RESULTS OF BEAM DYNAMICS SIMULATIONS IN THE MATCHING LINE AND FIRST ALVAREZ TANK OF THE UNILAC

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Parameters of the beam Ar^{10+} at input of the 1^{st} Alvarez tank for providing maximal transmission and brilliance, minimum emittance growth in all Alvarez for the different currents of beam and distribution of particles were optimized. The task solution had two stages. The first stage is beam dynamics calculation in Alvarez DTL for phase advance 53^0 in the 1^{st} Alvarez tank with 11 mA beam current and gauss distribution for finding the best Twiss-parameters to the 1^{st} Alvarez tank. The optimization was made with accounting longitudinal emittance and separatrix of channel. The second stage is beam dynamics calculation with optimal parameters of matching line to Alvarez DTL for measured input particle distribution. The results of beam dynamics simulation for Ar^{10+} with 10 mA at input energy 1.4 MeV/u using PARMI-GSI and PARMT-GSI codes are presented.

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1. INTRODUCTION

The GSI linear accelerator UNILAC has to serve as a high current injector for the future GSI-accelerator facility, especially for heavy ions like uranium. Presently the UNILAC is not able to provide for required beam brilliance at the synchrotron injection. In the next future it is necessary to start with a R and D program in the different sections of the GSI linac [3]. At the synchrotron injection the beam brilliance has to be increased by optimizing the focusing strength especially in the first Alvarez section, where increasing of the quadrupole strength leads to the higher phase advance of the focusing channel. Systematic numerical studies of the phase advance influence to the beam quality in the Alvarez DTL were executed for beam Ar^{10+} and for current up to 10 emA. After the stripping process the electrical beam current is increased. This leads to a significant beam emittance growth during the transport through the matching line to the Alvarez DTL. The research of the beam dynamics in the 1^{st} Alvarez tank during the optimization of the parameters of the matcing line carried out for the measured particle distribution.

2. BEAM DYNAMICS SIMULATION IN THE FIRST ALVAREZ TANK FOR DIFFERENT PHASE ADVANCES OF RADIAL OSCILLATIONS

Simulation of the Ar^{10+} the beam dynamics in the 1^{st} Alvarez tank are carried out for following phase advances 45^0, 50^0, 53^0, 55^0, 60^0 and for artificial $6D$ particle distribution. The results of the dynamics of for 11 emA are shown on Fig.1. The optimal value of phase advance of the radial oscillations in the first tank is 53^0. With this phase advance transverse emittance growth at the output of the first tank was $\varepsilon_x = 0.5$ percent, $\varepsilon_y = 2$ percent, and relative brilliance 0.96. For the calculations we used 1000 macroparticles. Particle transmission for all phase advances was 100 percent. The input Twiss parameters of the beam were optimized with account of matching longitudinal emittance with separatrix of the channel.

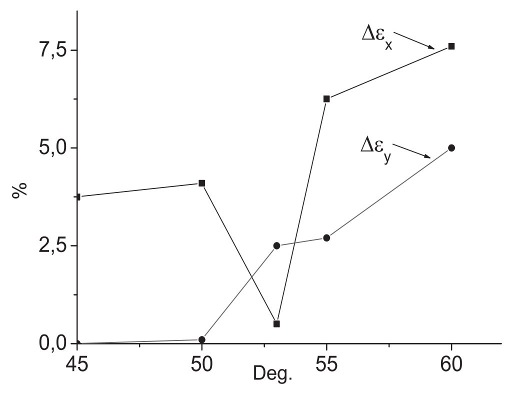

Fig.1. *Emittances growth behind the 1^{st} Alvarez section as a function of the transverse phase advances*

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3. MATCHING SECTION

After the separation the beam must be matched to the Alvarez DTL section. Matching line consist of 36 MHz rebuncher,the quadrupole doublet, the quadrupole triplet and the 108 MHz rebuncher (Fig.2) [2]. The measurement of the transverse phase space distribution was done between the quadrupole doublet and the quadrupole triplet, using the slit-grid device (Fig.3). Knowing the settings of the quadrupoles in the matching line, the measured distribution are transformed back to the entry of the matching line by means of PARMT-GSI code. Number of particles is 1641, current is 10 emA.

