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BEAM DYNAMICS DESIGN OF CIADS SUPERCONDUCTING SECTION *

Shuhui Liu, Zhijun Wang,Yuan He, Insititution of Modern Physics, China

Abstract

China Initiative Accelerator Driven system (CiADS) is a strategic plan to solve the nuclear waste problem and the resource problem for nuclear power plants in China, and it aims to design and build an ADS demonstration facility with 500 MeV in energy and 5mA in beam current. CiADS contains driver linac, target and reactor. In this paper, the beam dynamics philosophy applied to the design of the superconducting part of the linac as well as the beam dynamics performance of this structure are focused on.

INTRODUCTION

The CiADS linac, to be built in Huizhou, Guangdong, is a CW proton accelerator. The driven linac will deliver a 500 MeV, 5 mA proton beams in CW operation mode. The general layout is shown in Figure 1. The driver linac is composed of two major sections. One is the normal conducting section and the other is the superconducting (SC) section. The normal conducting section is composed of an electron cyclotron resonance (ECR) ion source with frequency of 2.45 GHz, a low energy beam transport (LEBT) line, a four-vane type copper structure radio frequency quadrupole (RFQ) with frequency of 162.5 MHz and a medium energy beam transport (MEBT) line. The normal conducting section will accelerate proton beam to 2.1 MeV. The SC section as the main accelerating section will accelerate the proton beam from 2.1 MeV up to 500 MeV. Then, the beam is transported to the beam dump going through the high energy beam transport (HEBT) line.

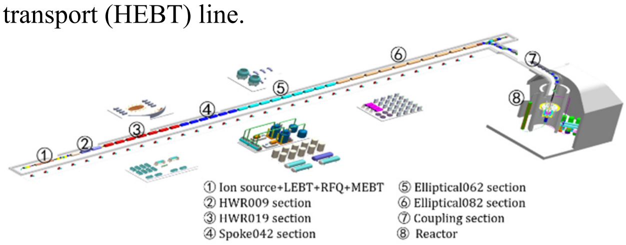

Figure 1: General layout of the CiADS linac.

In this paper, the design considerations of the superconducting section with different types cavity is discussed and the multi-particle simulation results are also presented.

GENERAL CONSIDERATION AND PHILOSOPHY ON SC SECTION DESIGN

Hands on maintenance and machine protection set strict limits,1 W/m and 0.1 W/m respectively, on beam losses and have been a concern in high power linacs [1]. Therefore, it is crucial to design a linac, which does not excite beam halo and keeps the emittance growth at a minimum level to avoid beam loss. Given the demands of stability and reliability, some guidelines are required to be considered in the design process. Although a lot of the design philosophy for the linac has been addressed in previous literature, we still consider some of them so important to be stated here, and the most important factors in designing our machine are the following [2]:

(1) Transverse period phase advances for zero current beams should be below 90° to avoid the structure resonance.

(2) Wave numbers of oscillations need change adiabatically along the linac, especially at the lattice transitions with different types of focusing structure and inter-cryostat spaces.

(3) Avoid strong space charge resonances through the judgment of Hofmann's Chart.

(4) Minimize the emittance growth and beam halo formation caused by mismatching in the lattice transition section.

(5) Enough redundancy to avoid the beam loss along the linac.

LATTICE DESIGN

Five types cavities are adopted in SC section based on the analytical results of optimization code. The general parameters of these cavities are determined through optimization as shown in table1. For beam dynamics design and simulation, Epeak is 75% of designed performance, and another 25% is used for element failure compensation, and this redundancy also benefits the cavity reliability.

Table 1: Parameters of the Cavities in the SC Section

Cavity type	βg	Frequency MHz	Emax MV/m	Bmax mT
HWR	0.10	162.5	28	56.75
	0.19	162.5	32	58.24
Spoke	0.42	325	35	65.91
Elliptical	0.62	650	35	67.34
	0.82	650	35	68.30

The optimized lattice structures for each section of the SC segment are shown in Figure 2. In the first segment with HWR010 cavity, in order to overcome the emittance growth and beam loss caused by strong space charge effect and nonlinear effect, short and compact structure is used, which is also beneficial to raise the accelerating efficiency and increase the longitudinal acceptance for the RFQ output beam. The output energy is about 8MeV. In

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the second segment with HWR019 cavity, quasi-period structure, which is beneficial for matching between cryomodules, is adopted. The output energy is 44MeV. In the last three segments, full period structure is used considering the matching between different structures.

