OPTIMIZATION OF THE SUPERCONDUCTION SECTION OF INJECTOR II FOR C-ADS*

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Abstract

The China Accelerator Driven System (C-ADS) project which includes a high current SC proton linac is being studied under Chinese Academy of Science [1]. Injector II, one of parallel injectors, is undertaken by Institute of Modern Physics (IMP). The lattice design of Injector II has been done. While in most case, the elements, such as SC cavities and SC solenoids, have different weight to the final beam parameters. What is more, in the real operation process of the machine, the optimized mode is hard to find. In the paper, Latin sampling method specified in DAKOTA code combined with TRACK [2] is adopted to build hundreds of virtual machines to analyse the sensitivity of the SC section and to find optimization operation mode.

INTRODUCTION

C-ADS project, which is a strategic way to solve the nuclear waste problem and the resource problem in China energy development, is being studied in CAS. It aims to accelerate a 10mA proton beam up to 1.5GeV. It operates in a continuous wave mode (CW). Injector II is under design and built by IMP. Injector II consists of ion source, LEBT, RFQ, MEBT and superconducting accelerating section. The layout of the Injector II is shown in the Figure 1.

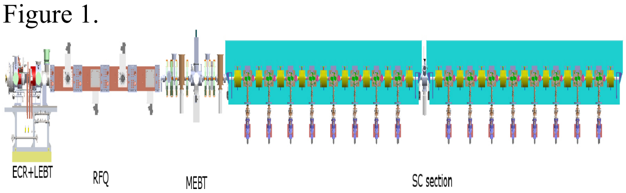

Figure1: Layout of the Injector II.

BEAM DYNAMICS OF SUPERCONDUCTING SECTION

The SC accelerating section in injector II will accelerate proton from 2.1MeV to 10MeV. In a present work, the design of the superconducting option, using low-β half-wave resonators (HWR) at 162.5 MHz has been investigated. There are sixteen cavities and eighteen solenoids included in the superconducting section separated by two cryomodules. Figure 2 shows the lattice structure of superconducting section. The main parameters of the design results are listed in Table1.

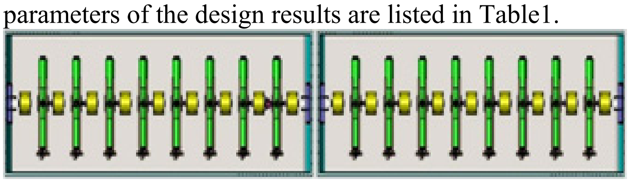

Figure 2: Lattice structure of superconducting section.

Table1: The Main Parameters of the Design Results

Parameters	Value	Unit
Particle type	proton	
Operation frequency	162.5	MHz
Beam current	10	mA
Beam kinetic energy	10	MeV
Growth of RMS ε_t	1.7	%
Growth of RMS ε_l	4	%
Number of cavities	16	
Number of solenoids	18	

The beam dynamic simulation of superconducting section has been done. In the simulation, the beam current is 10mA.The beam loss is not observed from simulation results.

The Phase Advance and the Envelope along the SC Section

In the simulation, the phase advance should be as smooth as possible along the SC section in order to maintain the stability of beam. Figure 3 shows the phase advance at zero current in each focusing period.

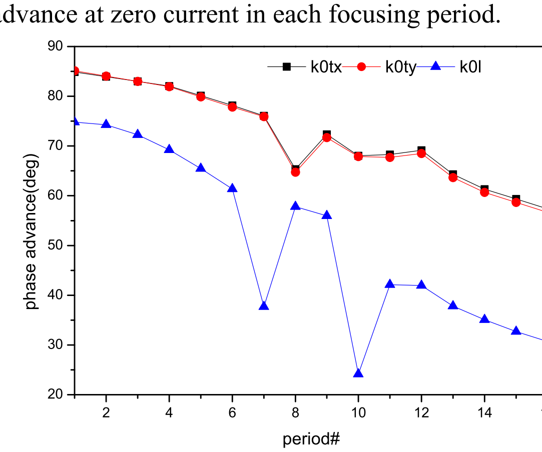

Figure3: Transverse and longitudinal phase advance of each period at zero current.

As can be seen from Figure 3, there are a few of jumps at the location of the transition section. This is because the matching between the two cryomodules. The cavities and solenoids next to the transition section are used as the matching element.

Figure 4 presents the beam envelope along the SC section. The smoothness of the envelope shows good match between the cryomodules.