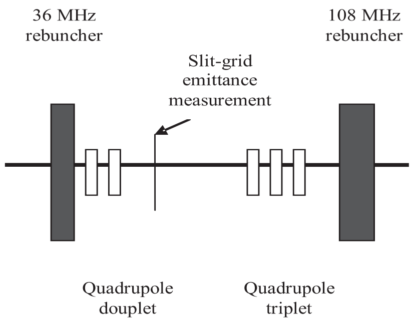

Fig.2. *Matching section to the* 1^{st} *Alvarez tank*

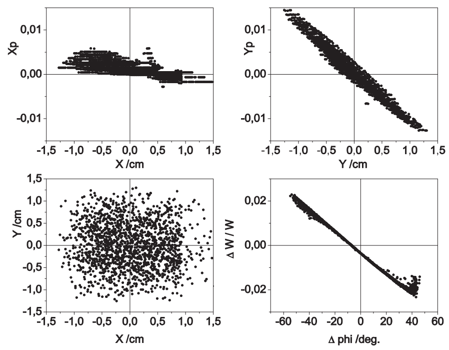

Fig.3. *Data of emittance measurement at matching section for* 10 *emA* Ar^{10+} *beam*

As we can see, the measured distribution has the spread by energy ±1.5 percent, phase range 80^0.

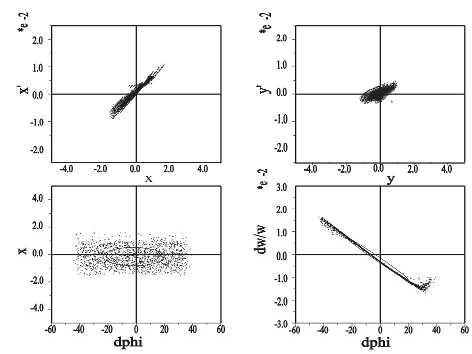

Fig.4. *Data of emittance measurement at entry of the matching section for* 10 *emA* Ar^{10+}*beam*

Such parameters of the beam will the inevitably result in the transverse emittance growth, and, so, decrease of the brilliance of the beam. On Fig.4 we can see the particles distribution at the entry of the matching line. The discussion of the reasons of such quality of measured distribution is out of borders of this article. The beam is mismatched with DTL.

4. BEAM DYNAMICS SIMULATION FOR OPTIMIZED PARAMETERS OF THE MATCHING LINE

The beam dynamics simulation was done in the matching line, using the PARMT-GSI code and in the 1-st Alvarez tank using PARMI-GSI code on the LINUX platform. The parameters of the elements of the matching line are got with method developed in KIPT and are shown in Table 1.

The main goal of the work was definition of the optimum parameters of the devices of the matching line providing the beam parameters at the input of the first Alvarez tank which allow obtaining the highest beam brilliance, transmission, and low emittance growth in the overall Alvarez structure.

In order to solve this problem a number of works have been carried out already where different optimization methods were used which are described in the literature; in these works different methods for optimization were used such as the method of beam envelope, method using linearized Kapchinsky-Vladimirsky equations; methods based on quasi-periodicity of the accelerating structure etc. Most of these methods include simplifications for calculations of charged particles dynamics; this may significantly distort the true beam parameters. Therefore, when high-current beams in long accelerating structures are discussed it is necessary to refuse from any simplifications when optimizing such beam parameters as brilliance, transmission, emittance growth, and to use detailed numerical simulation with account of non-linearity of external fields and space charge field and interrelation between longitudinal and transverse motion. The results of such calculations should be the subject of minimization. Experience of the work acquired in KIPT on experimental investigations of high-current beams in structures of multicharge ion linear accelerators allows formulating the following approach to the task of minimization beam emittance growth in the course of acceleration. The code for optimization was developed which uses a complex method for defining the minimum of a function of N variables lying in specified range. The method is based on comparison of the function values being optimized and does not require the smoothness of the function.

