BEAM DYNAMICS DESIGN OF CHINA ADS PROTON LINAC*

Z.H. Li, F. Yan, P. Cheng, H.P. Geng, Z. Guo, C. Meng, B. Sun, J.Y. Tang, IHEP, Beijing, China

Abstract

It is widely accepted that the Accelerator Driven System (ADS) is one of the most promising technical approach to solve the problem of the nuclear wastes, a potential threaten to the sustainable development of the nuclear fission energy. An ADS study program was approved by Chinese Academy of Sciences at 2011, which aims to design and built an ADS demonstration facility with the capacity of more than 1000 MW thermal power within the following 20 years. The 15 MW driver accelerator will be designed and constructed by the Institute of High Energy Physics (IHEP) and Institute of Modern Physics (IMP) of China Academy of Sciences. This linac is characterized by the 1.5 GeV energy, 10mA current and CW operation. It is composed by two parallel 10 MeV injectors and a main linac integrated with fault tolerance design. The superconducting acceleration structures are employed except the RFQ. In this paper the general considerations and the beam dynamics design of the driver accelerator will be presented.

INTRODUCTION

The C-ADS project is a strategic plan to solve the nuclear waste and resource problems for nuclear power plants in China. It is supported financially by the central government and administrated by the Chinese Academy of Sciences. With its long-term planning lasting until 2032 aiming at construction of an ADS demonstration facility with 1000MW thermal power, the project will be conducted in three major phases.

As part of the whole project, the C-ADS driver accelerator is a CW proton linac and uses superconducting acceleration structures except the RFQs. The design specifications for the proton beams are shown in Table 1. For the first phase, the project goal is to build a CW proton linac of 50 MeV and 10 mA by about 2015. The first phase itself will be executed progressively in several steps, with the first step to build two 5-MeV test stands of different designs.

Table 1: Specifications for C-ADS Accelerator

Energy	1.5 GeV	
Current	10 mA	
Beam Power	15 MW	
Frequency	(162.5)325/650MHz	
Duty factor	100%	
Beam loss	<1 W/m	
Beam Trips/Year[1]	<25000	1s<t<10s
	<2500	10s<t<5min
	<25	t>5min

GENERAL

The C-ADS accelerator is a CW proton linac characterised by the properties of very high beam power and stringent requirements for reliability and availability that are not possessed by any of the existing proton linac. Therefore, the linac design had to integrate the stringent requirements from the very beginning [2]. The C-ADS linac is composed by two parallel 10 MeV injectors, main linac and a section of beam line (MEBT2) used to transfer and match beams from injectors to the main linac. The total length of the linac is about 450 m and the layout of the C-ADS driver linac is show in Figure 1.

Injectors

Two parallel 10MeV Injectors are designed working at “hot spare” mode to satisfy the stringent requirements on reliability and availability. This is the most difficult part of the whole linac. At present different technical

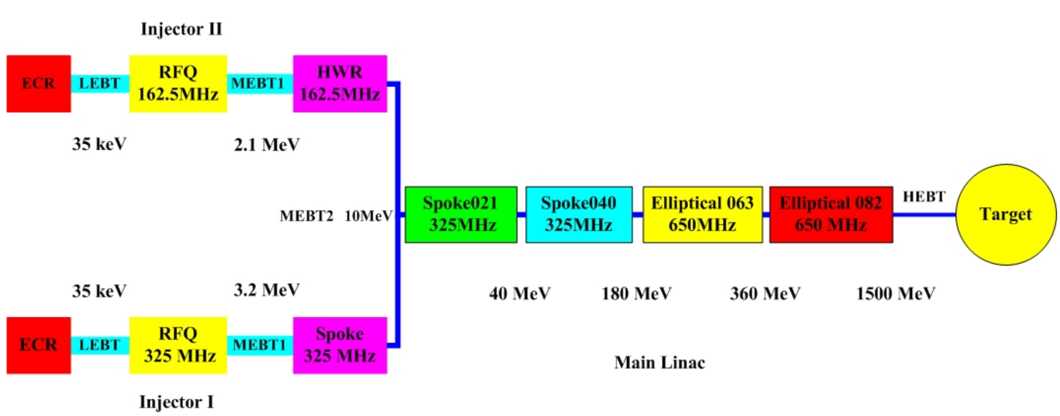

Figure 1: Layout of China ADS linac.

*Work supported by NSFC (10875099, 91126003), the China ADS Project (XDA03020000), IHEP special funding (Y0515550U1)
#lizhihui@ihep.ac.cn

approaches are applied for the two injectors reliability and availability. This is the most difficult part of the whole linac. At present different technical approaches are applied for the two injectors.