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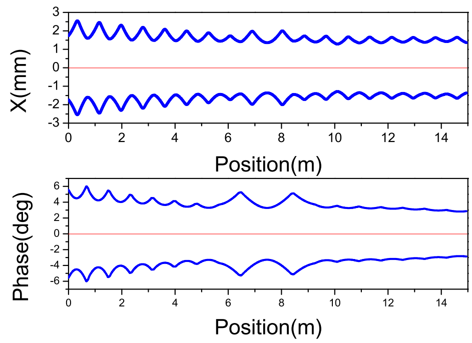

Figure 4: Beam envelope along the SC section.

Beam Emittance along SC Section

The emittance growth is very important for evaluate the beam performance, and it is desired to be small. Figure 5 shows the RMS emittance along the SC linac.

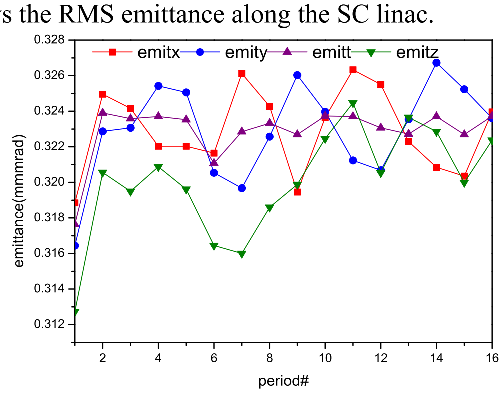

Figure 5: RMS emittance along the SC linac.

There is directed relationship between beam parameter and lattice element. The emittance growth will be affected when the parameter of cavity or solenoid change. For different requirement, the parameter of some elements should be adjusted. Base on above consideration, it is meaningful to study the relationship between beam parameter and lattice element.

RELIABILITY ANALYSES OF SUPERCONDUCTING SECTION OF INJECTOR Ⅱ FOR C-ADS

At present, the designing structure of superconducting accelerating section (SC) includes 16 HWR cavities and 18 solenoids. In order to obtain the database that satisfy different operation request, the impact on beam parameters which is resulted by lattice element should be studied. In this paper, the findings about the connection between solenoid magnet and the beam parameter are discussed.

In this work, DAKOTA code and TRACK code are used as the tools to find the optimal combination of component parameter and analyse the stability in superconducting section of C-ADS.

DAKOTA and Latin Sampling Method

The DAKOTA (Design Analysis Kit for Optimization and Terascale Applications) is a tool which provides a flexible and extensible interface between simulation codes and iterative analysis methods [3]. It includes methods for global sensitivity and variance analysis, parameter estimation, and uncertainty quantification with sampling and so on. In our work, the uncertainty quantification analysis with Latin sampling method module is used.

Latin hypercube sampling is a method of sampling that can be used to produce input values for estimation of expectations of functions of output variables [4]. The asymptotic variance of such an estimate is obtained. The estimate is also shown to be asymptotically normal. Asymptotically, the variance is less than that obtained using simple random sampling, with the degree of variance reduction depending on the degree of additivity in the function being integrated. A method for producing Latin hypercube samples when the components of the input variables are statistically dependent is also described. Latin hypercube sampling is suggested as a tool for structural reliability analysis. It is applied to the simulation of the performance of SC section of injector II of C-ADS.

Analysis of Results for SC Section of Injector Ⅱ for C-ADS

First, the strength range of each solenoid is set on the basis of design parameters, and then, 2000 samples which are used for beam simulation by track code are produced through Latin sampling method. The simulation calculation is carried out by parallel computation. Figure 6 shows the impact of each solenoid on transverse emittance and longitudinal emittance. The longitudinal axis presents the partial correlation coefficient and it gives the effect weights in response per unit change of each solenoid when all other solenoids are held fixed. It indicates the correlations between the solenoid and the emittance. Seen from Figure 6, the first four solenoids have bigger impact on maximum emittance compared with other solenoids in transverse direction and longitudinal direction. We can get that the first four solenoids have an important influence on beam match. Based on the statistical results, the verification work has been done, and the results of the verification reveal that the results from DAKOTA accord with reality.

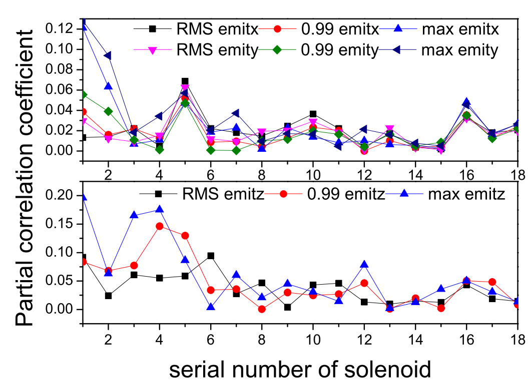

Figure 6: Impact of each solenoid on emittances in three directions.

