CONCEPT DESIGN OF A CW HIGH CURRENT PROTON LINAC FOR CHINA ADS*

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Abstract

A system ADS study program has been proposed and organized by Chinese Academy of Sciences. As part of the study program, concept design of a 10mA 1.5GeV Continue Wave (CW) superconducting proton linac has been started in the Institute of High Energy Physics (IHEP). In this paper the design of the 325MHz part of this linac, which is composed of a room temperature Radio Frequency Quadrupole (RFQ), eight 4-cell room temperature Cross bar H-type (CH) cavities and three kinds of spoke cavities with total number of 78, is presented. The main parameters and detailed beam dynamic simulation results of the CH and spoke section are introduced.

INTRODUCTION

China has increased its investment on nuclear power in the past two decades and this trend is foresee to be continue in the following several decades in order to satisfy the increased energy demand for the economic development. Thus it is more and more urgent to find a consensual solution to transmute the long-lived radioactive waste produced by the nuclear reactor. A sub-critical system using externally provided additional neutrons is very attractive, it allows maximum transmutation rate while operating in a safe manner. An ADS, coupling a proton accelerator, a spallation target and sub-critical core, could be used as a reactor [1].

In general the proton accelerator for industry scale ADS should provide proton beams with more than 1GeV in energy, 10 mA in average current. Superconductor has been considered as a very promising technical solution for high intensity proton linear accelerators. Great achievements in experiment both on low and high beta superconducting cavities have achieved in several labs. The excellent properties of the Superconducting Radio Frequency (SCRF) cavities, such as low AC power consumption, larger beam tubes, great potential in terms of reliability and flexibility thanks to its independently-powered structures [2], make it a good candidate for ADS applications. Both USA and Europe have proposed their design of high power proton accelerator based on superconducting cavities and intensive R&D are performed [3, 4, 5]. A study program on ADS organized by Chinese Academy of Sciences (CAS) was proposed and participated by several institutes of CAS. As the key part of the program, a 10mA, 1.5GeV CW S.C. proton linac is under studying in IHEP and planned to be built in 3 phases with energy of 40MeV, 600MeV and 1.5GeV in the following three decades, with the potential of upgradeable to 40 mA.

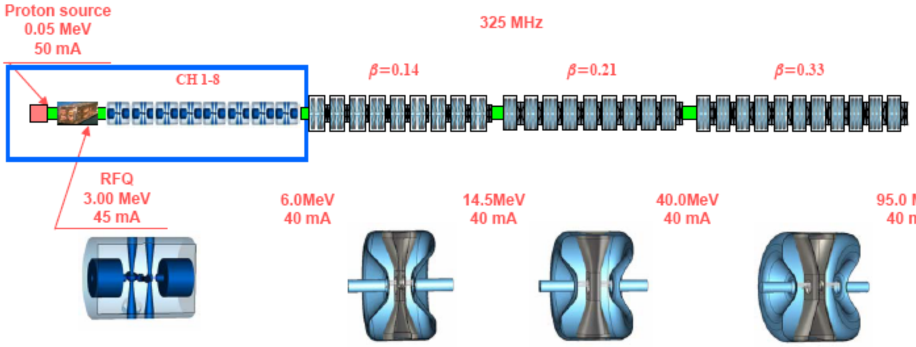

Figure 1: The block diagram of the 325 MHz part of the linac for China ADS.

LAYOUT OF THE LINAC

The block diagram of 325 MHz part of the Linac for China ADS is shown in Fig. 1. It consists of a 3MeV RFQ, eight 4-cell normal conducting CH cavities, and 3 kinds of spoke sections with geometry betas of 0.14, 0.21 and 0.33. Then the second harmonic frequency of 650MHz (or fourth harmonic of 1.3GHz) part will accelerate the beam to the final energy.

