STATUS OF THE CHINA SPALLATION NEUTRON SOURCE PROJECT

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Abstract

CSNS accelerator mainly consists of an H^- linac and a proton rapid cycling synchrotron. It is designed to accelerate proton beam pulses to 1.6GeV kinetic energy at 25 Hz repetition rate, striking a solid metal target to produce spallation neutrons. The accelerator is designed to deliver a beam power of 120 kW with the upgrade capability up to 500 kW, The CSNS accelerator is the first large-scale, high-power accelerator project to be constructed in China and thus we are facing a lot of challenges in some key technologies. A series of R&D for major prototypes have being conducted since 2006, including an H^- ion source, DTL tank, RF power supply for the linac, injection/extraction magnets and its pulse power supplies, dipole and quadrupole prototype magnets in the ring and its power supplies, ferrite-loaded RF prototype cavity, ceramic vacuum chamber, control and some beam diagnostics. This paper will briefly introduce the design and R&D status of the CSNS accelerator.

INTRODUCTION

The CSNS complex [1] is designed to provide multidisciplinary platforms for scientific research and applications by national institutions, universities, and industries. The high-flux pulsed neutrons from CSNS will compliment cw neutrons from nuclear reactors and synchrotron lights. The pulsed-beam feature allows studies not only on the static structure but also the dynamic mechanisms of the microscopic world. The project design proposal (equivalent to CD-1) with a budget of ~1.4 B CNY (~ US$0.2 B) was approved by the Chinese central government in September 2008.

In Feb. 2007, Guangdong provincial government agreed to offer free land and an auxiliary supporting fund of 0.5 B CNY for CSNS infrastructure construction in Dongguan, Guangdong. The site is located in the south of China, about 100km from Hong Kong. The construction ground-breaking is foreseen in early 2010, and the facility is expected to be accepted for user operations in about 6.5 years from the construction start.

Financially, the project must fit in China's present economical condition This limits the initial beam power to about 120 kW. On the other hand, we strive to reserve the upgrade potential up to 500 kW so that the facility is competitive in future. Since this is the first high-intensity proton machine in China, we intend to adopt mature technology as much as possible. We must keep the final component fabrication domestic as much as possible taking advantage of the relatively low labour cost, and seek worldwide collaborations for advanced technology. So a program for R&D and key-technology prototyping started in early 2006 with a budget of about US$10M. It covers most in this paper the major design features and R&D progress of the CSNS accelerator will be introduced.

FACILITY DESIGN

CSNS is a short-pulse accelerator facility mainly consisting of an H^- linac and a proton rapid cycling synchrotron [2]. It 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 for instruments, as shown in Figure 1. The accelerator is designed to deliver a beam power of 120 kW with the upgrade capability to 500 kW by raising the linac output energy and increasing the beam intensity. Table 1 lists the major parameters in the present first phase and future upgrade phases.

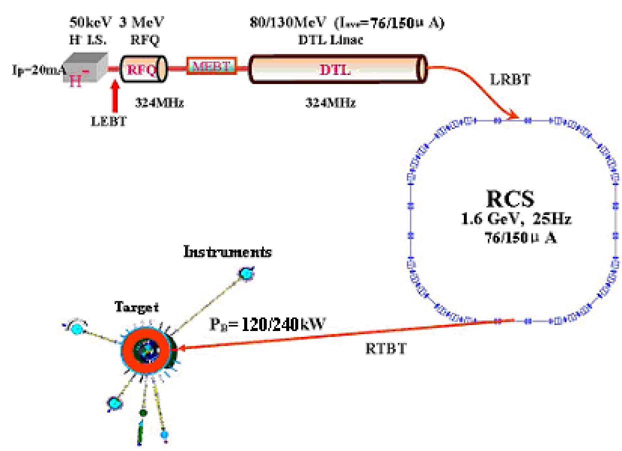


Figure1: Schematic layout of CSNS facility

Table 1: CSNS primary parameters in baseline and upgrade phases.

