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BEAM TRANSPORT OPTIMIZATION STUDIES OF THE PSI MW-CLASS PROTON CHANNEL

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Abstract

The proton channel of the PSI high intensity proton accelerator (HIPA) transports the beam from the extraction point of the ring cyclotron through two meson production graphite targets up to the SINQ spallation source. After many years of continuous improvement, the HIPA accelerator complex has now reached the remarkable beam power of 1.4 MW. The next power upgrade is foreseen for the near future. In order to achieve this further step, an optimization of the beam transport in the proton channel is required with the goal of keeping the beam losses at a reasonable extent and, at the same time, improve the beam distribution on the SINQ target.

INTRODUCTION

The PSI high intensity proton accelerator (HIPA) generates a continuous wave 1.4 MW beam. Protons are 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 1.4 MW beam is transported through a 60 m long channel provided with two meson production graphite targets (the 5 mm thick target M and the 40 mm thick target E, absorbing ~1% and ~8% protons respectively). The highly divergent 575 MeV beam leaving target E is reshaped by a system of four copper collimators (C0 to C3, see Fig. 3) in order to match the acceptance of the SINQ beam line. A total fraction of protons in excess of 20% is stopped by the collimators or by the local shielding, while over 8% is absorbed by target E. The remaining ~70% of protons are transmitted to the SINQ target through a 55 m channel [2].

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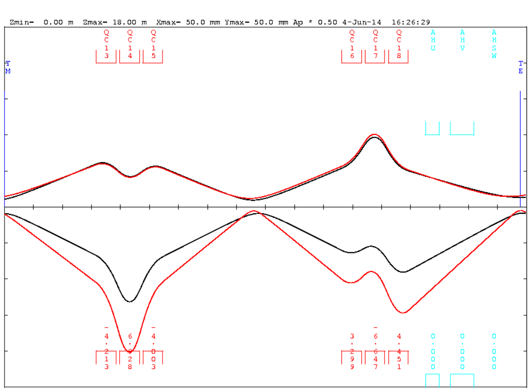

Figure 1: Transport envelope fit in the beam line section between target M and target E for 2008 (red) and 2012 runs. The lower (upper) half represents the x (y) plane.

The beam transport is carried out only by means of linear elements. As a result, the beam Gaussian transverse distribution generated by the scattering off target E is directly transferred to the SINQ spallation target. During the forty years of operation, the beam current of the PSI proton accelerator has been constantly growing from 0.1 to 2.4 mA. The aim for the next years is a further intensity upgrade towards the 3.0 mA (1.8 MW) limit. However, some modifications in the transport of the high power beam are a prerequisite for reaching this goal. The most critical issue is the reduction of the beam losses downstream of target E, in particular on the collimator C2. Moreover, an additional increase of the beam current should be combined by a beam flattening system that would allow for a more uniform temperature distribution in the SINQ target.

BEAM OPTICS STUDIES

The magnitude of the beam losses on the target E collimators depends upon the divergence of the beam leaving the target itself. The beam divergence, in turns, is given by two terms: the target E multiple scattering angle and the inherent divergence of the beam before entering the target. Since the target E contribution can not be changed, the only way of decreasing the total beam divergence is to optimize the beam optics upstream of target E. This goal was already achieved in the last years as shown in Fig. 1, where the beam envelope of the beam line section between target M and target E (fitted by means of the Transport simulation code [3]) is represented for two different running periods. The optimized 2012 optics allowed a reduction of the 2σ beam divergence

