THE PROJECT OF RFQ LINAC FOR AN EDUCATIONAL LABORATORY AT RAC OF MEPHI

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Abstract

RFQ linac of light ions with the energy up to 2-MeV/amu and the charge-to-mass ratio ≤1/3 is proposed at the Radiation-Acceleration Center (RAC) of Moscow-Engineering Physics Institute (MEPhI). The accelerator is intended for educational and research purposes. In the report, RFQ designs with two different frequencies of 150 MHz and 433 MHz are considered as possible candidates. Two types of the RFQ designs using either a constant or an increasing intervane-voltage distribution along the structures are compared and discussed. The former type is a conventional RFQ, and the latter type allowing an increased energy gain results in a shorter accelerating structure, while it requires a higher RF power.

INTRODUCTION

The State University "Moscow Engineering Physics Institute" (MEPhI) is the base institution for the newly established National Research Nuclear University "MEPhI". In the frames of the equipment upgrade program, several small particle accelerators at the Radiation-Acceleration Center (RAC) of MEPhI are considered to be modified or substituted for with modern ones.

RFQ linac of light ions with the energy up to 2-MeV/amu and the charge-to-mass ratio ≥1/3 is one of the possible candidates for this upgrade program. The accelerator is intended for educational and applied research purposes using the ion beams of different species (proton, deuteron, carbon etc.). This RFQ linac is considered as a low-intensity ion linac with neglected space-charge effects.

In the report, RFQ designs with two different frequencies of 150 MHz and 433 MHz are considered as possible candidates. The RFQ with the operating frequency of 150 MHz allows us to utilize the RF power generator existing in RAC, while the RFQ with the operating frequency of 433 MHz allows using of RFQ structure and technology developed at the NPK LUTS (Scientific Production Complex of Linear Accelerators and Cyclotrons) of D.V.Efremov Scientific Research Institute of Electrophysical Apparatus (NIIEFA) [1].

The allowable length of the RFQ accelerating structure is restricted by value about 3-3.5 m. This value is imposed by the available space of the existing accelerating room. In this report, the detailed designs of RFQs based on traditional approach of a constant intervane-voltage distribution along the structures are presented. In order to increase the final beam energy, alternative RFQ designs using the increasing intervane-voltage distribution along the structures can be implemented [2-4]. For comparison of alternative designs with traditional ones, the results of the paper [4] are used.

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CONSTANT-VOLTAGE RFQ DESIGNS

The design of traditional RFQs with of a constant intervane-voltage distribution along the structures has been performed with GENRFQ-code developed by S. Yamada [5]. This code is a complementary code to the standard beam dynamics code PARMTEQ developed at Los-Alamos Scientific Laboratory [6]. The GENRFQ-code has been successfully used for design of the low-intensity RFQ linacs in Japan. For example, the operating injector linacs for the cancer therapy synchrotrons in Japan [7] have been designed with this code.

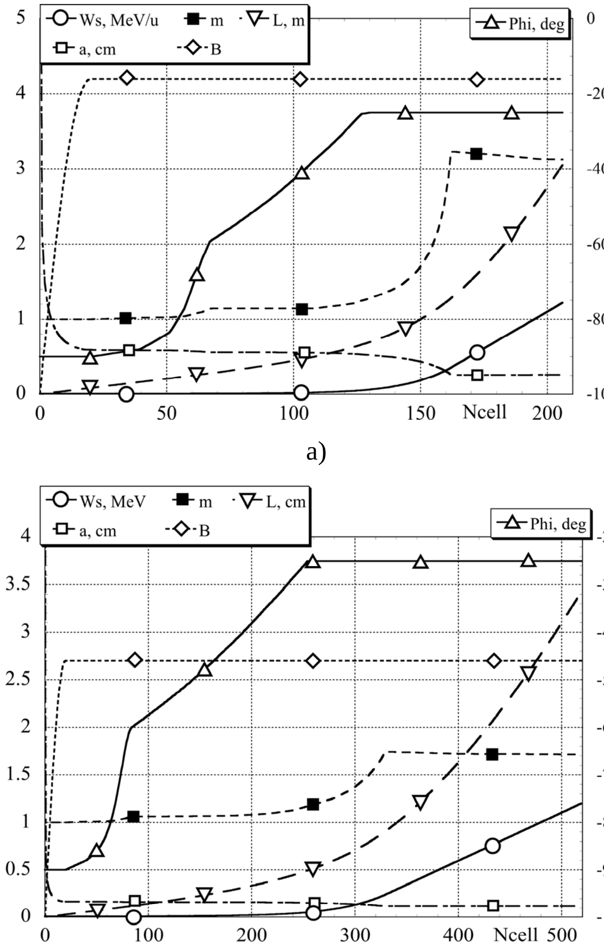
The GENRFQ code ensures rapid bunching and high acceleration rates, which are much faster then in high-current RFQs designed according to the K-T [8] and LANL [9] prescriptions. According to GENRFQ method, the RFQ is divided into six sections: Radial Matching, Shaper, Prebuncher, Buncher, Booster and Accelerators. The detailed explanations of these sections are given in the papers [5,10].