The results of beam dynamics simulation are shown on Fig.5 - Fig.9. All elements of the matching line, including two rebunchers, were used in the calculation, unlike the [2], where only five matching quadrupoles were used. As the matching line has two rebunchers, the first of which is 36 MHz, and the second is 108 MHz, results of the dynamics in these sections are shown in Table 2 separately.

Table 1.

No elem.	Element	Param.value
1	Rebuncher	0.1155 MV
2	US4QD41	1138.39 Gs/cm
3	US4QD42	−1060.45 Gs/cm
4	US4QT51	1634.63 Gs/cm
5	US4QT52	−1620.13 Gs/cm
6	US4QT53	1271.01 Gs/cm
7	Rebuncher	0.0842 MV

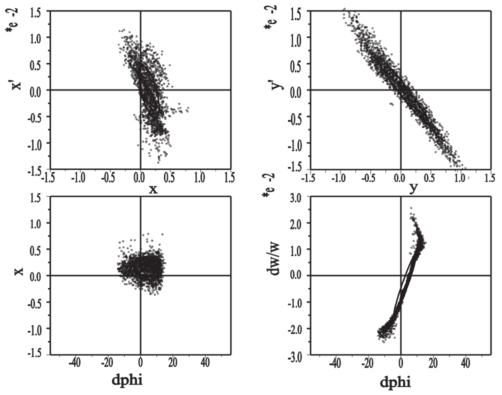

Fig.5. *The particle distribution in position behind the quadrupole triplet of the matching section for* 10 *emA* Ar^{10+} *beam*

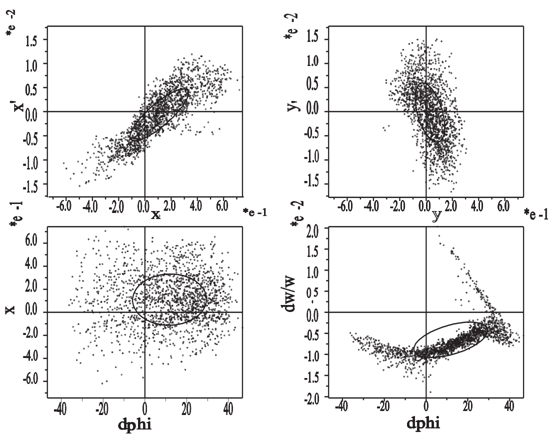

Fig.6. *The particle distribution at exit of the matching section for* 10 *emA* Ar^{10+} *beam*

On the Fig.5 the beam data after the 1^{st} rebuncher, quadrupole doublet and quadrupole triplet is shown. In this section rms emittanse growth are ε_x = 5.53 percent, ε_y = 8.69 percent. On the output of the matching line rms emittances growth are $\Delta\varepsilon_x$ = 9.8 percent, $\Delta\varepsilon_y$ = 8.75 percent, transmission is 100 percent,(Fig.6). Further, the beam dynamics calculation was done using the PARMI-GSI code. In the calculations of dynamics with the PARMI code, the field in the gaps of DTL sections is presented in the form of 'thin lens'. With such input beam parameters at the output of the 1st Alvarez tank we obtained rms emittances growth $\Delta\varepsilon_x$ = 15.8 percent, $\Delta\varepsilon_y$ = 79.5 percent, spread by energy is ±0.2 percent, phase range is 45^0, transmission is 100 percent, (Fig.7).

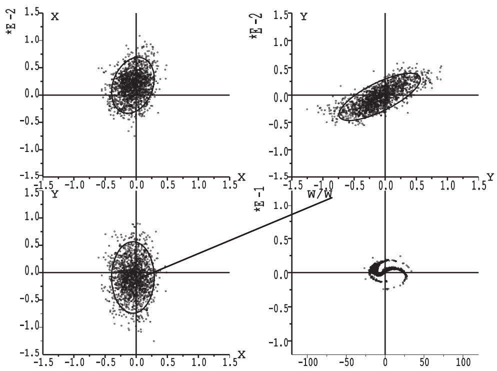

Fig.7. *The particle distribution at exit of the* 1^{st} *Alvarez tank simulated with PARMI-GSI code for* 10 *emA* Ar^{10+} *beam*

