STATUS OF CSNS PROJECT

S.N. Fu, H.S. Chen, Y.W. Chen, Y.B. Chen, H.Y. Dong, S.X. Fang, K.X. Huang, W. Kang, J. Li, H.C. Liu, L. Ma, H.F. Ouyang, H.M. Qu, H. Sun, J.Y. Tang, C.H. Wang, Q.B. Wang, S. Wang, T.G. Xu, Z.X. Xu, C. Zhang, J. Zhang, IHEP, Beijing 100049, China

Abstract

The China Spallation Neutron Source (CSNS) accelerator is designed to accelerate proton beam pulses to 1.6 GeV 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. The project construction has been formally launched in 2011 and it is planned to complete the project in March 2018. It is one of the high intensity proton accelerator projects in the world and it imposes a great challenge to Chinese accelerator community. This presentation will cover the status and challenges of the CSNS project.

INTRODUCTION

China has built several synchrotron light sources, such as Shanghai Light Source[1], and reactor-based neutron sources, such as CARR. They are providing multidisciplinary platforms for scientific research and technology development by scientific institutions, universities, and industries. As a complimentary tool to them, a high-flux pulsed neutron source is highly demanded by the user community. China Spallation Neutron Source project was proposed in 2001 and then formally approved by the Chinese central government in 2008. After several years for detailed design and key technology development, the project construction started in 2011 and will be completed in March 2018. The construction site is located at Dongguan, Guangdong Province, and the project is hosted by the Institute of High Energy Physics together with the Institute of Physics. At present, about 300 staff works for the project.

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[2]. It will be upgraded to 500kW beam power at the same repetition rate and same output energy in the second phase. For this reason, the present design has reserved a long beam line in LRBT for superconducting spoke cavity installation for the linac energy upgrade in order to reduce space-charge effect in the RCS when the beam current becomes 5-times higher. Table 1 lists the major parameters of the accelerator in the two phases. Although China has built several hadron accelerators [3], CSNS accelerator is the first high-energy and high-intensity accelerator in China. It imposes a great challenge in the accelerator design and key technology [4].

Table1: 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	+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
Target Material	Tungsten	Tungsten

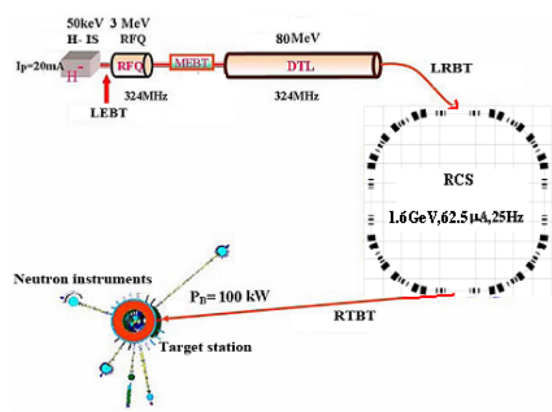

Figure 1: Schematics of the CSNS complex.

A schematic layout of CSNS phase-1 complex is shown in Figure 1. In the phase one, an 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, RCS accumulates and accelerates the proton beam to 1.6 GeV before extracting it to the target. 20 neutron channels are designed surrounding the target, but only 3 spectrometers will be built in the first phase due to limited budget.

ISBN 978-3-95450-122-9

Copyright © 2013 by JACoW — cc Creative Commons Attribution 3.0 (CC-BY-3.0)

The investment of $350 M for CSNS project is the largest for a single mega-scientific project up to now in China. Among it $270 M comes from the central government and $80 M from the local government. And the local government also provides free land and some infrastructure, such as the dedicated access road to the site from high way, main substation with capacity of 63 MVA, and site land preparation. In addition, about 300 staff for CSNS project is financially supported by CAS.

