PROGRESS ON THE PHYSICS DESIGN OF THE C-ADS INJECTOR SCHEME I *

Z.H. Li, C. Meng, H.P. Geng, F. Yan, B. Sun, P. Cheng, Z. Yang, H.F. Ouyang, J.Y. Tang,

IHEP, Beijing, China

Abstract

The China ADS (C-ADS) driver linac is composed of two parallel 10 MeV injectors and a main linac which boosts the beam further to 1.5 GeV. There are two design schemes for the injectors based on different working frequency and superconducting cavity structures and both are under developing at the same time on IHEP and IMP, respectively. The Injector Scheme I, which is proposed by IHEP, works at 325 MHz, the same frequency of the main linac, and superconducting Spoke cavities with geometry beta of 0.12, the same type of cavity as the main linac too, are applied after the RFQ. In this paper, the latest progress on physics design will be presented.

INTRODUCTION

The front end of the C-ADS proton linac is two parallel 10-MeV identical injectors, with one as the hot-spare of the other in order to meet the very strict requirements of high reliability and availability for the ADS application. A section of specially designed beam line called MEBT2 (compared with the beam line between RFQ and superconducting section in injector, which is called MEBT1) is applied to transfer and match the beam from two injectors to the main linac, and the main linac is composed of four superconducting sections to boost the proton beam to the final energy of 1.5 GeV. The general layout of the linac is shown in Fig. 1.

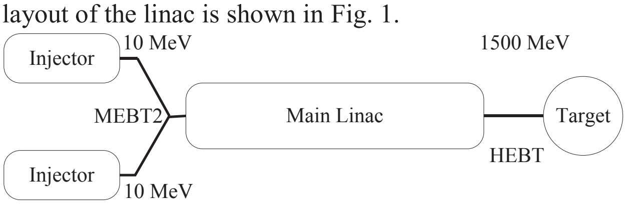

Figure 1: Layout of the C-ADS linac.

Like most of the front end of modern proton accelerators, the injector itself is composed of an ECR ion source, a low energy beam transport line (LEBT), a radio frequency quadrupole accelerator (RFQ), a medium energy beam transport line (MEBT) and a low energy DTL section to boost the energy up to 10 MeV. The Injector Scheme-I, as one of the two candidates which are under developing in parallel in IHEP and IMP simultaneously, is characterized by a 3.2 MeV 4-Vane RFQ and a superconducting DTL section, which is composed of 12 singe spoke cavities with geometry beta of 0.12. Before RFQ there is an ECR ion source with about 15 mA current and 35 keV energy followed by a LEBT with length about 1 meter. Between RFQ and superconducting Spoke012 section, there is a 2.13 meters long MEBT1, which is used to transfer and match beam from exit of RFQ to the entrance of the superconducting section, the schematic layout the Injector Scheme-I is shown in Fig. 2.

BEAM DYNAMICS DESIGN

The beam dynamics design of the injector is divided into four different sections: ion source and LEBT, RFQ, MEBT1 and the superconducting section. The ion source and LEBT is designed and fabricated by a group in IMP, and will be transported and installed in IHEP at the middle of this year as scheduled, and details can be found in reference [1]. In the following I will introduce the physics design of the RFQ, the MEBT1 and the superconducting section, with emphasis on the MEBT1 and superconducting section.

RFQ

The CW RFQ is one of the most critical parts in ADS applications. The key parameters for the RFQ follow the definitions for the C-ADS linac. As the beam current for the linac is 10 mA, the design beam current of the RFQ is

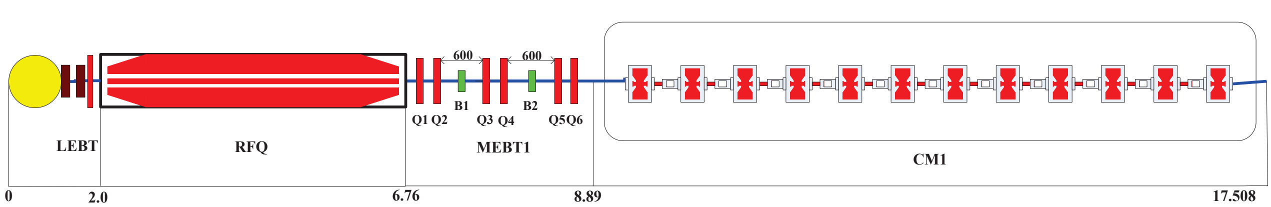

Figure 2: The schematic layout of the Injector Scheme-I.

