THE FINAL BEAM LINE DESIGN FOR THE HIRADMAT TEST FACILITY

C. Hessler, B. Goddard, M. Meddahi, CERN, Geneva, Switzerland

Abstract

The High Radiation to Materials facility - hereafter HiRadMat - is designed to allow testing of accelerator components, in particular those of the LHC and its injectors, with the impact of high-intensity pulsed beams. The facility is currently under construction, as an approved CERN project. The installation of the dedicated primary beam line and experimental area is planned during the 2010-2011 technical stop. It will be ready for users after commissioning and some test running in October 2011. A detailed proton beam line design has been performed in order to fulfil the beam parameter specification, in particular the demanding optics flexibility at the test stand location. The studies presented include trajectory correction and aperture studies as well as specifications of magnetic systems, power converters, beam instrumentation and vacuum systems.

INTRODUCTION

High intensity proton and heavy ion accelerators, such as the LHC, can easily reach beam intensities which are above the damage threshold of the most robust materials and can cause severe damage to accelerator components, resulting in significant downtime of the whole machine. A careful design and testing of the machine protection elements prior to their installation, such as collimators, is therefore mandatory.

In the past, beam shock impact tests have been carried out in the TT40 beam line [1] which is part of the transfer lines to LHC and CNGS [2] and cannot be used for this purpose any more. Therefore, the dedicated HiRadMat irradiation facility for beam shock impacts is currently under construction at CERN. It will provide high power LHC type proton and lead ion beams with the maximum SPS energy of 450 GeV and 177.4 GeV per nucleon, respectively. Pulse intensities of up to $5 \cdot 10^{13}$ protons and $3.6 \cdot 10^{9}$ ions will be available. The detailed beam specifications can be found in [3].

The HiRadMat facility will be located in the tunnel to the former West Area Neutrino Facility [4], in front of the former neutrino production target. The beam will be delivered from the SPS to the HiRadMat facility using the existing TT60 transfer line and the new HiRadMat primary beam line, named TT66. The final design of this beam line is presented in this paper.

BEAM LINE LAYOUT

The layout of the TT66 beam line, shown in Fig 1, is based on the studies presented in [5]. After its extraction from SPS, the beam will be first transported by the TT60 transfer line, which is also used for beam transfer to the TI 2 injection line of the LHC. After ~200 m from the SPS extraction point, the new TT66 beam line branches off. 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.

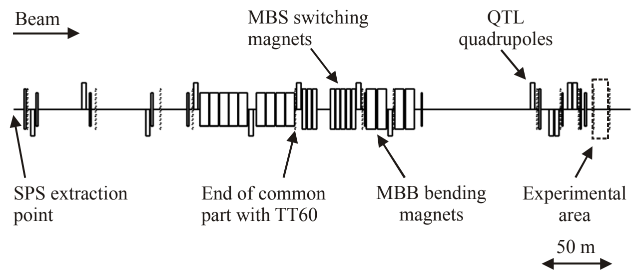

Figure 1: Layout of the HiRadMat primary beam line.

The experimental area can either house one long test object (up to 9m long) or two small test pieces (up to 2.2 m long, Fig. 2). This layout imposes demanding requirements on the flexibility of the beam optics: The focal point position must be adjustable between positions (1) and (3) in Fig. 2 and a wide range of beam sizes must be possible at each focal point position. The actual optics can provide 1σ radii at the focal point ranging from 0.1 mm to 2.0 mm, whereas radii below 0.5 mm are restricted to focal point positions in the centre of the experimental area (around position (2)) to not exceed the damage threshold of the exit window of the beam line.

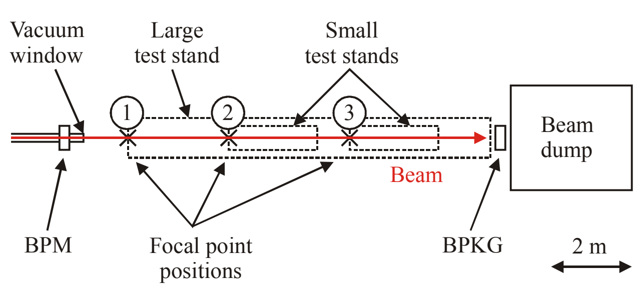

Figure 2: Layout of the HiRadMat experimental area. The focal point is adjustable between positions (1) and (3), with beam radii ranging from 0.1 mm to 2.0 mm.

OPTICS SIMULATION

The beam line design has been evaluated with the help of detailed optics simulations performed with MAD-X [6]. Extensive studies have been carried out for a wide range of beam sizes at the focal point. Figures 3, 4 and 5 show the simulated beta and dispersion functions along TT60 and TT66 for a typical beam radius of σ=0.5 mm and the ultimate beam radii of σ=0.1 mm and σ=2.0 mm at the target (s=404 m).