Project phase	I	II	II'
Beam ave. power, kW	120	240	500
Proton energy, GeV	1.6		
Ave. current, *I*, μA	76	151	315
Repetition rate, Hz	25		
Proton per pulse, 10^{13}	1.88	3.76	7.83
Pulse length, ns	<500		
Linac energy, MeV	81	134	230
Linac length, m	50	76	86
Linac rf freq. , MHz	324		
Macro ave. *I*, mA	15	30	40
Macro duty factor, %	1.1	1.1	1.7
Ring circumference, m	238	238	238
Ring filling time, ms	0.5	0.5	0.8
Uncontroled loss, W/m	< 1		
Target material	Tungsten		
Moderators	H_2O, (2) H_2		
No. neutron instruments	3	18	>18

The ISIS-type Penning source was adopted to provide 20mA H- ion current at 50keV. A pre-chopper in the LEBT is designed to chop the beam macropulse at a 50% ratio at the ring injection revolution period for a low-loss beam injection. The linac rf frequency is 324 MHz, the same as that of J-PARC so that the same klystron can be used for the RFQ and DTL. The four-vane RFQ similar to the one previously developed at IHEP for the ADS program accelerate the beam to 3MeV. Code simulation indicates a beam transmission rate of 97% at vane voltage of 80kV. Space is reserved in the Medium Energy Beam Transport (MEBT) to house both the secondary chopper for phase II and beyond when the beam intensity is higher. Five sets of power sources of 2.5 MW peak power are used to power the RFQ and four DTL tanks. An ac series resonance high-voltage power supply is under development for the klystrons avoiding step-up high voltage transformers and multiphase high voltage rectifiers. The debuncher located in LRBT reduces energy deviation and fluctuation.

Figure 2 shows the layout of the RCS ring. A four-fold symmetric lattice is favored over three-fold to separate injection, collimation, and extraction to different straights. The ring adopts a hybrid lattice with missing-dipole FODO arcs and doublet straights [3]. The dispersion is suppressed by using two groups of 3 half-cells (with 90°horizontal phase advance per cell) located on each side of a missing-dipole half-cell. The long (one 9 m and two 6 m uninterrupted drifts per straight) dispersion-free straights facilitate injection, extraction, and transverse collimation. The FODO arcs allow easy lattice optics correction. The 4 m gap created by the missing dipole near the maximum dispersion location allows efficient longitudinal collimation.

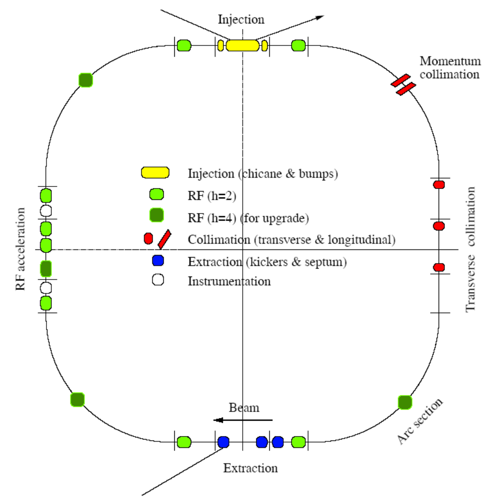


Figure 2: Functional layout of the CSNS synchrotron with four straights sections mainly used for beam injection, transverse and longitudinal collimation, acceleration, and extraction

R&D ACTIVITIES

This section highlights technology developments covering the front end, linac, and rapid cycling synchrotron (RCS).

There was no previous experience in high-current, low-emittance and long-lifetime H- ion source in China. Owing to the collaboration with ISIS, an H- Penning source is under development. The discharge chamber and the extractor were fabricated in China (Figure.3) and tested at the ISIS ion source stand. The beam current reached 55 mA with a pulse length of 500μm at 50 Hz repetition rate. For intensive research of the source features, an H- ion source test stand is building at IHEP, as shown in Figure 4.

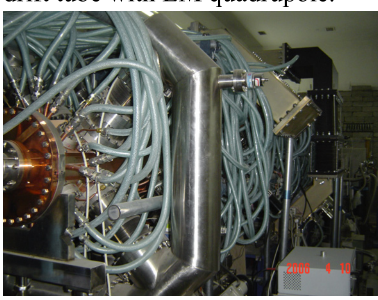
Figure 3: H^- Pinning source body tested at ISIS.

Figure 4: An Penning source test stand is setting up at IHEP.

