COLLIMATION SYSTEM FOR THE FERMILAB BOOSTER TO MAIN INJECTOR TRANSFER LINE

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Abstract

A collimation system has been created for removing proton beam halo in the 8 GeV transfer line from the Fermilab Booster to Main Injector. A pair of 1.14 meter long collimators with 5.08 cm rectangular apertures is installed in a 5-m straight section. Horizontal and vertical motion systems allow them to be positioned such that halo can be scraped from four sides. An additional pair of collimators, placed one cell (90 degrees) downstream, scrape halo which is of opposite phase. Each collimator pair can scrape about 600 Watts of beam power, limited by residual activation of beamline components and sump water outside of the beam line tunnel. Personnel exposure is reduced by surrounding the iron absorber with a layer of marble. Design features, radiation calculations and instrumentation considerations will be described.

OVERVIEW

The Fermilab program in neutrino physics demands high intensity operation of the Main Injector. Since 2005, the residual radiation has become at issue in more locations around the ring. By providing a well defined beam from the Booster, one can expect to avoid losses associated with minor aperture restrictions. For example, it has been noted that minor vertical aperture limitations near defocusing quadrupoles have resulted in many cells in which measurable residual radiation was found. Collimation in the Main Injector Ring will be required to address problems associated with losses due to stacking processes and other beam manipulations. The ability to control the halo from the injected beam will reduce the number of loss locations and can aid in understanding the overall loss control problem.

COLLIMATION CONCEPT

To control the emittance tails in a transfer line, one must scrape the halo on all sides in at least two locations. In the 750 m long Booster to Main Injector Line (MI8), the phase advance per cell is near 90^o, so, collimation in adjacent cells will control halo with large position or angle errors at the initial collimator. Much of the line is composed of half-cells with gradient magnet focusing. We have chosen adjacent cells in which 5-m straight sections are available for collimation. Collimator C836A is placed downstream of the first gradient magnet in half-cell 836(Fig. 1). It is 507 m from the Booster extraction septum. C838A is 30 m downstream in a similar location in half-cell 838. Following the design of the Booster collimation system [1], massive steel collimators surround a heavy-walled stainless steel vacuum liner which defines a rectangular collimation aperture. Collimators C836B and C838B are placed 0.5 m downstream of their counterparts. Adjacent collimators are positioned to scrape beam in opposite corners, removing halo top, bottom, left and right of the core beam. Halo with large divergence at 836 is scraped by an identical collimator pair 90^o downstream at 838.

DESIGN GOALS

The design criteria for this system require the ability to scrape 1% of the Fermilab Booster beam at each of two locations. We assume the Booster will provide 5×10^{12} protons/pulse at a rate of 10 Hz resulting in 64 kW of beam power. Radiological control requirements have been evaluated for these conditions and the design goal has been met. To achieve low residual radioactivity for hands-on maintenance as well as general occupancy needs, the collimator body has been surrounded by a marble shield. Marble was selected for it low activation rate. The shield thickness was selected to provide significant shielding of MeV gamma rays from the activation produced in the iron.

MECHANICAL DESIGN

To create the four 4 ton collimators [2], a 0.66 m wide by 0.51 m high by .89 m long steel main absorber

Figure 1: Collimators C836A and C836B with upstream magnet and bellows.

