THE OPTIMIZATION DESIGN AND TOLERANCE ANALYSIS OF DTL IN SSC-INAC*

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Abstract

The SSC(Separated Sector Cyclotron)-linac is being designed. According to the design requirements, $^{238}U^{34+}$ ions are accelerated from 0.143MeV/u to 0.976MeV/u through the DTL(Drift-Tube-linac). And the method coupling DAKOTA(Design Analysis Kit for Optimization and Terascale Application) and beam simulation code BEAMPATH is used to analyze tolerance of the structure. The tolerance of beam parameters to various type of random errors from quardpoles and cavities are studied with Monte Carlo sampling, so as to define the engineering tolerance and alignment requirements. In this paper, the beam dynamics simulation and the tolerance analysis of the SSC-linac are presented.

INTRODUCTION

To offer more beam current time to user, a new injector SSC-linac is being design. It includes an ECR ion source to produce $^{238}U^{34+}$ beam, LEBT(low energy beam transport),an RFQ(Radio Frequency Quadruple), MEBT(Middle Energy Beam Transport) to match the beam with DTL, a DTL to accelerate ions to 0.976MeV/u from 0.143MeV/u and HEBT(High Energy Beam Transport). The layout of the SSC-linac is shown in Fig. 1.

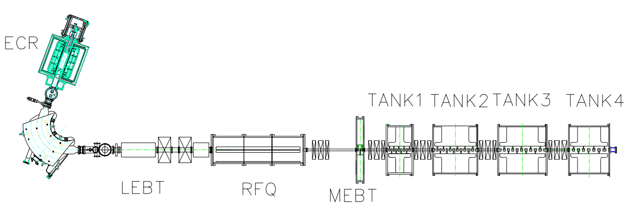

Figure 1: The layout of the SSC-linac.

The DTL, whose operation frequency is chosen to be 52.0MHz, is four accelerating cavities and four quadruple triplets. The four independent tanks, each operating at -20°, -25°, -35°, -25° synchronous phase successively, provide acceleration and longitudinal focusing, while quadruple triplets placed between tanks provide periodic transverse focusing. This structure is so-called separated function DTL. The advantage of this structure is low power consumption and flexible adjustment in online operation .

THE BEAM DYNAMICS SIMULATION

In the design of the DTL, the code LINREV which is developed for the design of RILAC booster at RIKEN [1] is used. The initial emittance is chosen to be 1.0π·mm·mrad in transverse and 50.0π·KeV/u·degree in longitude. 1000 ions initialized as homogeneous distribution are tracked through the DTL. The distributions of extracted beam in six-dimensional phase space are plotted in Fig. 2.

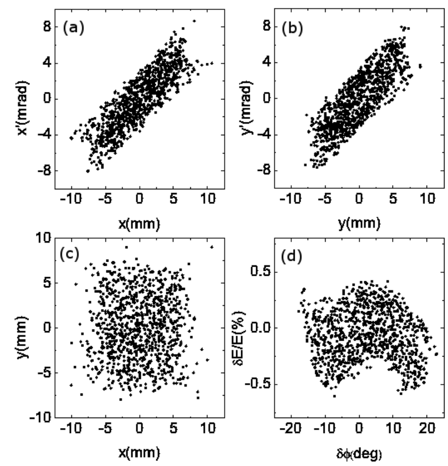

Figure 2: The distributions of the initial and extracted beam in six-dimensional phase space. the phase space distribution of the extracted beam:(a)in x direction. (b)in y direction. (c) in x-y plane. (d)in longitude.

As shown in Fig. 2, the energy spread of the extracted beam is about ±0.5%, the $\delta\phi$ is about ±20 degrees. In the transverse, normalized emittance is grows about 23.5% in X direction and 22.0% in Y direction. The emittance is comparable with both the acceptance of the SSC in transverse and longitude.

The beam envelope varying with acceleration is shown in Fig. 3. From this figure, we can seen that the envelope in transverse is biggest between the rebuncher and the first tank. The radius of the quadruple here is 2mm larger than others in order to increase the acceptance of the DTL.

