ACCELERATING STRUCTURE WITH ALTERNATING-PHASE AND PERMANENT MAGNET FOCUSING

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Proposed is the method for particle motion stability in linacs based on a combination of phase-alternating and longitudinal magnetic focusing using permanent magnets made of neodymium-iron-boron alloy. Presented are the results of the accelerating structure calculations.

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INTRODUCTION

The means to enhance stability of proton beam focusing in a linear resonance accelerator with alternating-phase focusing are under study at the Institute of Plasma Electronics and New Acceleration Methods of NSC KIPT. It is well known that there exists a very strong connection between longitudinal and transverse particle dynamics in linac accelerating channels with alternating-phase focusing. As a result, effective beam emmittance increases leading to current loses and activation of linac structural units [1].

To increase the effect of proton beam focusing by RF electric field and, therefore, to decrease an amplitude of particle radial oscillations in an accelerating channel, it is proposed to apply an external magnetic field in gaps between drift tubes [1].

There are several ways to produce a longitudinal magnetic field in accelerating gaps between axial-symmetric drift tubes. One of them is to introduce insertions made of ferromagnetic material with high saturation induction into drift tubes (Fig. 1). A sequence of the drift tubes with ferromagnetic core forms a magnetic circuit where magnetic field is concentrated in accelerating gaps between the tubes. To lessen dissipation of magnetic induction flux along the drift tubes, it is important to ensure the ferromagnetic material is not in the saturation mode and possesses high relative magnetic permeability μ_r.

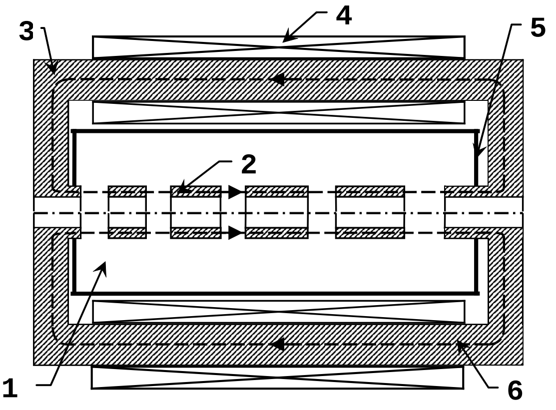


Fig. 1. Section with a combination of phase-alternative and magnetic focusing: 1 – resonator; 2 – drift tubes; 3 – magnetic conductor; 4 – solenoid; 5 – resonator bottom; 6 – magnetic induction flux line

Thus, the drift tubes have two functions: on the one hand they serve as electrodes with voltage difference to accelerate charged particles, and on the other hand they serve as magnetic poles for additional particle beam magnetic focusing. Fig. 1 illustrates a conceptual version of a section with combined alternating-phase and magnetic focusing [1].

The magnetic circuit is formed by the drift tube sequence and the yoke system with a coil to provide magnetic flux Φ, see Fig. 1. The coil is outside the vacuum chamber with the accelerating structure.

The above design of an accelerating channel with combined focusing was named *a structure with spatially combined alternating-phase and magnetic focusing*. Such structures can be used to accelerate proton beams in low and medium energy range (up to 100 MeV).

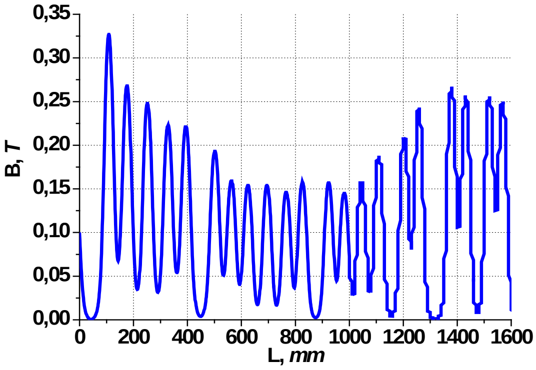


Fig. 2. Magnetic induction flux distribution along the accelerating section axis

However, the mentioned magnetic field generation procedure is effective only for a short accelerating structure due to strong magnetic field damping at the structure middle (Fig. 2).

A substantial advance has been recently achieved in the development of permanent magnets made of neodymium-iron-boron (NIB) alloy. This article presents some results of studies of an accelerating structure that implements a combination of phase-alternating and based on permanent NIB magnets magnetic focusing. Such magnets could be placed inside drift tubes of the structure. Thus the magnetic flux damping along the accelerating section does not develop.

DEVELOPMENT AND STUDIES OF THE ACCELERATING STRUCTURE WITH CONBIMED PHASE-ALTERNATING AND MAGNETIC FOCUSING BASED ON PERMANENT MAGNETS

Fig. 3 presents a general view of the acceleration structure that provides acceleration from 2.08 up to 3.86 MeV. A CH-structure serves as a resonator. To ensure mechanical stability of the structure, each drift tube has two holders diametrically opposed (cruciform-like mount).

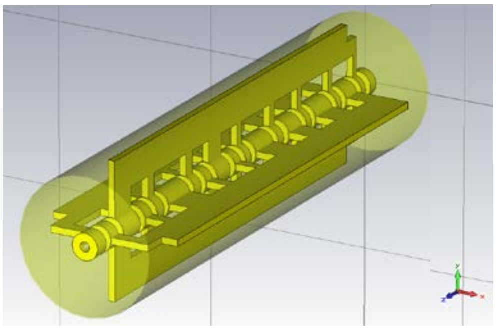


Fig. 3. General view of the accelerating structure

The structure contains 19 accelerating gaps (20 drift tubes). The outer diameter of the structure is 40.0 cm, operating frequency 201.25 MHz, excitation power 915 kW, Q-factor comes to 13000. The drift tubes measure 1.5 and 4.0 cm in inner and outer diameter, respectively. A NIB magnetic insertion is placed inside each drift tube with opposite orientation of magnetic poles in the adjacent tubes.