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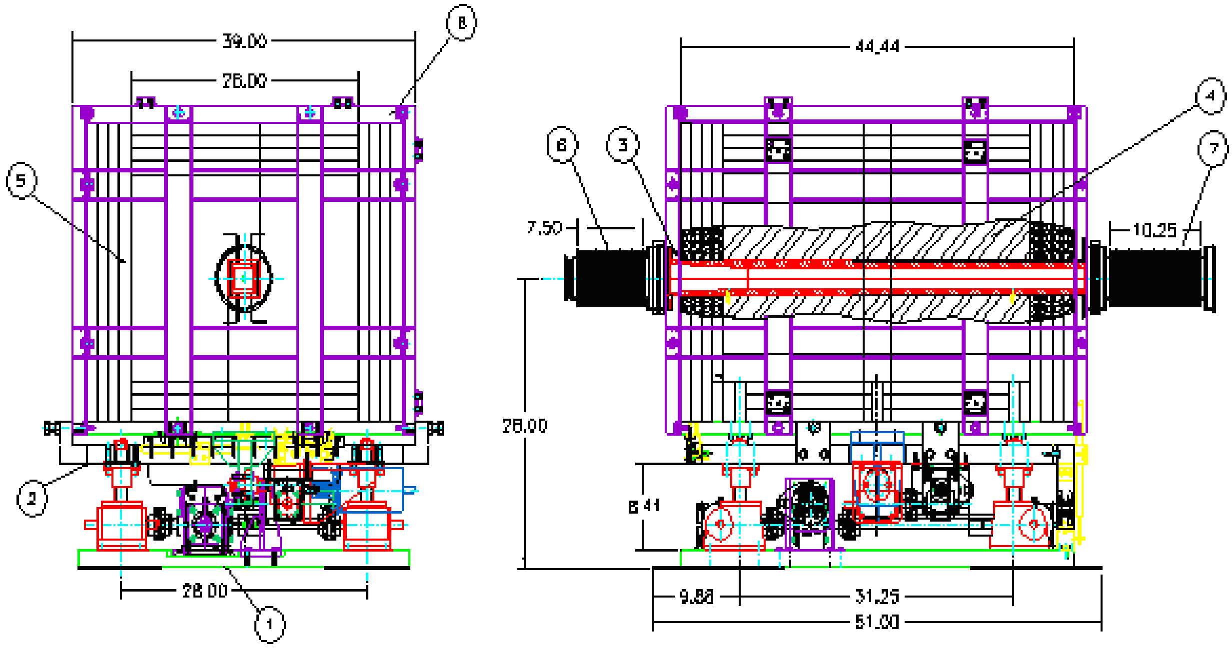

Figure 2: Mechanical design of 4-ton collimator. 1- Base Plate Assembly; 2 - Support Plate Assembly; 3 - Vacuum Liner Weldment; 4 - Steel Shielding Block Assembly; 5 - Marble plates; 6 - 7.5” Bellows Weldment; 7 - 10.25” Bellows Weldment; 8 – Aluminum Frame.

surrounds a stainless steel vacuum liner with 19-mm walls defining a 50.8 mm square vacuum aperture. The aperture tapers out at a 45 m-radian angle on the upstream end. This places the main interaction point well inside the collimator and also reduces out-scatter due to the large incident angle for halo particles. The steel is surrounded by 12 cm thick marble. The collimator is aligned with the axis of the beam. No remote control of pitch or yaw angles is included since the beamline is equipped with sufficient dipole trims to permit adequate alignment of the beam to the collimators. The collimator is mounted on a support plate on which mounts a ball-bearing rail system to permit radial motion. The support plates are mounted on vertical jacks attached to a floor-mounted base plate. The radial motion is coupled through jacks and each axis of motion is driven with a stepping motor and read out with an LVDT. Each system has a range of ±25 mm and nominal positioning least count of 0.025 mm. The vacuum system is completed using 10-cm diameter welded bellows assemblies; a 19-cm long bellows upstream and downstream and a 26-cm long bellows between the two collimators. Figure 2 describes the collimator assembly. Figure 3 illustrates the layout of the collimator straight section.

Downstream of the collimator pair, a marble mask is created by stacking 30-cm long plates around the beam pipe to form a 23-cm wide by 24-cm high stack. This protects the gradient magnet which follows the 5-m straight section.

INSTRUMENTATION

The MI8 Line is instrumented with a beam position monitor at the end of each half-cell with horizontal position measured at focusing locations (*e.g.* HP836) and vertical position measured at horizontally defocusing location (e.g. VP837). Multi-wire MW836 (adjacent to HP836) measures both horizontal and vertical profiles for each beam pulse. For the collimation system, VP836 was added upstream of C836A and HP837 was added downstream of the 836 marble mask to permit alignment of the beam parallel to the collimator axis. The 838 half-cell was similarly instrumented with VP838 and HP839. Corrector dipoles in the beam-line are controlled using an auto-tune program to maintain the beam position. In steady operation, position variation is typically 0.2 mm in each plane.

Fermilab gas-filled glass ionization chamber loss monitors are used to monitor lost beam. LM8C1 (LM8C3) is placed on the aisle side of the 836 (838) marble mask. LM8C2 (LM8C4) is mounted on the wall above the beam and at about the same longitudinal location as LM8C1 (LM8C3). Loss is restricted by interrupting beam delivery based on limits to single pulse and 20-pulse average loss monitor readings.

