RF QUADRUPOLE FOCUSING DRIFT TUBE LINAC RF DESIGN

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Drift tube linacs with quadrupole focusing based on Interdigital H-type (IH) resonators are used at medium energies of proton beams. The linac with spatially periodic quadrupole focusing designed by V.A. Teplyakov (SH-DTL, RFQ-DTL) provides enough energy gain rate and good focusing but it is too sophisticated at tuning. The DTL with magnetic quadrupole focusing is simpler then the first one at tuning but it is deprived of advantages of RF focusing. The IH-DTL linac proposed in Frankfurt University is new perspective but rare system. The new RF quadrupole focusing structure will be proposed in this paper. Such structure consists of periodic sequence of several number of drift tubes and RF quadrupole electrodes, located in the same IH-resonator. Different designs of the structure will be considered. Electrodynamic parameters of the one convenient structure will be determined. New structure will be compared with conventional DTL, RFQ-DTL and IH-DTL linacs.

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INTRODUCTION

The requirements of low particle losses and high currents of accelerating ion beams get RFQ more useful as an initial section of the linac. However the rate of energy gain in RFQ reduces with the energy increase. It equals 0.5…0.7 of energy gain for IH-DTL for $\beta \approx 0.05$. Thus using of the conventional RFQ at medium energies ($\beta > 0.07$) is impractical.

IH-DTL linac has several good performances at medium energies. It provides high energy gain, high shunt impedance and small tank diameter. The main problem in design of medium energy sections of the linac is the transverse beam focusing. The focusing by magnetic quadrupole fields or axisymmetric RF fields (for example alternating phase focusing, APF) are the most useful focusing types. Some of promising methods is Magnetic Quadrupole Triplet Focusing (IH-DTL) [1] and Spatially Periodic RF Quadrupole Focusing (RFQ-DTL) [2]. The first one could has some problems for heavy ions and the second one is complicated at design and tuning.

The Hybrid-RFQ (HRFQ) was proposed in [3] basing on these observations. "Triplet" RFQ mode is used in HRFQ in contrast to RFQ-DTL using "short lens" mode. It allows to extend the focusing period length and put inside the resonator more drift tubes. The same concept was applied earlier in [1] with magnetic quadrupole triplets.

We propose to use the mixed RFQ mode due to appointed requirements.

1. LATTICE CONFIGURATION

The idea is based on the several approaches [4]:

● The transverse acceptance of quadrupole lattice decreases as $1/n$ with the focusing period increases.

● The focusing gradient G decreases as $1/n^2$ with fixed strength of the lattice.

Here n is the number of "one-sign" lenses in the lattice.

Some variants of static quadrupole lattices are illustrated in Fig.1 [4], where L_F – the focusing period.

FOD and Triplet lattices have the shortest period length (on the approach that the lengths of "one-sign" lenses are the same), FODO lattice allows putting twice more drift tubes between lenses with acceptance reducing. FOF-DOD lattice has one of the lowest acceptances, but it allows reducing of the focusing gradient for four times.

It means that we can use twice bigger aperture to minimize the acceptance reducing.
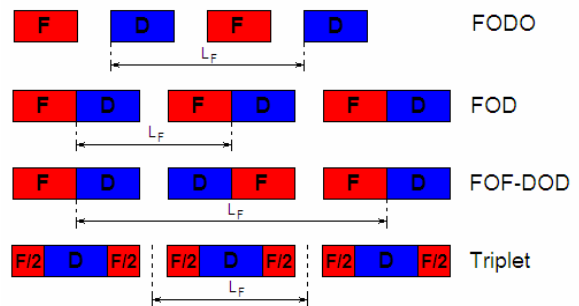

Fig.1. Some variants of static quadrupole lattices

2. RF QUADRUPOLE LENSES AND DRIFT TUBES DESIGN

Results of the beam dynamics simulation show that the most useful length of RF quadrupole electrode is $\beta_z\lambda/2$ in case of short lens and $\beta_z\lambda$ in case of doublet-triplet mode. It should be mentioned that the aperture radius of RF quadrupole lens can vary along the lens. But it will not be considered for simplicity of view in this paper.

