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Results from the HiRadMat Primary Beam Line Commissioning

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Abstract

The High Radiation to Materials facility (HiRadMat) is a new experimental area at CERN, for studies of the impact of high-intensity pulsed beams on accelerator components and materials. The beam is delivered from the SPS by a new primary beam line, which has been constructed during the 2010/11 winter technical stop. The paper summarizes the construction phase and describes the results from the beam line commissioning in spring 2011. Beam parameter and aperture measurements are presented, as well as steering tests. A special emphasis has been put on the handling of the exceptionally flexible beam line optics in the control system.

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INTRODUCTION

The High Radiation to Materials facility (HiRadMat) is a new irradiation facility at CERN designed for testing accelerator components and materials with the impact of high-intensity pulsed beams. This facility is capable to provide high-power LHC type proton and lead ion beams with energies of 440 GeV and 173.5 GeV per nucleon, and with pulse intensities of up to $5{\cdot}10^{13}$ protons and $3.6{\cdot}10^{9}$ ions, respectively. Due to these unique beam properties the facility is ideally suited for testing equipment for the LHC and other high-intensity accelerators. The detailed beam specifications can be found in [1].

HiRadMat primary beam line

The HiRadMat facility is located in the cavern of the former West Area Neutrino Facility [2], in front of the former neutrino production target. It shares the same extraction channel with the LHC beam 1, the latter being transported through the TI 2 transfer line down to the LHC: the HiRadMat beam is extracted from the SPS and sent down the existing TT60 transfer line, from which the new HiRadMat primary beam line (TT66) branches off after ~200 m (Fig. 1). The switching is performed by 8 powerful dipole magnets. The beam is then transported another ~200 m to the experimental area, where five quadrupoles provide the required focussing onto the test objects. The primary beam line design has been described in detail in [3].

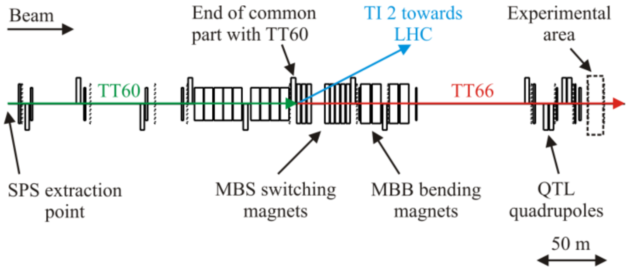

Figure 1: Layout of the HiRadMat primary beam line.

HiRadMat experimental area

The HiRadMat experimental area is equipped with three test stands, which can either house small test objects or can be combined for testing up to 9 m long objects (Fig. 2). To be able to serve all three test stands with focused beams the focal point position is adjustable between positions (1) and (3) in Fig. 2. The beam size at the focal point can be varied between σ=0.1 mm and σ=2.0 mm. For focal point positions near the beam line exit window or the beam dump entrance window (1 and 3), the minimum beam radius is limited to 0.5 mm to protect the windows against damage. For practical reasons exists a set of 18 predefined optics for the three focal points (1) to (3) and six different beam sizes.

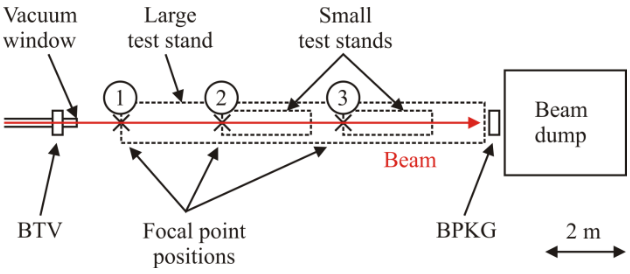

Figure 2: Layout of the HiRadMat experimental area. The focal point is adjustable between positions (1) and (3), with beam radii ranging from 0.1 mm to 2.0 mm.

A detailed description of the HiRadMat experimental area can be found in [4]. This paper focuses on the construction and the commissioning of the primary beam line.

BEAM LINE CONSTRUCTION

The HiRadMat primary beam line has been constructed during the years 2010 and 2011. Due to its vicinity to the TI 2 injection line to the LHC, the installation schedule was strongly influenced by the LHC operation schedule. While the installation work of the main subsystems has been carried out during the 2010/11 winter technical stop, which lasted several weeks, also the regular 4-day LHC technical stops every 6 weeks have been used for preparation and installation work. Furthermore, work was carried out within short accesses of a few hours between LHC fillings, where no beam is present in TI 2 and the area is accessible.