The Injector I, which is designed and built by the Institute of High Energy Physics (IHEP), is composed by a 15 mA ECR ion source with 35 keV output energy, then followed by a LEBT integrated with charge neutralization, which is used to transfer and match the beam to a 325MHz 3.2MeV 4-Vane RFQ. As the only normal conducting acceleration structure, the thermal management is believed to be one of the most difficult tasks for a CW machine, and several measures have been taken to decrease the surface energy density, such as 55 kV inter-vane voltages, much smaller than the popular design. This RFQ is also characterised by low input energy, which helps to get a relatively smaller output longitudinal emittance (0.16 mm.mrad), about 0.8 times the transverse one, which makes the following part more efficiency. Then a 2.06 m long MEBT (MEBT1) [3] is followed. It is composed by two bunchers, 6 quadrupoles and beam instruments devices, it is employed to match and transfer the beam to the superconducting section of Injector I.

The superconducting section of Injector I has one 9 m long cryogenic module with 12 single spoke cavities [4] and 11 solenoids inside, it will accelerate the beam to 10MeV. The geometry beta of the cavity is only 0.12 and is the smallest of the same type cavity, the Multipacting may be one of threatens for its steady operation. The physical and mechanical designs of the cavity have finished and the main parameters of the cavity are shown in table 2. Now the cavity is under construction, and the vertical test is foreseen at the October this year. The compact lattice with short solenoid (150 mm) and larger absolute synchronous phase (-46~-30 deg) is applied to improve the longitudinal beam dynamics.

Table 2: Main parameters of the Spoke012 cavity

β_g	Freq. MHz	V. Max MV	Emax MV/m	Bmax mT	R/Q Ω
0.12	325	0.82	32.5	47.5	148.7

The main difference between Injector I and Injector II is the working frequency. The half frequency of the spoke sections of main linac, 162.5 MHz, is applied for Injector II and the main motivation is to decrease the surface energy density of the RFQ. The details of the Injector II design can be found in reference [5].

At first step, two 5 MeV test stand based on the two different technical solutions will be built at the end of 2013 and the final solution of the two identical injectors will be chosen based on the behaviour of the two test stands.

MEBT2

Paragraphs The main function of the MEBT2 is to transfer and merge beams from two injectors and match it to the following main accelerator. As the only bending section of the linac, it is our only chance to collimate the tail particles coming from upstream here.

The bending angle is 15 degree and the distance from the injector axis to the main linac axis is 1.2 m. For each of the mainstream lines of the MEBT2, eight quadrupoles, two bending magnets and four bunchers are used. The design scheme satisfies the requirements of more-or-less uniform transverse focusing, achromatic bending and good control in the beam phase width. In the common part, three quadrupoles, two Spoke021 cavities and two solenoids are used for the matching in the phase spaces. Besides the main line, there is also an auxiliary line for each injectors and is used to transfer beams to the dump when the injector is working in offline mode. Another scheme without bunchers in bending section is under study too.

Main linac

The main linac is composed by two single spoke cavity sections working at 325MHz with geometry beta of 0.21 and 0.4 respectively, and then two 5-cell 650MHz elliptical cavity sections with geometry beta of 0.63 and 0.82 are applied to boost the beam to the final energy. The main parameters of the cavities are listed in table 3.

Table 3: Main parameters of the cavities in the main linac

Cavity type	βg	Freq. MHz	Vmax MV	Emax MV/m	Bmax mT
Single Spoke	0.21	325	1.64	31.14	65
Single Spoke	0.40	325	2.86	32.06	65
5-cell elliptical	0.63	650	10.26	37.72	65
5-cell elliptical	0.82	650	15.63	35.80	65

As a high power machine, beam loss control becomes more and more important as the energy increase. In order to satisfy the specifications listed in the table 1, we have followed the following considerations in the main linac design:

- Redundancy and fault tolerance design: for the nominal operation, the cavities only work at about 2/3 of maximum value listed in table 3, the maximum value is used when the cavity is involved in the local compensation, by which means the fault tolerance design is achieved [6].
- The mismatch is one of the sources of halo formation, which may cause particle loss. In order to keep the possibility of mismatch as small as possibility, periodic lattice structures are adopted. This is achieved by adding two long drifts at each side of the unit cell.
- Large transverse and longitudinal acceptance: this is very important for beam loss control. The aperture is

ISBN 978-3-95450-122-9

set as more than 10 times transverse RMS beam size and the absolute value of the synchronous phases are kept larger than 10 time RMS beam width throughout the whole main linac. The RMS beam size and synchronous phase are shown in figure 2.