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#lizhihui@ihep.ac.cn

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chosen to be 15 mA after taking into account the adjustability and its upgrading potential. The injection energy is also chosen to be a comparatively lower value of 35 keV, to enhance the bunching process in the RFQ and also ease the construction of the ion source and the LEBT while the space charge effects at 15 mA in the LEBT are manageable. The output energy is optimized to about 3.2 MeV as a compromise between the technical difficulties of the RFQ fabrication with higher energy and the favourable higher energy requirement by the low-beta superconducting spoke cavities in the injector. The total length of the RFQ is limited within 4.8 m. The RFQ will consist of two physical resonantly coupled segments and each segment includes two technical modules connected together with flanges. The length of the technical module is limited to 1.2 m by the machine capability in industry domestically based on the construction experience of the previous RFQ (or "973" RFQ: 3.5 MeV, 352 MHz, 7% duty factor) [2] built at IHEP several years ago. The main design parameters along cells are shown in Fig. 3.

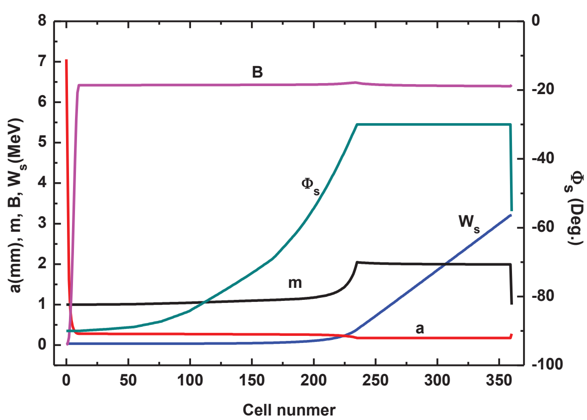

Figure 3: Main parameter variation with cell number, where a stands for the minimum bore radius, m modulation factor, B focusing factor, W synchronous energy and Φs synchronous phase.

The multi-particle simulation with ParmteqM is performed. The initial particle distribution at the entrance of the RFQ is assumed as 4D Water-bag distribution with transverse rms emittance of 0.2 πmm.mrad and 10^5 total particles, the 98.7 % transmission efficiency is obtained.

Now the fabrication of the RFQ is almost finished. The RFQ will be installed at IHEP at the middle of this year as plan and the details of the mechanical and thermal design of the cavity can be found in reference [3].

MEBT1

The MEBT1 is composed of 6 quadrupole lenses and two single-gap normal conducting bunchers, besides its main function of transfer and match the proton beam to the superconducting section, it also provide spaces for installation of the necessary diagnostic devices. After several iterations between the engineering design and physics design, the layout of the MEBT1 is shown in Fig. 4, and the main parameters of the MEBT1 elements are given in Table 1. Taken the particle distribution at the exit of the RFQ as the initial particle distribution, multi-particle simulations with traceWin show that both the rms emittance growth and the halo emittance growth are under control in the MEBT1, e.g. less than 5% for the rms emittance growth in all the three phase planes, and the engineering design of the MEBT1 has finished.

Table 1: Main Parameters of the MEBT1 Elements

Element	Effective length (mm)	Bore radius (mm)	Field gradient (T/m) / Effective voltage(kV)
Q1	70	17.5	27.13
Q2	70	17.5	-21.08
Q3	80	27.5	11.91
Q4	80	27.5	-11.19
Q5	80	27.5	11.25
Q6	80	27.5	-10.67
Buncher-1	250	-17.0	48.12
Buncher-2	250	-17.0	96.07

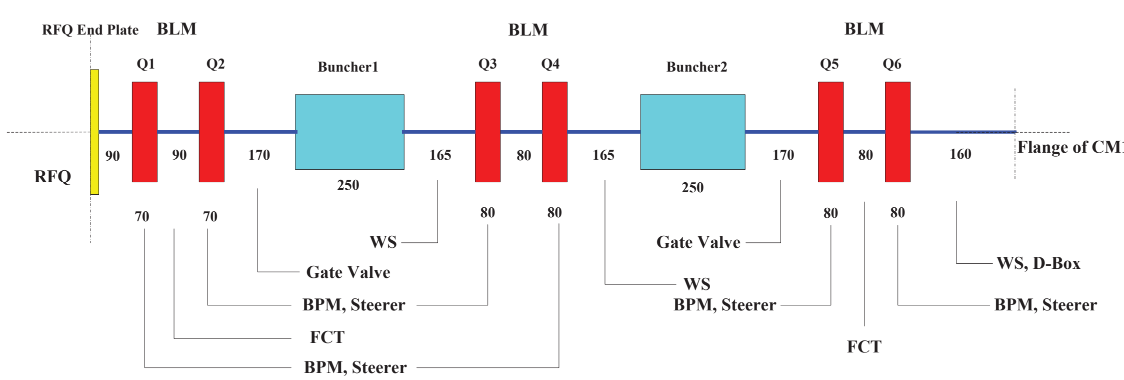

Figure 4: Schematic of the MEBT1 for Injector Scheme.