One possible design of RF quadrupole lens was invented by V.A. Teplyakov and applied in URAL-30 and URAL-30M linacs in IHEP, Protvino [2]. The general view of such lens is shown in Fig.2. It constitutes two half drift tubes with quadrupole fingers joined to ends of tubes in a gap. 2D electrical potential distribution in the lens is shown in Fig.3. Distributions of longitudinal component of electrical field (solid line) and vertical component of electrical field (dash line) at the radius equals to a half of aperture radius are shown in Fig.4. The voltage between drift tubes is equal to 100 kV. The electrostatic approach is used for this field simulation.
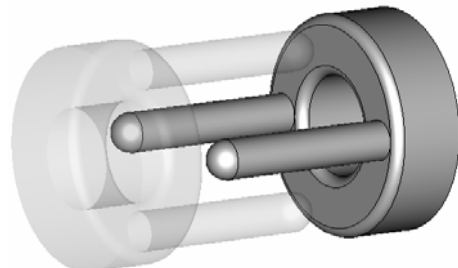

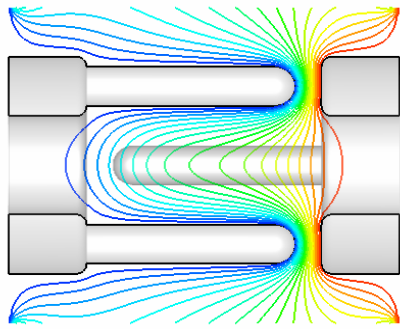*Fig.2. General view of RF quadrupole lens with fingers*

Fig.3. 2D potential distribution in RF quadrupole lens with fingers
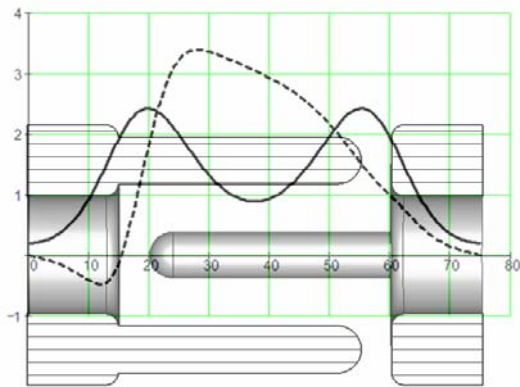

Fig.6. 2D potential distribution in 4-rod RF quadrupole lens

Fig.4. Distribution of longitudinal and vertical components of electrical field in RF quadrupole lens with fingers

Fig.7. Distribution of longitudinal and vertical components of electrical field in 4-rod RF quadrupole lens

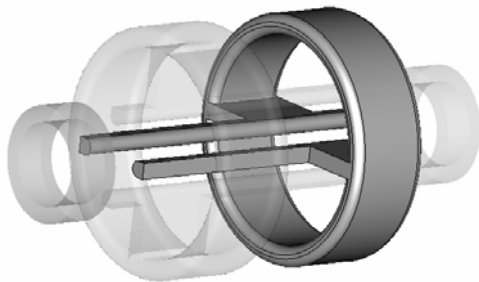The focusing gradient distribution along the resonator is shown in Fig.10. Uniform distribution of focusing gradient appears due to the strict symmetry and stiffness of single 4-vane resonator. Such quality of field distribution can't be obtained in any other design. Also this design provides the possibility of intervane voltage variation.

Fig.5. General view of 4-rod RF quadrupole lens

Other design of RF quadrupole lens is 4-rod design [3]. It becomes popular design for 4-rod IH-RFQ [1]. General view of 4-rod RF quadrupole lens is shown in Fig.5. It consists of four quadrupole rods joined in pairs to corresponding rings (short and large radius drift tube). 2D electrical potential distribution in the lens is shown in Fig.6. Distributions of the longitudinal component (solid line) and vertical component (dash line) of electrical field at the radius equals to a half of aperture radius are shown in Fig.7. Voltage between drift tubes is 100 kV.

Design of "rod and vane" RF quadrupole lens is shown in Fig.8. It consists of two vertical rods and two horizontal vanes. Unlike other designs this design provides only half of full voltage due to vanes connected to the reonator sidewall.

