THE CALCULATION TECHNIQUE FOR ACCELERATING CHANNEL OF THE STRUCTURE WITH THE SPACE-UNIFORM RFQ FOCUSING

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Calculations were carried out for the initial part of the heavy ion accelerator with the large mass-to-charge ratio (a/q = 46). The process of calculation is divided in four stages. At the first stage the average aperture radius and the field strength are determined according to the initial data. At the second stage the optimization of the accelerating tract is performed. To the purpose, the structure is divided in 6 sections: a funnel (a cone), a bunch former, a pre-buncher, an adiabatic buncher, a booster, an accelerating section. At the third stage the obtained data are re-calculated in the values of the modulation depth and lengths of the accelerating periods with taking into account the real fields. At the fourth stage the beam parameters at the accelerator output are determined for the tract built with taking into account the space charge forces and the input beam parameters.
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This technique was used for calculation of the initial part of the heavy ion accelerator with a large mass-to-charge ratio (A/q = 46) in the energy range from 3.22 keV to 42 keV.

The process of calculation is divided in four separate stages.

At the first stage, the average aperture radius (R_0 = 7 mm) and the amplitude voltage (U_L = 90 kV/cm) were chosen from the given wavelength of the RF field λ = 12.6 m and the channel penetrability V_p = 0.75 mm·mrad. In this section it is supposed to use the copper electrodes shaped in the form of a string with a semicircular cross-section of a radius R_e = 4.9 mm.

The modulation of the electrodes is of a sinusoidal type. The maximum electric field strength at the electrode surface is

$$E_S = \chi \frac{U_L}{R_0}$$

and does not exceed 168 kV/cm ($\chi \le 1.3$).

The calculation of the $\chi(kR_o,m)$ function (where $k = 2\pi/\beta\lambda$, β is the dimensionless velocity of the particle, m is the depth of the electrode modulation) was carried out with the RFQFLD code [1].

The function of the focusing hardness in the area of the transverse matching is:

$$k^2 = 1.62 \sin^2(\pi z / 6\beta\lambda)$$

With that the axially symmetric converging beam should be injected into the section. Parameters of its dimensionless contour should be the following:

$$\rho_x = \rho_y = 1.93$$
$$\rho'_x = \rho'_y = 0.59$$

The real beam contour $r_x(\tau)$ and $r_y(\tau)$ are related to the functions $\rho_x(\tau) = \rho_y(\tau)$ by the following relations [2]:

$$r_x(\tau) = r_x(\tau) = \sqrt{F_o}\,\rho_x(\tau), \quad r_y(\tau) = \sqrt{F_o}\,\rho_y(\tau), r_y(\tau)$$

where r = Z/S, S = $\beta\lambda$ is the focusing period length, $F_o = SV_p/\beta\gamma$, V_p is the normalized beam emittance, γ is the dimensionless particle energy.

At the second stage the optimization of the accelerating and focusing channel is carried out with the RFQOPT code. The aim of the stage is to find the accelerating efficiency T [2] and the synchronous particle phase ψ_s along the structure, which provide the maximum beam capture coefficient with the minimum length of the structure. For this aim the whole accelerating structure is divided in 6 sections.

1. The section of the radial matching ("funnel").
2. The buncher - the short section (10-20 accelerating cells), bunching.
3. The prebuncher - rapid beam contraction in phase with retention of the separatrix geometric length.

The adiabatic buncher - the completion of bunching process, maintenance of the maximum acceptable electric field at the electrode surface, slow rise in the longitudinal bunch length.

4. The booster - rapid rise in the acceleration rate due to the electrode modulation factor as far as the radial acceptance tolerates.
5. The accelerating section - acceleration to the final energy.

We would note that at this stage the real field calculation is not carried out, therefore the calculation of the particular case runs very quickly (for ~ 200 accelerating cells it takes ~ 2-3 s using the Pentium processor (150 MHz)). This enables to use effectively the dialog mode for the structure design.