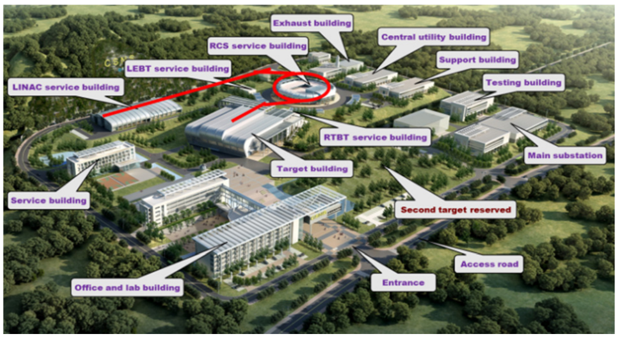

Figure 2: Artificial view of CSNS campus at Dongguan.

The site occupies an area about 0.7 km^2. CSNS phase–I use 40% of it and the remaining land backups for future project expansion. Figure 2 is an artificial view of the CSNS campus, with two office buildings, accelerator service buildings, target hall, auxiliary facility buildings, test buildings, etc. And an area is reserved for the second target hall saving for muon and white neutron sources in the second phase. The architectures for underground accelerator tunnel and experiment hall are plotted in Figure 3. The architecture for backscattering fast neutron beam will be built in this phase. A short tunnel section for the upgrade will also be built for future prolong.

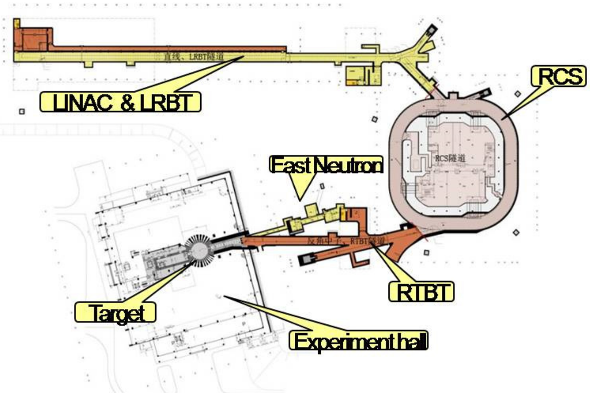

Figure 3: CSNS accelerator tunnel and experiment hall.

In the following sections, the paper will briefly introduce the present construction status of CSNS project, progress in accelerator component mass production and the design of the target.

CIVIL CONSTRUCTION STATUS

The CSNS project started construction in September 2011 after the site land and the access road had been prepared by the local government. Earth excavation for the building foundation and tunnel of the main facility has been completed up to now. And the architectures for the linac tunnel and klystron gallery are under construction and we plan to start installation of the front end of linac in September, 2013. The civil construction status is shown in Figure 4. From this photo, we can see the office building and service building in the right side, and the two test halls and utility buildings in the left side. The occupancy of the test halls can be foreseen in August. We expect to move in the new office in the end of this year.

Figure 4: Civil construction status.

ACCELERATOR STATUS

While the civil construction is making a rapid progress, mass production of the accelerator components has been started, on the basis of finalized design in detail and two R&D programs to overcome the major technology difficulty.

Front-end

The CSNS linac design, an H$^-$ ion source provides 25 mA peak current, 0.5 ms long, 0.2 πmm-mrad normalized emittance (rms) beam at 50 kV and 25 Hz repetition rate for phase-I. The ISIS type Penning H$^-$ surface source is chosen for CSNS. Based on prototype experience and some optimization in design, a new source for the project has been fabricated and set up at the laboratory of the Dongguan University of Technology for beam extraction test before the test hall is available, as shown in Figure 5. Beam emittance measurement is going to do in recent, when the double slits measurement setup is assembled.

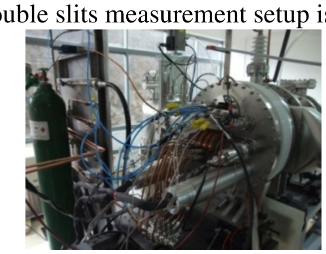

Figure 5: CSNS H$^-$ ion source in beam extraction test.

The LEBT consists of three-solenoid focusing structure for beam transportation with space charge neutralization and an electrostatic deflector as a chopper positioned at the end of the LEBT. A prototype of the chopper reaches a fast rise time less than 17 ns in a proton beam test, as shown in Figure 6. The solenoids and their power supply have been completed and are ready for installation when the linac tunnel is available.