It can be useful to place DTL and RF quadrupoles into two different resonators with external coupling in some cases. Simpler tuning and good linearity of focusing fields can be provided by such scheme. RF quadrupole lens resonator is illustrated in Fig.9.
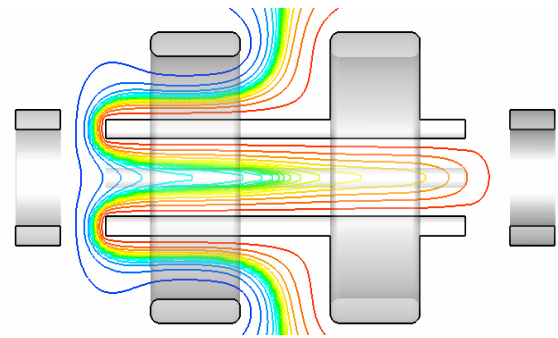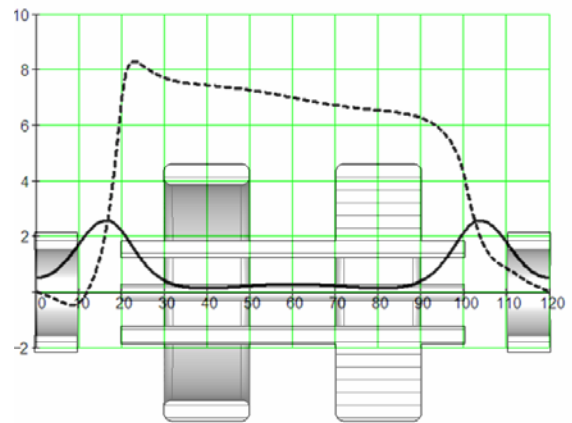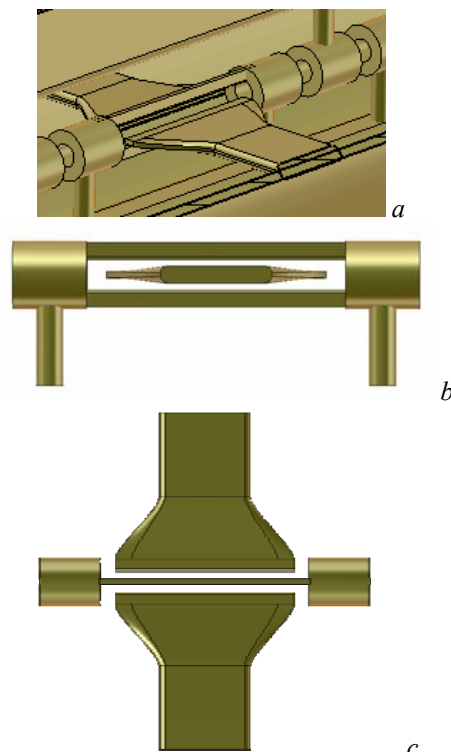

Fig.8. 3D (a), side (b) and top (c) views of "rod and vane" RF quadrupole lens
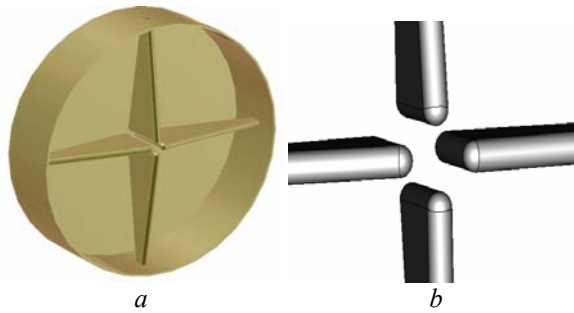
a   *b*

Fig.9. 3D view of 4 vane RF resonator (a)
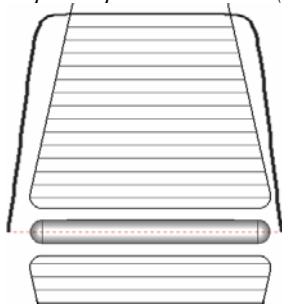*and quadrupole electrodes (b)*

Fig.10. Distribution of vertical components of electrical field in 4-vane RF resonator