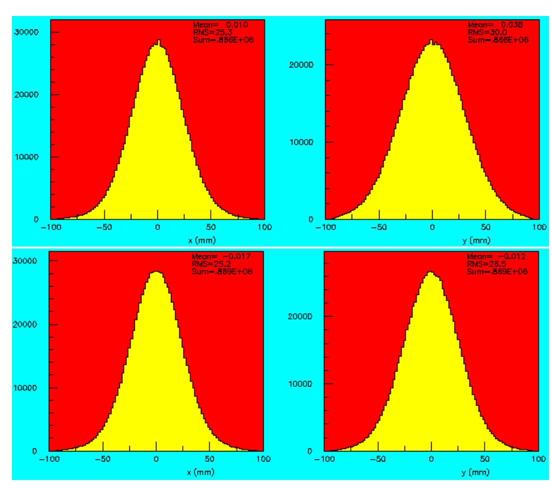

Figure 2: Turtle simulation of the beam transverse profiles in front of the C2 collimator for the 2008 (top) and 2012 runs. x and y coordinates are swapped with respect to Fig. 1.

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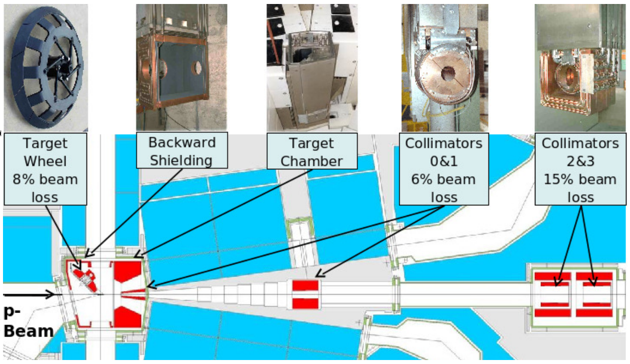

Figure 3: Drawing of the target E and collimators region (top view) and pictures of selected components.

in the x-plane from 7.7 to 4.5 mrad. Turtle [3] simulations of the beam distribution downstream of target E showed that, thanks to the improved optics, the beam x-plane divergence downstream of target E decreased from 12.8 to 11.4 mrad, corresponding to a reduction of the 2σ envelope in front of the C2 collimator from 60 to 53 mm (Fig. 2). According to this calculation, the beam losses on C2 and C3 dropped from 9.7 to 7.1% and from 6.2 to 4.6% respectively.

NEW DESIGN OF COLLIMATOR SYSTEM

The C2-C3 oxygen-free copper (OFE), water cooled collimator system is located 4.7 m downstream of target E. Each collimator is 30 cm long and presents a teeth structure whose thickness grows along the radial as well as the longitudinal direction. In the present configuration, the collimators elliptical aperture diverges along the beam direction in order to follow the increasing beam envelope. The collimator system was originally designed to withstand 2 mA (1.2 MW) beam current. ANSYS [4] simulations showed that, at 3.0 mA, C2 would reach a peak temperature of 570 °C in case of aligned beam (Fig. 5). This figure is well beyond the accepted safety limit of 405°C, corresponding to 50% of copper melting temperature. For this reason, a simulation based optimization of the collimator design is being carried out [5, 6]. Turtle beam line simulations have shown that a 12.5% widening of the collimator system aperture would be compatible with

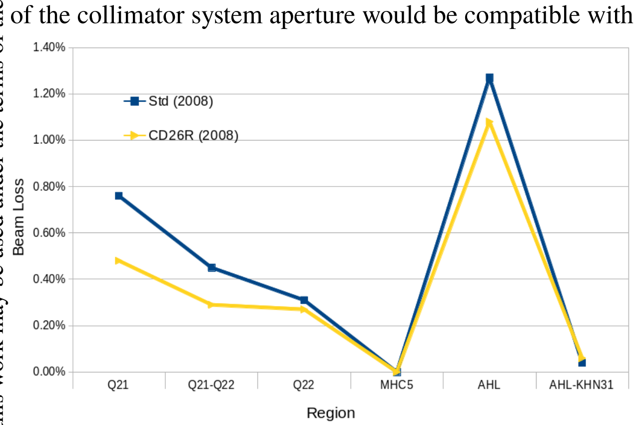

Figure 4: Beam losses downstream of the collimator C3 simulated with Turtle for the current (blue) and the proposed new collimator design .