CH SECTION

The geometry of one of the eight CH cavities is shown in Fig. 2. The four cells are identical for each cavity, and the period length is equal βg/2, where βg is the relative velocity corresponding to the particle energy at the cavity centre, so the length of cavities are increased as synchronous particle energy increased. The enlarged end

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tubes have multi-functions of both tuning the field flatness and housing the magnetic lens, by this way the lattice will be more compact and the longitudinal dynamics will be improved. The field level is decided by the power density of the cavity loss, which is set as 80kW/m, in the design, and the corresponding peak field is less than 1.3 times the Kilpatrick limit. The maximum power loss of eight cavities is less than 15kW.

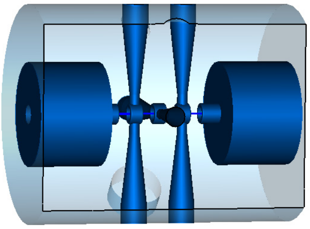

Figure 2: Schematic of CH cavity.

The comparative studies are performed for several schemes, including KNOUS [6] dynamic for 10-gap cavity with triplet lens, constant phase dynamic for 10-gap cavity with triplet, constant phase dynamic for 4-gap-identical cavity with doublet, constant phase dynamic for 4-gap ramped cavity with doublet. The 4-gap-identical cavity with doublet is decided as the final solution because of its good dynamic performance and similar focusing structure with the spoke section. It is clear shown in Fig. 3 that the transverse envelop is nearly the same for 10 and 40mA, but the emittance is quite different as show in Fig. 4, especially the longitudinal emittance of 40 mA, is increased more than 30%, but it is still within the requirement of the following section. The phase spaces are quite good in both 3 planes and without the appearance of halo.

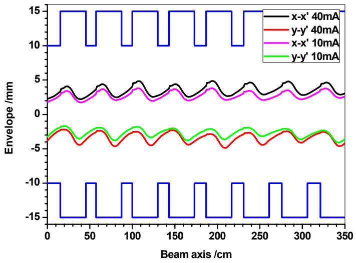

Figure 3: Transverse envelop of CH section.

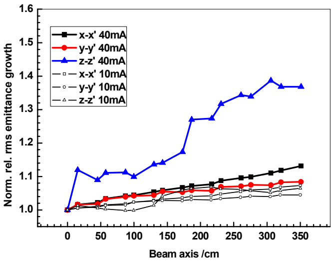

Figure 4: Normalized RMS emittance growth.

SPOKE SECTION

The spoke section design is based on the following specifications: 1) Use of 2-gap SC spoke cavities, which have large energy acceptance, and remain quite easy to fabricate as compared with multi-gap structure. 2) The peak electric field is less than 25MV/m and the peak magnetic field less than 60mT at this peak field, thus there is enough margin provided for the local compensation in case of cavity failure.

Lattice Design

The first step of lattice design is to determine how many kinds of cavity is needed to cover the energy range, around 6-90MeV, in our case. The trade off between acceleration efficiency and economic efficiency has to be made. One kind of cavity has highest acceleration efficiency just for one velocity, which is usually a little larger than the cavity geometry beta, and the further departure from this velocity, the less efficiency can obtain. This property is usually described by the transit time factor (TTF) as shown in Fig. 5. The efficient energy range of a certain cavity can be decided when relative TTF (defined as the effective voltage gain by particle with velocity β divided by which obtained by particle with velocity of cavity geometry beta βg) decreased to about 80% of the maximum.

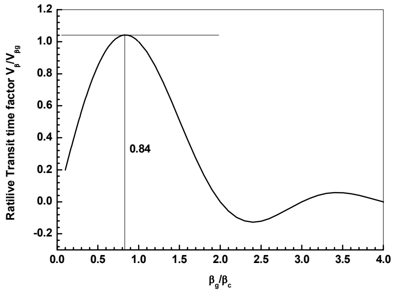

Figure 5: Relative transit time factor of 2-gap structure.

