TRANSPORT OF LANSCE-LINAC BEAM TO PROPOSED MATERIALS TEST STATION*

Barbara Blind#, Lawrence Rybarcyk, Kenneth F. Johnson, LANL, Los Alamos, New Mexico, USA

Abstract

Refurbishment of Experimental Area A and installation of a Materials Test Station (MTS) is planned at the Los Alamos Neutron Science Center (LANSCE). This paper describes the beamline to transport 800-MeV protons from the accelerator to Area A. The beamline has the minimum number of quadrupoles necessary to achieve the desired instantaneous beam parameters at the target, the appropriate beam-centroid excursions at the split target for painting the two target halves, and a beam-centroid crossover upstream of the target to facilitate shielding of upstream components from backstreaming neutrons. Options in the composition of the raster-magnet section represent trade-offs between the number of magnets and the severity of the effects of magnet failures. The crucially important instantaneous and painted beam sizes at the target can be computed by measuring the beam at properly chosen upstream locations.

INTRODUCTION

The proposed MTS target will be centered in the center of Area A at LANSCE. The beamline of Figure 1 will deliver beam from the accelerator to the target front face, a distance of some 100 m. The existing Line-A beamline is preserved in magnetic-element placement through LA-QM-04 and in magnetic-element setting through LA-BM-04. The new beamline downstream of the vertical bend (LA-BM-01 through LA-BM-04) is composed of two beam-optics modules. The upstream module has the required four matching-section quadrupoles (LA-QM-03 through LA-QM-06) to adjust the beam parameters at the target. The downstream module has a raster-magnet section and two crossover-forming quadrupoles (LA-QM-07 and LA-QM-08) to paint the beam at the target while producing a stationary beam-centroid crossover upstream of the target. The downstream module must be correctly tuned before the upstream module can be adjusted to achieve the desired beam focus. The number of magnets in the raster-magnet section is still under discussion. A beamline spur composed of two 15° dipoles (LA-BM-05 and LA-BM-06) leads to a tune-up beam dump.

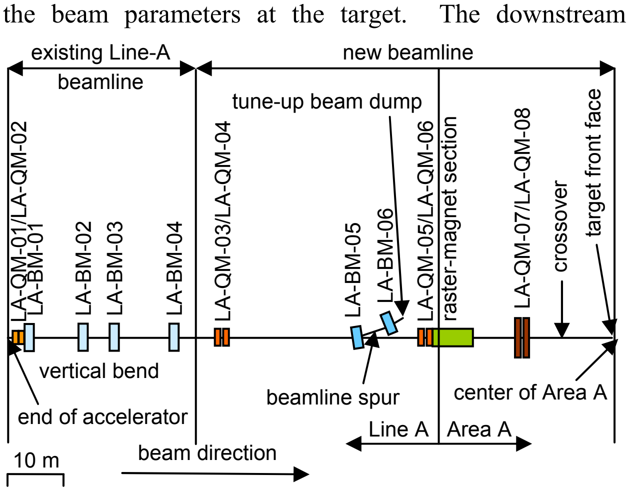

Figure 1: Sketch of beamline from end of LANSCE accelerator to MTS-target front face, and of beamline spur to tune-up beam dump.

The four 6-inch-ID quadrupoles (LA-QM-03 through LA-QM-06), two 12-inch-ID quadrupoles (LA-QM-07 and LA-QM-08), and two 4-inch-gap dipoles (LA-BM-05 and LA-BM-06) are at hand; the raster magnets must be fabricated.

BEAMLINE REQUIREMENTS

The MTS target consists of two target halves with materials samples between them. The target halves will be painted with beam, initially of 0.75-1.0-mA average current, and in an upgrade of 2.0-mA average current. Painting involves slow (macropulse time scale) horizontal and vertical raster magnets, and fast (for third-harmonic linearity, 20-kHz and 60-kHz) horizontal raster magnets. Figure 2 illustrates the planned painting scheme.