The longitudinal phase image of the injected monoenergetic bunch at the output of the accelerating structure (Fig. 1), longitudinal phase oscillations of the particles injected in different phases of the RF field, ψ, and dimensionless beam contours ρ_x, ρ_y (Figs. 3-5) are displayed on the computer monitor. ψ and $\rho_{x,y}$ are presented as functions of the accelerating number N, where N = 2 τ.

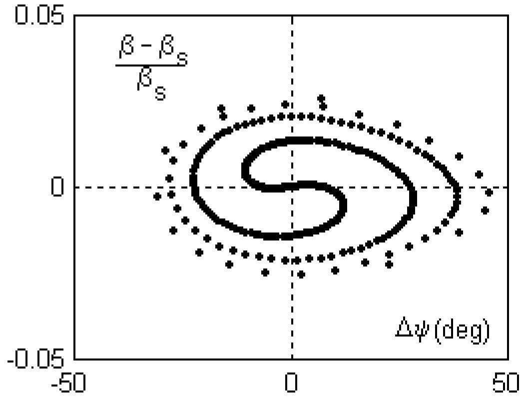


Fig. 1. The longitudinal phase image of the bunch at the output of the accelerating structure.

At the third stage from calculated values of the accelerating efficiency and synchronous phases, and using the chosen relation R_e/R_o, the type of the electrode modulation the accelerating cell lengths and the electrode modulation coefficient corresponding to the real fields of a particular structure are calculated with the code RFQTRT. The real fields of the RFQ structure are calculated with the RFQFLD code.

In Table I the parameters of the RFQ section and characteristics of the beam under acceleration after 3 calculation stages are given.

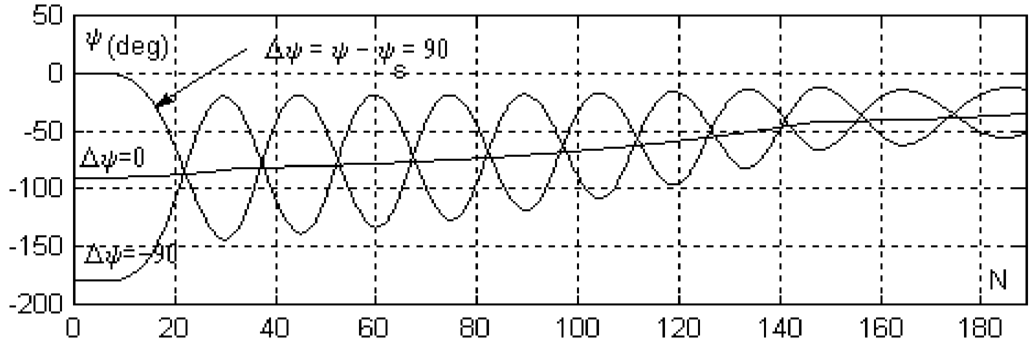
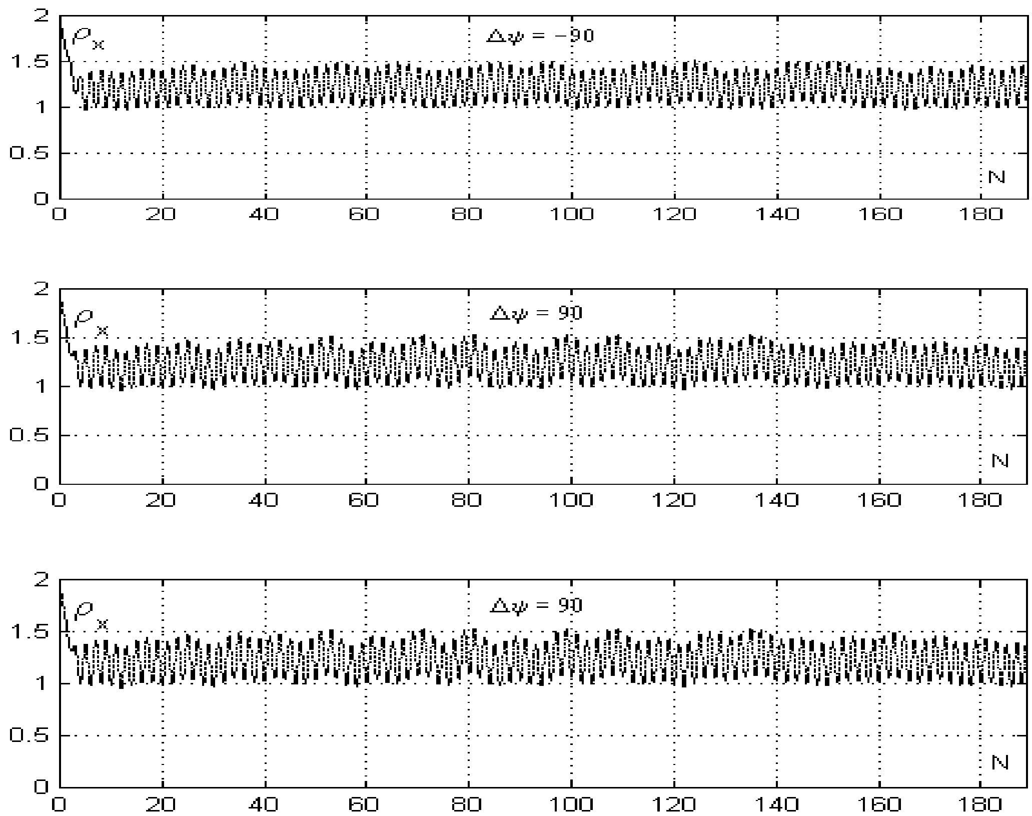


