TWO BEAM INDUCTION ACCELERATOR FOR GENERATION OF NEUTRONS AND GAMMA RADIATION

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A new scheme of a proton or electron accelerator with a pre-buncher of a driving electron beam and an accelerator of main and driving beams is presented.

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1. INTRODUCTION

Two projects of the electron-positron collider, CLIC at CERN and NLC at SLAC, and collective proton accelerator at Kharkov PTI assume to use the two beam method of acceleration [1,2,3]. In the both collider projects the high-energy main beam and the driving electron beam are accelerated in different accelerators. The RF power is generated by the driving e-beam when it passes special electrodynamic structures. Then this power is fed to the accelerating section of the main accelerator.

The driving e-beam can be used to excite the main accelerator cavities directly without the excitation of the electrodynamic structure in the driving channel. The driving and main beam pass one the same structure, which bunches the driving beam and accelerates the main beam (of protons or electrons). The particles of the main beam are accelerated wherein the accelerating electric fields are excited. Seeing the one mode regime of the accelerator-buncher structure can be realized all parasitic modes might be suppressed [4] including modes of beam-beam instability. Therewith, if an acceleration of the driving electrons by external field is used, the efficiency of the conversion of their kinetic energy into the energy of the main particles can be close to 1.

The accelerated driving beam allows generating the very high RF power, which is inaccessible now for modern powerful klystrons. Future accelerators will require such a level of the RF power, which is limited by output and input windows and mode transformers of the RF sources and the main accelerating modules. Such units are absent in the proposed scheme of the two beam accelerator.

2. DESIGN OF THE ACCELERATOR D

A scheme of a two beam accelerator for a generation of neutrons and gamma radiation is shown on Fig. 1. Particles of the main and driving beam move in opposite directions. An electron gun produces a driving beam. The driving electron beam is pre-bunched by e-buncher. To decrease an oscillation amplitude of the driving electron bunches the longitudinal dimension of this bunches have to be matched with the structure of the accelerator-buncher [5]. The dimensions of bunches have to be close to the equilibrium dimensions in the accelerator-buncher structure. The equilibrium bunch dimensions are determined by amplitude of the RF field excited by the driving beam and a value of the detuning of the accelerator-buncher cavities relative to the buncher frequency $\xi=2Q_0\,\Delta f/f$, Q_0 being the quality factor of the unloaded cavities.

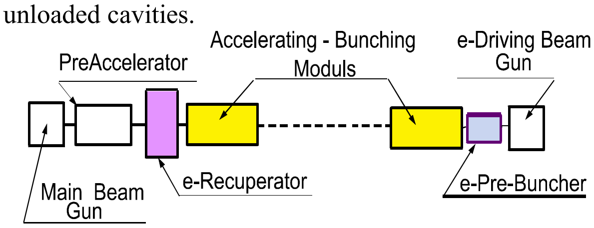

Fig. 1. *Scheme of the two beam accelerator with the excited by an electron beam copper cavities*

Energy loss, which driving electron beam puts out to excite the main beam loaded cavities, is recovered during its acceleration in an induction electric field of the accelerating-bunching modules. The required induction field is far less than the accelerating field because the phase of the induced voltage of the cavities is close to π /2 [6].

$$E_{ind} = E\cos\varphi_d = \frac{E}{\sqrt{1+\xi^2}},\ \xi>>1,$$

where $\phi_d \cong \pi/2$ is a locking phase of the driving electrons. So a low gradient induction accelerator allows one to produce a high accelerating gradient for the main beam.

Synchronism of the main beam particles and the excited field take place when a structure period of the accelerator-buncher is equal to ([5,6])

$$L = k\lambda\,(\beta_d^{-1} + \beta_m^{-1})^{-1},$$

where k is integer, λ - wave length, β_d and β_m - relative velocity of the driving and main particles.

An average accelerating gradient for the main beam depends on an intensity of the driving beam I_d, a quality factor Q and a shunt impedance R of the loaded by main beam cavities, a relative detuning of the cavities ξ and a number of cavities per meter.

