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CSNS ACCELERATOR DESIGN AND TECHNOLOGY DEVELOPMENT

Shinian Fu, Jingyu Tang, Yunlong Chi, Haiyi Dong, Lan Dong, Jian Li, Wen Kang, Huafu Ouyang, Huamin Qu, Hong Sun, Sheng Wang, Chunhong Wang, Taoguang Xu, Xuejun Yin, Jing Zhang

Institute of High Energy Physics, Chinese Academy of Sciences
Beijing 100049

ABSTRACT

The accelerator complex of China Spallation Neutron Source (CSNS) mainly consists of an H-linac of 81 MeV and a rapid-cycling synchrotron of 1.6 GeV. It provides the target 100 kW beam power in the first phase and has the capability for future upgrade to 500 kW. The physical and technical design of the accelerator has been progressing. The prototyping of some key components have been finished or under development for the feasibility demonstration of the related technologies. This paper will present the current status of the CSNS accelerator design and the progress of the technology development.

1. Introduction

The China Spallation Neutron Source (CSNS)[1-3] provides a multidisciplinary platform for scientific research and applications by scientific institutions, universities, and industries. The high-flux pulsed neutrons from CSNS will compliment cw neutrons from nuclear reactors and synchrotron lights from synchrotron radiation facilities. Strongly advocated by the users groups, the CSNS project was, approved by the Chinese central government in 2008 and is going to start construction in 2010. The 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 and then 200kW in the second phase by raising the linac output energy to 132MeV and doubles the beam intensity. The accelerator part has even the reserved potential to be upgraded to 500 kW. A schematic layout of CSNS phase-1 complex is shown in Figure 1. In the accelerator design, some conservative redundancy has been taken into account. So the designed beam current and thus beam power is higher than the nominal value. The major design parameters of the CSNS accelerator complex are listed in Table 1. In the phase one, an H^- ion source (I.S.) 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 in phase one and 132MeV in phase two. 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.

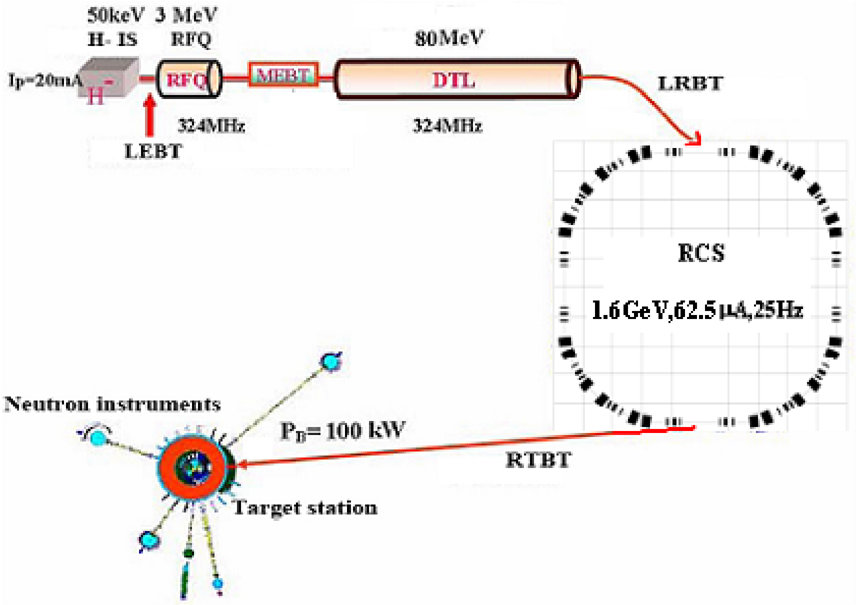

Figure 1 Schematics of the CSNS complex

Table I CSNS Design Parameters

Project Phase	I	II
Beam Power on target [kW]	100	200
Proton energy t [GeV]	1.6	1.6
Average beam current [μ A]	62.5	125
Pulse repetition rate [Hz]	25	25
Linac energy [MeV]	80	132
Linac type	DTL	DTL
Linac RF frequency [MHz]	324	324
Macropulse. ave current [mA]	15	30
Macropulse duty factor	1.05	1.05
RCS circumference [m]	228	228
RCS filling time [ms]	0.42	0.42
RCS harmonic number	2	2
RCS RF frequency [MHz]	1-2.4	1.3-2.4
RCS Acceptance [πmm-mrad]	540	540

2 Accelerator Design

2.1 The Linac Design

The CSNS linac accelerates H- to 80 MeV in the first phase, which consists of H- ion source, Low energy Beam Transport (LEBT), RFQ, Medium Energy Beam Transport (MEBT) and DTL, as shown in the Figure 1.