Nonzero transversal component of electrical field in accelerating gap is one disadvantage of IH resonators. It may cause the emittance growth. Therefore some field correctors are used. Tuning washers joined to drift tubes ends let us to minimize the transversal component of electrical field. General view of drift tubes with washer is shown in Fig.11. Vertical field component distribution at the longitudinal axis with (dash line) and without (solid line) tuning washers are shown in Fig.12. The amplitude of vertical component of electrical field was reduced to 20 times.
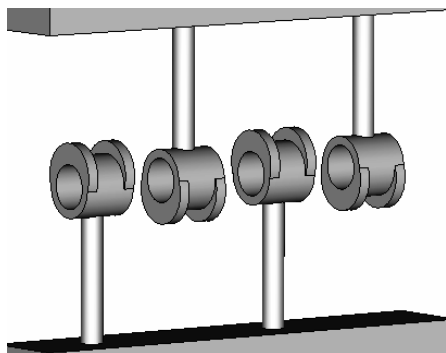

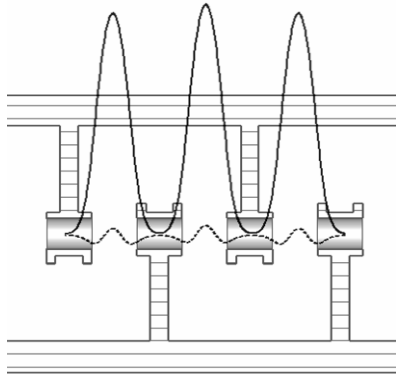*Fig.11. General view of drift tubes with tuning washers*

Fig.12. Distribution of vertical component of electrical field at the axis with (dash) and without (solid) tuning washers

3. RF RESONATOR

The RF model of the IH-resonator with RF quadrupoles was proposed (see Fig.13, 15). It consists of DTL and 4-rod $\beta\lambda$-length quadrupole (Fig.14). Several parameters of the resonator are represented in Table 1.
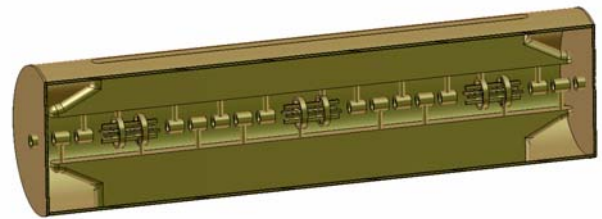

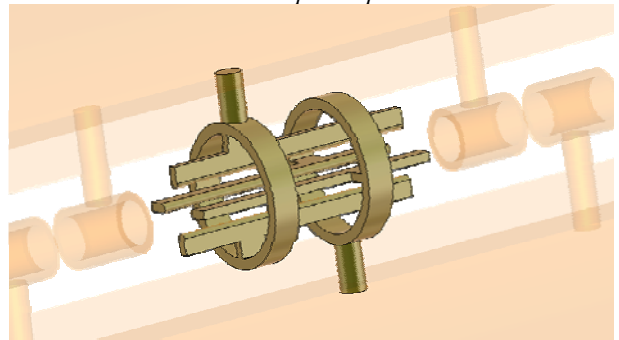*Fig.13. General view of IH – resonator with RF quadrupoles*

Fig.14. General view of RF quadrupole lens
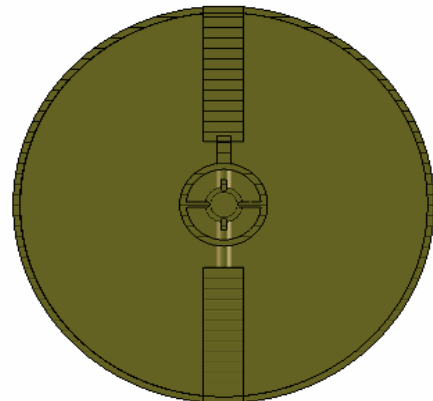
Fig.15. Cross-section of the resonator

Table 1

Resonator parameters

Parameter	Value
Operating frequency, MHz	150
Tank diameter, m	0,3
Tank length, m	1,2
β	0,05
Q_0	7695
Effective shunt impedance, MOhm/m	19,0
Types of lattice	FOD, FOFDOD

4. COMPARISON WITH OTHER STRUCTURES

The linac combines DTL and RF quadrupole focusing sections has some advantages and disadvantages comparatively other ion linacs in medium energy range (Table 2.)

