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IMPROVING MACHINE AND TARGET PROTECTION IN THE SINQ BEAM LINE AT PSI-HIPA

D. Reggiani*, R. Dölling, P.A. Duperrex, D. Kiselev, J. Welte, M. Wohlmuther
Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

Abstract

With a nominal beam power of nearly 1.4 MW, the PSI High Intensity Proton Accelerator facility is currently at the forefront of the high intensity frontier of particle accelerators. A key issue of this facility is to ensure safe operation of the SINQ spallation source. In particular, too large beam current density and/or inaccurate beam steering can seriously compromise the integrity of the spallation target. Recently, a campaign has been launched in order to improve the fast detection of improper beam delivery and therefore the reliability of the system. New beam diagnostics elements such as an absolute intensity monitor, a beam position and second moment monitor as well as additional loss monitors have been installed during the 2017 shutdown. In 2018 a new SINQ target will be installed featuring a system of thermocouples which will keep track of the beam position. Moreover, an additional monitor is currently under study which should reliably detect small beam fractions accidentally bypassing the muon production target TE and representing a dangerous occurrence for the SINQ spallation target. The present efforts to increase the efficiency of the SINQ protection system are reviewed in this contribution.

INTRODUCTION

The PSI High Intensity Proton Accelerator (HIPA) generates a continuous wave 1.4 MW beam [1]. After extraction, the beam is transported through a 60 m long beam line provided with two graphite target stations, so-called TM and TE and installed 18 m apart from each other. TM has a thickness of 5 mm and absorbs ~1% of the beam. TE is 40 mm (alternatively 60 mm) thick and absorbs ~8% (~12%) of protons. The highly divergent 570 MeV (560 MeV) beam leaving TE is reshaped by a system of four copper collimators and delivered to the SINQ spallation source. A total fraction of protons in excess of 20% (30%) is stopped by the collimators or by the local shielding while ~70% (~57%) of protons are transmitted to the SINQ target through a 55 m beam line. The SINQ target consists of a 40 cm deep vessel containing over 300 zircaloy tubes filled with lead rods and cooled by heavy water. During the 44 years of operation, the beam current of the PSI proton accelerator has been constantly growing from 0.1 to 2.4 mA. At the maximum beam intensity and when the 40 mm TE is in operation almost 1 MW power is dumped into the SINQ target. Under such conditions, a sudden change of the beam optics and/or position can easily lead to excessive thermomechanical stress of the spallation target. In order to avoid such occurrences, a redundant monitoring of the beam properties is mandatory.

* davide.reggiani@psi.ch

THE SINQ BEAM LINE

Figure 1 shows a 2σ beam envelope fit of the SINQ beam line obtained using the Transport simulation code [2]. The top (bottom) black line represents the horizontal (vertical) plane. The green dashed line represents the dispersion function. The bending plane is vertical. After passing through TE and the collimation system, the beam is first diverted downwards and then upwards by means of four dipole magnets (light blue rectangles) before being vertically dumped into the SINQ target. The quadrupole magnets are depicted by the red rectangles. The fit constraints are the beam widths measured by the profile monitors (black marks). During the design phase of the beam line beam position monitors (BPMs) were not foreseen. This way, a trajectory feedback system like the one present in the beam line section between the ring cyclotron and TE can not be carried out. A challenging issue is related to the potential misteering of the 590 MeV beam, which could cause a fraction of protons to miss the 6 mm wide TE graphite wheel. Since its relative current density is about 20 times larger compared to the beam going through TE, even small amounts of TE-bypassing beam must be detected within a time range of few ms in order to allow for a beam interlock before a damage in the SINQ target occurs. Due to the large momentum acceptance of the SINQ beam line, this unscattered full energy protons would reach the SINQ target. For this reason, a pair of movable copper collimators (KHNY30) were installed in 2004 in the high dispersion region located inside the quadrupole magnet QHJ30 [3]. This system can detect fractions of beam bypassing TE in the order of 1%, provided that the beam trajectory is well centred through the beam line. Due to the missing BPMs, it is actually not possible to guarantee this prerequisite. Another tool that could detect TE-bypassing

