INJECTION SYSTEM DESIGN FOR THE CSNS/RCS*

J.Y. Tang#, Y. Chen, Y.L. Chi, Y.L. Jiang, W. Kang, J.B. Pang, Q. Qin, J. Qiu, L. Shen, S. Wang, IHEP, Beijing 100049, China
J. Wei, IHEP, Beijing 100049, China / BNL, Upton, NY 11973, USA

Abstract:

The CSNS injection system is designed to take one uninterrupted long drift in one of the four dispersion-free straight sections to host all the injection devices. Painting bumper magnets are used for both horizontal and vertical phase space painting. Closed-orbit bumper magnets are used for facilitating the installation of the injection septa and decreasing proton traversal in the stripping foil. Even with large beam emittance of about 300 πmm.mrad used, CSNS/RCS still approaches the space charge limit during the injection/trapping phase for the accumulated particles of 1.9*10^13 and at the low injection energy of 80 MeV. Uniform-like beam distribution by well-designed painting scheme is then obtained to decrease the tune shift/spread. ORBIT code is used for the 3D simulations. Upgrading to higher injection energy has also been considered.

INTRODUCTION

China has proposed to construct the China Spallation Neutron Source (CSNS) of several hundreds kW [1-2]. It will be constructed in two phases (CSNS-I for 120 kW, CSNS-II for 240 kW, see Table 1). The first phase of the project is expected to be completed around 2011. CSNS has two accelerators in cascade, with an 80/130 MeV Linac as the injector and a 1.6 GeV rapid cycling synchrotron (RCS) as the main accelerator.

Table 1：Main Parameters of CSNS

	CSNS-I	CSNS-II
Beam power (kW)	120	240
Repetition rate (Hz)	25	25
Target number	1	1
Average current (μA)	75	150
Proton energy (GeV)	1.6	1.6
Linac beam energy (MeV)	80	130
RCS accumulated particles	1.9×10^{13}	3.8×10^{13}
RCS super-periodicity	4	4

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# email: tangjy@ihep.ac.cn

For high intensity circular proton accelerators, injection via H^- stripping is actually the only practical method. The design of the RCS injection system is to inject the pre-accelerated H^- beam into the RCS with high precision and high transport efficiency. At the same time, as strong space charge effects are main causes for beam losses in such high intensity accelerator, it is needed to increase the beam emittance and beam uniformity in the RCS to control the influence of space charge effects. In order to do so, the phase space painting method of injecting the beam of small emittance from the linac into the large ring acceptance was developed and used in the CSNS as in other similar accelerators.

INJECTION LAYOUT

Several injection schemes along with the RCS lattice schemes have been studied, and finally the design based on one long drift in a dispersion-free long straight section is favoured [3]. A dispersion-free long straight section other than a highly dispersive arc section is chosen for the design of the injection system due to the advantages: 1) that transverse phase space painting is not affected by the ramping bending magnets; 2) that the ring properties are essentially not affected by the local orbit bumping; 3) that the upgrading of the injection system in future is more feasible. At present, a four-fold anti-symmetric lattice has been chosen for the RCS, as shown in Figure 1. The lattice functions of the RCS ring are shown in Figure 2.

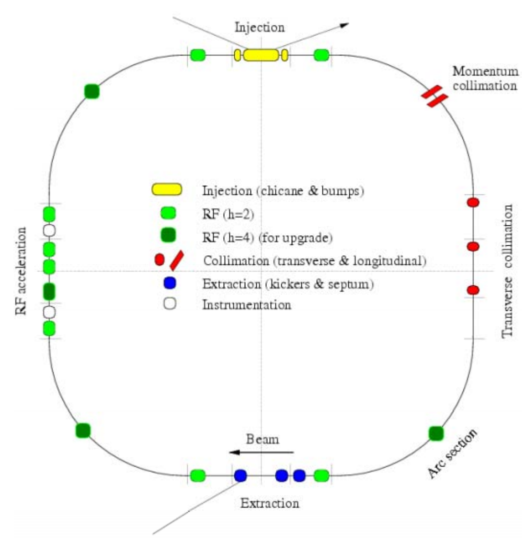

Figure 1：RCS layout and functions

The focusing structure of the RCS long straight sections uses DF doublets including one long drift of 9 m in the centre and two long drifts of 6 m on the sides. The linac beam is injected into the RCS by using horizontal bending magnets; all the injection elements are accommodated within the long drift of 9 m, see Figure 3.