Linac type	Advantages of DTL with RF quadrupole focusing over other linacs
Conventional DTL (Alvarez type)	- Smaller tank diameter - Available for heavy and low energy ions - Higher rate of energy gain at π – mode - No individual power supply for focusing - Unserviceable focusing lenses
IH/CH-DTL (PMQ inside DT)	- Unserviceable focusing lenses
SP-RFQ, RFQ-DTL (Double gap)	- Easier design, manufacturing and tuning
IH/CH-DTL (MQ Triplet)	- No individual power supply for focusing
Linac type	**Disadvantages of DTL with RF quadrupole focusing over other linacs**
Conventional DTL (Alvarez type)	- More strong influence of the beam current loading - Lower Q-factor - Lower shunt impedance at $\beta > 0.2$
IH/CH-DTL (PMQ at DT)	- Lower Q-factor and shunt impedance
SP-RFQ, RFQ-DTL (Double gap)	- Lower transversal acceptance due to lower focusing rigidity
IH/CH-DTL (MQ Triplet)	- More complicated RF-design - More overvoltage surfaces

CONCLUSIONS

The new RF quadrupole focusing DTL structure was proposed. Different designs of RF quadrupole lenses and drift tubes were considered. Electrodynamic parameters of proposed structure were determined. New structure was compared with conventional DTL, RFQ-DTL and IH-DTL.

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ЛИНЕЙНЫЙ УСКОРИТЕЛЬ С ТРУБКАМИ ДРЕЙФА И ВЫСОКОЧАСТОТНОЙ КВАДРУПОЛЬНОЙ ФОКУСИРОВКОЙ

А.С. Пластун, С.М. Полозов

Линейные ускорители с трубками дрейфа и квадрупольной фокусировкой на основе H- (IH)-резонаторов используются в диапазоне средних энергий протонных пучков. Линейный ускоритель с пространственно-периодической квадрупольной фокусировкой, разработанный В.А. Тепляковым (SH-DTL), обеспечивает достаточный темп ускорения и хорошую фокусировку, но слишком сложный в настройке. Ускоритель с трубками дрейфа и магнитной квадрупольной фокусировкой проще в настройке, но он лишён преимуществ высокочастотной фокусировки. Такой ускоритель (IH-DTL), предложенный во Франкфуртском университете, является новой перспективной, но мало распространённой системой. В статье предложена новая структура с высокочастотной (ВЧ) квадрупольной фокусировкой. Такая структура состоит из периодической последовательности нескольких трубок дрейфа и ВЧ-квадрупольных электродов, расположенных в одном IH-резонаторе. Будут рассмотрены различные виды моделей структуры и определены некоторые электродинамические параметры наиболее привлекательных структур. Будет произведено сравнение новой структуры с традиционным ускорителем с трубками дрейфа, SH-DTL и IH-DTL.

ЛІНІЙНИЙ ПРИСКОРЮВАЧ З ТРУБКАМИ ДРЕЙФУ І ВИСОКОЧАСТОТНИМ КВАДРУПОЛЬНИМ ФОКУСУВАННЯМ

О.С. Пластун, С.М. Полозов

Лінійні прискорювачі з трубками дрейфу і квадрупольним фокусуванням на основі H- (IH)-резонаторів використовуються в діапазоні середніх енергій протонних пучків. Лінійний прискорювач з просторово-періодичним квадрупольним фокусуванням, розроблений В.О. Тепляковим (SH-DTL), забезпечує достатній темп прискорення і хороше фокусування, але занадто складний в налаштуванні. Прискорювач з трубками дрейфу та магнітним квадрупольним фокусуванням простіший в налаштуванні, але він позбавлений переваг високочастотного фокусування. Такий прискорювач (IH-DTL), який запропонований у Франкфуртському університеті, є новою перспективною, але мало розповсюдженою системою. У статті запропонована нова структура з високочастотним (ВЧ) квадрупольним фокусуванням. Така структура складається з періодичної послідовності декількох трубок дрейфу і ВЧ-квадрупольних електродів, розташованих в одному IH-резонаторі. Будуть розглянуті різні види моделей структури та визначені деякі електродинамічні параметри найбільш привабливих структур. Буде проведено порівняння нової структури з традиційним прискорювачем з трубками дрейфу SH-DTL і IH-DTL.