INITIAL OPERATION OF THE FERMILAB MINIBOONE BEAMLINE*

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Abstract

The MiniBooNE neutrino experiment is projected to take more intensity in a single year than was delivered during the seventeen years of running the Fixed Target Program. The experiment will require almost continuous running (18,000 pulses/hour) at full intensity (5E12 protons per pulse). In order to safely handle this intensity various measures have been instituted. The design of the beamline ensures sufficient clearance between the beam and apertures. A MiniBooNE Beam Permit System has been installed that is able to check various digital and analogue information against nominal values on a pulse by pulse basis. An automated total beam loss monitoring system (electronic berm) measures any beam loss between the beginning and end of the line. An automated correction system (Autotune) finds and corrects minor beam wandering. A description of the beamline design and relevant instrumentation is given.

INITIAL DESIGN

The first consideration in the design of the very high intensity proton beamline was to make the size of the beam pipe large with respect to the size of the beam. Figure 1 shows the beam envelope and the apertures along the beamline. There were two major obstacles to achieving this goal. First, the beamline passes underneath an existing service building. Typically, a FODO channel is used to keep the beam tightly focused, but in this case the beam had to pass through a 43 m. berm pipe. The second consideration was that for a tight focus, the beam should be large in the final focus quadrupoles. Using elements with large apertures (6-3-120 dipoles, LEP trims, and LEP quadrupoles) ameliorated both problems.

OPTICS MEASUREMENTS AND COMPARISON TO THEORY

Dipole Measurements

To measure the quadrupole gradients, each dipole trim magnet was varied, and the change in beam position at each BPM was recorded. The optics program TRANSPORT was used to find the quadrupole gradients that gave the best fit to the data. Figure 2 shows a representative trajectory.

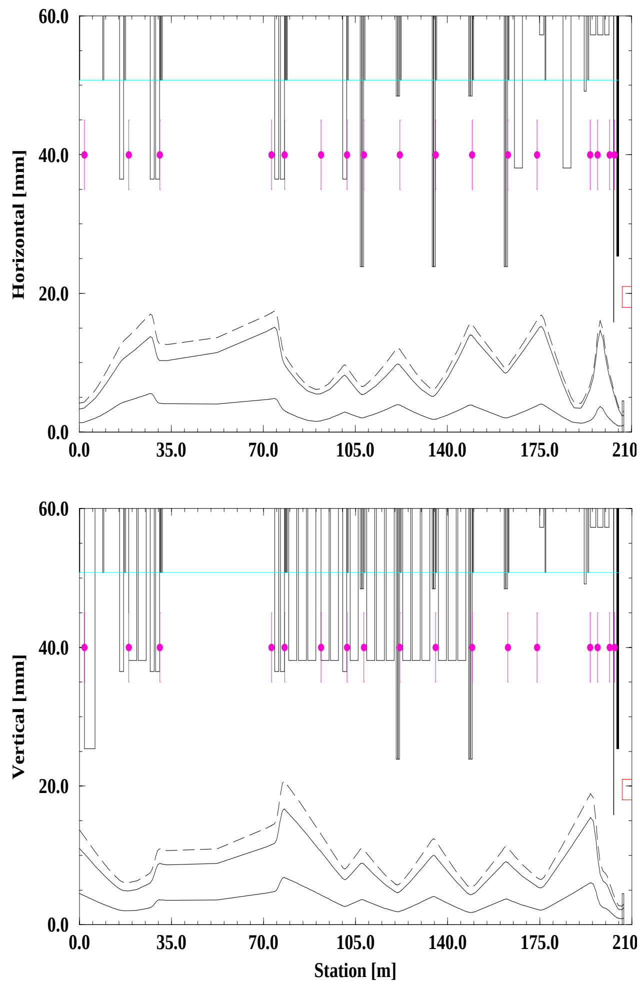

Figure 1. Beam envelope and apertures. The lower beam envelope is the one sigma and the two upper traces are the 95% and 99% with momentum folded in. The assumed emittances were 20 PI and a dp/p of .1%. The line indicates the total loss monitor coverage and the dots indicate the location of individual loss monitors.

Beam Profile Measurements

To measure the input lattice parameters, each profile monitor was inserted into the beam, one at a time to reduce scattering, and the beam size was recorded.

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TRANSPORT was used to vary the initial beam parameters to find the best fit to the measured profiles. The calculated beam sizes are compared with the measured profiles in Figure (3).