ENERGY DEPOSIT AND RADIATION

Using the MARS15 code [3], the energy deposition and resulting radiation field in the collimator system was modeled [4]. The model describes the 5-m straight section including two collimators, the marble mask, the

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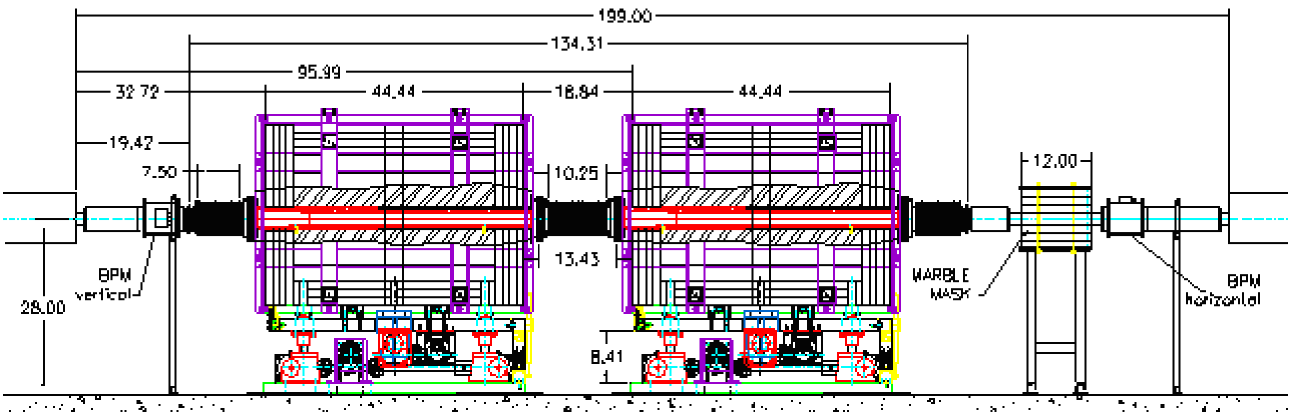

Figure 3: 5-m Collimator system straight section showing vertical BPM, bellows, collimator, bellows, collimator, bellows, marble mask and Horizontal BPM.

downstream gradient magnet and a complete tunnel cross section. For this simulation the first collimator cuts the bottom and left of the beam while the second one cuts the top and right.

Results for the energy deposition were available for an ANSYS thermal model [5]. Analytical fits to the energy deposition profiles were created for the ANSYS model. Static models at 656 watts lost beam energy showed peak temperature rise of 80^o C. with the peak temperature in portions of the vacuum liner surrounded by marble rather than steel. Poor thermal transport through the marble allows the liner to get hot. Transient calculations show that for a change to 6560 watts of beam loss, a rise of 20^o requires 18 minutes (thermal capacity dominated) while a rise of 30^o requires 40 minutes (conduction becoming important). Subsequent studies for future collimators show that placing the end of the taper, where the most intense beam strikes the collimator, a few centimeters further downstream will permit sufficient conduction to the iron to avoid concerns about thermal issues.

A variety of radiological issues are examined using the MARS output. Prompt dose for both normal operation and worst case accident conditions are not a problem due to the tunnel depth below ground level. The residual radiation "good practice" design goal of $P\gamma$ < 100 mrem/hr = 1 mSv/hr at 1 foot (30-day irradiation and 1-day cooling) is met at all but several rather inaccessible locations near the beam pipe where it is exceeded by a factor of a few. An absorbed dose of 4 Mrad/yr on motors and cables, and 60 Mrad/yr on the downstream gradient magnet face is calculated. The air activation is modest and requires either a modest wait or assurance that the circulation fans are in operation. The Fermilab concentration model [6] relates ground and sump water activation to star density in the dirt containing these waters evaluated by averaging over a dirt volume that contains 99% of stars. Our result is almost a factor of 4 below the limit for sump water and far below the ground water limit.

INSTALLATION AND OPERATION

The collimators were installed during the Spring 2006 Facility Shutdown. Operation has been approached incrementally. Since January 2007, the collimators have been positioned to scrape at about half of the design capability. Studies and results will be presented in a companion paper [7].

REFERENCES

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