For example, the average accelerating gradient of a two beam induction linac with cylindrical cavities is equal to ([5,7])

$$E = \frac{1-\eta}{\sqrt{1+\xi^2}}\cdot\frac{\rho_0 I_d}{\pi\delta}\cdot\Psi\ ,$$

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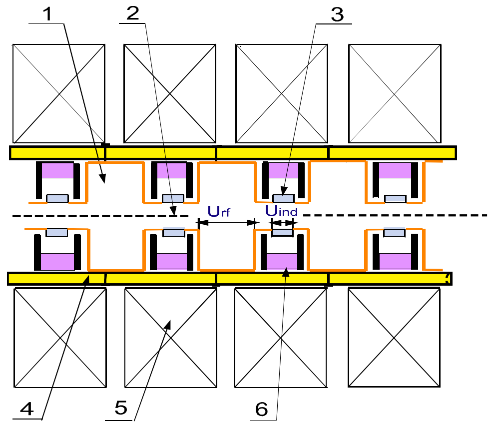

Fig. 2. *Scheme of the two beam induction linac. e: 1-RF cavity, 2-drift tube, 3-RF absorbing insertion, 4-ceramic tube, 5-induction core, 6-focusing system*

where $\rho_0 = \sqrt{\mu_0/\varepsilon_0} = 120\pi$ is the wave-forming resistance of free space, δ – skin-layer , η – efficiency of the energy conversion from the driving electron beam into the main beam and

$$\Psi = (\beta_d^{-1} + \beta_m^{-1} + \frac{h}{L}\frac{2\pi}{j_0})^{-1},$$

h – accelerating gap, j_0=2.4 is the first root of the Bessel function J_0.

Maximal accelerating gradient of the two beam accelerator is defined by a shunt impedance of unloaded cavities and achieved at a small value of the main beam. But the efficiency of the energy conversion is minimal in this case because the more energy of the excited field goes to expense in a wall of cavities. At a high value of the main beam current the efficiency grows but more intensive driving beam is required to keep the high accelerating gradient. Herewith there are not any more over-voltages in the RF mode transformers, vacuum windows and other RF transmission units.

The counter-propagating main beam is produced by an electron or proton gun and a pre-accelerator if the main beam is the proton beam. To reduce the relative value of the energy loss in the cavities of the accelerator-buncher and increase the efficiency of the beam energy conversion the average current of the main beam should be increased up to:

$$I_m = \eta \frac{I_d}{\sqrt{1+\xi^2}}$$

At such current of the main beam the efficiency of the beam-beam energy conversion will be equal to the chosen value of η [5,7]. The utilized driving beam is debunched and recuperated to increase a total efficiency of the two beam accelerator.

A scheme of the accelerating-bunching module is shown on Fig. 2. An electrodynamic structure of the module contains a row of RF cavities 1 and drift tubes 2 with RF absorbing insertions 3. To avoid excitation of parasitic modes of oscillation, the technique of distribution suppression of parasitic waves is used [4]. Together with the parasitic modes suppression, the resistive insertions distribute an electric voltage of the induction module. The electrodynamic structure is installed inside a ceramic accelerating tube of the induction section.

The main and driving beams are focused by a magnetic field of permanent magnets 6. The focusing of the main proton beam is increased by a space charge of the driving electron beam. The repetition rate of the focusing pulses of the counter-propagation electron bunches is much higher than the frequency of transverse oscillation of the protons and proton focusing is determined by average current of the driving beam I_d . The proton oscillation frequency in the potential well of the electron beam with current I_d and radius r_d is equal to [6]:

$$\varpi_p = \frac{c}{r_d}\sqrt{\frac{1}{2\pi}\frac{e\rho_0 I_d}{Mc^2}}$$

Equilibrium radius of the proton beam with emittance ε_p is equal to:

$$r_p^2 = \frac{\varepsilon_p \beta_p r_d}{\pi}\sqrt{2\pi\frac{Mc^2}{e\rho_0 I_d}}$$

Intensity of the driving and main beams determines the accelerating gradient for the main beam, the efficiency of the driving beam – main beam energy conversion and the amplification of the main accelerating gradient as compared with the induction system gradient. For example, to produce the main accelerating gradient equaled 50 MeV/m in accelerating-bunching module with induction gradient equaled 1 MeV/m, at 70% efficiency of the beam-beam energy conversion $(\eta = 0.7)$, the ~300 A driving beam current and ~4 A main beam current are required. At emittance $\varepsilon = 100 mm \cdot mrad$ the proton beam equilibrium radius will be equal to $r_p \approx 0.1\sqrt{\beta_p r_d}$ [r (m)].

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