CSNS Project Construction

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Abstract. The China Spallation Neutron Source (CSNS) is designed to accelerate proton beam pulses to 1.6GeV at 25Hz repetition rate, striking on a solid metal target to produce spallation neutrons for neutron scattering experiment with 20 spectrometers. The accelerator provides a beam power of 100kW for the target in the first phase and then 500kW in the second phase at the same repetition rate and in the same target station. The project construction launched in 2011 and it is planned to complete the first phase project in March 2018 for governmental acceptance. Now the accelerator construction and machine commissioning have been completed and the initial beam commissioning is in progress. Target station and three spectrometers are under final installation. This paper will update the recent construction status of the CSNS project.

1. Introduction
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 September 2011 and will be completed in March 2018[1]. 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, CAS. At present, more than 350 staff works at Dongguan site for the project construction.

The CSNS accelerator provides proton beam pulses of 1.6GeV kinetic energy at 25Hz repetition rate to a solid metal target to produce spallation neutrons for neutron scattering experiment. 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 25mA H- beam. RFQ linac bunches and accelerates it to 3MeV. DTL linac raises the beam energy to 80MeV. After H- beam is converted to proton beam via a stripping foil, the Rapid Cycling Synchrotron (RCS) accumulates and accelerates the proton beam to 1.6GeV[2]. Then the beam is extracted to the Tungsten target cladded by tantalum and cooled by water. 20 neutron channels are designed surrounding the target, but only 3 spectrometers will be built in the day-one operation due to limited budget from the centre government. More spectrometers are under planning together with users from universities, institution and local government. The beam power is 100kW on the target in the first phase. The facility design allows further upgrade to 500kW beam power at the same repetition rate and the same output energy in Phase-II by increasing the average beam current 5 times. For this purpose, we reserve 85m length in the LRBT for the installation of additional accelerating cavities, such as superconducting spoke cavity used in our ADS program or PIMS cavity used in LINAC-4 at CERN, for beam energy upgrade to more than 250MeV in the Phase-II.
Now the project construction will soon complete. As shown in Figure 2, all the civil constructions, including the accelerator building, the target and spectrometer hall, the utility buildings as well as the user building, are all put into usage. The accelerator has been installed. The linac is under beam commissioning and the RCS ring has completed machine commissioning. The target-moderator-reflector (TMR) has almost been installed and the construction of spectrometers is at the final stage. We can foresee the first neutrons from the target in this September. In the following sections we will report the construction status in more details.

![Figure 1. Schematics of the CSNS complex.](image1.png)

2. Accelerator Construction
The H\textsuperscript{-} linac is composed of a Penning H\textsuperscript{-} ion source, a LEBT with a beam chopper, an RFQ accelerator to raise beam energy to 3MeV from 50keV, a MEBT for beam match in transversal and longitudinal directions, and an 80MeV DTL with 4 tanks as the major accelerating structure of the linac. The linac has been installed in the tunnel, as shown in Figure 3.

The RCS adopts four-fold structure with triplet focusing lattice. In the four long-straight sections, we arrange injecting, collimating, extracting and accelerating elements separately. The circumference of the ring is about 228m. The RCS majorly consists of 24 dipole magnets and 48 quadrupole magnets which are all powered with DC+AC current from White resonant power supplies, 8 injection painting magnets plus 4 bump magnets, one primary collimator together with four secondary collimators, 8 kicker magnets and 8 accelerating cavities with harmonic number of two. All the ring components have been installed in the ring tunnel and Figure 4 shows an arc section of the ring.

![Figure 3. CSNS linac installed in the tunnel.](image2.png)