- The tune depression along the main linac is about 0.7, which indicates significant space charge effect. We follow the high current proton linac design recipes proposed by Gerick. The zero current phase advances per period are kept below 90 degree for three phase planes. The ratio between transverse one and longitudinal one is set to 0.75 according to the values of emittance in both directions, so that the working points can be located in the resonance free region in Hofmann Chart to avoid the emittance exchange.
- Keep the zero current phase advance per meter smooth at the transition of different sections.
- The normal conducting triplet is used in the 650 MHz sections, which makes the local compensation not so difficult when one of the quadrupole is failed in working compared with the case of doublet.

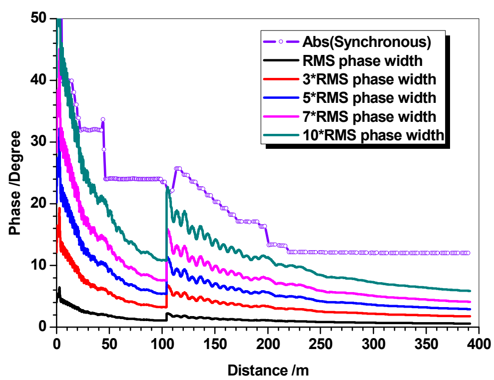

Figure 2: Synchronous and RMS phase width along main linac

END TO END SIMULATION AND ERROR ANALYSIS

The end to end multi-particle simulations are performed with TraceWin and Track. The initial particle distribution is obtained from RFQ simulation with ParmteqM and the total number of particles is 100000. The RMS envelop is very smooth even at the transitions between sections. Figure 3 shows the normalized RMS emittance evolution along the linac. We can see the transverse emittance growth is controlled about 10%, but significant longitudinal emittance growth can be observed at the junction between MEBT2 and main linac, the reason for emittance growth partly comes from the fact that the beam width is relatively large at the exit of RFQ, and partly comes from the imperfect matching between MEBT2 and the main linac. The optimization of MEBT2 is still on going.

The error analysis with proper correction scheme is performed with TraceWin code, 1000 linacs are produced with 10000 particles for each linac. The error settings are listed in table 4. The results show that particle loss is within the specification given in table 1 and prove the robustness of the design. Further error analysis with more particles will be performed with Track later.

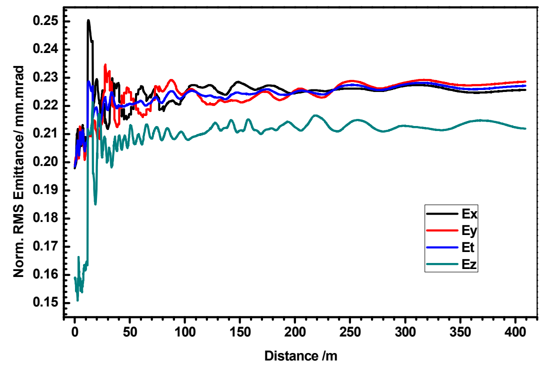

Figure 3: Norm. RMS emittance along linac

Table 4: Error settings for error analysis

Errors	Solenoid S/D	S.C. Cav. S/D	N.C. Quad. S/D
Align. Errors Translation x/y/z (mm)	±1/±0.01 ±1/±0.01 ±1/±0.01	±1/±0.01 ±1/±0.01 ±1/±0.01	±0.2/±0.002 ±0.2/±0.002 ±0.5/±0.002
Align Errors Rotation x/y/z (mrad)	±2/±0.02 ±2/±0.02 --/--	±2/±0.02 ±2/±0.02 --/--	±2/±0.02 ±2/±0.02 ±2/±0.02
RF Amp. Errors (%)	--/--	±1/±0.5	±1/±0.5
RF Phase errors (deg.)	--/--	±1/±0.5	±1/±0.5

Note: S stands for static and D stands for dynamic;

REFERENCES

[1] R.L. Sheffield, "Utilization of accelerator for transmutation and energy production", HB2010, Morschach, Switzerland, p.1.
[2] J-L.Biarrotte, Preliminary design studies of an experimental Accelerator-Driven System, XADS-DEL04-063, 2004.
[3] H.Geng et al., "The MEBT Design for the China Accelerator Driven System", IPAC'11, San Sebastian, Spain, p.2604.
[4] LI Han et al., Chinese Physics C, V.36, 2012, p.761.
[5] Y.He et al., "The Conceptual Design of Injector II of ADS in China", IPAC'11, San Sebastian, Spain, p.2613.
[6] J-L.Biarrotte, "Beam dynamics studies for the fault tolerance assessment of the PDS-XADS Linac design", EPAC 2004, Lucerne, Switzerland, 2004, p.1282.