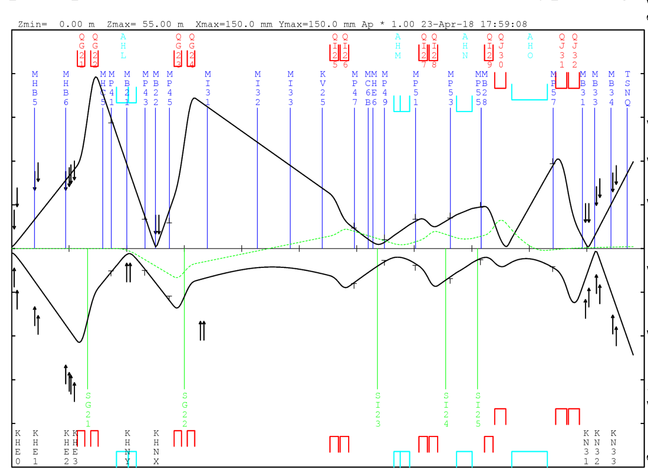

Figure 1: Beam envelope fit between TE and SINQ.

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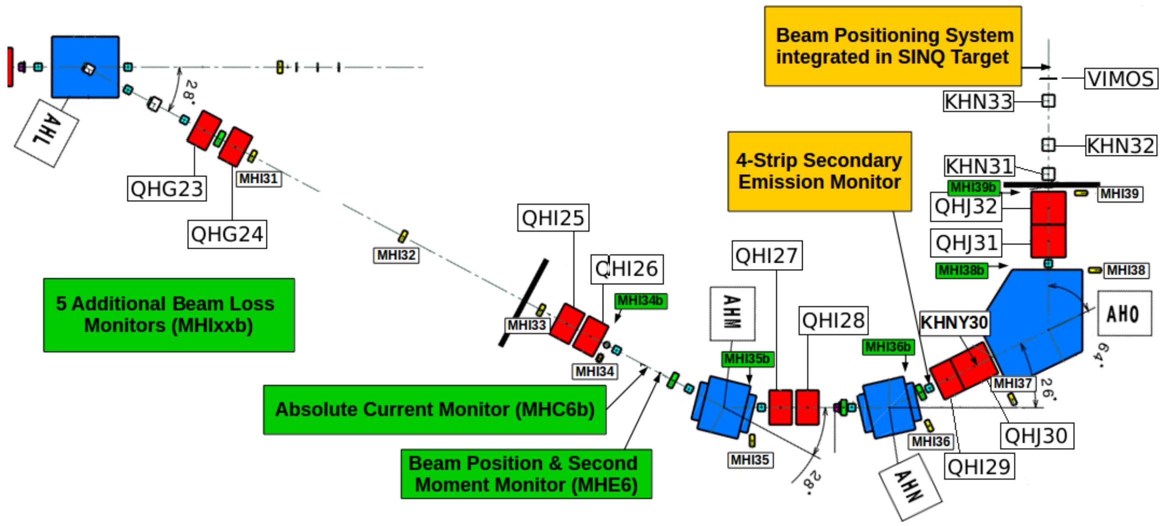

Figure 2: The SINQ beam line with the recently installed monitors (green) and the ones planned for 2018 (yellow).

beam is the computation of the beam transmission through TE performed by comparing the beam current measured by two monitors located respectively down- and upstream of TE. The sensitivity of this method is limited by the fact that the TE wheel, rotating at 60 rpm, presents 12 slits which allow for thermal expansion but, at the same time, introduce a 3% transmission modulation.

