FEASIBILITY STUDIES OF THE FOIL SCATTERING EXTRACTION IN CSNS/RCS

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Abstract

A slow extraction system based on foil scattering was suggested in the rapid cycling synchrotron of China Spallation Neutron Source to meet the requirement of very low intensity applications. The scattered protons by a carbon foil with large scattering angle will be extracted during 2 ms at the end of each RCS cycle. The feasibility of the extraction scheme is investigated. The extraction efficiency is studied by both single turn and multi-turn simulations with FLUKA and ORBIT, respectively. Beam losses due to multiple scattering to the downstream components are predicted.

INTRODUCTION

The China Spallation Neutron Source (CSNS) consists of an 80 MeV Linear accelerator and a 1.6 GeV Rapid Cycling Synchrotron (RCS) [1]. Two intense bunches containing 1.56×10^{13} protons are accumulated and accelerated in the RCS with a repetition rate of 25 Hz. A foil scattering based multi-turn extraction method is suggested for very low intensity applications, while maintaining single-turn extraction for the core beam [2]. The foil scattering method was also used for slow extractions at KEK-PS [3]. Prof. J.Y. Tang and his students have worked out a preliminary scheme for simultaneously multi-turn extraction for beam halo at the arc and single-turn extraction for beam core at the straight section. A new scheme was developed, which perform the foil scattering extraction at the fast extraction straight section. With the new scheme, the number of extraction particles per turn was largely increased, and also the foil scattering channel can share the same channel with fast extraction. The halo protons will be extracted for each turn during the last two milliseconds before the whole beam is fast extracted from the RCS. The feasibility of the extraction scheme is studied with ORBIT [4] and FLUKA [5] code, separately. The extraction efficiency is given by combing the results of the two simulations. As the scrapping of the beam will create a “shower” of elastically scattered particles, which will increase the activation of the downstream components, beam losses due to the multiple scattering are predicted.

FOIL SCATTERING EXTRACTION SYSTEM OVERVIEW

The lattice structure of the RCS has a four-fold symmetry, with four dispersion free straight sections for accommodation of injection, extraction, RF and beam collimation system. The ring has a circumference of 228 m. Single turn extraction is required for the RCS. A set of fast extraction kickers and a Lambertson are used to extract the beam from the RCS and deflect further into the Ring to Target Beam Transport line [6]. The schematic layout of the RCS is shown in Fig. 1.

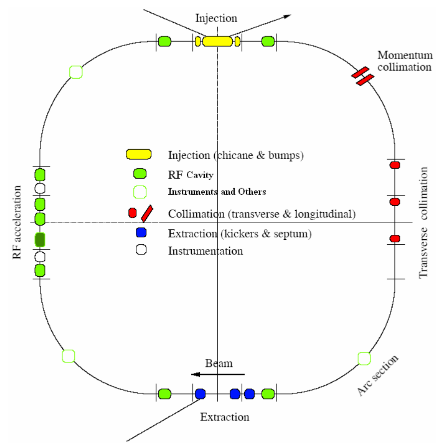

Figure 1: Schematic layout of the RCS.

The foil scattering extraction is designed to be compatible with the fast extraction for the spallation target. In the extraction section, a 3.6 m long free space between the fast extraction kickers and the Lambertson magnet can be used for the foil scattering extraction. When the beam is accelerated to the peak energy, the fast extraction process is postponed for one millisecond. During the last two milliseconds, small amount of the halo particles, about 0.01% of the beam, can be coulomb scattered by a carbon foil. A set of four vertical AC bumps will be used in conjunction with the Lambertson to extract the beam with large scattering angle before the rise of the extraction kickers. As only small part of the beam interact with the foil, the scattering extraction does not affect the fast extraction beam.

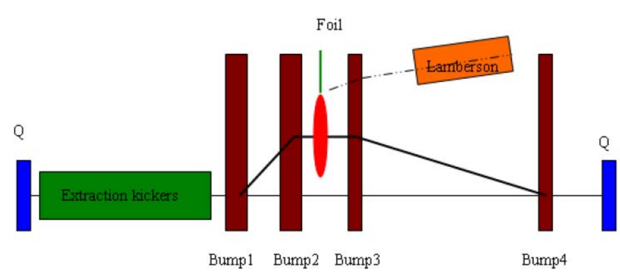

Figure 2: Layout of the foil scattering extraction system.

The layout of the extraction system is illustrated in Fig. 2. Three of the bumps are to be located upstream of the Lambertson magnet and the other one downstream of it. The foil has a dimension of 120 mm × 20 mm × 0.1 mm, which is located at the flattop of the bump orbit. Ceramic vacuum chambers are needed for the bump magnets. The

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decline of the orbit bump at the Lambertson is helpful to reduce the beam losses on it.

