SIMULATION OF A BEAM ROTATION SYSTEM FOR THE SINQ SPALLATION SOURCE AT PSI

D. Reggiani*, T. Reiss, M. Seidel, V. Talanov, M. Wohlmuther,
Paul Scherrer Institut, 5232 Villigen, Switzerland

Abstract

With a nominal beam power of nearly 1 MW on target, the PSI-SINQ ranks among the world's most powerful neutron spallation sources. The proton beam transport to the SINQ target is carried out exclusively by means of linear elements. As a consequence, at the SINQ target entrance the beam presents Gaussian transverse x and y distributions with tails cut short by collimators. This leads to a highly uneven temperature distribution inside the SINQ target, giving rise to thermal and mechanical stress. In view of a future beam intensity upgrade, the possibility of homogenizing the beam distribution by means of a fast beam rotation system is currently under study. Important aspects of this method concern the resulting neutron spectrum and flux distribution. The simulations of the beam distribution obtained with this technique as well as its consequences in terms of neutron production are presented in this contribution.

INTRODUCTION

The PSI high intensity proton accelerator (HIPA) generates a continuous wave 1.3 MW beam. Protons are provided by an ECR source and brought to 590 MeV energy by an accelerator chain composed by a Cockcroft-Walton generator followed by an injector and a ring cyclotron [1]. The 1.3 MW beam is transported through a 60 m long channel provided with two meson production graphite targets (target M and E, respectively 5 and 40 mm thick). The 575 MeV beam surviving target E is reshaped by a collimator system and about 70% of it is transmitted to the SINQ target through a 55 m channel [2]. Figure 1 represents the layout of the SINQ beam line starting from the first bending magnet located downstream of target E. Figure 2 depicts the SINQ target region along with the last section of the beam line where three water cooled copper collimators (KHN31-33) shield the rim of the target entrance window and, at the same time, prevent activation of the beam line from back scattered neutrons. The SINQ target consists of a 40 cm deep vessel containing over 30 rows of zircaloy tubes filled with lead rods.

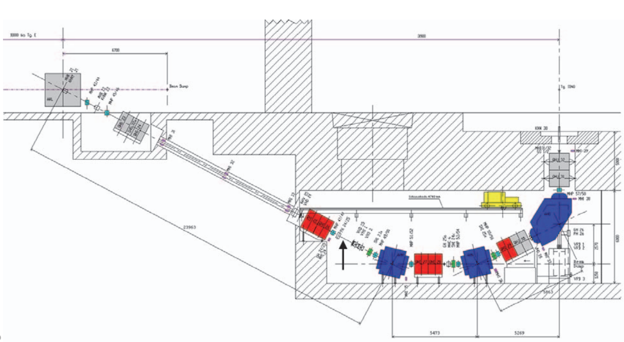

Figure 1: Layout of the SINQ beam line. The black arrow indicates the possible location of a beam rotation system.

* davide.reggiani@psi.ch

Since the beam transport is carried out only by means of linear elements, the beam transverse distribution at the SINQ target presents a Gauss peak in both x and y coordinates, whereas tails are cut by the collimators installed in the target E region (Fig. 4, top). This highly inhomogeneous current distribution causes large heat load and mechanical stress that could lead, on the long term, to damage the SINQ target, in particular in view of the 1.8 MW upgrade planned at HIPA. This issue triggered a systematic study aiming at the design of a magnetic beam rotation system that would yield a much more uniform beam distribution at the SINQ target.

