OPTIMIZATION METHOD AND DEVELOPMENT WITH USE OF ABC PROGRAM THE INPUT DYNAMICAL MATCHER WITH REDUCED SLOPE OF BEAM ENVELOPE IN WIDE RANGE OF BEAM CURRENTS FOR HEAVY ION HIGH CURRENT RFQ

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An analytical law developed earlier for an output matcher in an initial part of RFQ electrodes was adopted for an input unmodulated dynamical (radio) matcher (IRM). An analytical formula describing the different types of matchers was proposed. The modernization of the code ABC was carried out for channel optimization by applying the analytical formulae. Developed was the method for matchers' optimization with maintenance of beam dynamical matching in the wide range of currents and low sensitivity to the initial RFQ segment with a fringe field difficult to control.

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1. INTRODUCTION

A standard input dynamical matcher developed by A.I.Balabin [1] has a high-quality dynamical matching but high values of slopes of matched beam envelopes. The main characteristics of this matcher taken from [1] are shown in Fig.1. The need in reduced slopes of input envelopes [2] for preventing a high emittance growth in the LEBT requires the development of the appropriate dynamical matchers at the RFQ input.

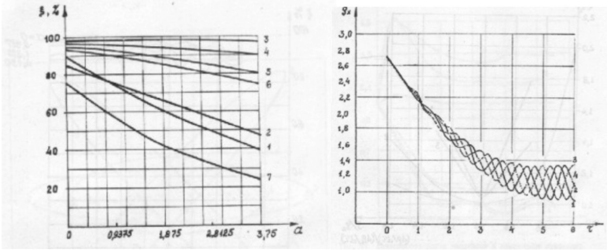

Fig.1. Dependences of ellipses' overlapping factors ξ for different laws of focusing rigidity and fringe field recessions on the characteristic Coulomb parameter a and beam normalized envelopes for different initial phases of the RF field [1]

A special law presented by Eq. (1) for an average radius of the RFQ rods for an adiabatic output matcher with beam transmission from crossover to crossover was developed in [3] with the use of normalized envelope equations (2). The direct application of this matcher to the RFQ input is not possible for a standard matcher length of 12 cells with a low matching coefficient *k*, Eq.(3), and requires additional investigations for providing a high value for ellipses' overlapping factor ξ [1].

$$R_0(n) = 0.5\left[R_0(N) - R_0(0)\right]\left(1 - \cos\frac{\pi n}{N}\right) + R_0(0)\,. \quad (1)$$

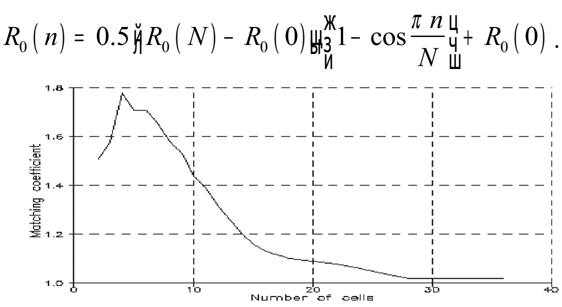

Fig.2. Dependence of the matching coefficient k on the number of RFQ cells in output adiabatic matcher

The envelope equations for a KV beam with a space charge are [4, p.161]:

$$\frac{d^2 r_x}{d\tau^2} + Q_x(\tau)\, r_x - \frac{F_0^2}{r_x^3} - \frac{2r_a^2}{r_x + r_y} = 0\,,$$

$$\frac{d^2 r_y}{d\tau^2} + Q_y(\tau)\, r_y - \frac{F_0^2}{r_y^3} - \frac{2r_a^2}{r_x + r_y} = 0\,.$$

The normalized form [1, 3] of these envelope equations [4, p.161] with the space charge is

$$\frac{d^2 \rho_x(\tau)}{d\tau^2} + Q_x(\tau)\,\rho_x(\tau) - \frac{1}{\rho_x^3(\tau)} - \frac{a}{\rho_x(\tau) + \rho_y(\tau)} = 0\,,$$

$$\frac{d^2 \rho_y(\tau)}{d\tau^2} + Q_y(\tau)\,\rho_y(\tau) - \frac{1}{\rho_y^3(\tau)} - \frac{a}{\rho_x(\tau) + \rho_y(\tau)} = 0\,. \quad (2)$$