Longitudinal motion of the beam we can see on Fig.8. The measured particles distribution was obtained after UNILAC RFQ, super lens, 2 IH-structures, gas stripper,10 emA Ar^{10+} and was used for matching including space charge. Parameters of the sections of the matching line optimized according to KIPT- method are summarized in the Table 2. It is enough big emittance growth in the first tank proves that much highly matching measured distribution to Alvarez DTL. For all Alvarez sections the parameters of Ar^{10+}, 10 emA beam for measured particle distribution we can see on Fig.9. Emittances growth $\Delta\varepsilon_x$ = 51 percent, $\Delta\varepsilon_y$ = 137 percent, transmission is 97.7 percent.

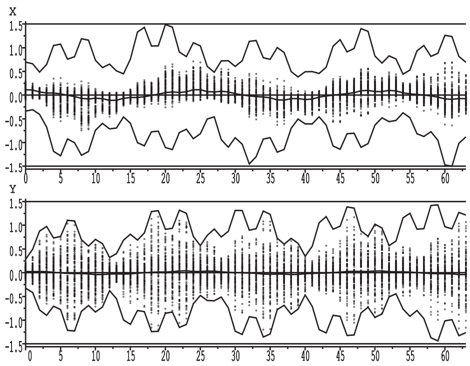

Fig.8. *Horizontal and vertical envelopes in the first Alvarez tank for* 10 *emA* Ar^{10+} *beam*

Table 2.

Pos.	ε_x	ε_y	$\Delta\ \varepsilon_x$	$\Delta\ \varepsilon_y$
1	0.338	0.299	–	–
2	0.357	0.325	5.53	8.69
3	0.371	0.326	4.00	0.06
4	0.371	0.326	9.80	8.75
5	0.391	0.537	15.8	79.5

In Table 2: position 1-entry of matching line, position 2-exit of 36 MHz section, position 3-exit of 108 MHz section, position 4-exit of matching line, position 5-exit of first tank; ε_x, ε_y have units of mm*mrad, $\Delta\varepsilon_x$, $\Delta\varepsilon_y$, have units of percent. Transmission is 100 percent.

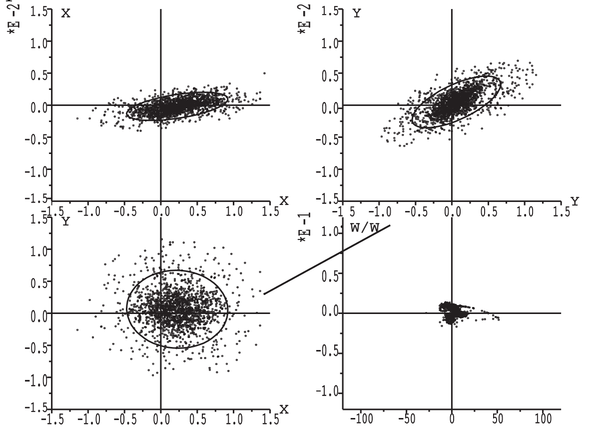

Fig.9. *The particle distribution at the exit all Alvarez sections for* 10 *emA* Ar^{10+} *beam*

Further, the comparison of the dynamics results described above, with the results calculated by PARMELA code. Field distribution in Alvarez cells for PARMELA code was calculated using Poisson Superfish code. On Fig.10 beam dynamics results calculated by PARMI-GSI and PARMELA codes are shown.

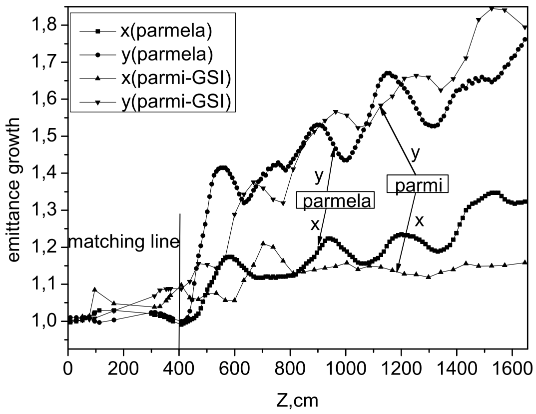

Fig.10. *Transverse emittances growth for* 10 *emA* Ar^{10+} *beam calculated with PARMELA and PARMI-GSI codes in the matching line and in the first Alvarez tank*

Table 3.

