ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA03

CALCULATIONS OF ION DYNAMICS AND ELECTRODYNAMIC CHARACTERISTICS OF 800 keV/NUCLON RFQ

M.A.Guzov, N.V. Zavyalov, A.V. Telnov, M.L. Smetanin, A.M. Opekunov, L.E. Polyakov, Russian Federal Nuclear Center – All-Russia Research Institute of Experimental Physics (RFNC-VNIIEF), Sarov
S.M. Polozov, Yu.Yu. Lozeev, A.I. Makarov, E.N. Indushniy, NRNU MEPhI, Moscow

Abstract

An accelerating structure with radio frequency quadrupole (RFQ) [1] focusing is considered. The RFQ is capable of providing bunching and acceleration of ion beams from H+ to O5+ to energies of the order of 1 MeV/nucleon, with an A/Z ratio from 1 to 3.2. The proton current reaches 2 mA, and the ion current reaches 1 mA.

The calculation of the dynamics of ions has been carried out. An electrodynamic model of a four-vane RFQ with magnetic coupling windows has been created. The dependence of the operating frequency of the cavity on its geometric parameters is found. The geometry of the magnetic coupling windows, which provides the optimal mode separation, is determined. Various types of cavity shells are considered and the corresponding electrodynamic characteristics (EDC) are obtained. The influence of additional frequency tuning elements (plungers and "spacers" of frequency tuning) on the EDC is investigated. As a result, an optimized electrodynamic model of the accelerating structure is obtained.

RESULTS OF CALCULATING THE ION DYNAMICS IN AN ACCELERATING STRUCTURE

The purpose of calculating the dynamics of ions in an accelerating structure is to obtain conditions for accelerating the beam with minimal losses [2]. There are two types of losses: transverse and longitudinal (phase). Transverse losses are eliminated by changing the modulation parameter. Longitudinal losses disappear due to a change in the phase of a synchronous particle, which in turn also depends on modulation. Therefore, the problem of finding the optimal parameters of the accelerating structure, which are interconnected, was solved.

The range of accelerated particles from H+ to O5+ is considered. Particle dynamics were simulated in three stages:

1) preliminary modeling in order to identify the main parameters of the accelerating structure;

2) dividing the structure into periods;

3) modeling the dynamics in the structure, divided into periods.

The initial data for calculating the dynamics of ions are presented in Table 1. The emittance for protons and O5+ ions were obtained (Figs. 1,2). The values of energy, particle velocity, particle current and particle loss are calculated (Table 2). The calculations of the dynamics of ions were carried out with a preliminary bunching device ("buncher") and without it.

Table 1: Parameters for Modeling the Dynamics of a Proton Beam

Ions	p^+	O^{5+}
Length of structure, cm	450,0	
Length of buncher , cm	280,0	
Emittance, π×cm×mrad	0,03	
Transverse beam size (x,y), cm	0,1	0,2
Voltage, kV	40,0	140,0
Frequency, MHz	81,25	
Particle current, мA	2,0	1,0

The calculation was carried out for the phase length of the beam 2π and 1.4π (pre-bunched beam).