During this period 25 magnets [5], 17 beam instrumentation elements and 200 m of new vacuum system have been installed. Furthermore, 460 new cables with a total length of 4000 m and 14 new or refurbished power converters [6] have been installed. Prior to the installation work, extensive dismantling work of old equipment of former beam lines to the CERN West Area has been carried out at the installation site [7].

The installation work required the temporary dismounting of four magnets in the TI 2 transfer line and part of its vacuum system. An additional beam stopper has been installed in TI 2 after the switch to ensure the accessibility of the downstream part of TI 2 and LHC during HiRadMat operation. Furthermore, the beam interlock system has been adapted for HiRadMat [8].

BEAM COMMISSIONING

The first beam has been sent to HiRadMat on 22 June 2011, followed by a period of a few days for validating the beam line design and testing the correct functioning of the beam line equipment. During this period only low-intensity LHC type "probe" single bunches with $\sim 8\times10^9$ protons per bunch were used. Tests with high intensity beams will follow. The detailed description of the tests and the results can be found in [9].

Beam line steering

The first beam sent to HiRadMat reached directly the end of the beam line. The corresponding uncorrected trajectory is shown in Fig. 3. After matching the energy to 439.2 GeV and correcting the trajectory, the trajectory shown in Fig. 4 has been obtained, which is well within the specification of the beam line aperture.

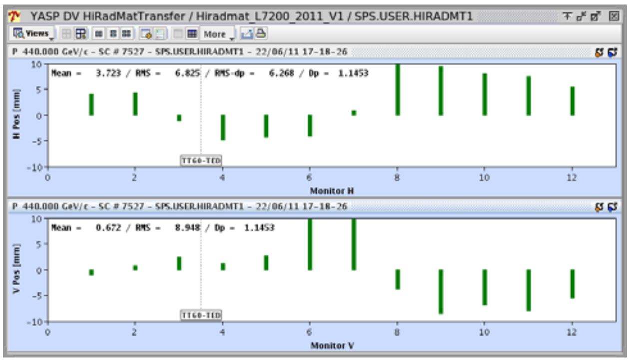

Figure 3: Horizontal and vertical uncorrected trajectory of the first beam in the HiRadMat beam line.

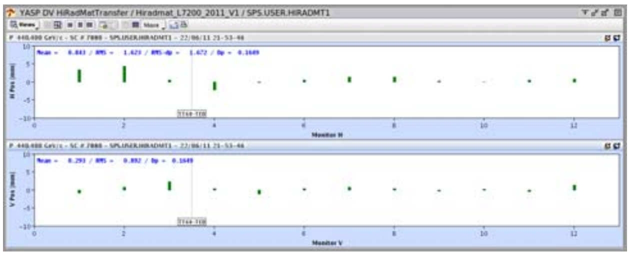

Figure 4: Corrected horizontal and vertical trajectory.

Beam instrumentation tests

In TT66 various beam instrumentation elements are installed, which were tested during the beam commissioning: Beam position monitors (BPM), screens (BTV), beam loss monitors (BLM) and a fast current transformer (FBCT).

It was verified with kick response measurements that the signal polarity of all BPMs is correct. The transverse beam profile was measured with the BTV screens. From this measurement reasonable values of the normalized emittance around 2 µm were calculated using the screen matching application.

The beam intensity measured with the FBCT in TT66 was in good agreement with that measured with the upstream FBCT in TT60 and the absolute accuracy will improve considerably as the bunch/total intensity is increased.

The beam loss monitors in the primary beam-line are connected to the beam interlock system in order to disable the extraction of the beam from the SPS in case of beam losses exceeding operational thresholds. During the low-intensity beam commissioning, most of the time no beam losses were detected, as expected for these intensities. Only towards the end of the commissioning period one BLM showed losses above the noise level. This was due to a steering setting which produced high beam excursions. During high-intensity beam operation a resolution of a few 10^{-4} Gy is expected.