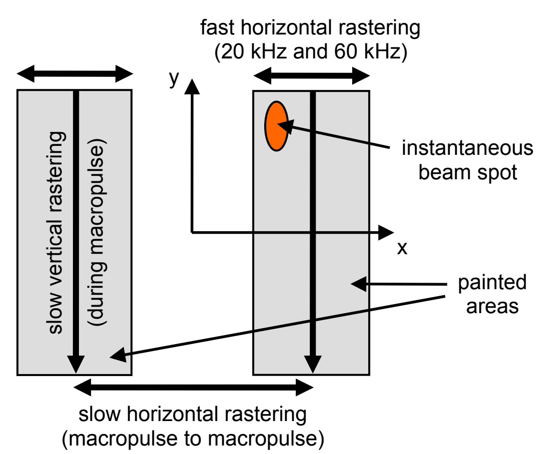

Figure 2: Painted areas at target, and instantaneous beam spot. Painting involves slow horizontal and vertical rastering and fast horizontal rastering.

Sharp vertical edges of the painted areas and good beam-density uniformity are essential for maximizing neutron yield in the sample volume. A beam spot with 3-4 mm FWHM, horizontally, and 8-10 mm FWHM, vertically, is requested for painting. Assuming Gaussian beam profiles and 0.5 rms of beam-centroid jitter, the instantaneous-beam horizontal (vertical) rms size at the

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#bblind@lanl.gov

target should be 1.14-1.53 mm (3.05-3.82 mm). The 3-mm (4-mm) FWHM horizontal size corresponds to 0.01% (0.2%) of beam in the horizontal tails and intensity variations of ±5.9% (±1.4%) in the horizontal profile.

In the 1.0-mA case, each painted area will likely be 1.5 cm wide by 6.0 cm high, with a separation between the two painted areas of between 1.5 cm and 3.5 cm. In the 2.0-mA case, the painted areas must double in size, probably to 2.0 cm wide by 9.0 cm high. To be conservative, the raster magnets and the apertures were dimensioned to accommodate horizontal and vertical beam-centroid excursions at the target of up to ±5.0 cm.

To minimize the shield-wall aperture, the beam waists should be at the beam-centroid crossover. However, with the requested small horizontal rms sizes at the target, the horizontal beam waist had to be placed at the target. The vertical beam waist was placed at the crossover.

Because of diagnostics requirements, the distance between LA-QM-08 and the beam-centroid crossover must be at least 5.5 m. Also, the distance between the crossover and the target must be at least 7.5 m. Finally, 7.5 m was set aside for the raster-magnet section.

EXPLORATION OF SOLUTION SPACE

The downstream module contains a set of horizontal and vertical raster magnets and two crossover-forming quadrupoles. The raster-magnet action centers are the locations where the horizontal and vertical deflections appear to originate. Once these action centers and the locations of the horizontal and vertical crossovers are chosen, the crossover-forming quadrupoles can have DF or FD polarities but their settings are otherwise determined. Attempts to gain insights into solution space by producing thin-lens models of the downstream module proved confusing, due to the large number of variables. The beamline was ultimately designed in upstream direction, starting with the desired beam at the target.

Because the beam is much larger horizontally than vertically at the downstream end of LA-QM-08, DF polarities were investigated first. With the horizontal and vertical raster-magnet action centers coinciding and the horizontal and vertical beam-centroid crossovers coinciding, the relative strengths of the two magnets cause a horizontally excessively large beam in the raster-magnet section and in LA-QM-05 and LA-QM-06. The horizontal beam sizes are reduced, although not enough, by lengthening the drift between LA-QM-08 and the beam-centroid crossover to its reasonable upper limit (dictated by the beam-centroid excursions at the downstream end of LA-QM-08) of 7.5 m, and by shortening the drift between the raster-magnet action centers and LA-QM-07 (which increases the required raster-magnet deflections). Different locations for the horizontal and vertical raster-magnet action centers and/or the horizontal and vertical beam-centroid crossovers did also not look promising. Thus, DF polarities had to be ruled out.

With FD polarities, the beam centroid makes very large horizontal excursions at the upstream end of LA-QM-07. To minimize these excursions, the distance between LA-QM-07 and LA-QM-08 was kept short, and the drift between LA-QM-08 and the crossover was at its lower limit of 5.5 m. The distance between crossover and target was 7.5 m. With this geometry, the fully rastered beam with the 1.14-mm horizontal rms size just clears raster magnets with the proposed full apertures of 5.125 inch, and quadrupole LA-QM-07.

