MAIN LINAC PHYSICS DESIGN STUDY OF THE C-ADS PROJECT*

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Abstract

The Chinese ADS (C-ADS) project is proposed to build a 1000MW Accelerator Driven sub-critical System before 2032. The accelerator will be operating on CW mode with 10mA average current and the final energy is 1.5GeV. The whole linac are composed of two major sections: the Injector section and the main linac section. There are two different schemes for the Injector section. Injector I is basing on 325MHz RFQ and superconducting spoke cavities and Injector II is basing on 162.5MHz RFQ and superconducting HWR cavities. The main linac design will be different for different Injector choice. If Injector II scheme is adopted, the main linac bunch current will be doubled. In this paper the main linac design basing on Injector II scheme is studied. The design principles and considerations are introduced; the base line design is presented.

INTRODUCTION

Along with the rapid economy growth, China is experiencing an increasing demanding on energy resources and in the mean while is facing an increasing prominent problem of energy resources shortage. In the next two decades, Chinese government will devote major efforts to developing nuclear power, as nuclear power is acknowledged as a clean, safe, economic energy resource in the international society. However the key roadblock to development of additional nuclear power capacity is the concern over management of nuclear waste and it is an open question not only in China. In China, the accumulated waste is estimated to be more than 10k ton in 2020, and it will be doubled in 2030. Worldwide, more than 250,000 tons of spent fuel from reactors currently operating will require disposal.[1,2] In the past two decades, the accelerator driven sub-critical systems (ADS) is raising more and more interest and is actively studied over the world, because it is recognized as the best option for reducing the radioactive toxicity by transmutation the long-life nuclear radioactive waste into short-life radioactive waste and in the mean while getting power production in a controllable way.[3,4] But until now, there are not any large scale ADS accelerator build yet.

The Chinese ADS project is proposed to build a 1000MW Accelerator Driven sub-critical System before 2032. The driven accelerator will be operating in CW mode and the final goal is 1.5GeVwith average current of 10mA. The C-ADS linac includes two major sections: the Injector section and the main linac section. The Injecor accelerate the proton up to 10MeV and the main linac boost the energy from 10MeV up to 1.5GeV. It is staged in three phases. The first phase is aimed to accomplish two different schemes of the Injector designs (IHEP and IMP independently) by 2015 and in the mean time accomplish a part of the main linac up to the energy of 50MeV by 2016. The second phase is planned to extend the main linac energy up to 600MeV with 10mA average current by 2022 and the phase three is to achieve 1.5GeV 10mA final goal by 2032.

The main linac is a critical part of the whole driven accelerator as any design philosophy has to be considered to ensure the beam going through the whole linac and most of the design problems or defects may not appear until the beam is tracked through to the very end of the linac. This paper will present the design considerations of the main linac lattice basing on Injector II scheme.

LATTICE DESIGN AND BEAM DYNAMICS

For ADS applications, it has a rigorous demand on the accelerator stability and reliability. In order to ensure the availability of the ADS reactor and avoiding thermal stress causing damage to the subcritical reactor core, the number of unwanted "beam trips" should not exceed a few per year. This extremely high reliability specification is several orders of magnitude above usual accelerator performance. [5] To fulfill this strict reliability constrains, over-design, redundancy and fault tolerance strategies are implemented in the basic design.

In order to keep the beam in the stable area of Hofmann stability chart [6] and avoid energy change causing emittance growth and beam quality deterioration by thermal equilibrium between transverse and longitudinal planes. The approximately equipartitioning condition is applied on basis of formula (1) [7] and in the mean time to assure a current-independent lattice. According to this formula, once the normalized emittance ratio is fixed the zero current phase advance ratio is fixed accordingly.

$$\sigma_{0t}/\sigma_{0z} = \frac{k_{t0}}{k_{z0}} = \left(\frac{3}{2}\frac{\varepsilon_{nz}}{\varepsilon_{nt}} - \frac{1}{2}\right)^{1/2} \quad (1)$$

For conservative and especially avoiding any potential reasons which may cause the beam to be unstable such as envelope resonant, the zero current phase advances in all three planes remain below 90 degree.

One of the most critical characters of C-ADS accelerator is keeping the beam loss rate down to 10^{-8}. In order to meet this strict criterion, one has to control the halo growth as small as possible which means the mismatch factor has to be reduced to the maximum extent. Several methods are applied for approaching this goal. The focusing periods of the main linac are designed to have long drifts at both ends to accommodate the cryomodule warm to cold transition without destroying

