CONCEPTUAL PHYSICS DESIGN FOR THE CHINA-ADS LINAC

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Abstract

The China-ADS project was launched in 2011 to pursue the R&D on key technologies towards a final demonstration facility on ADS with the capability of more than 1000 MW thermal power. The driver linac is defined to be 1.5 GeV in energy, 10 mA in current and in CW operation mode. It employs the superconducting structures except the RFQs. To meet the extremely high reliability and availability, the linac is designed with much installed margin and fault tolerance, including hot-spare injectors and local compensation method for key element failures. The accelerator complex consists of two parallel 10-MeV injectors, a joint medium-energy beam transport line, a main linac and a high-energy beam transport line. The conceptual physics design including beam dynamics studies with multiparticle simulations is presented here.

INTRODUCTION

The C-ADS (or China-ADS) project is a strategic plan to solve the nuclear waste problem and the resource problem for nuclear power plants in China. With its long-term planning, the project will be conducted in three or four major phases with the final goal to build a demo transmutation facility by 2032.

The C-ADS accelerator complex is a large CW proton linac consisting of several sections and uses superconducting (SC) acceleration structures except the RFQs, which is under developing in collaboration at IHEP and IMP. The main design specifications for the proton beam at the ultimate stage are shown in Table 1.

Table 1: Specifications for the C-ADS Linac

Particle	**Proton**	**Unit**
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[1]	<25000 <2500 <25	1s<t<10s 10s<t<5m t>5m

DESIGN CONSIDERATIONS

The C-ADS linac is designed to have very high beam power and very high reliability, which surpasses those of the existing proton linacs by far. However, several proposed CW proton/deuteron linac projects such as Project-X [1-2], EFIT or MYRRHA [3], IFMIF [4] and EURISOL [5], etc. are good models for the physics design and technical design of the accelerator. In addition, some pulsed high power proton linacs and some CW heavy ion linacs using SC cavities also serve as good reference examples. Although most of the design philosophy for the linac has been addressed by previous literatures, we still list the main principles here: 1) the whole linac consists of SC cavities except the RFQ which is room-temperature; 2) installed redundancy for all the parts of the accelerator will be applied; 3) as low as possible beam losses along the linac, with an upper limit of 1 W/m in warm sections and even lower in cold sections; 4) the acceleration efficiency and the number of cavity types will be balanced; 5) different transverse focusing structures are used to follow the acceleration structures and beam properties in different acceleration sections; 6) tune depression will be controlled to stay in the emittance dominated regime preferably; 7) the growths in both the rms emittance and halo emittance should be controlled strictly, and the ratio of acceptance and rms emittance should be kept large to avoid severe beam beams; 8) the phase advance per period is controlled below 90° to avoid parametric resonances.

DIFFERENT ACCELERATION SECTIONS

The linac consists of two injectors, a special medium-energy beam transfer line (MEBT2), and the main linac, as shown in Figure 1. Two identical injectors will be operated in the mode of one as the hot-spare of the other to provide quick switch in case of failure of the one in delivering beam to the main linac, which is considered crucial to achieve very high reliability of the whole accelerator. MEBT2 is to transport and match the beam from either of the two injectors to the main linac. However, in the early developing phase two different approaches of injector will be developed in parallel by two different teams. At a later phase, a decision based on the R&D development will be made about which injector scheme will be used in the future phase. The main linac section that consists of different acceleration sections will be developed in phases.

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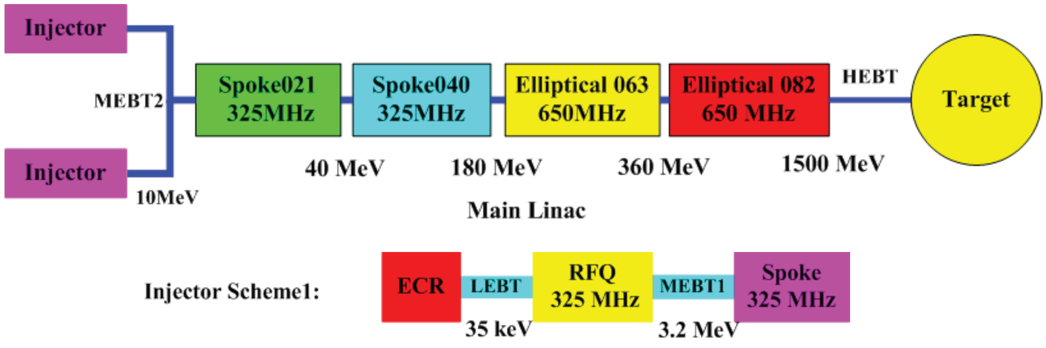

Figure 1: Layout of the C-ADS linac.

