METHOD FOR MINIMIZATION OF THE BEAM PHASE VOLUME GROWTH ON THE POST-STRIPPING SECTION OF THE UNILAC

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The method for determination of the optimum parameters of the matching line of UNILAC post-stripping section (Alvarez structure) is presented. The distinctive feature of this method is the fact that the object of minimization is a numerical model for calculation of the dynamics of realistic beam in the realistic accelerating fields. Such approach allows solving optimization problems in the full setting of the problem. There exist no limitations on the kinds of devices being optimized: magnetic quadrupoles, accelerating gaps etc. It is possible to carry out simultaneous optimization of the matching line parameters and values of magnetic lens quadrupole gradients along the accelerating section. Calculation of the optimum parameters of the matching line for the measured Ar^{+10} beam distribution is presented with the current of 10 emA; for the calculated parameters output beam parameters are presented.

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1. INTRODUCTION

Presently, the problem of estimation the optimum parameters of ion linear accelerators is especially important. This is associated with the necessity to obtain high current ion beams with high acceleration rate and low beam losses in the course of acceleration. Matching the accelerating structures possessing different properties are especially important for obtaining the optimum beam parameters. Such problems in general setting are rather complicated, and necessity arises to turn to some simplification. Most often, the beam is described as a three-dimensional ellipsoid, fields in the structures is presented in the approximation of "thin" lens or "rectangular wave", accelerating structures are considered to be periodic. In the presented work the general approach is proposed to solve the tasks of optimization using real field and beam characteristics. Calculations of the optimum parameters of the matching line of the UNILAC [1 - 2] post-stripping section were performed in the frames of the proposed approach.

2. SETTING OF THE PROBLEM

Calculations and experimental investigations of the high current bean dynamics in the structures of multicharge ion linear accelerators allow formulating the following approach to the problem of minimization the emittance growth in the course of acceleration. It was found that application of the method of envelopes, Kapchinckij-Vladimirckij linearized equations, assumption of quasi-periodicity of the accelerating structure and other simplifications for calculations of charged particles dynamics may essentially distort the real beam parameters. Therefore, when high-current beams are discussed in long periodic structures for minimization such beam parameters as brilliance, emittance growth, and beam losses we should refuse from any simplified methods for description of the beam dynamics, and to use detailed numerical simulation with account of non-linearity of external and Coulomb fields and interrelationship between transverse and longitudinal movement. These are the results that should be the object for minimization task. Taking this reason into consideration we will formulate the task in the following way. Let the beam of charged particles at the input of the accelerating structure is presented as having its phase distribution which is measured experimentally and it is approximated by specification of coordinates of N particles in $6D$ phase space. Geometry of the structure cells and HF field distribution are the specified values. The parameters being optimized are:

- gradients of magnetic quadrupole lenses and voltages on the bunchers and debunchers in the matching section;
- gradients of magnetic quadrupole lenses in the main sections of the Alvarez structure and matching elements between them.

It is required to determine such optimization parameters with which the transverse phase volume $\varepsilon_x, \varepsilon_y$ of the beam reaches the minimum with the maximum transmission T_p.

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3. PROCEDURE OF SOLVING

It is possible to solve the task in the following way. A controlling and optimizing procedure was developed for the program for calculation of beam dynamics accounting space charge which executes the following functions:

- launch the program for calculation of the beam dynamics with different values of the parameters being optimized;
- analyzes the beam parameters at the output ($\varepsilon_x, \varepsilon_y$, T_p);
- calculates the minimum ($\varepsilon_x, \varepsilon_y$) with the maximum beam transmission;
- stops the optimization process when the minimum ($\varepsilon_x, \varepsilon_y$) is achieved with the maximum value of T_p.

The procedure is iterative and is realized automatically. For calculation of beam dynamics the PARMELA [3] program was chosen. This program allows to input external HF - fields in the mesh form and in the form of Fourier coefficients and to use several different methods for calculation of space charge forces. One of the difficulties that arises with development of the optimization code lies in the following. The goal function, or the function being optimized, should be a combination of $\varepsilon_x, \varepsilon_y$ and T_p parameters. Since beam transmission T_p changes discretely the goal function $F(\varepsilon_x, \varepsilon_y, T_p)$ is discontinuous which complicates the optimization process. Therefore the developed code uses a complex method for determination the minimum for the functions of N variables lying in the specified range. The method is based on comparison of the values of the function being optimized and does not require the function smoothness. To calculate the optimized parameters the following steps should be performed.

1. Input geometry of the cells of the structure and HF field distribution in the PARMELA program. Values of the fields may be presented in the mesh form in the form of Fourier coefficients.

2. Input the initial phase distribution of the beam. There exists a possibility to specify any external distribution and a large set of phase distributions generated with the program.

3. Input into the code the number of optimization parameters and acceptable range of changing for each of them.

As a results of calculations with the code we will obtain values of the optimum parameters, values of transverse emittances ($\varepsilon_x, \varepsilon_y$), beam transmission T_p and other beam characteristics in numerical and graphical form.

