LINAC CONSTRUCTION FOR CHINA SPALLATION NEUTRON SOURCE

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Abstract

Construction of China Spallation Neutron Source (CSNS) has been launched in September 2011. CSNS accelerator will provide 100kW proton beam on a target at beam energy of 1.6GeV. It consists of an 80MeV H- linac and 1.6GeV rapid cycling synchrotron. Based on the prototyping experience, CSNS linac, including the front end and four DTL tanks, has finalized the design and started procurement. In this paper, we will first present an outline of the CSNS accelerator in its design and construction plan. Then the some prototyping results of the linac will be presented. Finally the linac construction progress in recent will be updated.

INTRODUCTION

China Spallation Neutron Source(CSNS) project was approved by the Chinese central government in 2008[1-2]. It has been launched in September 2011. Figure 1 shows the linac tunnel construction status up to now. It is planed to provide neutrons to the users in the first half of 2018. CSNS has a total budget of $260 M for construction of the accelerator, the spallation neutron target and 3 neutron spectrometers. Its site is at Dongguan, south part of China. The local government will support free land, additional budget of $57M, infrastructure, dedicated high-way and power transformer station.

Figure 1: Civil construction status of the linac tunnel.

CSNS accelerator is the first large-scale, high-power accelerator project to be constructed in China. The CSNS is designed to accelerate proton beam pulses to 1.6 GeV kinetic energy at 25 Hz repetition rate, striking a solid metal target to produce spallation neutrons The accelerator provides a beam power of 100 kW on the target in the first phase and then 500 kW in the second phase by increasing the average beam intensity 5 times while raising the linac output energy to 250 MeV. A schematic layout of CSNS phase-I complex is shown in Figure 2. The major design parameters of the CSNS accelerator complex for the two phases are listed in Table 1. In the phase-I, an H^- ion source produces a peak current of 25 mA H^- beam. RFQ linac bunches and accelerates it to 3 MeV. DTL linac raises the beam energy to 80 MeV. After H^- beam is converted to proton beam via a stripping foil, the RCS accumulates and accelerates the proton beam to 1.6 GeV before extracting it to the target.

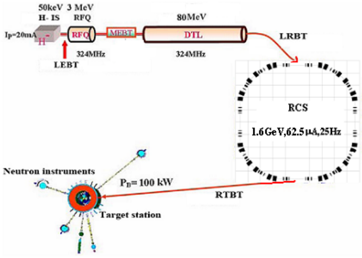

Figure 2: Schematics of the CSNS complex

Table 1: CSNS Design Parameters

Project Phase	I	II
Beam power on target [kW]	100	500
Proton energy [GeV]	1.6	1.6
Average beam current [μA]	62.5	312.5
Pulse repetition rate [Hz]	25	25
Linac energy [MeV]	80	250
Linac type	DTL	+SC Spoke
Linac RF frequency [MHz]	324	324
Macropulse. ave current [mA]	15	40
Macropulse duty factor	1.0	1.7
RCS circumference [m]	228	228
RCS harmonic number	2	2
RCS acceptance [πmm-mrad]	540	540

LINAC DESIGN AND DEVELOPMENT[3]

Penning H^- ion source is adopted for CSNS linac. The source provides 25 mA peak current, 0.5 ms long, 0.2πμm normalized emittance (rms) pulses at 50 kV and 25 Hz repetition rate for Phase-I.

The LEBT is for matching and transporting the H^- beam from ion source to RFQ accelerator, and pre-chopping the beam according to the requested time structure by the RCS with a chopping rate of 50%. Three-solenoid focusing structure is adopted for space charge neutralization, as shown in Figure 3. An electrostatic deflector is chosen as pre-chopper, positioned at the end of the LEBT. A prototype pre-chopper was installed at the entrance of the 352MHz proton RFQ, and it reached a fast rise time of 15 ns in the beam measurement at the exit of the RFQ[4].

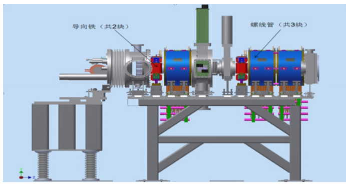

Figure 3: Front end of CSNS linac.