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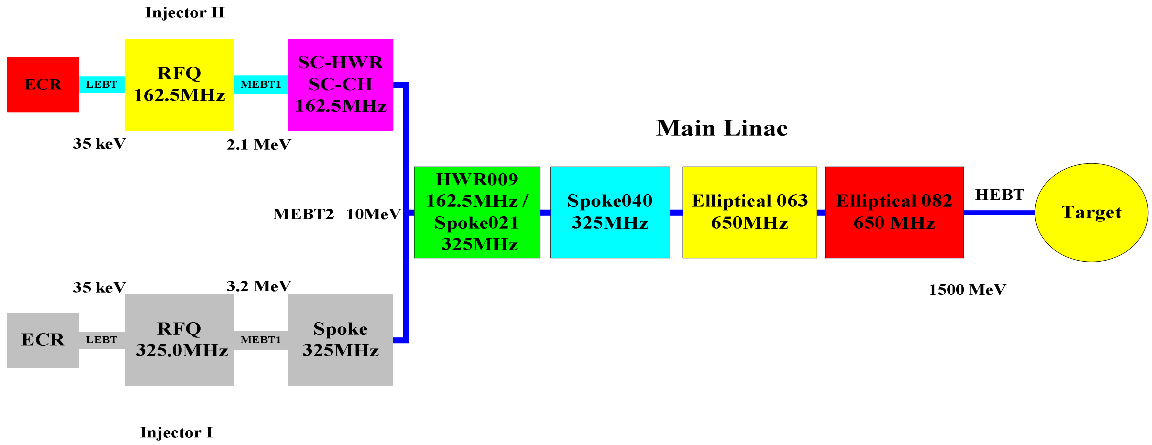

Figure 1: the schematic base line configuration of the C-ADS driver linac.

Table 1: Baseline Design of the C-ADS Superconducting Main Linac Basing on Injector II

	Focusing type	Period length (m)	No. of periods	No. of cavities	Focus devices No.	Eacc* (MV/m)	Nominal Ep (MV/m)	Energy range(MeV)
HWR009	solenoid	2.088	8	16	8	4.1	25	10-17.9
Spoke021	Solenoid	2.168	18	36	18	6.1	25	17.9-49.5
Spoke040	Solenoid	3.856	13	52	13	6.1	25	49.5-139
Ellip063	Triplet	6.074	17	51	17	10.8	30	139-370
Ellip082	Triplet	9.68	21	105	21	12.9	30	370-1500

*The Eacc listed here is corresponding to the nominal design and the effective length used in this paper is $\beta_g\lambda$.

the periodical properties and avoiding possible emittance growth caused by mismatch. The intersection matching is ensured by keeping zero current phase advances per meter smooth along the whole linac. The smoother that the zero current phase advances per meter of the intersection could be designed, the much easier the matching will be. In some cases this is a trade-off because the cavity efficiency may not be fully exploited if the phase advance per meter smooth condition is ensured. The transverse acceptance is ensured by keeping the beam pipe aperture bigger than 8 times of the rms beam size. The longitudinal acceptance is ensured by keeping the synchronous phase bigger than 10 times of the beam rms phase spread. During the intersection matching, the longitudinal acceptance condition must be kept.

Baseline Design

As shown in figure 1, the main linac on basis of Injector II are composed of five sections: two types of two-gap spoke cavities working at 325MHz with geometry beta of 0.21 and 0.40 and two types of 650MHz 5-cell elliptical cavities with geometry beta of 0.63 and 0.82. One additional HWR009 section (the same structure with Injector II cavities) is added in front of spoke021 section. This section is added to meet the longitudinal acceptance condition while keeping the peak gradient of Spoke021 cavity Ep>12.5MV/m to avoid multipacting effects.

The general layout of the main linac base line design is showing in table 1. The total cavity number is 260, the total length is 414 m. For the HWR and spoke section, an additional 117mm space is reserved for the tuner and bellows in each side of the cavity physical length. This number is referenced from the lattice design of the

Project-X. The effective length of the solenoid is 150 mm while 75 mm in each side is left for the flange and necessary shielding according to the electromagnetic and mechanical design of the FRIB solenoid. A 100mm is located in between the solenoid and cavity for a cold BPM in case it is needed. At each side of the unit there are two 400mm long drift space, so that 800mm is remained in between the period for accommodating the cryomodule separation. For the ellipse section an inter-cavity distance of 500 mm (100 mm more than the ESS [8] design to ensure there is enough space) nullifies the crosstalk between neighbour cavities, and accommodates both the main power couplers and also higher order mode couplers in case the latter is proven necessary. The relationship between the synchronous phase and 10 times of rms phase spread is shown in figure 2.

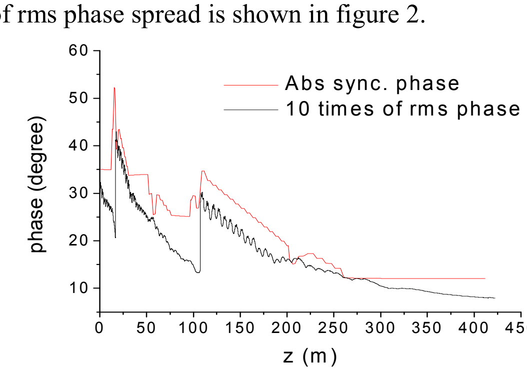

Figure 2: Absolute synchronous phase (red) and 10 times of rms phase spread of the beam (black).