4. CALCULATIONS OF THE OPTIMUM PARAMETERS OF THE MATCHING LINE ON THE POST-STRIPPING SECTION OF THE UNILAC

Let us discuss the problem of determination of the optimum parameters of the matching line of the post-stripping section of the UNILAC (Alvarez structure) for different input beam distributions. The values of these parameters should be so that at the output of the 1st Alvarez section transverse emittances $\varepsilon_x, \varepsilon_y$ have the minimum values with the maximum beam transmission. With our optimization code the solving procedure may be presented as follows Fig.1. The $6D$ matching of the beam is carried out by a system consisting of the 36 MHz rebuncher, the quadrupole doublet, the quadrupole triplet and the 108 MHz rebuncher [4].

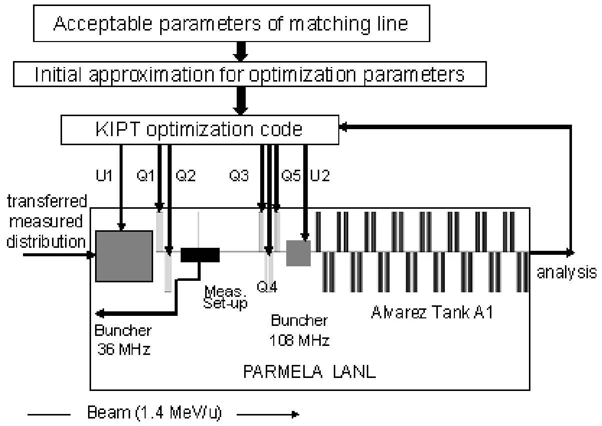

Fig.1. *General scheme for optimization of the parameters of the matching line*

The number of optimization parameters and acceptable range for each parameter are given in the table.

Parameter being optimized	Range	Units
$U1$ (voltage on the buncher gaps)	0.06, 0.15	MV
$G1$ (gradient of the 1st lens of the quadrupole doublet)	900, 1200	Gs/cm
$G2$ (gradient of the 2nd lens of the quadrupole doublet)	-1200, -400	Gs/cm
$G3$ (gradient of the 1st lens of the quadrupole triplet)	1000, 1800	Gs/cm
$G4$ (gradient of the 2nd lens of the quadrupole triplet)	-2000, -1600	Gs/cm
$G5$ (gradient of the 3d lens of the quadrupole triplet)	500, 2000	Gs/cm
$U2$ (voltage on the debuncher gaps)	0.05, 0.2	MV

Parameters of input distribution of particles at the input of the matching line for Ar^{+10} beam and current of 10 emA are shown in the Fig.2. These parameters were obtained in the following way. $6D$ phase volume of the beam was measured on the matching line between the quadrupole doublet and quadrupole triplet; then was transferred back numerically to the input of the matching line.

Electric fields in the Alvarez accelerating section was calculated with SUPERFISH code [5] with account of real geometry of the drift tubes. Then these fields in the mesh form were input in PARMELA code. The number of the mesh nodes in longitudinal direction was 122, and in transverse direction it was 11. 1641 macroparticles were used for beam dynamics simulation.

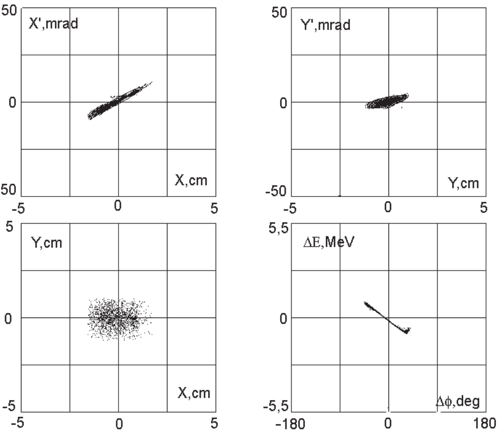

Fig.2. *Parameters of input particles distribution a the input of the matching line*

In the course of calculations with the presented code values of parameters for real field distribution were obtained: $U1 = 0.115525\,MV$, $G1 = 1138.39\,Gs/cm$, $G2 = -1060.45\,Gs/cm$, $G3 = 1634.13\,Gs/cm$, $G4 = -1620.13\,Gs/cm$, $G5 = 1271.01\,Gs/cm$, $U2 = 0.0842\,MV$. In the Fig.3,4 the beam parameters are given at the output of the 1st Alvarez section with using the optimized parameters.

In the Fig.5 emittance growths are given along the matching line and 1*st* Alvarez tank with real description of the field.