The second step is the design and optimization of the cavities with geometry betas decided in first step. With 3D electromagnetic field calculation code, the ratio of peak surface field to the acceleration field should be optimized as small as possible. Then setting the maximum peak electric field to a reasonable value (25MV/m in our case), the energy gain of particle with different velocity can be integrated and the relative TTF can be deduced. Using the following equation,

$$\Delta W = qV_gT_r(\beta)\cos\varphi_s \qquad (1)$$

where Vg is the energy gain of particle with velocity of βg. The synchronous phase can be set as -30 degree and the cavity number of each kind can be decided by continually apply equation (1). The energy gain per meter is shown in Fig. 6.

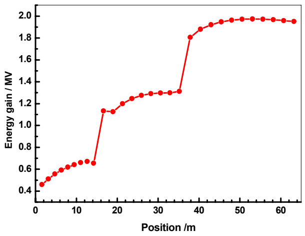

Figure 6: The energy gain per meter along the spoke cavity section.

Finally with the help of Trace3d, the transverse and longitudinal focusing structure, with the consideration of the space required for the cryostat, can be designed. Special attention should be payed to avoid zero-current resonances and strong space charge resonances by setting the transverse zero current phase advance less than 90 degree and be sure to make the envelop as smooth as possible. The matching between different sections should be provided in this step too. The final phase advance and envelop are shown in Fig. 7 and 8.

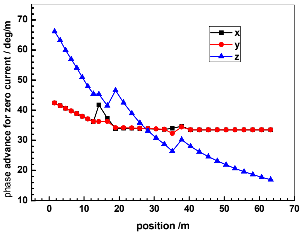

Figure 7: Zero current phase advance per meter.

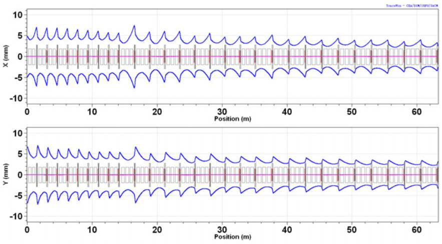

Figure 8: Transverse envelop along axis.

After several iterations of the procedure mentioned above, the final proposed 6-95MeV spoke section is composed of 78 spoke cavities, for an overall length of 70 meters.

Multi-Particle Simulation

Beam dynamics simulations have been performed for 10mA using TraceWin. The calculations include space charge effects and multi-particle simulations are done using 10000 particles. The normalized rms emittance is 0.3 mm.mrad in the transverse phase plane and 245 keV.deg in longitudinal. The Gauss distribution is applied for input particles. The emittance growth and output particle distributions are given in Fig. 9 and 10. We can see from Fig. 9 that the transverse emittance growth rapidly in the first section, while the longitudinal one is decreasing. This may result from the coupling between transverse and longitudinal plane or mismatching of the input beam.

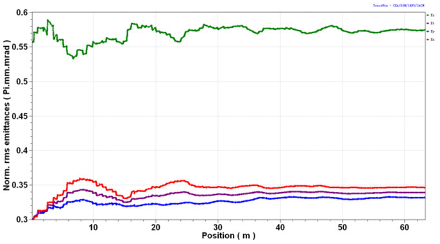

Figure 9: Emittance growth along spoke section.

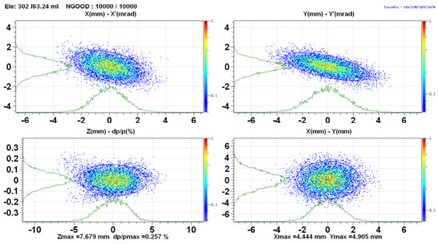

Figure 10: Beam distribution at exit of spoke section.

CONCLUSION AND PERSPECTIVE

The concept design of the 325MHz part of the 1.5GeV, 10mA SC proton linac is presented. The first beam dynamic simulation shows excellent performance. There still are lots of work to be done in the future, including the match between RFQ and DTL section, the front-to-end simulation with the particle distribution at the exit of RFQ. A power cavity of 4-gap CH cavity will be built to test the cooling and mechanic design.

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