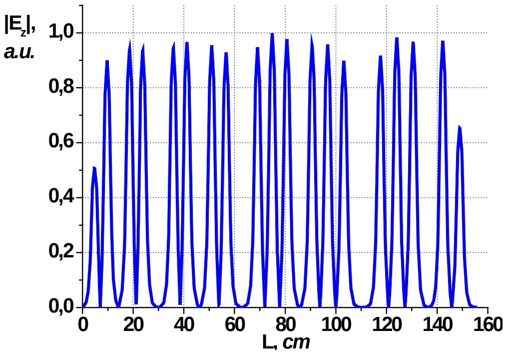
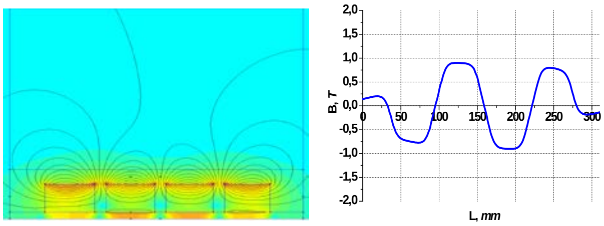


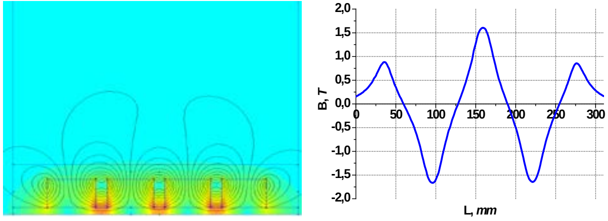
Fig. 4. Electric field distribution along the structure axis

Average amplitude of rf electric field in the gap center runs as high as 108.8 kV/cm (Fig. 4) making magnetic lens focusing ineffective for particle motion stability. Thus, to ensure reasonable stability of particle motion it is better to take advantage of phase-alternating focusing. Hence a combination of magnetic and phase-alternating focusing assures particle motion stability in the structure.



a *b*

Fig. 5. a – magnetic field lines by longitudinally oriented magnets; b – magnetic induction distribution along the structure axis



a *b*

Fig. 6. a – magnetic field lines by radially oriented magnets; b – magnetic induction distribution along the structure axis

Basically, a magnet can be magnetized in two major directions, namely, through its thickness (here we call it transverse or radial orientation) or its length (a longitudinally oriented magnet).

Fig. 5,a and Fig. 6,a depict magnetic line distribution in radially and longitudinally oriented system of four magnetic units respectively. Axial distribution of magnetic induction is presented in Fig. 5,b and Fig. 6,b. It is worth to mention that magnetic insertions in radially and longitudinally oriented systems are of equal volume. As is obvious from the plots, magnetic induction in the system with radially oriented magnetic insertions exceeds magnetic induction in the system with longitudinally oriented magnets by factor of 1.5.

Besides, it is worthy of note that the behavior of induction distribution along the axis in the case of radial magnetic orientation differs from the case of longitudinal one. In the former case induction distribution reaches its maximal magnitude in the middle of each gap while in the latter case the maximum is observed in the center of each drift tube. And since the magnetic field is almost zero in the gaps, gap electric strength increases [2].

It is believed that radially oriented magnetic insertions provide stronger focusing than longitudinally oriented magnets. This suggestion is supported by the results of numerical simulation of particle dynamics. Fig. 7 shows the dependence of output current on input one for three options, namely, longitudinally and radially oriented magnet insertions, and without external magnetic field.

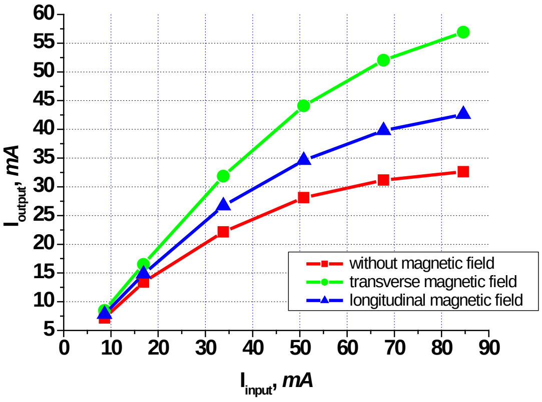


Fig. 7. Dependence of output current on input current

As Fig. 7 suggests, magnetic focusing increases the upper limit of current accelerated.

SUMMARIES

It has been shown that adding magnetic focusing yields higher output current. Magnetic focusing could be realized by magnets made of NIB alloy. The radial magnetic orientation is preferable.

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УСКОРЯЮЩАЯ СТРУКТУРА С СОВМЕЩЕННОЙ ПЕРЕМЕННО-ФАЗОВОЙ И МАГНИТНОЙ ФОКУСИРОВКОЙ НА ПОСТОЯННЫХ МАГНИТАХ

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Предложен метод обеспечения устойчивости движения частиц в линейных ускорителях на основе комбинации переменно-фазовой фокусировки и продольного магнитного поля на постоянных магнитах на базе сплава неодим-железо-бор. Приведены результаты разработки ускоряющей структуры.

ПРИСКОРЮЮЧА СТРУКТУРА З СУМІСНИМ ЗМІННО-ФАЗОВИМ ТА МАГНІТНИМ ФОКУСУВАННЯМ НА ПОСТІЙНИХ МАГНІТАХ

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Запропоновано метод забезпечення стійкості руху часток у лінійних прискорювачах на основі комбінації змінно-фазового фокусування та повздовжнього магнітного поля на постійних магнітах на базі сплаву неодим-залізо-бор. Наведено результати розробки прискорюючої структури.