The H- ion source provides 25 mA peak current, 0.5 ms long, 0.2π μ m normalized emittance (rms) pulses to 50 keV at 25 Hz for phase I. The ISIS type Penning H- surface source is chosen for CSNS, because it can well meet the specification of CSNS phase-1. The operation experience in ISIS shows that the reliability and stability of Penning source are very good, and also the cost is lower than the other type H- ion source.

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 RCS. The control of emittance growth in LEBT is a key point in the design. Three-solenoid focusing structure is adopted for space charge neutrilization. An electrostatic deflector is chosen as pre-chopper, positioned at the end of the LEBT.

A four-vane type RFQ is adopted, with total length of 3.62 m, which consists of four segments. RFQ accelerates H- beam from 50keV to 3MeV, with duty factor of 1.05%. The selection of 3MeV output energy is a compromise between the chopper design in MEBT and injection energy of DTL.

The MEBT matchs the H- beam from RFQ to DTL in 6-dimentional phase space, and chops beam with fast (~10 ns) rise time. The total length of MEBT is 3 m, including 8 magnets, two bunchers and two J-PARC type RF choppers. Beam instruments for beam current, beam position and beam loss are also installed in the MEBT.

The DTL accelerates the 3 MeV beam from the RFQ to 80 MeV. To reach a high effective shunt impedance, the cell shape and size are tuned with β stepwise in the low β segment, and keeping the maximum surface field below 1.3 times the Kilpatrick limit. The FD focusing lattice is used in the dynamic design, and J-PARC type EM quadrupoles are adopted.

2.2 The RCS Design

Due to the requirement of the beam collimation for beam loss control in a high intensity proton synchrotron, the lattice with 4-fold structure is preferred for separated-function design: the collimation can be performed in a separate straight section. Also the lattice superperiodicity of 4 is better for reducing the impact of low-order structure resonance than superperiodicity of 3. CSNS/RCS design chooses this kind of 4-super-period structure. The dedicated functions are accommodated in the different sections of ring, as shown in Figure 2.

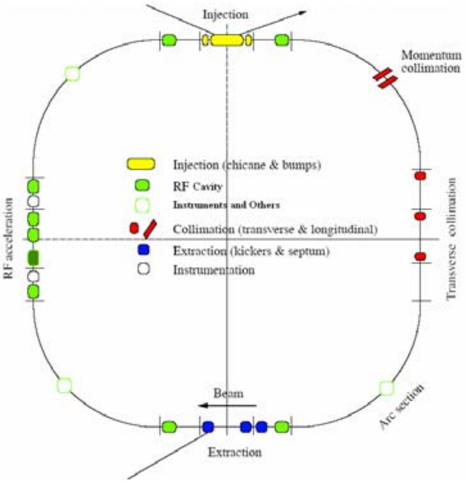

Figure 2 The dedicated functions separaytely distributed in the four long straight sections of ring

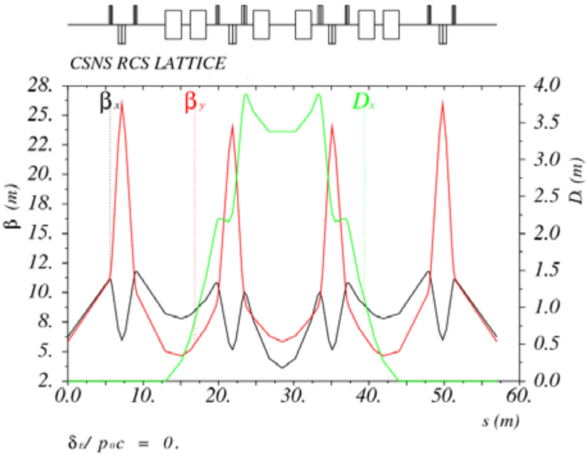

Figure 3 The structure and the twiss parameters in one super-period

The lattice is based on triplet cell, and the whole ring consists of 16 triplet cells, with circumference of 227.92m. In the each super period, an 11m long drift space is left in a triplet cell, and this uninterrupted long space is very good for accommodation of injection, extraction and transverse collimation system. Figure 3 gives the twiss parameters of one super-period. The maximum beta function is less than 26m, and the maximum dispersion function is less than 4m. Especially in the middle of the arc, the dispersion is large and the horizontal beta function is small, and this is good for high efficiency momentum collimation.