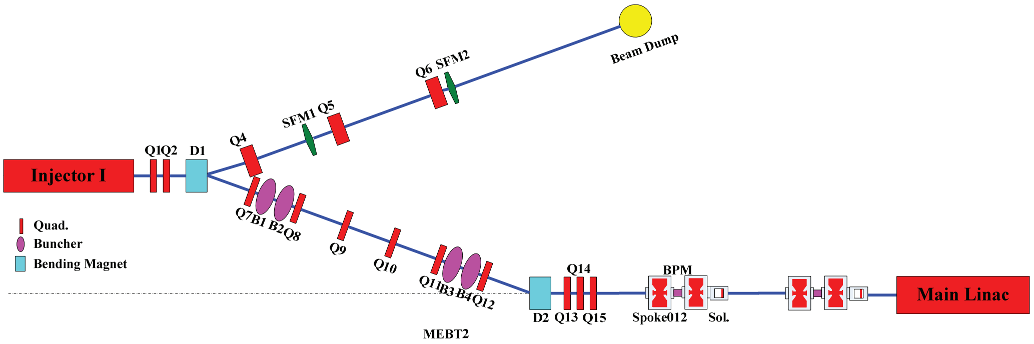

Figure 2: Schematic for MEBT2.

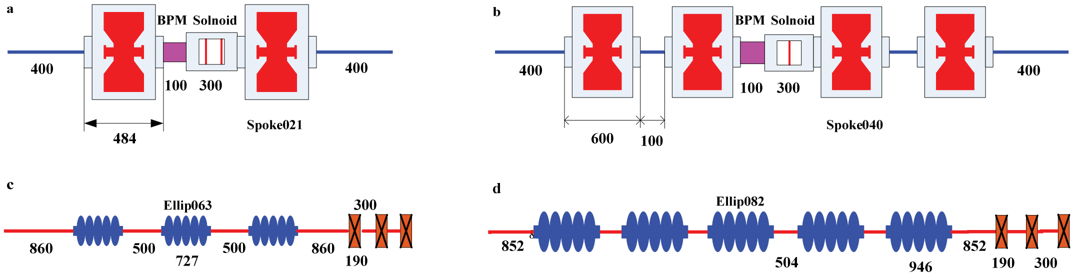

Figure 3: Lattice for the four sections in the main linac.

Injector

For the Injector-I scheme, a 325-MHz, 3.2-MeV, 4-Vane RFQ has been designed and a test stand is under fabrication. The inter-vane voltage is 55 kV, much smaller than the popular design, aiming to decrease the power density to a safe level. The injection energy of 35 kV is helpful in obtaining a relatively smaller output longitudinal emittance (0.16 mm.mrad in normalized rms), which is about 0.8 times the transverse one. The small longitudinal emittance is found very useful in designing the downstream SC sections. Then the MEBT1 [6] is to match the beam between the RFQ and the SC section of the injector. It is mainly composed of two bunchers, six quadrupoles and beam instrument devices.

The SC section of the injector has one long cryomodule (CM) of 8.5 m with twelve single spoke cavities [7] and eleven solenoids inside; it will accelerate the beam to 10 MeV. The geometry beta of the cavity is only 0.12 which is considered very small, and it increases the difficulty of developing the cavity. The compact lattice with short solenoid (150 mm) and larger absolute synchronous phase (-46 ~ -30°) is applied to improve the longitudinal beam dynamics.

MEBT2

It is a real challenge to design a merging beam line to connect the two injectors to the main linac, as this is a high-intensity beam requiring very strict control over beam loss and emittance growth. It is found difficult to control the emittance growths when a bending section is present, especially with the bunchers within the section. MEBT2 is also supposed to have a good collimation system to scrape the beam halo and non-trapped particles. The beam will be directed to a beam dump through an auxiliary beam line with a much reduced beam power when the injector is working in the hot-spare mode. The dump line is also used for the commissioning or beam setup of the injector.