The transverse position of the foil should take into account both the circulating beam and the extracted beam. As the emittance of the beam shrinks during the acceleration, the acceptance at the position of the foil at injection stage is set to be 540 π mm·mrad, while at extraction stage is determined by the distribution of the extraction beam.

EXTRACTION EFFICIENCY

The efficiency of the foil scattering extraction scheme is investigated by both single turn and multi-turn simulations with FLUKA and ORBIT code.

Multi-Turn Simulations

Multi-turn tracking has been carried by using ORBIT code. The foil scattering packages in ORBIT include multiple Coulomb scattering, Rutherford scattering, nuclear scattering, and ionization energy loss. The initial distribution of the halo particles is determined by the parameters of the extracted beam obtained by full cycle simulations of the RCS. According to the beam distribution at extraction, the initial beam distribution, which is supposed to interact with the foil, is formed by the halo particles with vertical emittance from 120 π mm·mrad to 146 π mm·mrad. For simplicity, uniform distributions in the transverse phase space have been assumed in the simulation.

The vertical emittance and twiss parameters are used to generate up to 1×10^5 macro particle coordinates as vertical phase space coordinates. In the horizontal plane, beam with large vertical emittance is supposed to have small emittance horizontally and vice versa, while keeping the sum of the two emittance smaller than 180 π mm·mrad. The distribution of the halo particles in the transverse phase space is shown in Fig. 3.

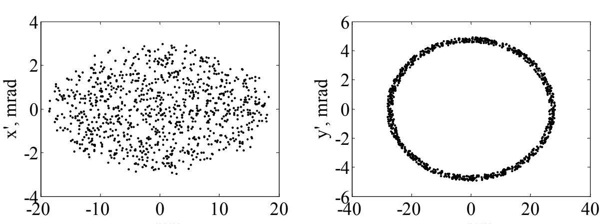

Figure 3: Distributions of the halo particles in the horizontal (left) and the vertical (right) phase spaces.

The particles are tracked for 2500 turns, about 2 ms. The number of hits on the foil and the coordinates of the protons at the entrance of the Lambertson magnet are recorded. According to the computation, each particle traverses the foil 217 times in average, corresponding to 1.35×10^8 hits per turn. The number of hits on the foil at each turn during the extraction process is presented in Fig. 4. Considerably good uniformity among different turns has been achieved.

The vertical divergence of the extraction beam is restricted in the range of 19.5 mrad to 33.5 mrad to access to the fast extraction tunnel. Totally, 7×10^5 protons can be extracted during 2 ms, which indicates that about 200 particles can be extracted in each turn.

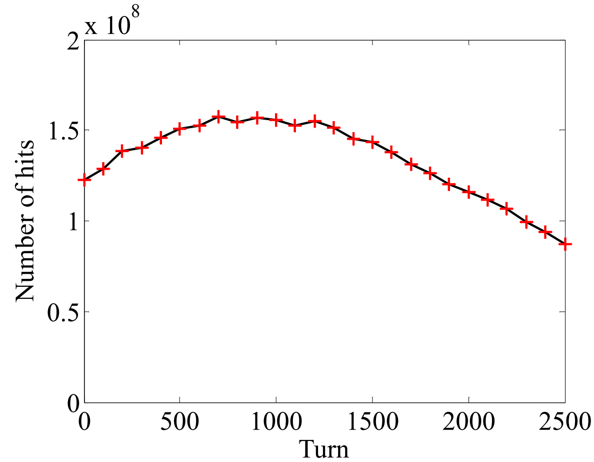

Figure 4: Number of hits on the foil at each turn during the extraction process.

Single-Turn Simulations

The average traverse time and the extraction uniformity have been evaluated in the multi-turn simulations. In view that the number of macro particles in the multi-turn tracking is restricted by the computing time, and a simplified scattering model has been used in ORBIT, the FLUKA code is used to simulate the scattering process during a single traversal.

For simplicity, a truncated Gaussian distribution of 1×10^8 macro-particles is used in the calculation. The distribution of the scattering angles and momentum deviation of the particles are further studied to estimate the number of extraction particles more precisely.