The acceleration is performed by eight ferrite-loaded cavities which provide 165 kV RF voltage with harmonic number of two. An RF acceleration period consists of three stages: injection, capture and acceleration. The designed bunching factor in the beginning of the acceleration is about 0.4, and with the increasing of RF voltage, the bunching factor is decreased to 0.12.

The injection is by using H- painting method in both horizontal and vertical planes. The whole injection chain is arranged in an 11 m long straight section, consists of four horizontal painting magnets, four vertical painting magnets, and four fixed field bumping magnets. The one-turn extraction from the RCS is achieved by using 7 vertical fast kickers followed by a Lambertson septum.

2.3 The Interface Design

There are two beam transport lines: LRBT and RTBT. LRBT transports H- beam to the ring, and transverse and momentum collimators are designed to scrape the halo particles. The debuncher is used in the LRBT to decrease momentum spread. RTBT transports extracted beam from RCS to target. The beam loss due to malfunction of kickers is minimized in the design. Collimation system is designed at RTBT for protection of the target and shielding of back scattering neutrons.

3 R&D of the Key Technology

Design and construction of a high beam power proton accelerator are world frontier topics in terms of both accelerator technology and accelerator physics. CSNS will build the first high intensity proton accelerator in China. To minimise the technology risk, two R&D programs for some key components have been conducted since 2006.

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 and tested at the ISIS ion source stand. The beam current reached 55 mA with a pulse length of 500 μ m 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.

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%. We are pushing 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.

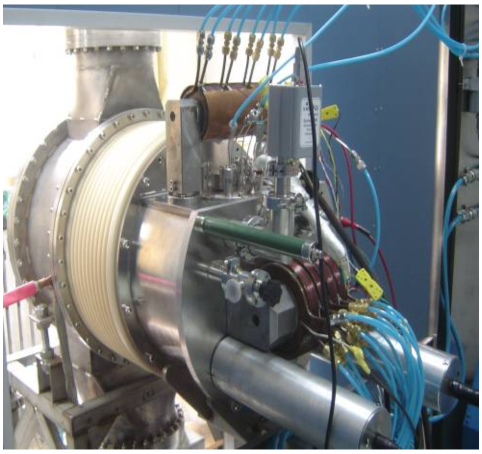

Figure 4 H^- ion source test stand at IHEP

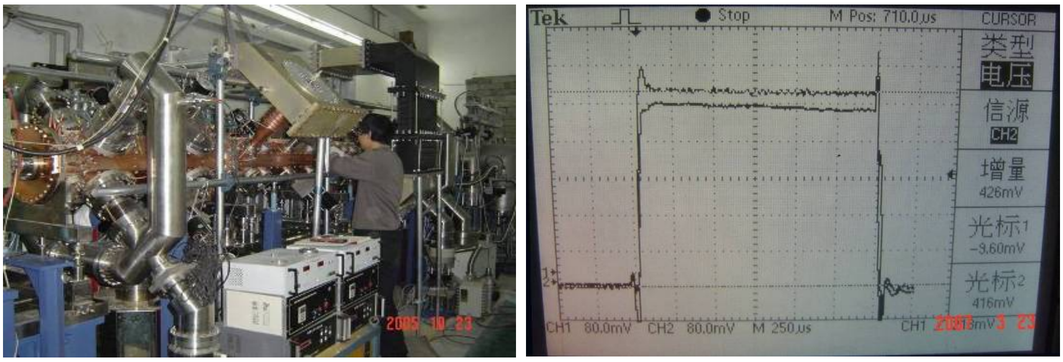

Figure 5 A proton RFQ of 3.5MeV for ADS study has been built at IHEP(left) with 46mA output beam at 7% duty factor with a transmission rate>93% (right)

R&D of DTL is emphasised in the linac R&D program [5], even though IHEP built a 35 MeV DTL at 201 MHz about 20 years ago. 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 6 shows the tank and the drift tube with EM quadrupole.