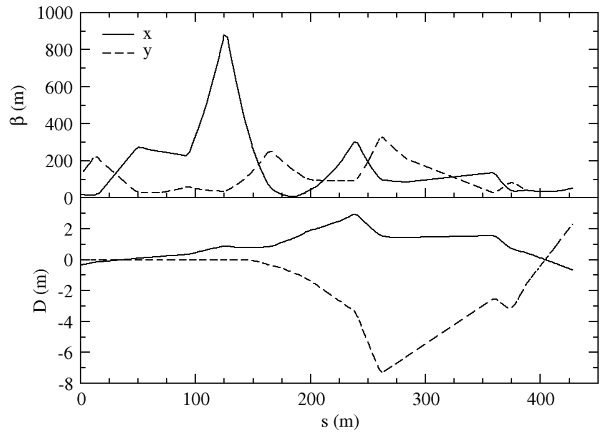

Figure 3: Simulated beta and dispersion functions for a typical beam size of σ=0.5 mm at the target.

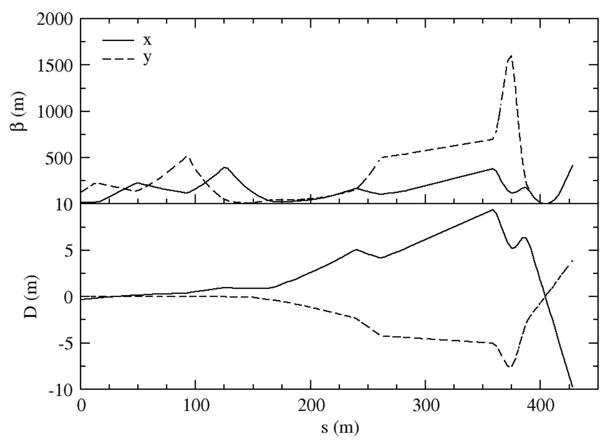

Figure 4: Simulated beta and dispersion functions for the minimum beam size of σ=0.1 mm at the target.

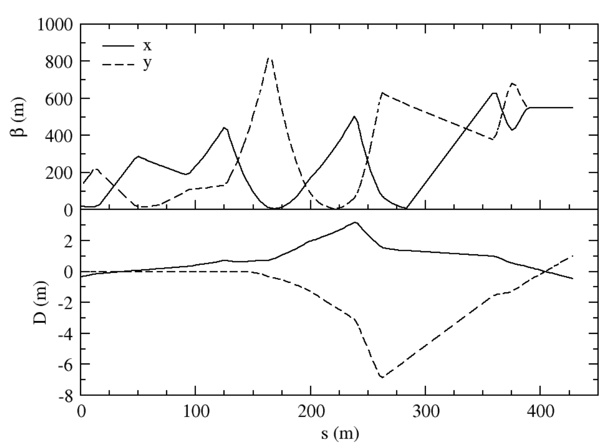

Figure 5: Simulated beta and dispersion functions for the maximum beam size of σ=2.0 mm at the target.

APERTURE CALCULATION

Additionally, aperture calculations for TT66 have been carried out using the MAD-X aperture module [7]. Figure 6 shows the maximum beam size n_l in σ as a function of the longitudinal position in the beam line for the smallest and the largest beam size at the target. For these calculations, a momentum spread of $\Delta p/p$=0.0006, a 5 mm trajectory excursion and a beta beating factor of 1.1 have been assumed. It can be seen that, despite of the large values of the beta function, the available aperture is at each position in the beam line larger than 6σ and therefore within specifications.

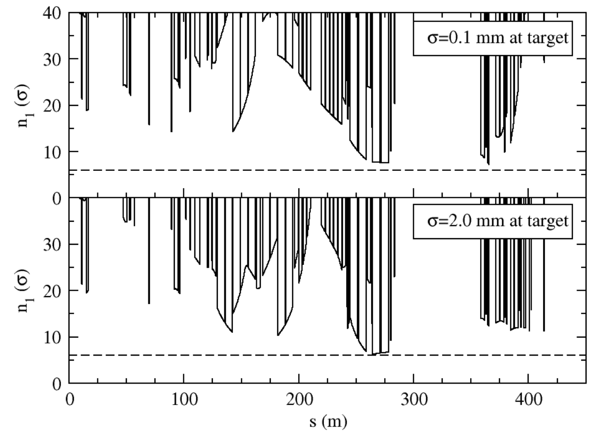

Figure 6: Calculated maximum beam size n_l along TT60 and TT66 for beam radii of σ=0.1 mm (top) and σ=2.0 mm at the target (bottom). The dashed line indicates a beam size of 6σ.

