ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB200

STUDY ON THE MEASUREMENT AND RESIDUAL DOSE OF THE CSNS STRIPPING FOIL*

Ming-Yang Huang[1#], Sheng Wang[1], Shou-Yan Xu, Hua-Chang Liu, Yu-Liang Zhang, Ling Kang, Jia-Xin Chen, Wei-ling Huang, Qing-Biao Wu
Institute of High Energy Physics, Chinese Academy of Sciences (CAS), Beijing, China
Spallation Neutron Source Science Center (SNSSC), Dongguan, China
[1]also at University of Chinese Academy of Sciences, Beijing, China

Abstract

In this paper, firstly, the application and service life of the main stripping foil for the China Spallation Neutron Source (CSNS) were introduced. The stripping efficiency of the main stripping foil have been measured and studied. Then, by using the codes FLUKA and ORBIT, the particle scattering of the main stripping foil has been simulated and the theoretical residual doses in the injection region caused by the foil scattering were obtained. By weekly measurement of the residual doses in the injection region, the actual residual doses near the main stripping foil were given. The residual doses comparison results have confirmed that the particle scattering of the main stripping foil is the most important source of the residual doses in the injection region.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is a multidisciplinary platform [1, 2]. Its accelerator consists of an 80 MeV negative (H^-) Linac and a 1.6 GeV rapid cycling synchrotron (RCS) with a repetition rate of 25 Hz which accumulates the injection beam, accelerates the beam to the design energy of 1.6 GeV and extracts the high energy beam to the target. The design goal of beam power on the target is 100 kW [3] which has been achieved in Feb. 2020. Figure 1 shows the layout of the CSNS.

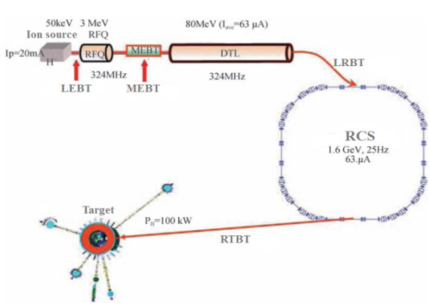

Figure 1: Layout of the CSNS.

The injection system is the core component of the accelerator [4] and the injection beam loss is one of the decisive factors that limit whether the RCS can operate at the high power. After the optimization of the injection system in the beam commissioning, the particle scattering of the main stripping foil becomes an important source of the injection beam loss. Therefore, the application and residual dose of the main stripping foil should be studied and measured accurately [5, 6].

There are two carbon stripping foils in the CSNS injection system, including the main stripping foil and second stripping foil [7]. When the H^- beam traverses the carbon stripping foil, the particles after the 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. The design stripping efficiency of the main stripping foil is 99.7%.

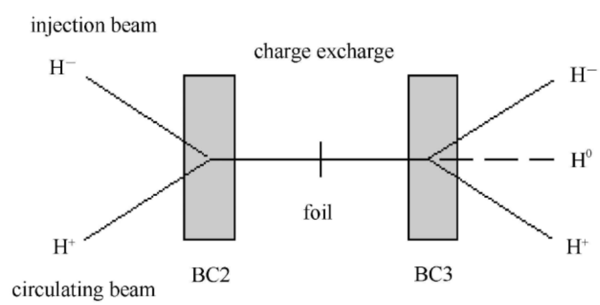

Figure 2: Production of H^-, H^0 and H^+ by the foil stripping.

During the beam commissioning, in order to study and reduce the un-stripped particle loss, the accurate stripping efficiency of the main stripping foil should be measured. Furthermore, in order to reduce residual doses and beam loss in the injection region, the particle scattering of the main stripping foil should be studied. At the same time, the simulation and measurement results of the residual doses in the injection region should be compared and discussed.