We omitted RFQ from this R&D plan, because we have already built a similar RFQ in an ADS program [4], as shown in Figure 5. Its duty factor reached 7% with 1.43ms pulse length at 50Hz. An output beam current of

46mA was obtained with an input beam current of 49mA, resulting in a beam transmission rate more than 93%, as shown in Figure 6. We are push its duty factor to a higher value and now the cavity RF duty-factor reached 15%. Commissioning of the ADS RFQ is encouraging for us to be optimism for the direct construction of CSNS RFQ without any more R&D.

R&D of DTL is emphasised in the linac R&D program [5], even though IHEP built a 35 MeV DTL about 20 years ago, which was operated at 201 MHz. For the higher frequency DTL for CSNS, we are still facing some challenges and some R&D is crucial. A prototype of the first section of the CSNS DTL is under fabrication. The electro-magnetic (EM) quadrupole uses J-PARC-style coil with cooling channel made by periodical reverse electroform technology. Figure 7 shows the tank and the drift tube with EM quadrupole.



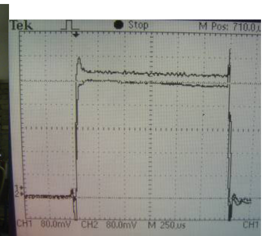


Figure 5: 352MHz RFQ for an ADS basic study program has been built at IHEP, Beijing.

Figure 6: Measured input and output beam current.

The RFQ and the DTL are to be powered by imported klystrons with domestically developed power supplies. An AC series resonance high-voltage power supply was proposed and developed for the klystrons, avoiding step-up high-voltage transformers and multiphase high-voltage rectifiers. A digitalized low-level RF control system based on FPGA was realized in the RFQ operation. A prototype of modulator and a crowbar is under development.

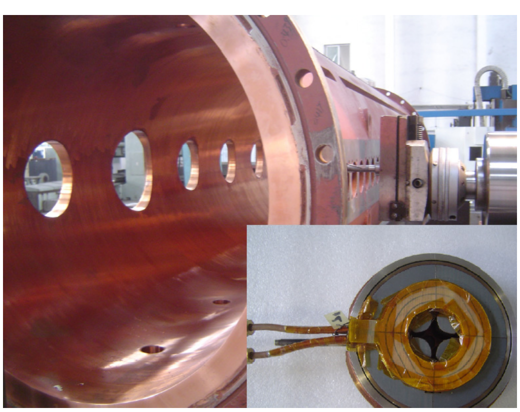


Figure7: Prototype of the DTL tank and drift tube

Developments on the RCS technology for the CSNS project focus on major components including the dipole and quadrupole magnets, magnet power supplies, ceramic vacuum chamber, ferrite loaded RF cavity, RF power source, inject and extraction magnets and their pulsed power supplies, beam diagnostics, and control system.

To reduce the eddy current of the dipole magnet coil, stranded aluminium coil with a stainless steel water-cooling channel was made in China with which the prototype dipole magnet was also fabricated. The dipole magnet and its curved AC plus DC magnet measurement system are shown in Figure 8. Quadrupole magnet was also prototyped with split four-conductor copper coil. It has rather large bore radius of 154mm, as seen in Figure 9.

Figure 8: The prototype dipole magnet of stranded coil and the measurement system

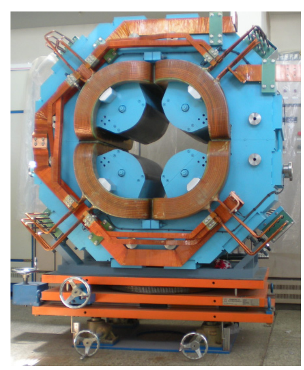


Figure 9: The prototype quadrupole magnet

White resonant circuit was chosen as the magnet power supply for its merit in avoiding power impact to the grid. Its components, including power supply with DC plus AC sources, choke, and capacitor bank, were fabricated and installed at IHEP, as shown in Figure 10. The key feature of the power supply is a high tracking accuracy in its AC variation. Now the dipole magnet and its power supply system were assembled at IHEP. Initial magnet measurement is encouraging for the dipole magnet. However cracking in the epoxy resin related to the fabrication process and to vibrations at a 25-Hz repetition rate remains an unsolved problem.

Figure 10: Choke and capacitor bank for White circuit of CSNS magnet power supply.