Subsequently, DF polarities had to be chosen for quadrupoles LA-QM-05 and LA-QM-06 in order for the beam to clear their apertures. The polarities of LA-QM-03 and LA-QM-04 can be either FD or DF, with little change in the aperture requirements. However, FD polarities result in better performance of the planned emittance station upstream of the beamline spur.

NOMINAL SOLUTION

The 7-rms beam envelopes through the new beamline are shown in Figure 3, for a 1.14-mm-rms by 3.05-mm-rms beam spot at the target. Also shown are the beam-centroid excursions along the beamline for a beam steered to x = y = 5.0 cm at the target, and the locations and apertures of the magnetic elements. Magnet apertures are sufficient to clear the beam. A round aperture through the 2-m-thick shield wall should have a radius of 3.5 cm, but an elliptical aperture or an aperture tailored to the beam is a possibility to minimize the number of backstreaming neutrons.

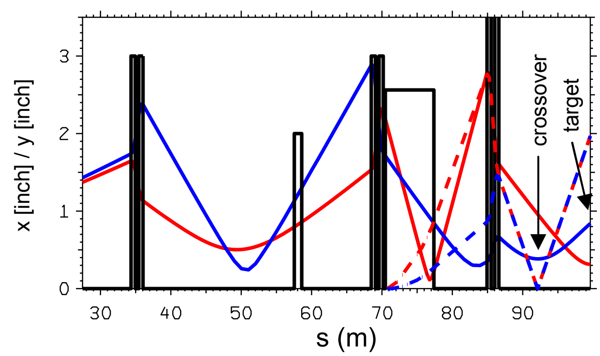

Figure 3: Horizontal (red) and vertical (blue) 7-rms beam envelopes (solid lines) and beam-centroid excursions (dashed lines) in new beamline. Element positions and apertures are indicated in black.

RASTER-MAGNET SECTION OPTIONS

If no amount of beam-centroid motion at the nominal beam-centroid crossover is allowable, the raster-magnet section must be configured such that the action center of each type of magnet (slow horizontal, 20 kHz, 60 kHz, slow vertical) coincides with the action center specified for the design. Each type of magnet must thus operate in pairs (a magnet centered at the action center was ruled out, because that location is needed for placement of a diagnostic). For a single pair, both magnets must be operational. With two pairs, one pair can be turned off and the other operated at twice the nominal strength to recover the nominal beam-centroid excursions.

Before fast rastering was introduced, two pairs of slow horizontal and two pairs of slow vertical raster magnets were planned. With 0.7 m between magnet centers, this meant a 5.6-m long raster-magnet section. With four types of magnets, this approach becomes unworkable.

It will be acceptable to have a single 20-kHz and a single 60-kHz raster magnet. Nominally, the 60-kHz magnet produces beam-centroid excursions at the target that are 10% of the excursions of the 20-kHz magnet. The 20-kHz magnet, centered 0.35 m upstream of the (nominal) horizontal action center and rastering the beam by ±1.5 cm (an upper limit) at the target, causes the beam centroid at the (nominal) crossover to move by ±0.057 cm and adds 0.050 cm to the aperture-radius requirement of the restricting aperture. The 60-kHz magnet, centered 0.35 m downstream of the horizontal action center and rastering the beam by ±0.15 cm at the target, causes the beam centroid at the crossover to move by ±0.0073 cm and adds 0.0083 cm to the aperture-radius requirement.

For a single pair of slow horizontal raster magnets, centered 1.05 m from the horizontal action center and rastering the beam to ±3.5 cm (a probable upper limit) at the target, the beam-centroid excursion at the target at the moment of failure of the upstream (downstream) magnet is 31.4% (68.6%) of nominal. After recovering the nominal excursion at the target with the downstream (upstream) magnet, the beam moves by ±0.714 cm (±0.329 cm) at the crossover and 0.812 cm (0.287 cm) is added to the horizontal half-aperture requirement of the restricting aperture.