APPLICATION AND SERVICE LIFE OF THE STRIPPING FOIL

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 holes without being stripped. In order to reduce the holes and the un-stripped particles, the structure of the main stripping foil

* Work supported by National Natural Science Foundation of China (Project Nos. 12075134 and U1832210)
# huangmy@ihep.ac.cn

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2021). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB200

© Content from this work may be used under the terms of the CC BY 3.0 licence (© 2021). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

should be optimized. During the beam commissioning, the double-layer foil was instead of the single-layer foil in order to reduce the holes and beam loss. In [8], it has been discussed in detail. In order to further reduce the beam loss, the stripping foils with different materials have been tried, such as HBC and GRA. The beam study results show that there is no significant difference between these two materials in terms of the beam loss.

At present, HBC is used as the material of the CSNS main stripping foil which is the double-layer structure. According to the residual dose requirement of the CSNS accelerator operation, with different beam power on the target, the service life of the main stripping foil is also different. Table 1 shows the service life of the main stripping foil for different beam power on the target. It can be found that, at the design beam power of 100 kW, the service life of the main stripping foil is relatively short, only 1.5 months. Figure 3 shows the situation of the foil surface after used. It can be seen that, if overused, the stripping foil will be severely deformed, which will cause a large amount of un-stripped particle loss.

Table 1: Service Life of the Main Stripping Foil

Power	Service life
50kW	2.0 months
80kW	1.8 months
100kW	1.5 months

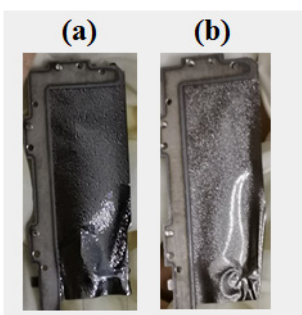

Figure 3: Stripping foils after used. (a) normal situation; (b) overused situation.

MEASUREMENT OF THE STRIPPING EFFICIENCY

In this section, a method to measure the stripping efficiency of the main stripping foil will be proposed and applied to the beam commissioning.

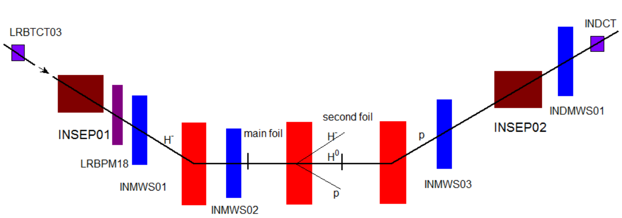

Figure 4: Layout of the I-Dump beam line.

During the stripping efficiency measurement of the main stripping foil, the normal operation mode is used. In this mode, most particles H^- are stripped by the main stripping foil and the remaining particles H^0 are all stripped by the second stripping foil, as shown in Fig. 4. By using the LRBTCT03 on the beam line from the Linac to the RCS (LRBT), the H^- beam current before the main stripping foil can be measured, i.e. I_{H^-}. After the main stripping foil, the remaining particles H^0 are all stripped to the protons H^+ by the second stripping foil and then can be measured by INDCT, i.e. I_{H0}. Figure 5 shows the current signal measured by INDCT which represents the beam current of the remaining particles H^0. For the CSNS, after the main stripping foil, the remaining particles H^- are much smaller than the remaining particles H^0 [4]. Therefore, the stripping efficiency of H^+ can be approximately calculated by

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

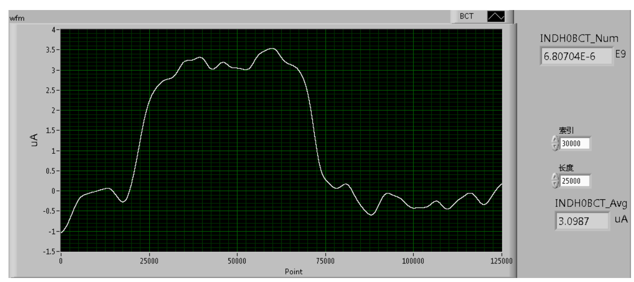

Figure 5: Current signal measured by INDCT which represents the beam current of the remaining particles H^0.