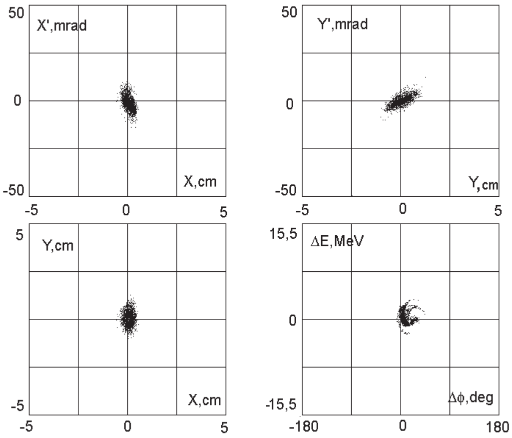

Fig.3. *Beam parameters at the output of the first tank*

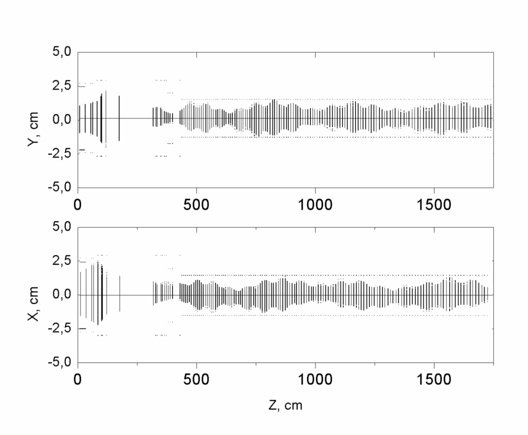

Fig.4. *Beam profile in the first Alvarez tank*

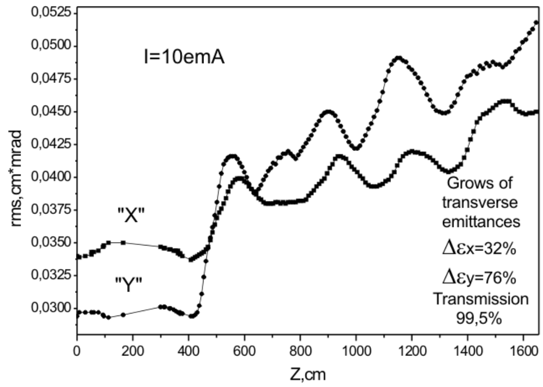

Fig.5. *Emittance growth along the matching line and first tank*

5. CONCLUSION

Distinctive features of this method are following:

- Values of the optimum parameters of the matching line are determined for any input beam distribution (artificially generated or measured experimentally.
- These values are determined for the entire accelerating section with account of space charge forces.
- There are no limits on all types of the devices being optimized: these may be magnetic quadrupoles, accelerating gaps or other devices.
- There exists a possibility to carry out optimization of the parameters the matching line and values of quadrupole gradients of the magnetic lenses along the accelerating structure simultaneously.
- The developed method may be applied for different types of optimization tasks.
- For the post-stripping section of UNILAC the developed method for optimization allows to determine parameters of the matching line operatively (calculation time for one variant 80 minutes.

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МЕТОДИКА МИНИМИЗАЦИИ РОСТА ФАЗОВОГО ОБЪЕМА ПУЧКА НА ПОСТОБДИРОЧНОМ УЧАСТКЕ УСКОРИТЕЛЯ UNILAC

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Представлена методика определения оптимальных параметров согласующей линии постобдирочного участка ускорителя UNILAC (структура Альвареца). Особенностью данной методики является то, что объектом оптимизации является численная модель динамики реального пучка в реальных ускоряющих полях. Такой подход позволяет решать оптимизационные задачи в полной постановке для любых входных распределений пучка. При этом нет никаких ограничений на виды оптимизируемых устройств: это могут быть магнитные квадруполи, ускоряющие зазоры и т.д. Имеется возможность одновременно проводить оптимизацию параметров согласующей линии и величин квадрупольных градиентов магнитных линз вдоль ускоряющей секции. Приведен расчет оптимальных параметров согласующей линии для экспериментально измеренного входного распределения пучка частиц Ar^{+10} при токе 10 emA, представлены выходные параметры пучка для вычисленных параметров.

МЕТОДИКА МІНІМІЗАЦІЇ РОСТУ ФАЗОВОГО ОБ'ЄМУ ПУЧКА НА ПІСЛЯОБДИРКОВОЇ ДІЛЯНКИ ПРИСКОРЮВАЧА UNILAC

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Представлено методику визначення оптимальних параметрів узгоджуючої лінії післяобдиркової ділянки прискорювача UNILAC (структура Альвареця). Особливістю даної методики є те, що об'єктом оптимізації є чисельна модель динаміки реального пучка в реальних прискорювальних полях. Такий підхід дозволяє вирішувати оптимізаційні задачі в повній постановці для будь-яких вхідних розподілів пучка. При цьому немає ніяких обмежень на види пристроїв, що оптимізуються: це можуть бути магнітні квадруполі, прискорюючі зазори й т.д. Є можливість одночасно проводити оптимізацію параметрів узгоджуючої лінії і величин квадрупольних градієнтів магнітних лінз уздовж прискорювальної секції. Наведено розрахунок оптимальних параметрів узгоджуючої лінії для експериментально виміряного вхідного розподілу пучка часток Ar^{+10} при струмі 10 emA, представлені вихідні параметри пучка для обчислених параметрів.