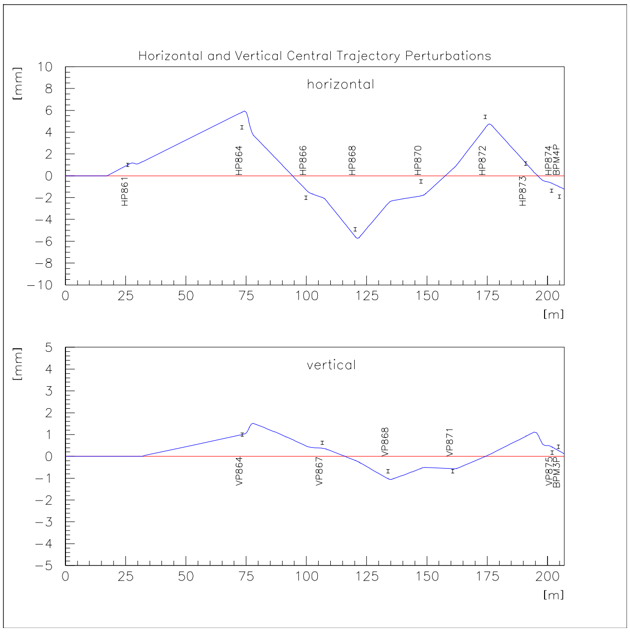

Figure 2. Example horizontal and vertical dipole changes

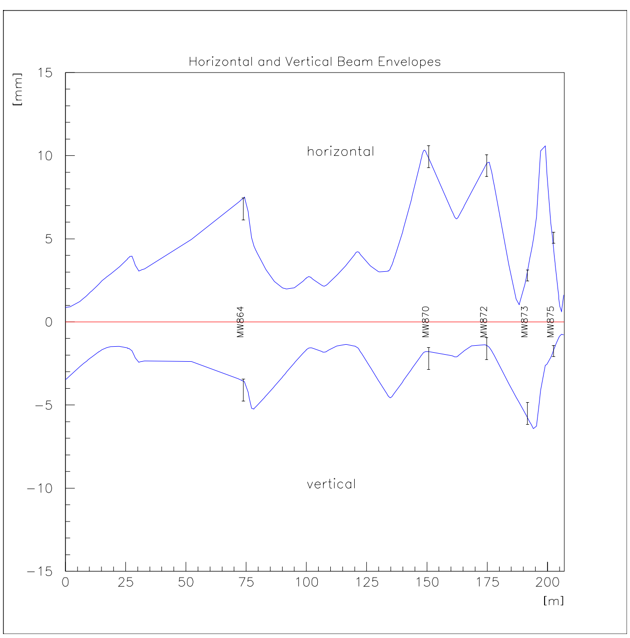

Figure 3. Beam sizes compared to prediction

Dispersion Measurements

To measure the dispersion, three foils of different thicknesses were inserted into the beam, one at a time, at the same location. For a given foil thickness, the energy loss, and hence the momentum change caused by the foil, is known. The changes in positions at the downstream BPMs were recorded for each foil to make a direct measurement of dx/(dp/p). The measurement was modeled in TRANSPORT and the comparison between the measured data and predicted dispersion wave is shown in Figure (4), with the error bars indicating the spread in measurements from the three foils

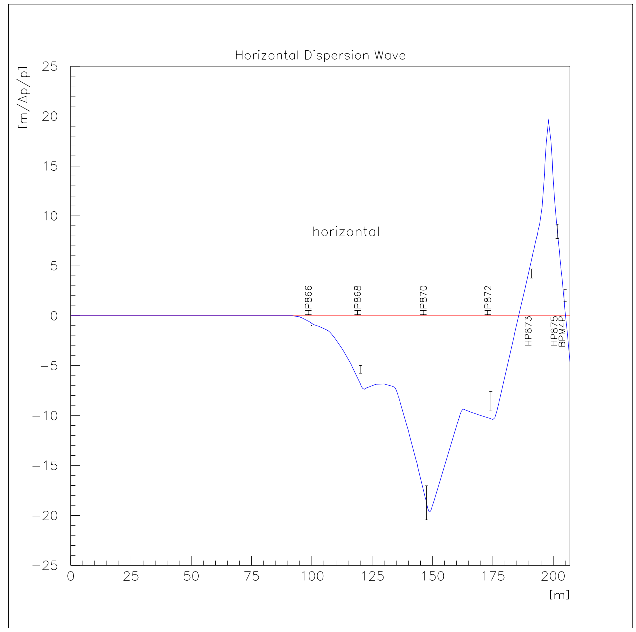

Figure 4. Dispersion measurements

Local Bumps and Target Mults

Local bumps were developed to perform aperture scans during commissioning. Nominal beam positions were defined by centering the beam in the apertures. Position and angle mults were developed for target scans, and were used in conjunction with a 90 degree monitor to center the beam on target.

AUTOTUNE

An automatic beamline correction program, Autotune, was developed to aid in keeping the proton beam on the nominal trajectory [1]. The procedure of the program is as follows: for every trim magnet in the beamline, the current is changed by a small amount and the change in position at every BPM is measured. The measurements are used to solve the linear equations relating the change in current to the change in position. The trim magnets and BPMs are chosen such that the matrix can be inverted. Once the transfer matrix is found, Autotune finds the trim currents needed to correct deviations of the beam from the nominal trajectory.