As shown in Figure 2 [8], each of the mainstream lines of the MEBT2 consists of eight quadrupoles, two 20°-bending magnets and four 325-MHz single-gap normal conducting re-entrant type bunchers. In the common part, three quadrupoles, two Spoke012 cavities and two solenoids are used for the matching, while another two Spoke012 cavities serve as the back-ups.

Main Linac

To meet the strict requirement on stability and reliability, over-design, redundancy and fault tolerance strategies are implemented in the basic design. The fault tolerant design in the main linac is guaranteed by means of the local compensation and rematch method [9-10]. To cover the whole energy range from 10 MeV to 1.5 GeV in the main linac, at least four types of SC cavities are needed. We have chosen two single-spoke cavities working at 325 MHz with geometry β of 0.21 and 0.40, respectively, and two 5-cell elliptical cavities working at 650 MHz with geometry β of 0.63 and 0.82, respectively. For the nominal design, only 3/4 of the maximum available cavity voltage is used, whereas another 1/4 is reserved for the local compensation, and this redundancy is also beneficial to the cavity reliability.

There are four sections each consisting of one type of cavity, Spoke021 and Spoke040 for the lower energy part and Ellip063 and Ellip082 for the higher energy part. The lattice structures for each section are shown in Figure 3. The matching between two neighbouring sections is guaranteed by varying the parameters of the adjacent cavities and transverse focusing elements. With warm transitions between CMs, the replacement of failed CMs can be easily carried out; in addition, beam diagnostics and collimators can be arranged in the warm sections.

In total, thirty-eight Spoke021 cavities in seven CMs, sixty-four Spoke040 cavities in eight CMs, forty-two Ellip063 cavities in fourteen CMs and one hundred Ellip082 cavities in twenty CMs are used in the main linac. All the CMs have modest length of 5-10 m.

SOME SIMULATION RESULTS

End-to-end beam dynamics simulations are performed from the input of the RFQ to the end of the linac to verify the general beam dynamics and the matching between each part. 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 the total particle numbers are 100000, and the optimized distributions at the RFQ exit are applied as the initial particle distributions for TraceWin.

The evolutions for both the rms emittances and halo emittance with different fractions are studied (see Figure 4). MEBT2 contributes to very important growth of the 100% emittance, almost 5 times in the transverse planes. It is expected that some halo particles can be collimated in MEBT2 with proper collimation schemes.

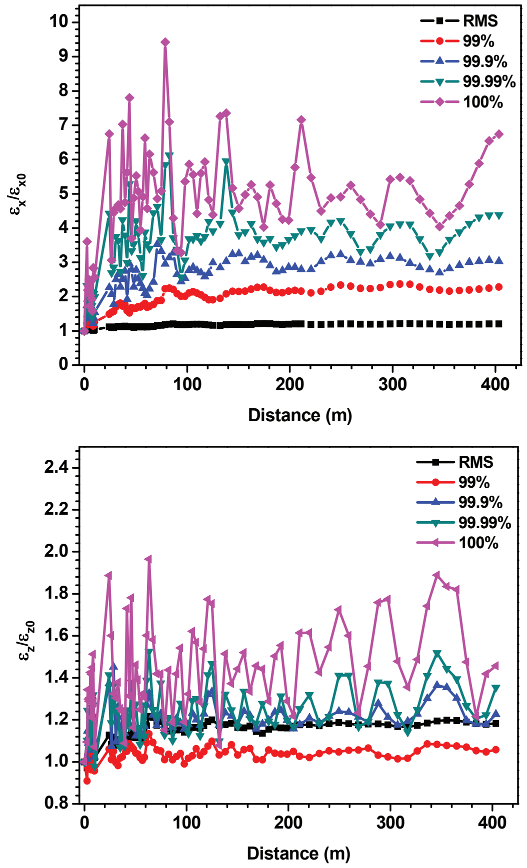

Figure 4: Halo development along the linac for different beam fractions.

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