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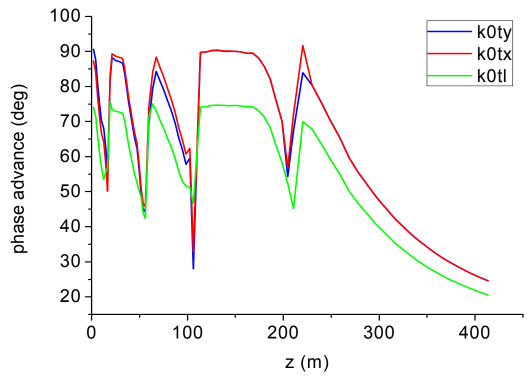

Figure 3: The evolution of transverse (red and blue) and longitudinal (green) phase advances.

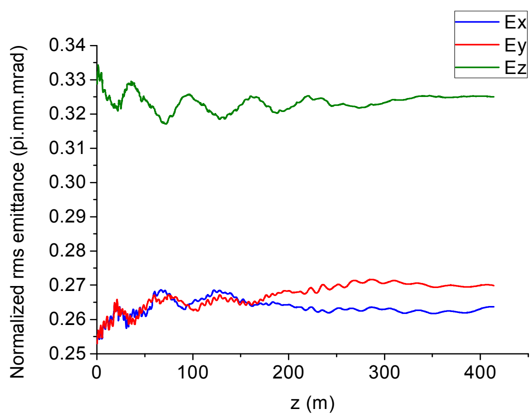

Figure 4: The normalized rms emittance growth along the main linac.

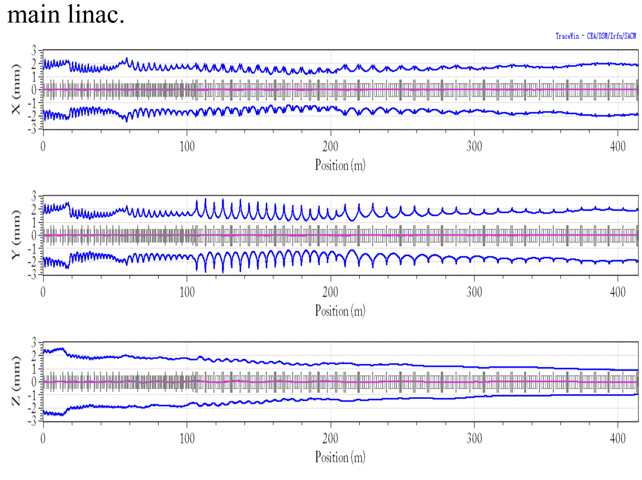

Figure 5: The rms envelope evolution along the main linac

Beam Dynamics Simulations

The beam dynamics programs used for the simulations are TraceWin and Track. The transverse and longitudinal emittance at the exit of RFQ are $0.21\pi mm.mrad$ and $0.273\pi mm.mrad$ respectively. An emittance growth of about 20% is assumed in the injector and MEBT2 section.

Without taking into account all kinds of errors and with an input 6D parabolic distribution of 100000 particles, the multi-particle simulations for the whole main linac section have been carried out. As shown in figure 4, the transverse rms emittance growth are 4.3% and 6.7% for the horizontal and vertical, respectively, the longitudinal emittance growth is -1.1%. From the simulation results, it is find that the rms emittance growth along the linac is under control in all the three phase spaces, e.g. a few percent. The beam halo information is also studied. The 100% emittance growths are under 95%, 120% and 70% for horizontal, vertical and longitudinal directions respectively. These are expected numbers as it is a space charge dominated beam with an average current of 20mA in this design. The envelope evolution is also smooth along the linac as showing in figure 5. The RMS beam size is 2 mm.

SUMMARY AND PERSPECTIVE

A review of the C-ADS main linac basic design and beam dynamics results has been presented. The lattice is designed to be very conservative to meet the reliability and stability specification to the maximum extent. The foot print of the working point in Hoffman Chart is keeping in the stable area to make sure there is no energy change between different freedoms. The error analysis will be processed basing on this design.

REFERENCES

[1] Shinian Fu, Shouxian Fang, Jiuqing Wang, Xialing Guan, Proton linac for ADS application in China, Proceedings of Linear Accelerator Conference LINAC2010, Tsukuba, Japan .

[2] R. L. Sheffield, Utilization of accelerators for transmutation and energy production, Proceedings of HB2010, Morschach, Switzerland.

[3] Shouxian Fang, Xialing Guan, Shinian Fu, Accelerator driven sub-critical research, Proceedings of the 7th Chinese particle accelerator conference 2004:184-190.

[4] Zhixiang Zhao, International research development of the accelerator driven subcritical system. Nuclear Physics Review, 1997, 14 (2): 121-124.

[5] J. L. Biarrotte, Didier Uriot. Dynamic compensation of an rf cavity failure in a superconducting linac, Physical review special topics-Accelerators and beams, 2008, 11 (072803): 1-11.

[6] I. Hofmann Stability of anisotripic beams with space charge. Physical Review E, 1998, 57 (4), 4713-4724.

[7] Martin Reiser, Theory and Design of Charged Particle Beams, Weinheim: Wiely-VCH,208:612.

[8] M. Eshraqi et al, Beam dynamics and design of the ESS linac, Morschach: proceedings of HB2010, 2010:300-303.