DESIGN ASPECTS

In a beam transport line two different techniques can be employed in order to produce a uniform beam distribution. One can either apply a static approach, where beam fringes are folded by means of nonlinear elements

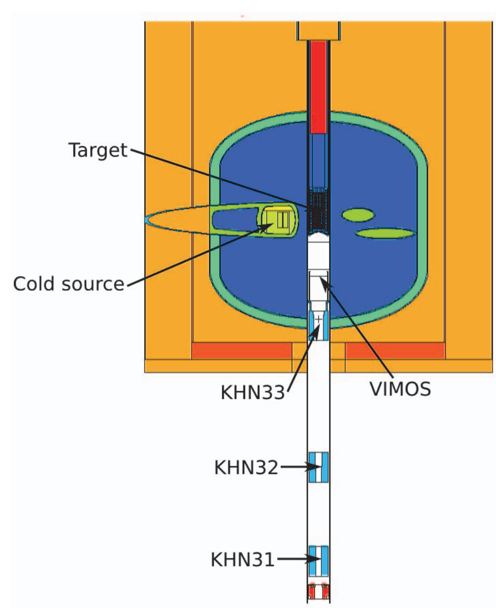

Figure 2: Schematic of the SINQ target region. The proton beam comes from the bottom.

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(octupoles and/or dodecapoles), or a dynamic one, where beam rotation or rastering are provided by high frequency AC or sawtooth wave dipoles. The first method has several drawbacks which make it very difficult to apply in the SINQ facility. In its latest development, the SINQ target presents a 120 mm diameter circular cross section. The folded beam would have instead a rectangular footprint with sharply peaked edges that could damage the target rim or cause large activation if absorbed by a collimator. Moreover, the installation of octupoles and/or dodecapoles magnets in the already almost fully packed beam line would require an extensive modification of the present setup. On the contrary, the two dipole magnets needed for the beam rotation could be integrated in one relatively small element that would find place in the only free section located some 24 m upstream of the SINQ target (Fig. 1). Such a solution would also permit an easy and reasonably safe preliminary test. An issue related to this method is that a relatively large rotation frequency is needed in order to allow a time independent neutron production and, at the same time, avoid local overheating of the target. For the SINQ spallation source, a rotation frequency around 200 Hz is foreseen, yet more studies are necessary in order to confirm this value.

BEAM OPTICS SIMULATIONS

The simulation of the beam optics for the rotating beam was carried out by using standard tools like Graphic Transport and Turtle [3]. A modified version of the SINQ beam optics was simulated by means of Transport. The aim was to reduce the beam footprint radius by 20 to 30% and make therefore the beam optics suitable for the rotation. Figure 3 shows the x (bottom) and y (top) 2σ SINQ beam envelope for the current running conditions (green) as well as the modified version (black) that could be employed for the beam rotation. The lable "ROT" represents the location of the rotation system while "TSNQ" is the position of the SINQ target. The beam rotation was then introduced by means of Turtle, a ray-tracing code through which beam distributions as well as losses can be calculated. The

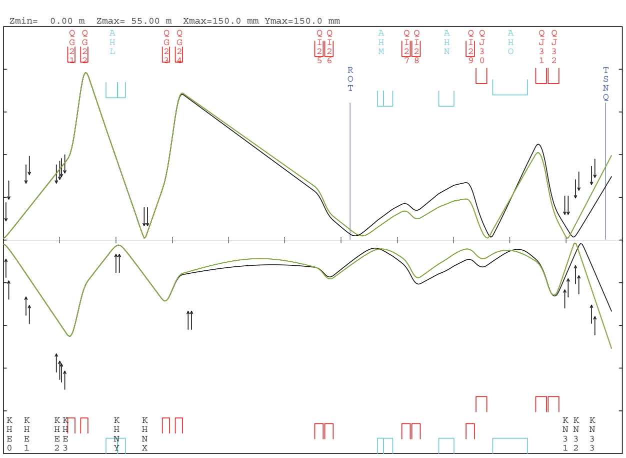

Figure 3: 2σ beam envelope from target E to the SINQ target. Arrows represent collimators. More details are presented in the text.

beam rotation was simulated by adding a 4.5 mrad kick to the beam centroid at the location foreseen for the rotation dipoles. This procedure was repeated 36 times with an azimuthal step of 10°. The amplitude of the kick was chosen in order to match the SINQ target cross section. A crucial boundary condition of the new beam optics was to minimize additional losses with respect to the standard case.