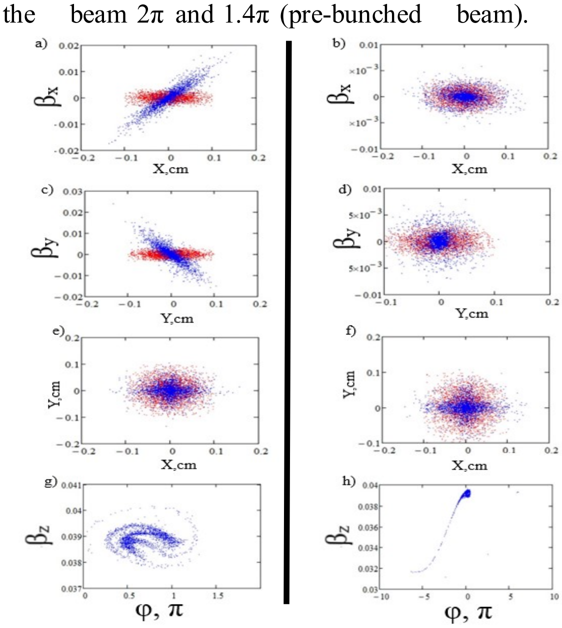


Figure 1: Results of calculations of the dynamics of protons :in RFQ (particles are indicated in red at the beginning of the structure, blue at the end), a - transverse emittance (X), without buncher; b - transverse emittance (X), with a buncher; c - transverse emittance (Y), without buncher; d - transverse emittance (Y), with a buncher; e - cross-section of the beam, without a buncher; f - cross-section of the beam, with a buncher; g - longitudinal emittance, without a buncher; h - longitudinal emittance, with a buncher.

Content from this work may be used under the terms of the CC BY 4.0 licence (© 2021). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA03

Content from this work may be used under the terms of the CC BY 4.0 licence (© 2021). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

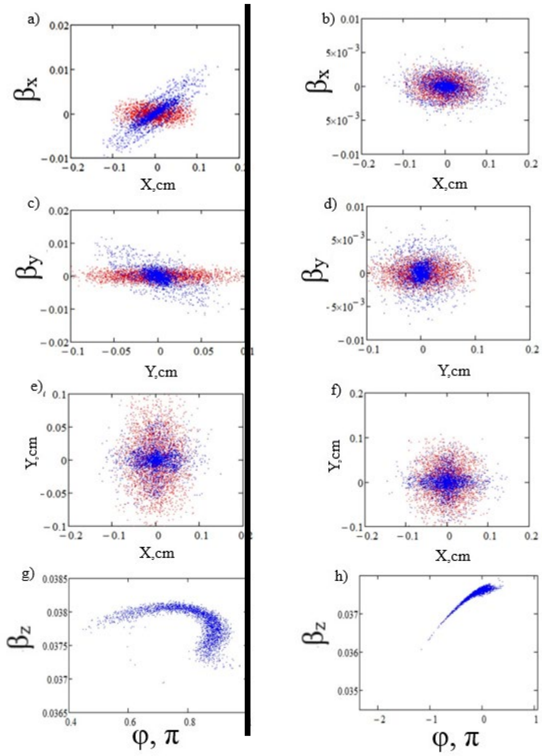


Figure 2: Results of calculations of the dynamics of O5+ in RFQ (particles are indicated in red at the beginning of the structure, blue at the end), a - transverse emittance (X), without buncher; b - transverse emittance (X), with a buncher; c - transverse emittance (Y), without buncher; d - transverse emittance (Y), with a buncher; e - cross-section of the beam, without a buncher; f - cross-section of the beam, with a buncher; g - longitudinal emittance, without a buncher; h - longitudinal emittance, with a buncher.

Table 2: Results of Modeling the Dynamics of Ions

Ions	p^+		O^{5+}	
	with a buncher	without a buncher	with a buncher	without a buncher
Velocity β	0,037	0,037	0,037	0,037
Energy, keV/nuclon	654,3	654,3	654,3	654,3
Current, mA	2,0	1,845	1,0	0,931
Current transmission coefficient, %	100,0	92,2	100,0	93,1
Transverse particles loses, %	0,0	0,0	0,0	0,0
Longitudinal particles loses, %	0,0	7,8	0,0	6,9

As a result of the calculations, a structure with a preliminary buncher was chosen, since it ensures the transportation and acceleration of the beam without losses.

ELECTRODYNAMIC MODEL OF RFQ

The electrodes in the structure under consideration have the same shape and are installed in such a way that the windows in the perpendicular planes are displaced by half a period (Fig. 3) [3].