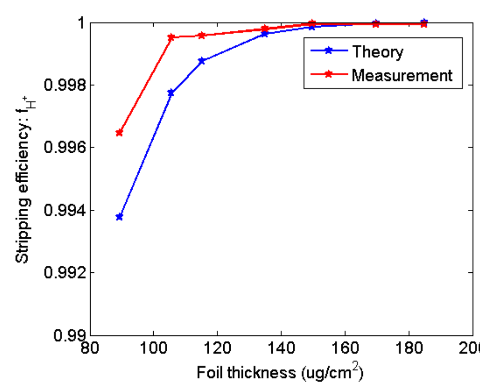

Figure 6: Measured and theoretical stripping efficiencies.

In the beam commissioning, with the above method, the stripping efficiencies for different foil thicknesses were measured. Figure 6 shows the comparison of measured and theoretical stripping efficiencies. It can be found that there is a little difference between the theoretical and actual measured results. This difference is mainly caused by the measurement errors of the stripping foil thickness and INDCT. At the same time, it can be seen from Fig. 6 that the stripping efficiency of the CSNS main stripping foil is greater than 99.6% at present.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB200

SIMULATION AND MEASUREMENT OF THE RESIDUAL DOSE NEAR THE STRIPPING FOIL

The injection beam loss is the main source of the RCS beam loss which is one of the decisive factors that limit whether the RCS can operate at the high power. After the injection optimization in the beam commissioning, the particle scattering of the main stripping foil becomes an important source of the injection beam loss. In this section, the particle scattering of the main stripping foil would be simulated and the theoretical residual doses caused by the foil scattering would be obtained. At the same time, the measurement results of the residual doses in the injection region would also be presented.

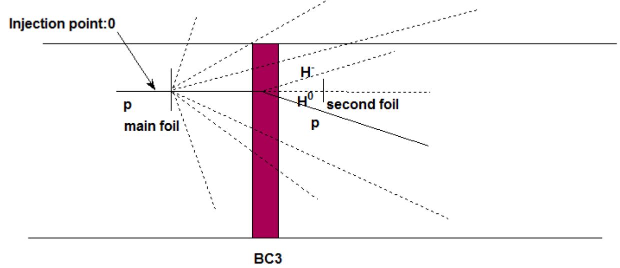

Figure 7: Main stripping foil scattering model.

By using the codes FLUKA [9] and ORBIT [10], the beam transport and particle scattering of the main stripping foil can be simulated. Figure 7 shows the main stripping foil scattering model. Firstly, by using the code ORBIT, the multi-turn phase space painting injection process was simulated. The average traversal number and the beam distribution after injection can be obtained. Then, with the beam distribution after injection, the particle scattering of the main stripping foil can be simulated by the code FLUKA. In the simulation, the accelerator was set to run for 6 days and then shutdown for 2 hours before the residual doses were calculated, which was consistent with the actual situation of the CSNS. The average traversal number was also considered in the simulation. Figure 8 shows the simulation results of the residual doses in the injection region caused by the foil scattering. It can be seen that the maximum residual dose caused by the foil scattering is less than 2 mSv.

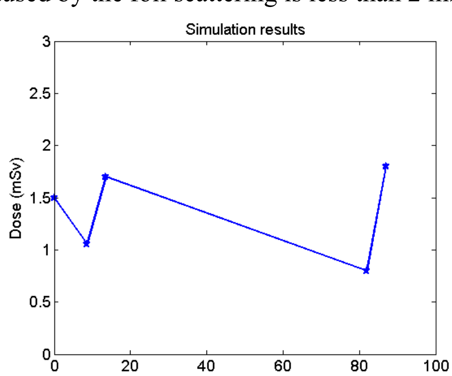

Figure 8: Simulation results of the residual doses in the injection region caused by the foil scattering.

In the weekly actual operation, the accelerator runs for 6 days and then shutdown for 2 hours before the residual doses are measured. Figure 9 shows the measurement results of the residual doses in the injection region. It can be seen that, due to the effects of different beam states and measurement errors, the measurement results of the residual doses have some deviations in different weeks. By comparing the Figs. 8 and 9, it can be confirmed that the particle scattering of the main stripping foil is the most important source of the residual doses in the injection region.

