i)}\left|\frac{v_i m_i}{q_i} - \frac{v_e m_e}{q_e}\right|, \qquad (5)$$

$$B_{\perp} = \frac{1}{R(v_e + v_i)}\left(\frac{v_e^2 m_e}{q_e} + \frac{v_i^2 m_i}{q_i}\right). \qquad (6)$$

The circular accelerator may be performed from such deflectors and linear RF strictures, described before (Fig.1(a)). RF accelerator may consist of linear ion accelerator structure and linear electron accelerator structure, each part is exited on various frequencies.

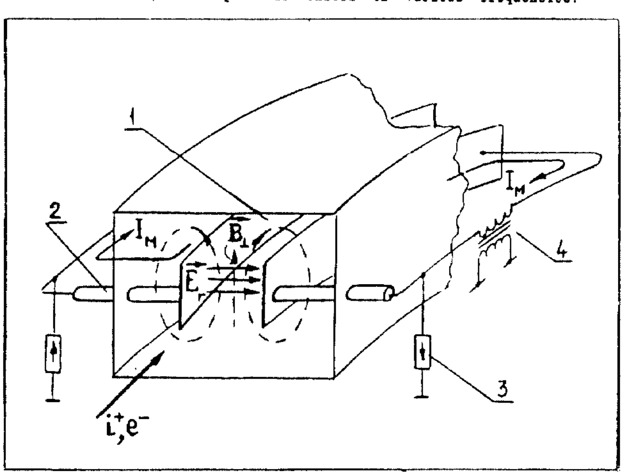

Fig.2. The point view of the electron-ion deflector in circular accelerator.

The focusing of electron beam in deflector may be performed by means of special configuration of magnet field, that is suitable currents in each deflector plate, as it is in synchrotrons. The ion beams may be focused by negative electron charge or by special configuration of electric field between deflector plates.

Described scheme may be useful for heavy ion acceleration. Their energy may surpass some hundred MeV, and the ion beam current may be higher than in other accelerators.

The accelerators dimensions may be decresed by inreased strength $\vec{E}$. It is possible because currents create "magnet insulation" regime, when field emission electrons can not move between deflector plates and cause the discharge.

It may be cited for example a variant, when the beams directions are the same, and $v_i = 5\times10^{-2}$ c (c- the light velocity); $v_e = 0.5$ c; $B_\perp = 3\times10^{-2}$ T; $E_r = 5\times10^{6}$ V/m, $R = 0.5$ m.

If these directions are opposite, and $B_\perp = 0.25$ T, the radius R must be equal to 5×10^{-2} m. If the beams directions are the same, and $v_i = 0.8$ c, $v_e = 0.2$ c, $B_\perp = 0.054$ T, radius R must be equal to 125 m, and if these directions are opposite, and $B_\perp = 0.09$ T, R must be equal to 24 m.

So, linear and circular acceleration may be performed by means of known and improved acceleration systems, and the possibilities of physical experiments and beam technology may be essentially extended.

References.

1 . E.Dikova. Reseach and Development of Partioning and Transmutation Technologies. Express Information, N 19 (1599), 1989, p.p.10-12.

2 . N.A.Abramenko,etc. "Linear resonance proton accelerator on energy 1 MeV with acceleration field generation by means of focusing electron beam." Questions of atom science and technique. Ser."Phys. experim. technique.", vol.2(23), p.p.48-50, 1985.

3 . M.D.Gabovich, N.V.Pleshivtsev, N.N.Semashko. Ion and Atom Beams for Termonuclear Synthesis and Technology. Moscow, EAP, 1986, p.p.29-30.

4 . G.I.Budker, "The Relative Stabilised Electron Beam." Atom energy, vol.1, p.p.9-14, 1956.

5 . V.P.Sarantsev, E.A.Perelshtein. Collestive Ion Acceleration by Means of Electron Rings. Moscow: AP, 1979.