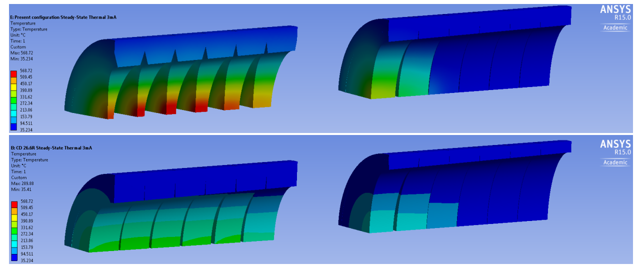

Figure 5: ANSYS simulation of the temperature distribution (same scale) in the collimators C2 (left) and C3 for the current (top) and the proposed new design.

the beam line acceptance and would not have any negative impact on the loss rate on the beam line components located behind C3. Moreover, the shielded region located directly downstream of the collimators would profit from the decreased scattering rate (Fig. 4) and the overall beam line transmission would raise by ~4%. A slight re-tuning of the beam optics would allow to keep the beam footprint at the SINQ target window almost unaltered. This outcome represents the starting point for the optimization of the collimator geometry performed by means of ANSYS. The proposed new design exhibits a 12.5% wider opening at the downstream end of C3, thicker teeth (C2) and a convergent-divergent (C2-C3) aperture scheme. The results are a much more uniform temperature distribution and a peak temperature at 3.0 mA of only 290 °C in case of aligned beam (Fig 5) and 386 °C considering a 1 mrad beam tilt. The beam phase-space at target E employed for this simulations was extracted from the 2008 highly divergent beam optics. With the optimized 2012 beam optics, the peak temperature would be reduced by about 17%.

BEAM ROTATION SYSTEM

The SINQ target consists of a 40 cm deep vessel containing over 30 rows of zircaloy tubes filled with lead rods. The Gaussian peaked, highly inhomogeneous impinging proton beam causes thermomechanical stresses that could lead, on the long term, to damage the target structure. This is a critical issue for the beam current upgrade program. In the SINQ beam line, the employment of non-linear magnetic elements like octupoles to fold beam fringes is ruled out by the strong influence of such elements on the footprint shape. Additionally, octupole fields generate sharply peaked beam edges that would cause large activation of the three SINQ collimators. On top of that, due to lack of space, these elements could not be installed without a major reshuffle of the beam line. A relatively simple way of flattening the beam distribution could be accomplished by means of a beam rotation system [7]. The space needed for the installation of the two small dipoles would be available some 24 m upstream of the SINQ target entrance window (Fig 6). Beam optics simulations were carried out with the goal of getting an efficient beam flattening with reasonable losses on the SINQ collimators. The resulting beam distribution (shown in Fig. 7 along with the present one) exhibits a 50% reduction of the beam current

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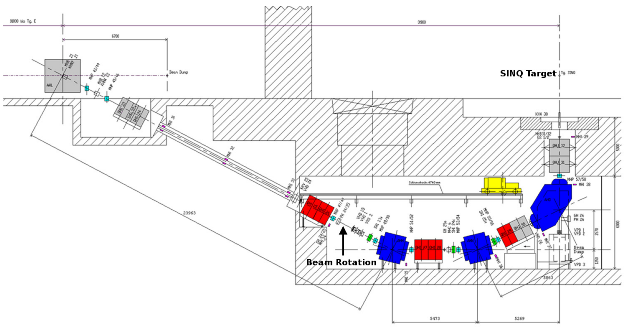

Figure 6: Layout of the SINQ beam line with the possible location of a beam rotation system.