The relation between the real *r* and normalized ρ envelopes in transverse planes are given below [4]:

$$r_{x,y}(\tau) = \sqrt{F_0}\cdot\rho_{x,y}(\tau)\,,\ F_0 = \frac{SV_0}{\beta\gamma}\,,\ \tau = \frac{z}{S}\,,$$

where S – focusing period, V₀ – normalized emittance in Lapostolle form, β, γ – relativistic parameters. In the normalized envelope equations (2) a characteristic Coulomb parameter *a* differs from a characteristic Coulomb radius r_a and a Coulomb parameter *h* of I.M.Kapchinsky [4, p.163] and is given as follows [3]:

$$a = 2\frac{r_a^2}{F_0} = 4\mu_0 h = \frac{4S}{(\beta\gamma)^2 V_0}\cdot\frac{I_{peak}}{I_0}$$

where I_{peak} – peak beam current, I_0 – characteristic current (for ions I_0=3,13·10^{7}A$_m$/Z A, A$_m$ – mass and Z - charge numbers, respectively) [4], μ_0 – characteristic parameter of a channel (phase advance for zero beam current). If [S] = L, then [V_0] = L·radian.

The matching (mismatch) coefficient *k* was calculated according to I.M.Kapchinsky method [4].

$$k = 1 + \sqrt{c^2 - 4}\,, \quad (3)$$

$$.\,c = \frac{\rho_0^2}{\sigma_0^2} + \frac{\sigma_0^2}{\rho_0^2} + \left(\rho_0\frac{d\sigma_0}{d\tau} - \sigma_0\frac{d\rho_0}{d\tau}\right)^2\Bigg|_{\tau=0}\,.$$

For the exact matching *k*=1.

An advantage of the normalized envelope equations is their independence on the channel parameters. This makes it possible to apply the results, obtained for one channel and beam parameters variant, to another variant with similar dynamics. The similarity is provided by the force function $Q_{x,y}(\tau)$ equality, matching conditions o_0, d o_0/dτ and the characteristic Coulomb parameter *a*.

2. MODIFIED ANALYTICAL LAW FOR FOCUSING RIGIDITY

The special law (1) for the adiabatic output matcher, developed previously in [3], was generalized to a proposed law (4) for focusing rigidity and introduced into the optimizing program ABC [5, 6]:

$$K^2(\tau) = \mathbf{0.5}\cdot\mathbf{c_4}\cdot K_0^2\cdot\left[\left(\mathbf{1}-\mathbf{sign}(\cos(\arg))\cdot(\cos(\arg))^{c_2}\right)^{c}\right.$$

$$\arg = 2\pi\cdot c_1\cdot(\tau-\tau_{\min})/(\tau_{\max}-\tau_{\min}) \qquad (4)$$

The region $0<c_1<0.5$ in (4) provides monotonous function. With $c_1>0.5$ it is possible to obtain non-monotonous profiles [7]. Values $c_1=0.5$, $c_2=c_3=c_4=1$ correspond to the adiabatic matcher (1). At the values $\tau_{min}=0$, $\tau_{\max}=\tau_0=6$, $c_1=0.25$, $c_2=c_4=2$, $c_3=1$, $c_5=0$ the formula (4) describes the matcher by A.I.Balabin [1]:

$$K^2(\tau) = K_0^2\sin^2\left(\frac{\pi\tau}{2\tau_0}\right)$$

As it can be seen, the proposed formula (4) generalizes a series of different laws for the RFQ matchers.

The first “IRM37” matcher was optimized for a beam current 55 mA and the second one, “IRM37-400”, was optimized for a 400 mA current and worth fringe field recession. Having the monotonous rods profiles at 12 RFQ cells with an initial fringe field of 0.57 of normalized length they were developed with the use of formulae (2), (4) in the code ABC [6].

3. MODERNIZED MATCHER “IRM37”

The optimization results for a beam current 55 mA are shown in Table 1-2 and Figs.3-4.

***Table 1**. The Average Matched Beam Normalized Envelope Parameters at Various Currents of Beam1*

I, mA	A.I.Balabin		“IRM37”	
	1ρ	1*d*ρ/*d*τ	1ρ	1*d*ρ/*d*τ
0	12.680	1-0.533	1.679	-0.164
55	13.382	1-0.799	2.158	-0.259
200	14.231	1-1.346	3.326	-0.519
300	15.990	1-1.635	3.989	-0.651
400	16.838	1-1.882	4.568	-0.761

The fitted parameters in the formula (4) are: $0.57<\tau<5.07$, $c_1=0.482$, $c_2=27.626$, $c_3=1.7004$, $c_4=1.4099$, $c_5=0{,}118$.