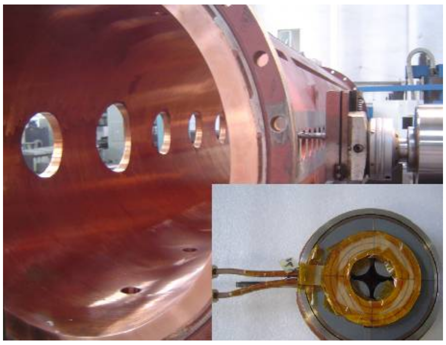

Figure 6 Prototype of the DTL tank and drift tube

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 have also been developed.

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, injection 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 7. Quadrupole magnet was also prototyped with split four-conductor copper coil. It has rather large bore radius of 154mm, as seen in Figure 8.


Figure 7 The prototype dipole magnet of stranded coil and the measurement system


Figure 8 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 9. 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 9 Choke and capacitor bank for White circuit of CSNS magnet power supply.

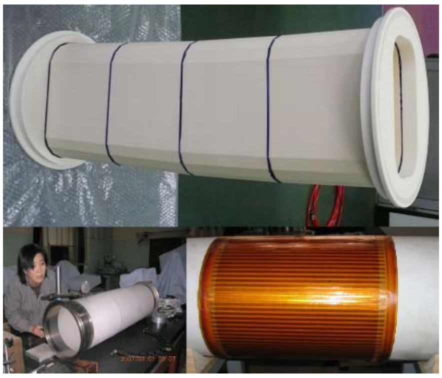
Figure 10 The short prototype of the dipole ceramic chamber (upper) and two full-size quadrupole ceramic chambers (lower)

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.10. Also developed were detachable, external metal-strip wrappings for the RF shielding and a sputtering facility for TiN coating of the inner surfaces.

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. 11. 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. A 500kW RF power source with a freuncy swing from 0.9 to 2.5MHz has been developed for high power experiement together with the ferrite loaded cavity, as shown in Fig. 12.

Figure 11 The prototype of the ferrite loaded RF cavity.

Figure 12 A 500kW RF power source has been developed

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.

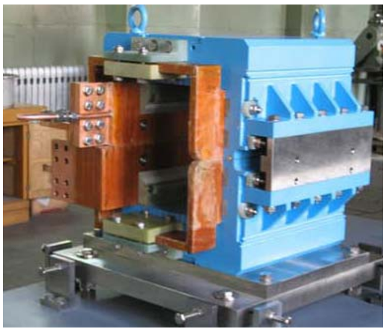

Figure13 The prototype injection bump magnet.

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.

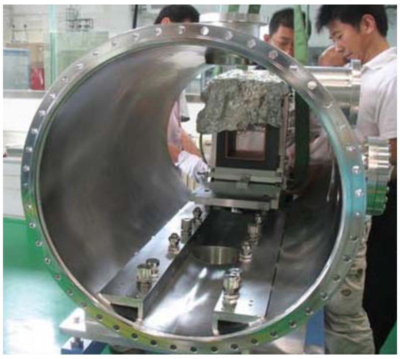

Figure 15 The prototype extraction kicker magnet.

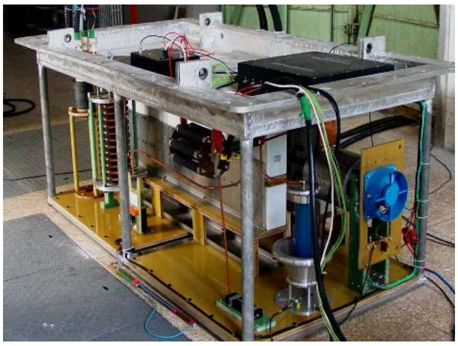

Figure 16 The prototype pulse power supply for the extraction kicker magnet.

4 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.

5. Acknowledgements

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6. References

[1] 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).
[2] Jie Wei, Shinian Fu, Shouxian Fang,. Proceedings of EPAC 2006, Edinburgh, Scotland, (2006).
[3] J. Wei, S. X. Fang, et al., J. Korean Phys., 50 (5), 1373 (2007).
[4] S.N.Fu, S.X.Fang, X.L.Guan, H.F.Ouyang, et al, Proc. of LINAC06, August 2006, Knoxville, Tennessee, USA (2006)
[5] S.N.Fu, H.F.Ouyang, et al., Proc. of LINAC08, Oct. 2008, Victoria, Canada, p.21 (2008).