Simulation results are presented in Fig. 4 where the reference (top) as well as the rotating (bottom) x and y beam distributions are displayed. The simulations start at the upstream end of target E and the initial number or protons is the same in both cases (3.6 million). The distribution of the rotating beam appears much more uniform in both coordinates. Indeed, a quantitative analysis shows that in the central cm^2 the beam current density is reduced to 50% of its original value (from 36.5 to 17.7 μA/cm^2). Compared to the standard beam, the footprint of the rotating beam is smaller in x and larger in y, becoming almost circular and matching therefore much better the geometry of the SINQ target. These results are partially obtained at the cost of increasing the losses at the collimator system KHN31-33. While in the standard case losses in this region are very low (0.02% corresponding to 0.34kW in KHN33 and almost negligible in KNH31-32), in the rotating case beam losses as high as 0.34% (4.37 kW) and 0.22% (2.81 kW) would take place in KHN31 and KHN33, respectively.

NEUTRONICS SIMULATIONS

The effects of the rotating beam on the neutron flux were checked by means of the Monte Carlo code MCNPX [4]. In order to start with a realistic source, the proton beam distributions generated by means of Turtle were used as input for MCNPX. The integration between Turtle and MCNPX was developed at PSI for the first time for this application and was made possible by a modification of the

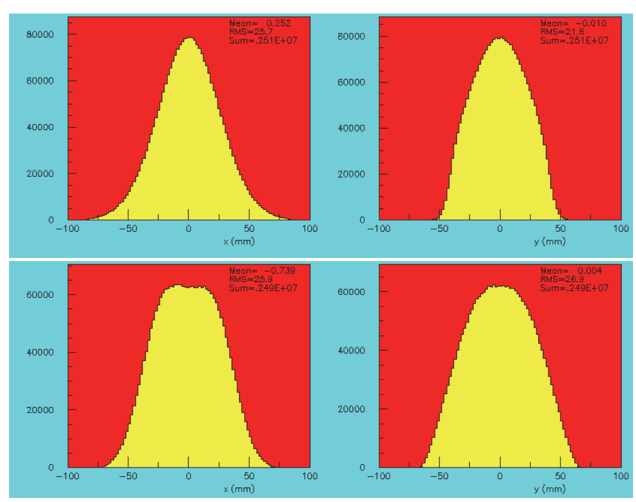

Figure 4: 2σ Turtle simulation of the proton beam transverse distributions at the SINQ target entrance window in normal running conditions (top) and applying a beam rotation system (bottom). The coordinate system follows the Turtle convention (x is the bending plane).

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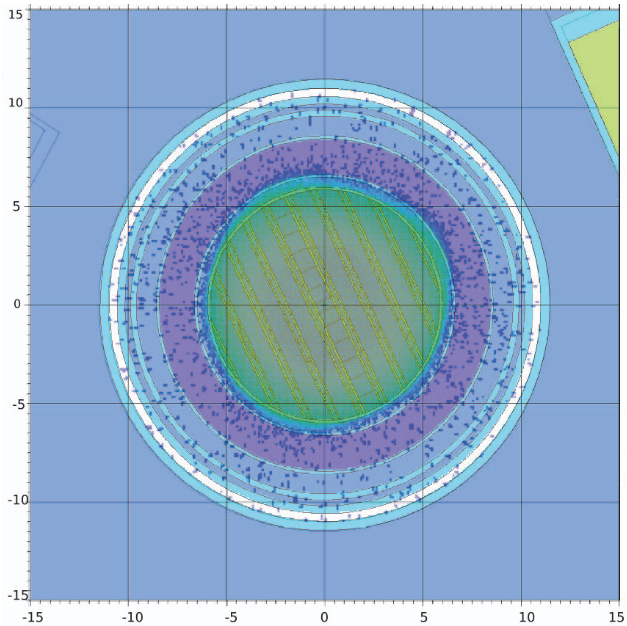

Figure 5: Beam footprint on the first row of the target tubes. For the calculation of the energy deposition the central tube was divided into 13 sections (red segments).