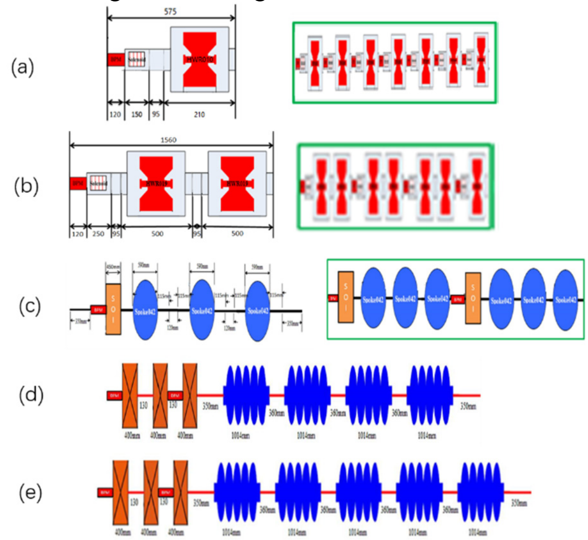

Figure 2: Lattice structures of each section.
(a) HWR010 segment, (b) HWR019 segment, (c) spoke042 segment, (d) elliptical062 segment, (e)elliptical082

The phase advance in the three planes are kept below 90° to avoid the parametric resonance. The focusing fields in both the transverse and longitudinal directions are kept almost constant in each section to have almost constant envelope amplitude when the rms emittance is shrinking along the acceleration [3]. This also means constant phase advance in each section, but the absolute value of the synchronous phase decreases from the lower-energy section to the higher-energy section to obtain higher acceleration rate. Because of the limitation in the longitudinal phase advance per cell, a big synchronous phase (absolute value) should be kept ensuring longitudinal acceptance, therefore, the cavity voltages at the beginning parts of the SC section may not be fully exploited. The period phase advance and synchronous phase evolution of the SC section are shown in Figure 3 and Figure 4.

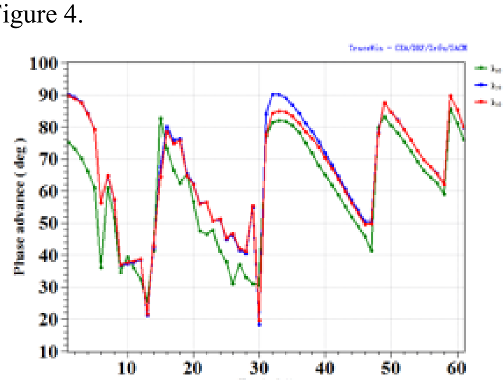

Figure 3: Period phase advance of SC section.

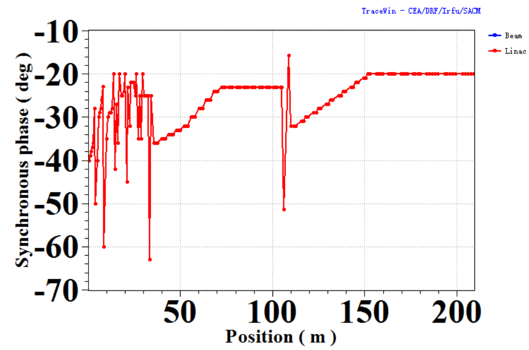

Figure 4: Synchronous phase of SC section.

MULTI-PARTICLE SIMULATION

The multi-particle simulation is performed with 100000 micro particles with TraceWin [4] code. The beam current is 5mA. The initial beam emittances at the entrance to the SC section are 0. 216mm.mrad in the transverse planes and 0. 25mm.mrad in the longitudinal plane which are the beam parameters out of normal conducting section. The input beam distribution is initially at 3sigma Gaussian distribution in the transverse plane and 5sigma Gaussian distribution in the longitudinal plane respectively. The simulations carried out here assumes error free lattice. The 2D PICNIC space charge routine with a 30*50mesh is employed for space charge calculations. The 2.1MeV proton beam will be accelerated up to 500MeV. The figure 5 shows the beam density distribution of the SC section, and the Figure 6 shows the RMS beam emittance evolution. The maximum beam size is at least half of the aperture, and the particles are all in bucket. The normalized RMS emittance growths are 5%, 7.6% and 3% (x, y and z planes) respectively. During the design, the normalized RMS emittance growths are considered as one major criterion for determining the matching results between the two CMs.

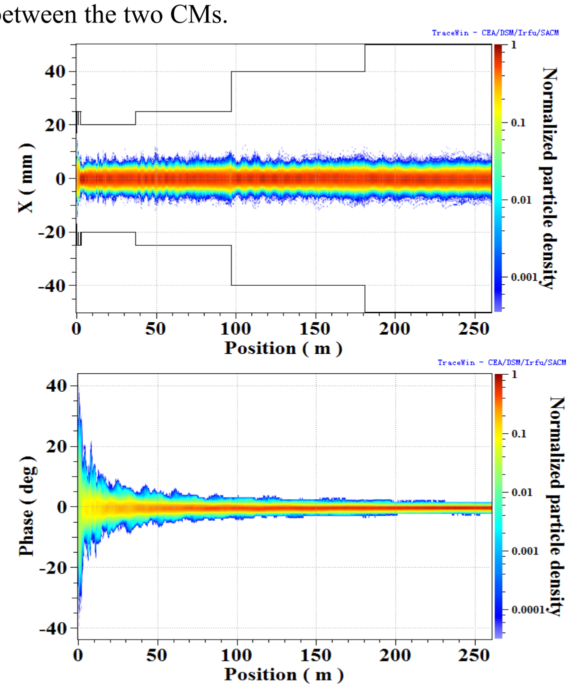

Figure 5: Beam density distribution of SC section.