ADDITIONAL DIAGNOSTICS

During the last two years a great attention is being devoted in order to improve the safety of the SINQ target and, at the same time, to get a better insight of the beam properties in the SINQ beam line. Additional monitors were installed in 2017 and more are planned for the 2018 shutdown (Fig. 2).

New Beam Loss Monitors

The last six out of the nine original BLMs (MHI31-39) are installed on the bottom side of the beam line. Due to the momentum dispersion introduced by the AHL dipole, the distribution of the low energy tail of protons scattered off TE results in a top/bottom asymmetry. In the downstream part of the beam line (starting from the quad QHI25), losses due to this tail will affect the upper side of the beam line up to the point where the dispersion is canceled by the AHO dipole. In order to try to assess this asymmetry, five additional BLMs were installed on the top side of the beam line, three of them in the non zero dispersion region (MHI34b, MHI35b, MHI36b) and two in the dispersion free region (MHI38b and MHI39b). A first analysis of the data collected during the 2017 run shows that the signals measured by MHI34b and MHI35b are respectively two and six times larger than MHI34 and MHI35, while MHI39 and MHI39b show exactly the same amount of losses, as one would expect. A more accurate data analysis will be performed before the beginning of the next run.

Absolute Current Monitor

The fast measurement of the beam current in the SINQ beam line plays a crucial role for the detection if unexpected losses [4]. This task is taken over by two 2nd harmonic resonators, MHC5, installed in the highly activated region downstream of TE, and MHC6, located some 25 m downstream. Although very fast, these monitors can only measure relative beam currents and must be calibrated by means of the absolute current measurement provided by a Bergoz® [5] monitor upstream of the first target station TM multiplied by the transmission of the beam passing through targets and collimators before reaching MHC5 or MHC6. The critical point here is that small changes in the beam divergence upstream of TE reflect in a variation of the amount of beam absorbed by the TE collimators [6]. Tests have shown that the beam transmission can vary by over 2% by slightly changing the quadrupole setting in the TM-TE beam line section. For this reason, a precise determination of the beam transmission can not be performed without the help of a second DC current monitor from Bergoz® recently installed in the SINQ beam line and commissioned during the 2017 run (Fig. 3). Moreover, the Bergoz® turns out to be very useful when a temperature induced drift of the resonance frequency causes a change in the calibration of MHC5 or MHC6. A refined calibration procedure of all beam current monitors installed in the HIPA proton channel which takes into account the information delivered by the new Bergoz® monitor is currently under study and will be implemented during the 2018 run.

Beam Position and Second Moment Monitor

Next and concurrently to the Bergoz®, a beam position and second moment monitor (BHE6) was installed in 2017. This monitor is made out of 8 wide-band magnetic pickup coils and can measure the moments M=0, 1 and 2 of the magnetic field of the proton beam, enabling the simultaneous determination of the beam current, position and ellipticity.

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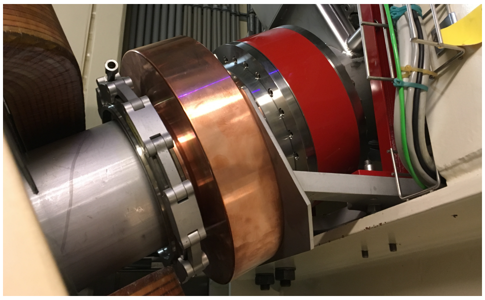

Figure 3: The Bergoz® absolute current monitor (right) and the beam position and second moment monitor (left) installed in 2017 in the SINQ beam line. The beam comes from the right.

It is meant to be a first prototype which could be eventually replicated in other positions along the beam line in order to solve the problem of the absence of BPMs. During the first tests the BHE6 has been employed as current and position monitor, comparing its measurements with the ones delivered by the Bergoz® and by a profile monitor located close to it. Both results appeared to be very satisfactory. The further commissioning of this element as a second moment monitor will be carried out during this year.