density in the central cm^2 (from 36.5 to 17.7 μA/cm^2). The energy deposition in the SINQ target and the effect of the beam rotation on the neutron flux were checked by means of the Monte Carlo code MCNPX [8]. In order to start with a realistic source, the proton beam distributions generated by means of Turtle were used as input for MCNPX. The comparison of the peak energy deposition in the central rods over the target length for the present and the rotating beam (Fig. 8) shows the benefits of the beam rotation. Furthermore, a significant decline in the neutron production was ruled out. Nevertheless, due to the rotation of the proton beam, a time dependent oscillation of the neutron fluxes coming from the cold source as well as the thermal scatterer has to be expected. This modulation was simulated for different rotation frequencies (Fig. 9). According to the results, in order to limit the neutron flux modulation to ~2%, a rotation frequency in the order of 1000 Hz is required.

CONCLUSION

A summary of the ongoing studies concerning the optimization of the transport of the MW-class proton beam at the PSI HIPA accelerator facility was presented. The future implementation of the proposed modifications will make the proton channel suitable for the 1.8 MW power upgrade.

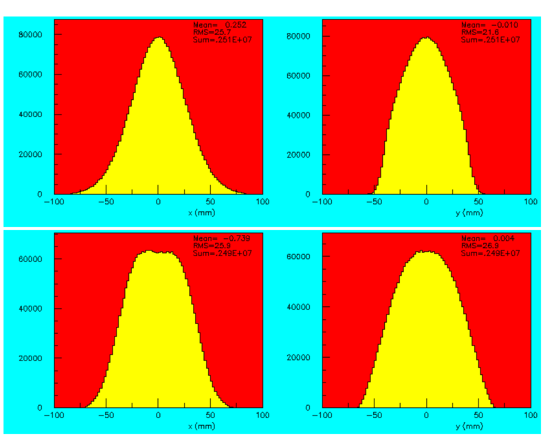

Figure 7: 2σ Turtle simulation of proton beam transverse distributions at the SINQ target entrance window with present optics (top) and applying a beam rotation system.

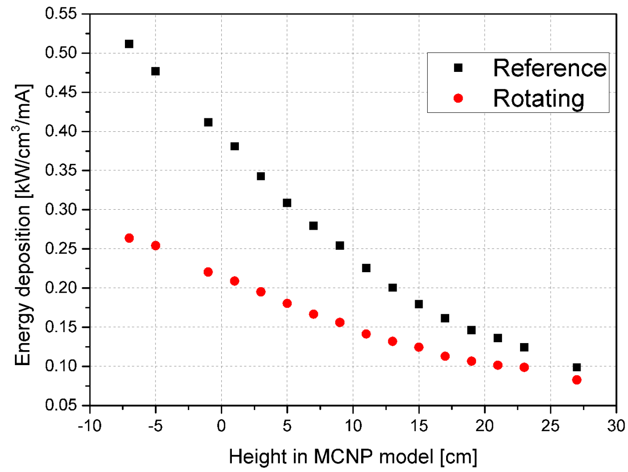

Figure 8: Peak energy deposition in the central rods along the target.

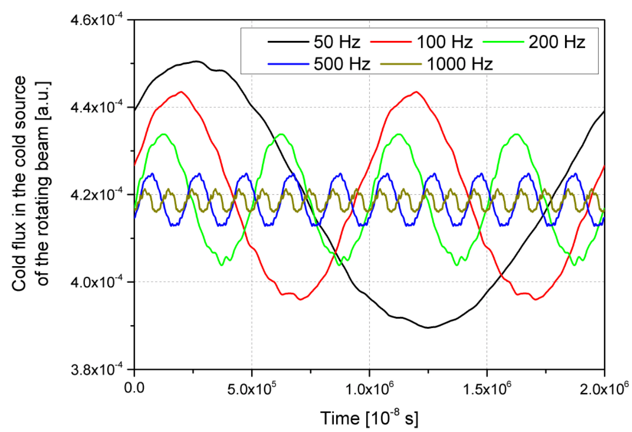

Figure 9: The time-dependent cold neutron flux in the cold source with different rotation frequencies.

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