TRAJECTORY CORRECTION AND STEERING

For trajectory correction, four vertical and two horizontal correctors are foreseen in TT66, as well as the usage of the regular bending magnets. The lattice quadrupoles are equipped with dual-plane beam position monitors (BPM). Additional BPMs will be installed in front and behind the test stand. The latter BPM (BPKG type) uses coupler plate technology and operates in air. Detailed trajectory correction studies have been carried out with MAD-X, assuming the following errors:

- Quadrupole displacement errors: Gaussian distribution in x/y-plane with σ=0.2 mm;
- Dipole field errors: Gaussian distribution of deflection angle with σ=10 μrad (corresponds to a relative field error of ~$1\cdot10^{-3}$);
- Dipole tilt errors: Gaussian distribution with σ=0.2 mrad;
- Monitor errors: Flat random distribution of ±0.5 mm in both planes;
- Injection error: Gaussian distribution of position and angle with σ=0.5 mm and 0.05 mrad respectively.

These studies include also the investigation of orthogonal steering onto the target, which is required within the range ±4 mm, independently in both planes. As an illustration Fig. 7 shows 50 corrected trajectories of a beam steered to x=+4 mm and y=-4 mm onto the target with a focal point size of σ=0.5 mm. The accuracy of the angle at the target is of the order of 0.05 mrad.

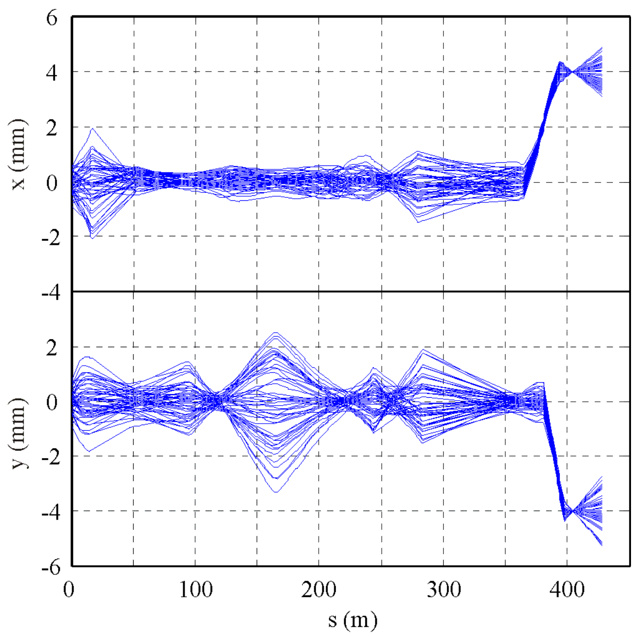

Figure 7: Plot of 50 corrected trajectories of a beam steered to x=+4 mm and y=-4 mm onto the target with a focal point size of σ=0.5 mm.

EQUIPMENT SPECIFICATION

Magnets and power converters

To minimize the project cost, only recuperated SPS magnets will be used for TT66. Part of the power converters will also be refurbished devices. The magnets types used in TT66 and their specifications are listed in Tab. 1 together with the number of needed power converter circuits [8].

Table 1: Magnet specification

Magnet type	Quantity/ circuits	Length [m]	max. Field, Gradient
MBS	8/1	3.0	1.47 T
MBB	4/1	6.26	1.44 T
QTL	7/5	2.99	24 T/m
MDS	4/4	0.7	0.85 T
MDL	2/2	1.4	0.80 T

Vacuum system

The vacuum system will be of the TT60 standard with 156 mm diameter beam pipes and conical flanges. Due to availability and costs, most of the beam instrumentation elements will have a reduced aperture of 60 mm or 80 mm diameter. Simulations showed that these apertures are sufficient at these locations (Fig. 6). The vacuum system is designed for a pressure of 10^{-8} mbar and will be maintained by ion pumps. Two new sectors (TT66 sector, Y-shaped sector at the junction) will be added to the existing TT60/TI 2 vacuum system.

Beam instrumentation

For the beam instrumentation elements, standard screens (BTV), BPMs, beam loss monitors (BLMs) and a fast beam current transformer (BCTFI) will be used (Tab. 2).

Table 2: Beam instrumentation specification

Instrument	Quantity	Type	Aperture [mm]
BPM	6	LEP buttons	80
BPKG	1	CNGS	60
BTV	3	LHC	60
BLM	6	LHC	-
BCTFI	1	CNGS	160

CONCLUSION AND OUTLOOK

The simulation studies showed that the design for the HiRadMat primary beam line fulfils all requirements and is flexible to provide a wide range of beam sizes at different focal point positions. The beam line design has been completed and the beam line equipment has been specified. The installation work for the HiRadMat facility has started and it will be ready for users in 3rd quarter 2011.

ACKNOWLEDGEMENTS

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