The parameters of DTL are listed in Table 1.

THE TOLERANCE ANALYSIS OF DTL

The Introduction of Method

To study the tolerance of beam to various type of random errors from quardpoles and cavities and offer engineering tolerance and alignment requirements, the tolerance analysis have been done with the method coupling DAKOTA with the beam simulation code BEAMPATH.

The BEAMPATH code has been developed since the early 1980s as a many-purpose tool for studying for 2D and 3D space charge dominated beam dynamics in linear accelerators and beam lines . The program can be used for

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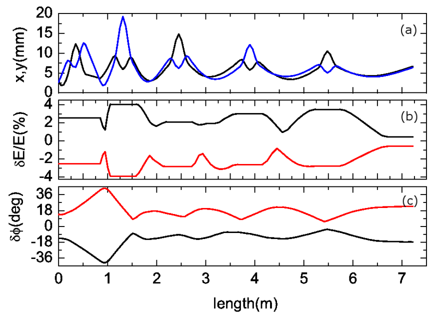

Figure 3: The envelop varying with acceleration. (a)The transverse envelop in both X and Y direction. (b)The energy spread. (c)The phase spread width.

Table 1: The Summary of Parameters in DTL

Parameters	Value	Unit
Ions	$^{238}U^{34+}$	
Operation frequency	52.0	MHz
Injection energy	0.143	MeV/u
Exaction energy	0.976	MeV/u
Inner radius of drift tubes	17.0	mm
E_{acc}	2.15	MV/m
ϵ_{xi}(normalized)	1.0	π·mm·mrad
ϵ_{yi}(normalized)	1.0	π·mm·mrad
δW_i-$\delta\phi_i$ emittance	50.0	π·Kev/u·degree
ϵ_x(normalized) growth	23.5	%
ϵ_y(normalized) growth	22.0	%
$\delta W_f/W_f$	$\pm$0.5	%
$\delta\phi_f$	$\pm$20	degree
Total power of cavities	105	KW
Total length	7.22	m

particle-in-cell simulation of axialsymmetric, quadrupole-symmetric and z-uniform beams in a channel containing RF gaps, radio-frequency quadrupoles, multipole lenses, solenoids and bending magnets [2].

The DAKOTA [3] toolkit developed by the Department of Energy¡¯s Sandia National Laboratories is a multilevel parallel object-oriented framework for design optimization, parameter estimation, uncertainty quantification and tolerance analysis. It provides a flexible and extensible interface to the third part codes.

BEAMPATH is linked with DAKOTA through the use of script languages(Bourne shell and Perl). The flowchart of the process of tolerance analysis is shown in Fig. 4.

Taking the tolerance analysis of misalignments error of quadrupoles in X direction as an example,each block of flowchart is described next.

- The first step is to produce the samples simulated by BEAMPATH. In this step, a multi-variable parameter space is produced by treating the misalignment error of each quadruple as a parameter. DAKOTA will select a certain amount of samples, which are just the input files of BEAMPATH within the parameters space by monte carlo sampling. This sampling method can guarantee to produce errors that are in accord with practical condition.
- The second step is to simulated the samples produced in the first step using BEAMPATH code.
- The third step is to analyze the simulation results gotten in the second step by DAKOTA. Also, you can analyze the simulation results by other data processing software. Then the tolerance of beam to misalignment errors of quadrupoles can be gotten finally.

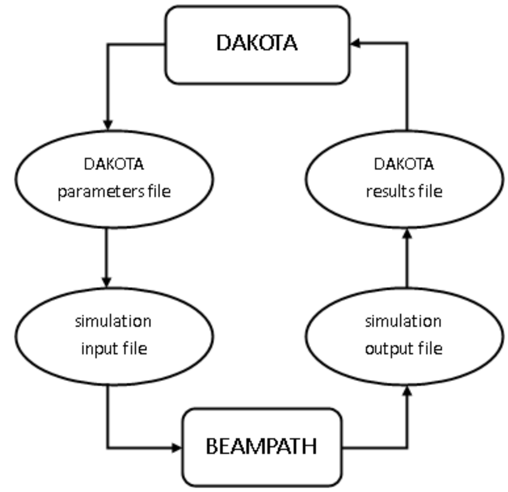

Figure 4: The flowchart of the process of tolerance analysis.