2.1. Linac beam commissioning
Beam commissioning of the frontend started in 2014. The ion source could provide maximum 40mA H\textsuperscript{-} beam, but with large emittance. Within the design emittance of 0.2π mm.mrad, the beam current is about 15mA, which can meet the requirement of 100 kW beam power of CSNS. In order to raise further the RFQ beam transmission efficiency, a collimator at LEBT to scrape the beam beyond the
acceptance of RFQ was installed. Many efforts were also put on the operation stability of the ion source, and up to now, beam trip number is around 3 per day with output H beam current above 50mA. The beam commissioning of RFQ was done together with MEBT. In April 2015, we got a 3MeV H beam of 28mA from the RFQ, which is much better than our Phase-I specification. Many beam diagnostics have been done, including BPM offset measurement, response matrix measurement, orbit measurement and correction, emittance measurement and beam chopping test. An electrostatic chopper is adopted in the LEBT, instead of a fast kicker in MEBT. The waveform measured in the MEBT shows the rise time is about 15ns (5 RF periods), as shown in the Figure 5. The rise time is comparable to the fast chopper that usually used in MEBT. In January 2016, DTL tank-1 started beam commissioning with a diagnostics plate. The commissioning started from the low peak beam current, low repetition rate and short pulse length, and then increase the average beam current to the designed peak current and pulse length. Phase scanning method is applied to searching for the RF synchrotron phase by TOF technology with two FCTs. Beam transmission rate reached 100% at 18mA output beam current, as shown in Figure 6. Same beam tuning method was also applied to the DTL tank-2 beam commissioning, which was conducted in November 2016. At present, we are conducting beam commissioning for the following tank.

Figure 5. Rise time of the chopped beam. Figure 6. CT data in DTL-1 beam commissioning.

2.2. RCS machine commissioning
Machine commissioning was conducted in two steps: system commissioning and joint commissioning. Now we are coming to the second step. All dipole and quadrupole magnets were powered with their power supplies at the specified field for 7-day continuous operation. Due to 25Hz AC excitation, vibration of the magnets resulted in the break of a ceramic chamber in a quadrupole magnet. It was replaced with spare one and counter measure has been applied to all ceramic chambers to reduce the vibration. Second 7-day operation demonstrated the effectiveness of the measure. To deal with time harmonics in AC magnetic field due to nonlinearity, we proposed a new harmonic injection scheme to compensate for it, and the perfect effectiveness was confirmed with field measurement of the magnets. All 8 RF ferrite-loaded cavities and their RF power sources together the LLRF systems have been commissioned for 7-days continuous operation. LLRF control reached a satisfactory stability without beam loading, but further debugging and confirmation of LLRF operation will soon be conducted with injected beam.

3. Constructions of Target Station and Spectrometers
CSNS target station is designed to accept a proton beam power of 100 kW with the upgrade capacity to 500 kW. It means that the shielding, the embedded pipes are designed for 500 kW beam power while the TMR system is optimized for 100 kW. Figure 7 shows the engineering and technical designs of CSNS target station. Three wing-type moderator, one ambient water moderator and two cryogenic hydrogen moderators (20 K) supply diverse characteristics of pulsed neutron beams. The solid tungsten clad by tantalum is selected as CSNS target plates. The TMR neutronics design is performed and optimized by Monte Carlo simulation. The goal of radiation dose rates of 2.5 μSv/h and 25 μSv/h are set in the CSNS user area and target station high-bay area, respectively. All calculations are done for the upgrade 500 kW beam power because most shielding blocks are immovable.
Following the characteristic of the short pulse, the scientific frontier, the demands of potential users in China and experiences of spallation source operated overseas, CSNS has planned 20 neutron scattering instruments for 20 beam lines. Because of budget limitations, only three day-one instruments: General Purpose Powder Diffractometer (GPPD), Small Angle Neutron Scattering (SANS), and Multipurpose Reflectometer (MR), are funded by the project. Figure 8 shows the engineering design of the three spectrometers. Up to now, the main equipment of target station, including of helium vessel, target trolley, shielding blocks and neutron shutters, have been installed in place, as shown in Figure 9. The water cooling system and the cryogenic system are in commissioning, and the joint commissioning with target, moderator, reflector, and proton beam window, will start in the middle of April, 2017. And then the moderator-reflector plug and beam window plug are installed. Most equipment of the three day-one neutron instruments have arrived at CSNS, and the installation is underway, as shown in Figure 10. The automatic control is debugged one by one. We expect that the first turn of joint commissioning will be completed in June, 2017, and that the first neutron beam will be produced near the end of September, 2017. Currently, all hardware of three instruments has arrived, the installation is in progress and will be completed in this July, the joint commissioning is expected to complete in this September to see the first neutron beam.

CSNS user meeting is held annually to plan the day one experiments. A few of neutron instruments, funded by local government and universities, are negotiated tightly.

Conclusions

CSNS project is going well and now at the stage of final construction and commissioning, and first neutron beam from target can be expected in the September 2017.

References

[1] Hesheng Chen, Xunli Wang, Nature Materials, VOL 15, 689-691 (2016)
[2] Shinian Fu, Hesheng Chen, et al., Proc. of IPAC2013, Shanghai, May 2013