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In Figure 7, the impact of each solenoid on transmission efficiency is shown. As the chart shown, the solenoids from the first to the third and from the twelfth to the sixth have important impact on beam transmission efficiency.

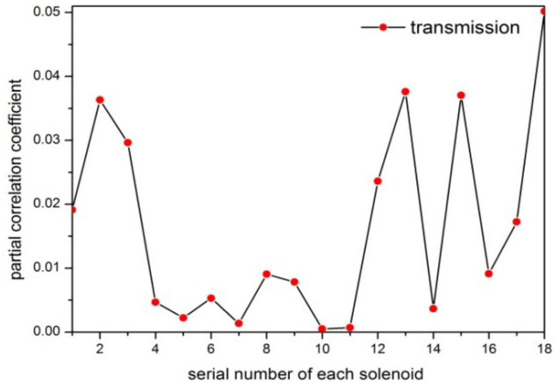

Figure7: Impact of each solenoid to transmission efficiency.

The range of variation of energy with the change of solenoids is plotted in Figure 8. We can see that the energy change compared with the designed value is small. The beam coupling between transverse and longitudinal direction is not serious.

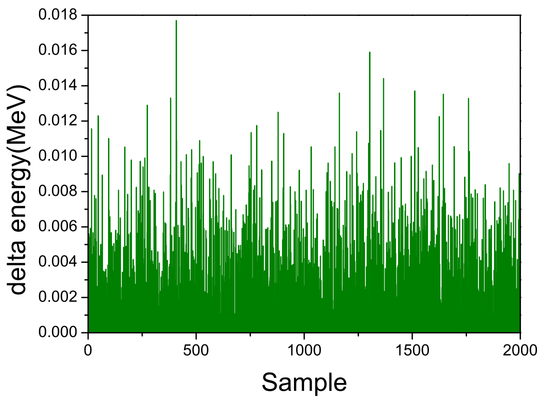

Figure 8: Range of variation of energy with solenoids.

A database corresponding to different beam parameters can be obtained through sampling method which will give large amounts of data. It is benefit to beam operation and commissioning. Figure 9 shows the change of emittance in three directions. The horizontal axis represents one sample that is comprised of eighteen solenoids with random value, and the vertical axis represents emittance corresponding to different samples. It can be seen, the emittance in transverse and longitudinal is continuously adjustable. It is easy to get different combinations of parameters of solenoids corresponding to different emittance from this figure .It is good for commissioning.

Based on these results, we can find the optimal solenoids parameters. The simulation was done with the optimal solenoids parameters, and the results are as good as our designing scheme.

Figure 10 shows the sample distribution corresponding to emittance. As can be seen, the emittance which next to designed value is the majority. We can get the information that our lattice structure is relatively stable.

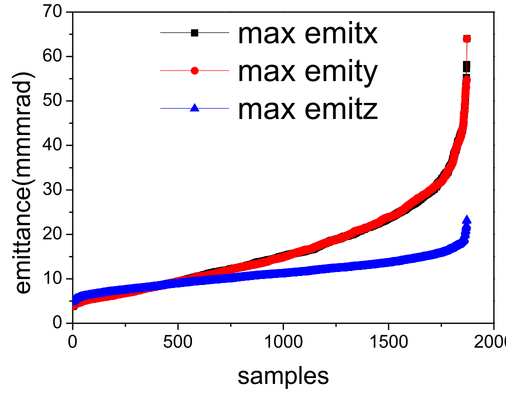

Figure 9: The change of emittance in three directions.

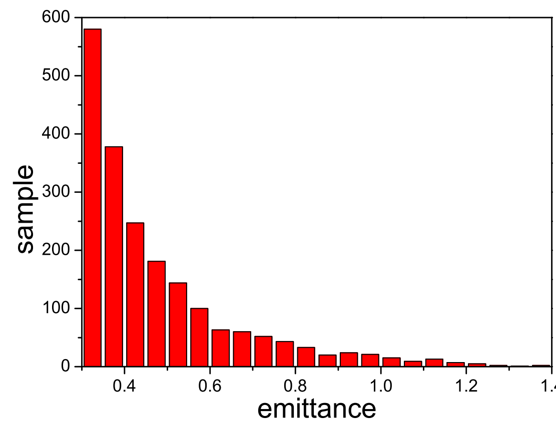

Figure10: Sample distribution corresponding to emittance.

CONCLUSION

The results of calculation show that database of beam parameters are obtained. The relationship between solenoid and beam parameter has been got, and it is benefit to commissioning.

Furthermore, more detailed calculation will be done. The optimization based on the beam extent minimization appears to be a relevant method, transposed in operation to beam loss minimization [5]. This technique is then proposed for the C-ADS tuning procedure.

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