***Table 2**. Ellipses’ Overlapping Factor ξ at Different Beam Currents and Fringe Field Recessions*

1I, mA	1Linear	1Power (n=4)	1Sine
0	194.25	191.51	191.62
400	165.94	150.98	160.17

As it can be seen from the results obtained, the “IRM37” matcher has a low value of ellipses’ overlapping factor ξ at a current 400 mA and it leads to develop the “IRM37-400”.

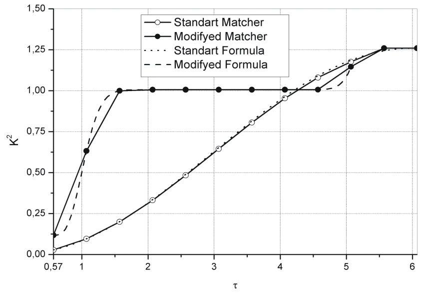

Fig.3. Dependences of focusing rigidity on the longitudinal normalized coordinate τ in the matcher by A.I.Balabin and the modified”IRM37” dynamical one

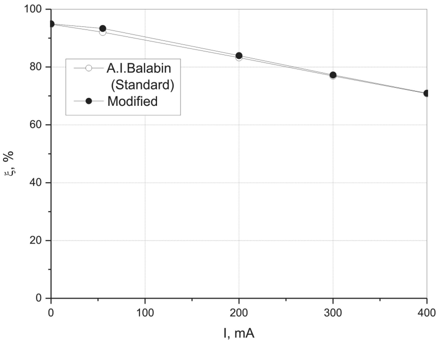

Fig.4. Dependences of the coefficient ξ on beam current in the matcher by A.I.Balabin and the ”IRM37” one

4. OPTIMIZED MATCHER “IRM37-400”

The optimization results for a beam current 400 mA and power n=4 for recession of the fringe field are shown in Figs.5-7.

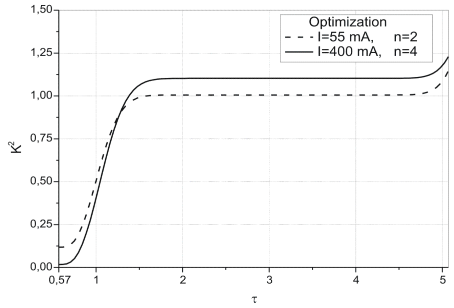

Fig.5. Analytical dependences of focusing rigidity on the longitudinal normalized coordinate τ in the “IRM37” and “IRM37-400” dynamical matchers

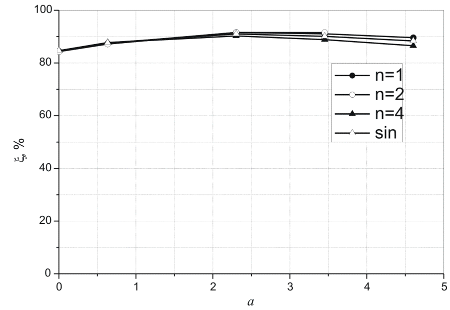

Fig.6. Dependences of the coefficient ξ on the parameter a at different fringe field recessions in the “IRM37-400” matcher

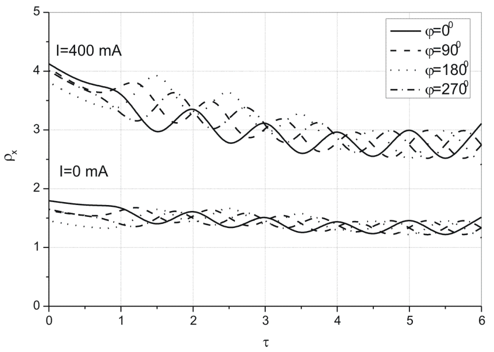

Fig.7. Dependences of normalized envelopes on the longitudinal coordinate in the dynamical matcher "IRM37-400" for different initial phases of the RF field

The "IRM37-400" matcher also provides almost constant and close to the "IRM37" the normalized envelope parameters, averaged on RF phases, at various fringe field recessions The fitted parameters in the formula (4) are: c_1=0.47286, c_2=23.6828, c_3=1.6829, c_4=1.7246, c_5=0.01691.