Copyright © 2013 by JACoW — cc Creative Commons Attribution 3.0 (CC-BY-3.0)

ISBN 978-3-95450-122-9

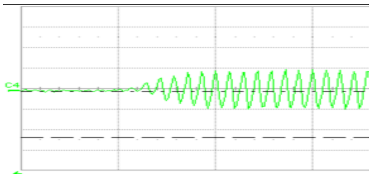

Figure 6: Chopped beam pulses of 1 MHz with a rise time about 5 periods of 352 MHz.

RFQ accelerates H$^-$ beam from 50 keV to 3 MeV, with duty factor of 1.05%. A four-vane type RFQ at 324 MHz has total length of 3.62 m, composed of four technical modules. To stabilize the field in the long cavity it is divided into two section cavities, and then resonantly coupled together with a coupling plate in the middle. Without adding the dipole stabilizer roads, the frequency interval between the operation quadrupole mode and its two neighbouring dipole modes can reach -6.102 MHz and 4.924 MHz, respectively. Thermal stabilization can be achieved by 20 water-cooling channels in the cross-section of the cavity with 8 on the four vanes and 12 on the skirt wall. And the water temperature difference between the vane and wall will be utilized as a frequency tuning knob in operation, and thus there is no dynamic tuner. Two 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. Another set of backup pumps can be easily added if it is found to be necessary. Figure 9 shows the RFQ assembly. Fabrication of the RFQ cavity started in the early of 2012 and until now the four technical modules have been completed. Figure 7 shows the RFQ structure design and brazed module cavities. Now the four modules is under assembly to form a whole-length cavity for field tuning with 48 slug tuners, aiming at the field flatness of working quadrupole mode less than 1% and dipole component less than 2%, which is essential for a high beam transmission rate. Two sets of Burle 4616 Tetrode feed 530 kW total RF power to the RFQ through two coaxial power couplers. In the power test, the source can reach 400 kW pulse power with pulse length of 700 μ s at 25 Hz, as shown in Figure 8.

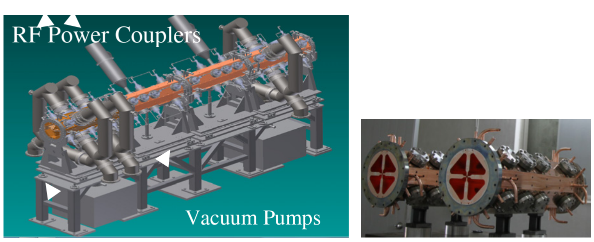

Figure 7: RFQ design and brazed module cavities.

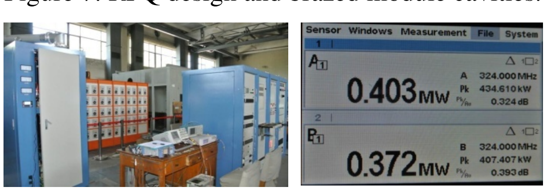

Figure 8: RFQ power source and its output power in test.

The total length of MEBT is about 3 m, including 10 qaudrupole magnets, 2 bunchers, 12 steering magnets, as well as some beam diagnostics, including 8 BPM, 5 FCT, 4 BPrM, 3 BLM, 2 CT and EM. As the LEBT chopper has already reach a rise/fall time less than 17ns, we will not install the RF chopper in Phase-I, but leaves space for them for upgrade. The quadrupole magnets are ready for installation and their power supplies are under fabrication. The buncher cavity is composed with two half copper cavities. They have been fine-machined and are read for brazing together to form a cavity. Their solid-state power sources are also under fabrication.

In reference to the present progress of the front end, it can be foreseen that the front end can be installed in the tunnel in September 2013.

