THE STRUCTURE OF THE HIGH FREQUENCY FOCUSING CELLS IN LINEAR ION ACCELERATORS

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Abstract

The versions of the high frequency quadrupole doublets (RFQD) for proton and heavy ion linear accelerators are discussed. Advantages of focusing of this type over magnetic quadrupoles lie in the simplicity of the structure and high efficiency and reliability of focusing. In the multi-gap structures, focusing periods contain a sequence of focusing and accelerating cells. The elaborated technique of the local cell adjustment provides the high acceleration rate. Various RFQD versions for the specific peculiarities of accelerating structures are discussed. Application of the RF-quadrupole doublets in the spoke cavity and CCDTL structures will allow the application of superconductive cavities for proton acceleration in the range of intermediate energies of 5-100 MeV. In the interdigital H-structures, the application of RFQDs will allow to increase the efficiency of ion beam focusing and to expand the energy range of the ions being accelerated over 10 MeV/u.

INTRODUCTION

In the ion linear accelerators the problem of the radial phase stability is solved in different ways.. Depending on the sort of the ions being accelerated, their energy range, accelerated beam intensities, requirements on the accuracy on their parameters a number of techniques are elaborated and used for providing radial and phase stability of the bunches. Among the versions of accelerating systems the principle of strong focusing with magnetic quadrupoles [1], the principle of alternating phase focusing [2, 3] in its various modifications [4-7] was used most often. Considerable success is achieved in elaboration of the beam focusing with RF-field of the RFQ [8]. This type of focusing is presently used in the most proton and heavy ion accelerators at the initial stage of ion acceleration and beam formation. A version for focusing with RF-field was proposed [9] and employed in the construction of the operating proton accelerator for 30 MeV with the pulsed beam current of about 100 mA [10]. In this construction, RF-quadrupoles having the shape of ‘fingers’ are installed on the end walls of the drift tubes bearing the potentials of opposite polarity.

In the report, the results of elaboration of effective structures of focusing periods with RF-focusing doublets for acceleration of high current beams in the range of 3-100 MeV and acceleration of heavy ions in the interdigital H-structure rated for 0.1-10 MeV/u are presented.

ACCELERATING STRUCTURE WITH RF-QUADRUPOLE DOUBLETS

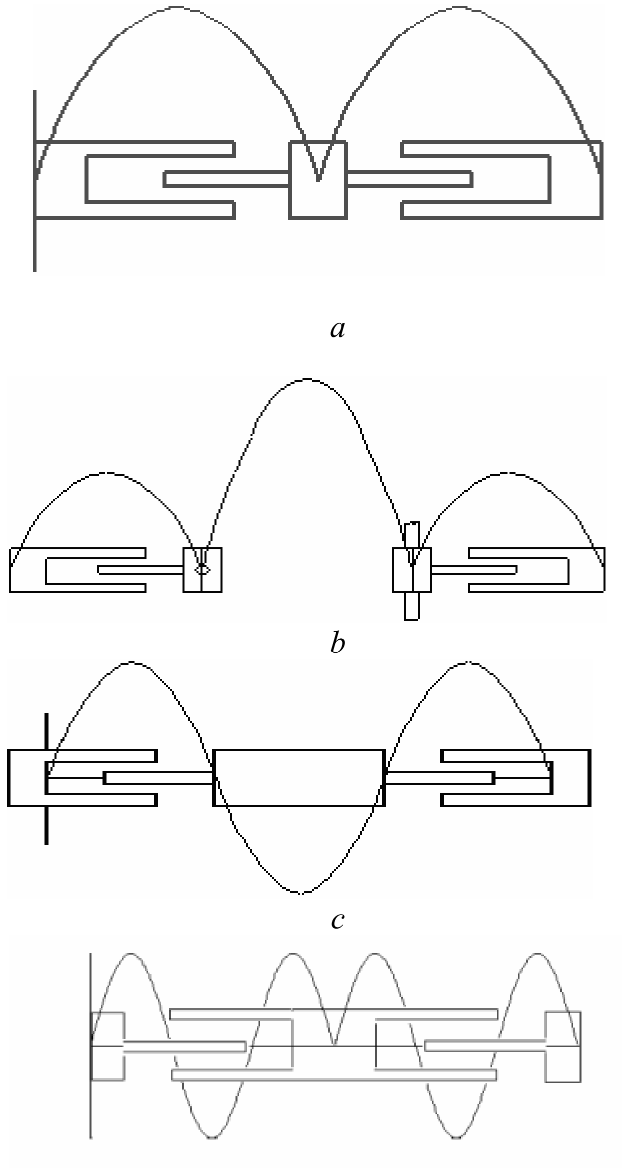
The structure of the accelerating channel of the linear ion accelerator in which RF-quadrupole doublets, RFQD, are used instead of magnetic quadrupoles in which focusing electromagnetic field is excited with RF-power. These quadrupoles are located in the structures of the same type as the accelerating ones. The difference lies in the fact that in the focusing cells the drift tubes have the ‘fingers’ on the ends in the form of cylindrical rods located along the gaps at the distance from the axis which is equal to the drift tube aperture.

A number of specific features are intrinsic to the accelerating structure that consists of a series of accelerating and focusing cells:

1. The focusing period begins and ends with cells which comprise the RF-quadrupole doublets
2. A series of accelerating cells with alternating synchronous phase is located between the focusing cells; a part of the accelerating cells is rated for effective grouping action, another part is rated for the highest acceleration rate.
3. Focusing quadrupoles are located at the sections where synchronous phases have low absolute values, and the electric field is the highest.
4. In the focusing cells, acceleration also occurs with the potential applied to the ends of ‘fingers’ and drift tubes.
5. With the constant value of the drift tube aperture and the constant distance between the ‘fingers’, the focusing field remains constant despite the growth in the particle velocities and cell lengths. This causes the drop in acceleration rate in regular multi-cell structures where difference of potentials between drift tubes is limited by the voltage between interdigit ‘fingers’ of the quadrupoles.