Beam line aperture

Aperture measurements were performed using a typical beam with a 1σ radius of 0.5 mm at focal point 1. While observing the signal of two fast current transformers, located in TT60 and at the end of TT66 respectively, orbit oscillations were induced for both horizontal and vertical planes using corrector magnets at the start of TT60 and recorded with beam position monitors. These oscillations were induced for different phases in 30° steps and different amplitudes of up to $10\,\sigma$ to cover as much as possible of the beam line. As an example, measured and simulated beam position values for two oscillations in the horizontal and vertical plane are shown as a function of the BPM position in Fig. 5.

No significant intensity decrease has been observed between the two fast current transformers and no beam losses above background have been detected with the beam loss monitors. This shows that there are no unforeseen aperture restrictions in the TT66 beam line.

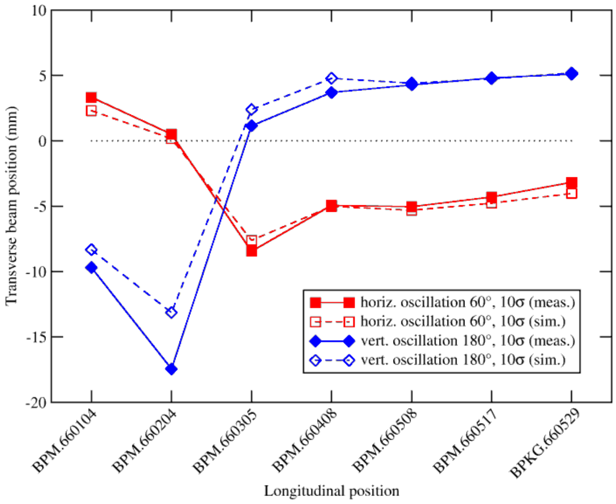

Figure 5: Horizontal and vertical oscillation along the beam line for 10 σ and phases of 60° and 180°, respectively. The measured and simulated values are shown, which are in good agreement.

Orthogonal steering onto the future test stand location

Experiments require that the beam can be steered onto the test object independently in both planes. This was demonstrated for a typical beam with a σ=1.0 mm radius on the last screen in the beam line within a range of +/ 4 mm (Fig. 6), which is within the HiRadMat specifications.

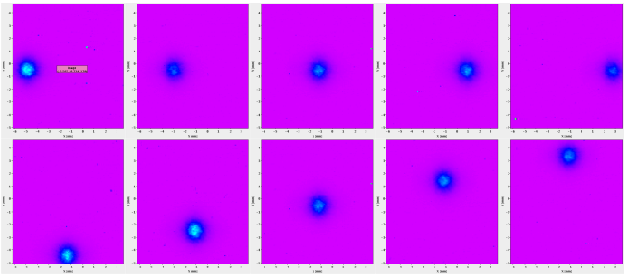

Figure 6: Steering of the beam onto a screen at the end of the beam line independently in the x (upper row) and y plane (lower row) within the range +/-4 mm.

Change of beam line optics

The beam line has to deliver a wide range of beam radii between σ=0.1 mm and σ=2.0 mm to the target, which itself can be located at three different focal points. To change these parameters, the corresponding beam optics must be loaded into the control system each time. For this purpose a dedicated control application has been developed. The functionality of this software has been verified during the low-intensity beam commissioning. The tests showed that for each optics the steering must in general be corrected. The steering settings can be saved in a catalogue, such that they are available for future uses of the corresponding optics.

Safety aspects of the beam line operation

The specifications of HiRadMat foresee an ultimate beam intensity of 4.9×10^{13} protons per pulse [1], which can severely cause damage and activation of material. To avoid sending pulses accidentally and therefore to minimize activation and/or damages, a special timing scheme has been developed, which differs significantly from other CERN transfer lines, like e.g. TI 2: instead of sending the beam continuously to HiRadMat, each pulse must be separately requested by using a newly developed dedicated control application. The correct functioning of this application and the beam requests has been verified during the beam commissioning period.

CONCLUSION AND OUTLOOK

The HiRadMat primary beam line construction is complete and the beam line has been successfully commissioned with low-intensity proton beams. No serious problems were discovered. The second beam commissioning period with high-intensity beams is scheduled for September and the first experiment is foreseen to take place in autumn this year.

ACKNOWLEDGEMENTS

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