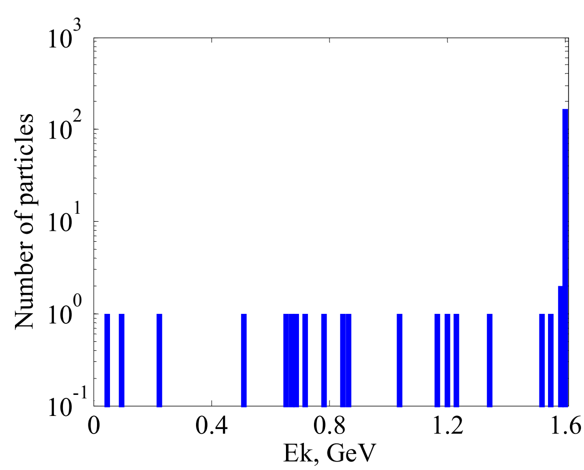

Figure 5: The energy distribution of the extracted particles.

Simulations indicate that 185 particles can access to the extraction channel, in which 164 particles have kinetic energy spread smaller than 0.6%. The result agrees very well with that obtained in the multi-turn studies. The energy distribution of the extraction particles is illustrated in Fig. 5.

By combing the multi-turn and single turn results obtained above, we find the number of particles extracted per turn through foil scattering as shown in Fig. 6. In this evaluation, the number of extracted particles is assumed to be proportional to the number of hits on the foil, which means that the variance of the distribution among different turns has been neglected.

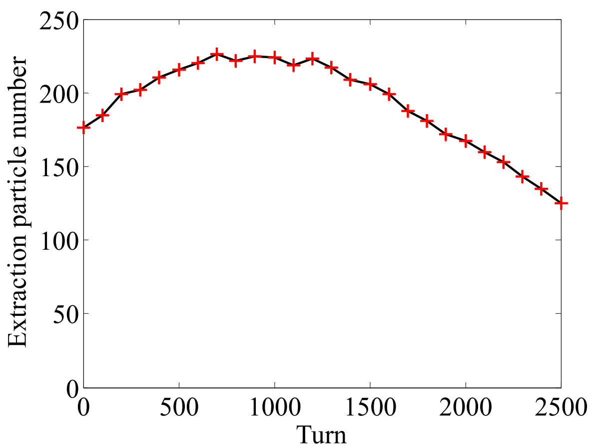

Figure 6: Number of extracted protons per turn.

BEAM LOSSES DUE TO THE FOIL SCATTERING

In the physical design, the uncontrolled beam loss is the primary concern of the high intensity proton machines. The foil scattering will contribute to the increase of the beam halo outside the beam core, and results in additional beam losses.

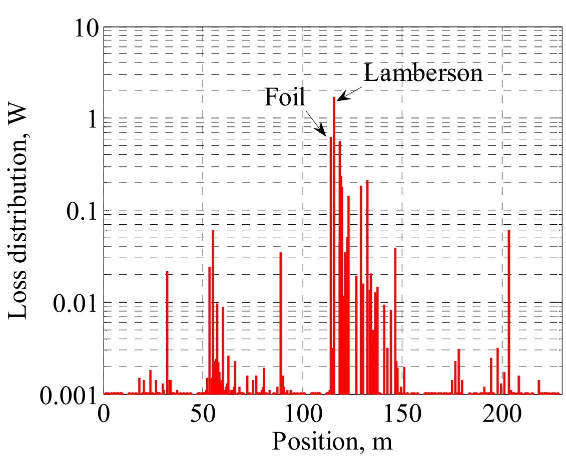

Figure 7: Beam loss distribution around the ring due to the foil scattering.

In our case in total of 1.56×10^9 protons are scattered at each RCS cycle. The scattered beam has a total power of 10 W. According to the multi-turn simulations, the beam loss due to the foil scattering is in the range of 4 ~ 6 W. The beam loss distribution around the ring due to the foil scattering is illustrated in Fig. 7.

As shown in the figure, most of the losses deposit in the extraction region and the first arc in the downstream of the foil. The result indicates that beam losses at the ring elements are less than 0.3 W except that within the Lambertson magnet or the circulating beam chamber at the extraction region. The Lambertson magnet gets the largest beam loss of 1.7 W.

In addition, as only 0.01% of the beam intensity would hit the foil, the scattering will not play an important role to the increment of the beam emittance.

CONCLUSIONS

The feasibility of the foil scattering extraction scheme has been studied. The scheme of the foil extraction is presented. The number of protons to be extracted per turn is predicted by both multi-turn and single turn simulations. By combining the results of the simulations, we obtain the number of protons to be extracted per turn. The average traversal time and the extraction uniformity are evaluated. According to the studies, the quantity and the uniformity of the particles extracted through the foil scattering can fulfil the requirement of the single particle calibration experiment. Finally the beam losses contributed by the foil scattering are estimated. The beam power losses along the RCS outside the extraction region are all below 0.3 W.

ACKNOWLEDGMENTS

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