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Introduction to the overall physics design of CSNS accelerators

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Abstract The China Spallation Neutron Source (CSNS) is an accelerator-based facility. The accelerator of CSNS consists of a low energy linac, a Rapid Cycling Synchrotron (RCS) and two beam transport lines. The overall physics design of CSNS accelerator is described, including the design principle, the choice of the main parameters and design of each part of accelerators. The key problems of the physics design, such as beam loss and control, are also discussed. The interface between the different parts of accelerator, as well as between accelerator and target, are introduced.

Key words China spallation neutron source, rapid cycling synchrotron, physics design

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1 Introduction

For accelerator-based spallation neutron source, there are always two schemes for accelerator. One scheme is high energy H$^-$ linac plus proton accumulator ring (AR), and this is always the choice with beam power more than 1 MW; the other scheme is low energy H$^-$ linac plus a high energy proton Rapid Cycling Synchrotron (RCS), and this is good for a spallation neutron source with beam power of several hundred kW.

The design beam power of the China Spallation Neutron Source (CSNS)[1, 2] is from 120 kW to 500 kW for different phases, and the scheme of accelerator is chosen as a low energy linac plus a high energy RCS. As a compromise among proton current, kinetic energy and the upgrade capability, in the first phase with designed beam power of 120 kW, the linac output energy is chosen as 81 MeV, and the extraction energy from the RCS is 1.6 GeV. The large ratio of injection/extraction energy makes the beam power upgrade easy by increasing the injection energy, as well as the injection beam current.

The primary parameters of CSNS accelerator complex are shown in Table 1. At the repetition rate of 25 Hz, the accelerators can deliver a beam power of 120 kW at Phase I. Table 1 also shows two set parameters for upgrade to different bema power. The upgrade potential is an important point to be considered in the Phase I design. The upgrade path is to increase the injection energy and beam current, while the reparation rate and extraction energy are kept no change. To keep the upgrade potential of 500 kW beam power, the linac should be capable of upgrade to 250 MeV output energy to increase the accumulated average proton current to 315 μA. The 85 m space after the linac is reserved for linac upgrade, and the space is filled by transport line in the Phase I design. Fig. 1 shows the schematic layout of CSNS facility.

Table 1. The primary parameters of CSNS.

project phase	I	II	II’
beam power/kW	120	240	500
repetition rate/Hz	25	25	25
average current/μA	76	151	315
beam energy on target/GeV	1.6	1.6	1.6
LINAC energy/MeV	81	134	250
linac RF frequency/MHz	324	324	324
linac length/m	41.5	66.5	126.5
linac duty factor (%)	1.1	1.1	1.7
Accum. particles (10^{13})	1.88	3.76	7.8
target	1	1	1 or 2

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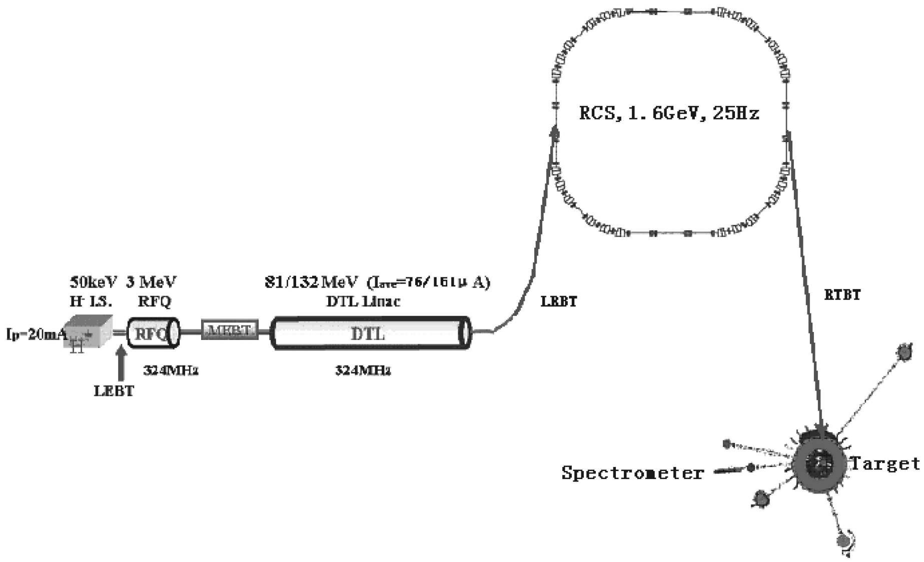

Fig. 1. The schematic layout of CSNS.

2 The design principle and challenges

The CSNS accelerator is the first high-intensity proton machine in China, and it should be an advanced facility with sufficient upgrade potential. As a user facility, to reach high reliability, the mature technologies are adopted as many as possible in the design. The choice of the key technology and cost control are two issues which must be seriously considered during physics design. Based on various international technology collaborations, developing domestic technology and keeping final fabrication in domestic vendor are most important for cost control.