Code	$\Delta\varepsilon_x$	$\Delta\varepsilon_y$	Transmission
PARMI	15.38	79.5	100
PARMELA	32.0	76.0	99.5

One can say that good coincidence of the results for the 1^{st} Alvarez tank is watched (see Table 3). In Table 3 $\Delta\varepsilon_x$, $\Delta\varepsilon_y$, Transmission have units of percent.

5. CONCLUSIONS

Beam dynamics simulation for Ar^{10+}, 10 emA has shown that the best phase advance of the radial oscillations in the 1^{st} Alvarez tank is 53^0. So the quadrupole feeding system must be modernized at least in the 1st tank. The measured $6D$ particle distribution must be coordinated at the input of the Alvarez DTL. The optimization methods developed in KIPT that allows to calculate parameters of the matching line operatively, has tested by different codes. Good coincidence of the dynamics results has been got. We acknowledge the support under INTAS project $03-54-3543$.

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РЕЗУЛЬТАТЫ МОДЕЛИРОВАНИЯ ДИНАМИКИ ПУЧКА ИОНОВ В СОГЛАСУЮЩЕЙ ЛИНИИ И В ПЕРВОМ ТАНКЕ АЛЬВАРЕЦА УСКОРИТЕЛЯ UNILAC

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Оптимизировались параметры пучка ионов Ar^{10+} на входе в первую секцию Альвареца для обеспечения максимальных величин трансмиссии, яркости и минимального роста поперечных эмиттансов во всех секциях Альвареца для различных токов пучка и распределений частиц. Задача решалась в два этапа. На первом этапе - расчет динамики пучка в структуре Альвареца для оптимального набега фаз радиальных колебаний 53^0 в первом танке при токе пучка 11 мА с гауссовым распределением с целью определения наилучших значений Twiss - параметров пучка на входе в первый танк. Оптимизация велась с учетом согласования продольного эмиттанса с сепаратрисой канала. На втором этапе - расчет динамики пучка при оптимальных параметрах элементов согласующей линии и измеренном входном распределении. Приводятся результаты моделирования динамики пучка ионов Ar^{10+} с входной энергией 1.4 МэВ/н при токе 10 мА в согласующей линии и в первом танке Альвареца с помощью программ PARMI-GSI и PARMT-GSI.

РЕЗУЛЬТАТИ МОДЕЛЮВАННЯ ДИНАМІКИ ПУЧКА ІОНІВ В ЛІНІЇ, ЩО ПОГОДЖУЄ, І В ПЕРШОМУ ТАНКУ АЛЬВАРЕЦЯ ПРИСКОРЮВАЧА UNILAC

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Оптимізувалися параметри пучка іонів Ar^{10+} на вході в першу секцію Альвареця для забезпечення максимальних величин трансмісії, яскравості і мінімального зростання поперечних еміттансів у всіх секціях Альвареця для різних струмів пучка і розподілів частинок. Завдання вирішувалося в два етапи. На першому етапі - розрахунок динаміки пучка в структурі Альвареца для оптимального набігу фаз радіальних коливань 53^0 у першому танку при струмі пучка 11 мА з гауссовим розподілом з метою визначення найкращих значень Twiss-параметрів пучка на вході в перший танк. Оптимізація велася з урахуванням узгодження подовжнього еміттансу з сепаратрісою каналу. На другому етапі - розрахунок динаміки пучку при оптимальних параметрах елементів лінії, що погоджує, і виміряному вхідному розподілі. Приведені результати моделювання динаміки пучка іонів Ar^{10+} з вхідною енергією 1.4 МеВ/н при струмі 10 мА в лінії, що погоджує, і в першому танку Альвареця за допомогою програм PARMI-GSI і PARMT-GSI.