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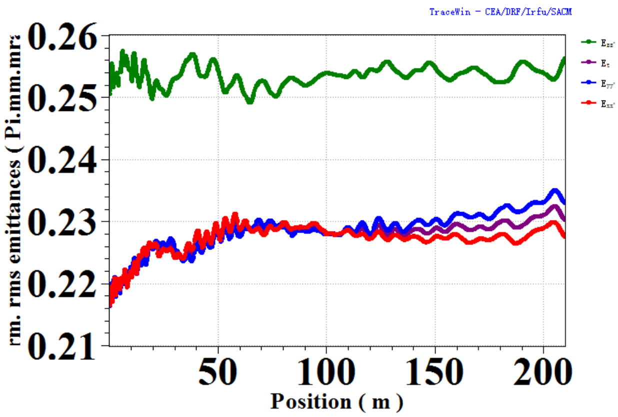

Figure 6: Normalized RMS emittance evolution.

The halo development due to errors, mismatches and resonances is the key causing beam loss, it becomes the central focus of the beam dynamics studies. The emittance evolutions for RMS, 95%, 99%, 99.99% beam fractions have been studied, using TraceWin [4] code. The number of macro-particles is 100000 for the simulations. The Figure 7, Figure 8 and Figure 9 are listed the emittance evolutions in three directions. The emittances with different fractions of particles indicate that the basic design is robust.

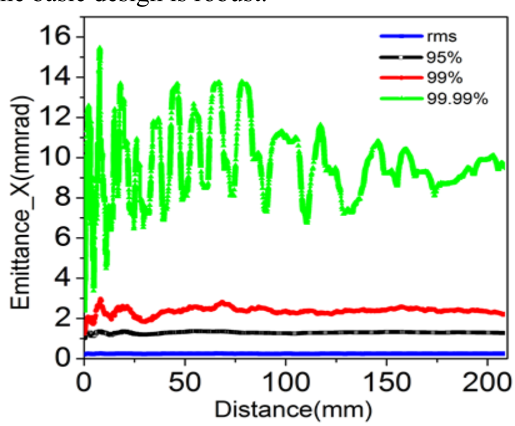

Figure 7: Emittance evolution in X direction.

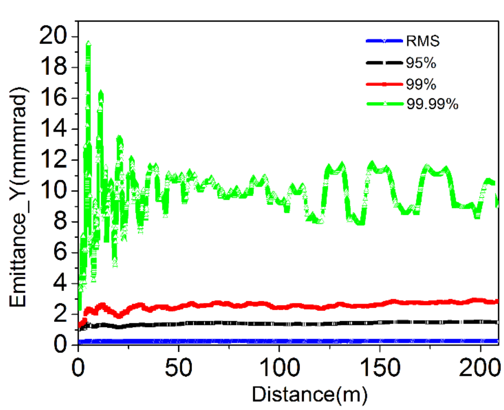

Figure 8: Emittance evolution in X direction.

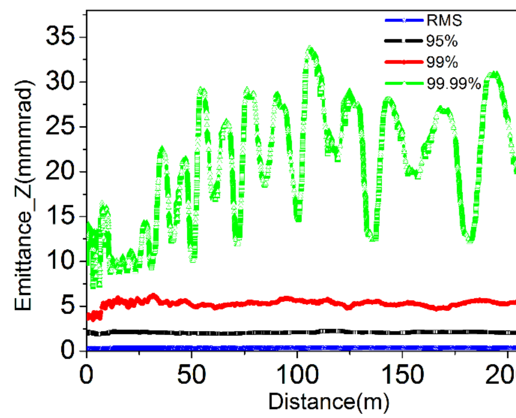

Figure 9: Emittance evolution in X direction.

SUMMARY

The physics design of the CIADS SC section is presented which considered the rules of the thumb in high intensity ion linacs. Period phase advance at zero current less than 90° are considered to avoid resonance and to reduce the possible beam losses. Multi-particle simulation results with Gussian distribution are shown. The RMS emittance growths are 5%, 7.6% and 3% in the x, y and z planes, respectively. Emittance evolution with different fractions of particles are studied in three plane phases, and the results indicate that the basic design is robust. Further optimizations and other discussions will be carried out in the future.

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