BEAM PERMIT SYSTEM

Beam Permit Systems have long been implemented for various accelerators and beamlines at Fermilab, with inputs generally in the class of simple go/no-go status. The new MiniBooNE Beam Permit System hardware consists of a supervisory micro-controller sampling multiple analogue and digital inputs in accord with programmed state logic and delays sensitive to accelerator clocks. Limits or allowable ranges are downloaded to the micro-controller via the Accelerator Controls Network (ACNET). Sampled results are compared to these limits, and out of limit inputs effect a trip of the beam permit system, thereby preventing transfer of beam until the limit situation is corrected. Up to eight different sampling times are accommodated, with the process of sampling, determination, and trip taking less than 100 microseconds.

The Beam Permit System, currently in use, successfully prevents beam transport when monitored conditions are not proper, and inhibits repetitive transport of beam when beam losses or other conditions are abnormal. Monitored quantities include analogue representations of magnet power supply ramped outputs, sampled both before and during beam extraction to the MiniBooNE beamline, and all of the beamline loss monitors (with different signal time constants), which are sampled immediately after beam transport. There is complete coverage of the beamline with long loss monitors and spot coverage with short loss monitors (shown as the dots in Figure 1). Loss monitor readings taken during the dispersion measurements (described above) also demonstrated that the total loss monitor trip points are set to a level corresponding to a 0.02% beam loss.

E-BERM

To minimize air and groundwater activation and radiation in areas outside the overburden, a total beam loss monitoring system termed an Electronic Berm (E-Berm) was developed. The E-Berm, shown in Figure 5, consists of two Pearson 3100 toroids, associated integrating electronics, a resistive wall monitor, and a comparator module, used in conjunction with two toroid calibration modules. The toroids are located at the beginning and end of the beamline. The comparator module calculates the difference between the two toroids for each pulse, and for the sum of the previous ten pulses. The instantaneous and integrated losses are designed to be output to the radiation safety interlock system, which automatically inhibits the next beam pulse if the per-pulse losses are greater than 6%, or if the average losses are greater than 2%.

In addition to the total beamline losses, the E-Berm checks for other abnormal conditions on each pulse. The timing of the toroid signal in the integrator gate is verified to be within an acceptable envelope by comparison with the timing signal from a nearby resistive wall monitor. The beam-off readings of the two toroid integrators are also measured and checked against a reasonable interval, to guard against integrator failure. Finally, the relative calibration of the toroids is measured for each beam pulse. The calibration sequence consists of a series of 10 current pulses that are sent through a toroid calibration loop and read back through an integrator. The calibration occurs simultaneously for both toroids, over the full dynamic range (0.5E11 to 5E12 protons per pulse) of the beam intensity. A linear regression is performed on the measured and ideal values of the integrated toroid output in the calibration module. Gain and pedestal corrections are obtained for each toroid, and are compared with an acceptable range. If any of the monitored quantities are abnormal, the system is designed to trip the radiation safety interlock system.

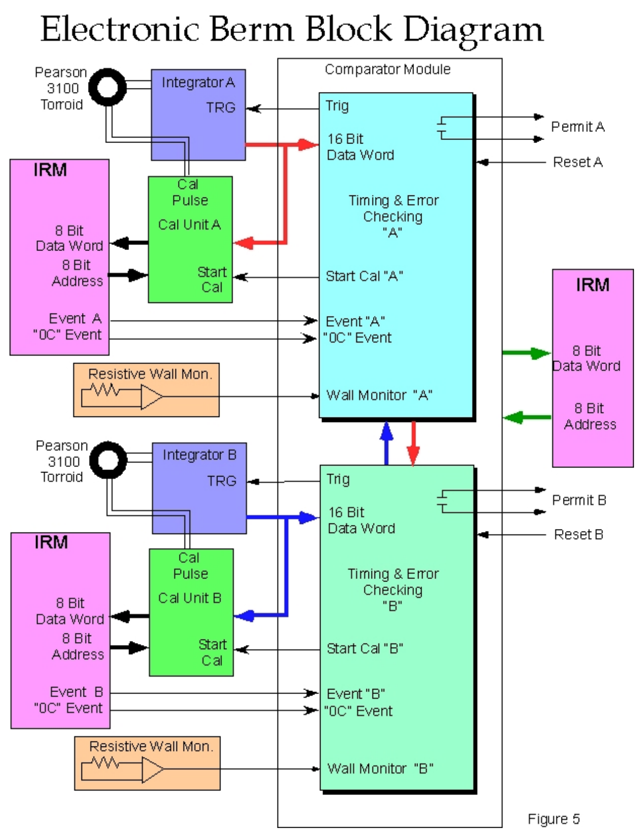

Figure 5: Electronic berm block diagram

CONCLUSION

The beamline has worked very well. The limitation on MiniBooNE intensity has been Booster losses; however up to 60% of the design intensity has been transported to the target with minimal losses until the final horn protection collimator. The highest contact reading before the final focus region is less than 10 millirem/hour. The highest contact reading in the final focus region is 200 millirem/hour on the horn protection collimator.

REFERENCES

[1] T. Kobilarcik, J. DeVoy, C. Moore, "Automatic Beamline correction", This Conference