ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPMP012

BEAM LOSS AND THE STRIPPING EFFICIENCY MEASUREMENT FOR CSNS INJECTION SYSTEM*

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Abstract

The injection beam loss is the main beam loss of the rapid cycling synchrotron (RCS) for the China Spallation Neutron Source (CSNS). After the optimization of injection system during the beam commissioning, the current injection beam loss for CSNS/RCS is approximately 1%. There are several sources of injection beam loss. In order to distinguish these different sources, the stripping efficiency of the main stripping foil should be studied and measured accurately. In this paper, a scheme for the accurate measurement of the stripping efficiency for CSNS will be proposed and studied. It can not only reduce the injection beam loss, but also be used to estimate the operation state and lifespan of the main stripping foil accurately. This method will be applied in future beam commissioning.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is a multidisciplinary platform [1][2] and had completed the national acceptance in August, 2018. Its accelerator consists of an 80 MeV H^- Linac which is upgradable to 300 MeV and a 1.6 GeV rapid cycling synchrotron (RCS) with a repetition rate of 25 Hz which accumulates the 80 MeV injection beam, accelerates the beam to the designed energy of 1.6 GeV and extracts the high energy beam to the target. The design goal of beam power is 100 kW and capable of upgrading to 500 kW [3].

The injection system is the core component of CSNS accelerator and the injection efficiency is an important factor that determines whether the accelerator can operate safely [4]. Figure 1 shows the physics design layout of CSNS injection system. The injection beam loss is one of the decisive factors that limit whether the RCS can operate at high power. After the optimization of the injection system during the beam commissioning, the current injection beam loss is approximately 1%. Through careful study and analysis, we were able to identify many sources of injection beam loss: mismatch of the injection parameters, choice of injection method, stripping foil scattering, and non-stripped particle loss. During the beam commissioning of CSNS, it is very important to distinguish these different sources of injection beam loss. Therefore, the stripping efficiency of the main stripping foil should be studied and measured accurately [5][6].

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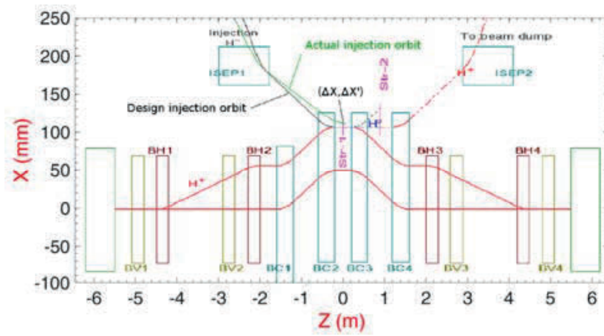

Figure 1: Physics design layout of CSNS injection system.

When the H^- beam traverses the carbon stripping foil, the particles after foil stripping are H^-, H^0 and H^+, as shown in Fig. 2. The stripping efficiency of H^+ is defined as the ratio between the particle number of H^+ after foil stripping and that of H^- before foil stripping.

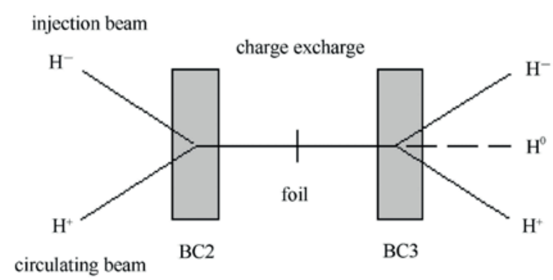

Figure 2: Production of H^-, H^0 and H^+ by foil stripping.

There are two carbon stripping foils in the injection system of CSNS, including the main stripping foil and the second stripping foil. The design stripping efficiency of the main stripping foil is about 99.7% and that of the second stripping foil is close to 100%. During the beam commissioning, in order to study and reduce the non-stripped particle loss, the accurate stripping efficiency of the main stripping foil should be measured. In this paper, a method to measure the accurate stripping efficiency will be proposed and studied.

INJECTION EFFICIENCY AND BEAM LOSS DURING THE INJECTION PROCESS

For the RCS, the injection process determines the initial state of the cyclic beam and has an important influence on the process of beam accumulation and acceleration. The injection beam loss is one of the decisive factors that limit whether the RCS can operate at high power. Therefore, improving the injection efficiency and reducing the

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injection beam loss are the main goals of the beam commissioning of the injection system. By optimizing the injection commissioning, the injection efficiency should be improved and the injection beam loss can be reduced.

During the early stage of the beam commissioning of CSNS, the fixed point injection was used and there was a sudden beam loss during the injection process. However, when painting injection was used, the sudden beam loss during the injection process was gone. Figure 3 shows the RCS direct-current current transformer (DCCT) displays when the fixed point injection and the painting injection were used. We concluded that, by optimizing the injection method, the sudden beam loss was gone and the injection efficiency had increased (about from 95% to 98%).