The challenges come from many aspects. In beam dynamics design, beam loss due to space charge and halo, beam chopping, electron cloud, fringe field, impedance and instability, injection and extraction to RCS, need to be well controlled. The engineering challenges come from the construction of Radio Frequency Quadrupole (RFQ) and Drift Tube Linac (DTL), The key technologies of RCS: power supply, ceramic vacuum chamber, RF shielding, RF system, magnet/coil, etc. The commissioning experience of other RCS, such as AGS, ISIS, and PSR, shows that the commissioning of RCS is much difficult than the storage ring. All these challenges should be carefully considered in the physics design.

3 The physics design

3.1 The design of linac[1,2]

The CSNS linac accelerates H^- to 81 GeV 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 Fig. 1.

The H^- ion source provides 25 mA peak current, 0.5 ms long, 0.2 $\pi\mu$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, as it can well meet the specification of CSNS, 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 of H^- ion sources.

The LEBT is for matching and transporting the H^- beam from the ion source to the 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 solenoids focusing structure is adopted, and a magnet-alloy loaded cavity is chosen as pre-chopper[3].

A four-vane type RFQ cavity is adopted, with a total length of 3.62 m, which consists of four segments. RFQ accelerates H^- beam from 50 keV to 3 MeV, with a duty factor of 1.05%. The choice of 3 MeV output energy is a compromise between the chopper design in MEBT and the 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 of 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 81 MeV. To reach a high effective shunt impedance, the cell shape and size are tuned with β stepwise in the low β segment, and keep the maximum surface field below 1.3 times the Kilpatrick limit. The FODO structure is used in the dynamic design, and J-PARC type of EM quadrupoles are adopted.

3.2 The design of RCS[4]

The lattice is the backbone of a synchrotron. A 4-fold symmetric lattice is chosen to separate injection, collimation, and extraction to different straights. Fig. 2 shows the structure and the twiss parameters of one super-period. There are 3.5 FODO cells at each arc, the lattice function is anti-symmetric. It contains 24 dipoles and 48 quads. The circumference is 238.8 m. The base tunes are (5.82, 5.80). The straight section adopts doublet structure, and each straight section consists of two 6.3 m and one 9.2 m long drift spaces. In the middle of the arc the missing dipole forms a 4.1 m straight section for momentum collimation. The uninterrupted long straight section is good to accommodate the injection, extraction and RF devices, and the FODO arc should allow easy lattice correction.

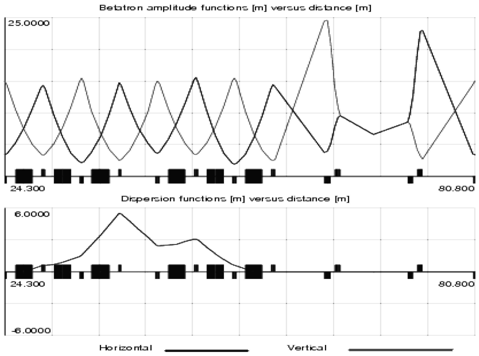

Fig. 2. The structure and the twiss parameters in one super-period.

To decrease the tune spread due to chromaticity, the chromaticity is corrected only in the injection energy by 4 families of DC sectupoles. The dipole corrector and trim quadupole are designed to correct the closed orbit and twiss parameters. The power supplies for dipole corrector and trim quadrupoles are programmable to ramp 10 to 20 steps during one RCS cycle.

The acceleration is performed by eight ferrite-loaded cavities which provide 165 kV RF voltage with harmonic number of 2. 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 increase 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 a 9.2 m long straight section, which 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 10 vertical fast kickers followed by a Lambertson septum[5].

3.3 The interface design

There are two beam transport lines: LRBT and RTBT. LRBT transports H^- beam to the ring, and the transverse and momentum collimators are designed to scrape the halo particles. The debuncher is used in the LRBT to decrease momentum spread. RTBT transports the extracted beam from RCS to target. The beam loss due to malfunction of kickers is minimized in the design. The required beam profile to target is matched and tailored. Collimation system is designed at RTBT for protection of the target and shielding of back scattering neutrons[5].

4 The beam loss and control

To decrease and control beam loss, various methods are considered in the design: In each part of accelerator, adequate acceptance is set, for example, in the RCS, the transverse acceptance is 350 πμm at the collimator, and 540 πμm elsewhere; the space charge effect is minimized by injection optimization, the beam loss is localized to shielded area by collimation systems in LRBT, RCS and LRBT, ramping dependent correction is adopted in RCS, the flexible dynamics design, and the accident prevention and protection by the machine protection system.

5 Summary

The design of each part of accelerators is now in different stages, and with the progress of the project, the physics design will be iterated and upgraded.

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