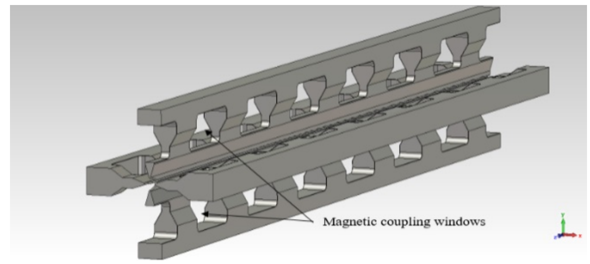


Figure 3: Electrodes with offset magnetic coupling windows

In such structures, windows exist to achieve the following goals:

1) providing frequency separation with the H_{110} wave;
2) simplification of tuning the resonator to the operating frequency;
3) stabilization of the distribution of electromagnetic fields;
4) reducing the size of the resonator by reducing the total inductance.

A structure with seven magnetic coupling windows is considered. Frequency separation was 9.3 MHz. The geometry of the coupling windows with the distribution of the transverse electric field along the resonator axis is shown in Fig. 4.

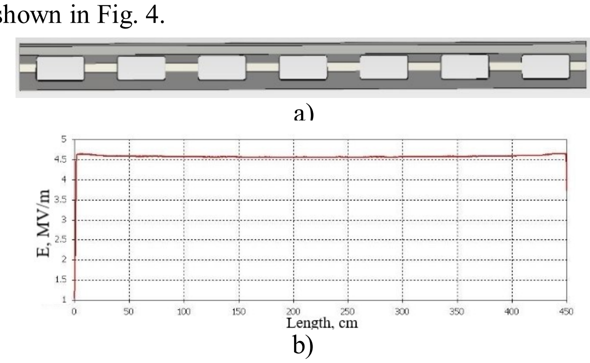


Figure 4: Results of modeling the coupling windows in the electrodes, a - the geometry of the coupling windows in the electrode, b - the distribution of the electric field along the central axis of the resonator

Calculations of quality factor, power losses in the walls and the transverse shunt impedance of the accelerating structure were carried out for three different body shapes (Fig. 5): rectangular (a), round (b) and octagonal (c). The calculated EDCs depending on the shape of the body of the accelerating structure are presented in Table 3.

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA03

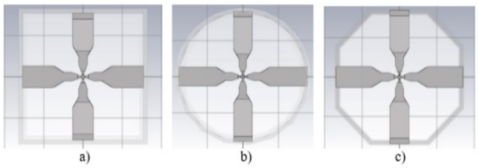
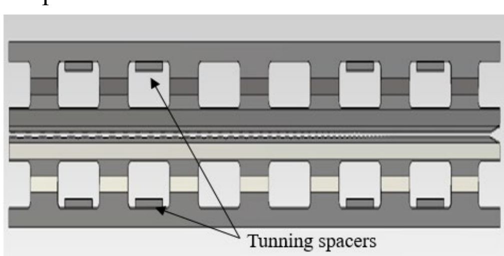


Figure 5: Shapes of the cross-section of the cavity.

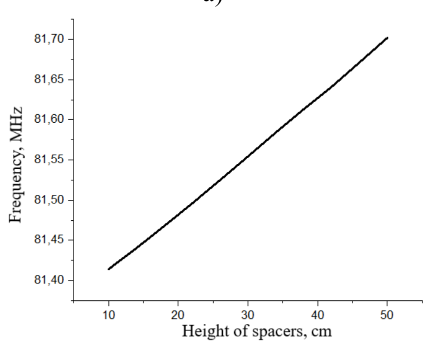
Table 3: EDC of Resonators with Different Body Shapes

Type of cross-section of the cavity	Frequency, MHz	Radius of cavity, cm	Quality factor	Voltage, kV: 40	Voltage, kV: 140	Transverse shunt impedance kOhm/cm
				Power loss, kW		
rectangular	82,30	29,0	15541,0	17,1	208,9	30,0
cylindrical	79,57	34,0	15757,0	17,4	213,2	33,0
octagonal	80,86	32,0	15729,0	17,1	209,6	29,0

As you can see, the EDCs differ insignificantly. Therefore, we will choose a cylindrical resonator (Fig. 5a). This type of form is very popular in the scientific community, and the shell manufacturing technology is quite simple.



a)



b)

Figure 6: Model of cavity with tuning spacers, a - the location of the "cubes"; b - the dependence of the cavity operating frequency on the height of the "cubes".