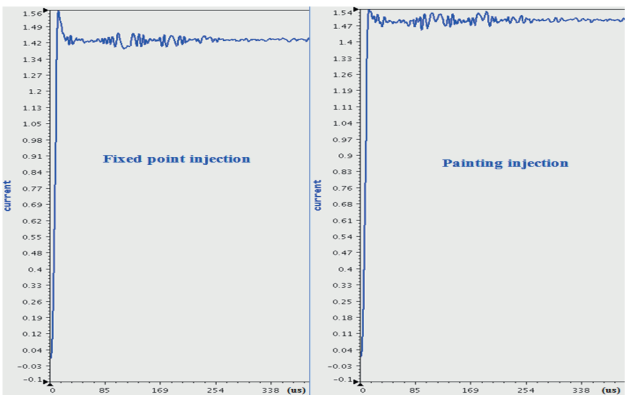

Figure 3: RCS DCCT displays while the fixed point injection and the painting injection were used.

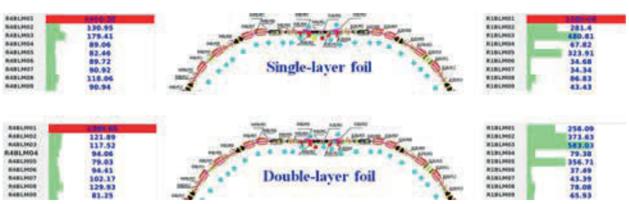

Figure 4: Different injection beam loss while the single-layer foil and double-layer foil were used.

In order to reduce the non-stripped particle loss, the structure of the stripping foil should be optimized. Due to the production craft of the stripping foil, there may be some holes on the stripping foil and the H^- particles may pass directly through the hole without being stripped. In order to reduce the holes on the main stripping foil and to increase the stripping efficiency, the main stripping foil with double-layer structure was used. Figure 4 shows different injection beam loss with single-layer and double-layer structure for the main stripping foil. We found that the beam loss in the injection region can be greatly reduced by using the main stripping foil with double-layer structure.

In theory, after the injection energy is determined, the stripping efficiency depends on the material and thickness of the stripping foil. In order to improve the stripping efficiency and to reduce the injection beam loss, the thickness of the stripping foil should be optimized. Figure 5 shows different injection beam loss with different thicknesses of the main striping foil. It can be seen that the beam loss in the injection region can be reduced by optimizing the thickness of the main stripping foil.

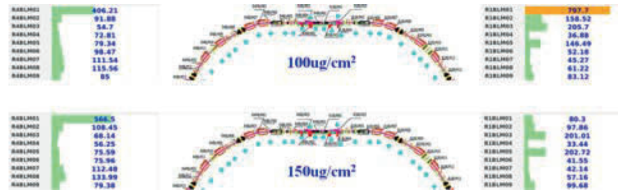

Figure 5: Different injection beam loss while the main stripping foils with different thicknesses.

After the optimization of the injection system during the beam commissioning, by using the current transformer (CT) on the LRBT and the DCCT on the RCS, the injection efficiency can be measured which is currently approximately 99%. Then, the current injection beam loss is approximately 1%. Before further optimization of the beam loss in the injection region, the stripping efficiency of the main stripping foil should be measured more precisely. In the following section, a scheme for the accurate measurement of the stripping efficiency will be presented and studied.

MEASUREMENT SCHEME OF THE STRIPPING EFFICIENCY

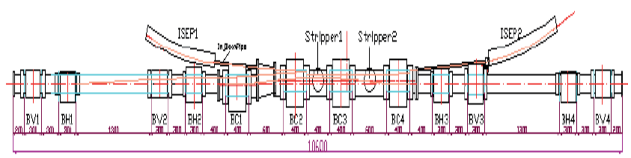

Figure 6: Machine layout of CSNS injection system.

For the injection system of CSNS, there are two carbon stripping foils, including the main stripping foil and the second stripping foil. Figure 6 shows the machine layout of CSNS injection system. The design thickness of the main stripping foil is about 0.5 μm (i.e. 100 $\mu g/cm^2$) and its design stripping efficiency is about 99.7%. The design thickness of the second stripping foil is about 1.0 μm (i.e. 200 $\mu g/cm^2$) and its design stripping efficiency is close to 100%.

There are two main reasons to measure the stripping efficiency of the main stripping foil. On the one hand, it can help us to optimize the stripping efficiency and reduce the injection beam loss. On the other hand, while the main stripping foil has some problems or its lifespan is close to the end, the stripping efficiency will decrease and the injection beam loss will increase. The stripping efficiency measurement can be used to estimate the operation state and lifespan of the main stripping foil accurately which can avoid large amount of injection beam loss.