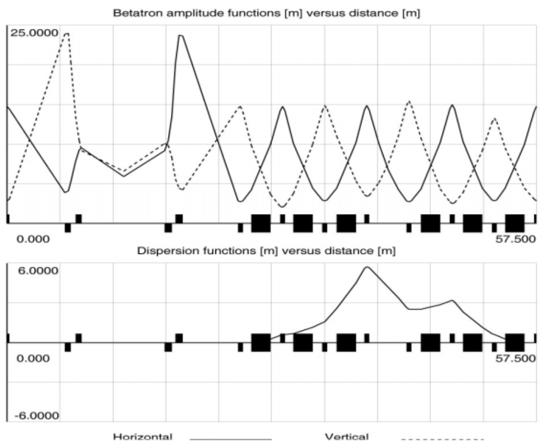

Figure 2：The lattice functions for one RCS super-period

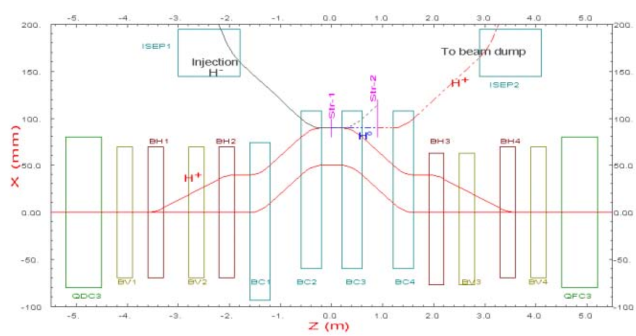

Figure 3：Layout of RCS Injection System

(BC1~BC4：closed-orbit bump magnets，BH1~BH4：horiz. painting bumpers，BV1~BV4：vert. painting bumpers，QDC3 & QFC3：quads，ISEP1&2: septa)

Two pairs of horizontal bump magnets (BH1-BH4) are for painting in *x-x'* plane, and two pairs of vertical bump magnets (BV1-BV4) are for painting in *y-y'* plane. Whereas two pairs of horizontal bump magnets (BC1-BC4) in the middle are for additional closed-orbit shift of 50 mm (chicane magnets), and this is important for the space clearance of the injection elements. The BC bump magnets will collapse after the beam injection to reduce the proton traversal in the stripping foil and to regain super-periodicity for the ring. All the bumpers are powered in series for the reason of eliminating tracking errors.

As shown in Figure 3, CSNS/RCS has adopted position bump for both horizontal and vertical planes. The merits are that the injection system is almost independent of the ring focusing structure thus the operations such as the tune adjustment during the injection do not affect the painting process, that everything in one long drift of 9 m saves longitudinal space and avoids additional aperture requirement in the case of intercrossing with quadrupoles. The design is considered technically realizable for both CSNS-I and CSNS-II, taking into account the recent development in pulsed power supplies based on IGBT for fast bump magnets. The design of double waists at the injection point is very useful in decreasing the apertures for the bump magnets and minimizing the influence of the edge focusing of the bump magnets to the ring lattice.

The DC chicane solution suggested by YY Lee of BNL, US is also under consideration.

TRANSVERSE PHASE SPACE PAINTING

The injection with phase space painting is mandatory to reduce the tune shift due to space charge effects. According to the beam loss tolerance in different accelerators, the tune shift is controlled at about -0.3~-0.4 for hundreds kW accelerators and within –0.2 for MW accelerators. In the RCS, large ring physical acceptance of 540 πmm.mrad and the collimated acceptance of 350 πmm.mrad are used, thus the painted beam emittance is about 250 πmm.mrad. Even with the phase space painting, the space charge effects still result in the emittance blow-up and thus a careful designed painting scheme is important to control the blow-up. Both correlated painting and anti-correlated painting schemes have been considered for the CSNS injection system. With the correlated painting scheme, the beam fills both the horizontal and vertical acceptance ellipses from inner to outer and the final distribution in the real space *x-y* will be almost rectangular. With the anti-correlated painting scheme, the beam fills the vertical acceptance ellipse from outer to inner and the final distribution in *x-y* will be elliptical. The latter is chosen as the nominal painting scheme for the CSNS. At the same time, the correlated painting scheme is kept as an alternative.