The Results of the Tolerance Analysis

In the paper, the tolerance of the DTL to the misalignments error of the quadrupoles in X direction, taken as an example, are presented. In the tolerance analysis, the effect on transmission and longitudinal emittance of different displacements,$\pm$0.5mm,$\pm$0.2mm,$\pm$0.1mm,$\pm$0.05mm,are comprised and analyzed.

In the simulation, 20000 ions are transported thought the DTL, and for each misalignments error, 5000 samples are selected. The effects of misalignment of quadrupoles in X direction on transmission are shown in Table 2.

Table 2: The Effects of Misalignment Error on Transmission

Displacement(mm)	Transmission(%)
$\pm$0.5	23.15
$\pm$0.2	94.25
$\pm$0.1	99.75
$\pm$0.05	99.95

In Table 2, the transmission shown is the worst condition

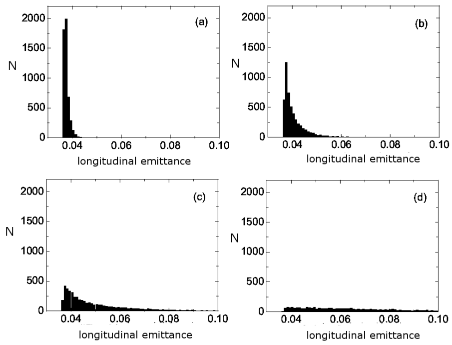

Figure 5: The effect on longitudinal emittance from misalignment error of ±0.5mm, ±0.2mm, ±0.1mm and ±0.05mm.

among the selected samples.

In the Figure 5, the x dimension stands for longitudinal emittance,the unit is π·MeV/u·deg. The y dimension means the number of samples. The more number of samples close to small longitudinal emittance means less effect to longitudinal emittance from the corresponding misalignment error.

As shown in Table Table 2 and the Figure 5, when the misalignment error is smaller than ±0.1mm, there is no obvious effect to the transmission. While in the view of longitudinal emittance, the effect from misalignment error of ±0.05mm is much weaker than that from misalignment error of ±0.05mm. The small longitudinal emittance is critical for the further acceleration in SSC. So taking account of practical alignment technique and physics requirements, the standard that misalignment error of quadrupoles should be less than ±0.05mm is offered to engineering technical personnel.

With the same method, the tolerance analysis of quadruple and accelerating cavity have been done. The results are list in Table 3.

SUMMARY

The optimization design of a separated function DTL was presented. The parameters of the extracted beam are comparable to the design requirements and can be accelerated further.

By integrating the software DAKOTA and beam simulation code BEAMPATH, the tolerance of DTL to error from quadrupoles and cavities could be conveniently and accurately obtained. The result is very useful in the paretical work.

Acknowledgments

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Table 3: The Results of Tolerance Analysis

Elements	Property	Permissible Error
For quadrupoles	Misalignments error in X direction	±0.05mm
	Misalignments error error in Y direction	±0.05mm
	Misalignments error in Z direction	±0.1mm
	The error of magnet field magnitude	1%
For cavities	Transverse displacement in X direction	±0.05mm
	Transverse displacement in Y direction	±0.05mm
	Transverse displacement in Z direction	±0.1mm
	The error of accelerating field magnitude	1%
	The error of synchronous phase	±1.0deg

REFERENCES

[1] Kamigaito O, Kase M, Sakamoto N et al. Review of Scientic Instruments,76(2005), 013306.

[2] Yuri K. Batygin,Nuclear Instruments and Methods in Physics Research. A, 539 (2005), 455¨C489.

[3] http://www.cs.sandia.gov/DAKOTA/documentation.html, DAKOTA Version 4.2 User's Manual.