For a single pair of slow vertical raster magnets, centered 1.05 m from the vertical action center and rastering the beam to ±5.0 cm at the target, the beam-centroid excursion at the target at the moment of failure of the upstream (downstream) magnet is 44.2% (55.8%) of nominal. After recovering the nominal excursion at the target with the downstream (upstream) magnet, the beam moves by ±0.070 cm (±0.055 cm) at the crossover and 0.080 cm (0.050 cm) is added to the vertical half-aperture requirement of the restricting aperture.

Thus, for a single pair of slow vertical raster magnets there is the possibility of operating just one magnet, should one fail, but for a single pair of slow horizontal raster magnets both magnets must be functioning. Also, considering a single pair of slow vertical, as opposed to slow horizontal, raster magnets is logical because it takes a horizontal deflection of −4.472 mrad to steer the beam to x = +3.5 cm at the target, but a vertical deflection of only −1.988 mrad to steer the beam to y = +5.0 cm at the target. Still, the presently proposed configuration, shown in Figure 4, retains two pairs of slow horizontal and two pairs of slow vertical magnets.

BEAM-SIZE MEASUREMENTS

A horizontal emittance measurement downstream of LA-BM-05 is neither possible nor needed; the beam sizes at the target can be inferred using harps at properly

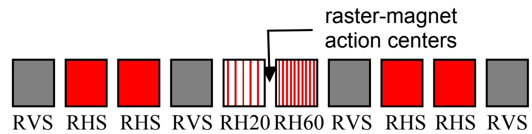

Figure 4 : Likely raster-magnet-section configuration, with two pairs of slow horizontal magnets (RHS), two pairs of slow vertical magnets (RVS), a 20-kHz magnet (RH20), and a 60-kHz magnet (RH60).

chosen locations. A beam-size measurement x_1 (y_1) by a harp placed such that $R_{12} = 0$ ($R_{34} = 0$) from the harp to a location of interest allows calculation of the beam size x_2 (y_2) at that location using the relation $x_2 = |R_{11}|\cdot x_1$ ($y_2 = |R_{33}|\cdot y_1$) with the nominal values of R_{11} and R_{33}.

For the nominal design, $R_{12} = 0$, $R_{11} = -2.768$ from a point inside the raster-magnet section to the target, and $R_{34} = 0$, $R_{33} = -2.787$ from a point downstream of the raster-magnet section to the target (see Figure 5). This allows computation of the instantaneous horizontal and vertical beam size at the target from the corresponding instantaneous beam sizes at the two diagnostics. With rastering, the painted areas at the target can be computed from the time-averaged beam-size measurements.

Since $R_{12} = R_{34} = 0$ (and $R_{11} = -0.958$, $R_{33} = -0.298$) from the location of the raster-magnet action centers to the location of the crossover, the horizontal and vertical beam size at the crossover can be computed from the instantaneous horizontal and vertical beam size measured at the location of the raster-magnet action centers.

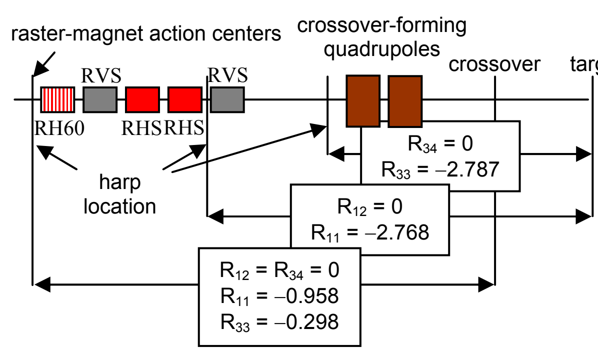

Figure 5: Sketch of beamline from raster-magnet action centers to target, showing locations of harps used to determine beam sizes at crossover and target. Relevant transfer-matrix elements are given.

Simulations show that for a well-characterized downstream module (quadrupoles placed within 2.0 mm of their nominal locations, effective lengths characterized to 2.0 mm, gradient-length products known to 0.2%), error-free measurements by diagnostics placed within 1.0 cm of their nominal locations result in insignificant errors in the inferred beam sizes at the crossover and target. However, when computing the beam sizes at the target, the measurement errors of the harps will be magnified by a factor of almost 2.8.