HIGH FREQUENCY QUADRUPOLE DOUBLETS

A few combinations of accelerating and focusing elements comprising the structure of the focusing periods and modifications of high frequency quadrupole doublets are studied.



a

b

c

d

Figure 1: The scheme of the RF-quadrupole doublets

1. A scheme of the doublet consisting of two π-cells with the total length of βλ is shown in the Fig.1. The level of the electric field acting on the synchronous particle during its traveling along the RFQD is also shown in this figure. Its construction corresponds to two-gap cavity of the spoke-cavity type of half-wave resonance with the π-structure of the field distribution in each cell. This version is also favorable for the accelerating structure of the interdigital type (interdigital H-structure). The combined arrangement of the quadrupoles with perpendicular distribution of E_x and E_y provides the maximum focusing effect. In the case of the spoke cavity, tuning the level of necessary focusing gradients may be provided by tuning the RF-power supplied to the cavity. In this case, for the interdigital H-structure for supporting the high acceleration rate a local adjustment of the focusing cells is required. The procedure of the tuning is presented below.

2. 3-gap cavity 3/2 βλ in length in which the cells containing the quadrupoles are divided by an accelerating gap (Fig.1 b). The structure is favorable for 3-gap spoke cavity in which the level of the electric field in the intermediate gap is twice higher than that in the focusing cells where the difference of potentials is limited by the distance between interdigit 'fingers'.

3. The quadrupole doublet is located in the two-gap cell of the total length of 3/2 βλ, Fig.1 c. As one can see from the figure, in the intermediate part of the cell there is a half-period of the RF-field of the opposite sign which is necessary to be shielded from the decelerated action of the filed. The structure of the focusing doublet is favorable for the CCDTL cavity.

4. One more version of the focusing doublet that consists of two cells of the total length of 3/2 βλ is presented in the Fig.1 d. Its peculiarity is using a field of the decelerating period for focusing.

RFQD WITH THE INTERMEDIATE DRIFT TUBE

Usually, the potential difference in the RFQD is sufficiently lower than in the regular accelerating cells. Therefore the first problem is creation the construction which allows dividing the total potential difference in 2, 3 or 4 gaps between intermediate drift tubes. The idea to use two-gap cells in the regular RFQ structure with 'fingers' is realized in the proton accelerator "URAL-30" [11].

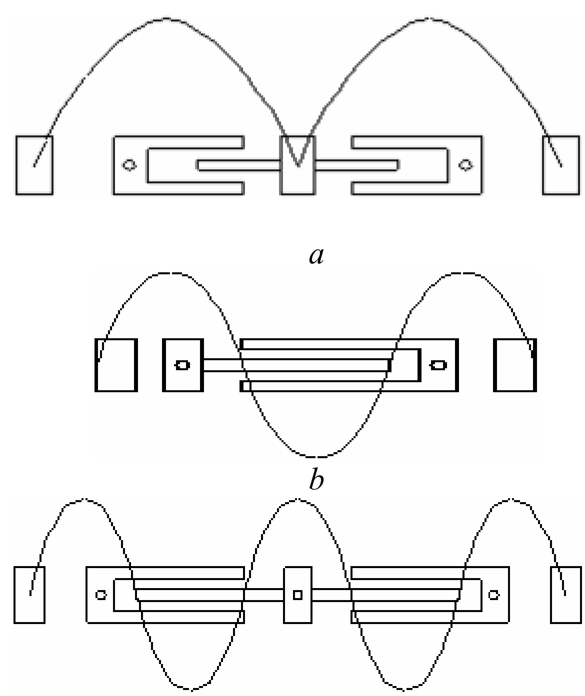


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Figure 2: The versions of RFQD structure with intermediate drift tubes

In the Fig.2 the schemes of several versions of the doublets are given. In the Fig. 2a a doublet with two two-gap cells is shown. From our viewpoint, this version is

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more effective because the application of the doublets in the structure of multi-cell allows increasing the total acceleration rate; besides that the fields in the doublet pairs are not connected in the space the axially symmetric gaps that simplifies the tuning resulting in that the axially symmetric gap can 'uptake' the excess field of the quadrupole or compensate the field deficiency.

In the Fig.2b the version of 3-gap cell with two intermediate drift tubes is shown in which the quadrupole is located in the decelerating half-period. The difference in potentials is divided between the quadrupole and two axially symmetric gaps. The version presented in the Fig.2c is even more effective. The doublet 5/2 $\beta\lambda$ with combined quadrupoles of large length ($\beta\lambda/2$) provides effective focusing and high acceleration rate.

TUNING MULTI-GAP DOUBLETS

For each of the modifications of the quadrupole doublets presented before which are included into the focusing period structure a necessity arises in the local tuning of the cells which contain RFQD. In this case, the method of alternating 'interdigity' of interdigit rods is the most effective which is used for accelerating structures of the interdigital H-type [12, 13]. For RFQD, the adjustment of the field level is carried out by alternating the azimuthal orientation of the stems of intermediate drift tubes. We have carried out experimental studies of various multi-gap RFQDs. The results have shown that with application of this method it is possible to adjust the field level in the gaps within the wide range through comparatively small alteration of the azimuthal orientation of the intermediate drift tubes.

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