MCNPX source code. The two sets of Turtle proton distributions (standard and rotating beam) were taken at the upstream end of collimator KHN31. The whole collimator system was therefore included in the MCNPX simulation. Losses occurring in the collimators KHN31-33 calculated with this method (0.35% in KHN31 and 0.28% in KHN33) are in good agreement with the ones computed by Turtle. Figure 5 shows the proton beam footprint at the upstream end of the SINQ target. Figure 6 displays the energy deposition in the first two odd rows of lead filled zircaloy tubes (the very first row is filled with water). As a consequence of the more uniform current distribution, the energy deposition is much flatter in case of beam rotation (red curves) and is reduced by 25% in the central rods. Figure 7 shows the energy deposition in the central section of the odd numbered central rods (see Fig. 5) with a significant decrease of about 50% for the most heated rod when using the rotating beam. As far as the neutronic performance is concerned, no significant difference between the standard and the rotating beam was recorded. At the thermal scatterer, the flux of neutrons with wavelength between 1.0 and 2.5 Å generated by the rotating beam is only 1.2% smaller than in the standard case. A similar result was found at the cold source for neutrons with wavelength between 2.5 and 5 Å. Further details of the MCNPX simulations are given in [5].

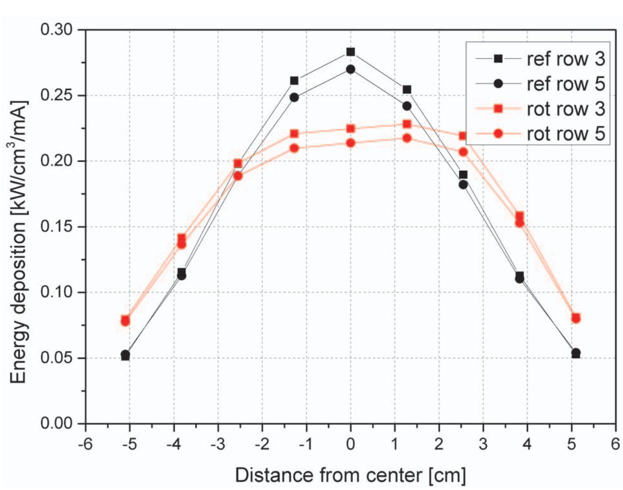

Figure 6: Energy deposition in the rods of the first two odd numbered rows for reference (black) and rotating beam.

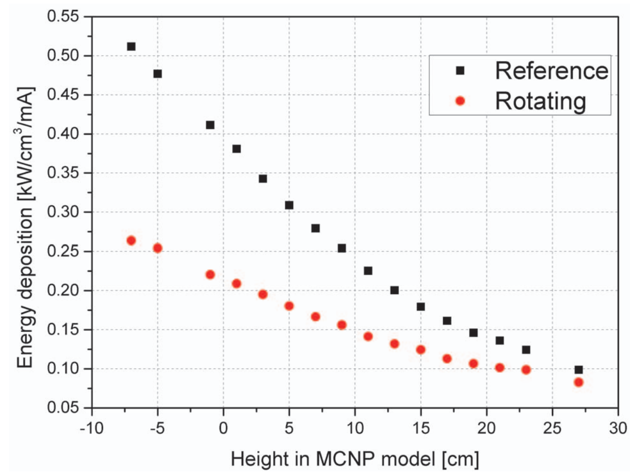

Figure 7: Energy deposition in the central section of the central odd numbered lead rods. Missing points are due to zircalloy tubes filled with probes instead of lead.

CONCLUSIONS

The preliminary design of a beam rotation system for the SINQ spallation source at PSI was presented. Results showed that the beam rotation would bring substantial benefits in terms of distribution of the energy deposition in the SINQ target without affecting the neutron spectrum and flux yield. The magnitude of the rotation frequency is still a matter of investigation. This issue is of great importance because of its implication on the technology to be employed for the rotation magnets. Moreover, an improvement of beam losses in the collimators is under study.

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