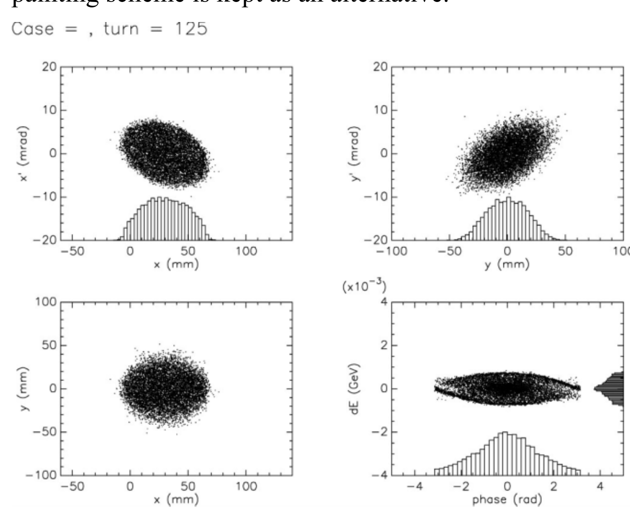

Figure 5：Beam distribution in phase spaces at the injection end (anti-correlated, Ip= 15mA, VRF=15kV)

By using ORBIT code [4], one can simulate the injection process including 3D space charge forces. The painting curves (orbit bump varying with time) can be optimised by using the trial and error procedure. Figure 5 shows one of the simulated results in phase spaces at the injection end without chopping, and Table 3 shows the statistical results. Other factors that influence the painting results, including the painted emittance, the injection peak current, the chopping injection, the ring working point, and the comparison between anti-correlated and correlated painting etc. are under study.

Table 2: Injection conditions and simulation results

Circumference (m)	232
Tunes (Qx/Qy)	5.76/5.88
βx/βy at injection point (m)	5.17/5.99
Injection energy (MeV)	80
Injection beam peak current (mA)	15
Linac emittance $\varepsilon_{x/y}$ (πmm.mrad, rms)	1.0
Accumulated particles	1.9×10^{13}
Painted emittance $\varepsilon_{px}/\varepsilon_{py}$ (πmm.mrad)	255/178
Emittance at injection end (turn 152)	287/330 (99%)
	255/252 (95%)
$\varepsilon_x/\varepsilon_y$ (πmm.mrad)	230/210 (90%)
	114/89 (50%)

OTHER CONSIDERATIONS

Partial stripping of H^- beam and stripped electrons

Due to the Lorentz stripping of H^- beam in magnetic field, the magnetic field of the magnets in the high energy part of the linac, the injection beam line and the injection system is designed at a relatively low level. Taking account of possible linac upgrading to 230 MeV, magnetic field is designed below 0.7 T.

It is considered to use a carbon or an alumina foil of 80 μg/cm^2 for CSNS-I to achieve the stripping efficiency of higher than 98%, and 125 μg/cm^2 for CSNS-II. Among those non- or partially stripped particles, overwhelming majority is H^0 and very small part is still H^-. It is planned to strip the H^0 particles into protons with a thicker stripping foil and send them to the injection beam dump. The remained H^- beam can be stopped directly by an absorber. Some H^0 particles in excitation states are stripped by the magnetic field when passing though BC3 magnet and will be lost or become the ring beam halo that will be removed by the ring transverse collimators.

Every H^- particle will produce two electrons when stripped into proton. If the electrons are left freely in the vacuum, they may enhance the possibility of e-p instability. On the other hand, the electrons are also harmful if bent back into the foil. Here the edge field of BC3 magnet is considered to bend the electrons to an electron catcher. The beam power of the electrons is below 20 W even at CSNS-II, so it is suitable for natural cooling.

Proton traversal in the stripping foil

During the beam injection, the circulating protons have also large probability to cross the stripping foil. Depending on the painting scheme, the proton traversal can be from about two to several tens. On the one hand, the proton traversal will increase the damage rate of the stripping foil or reduce its lifetime; on the other hand, the nuclear elastic scattering and the multi-scattering process by multiple crossing of protons through the foil will produce more beam halo and result in the increase of beam losses. Therefore, phase space painting is designed not only to obtain a good beam distribution but also to reduce the proton traversal.

With the actual painting scheme, the proton traversal is about 3 and the maximum temperature of the foil is about 1500 K at CSNS-I.

CONCLUSIONS

The injection system based on one long uninterrupted drift of 9 m has been designed. Both anti-correlated and correlated painting schemes can be used. The painting scheme has been optimised to obtain uniform beam distribution and reduce proton traversal in the stripping foil. ORBIT simulations show good painting results. The design also includes the treatment on partially stripped H0 beam and stripped electron. Upgrading potential has also been considered. Further optimisation of the design will be continued.

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