MULTIPLE CHANNEL ACCELERATOR STRUCTURE WITH SPACE LATTICE FOCUSING FOR EXPERIMENTAL ION LINAC'

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Abstract

Ion beam focusing by RF accelerating fields is considered now as one of prospective ways for multiple channel resonant linac. Taking into account that rigidity of RF focusing is decreased with beam velocity increasing the problem of beam RF focusing gradient keeping by use of additional focusing electrodes called space lattices (SL-focusing) into accelerator channel gaps is considered. The results of numerical analysis of SL-focusing system of 2.2 MeV experimental ion linac that works at 148.5 MHz are presented as an example. Some aspects of RF voltage dividing to supply additional focusing elements such that to ensure RF field gradient uniformity within accelerator gaps are also considered. The RF voltage divider design is based on rectangular poly-frame H-resonator with drift tubes. Every the next rectangular frame is enclosed into the previous external frame and drift tubes as well as focusing electrodes are attached in turn to every the side frames of the resonator. The results of the structure tuning on both given working RF frequency and longitudinal field distribution are presented.

1 INTRODUCTION

Usually in linacs an ion source provided certain brightness B_{is} which upon passage through the accelerator channel degrades to a lower value B_{out} delivered to the application. The level of the beam quality degradation is caused by effects of self-fields of the bunch and geometric and optics aberrations. The self-field causes firstly by Coulomb collisions and space-charge repulsion. The degradation from ion source to exit is considerable, and an order of magnitude might be gained by reducing the effects of self-field and optics [1].

At present there is enough information that allows to compare single and multiple beam systems [2-4]. These features may be roughly summarized to the following starting points. Although a limit current in traditional single channel RF linac with beam radius R depends on many parameters its increasing appears to be possible mainly at the cost of beam radius increasing because the remaining parameters of linac are supposed to be chosen optimally. Expressions for beam current and brightness show that beam current in a traditional single channel RF linac may be increased only with beam brightness reduction as R^{-2}.
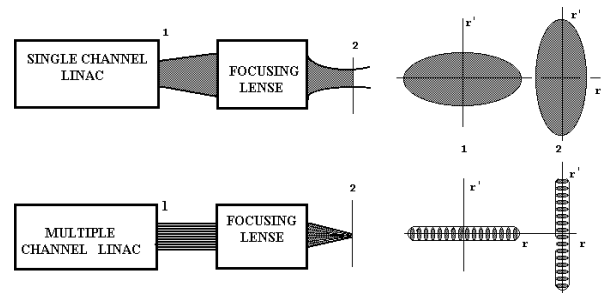

Fig.1. Comparison of single and multiple beam linacs at the same value of total current

In multiple channel systems beam increasing is achievable by increasing of initial beams number. In this case the same total beam intensity may be reached even at decreasing of beamlet radius. Now if we combine n accelerated beamlets at some stage to the common beam transversely we have relationships that are bounded parameters of summary beam with parameters of combined beams as follows (such combining may be performed by merging of beams by parallel transfer of their axes):

$$I_\Sigma = I_1 = nI_0, \qquad \alpha_\Sigma = \alpha_0 = \alpha_1 n^{-0.5}, \qquad B_\Sigma = n B_1 = B_0 /k^2,$$

Here I_Σ, α_Σ, B_Σ are the total current, divergence and brightness of combined beam in n channel system, I_0, α_0, B_0 are the same parameters for single channel matched beam, index 1 conforms to parameters of single beam system, at last k is the ratio that shows the rate of increasing of 4D transversal phase space because of its non-ideal filling with representing points of combined beams. In ideal case, when 4D phase space of total beam is equal to the sum of 4D phase spaces of combined beams, i.e. $k=1$, the brightness of the total beam is equal to the brightness of initial beam.

Let us consider now the part of the problem that deals with the realization of simultaneous acceleration of many beamlets at the initial stage of RF linac. The available technical decisions deal mainly with electrostatic [4] or RF quadruple [5] multiple beam focusing systems. In all these systems the ratio of k is rather high because of necessity of space filling with quadruple focusing elements. On the other hand, estimates show that advantages of multiple beam approach are especially noticeable if amount of simultaneously accelerated micro beams is pretty high, i.e.

some hundred or even thousands [4,6]. The multiple channel system with alternating phase focusing (APF) seemed to be an adequate one from the point of view of space filling with acceleration channels while its rigidity of focusing is decreased significantly at beam velocity increase that leads to growing of single beam radius.