DTL Linac

The 324 MHz DTL accelerates the 3 MeV beam from the RFQ to 80 MeV. The DTL linac is composed of 4 tanks with a total length of 35 m. Each tank is about 9m long and assembled with three technical modules, as shown in Figure 9. The tank is made of a carbon steel tube with copper plated on the inner tank surface and all ports surface by the technology of PR (Periodical Reverse) electroforming. The thickness of the 99.97% OFC copper is 0.2 mm after polished for high conductivity. Each tank has 9 vacuum ports with grilles for connecting with 6 ion pumps of 1000 *l*/s and 3 turbo-molecular pumps of 620 *l*/s to achieve the designed vacuum of 1.0×10^{-6} Pa. On the top of the tanks there are 153 ports for fixing the drift tubes. And on the bottom there are 12 slug tuners on each tank.

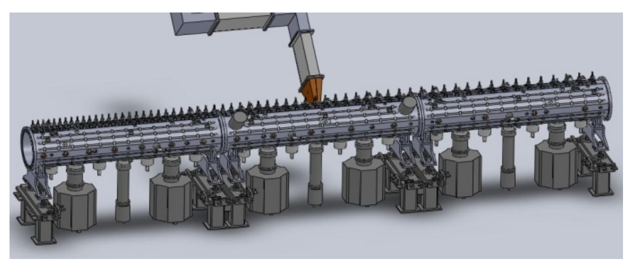

Figure 9: A 9 m long DTL tank with three modules and one power coupler.

Each drift tube assembly is comprised of a tube body and a stem. One of the main features of the CSNS DTL is the use of OFC in all parts of DTs. Long-term deformation test has been done which convinced us of the material selection and design. All parts of the DT and the stem are welded together by electron beam welding after the installation of the EMQ into the DT. The quadrupole coil is J-PARC type which is made from a bulk copper with wire-cutting and electroforming to generate a cooling water channel. A new rotating coil measurement stand is set up for the quadrupole magnet field measurement to guide the position tuning for coincident of the tube geometric centre with magnetic centre, with an error allowance less than ±0.05mm. And it can also measure the quadrupole rotating error.

Copyright © 2013 by JACoW — cc Creative Commons Attribution 3.0 (CC-BY-3.0)

ISBN 978-3-95450-122-9

Mass production of the tank and tube started in early 2012. The progress is delayed due to the difficult in high accuracy fabrication. Figure 10 shows the fabricated tubes and tank. They will be assembled for field measurement and tuning with slug tuners and coupling stems.

Figure 10: The fabricated drift tubes.

The RF power source for DTL is 324 MHz klystron from CPI, with maximum output power of 3 MW. The first klystron will be installed in the klystron gallery in the end of this year. The adopted HVPS scheme is 400 Hz AC series resonance high voltage power supply. One power supply feeds the same voltage of 120 kV to two klystron cathodes through their m-anode modulators. We proposed such a new type of HVPS for klystron and demonstrated its feasibility with an 100 Hz prototype. Now a 400 Hz set is running in Tsinghai University for a 325 MHz klystron from CPI. Two sets of the power supply are under manufacture for CSNS DTL. Figure 11 shows the klystron and its HVPS under assembly.

Figure 11: 3MW klystron and its 120 kV HVPS under manufacture.

A new version LLRF control system was updated by improving hardware device and control software. It has been commissioned with the ADS RFQ. The test results show that the amplitude and phase variations in the cavity are less than ±0.25% and ±0.35° with beam loading, much better than the requirements of ±1% in amplitude and ±1° in phase, as shown in Figure 12.

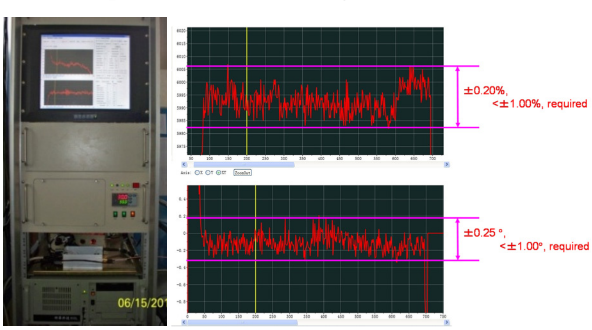

Figure 12: New reversion digitalized linac LLRF system and its test results with beam loading.