The 150-MHz and 433-MHz RFQs has been designed with GENRFQ code. Their principal parameters are listed in Table 1.

Table 1: The principal parameters of the 150-MHz and 433-MHz RFQ.

Parameter	150-MHz	433-MHz
Charge-to mass ratio	≥1/3	≥1/3
Input energy $W_{s,in}$ (keV/u)	8	8
Output energy $W_{s,out}$ (MeV/u)	1.2	1.2
Normalized emittance (mm·mrad)	1.0·π	0.4·π
The total vane length (m)	3.05	3.43
Total number of cells	206	519
Minimum aperture, a_{min} (mm)	2.57	1.19
Maximum vane modulation, m	3.23	1.74
Focusing strength, B	4.2	2.7
Max. intervane voltage, V (kV)	103	45
Max. surface field (Kilpatrick)	1.8	1.8
Beam transmission, %	92	90

The RFQ parameters of 150-MHz and 400-MHz designs are graphically shown in Fig.1. The right scale serves for synchronous phase in degrees, and the left scale serves for 5 parameters: 1) the kinetic energy of synchronous particle, W_s in MeV/u; 2) the vane modulation parameter, m; 3) the vane length, L in meters; 4) the aperture, a in cm; 5) the focusing parameter, B.



a)

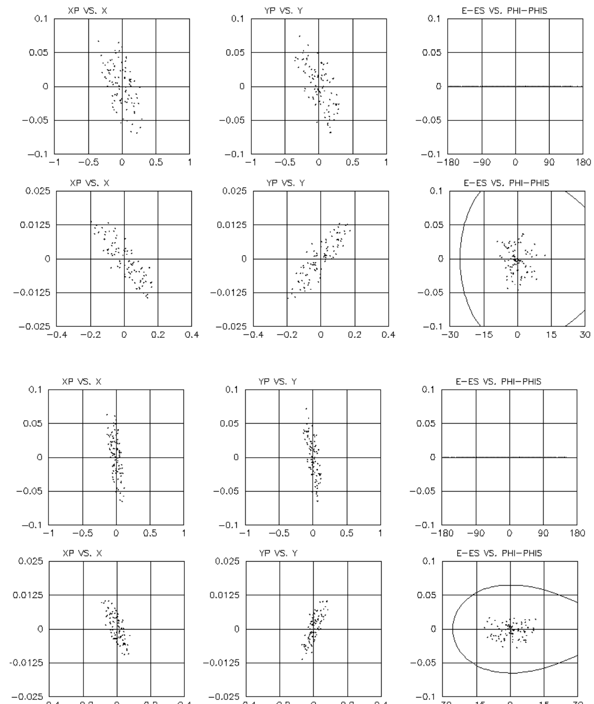
b)

Fig.1 RFQ Parameters as function of cell number:
a) 150-MHz design; b) 433-MHz design.

Simulated beam profiles and phase spaces have been generated with the aid of the OUTPROC code. Figure 2 shows the phase spaces at input and output ends of the RFQs. The two radial and the longitudinal phase spaces are shown from left to right.

Figure 3 shows the radial, phase, and energy profiles of the beam. The dotted lines on the x-profile plot indicate the aperture size. The dotted lines on phase and energy profile-plots indicate the separatrix of the longitudinal oscillations. It is seen that the envelopes of the phase and energy profiles are close to the separatrix during the bunching process.

The both presented RFQ-designs have a quite high-beam transmission (more 90 %) and approximately the same length of vanes. However, 433 MHz design requires about twice smaller emittance of the injected beam. More detailed comparison will require further evaluations, e.g. required RF power, mechanical tolerances etc.



a)

b)

Fig.2 The phase spaces of input (upper row)
and output beam (lower row):
a) 150-MHz design; b) 433-MHz design.

Both structures are designed for the final beam energy of 1.2 MeV/u. It may be desirable to increase the final beam energy up to 2MeV/u. It can be principally obtained with RFQ designs using the increasing intervane-voltage distribution along the structures. For evaluations of an achievable final energy, let's use the results of the paper [4].