The system with space lattice focusing (SLF) [6-8] seems to be an adequate decision that allows to realize in practice the system with some hundred or thousands simultaneously accelerating beams of small angular divergence at rather small value of *k*. Besides, the system with SLF is probably able to provide enough screening of separate beamlets from each other during the acceleration in common accelerating gaps by arranging of appropriate number of focusing elements within these gaps.

2 DESIGN PARAMETERS OF EXPERIMENTAL LINAC WITH SLF

The basics of SL focusing approach for RF linac were stated in [7]. Here we consider some aspects that deal with developing of accelerator and focusing channel for experimental proton linac with the main parameters that are listed in Table 1.

Table 1.

Injection energy	175 keV
Output energy	2.2 MeV
Number of accelerator channels	140
Aperture sizes for single channel	2.2x2.2 mm^2
Thickness of walls between channels	0.5 mm
Number of accelerator gaps	96
Length of structure	750 mm
Length of SL electrode	4 mm
Diameter of SL electrodes	50 mm
Maximal gradient of RF electric field	125 kV/cm
Number of SLs within acceler. period	2 ÷ 6
Working frequency	148.5 MHz

As it is seen from the table 1, the same sizes of all the accelerating and focusing elements (SL-electrodes) were chosen. Acceleration gaps between neighbour SL electrodes within every the acceleration period are also the same. The initial part (first five accelerator periods) of multiple channel SLF structure is shown schematically in fig.2.
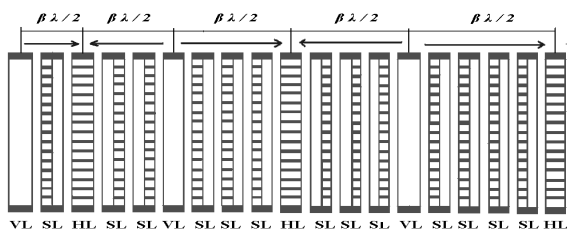
Fig.2. Structure of multiple beam array with $S = \beta\lambda$ (VL-vertical louver, SL-space lattice, HL – horizontal louver)

It is seen that vertical and horizontal louver electrodes (VL and HL) are arranged along the structure with a pe-

riod of $\beta\lambda/2$ and serve as drift tubes. The increasing a number of SL electrodes that are arranged between every the pair of louver electrodes along the structure is trained on both keeping of focusing gradient constant and screening of multiple parallel beamlets from each other at as much as possible.

In fig.3 and fig.4 longitudinal and transversal phase characteristics of individual beam channel are shown.
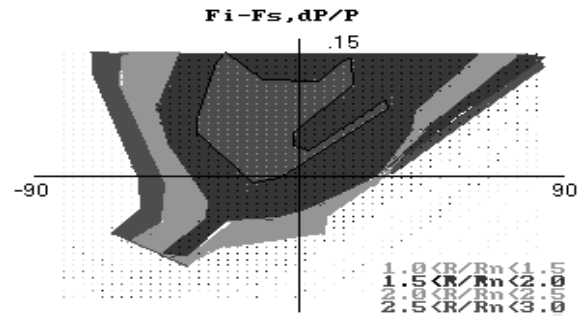
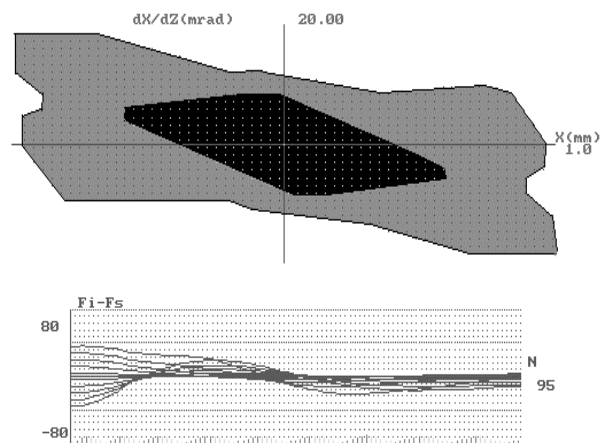Fig.3. Stability region at longitudinal phase plane for SLF channel

Fig.4. Transversal phase plane stability region (upper, grey – synchronous phase, black- overlapping of various phase ellypses) and phase trajectories for particles with various input phases (bottom)

Preliminary study of SLF features points to principal possibility to provide transversal stability for all particles independently on their input phases [7]. To increase the capture ratio for every the beamlet in the system with SLF, efforts are under way to find an effective approach for multiple channel matching. Usually an RFQ system is provided with a matching stage arranged before the main part of the structure. This procedure helps to increase the capture ratio up to 80-90%. In multiple channel structure with SLF we suppose to use multiple aperture focusing lenses may be arranged at the input of RF matching section to provide required values of initial radius and divergence for every the beamlet. The longitudinal matching of every the beamlet, i.e. adiabatic decreasing of bunch phase length from 360^0 to phase length of separatrix at the

input of the regular stage of RF structure, may be carried out by smooth increasing of longitudinal phase advance from zero to some nominal value of μ_L. The transversal matching of continuous monochromatic beamlets with RF channels may be ensured by smooth increasing of transversal phase advance (RF focusing gradients) within every the channel from zero to some nominal value of μ_T that corresponds to the input of regular acceleration stage.