Superconducting Section

One of the most important principles in high current linac design is to keep the zero current phase advances per period in all directions less than 90 degrees. From our studies, the phase advance limit is found even more important for low energy superconducting machines in which some kind of parametric resonance may be excited because of the violation of the smooth approximation [4]. The transverse one can be controlled by properly setting the focusing gradients of the transverse focusing elements, while the longitudinal one is directly related to the period length, synchronous phase and acceleration gradient. The period length is determined by the lengths of the cavity, the transverse focusing elements and the diagnostic devices and the spaces necessary for assembling, and the shorter the better. Compared with a quadrupole doublet, a superconducting solenoid has more advantages in focusing the low-energy and round beam. Together with the RF defocusing, the transverse focusing structure of SR is determined, where S denotes solenoid and R for cavity. The element lengths and the spaces for assembling are determined based on the engineering designs, and kept as short as possible. Multi-particle simulations were performed with the help of traceWin. The initial particle distribution is the output of parmteqM at the exit of RFQ, and all cavities are presented by 3D field maps. The results are quite promising and the rms emitance growth is less than 10% in all three phase planes. With proper correction scheme, the beam loss is less than 10^{-7} as the error analysis indicates, and the details can be found in reference [5].

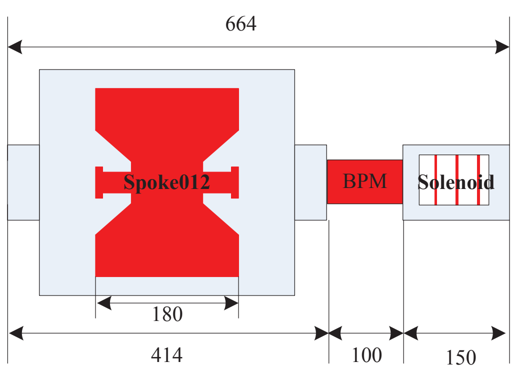

Figure 5: Layout of one focusing period in Injector Scheme-I.

5-MEV TEST STAND

In order to develop the relevant techniques of the injector and the beam tuning method, a 5-MeV test stand will be built in IHEP. It consists of ECR ion source, LEBT, RFQ, MEBT1, one cryogenic module housing six superconducting spoke cavities, and a part of MEBT2. Except for the superconducting section, the other parts share the same design for Injector Scheme-I and MEBT2 and the schematic layout is shown in Fig. 6.

As the 5-MeV test stand is an important development stage of the C-ADS, redundancy has been implanted in this design. With the nominal cavity settings, the superconducting section can accelerate the beam to 5.38 MeV. With reduced cavity performance or even one cavity less, one can still obtain the output energy of 5 MeV by large synchronous phases with the tolerance of larger emittance growth. The beam line from the superconducting section to the beam dump takes the same design as MEBT2 [6], by taking into account the importance of very dense heating deposit in the dump and the radioactivity shielding.

This test stand can be upgraded to include another identical cryogenic module also housing six spoke cavities to reach the beam energy of 10 MeV. The MEBT2 components have been designed with the beam energy of 10 MeV, and will be displaced to install the second cryomodule. With Nickel-coated beam dump, there is no residual radioactivity after the operation at 5 MeV. Therefore, there is no problem for the relocation of the dump. The emittance growth due to the breaking of periodicity of the focusing can be tolerated for the test stand.

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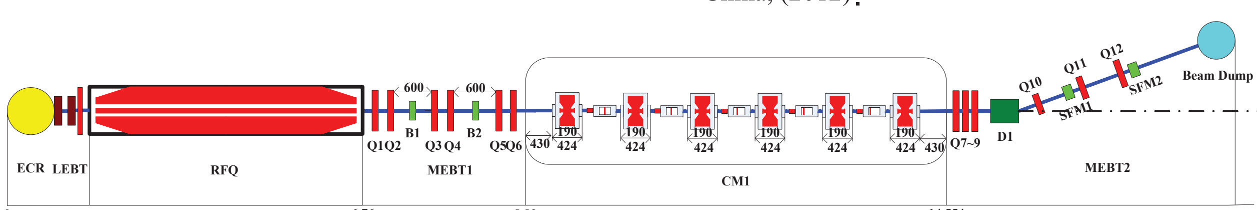

Figure 6: Schematic layout of the 5-MeV test stand.

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