The CSNS RFQ construction is based on our experience of ADS RFQ design and manufacture[5]. A four-vane type RFQ is adopted with RF frequency of 324MHz. It accelerates H- beam from 50 keV to 3 MeV, with duty factor of 1.05%. The inter-vane voltage is 80 kV with Kilpatrick factor of 1.78. It has a total length is 3.62 m and is separated in two segments(Figure4). They are resonantly coupled with the coupling cell in the middle. Each segment technically consists of two modules and each module is composed with two major vanes and two minor vanes, and they are brazed together to form a vacuum cavity. Three sets of 1000 l/s ion pumps and 500 l/s turbo-molecular pumps are designed for an order of 10^{-7} torr dynamic vacuum pressure. Along the RFQ cavity there are 12 tuners in each quadrant for tuning field flatness and minimal dipole component. 20 cooling-water channels are distributed in the cross-section of the cavity for thermal stabilization and frequency tuning during operation. Four RF power couplers feed a pulse power of 510 kW into the cavity.

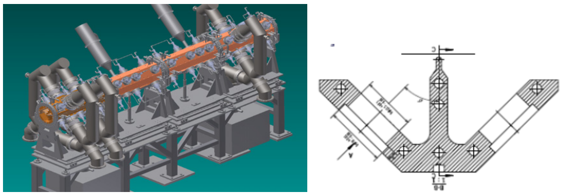

Figure 4: RFQ cavity (right), major vane with cooling-water channels (left).

The total length of MEBT is about 3 m, majorly including 10 qaudrupoles, two bunchers in the first phase. Two J-PARC type RF choppers will be added for the second phase. Beam instruments for beam current, beam position and beam loss are also installed in the MEBT. Figure 5 shows a scheme of the MEBT elements installation. Multi-particle simulation indicates the linac emittance growth majorly occurs in the MEBT. The RMS emittance growths in the x, y, z directions are respectively about 20%, 19% and 16% for 15mA beam in the first phase.

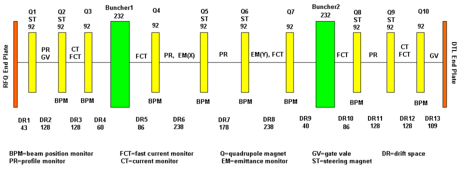

Figure 5: CSNS MEBT elements arrangement.

The DTL accelerates the 3 MeV beam from the RFQ to 80 MeV. The maximum surface field is below 1.3 times the Kilpatrick limit. In the old vision of the DTL design, we used FD lattice with a small drift tube bore radius[4]. It was found the particle losses was more than the limit of 1W/m when all errors were taken into account in the end-to-end multiparticle simulations. So FFDD focusing lattice is used in the new vision of DTL design with a lager bore radius for the drift tubes and lower quadrupole gradient. In this new design, the accelerating field keeps constant in each tank. The major parameters of the DTL tanks are listed in Table 2.

Table 2: The Major Parameters of the DTL Tanks

Tank number	1	2	3	4	total
Output energy (MeV)	21.67	41.41	61.07	80.1	80.1
Length (m)	8.51	8.56	8.78	8.8	
Number of cell	64	37	30	26	157
Cavity power (MW)	1.35	1.32	1.32	1.34	5.33
Total RF power (MW)	1.91	1.92	1.92	1.93	7.68
Accelerating field (MV/m)	2.86	2.96	2.96	3.0	
Synchronous phase (degree)	-35 to -25	-25	-25	-25	

A tank consists of three unit tanks with a length about 2.8 m for fabrication. Drift tubes are mounted on the tank through holes on the top of the tank. DC power supply is used for the focusing quadrupole in the drift tube. Each tank has 12 plug tuners and 2 dynamic tuners. A power coupler with ridged waveguide feed 2 MW RF power to a tank from a klystron. Vacuum of 1×10^{-6} Pa is guaranteed with 6 ion pumps and 3 molecular turbo pumps in each tank. The first tank of the DTL is plotted in Figure 6.

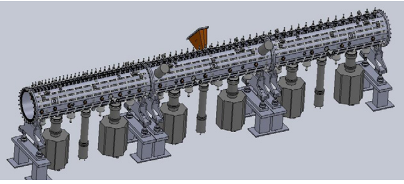

Figure 6: First tank of the CSNS DTL.