3 ACCELERATING RESONATOR FOR LINAC STRUCTURE WITH SLF

The basic feature of multiple channel structure with SLF is concerned with the necessity of arrangement of some additional electrodes within accelerator gaps. It might be principally easy realize by means of insulator stems while it is hard to use in practice because of their low surface electric durability. So the SL accelerating and focusing system is assumed to be furnished with RF divider that helps to reach uniform RF field distribution within the accelerating gaps at inserting some SL electrodes between drift tubes[8]. Let us consider the system of SL electrodes arranged according to that presented in Fig.5.
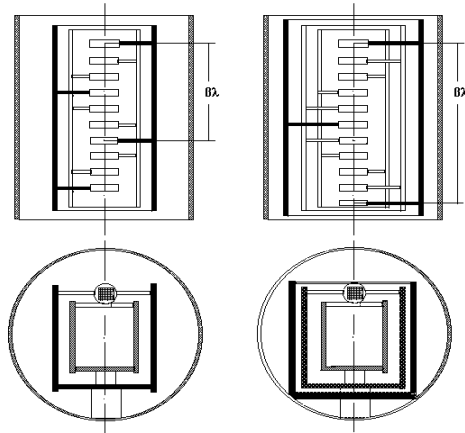

Fig.5. Two-frame (left) and three-frame(right) H resonators with SLF

For example, to arrange two SL electrodes within the acceleration period of $\beta\lambda/2$, let us consider the RF divider that includes two-frame H-type rectangular resonator with SL. The outer frame is mounted inside the vacuum tank through the electric support that connects the middle of bottom plane of the frame with vacuum tank. The inner frame is put inside the outer frame through the electric support that is fixed at the middle of upper side of bottom plane of the outer frame

Multiple apertures accelerating and focusing elements (SL,VL,HL) are arranged along the acceleration axis. The border electrodes (VL, HL) are fixed alternatively to both side walls of the outer frame. For simplicity these thin electrodes may be considered as drift tubes because they are fixed alternatively at opposite side walls of the outer frame with a longitudinal period of $\beta\lambda/2$. SLs are mounted alternatively at both side walls of the inner frame. By sup-

plying the system with RF energy the accelerating voltage is appeared between border electrodes. Single-phase current is exited in both outer and inner frames. It generates magnetic flux that run through the volumes that are between walls and bottom plates of both frames in the same direction and closes the loop through the volume between outer surfaces of the outer frame and punched outer shell that fixed at vacuum tank. So the single-phase voltage with differ amplitude values is generated at side walls edges of both frames where SLs are fixed. The SLs that are mounted at side walls of the inner frame are under lower potentials than the SLs that are fixed at the walls of the outer frame. So, we have RF divider that allows to reach uniform field distribution along the whole accelerating period of $\beta\lambda/2$. Within the next accelerating gap we also can reach the uniform longitudinal RF field distribution but with the appropriate field gradient amplitude and opposite sign of RF field as it required for SL focusing with the focusing period of $\beta\lambda$.

In those cases when we need in arranging of four additional focusing SLs within the accelerating period we can use 3-frame resonator that works analogous to 2-frame divider. The typical view of RF field distribution that have been reached at 3-frame resonant model is given in fig.6.
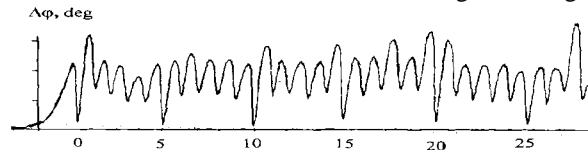

Fig.6. Electric field distribution ($\Delta\varphi \sim E^2$) along the accelerator structure vs. No. of the electrodes for 3-frame resonator with space SLF

Theoretically any small beam divergence of total accelerated beam may be reached in SLF array while features of practical use of SL focusing in RF linacs seem to be established by adequate ion injectors as well as advanced level of technology and practice.

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