During the stripping efficiency measurement of the main stripping foil, first of all, two operation modes should be considered: (1) the normal operation mode while most particles H^- are stripped by the main stripping foil and the remaining particles H^0 are all stripped by the

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second stripping foil; (2) the I-Dump operation mode while the main stripping foil is not used and all particles H^- are stripped by the second stripping foil. Secondly, a current transformer INDCT will be added near the second septum magnet INSEP02, as shown in Fig. 7. In the normal operation mode, the remaining particles H^0 after the main stripping foil are all stripped to the protons H^+ by the second stripping foil which can be measured by INDCT. Due to the 100% stripping efficiency of the second stripping foil, the intensity of proton beam H^+ measured by INDCT is the same to that of the remaining neutral beam H^0 after the main stripping foil I_{H0}. In the I-Dump operation mode, since the main stripping foil is not used and the stripping efficiency of the second stripping foil is close to 100%, all particles H^- are stripped to the protons H^+ by the second stripping foil which can be measured by INDCT. Due to the 100% stripping efficiency of the second stripping foil, the intensity of proton beam H^+ measured by INDCT is the same to that of the beam current H^- before foil stripping I_{H-}. While the injection beam energy is 80 MeV and the thickness of the main stripping foil is larger than 0.25 μm, after being stripped by the main stripping foil, the remaining particles H^- are much smaller than the remaining particles H^0. Therefore, the stripping efficiency of H^+ can be approximately given as

$$f_{H^+} = 1 - \frac{I_{H^0}}{I_{H^-}} \ .$$

Figure 7 shows the physics design layout of the I-Dump beam line. Different beam paths in the normal operation mode and I-Dump operation mode are shown in the figure. Furthermore, the preliminary design position of INDCT is also given in the figure.

For the beam current transformer INDCT, there are two gears: high current gear to measure the beam current of H^- before foil stripping I_{H-} which is about 10～15 mA; low current gear to measure the beam current of H^0 after foil stripping I_{H0} which is about 30～50 μA. INDCT was currently in the manufacturing process and will be installed in this summer shutdown. During machine studies in the next half year, it will be tested and adjusted. Then, the accurate stripping efficiency of the main stripping foil will be measured.

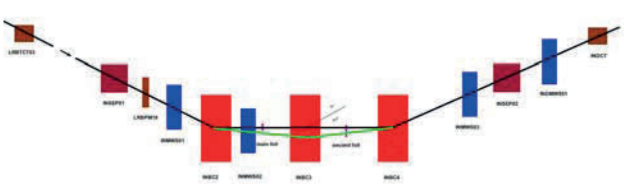

Figure 7: Physics design layout of the I-Dump beam line. The beam path with black colour is for the normal operation mode and the beam path with green colour is for the I-Dump operation mode.

CONCLUSIONS

The injection system is the core component of CSNS accelerator and the injection efficiency is an important factor that determines whether the accelerator can operate safely. Improving the injection efficiency and reducing the injection beam loss are the main goals of the beam commissioning of the injection system. Through careful study and analysis, there are several sources of injection beam loss: mismatch of the injection parameters, choice of injection method, stripping foil scattering, and non-stripped particle loss. By optimizing the above sources of injection beam loss, the injection efficiency should be improved. For CSNS/RCS, after the optimization of the injection system during the beam commissioning, the current injection efficiency is approximately 99% and the current injection beam loss is approximately 1%.

Before further optimization of injection beam loss, the stripping efficiency of the main stripping foil should be measured more precisely. In this paper, a scheme for the accurate measurement of the stripping efficiency was presented and studied. It can not only reduce the injection beam loss, but also be used to estimate the operation state and lifespan of the main stripping foil accurately. A current transformer INDCT would be added near the second septum magnet INSEP02. It is currently in the manufacturing process and will be installed in this summer shutdown. The accurate stripping efficiency of the main stripping foil will be measured during machine studies in the next half year.

ACKNOWLENDGMENTS

The authors would like to thank other CSNS colleagues for the discussions and consultations.

REFERENCES

[1] S. Wang *et al.*, "Introduction to the overall physics design of CSNS accelerators", *Chin Phys C*, vol. 33, Suppl. II, pp. 1-3, Jun. 2009.

[2] H.S. Chen *et al.*, "China Spallation Neutron Source Feasibility Research Report", CAS, Beijing, China, Jun. 2009, unpublished.

[3] J. Wei *et al.*, "China Spallation Neutron Source - an overview of application prospects", *Chin Phys C*, vol. 33, no. 11, pp. 1033-1042, Nov. 2009.

[4] M.Y. Huang *et al.*, "Effects of injection beam parameters and foil scattering for CSNS/RCS", *Chin Phys C*, vol. 37, no. 6, p. 067001, Jun. 2013.

[5] P.K. Saha *et al.*, "State of the art online monitoring system for the waste beam in the rapid cycling synchrotron of the Japan Proton Accelerator Research Complex", *Phys. Rev. ST Accel. Beams*, vol. 14, p. 072801, Jul. 2011.

[6] P.K. Saha *et al.*, "Measurement of 181 MeV H^- ions stripping cross-sections by carbon stripper foil", *Nucl. Instr. Meth. A*, vol. 776, pp. 87-93, 2015.