A prototype DTL has been fabricated for the technology development and cold measurement[6]. Figure 7 shows the prototype tank and measured alignment result of the drift tubes with error less than 0.03 mm.

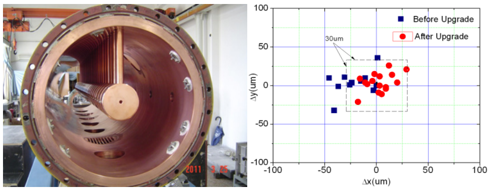

Figure 7: Prototype DTL and the measured center of the drift tubes.

LINAC CONSTRUCTION

CSNS linac is planed to start installation at the end of 2013 when the linac tunnel becomes available. Now most of the linac components have started fabrication or procurement.

The ion source has been ready for assembly. Figure 8 shows the major components of the source body. As we have set up a prototype H$^-$ ion source at IHEP with a satisfactory beam current, we can take the advantage of this experience to start beam extraction test and beam transmission tuning in the LEBT in the early of the next year at IHEP before the laboratory at CSNS site becomes available.

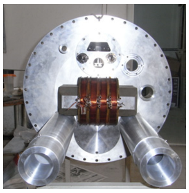

Figure 8: H$^-$ ion source body during assembly.

RFQ cavity is now under fabrication. The 16 major vanes have been drilled the cooling water channels and will start semi-fine machining, while the 16 minor vanes are under fine machining. It is planed to complete the cavity fabrication in the middle of the next year. The RFQ will be powered by two 4616V4 tetrode amplifiers at 324 MHz with an output pulsed power of 350 kW for each. We replaced klystron in the old design with this tetrode just for less cost. Now one of the tetrode power sources has been set up at IHEP, and the test result shows it reached the output power 400 kW with a pulse length of 700ms at 25 Hz. Based on this successful experience, another set of the power source will soon start construction. Figure 9 shows the RFQ vanes under fabrication and tetrode power source.

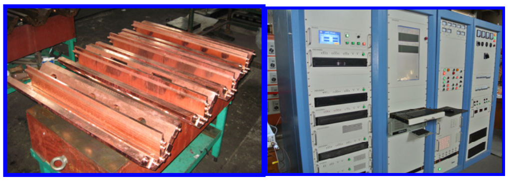

Figure 9: RFQ vanes under fabrication (right) and tetrode power source (left).

For the MEBT, we will not fabricate any magnet and its power supply, as we are going to make use of the existing magnets of the beam line for ADS experiment. Two bunchers will start fabrication in recent and their solid state power sources of 25 kW have been ordered.

The DTL manufacture started in the end of the last year at the workshop of IHEP, at which a prototype DTL has been made. We will basically follow the manufacture technology of the prototype. The tank is made of carbon steel and the inner surface is copper-plated, with a thickness of 0.15mm after polishing. The drift tube is made of full copper and so does the stem. The quadrupole coil is SAKAE type, the same as J-PARC DTL. As the coincident of the mechanical center of the drift tube with the magnetic center of the quadrupole is rather essential requirement beam loss control and the work is very time costing during the manufacture of the drift tube, we built a new rotating-coil measurement system so as to reach a high accuracy of 6mm and high efficiency in the measurement of the magnetic center, as well as high-order modes, of the quadrupole. The system is now under test, as shown in Figure 10.

Figure 10: Rotating-coil magnetic measurement system.

Now the first tank is under fabrication, as shown in Figure 11. It is expected the first tank can be installed in the linac tunnel in the January 2014 after the beam commissioning of the RFQ. Then the following three tanks will be installed after the beam commissioning of the MEBT and the first DTL tank in August of 2014.

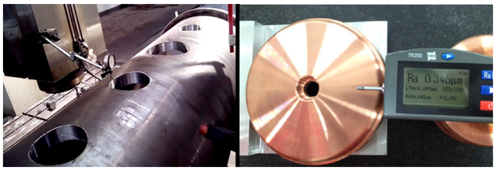

Figure 11: The DTL tank and drift tube under machining.

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