Ceramic vacuum chambers must be used in the RCS dipole and quadrupole magnets to avoid the eddy current. Fabrication of a prototype ceramic vacuum chamber followed two technical approaches: ISIS-type glass joining and J-PARC-type metallic brazing. Difficulties were experienced in meeting the strength and accuracy tolerance of the ducts and joints, and in stress-induced cracking and leakage. An 1-m long curved prototype of the ceramic chamber for dipole magnet was made by a Japanese vendor with 4 small sections connected by glass joining. Chinese vendors independently produced full-size prototype chambers for quadrupole magnet, as shown in Fig.11. Also developed were detachable, external metal-strip wrappings for the RF shielding and a sputtering facility for TiN coating of the inner surfaces.

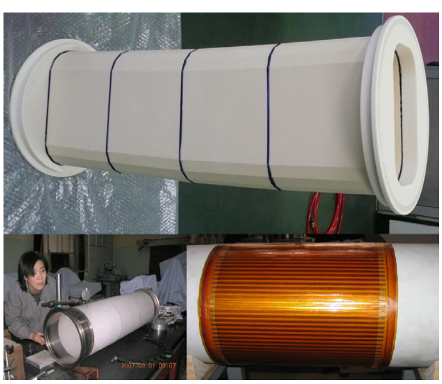


Figure 11: The short prototype of the dipole ceramic chamber (upper) and two full-size quadrupole ceramic chambers (lower) .

A prototype of the ferrite loaded RF cavity with two accelerating gaps is made in full-size. It is now assembled for vacuum leakage check in recent, as shown in Fig. 12. Between each ferrite plates is a copper plate with cooling water for heat release. The copper plate is formed by winding a hollow copper conductor. To reach an efficient heat conduction a high flatness is essential for a tight contact between the ferrite and the copper plates. Several iterations were made in the fabrication technology development of the thin copper water-cooling plates.

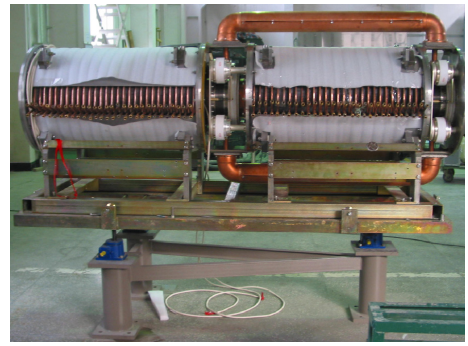


Figure 12: The prototype of the ferrite loaded RF cavity.

Injection bump magnets are designed for H^- stripping injection into the ring. A prototype magnet was fabricated at IHEP with water-cooled windings of the copper plate, as shown in Figure 13. A pulsed power supply with 18,000A output current in maximum during injection time of 500μs has also been developed and connected with the bump magnet together with some dummy loads for the magnet measurement as shown in Figure 14.

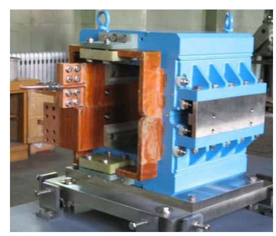


Figure13: The prototype injection bump magnet.

Figure14: The prototype pulse power supply for the injection bump magnet

Fast extraction kicker and its high voltage pulsed power supply are prototyped with a magnetic field of 520 Gauss and a rise time of 250ns. The in-vacuum magnet uses a ferrite core for a high magnetic flux, as shown in Figure 15. The pulse power supply uses blumlein type pulse forming network to get a short pulse with a current of 5840A and a flattop of better than ±1.5%, as shown in Figure 16.

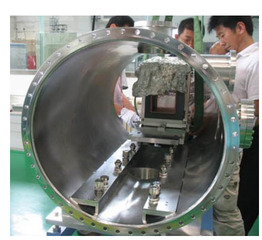


Figure 15: The prototype extraction kicker magnet.

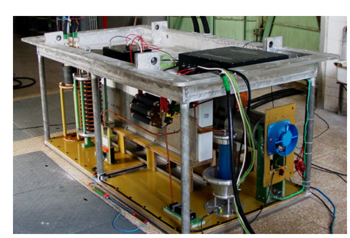


Figure16: The prototype pulse power supply for the extraction kicker magnet.

SUMMARY AND DISCUSSIONS

This paper presents the current status of CSNS project and summarizes the technology development during the past several years in the field of high intensity proton accelerators.

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