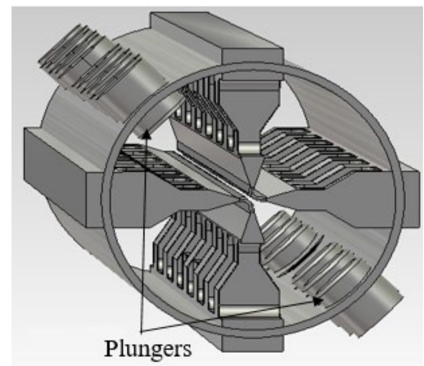
In a real cavity, due to various mechanical deformations and inaccuracies in the manufacture of the resonator, the operating frequency differs from the calculated one. In this regard, various options for frequency tuning were considered:

a) frequency adjustment with the help of "tuning spacers" (Fig. 6);

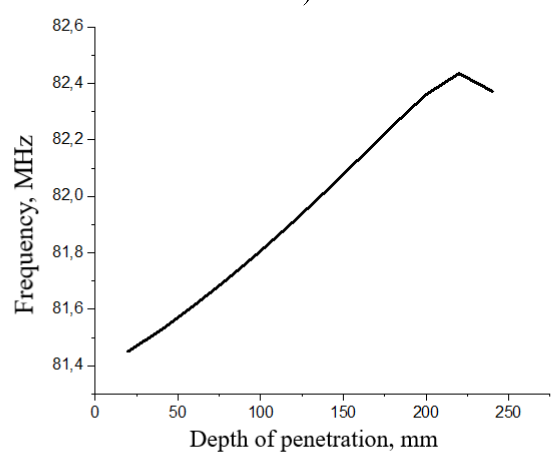
b) frequency control plungers (Fig. 7).

In fig. 6b shows a graph of the change in the operating frequency of the resonator with a change in the height of the "spacers". The sizes of regular "spacers" are 136x380 mm.

In fig. 7 shows the location of the plungers at half of their working stroke of 50 mm (a) and the graph of the dependence of the operating frequency of the cavity on the immersion depth of the plunger (b). diameter of plunger is 145 mm.



a)



b)

Figure 7: Model of cavity with frequency tuning plungers depth.

CONCLUSION

The calculation of the dynamics of ions has been carried out (Fig. 1, 2). The transverse and longitudinal emittance and the beam cross section view have been obtained. An electrodynamic model of RFQ has been constructed, with the corresponding elements of dynamic and static frequency tuning. The operating frequency of the accelerating cavity is 81.25 MHz. Various shapes of cavity have been calculated, for which EDCs are given (Table 3).

Content from this work may be used under the terms of the CC BY 4.0 licence (© 2021). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA03

REFERENCES

[1] Kapchinsky I.M. “Linear Resonance Accelerators Theory: Particle Dynamics”, Moscow, Energoatomizdat, 1982.

[2] S.M. Polozov, *Prob. of Atomic Sci. and Tech*., 3(79), 131-136, 2012.

[3] S. M. Polozov, A. E. Aksentyev, and T. Kulevoy, “Beam Dynamics and Accelerating Cavity Electrodynamics' Simulation of CW 2 MeV Proton RFQ”, in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, Jun. 2014, pp. 3286-3288. doi:10.18429/JACoW-IPAC2014-THPME030

Content from this work may be used under the terms of the CC BY 4.0 licence (© 2021). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI