DESIGN STUDIES OF THE C-ADS MAIN LINAC WITH ONLY SPOKE CAVITIES *

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Abstract

The China ADS(C-ADS) project undertaken by the Chinese Academy of Science is based on superconducting proton linac. The design goal is to accelerate 10mA CW proton beam up to 1.5GeV. The accelerator includes an injector section and a main superconducting linac. Two injectors are under studying by IHEP and IMP respectively. In this paper, an alternative design of the main linac with full spoke cavity base on the beam characteristics from IMP injector II is described. In addition, multi-particle beam dynamics simulations have been performed using TraceWin code to estimate the space charge effect.

INTRODUCTION

The C-ADS linac is a CW proton accelerator which is a strategy plan to solve the nuclear waste problem and the resource problem for nuclear power plants in China [1]. The C-ADS linac includes a 15MeV injector section and a superconducting main linac. The injector section has two parallel injectors in order to meet the requirement of extreme high availability and reliability for the power production. The designing parameters are presented in Table 1. The designed proton beam current is 10mA. The main superconducting linac will boost the energy from 15 MeV up to 1.5 GeV to reach a beam power of 15MW. There is a MEBT (Middle energy beam transportation) which is used to transfer and match the beam between the injector section and the main linac section.

Table 1: Specifications of the Required Proton Beams

Particle	Proton	
Energy	1.5	GeV
Current	10	mA
Beam power	15	MW
RF frequency	(162.5)/325/650	MHz
Duty factor	100	%
Beam Loss	<1	W/m
Beam trips/year	<25000	1s<t<10s
	<2500	10s<t<5m
	<25	t>5m

Original design of the accelerator of IHEP includes a 162.5MHz 10MeV injector I; a 325MHz spoke cavity mid-section and a superconducting 650MHz multi-cell main linac to 1.5GeV. Considering the issues of 3 times of RF frequency jumps from injector II to main linac, a new design scheme about the main linac is present here, which will use only spoke cavities with frequency of 325MHz to accelerate the proton beam from 15MeV up to 1.5GeV. In this scheme, there is only one RF frequency jump, which will keep beam line matching easier and also to benefit the beam quality and availability during commissioning and operations.

In this paper, the design considerations of such superconducting main linac based on only with spoke cavities is discussed and the multi-particle simulation results are also presented.

GENERAL CONSIDERATION ON THE MAIN LINAC DESIGN [2]

In original design of the C-ADS proton linac carried out by IHEP, there are mainly 3 categories of RF cavities working at 162.5MHz, 325MHz and 650MHz. The RF frequency jumps from one to another might cause difficulties in matching between these sections. Furthermore, since the accelerator will operate in high intensity regime, the slightest mismatch will induce large emittance growth and beam halo generations. And it will increase the RF system complexity and probably affect operation reliability. In order to avoid these harmful effects caused by jump frequency, the superconducting spoke cavities with identical frequency are proposed for main linac section. To cover the whole energy range of from 15MeV to 1.5GeV in the main linac section, four types of spoke cavities with identical working RF frequency of 325MHz are considered here. The parameters of the spoke cavities are shown in Table 1. There are four types spoke cavities with geometry betas of 0.21, 0.40, 0.63 and 0.85 respectively. The TTF and the optimal energy range are shown in Fig.1, and the TTF indicates the acceleration efficiency. The parameters of the cavities are listed in Table 2.

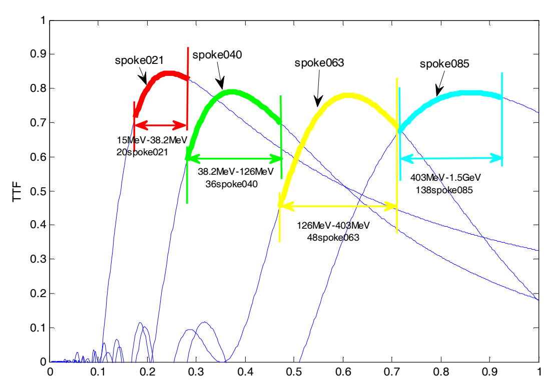

Figure 1: TTF and the optimal energy range.

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Table 2: Parameters of the Cavities in Main Linac

Cavity type	βg	Frequency MHz	Emax MV/m	Bmax mT
2-cell Spoke	0.21	325	32	65
3-cell Spoke	0.40	325	32	65
4-cell Spoke	0.63	325	35	65
3-cell Spoke	0.85	325	35	65

The optimized lattice structures for each section of the main linac are shown in Fig. 2. Full period structure is applied in each section which leads to long drift in both side of each period [2]. There are two advantages using this kind of structure: firstly, this kind of structure makes the cryomodule structure is more flexible. Secondly, it can accommodate various periods with more correction and beam diagnostic module in one cryomodule without compromising the beam dynamics performance, which is convenient to obtain symmetrical beam. Furthermore, this kind of structure avoids the mismatch caused by matching of different cryomodules repeatedly. Table 3 shows the number of the elements in main linac of C-ADS.

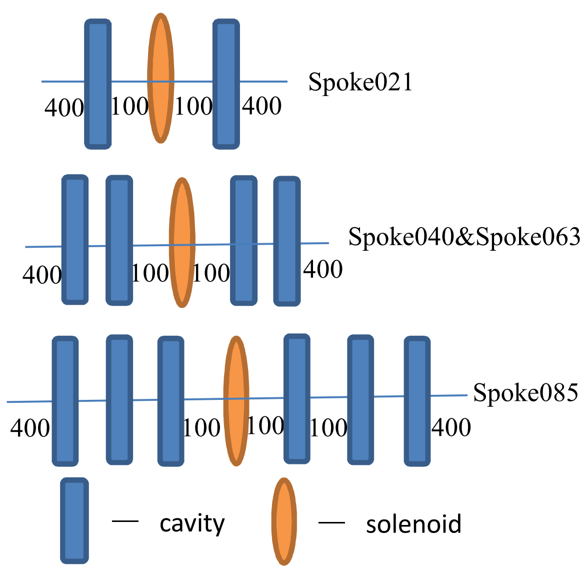

Figure 2: Lattice structures for each section of the main linac.

BEAM DYNAMICS SIMULATION

In order to validate the design at the full operation current, the beam dynamics tracking studies has been carried out at 10mA with space charge effects included. The guidelines for the design of the linac with full beam current are:

- The transverse and longitudinal phase advance per period is limited to 90 degree.
- Smooth variation of the average phase advance.
- At the same time the tune depression is being kept above 0.4 limiting the number of mismatch resonances [3].
- Keeps the beam working point away from the resonance region in the Hoffman chart.

The main linac simulation is performed with 100000 micro particles using the code TraceWin [4]. The beam current is 10mA. The initial beam emittances at the entrance to the main linac are 0.263 mm.mrad in the transverse planes and 0.25 mm.mrad in the longitudinal plane, which are the beam parameters out of the injector. 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 beam out of the injector with 15MeV will be transport up to 1.5GeV. The phase advance is shown in Fig.3, which exhibit a smooth variation with beam energy along the main linac. Figure 4 shows the beam envelope along the main linac, which is smooth along most of the linac. The aperture to rms beam size in the main linac is kept below 2.5 mm in transverse. The physical aperture is 25 mm, which is about ten times the rms beam size. The working points are kept away the resonance region in the Hoffman chart as shown in Fig.5.

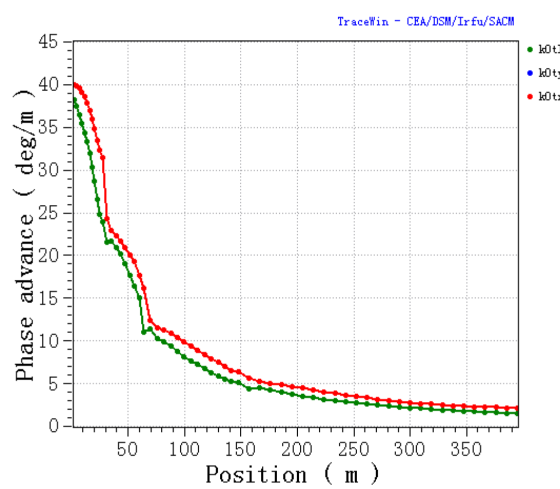

Figure 3: Transverse and longitudinal phase advance of each period at zero current.

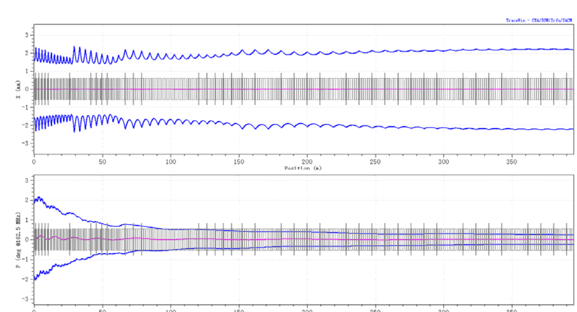

Figure 4: Beam envelope along the main linac in X and Z planes.

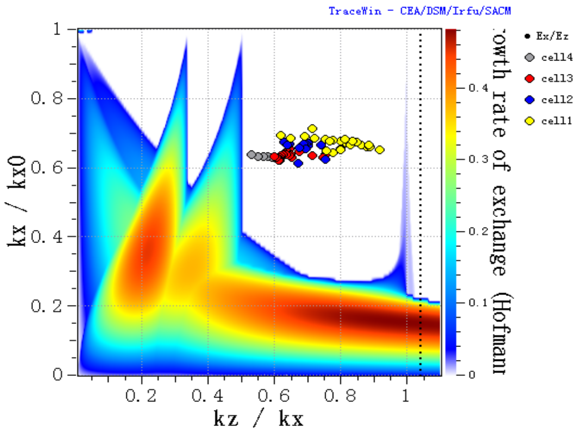

Figure 5: Hoffman chart.

The rms beam emittance and the maximum beam emittance are presented in Fig.6 and Fig.7. From the multi-particle simulation results, the transverse RMS emittance growth is 3%, and the longitudinal RMS emittance growth is about 8%. And the RMS emittance growth along the main linac is acceptable in all the three phase spaces. In addition, the beam halo information is also studied. The maximum emittances are 82%, 84%, 121% in all three planes respectively. The large beam halo is formed mainly due to the space charge forces.

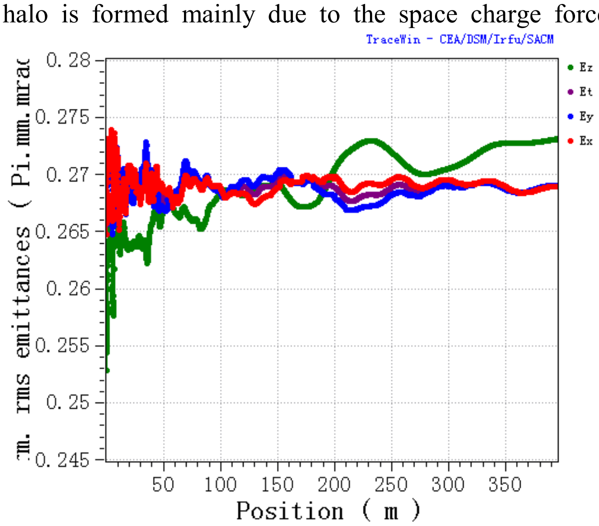

Figure 6: rms emittance along the main linac.

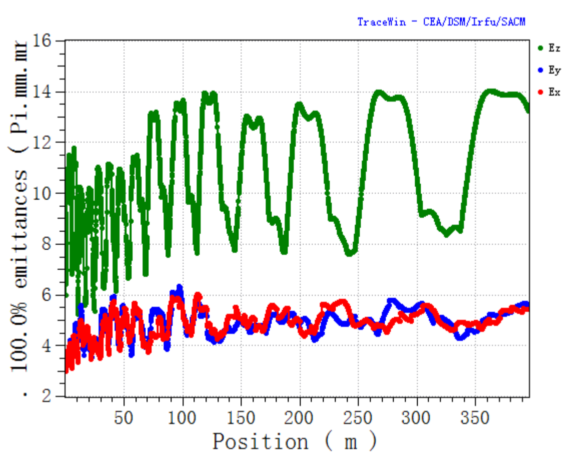

Figure 7: 100% emittance along the main linac.

SUMMARY

The alternative lattice design and beam dynamics studies of the main linac with only the superconducting spoke cavities of the C-ADS was presented with emphasis on avoiding the frequency jump from 325MHz to 650MHz. The linac designing satisfying all the requirements for reliability and stability in high intensity for the C-ADS needs. The designing shows a smooth variation of phase advance and away from harmful resonance. Multi-particle simulations show that the emittance growths are well within requirements. This designing is only at the preliminary stage. Furthermore optimizations and error analysis will be carried out in the future. And the cost benefits of simple RF system versus longer main linac together with beam dynamics will be further analysed.

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