Figure 4 shows dependence of the final ion energy on the RFQ length for 3 versions of 200-MHz RFQs: 1) "V-const" using the constant intervane voltage; 2) "V-gradient" using the increasing intervane-voltage distribution; 3) "AP&V-gradient" using the increasing intervane-voltage distribution and modulation of synchronous phase.

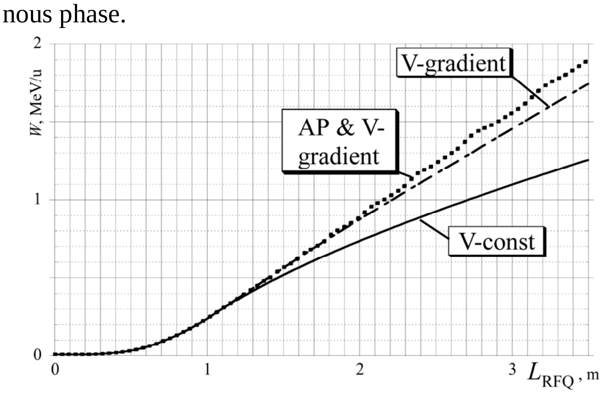


Fig. 4 The ion energy vs. the total length of RFQ [4].

The basic parameters of the "V-const" 200-MHz RFQ design are very close to the presented here the "V-const" 1.2 MeV/u 150-MHz RFQ. Therefore, one may conclude that 150-MHz RFQ designed as "V-gradient" (or "AP&V-gradient") structure can achieve the final energy up to 2.0 MeV/u.

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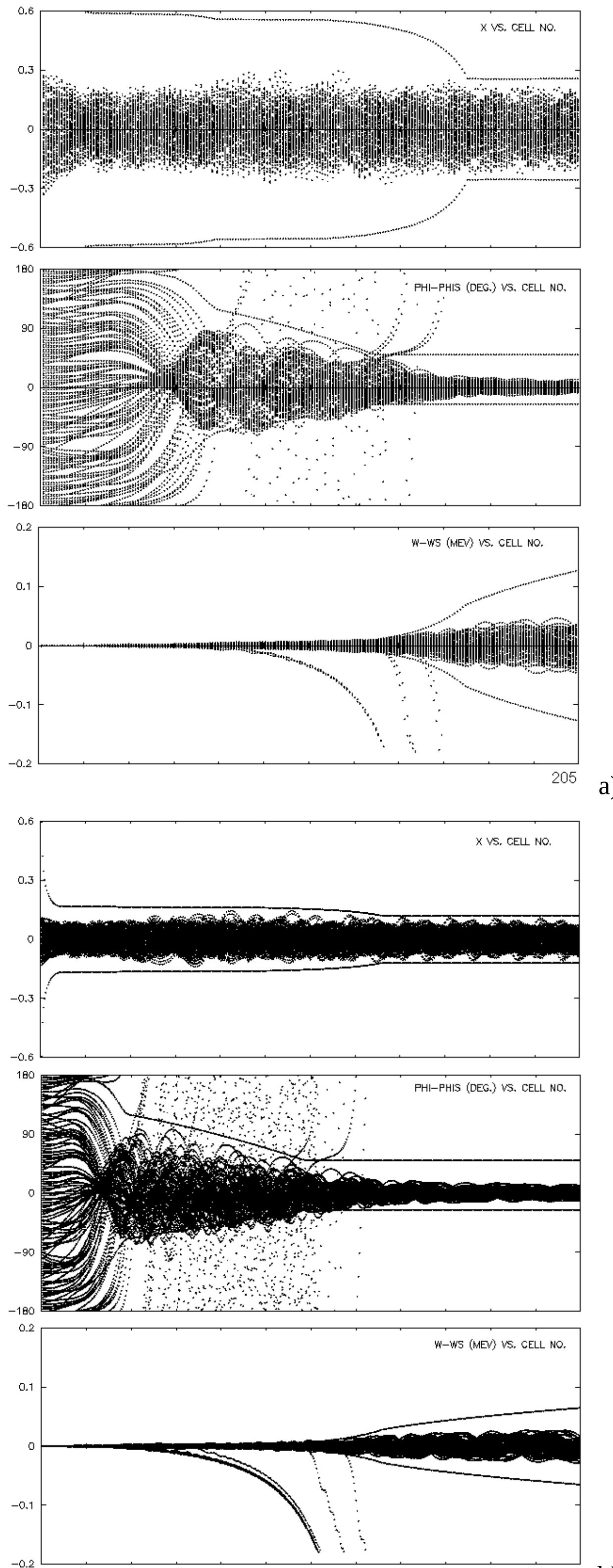

Fig.3 The radial, phase, and energy profiles: a) 150-MHz design; b) 433-MHz design.