RCS

The RCS lattice consists of 48 quadrupoles and 24 dipole magnets, forming a four-fold ring with circumference of 227.92m. In the each super period, an 11 m long drift space is left in a triplet cell. These four uninterrupted long straight sections are arranged with injection, extraction, RF acceleration and transverse collimation. To reduce space charge effect, H^- beam from linac is stripped by a carbon foil and painted into a large phase space about 240 π mm-mrad in two transversal directions with 8 pulsed bump magnets. The maximum space charge tune shift is -0.28 in bunching stage. A two-stage collimator system with an acceptance of 350 π mm-mrad is utilized for removing halo particles.

During R&D period, crack of the dipole core with AC excitation had been a major obstacle for us to overcome for a long time. For the quadrupole we also met the crack trouble of the coil epoxy resin. Now, the RCS AC dipole and quadrupole prototype magnets in mass production have been fabricated. They have been continuously operated with full AC current of 877 A for 72 hours. The coils and cores of the magnets are robust enough, and no crack was found on their surfaces. The field of the two prototype magnets has also been measured, and the results meet the specifications. With the success of the prototype magnets, mass production of the main magnets has been started at the workshop of IHEP. The first dipole and quadrupole magnets in mass production have been produced as shown in Figure 13. The magnet installation in the ring tunnel is foreseen in the middle of 2015.

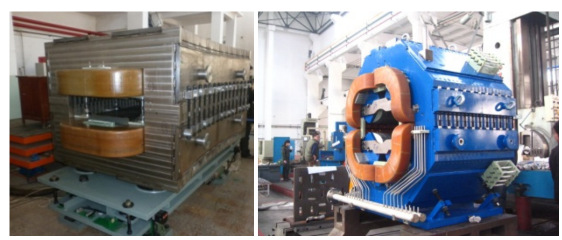

Figure13: RCS dipole and quadrupole prototype magnets in mass production.

The power supply for the magnets uses White resonant circuits to avoid the impact to the grid. Due to nonlinear feature of the magnet core, a pure sinusoid AC current from the power supply will result in a deformed sinusoid magnetic field with an unacceptable tracking error in our measurement of the magnetic field. To deal with this issue, high order harmonic current is injected into the power supply for compensating for the nonlinearity. The 24 dipole magnets are powered with one set of current supply and the 48 quadrupole magnets are powered with 5 sets of current supplies. All of these power supplies are under mass production. The first set will be available in July of this year.

The RCS has eight ferrite-loaded cavities for proton acceleration, of which seven cavities provide total 165 kV RF voltage with additional one as backup. The cavity resonant frequency shifts from 1.02 MHz to 2.44 MHz in 20 ms by a bias current supply. In the prototype RF

Copyright © 2013 by JACoW — cc Creative Commons Attribution 3.0 (CC-BY-3.0)

system, the response bandwidth of the bias current supply has been improved up to 10 kHz by adding a small linear shunt modulator to the existing switching power supply. The resulted tracking error apparently reduced within to the specification of ±0.2%. Based on the experience of high power operation of the RF system prototype, the design of the RF cavity structure has been optimized to ameliorate the cavity and RF transmitter performance. Manufacture of 8 sets of RF cavities and 500 kW transmitters has been in good progress. Figure 14 shows the fabricated cavity to be assembled. It can be foreseen the first set of the RF system will soon be completed in next month, as planned.

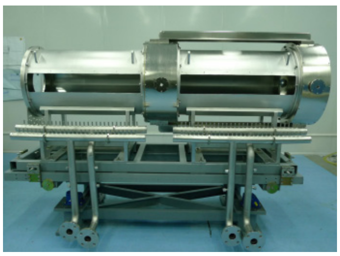

Figure 14: RCS cavity in mass production.