Fig. 2. Longitudinal phase oscillations of the particles injected in the different RF field phases.



Figs. 3-5. Normalized beam contours related to particles presented in Figure 2.

Table I

Average distance from electrodes to the axis	R_o	mm	56 ... 7
The aperture radius	a	mm	56 ...4.4
The radius of the electrode rounding	R_e	mm	4.9
The electrode length	L_e	mm	5140
Number of the accelerating periods	N		183
Coefficient of the electrode modulation	m		0... 2.18
Efficiency of accelerating	T		0... 0.46
Factor of defocusing	γ_s		0... 0.05
Hardness of focusing	k^2		0...1.62
Synchronous particle phase	ψ_s	grad	- 90 ... -35.6
Phase length of bunches	$\Delta\psi$	grad	360...70
Normalized transverse acceptance	A	mm·mrad	0.75π
Coefficient of the beam capture with the zero inject current		%	94
Pulse oscillation amplitude	$(\Delta P/P)_a$	%	0 ... 2.5

As one can see from Figure I at the output of this accelerating and focusing channel the charged particle bunch is bunched adequately in phases and longitudinal pulses, and phase oscillations of unstable particles does not cause any considerable loss in the transverse acceptance of the channel calculated for the synchronous particle.

At the fourth stage the parameters of the accelerated charged particle bunch are determined for the calculated accelerating and focusing channel at the output of the accelerating structure with taking into account the space charge forces and the input beam parameters.

The real fields of the RFQ structure are calculated with the RFQFLD code.

In Table I the parameters of the RFQ section and characteristics of the beam under acceleration after 3 calculation stages are given.

In conclusion, it may be noted that the presented procedure has a general nature and could be used for calculation of the accelerating structures for various types of ions.

REFERENCES

1. Tishkin S.S. The numerical field calculation in structures with the space-uniform quadruple focusing with the method of the auxiliary charges //3 *Problems of Atomic Science and Technology. Issue: Nuclear-Physics Research* (38). 2001, v. 3, p. 121-123.
2. Kapchinskij I.M. *The theory of linear resonance accelerators*. Moscow: Energoizdat, 1982. (in Russian).