4-Strip Secondary Emission Monitor

Protons missing TE are not decelerated and hence shifted vertically in the dispersive section at QHJ30 (where the slit KHNY30 is located) as well as upstream of it, where the 4-strip secondary emission monitor MHB28 will be placed (Fig. 4). By limiting the signal currents allowed at the close inner strips, the main beam is forced to be centred vertically. This requirement can only be provided less strictly by KHNY30, since heat load and activation of its massive and uncooled copper blocks force the gap size to rather wide apertures. In this ideal condition of centred beam, the signal currents at the outer strips result from less than 0.1% of the regular beam. Even a small fraction of approximately 1% of beam missing TE will clearly increase the signal at the outer lower strip, which can be used to trigger a beam interlock. The relative difference of the signal currents at the inner strips provides the information for vertical beam centring. Scattering of the beam by the 20 μm Molybdenum foil strips is negligible according to TURTLE simulations. This monitor will be discussed in detail in [7].

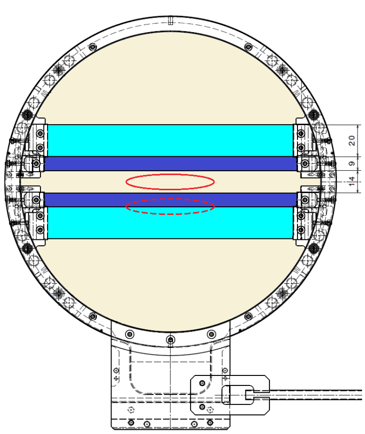

Figure 4: Layout of 4-strip secondary emission monitor. Signals from the four strips (cyan, blue) are read out individually. 2σ beam contours are indicated for regular (full red) and irregular (dotted red) beam

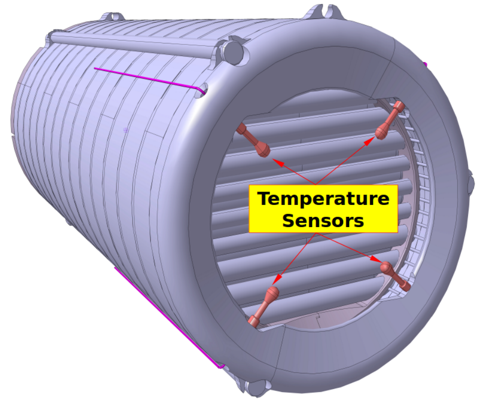

Figure 5: Drawing of SINQ target 13 with the new temperature based Beam Positioning System.

SINQ Beam Positioning System

The SINQ targets employed during the past runs have been furnished with a number of temperature sensors providing important information about the beam setting. The experience collected so far has allowed the development of a temperature based Target Beam Positioning System (TBPS) shown in Fig. 5. This tool, available on the SINQ target 13 to be employed during the 2018 and 2020 runs, is composed of four temperature sensors attached to the target rim and positioned along the elliptical edge of the beam footprint [8]. In case of a perfectly centred beam, the four sensors should measure similar temperature values, while analog temperature variations should result from beam overfocussing or defocussing. A non-centred beam will cause a more complicated effect on the measured temperatures. Two additional temperature sensor located in the center of the SINQ target and installed in two different zircaloy tubes (rows 12 and 14 respectively) will measure the temperature in the region of maximum energy deposition. An algorithm to calculate the beam position starting from these parameters is under study and will be applied after a first beam test of the TBPS. All the information coming from the TBPS will be available in the HIPA control room. In the future, these signals could be used by the machine interlock system.

OUTLOOK

Besides the new diagnostic tools described in this paper, new ideas are also being evaluated. Among them, the implementation of a Machine Learning algorithm which can correlate the signal from the BLMs and the quadrupole setting in SINQ beam lines with the beam footprint detected by

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the VIMOS monitor [9]. Another new tool currently under evaluation is a TE "beam trajectory assistant" consisting of a number of small grooves located at the two sides of the TE wheel which would generate a high frequency modulation of the transmission measurement whenever hit by the beam.

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