Ceramic vacuum chambers are used in the RCS dipole quadrupole magnets, injection bumps and extraction kickers to avoid the eddy current. The chamber size for dipole magnet is rather large with a length of 2.8 m and a cross-section of 135(V)×218(H) mm in inner diameter. All of these chambers have started mass production by a Germany vendor for dipole magnet chambers and domestic vendors for the rest. The inner surface of the chamber will be coated with TiN for low SEE. Now a coating facility with a bending magnetron sputter has been set up with a satisfactory performance in test.

The Beam Lines and Interface

The LRBT transports the H^- beam to the ring and it has a length of 197 m with 47 quadrupoles and 4 bending magnets. A rebuncher is installed for reduction of the beam momentum spread. The quadrupole magnets are under mass production and will be installed in the tunnel before the end of this year. 12 injection bump magnets are under fabrication for H^- painting injection into the ring. A pulsed power supply for the four horizontal bumpers with 9,000 A output current in maximum during injection time of 550 μs has also been developed and another set for the four vertical bumpers is under production. The stripping foil facility has been manufactured with 20 carbon foils on a rotating frame, as shown in Figure 15.

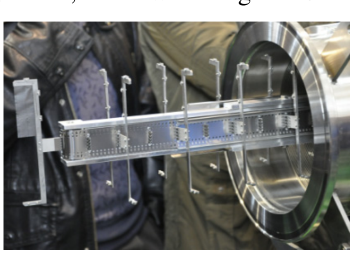

Figure 15: Stripping foil for H^- injection.

The proton beam is extracted from the ring with 8 kickers and a Lambertson magnet. The in-vacuum kicker magnet uses a ferrite core for a high magnetic flux. The pulse power supply uses Blumlein type pulse forming network to get a short pulse with a current of 6660 A and a flattop of better than ±1.0% in 600 ns. The RTBT transports extracted proton beam from the RCS to the target. The total length is about 144 m with 4 dipole and 37 quadrupole magnets. To generate a uniform footprint of beam onto the target, two octapole magnets are designed in the RTBT. The RTBT has three collimators for protection of the target and shielding of back scattering neutrons.

TARGET DESIGN

CSNS target station design has been finalized. It is optimized for 100 kW operation in the first phase and reserved the feasibility to upgrade its capability to 500 kW, with tungsten as target material in the two phases. The target is maintained with a horizontal plug while the moderator and reflector are maintained with a vertical plug, as shown in Figure 16. 20 neutron beam ports are designed for instrument increase, even though only three will be used in the first phase. A prototype moderator is under development. A mock-up of the moderator-reflector remote-handling system has been set up to confirm the design and to demonstrate the maintenance scheme. It is planned to complete the TMR construction in the middle of 2016.

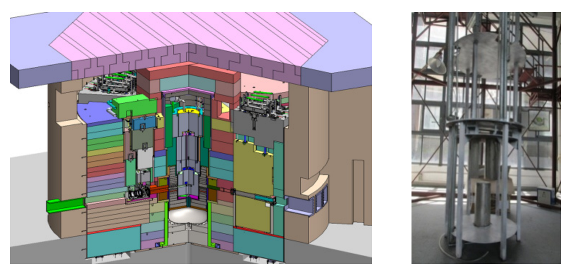

Figure 16: Target-moderator-reflector design and its maintenance mock-up.

ACKNOWLEDGEMENTS

The authors thank the team members of the CSNS project for their devotion and hard work.

REFERENCES

[1] Jiang MianHeng, Yang Xiong, Xu HongJie, et al. Shanghai Synchrotron Radiation Facility. Chinese Science Bulletin, 2009, 54(22): 4171-4181
[2] S. X. Fang, S. N. Fu, Q. Qin, J. Y. Tang, S. Wang, J. Wei, and C. Zhang, J. Korean Phys., 48 (4), 697 (2006).
[3] Fu Shinan, Research progress on high intensity hadron accelerator in China, Chinese Science Bulletin, Vol. 57(36), 4663-4667 (2012)
[4] Jie Wei, Hesheng Chen, et al., NIM A (600) 10-13 (2009).

ISBN 978-3-95450-122-9

Copyright © 2013 by JACoW — cc Creative Commons Attribution 3.0 (CC-BY-3.0)