5. CONCLUSION

The analytical law for focusing rigidity distribution along the channel axis, generalizing the number of previously offered laws for the RFQ dynamical matchers, is proposed. The optimization method, based on the proposed law and taking into account the worth conditions for beam dynamics, is created. The coefficients in the formula proposed are fitted with the use of the high speed optimized program ABC and may provide a monotonous RFQ electrode profile. The method developed allows calculating the dynamical matchers with practically constant value of ellipses' overlapping factor and reducing the sensitivity to the initial part with a fringe field, difficult to control, in a wide range of beam current.

In the matchers developed with the monotonous electrode profile, the envelope slope at the RFQ input is reduced by almost 2.5 times in comparison with the applied matchers with the high-quality of matching in a wide range of beam current and fringe field recession.

The results obtained allow facilitation of the requirements for the beam formation system at the RFQ input and reduction of the emittance growth in the LEBT.

REFERENCES

1. A.I. Balabin, V.S. Kabanov, V.V. Kushin, I.M. Lipkin. *The numerical investigation of matching of beam with space-uniform quadrupole channel.* Preprint ITEP, № 28, 1984.
2. J.W. Barth, L. Dahl, J. Glatz et al. *Achievements of the High Current Beam Performance of the GSI Unilac.* Proc. of EPAC-04, Lucern, Switzerland. 2004, p.1171.
3. I.A. Vorobyov. *Evolution of phase volume and beam matching in high power Linac.* Autoreferate of doctor dissertation on physics and mathematics sciences. Moscow, 2002
4. I.M. Kapchinsky. *Theory of Linear Resonance Accelerators*. M.: "Energoizdat", 1982
5. I.A. Vorobyov. *Program ABC*. Information fond of algorithms and programs on accelerator theme. AS and Minatom RF, M., 1992, p.159.
6. I.A.Vorobyov. *Analytical law for focusing rigidity and calculation with use of optimizing ABC code of dynamical unmodulated matcher with reduced slope of beam envelope at the RFQ entrance.* Preprint ITEP, № 8-05, 2005.
7. D.G. Koshkarev, L.G. Vorobjev. New Algorithm for RFQ Matching Section Design // *Nucl. Instr. and Methods.* 1993. v.A336, p.291-300.

МЕТОД ОПТИМИЗАЦИИ И РАЗРАБОТКА С ИСПОЛЬЗОВАНИЕМ ПРОГРАММЫ ABC ВХОДНОГО ДИНАМИЧЕСКОГО СОГЛАСОВАТЕЛЯ СО СНИЖЕННЫМ УГЛОМ НАКЛОНА ОГИБАЮЩЕЙ ПУЧКА В ШИРОКОМ ДИАПАЗОНЕ ТОКОВ ДЛЯ СИЛЬНОТОЧНОЙ ТЯЖЕЛОИОННОЙ СЕКЦИИ ПОКФ

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Ранее разработанный аналитический закон для выходного согласователя начальной части ПОКФ адаптирован для входного немодулированного динамического согласователя. Предложена аналитическая формула, описывающая различные типы согласователей. Выполнена модернизация программы ABC для оптимизации каналов с применением аналитических формул. Разработан метод оптимизации согласователей с сохранением динамического согласования в широком диапазоне токов и сниженной чувствительностью к начальному участку ПОКФ с трудно контролируемым спадом краевого поля.

МЕТОД ОПТИМІЗАЦІЇ І РОЗРОБКА З ВИКОРИСТАННЯМ ПРОГРАМИ ABC ВХІДНОГО ДИНАМІЧНОГО УЗГОДЖУВАЧА ЗІ ЗНИЖЕНИМ КУТОМ НАХИЛУ ОБІГАЮЧОЇ ПУЧКА В ШИРОКОМУ ДІАПАЗОНІ СТРУМІВ ДЛЯ ПОТУЖНОСТРУМОВОЇ ВАЖКОІОННОЇ СЕКЦІЇ ПОКФ

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Раніше розроблений аналітичний закон для вихідного узгоджувача початкової частини ПОКФ адаптовано для вхідного немодульованого динамічного узгоджувача. Запропоновано аналітичну формулу, що описує різні типи узгоджувачів. Виконано модернізацію програми ABC для оптимізації каналів із застосуванням аналітичних формул. Розроблено метод оптимізації узгоджувачів із збереженням динамічного узгодження в широкому діапазоні струмів і зниженою чутливістю до початкової ділянки ПОКФ з важко контрольованим спадом крайового поля.