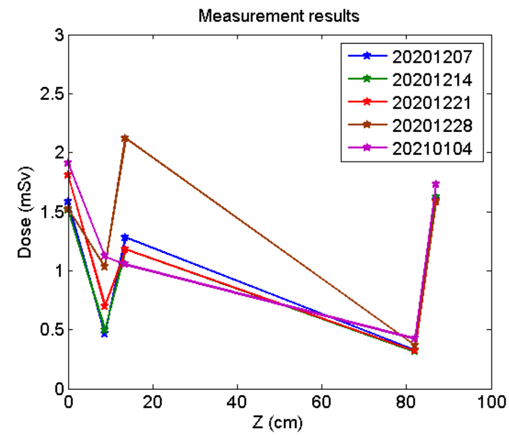

Figure 9: Measurement results of the residual doses in the injection region (Design beam power of 100 kW).

CONCLUSIONS

Firstly, the application and service life of the main stripping foil for the CSNS were introduced. The operation results of the CSNS accelerator show that the service life of the main stripping foil is only 1.5 months at the design beam power on the target of 100 kW. During the beam commissioning, a method to measure the accurate stripping efficiency had been proposed and applied. The beam study results show that the stripping efficiency of the main stripping foil is greater than 99.6% at present.

By using the codes FLUKA and ORBIT, the particle scattering of the main stripping foil had been simulated and the theoretical residual doses caused by the foil scattering had be obtained. By weekly measurement of the residual doses in the injection region, the residual doses near the main stripping foil were given. The residual doses comparison results confirmed that the particle scattering of the main stripping foil is the most important source of the residual doses in the injection region.

ACKNOWLEDGMENTS

The authors would like to thank other CSNS colleagues for the discussions and consultations. M.Y. Huang also would like to thank Yoshiro Irie of KEK for helpful discussions.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2021). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB200

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2021). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

REFERENCES

[1] W. Sheng *et al.*, "Introduction to the overall physics design of CSNS accelerators," *Chinese Physics C*, vol. 33, no. S2, pp. 1–3, Jun. 2009. doi:10.1088/1674-1137/33/s2/001

[2] CSNS Project Team, *China Spallation Neutron Source Feasibility Research Report*, Chinese Academy of Sciences, 2009 (in Chinese).

[3] W. Jie *et al.,* "China Spallation Neutron Source - an overview of application prospects," *Chinese Physics C*, vol. 33, no. 11, pp. 1033–1042, Nov. 2009. doi:10.1088/1674-1137/33/11/021

[4] M.-Y. Huang, S. Wang, J. Qiu, N. Wang, and S.-Y. Xu, "Effects of injection beam parameters and foil scattering for CSNS/RCS," *Chinese Physics C*, vol. 37, no. 6, p. 067001, Jun. 2013. doi:10.1088/1674-1137/37/6/067001

[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," *Physical Review Special Topics - Accelerators and Beams*, vol. 14, no. 7, Jul. 2011. doi:10.1103/PhysRevSTAB.14.072801

[6] P. K. Saha *et al.*, "Measurement of 181 MeV H − ions stripping cross-sections by carbon stripper foil," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 776, pp. 87–93, Mar. 2015. doi:10.1016/j.nima.2014.12.068

[7] M. Y. Huang *et al.*, "Study on the anti-correlated painting injection scheme for the Rapid Cycling Synchrotron of the China Spallation Neutron Source," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment,* vol. 1007, p. 165408, Aug. 2021. doi:10.1016/j.nima.2021.165408

[8] M.-Y. Huang, S. Wang, and S.-Y. Xu, "Beam loss and the stripping efficiency measurement for CSNS injection system," *Journal of Physics: Conference Series*, vol. 1350, p. 012107, Nov. 2019. doi:10.1088/1742-6596/1350/1/012107

[9] A. Ferrari *et al.,* "FLUKA: multi-particle transport code," CERN, Geneva, Switzerland, Rep. CERN-2005-010, Oct 2005. doi:10.2172/877507

[10] J. Gabambos *et al.*, "ORBIT User's Manual," SNS/ORNL/AP Technical Note 011, Jan. 1999.