Neutrino Muon Beamline G2 to NM1 Aperture

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Introduction

In the spring of 2011, the berm pipe from Enclosure G2 to NM1 developed a significant leak. Vacuum pumps were destroyed when ground water infiltrated the quarter inch thick steel wall pipe. After months of troubleshooting and surveying, the idea to sleeve this pipe is necessary. The existing trajectory was close to the top of the flange in Enclosure G2 and low on the bottom of NM1. With new pipe inserted into this 760 foot stretch of bermpipe the aperture will be reduced.

Reduction in aperture, a closer look into the current trajectory is taken. As seen in both enclosures, the beam pipes that enter the berm pipe are within close proximately to the edge of the 16” flanges. The measurements and the data presented are calculated to achieve proton beam to the NM3 target and absorber.

The E-906 beamline will be using the same enclosures that were used in 2000 when the beamline was last operational. Its operational energy was 800 Gev provided by the Tevatron. Currently beam provided for Switchyard 120 is by the Main Injector. Main Injector’s flattop energy for slow extraction is 120 Gev. Since 120 Gev proton beam was never the operational energy there have been changes to the elements and a closer look into the beam size through the beam line.[[1]](#footnote-1)

Beam Envelope

To reduce halo lost in the berm pipe with what ultimately will be a smaller aperture, not only centering the trajectory is needed, but creating an optical lattice to reduce the size of the beam through the pipe should be considered.

Shown in Figure 1 is a plot of the beam size from G2 to NM1. The darker lines of black and gray are the limiting apertures in the transverse plane. Since the Quadrapoles in Enclosure C and G2 have a limiting aperture of their 3 inch beamtubes, the maximum aperture that is drawn on the plot is 3 inches. Also included in the plot is the half width size of the 1 sigma and the 6 sigma (95% Normalized Emittance). Both horizontal (XBEAM) and Vertical (YBEAM) planes are included in the plot. The highlighted section, from 2500 to 3260 ft, is the location of the berm pipe from G2 to NM1.

Figure 1 Plot of Half width size and limiting apertures

To achieve this beam envelope through the berm pipe, some Quadrapole magnet settings were changed from pervious settings. Table 1 shows the settings to accommodate this envelope.

|  |  |  |  |
| --- | --- | --- | --- |
| Quads | Current (Amps) | Type | Type of Focusing |
| Q106 | 34.0 | 3Q120 | QF |
| Q107 | 34.0 | 3Q120 | QD |
| Q418 | 21.7 | 3Q120 | QF |
| Q419 | 22.4 | 3Q120 | QD |
| NM2Q1 | 386 | 4Q120 | QD |
| NM2Q2 | 387 | 4Q120 | QF |

Table 1 Quadrapole magnet current settings

Measuring the Berm Pipe

The first order of laying out the new pipe is to know where the existing berm pipe lays in the ground. This pipe is a standard 16 inch pipe, which means that the inside diameter is 15.25 inches. Also this pipe includes three transitions. These transitions are either 60’ or 40’ long and the pipe diameter changes from 16” to 30” and back to 16”. However since the year that it was installed, this pipe is not a straight line from G2 to NM1. Transversally this pipe wanders randomly horizontally and in elevation.

Fermilab’s PPD Alignment and Meteorology Department tracked a prism on a moveable cart that has the capability of traversing the entire length of the pipe, including the 30” sections of pipe. With a previous run, there were many factors that created error in the measurement.

* The prism was not centered on the cart.
* Water was in the three 30” transition sections creating a reflection that the instrumentation tracked
* For each station there was only one shot taken in each direction.
* The atmosphere of the berm pipe was diffracting the instrument, making it hard to lock on the prism.

To reduce the error, we have completed the following tasks for the second run:

* First the prism was radial centered on the cart.
* Water was properly pumped out of the transitions.
* Each station we took three different shots after pushing and pulling the cart to increase the chance of the cart finding the bottom of the pipe.
* For every 50 feet, we checked the repeatability of the measurements.

Only one factor was not able to be fixed, the atmosphere of the berm pipe. After the second run with all the changes implemented, Figure 2 shows the elevation change of the berm pipe. Also included are three highlighted sections. Each highlighted section is a transition mentioned earlier. For these three regions the centered prism could not be tracked due to the elevation change of the prism. Therefore in the plot in of Figure 2 lines have been drawn in to bridge these transitions.

Figure 2 Plot of current Berm pipe from G2 to NM1

Error in Berm Pipe Measurement

Taking measurements with Alignment’s tracking gun was pushed to the manufacturer’s recommendation of accurate readings. The farthest distance that the gun was asked to shoot was 650 feet inside the pipe. For increased statistics and precision we accomplished the multiple shot technique for each station we took measurements. The data has been stored in Fermilab’s Alignment and Meteorology database Request: 6270 Project: 1602.

Analyzing the data for each individual station, for the three shots when averaged there is a sigma. There are stations for every ten feet of 16” pipe, making 53 stations along the 16” pipe. Figure 3 is a plot of these measurements’s sigma on a histogram, and Table 2 gives the range of sigmas values with a 95% confidence level.

|  |
| --- |
| (inches) |
| (inches) |

Table 2 Sigma range with 95% confidence level

Figure 3 Histogam of measurements sigma

Old Trajectory

In the plot of Figure 3, the berm pipe walls have been plotted and the old trajectory for when the beamline was last running 800 Gev protons. As shown by the plot, a 12” sleeved steel pipe of wall thickness .250 inches will interfere with the beam trajectory within the first 50 feet. Any smaller pipe or aperture will interfere with the last known trajectory. A 12” steel pipe is the largest pipe that is manufactured on a regular basis, unless it is a specialized order, this is the best aperture available.

Figure 4 Current Berm pipe elevation with 800 Gev trajectory

New Trajectory

Using any smaller aperture pipe to sleeve the current berm pipe, the trajectory used by 800 Gev protons would not be the most effective in 120 Gev running. Using this new trajectory additional magnets will be installed in Enclosure G2 and magnet current values will be changed. To summarize these changes:

* Two magnets in G2 will be installed to create a dogleg
  + V420
  + V424
* The upstream trim magnet will be bending the beam down rather than up
* Realignment and new placement of magnets
* G2BND string (6)
* HT424
* VT424
* Different settings for Quadrapoles in G2 to minimize beam size in the berm pipe

Sleeving with Steel

Figure 5 shows that a 12” steel pipe with a different trajectory will not interfere with the beam. Also plotted is an imaginary beam tube of 4” inner diameter. This represents the standard beam pipe in adjacent enclosures.

Not plotted is the amount of sag created by the steel pipe spanning across each transition. For the initial conditions that we have seen in the berm pipe two calculations can be used as a range of the possible deflections of steel pipe in the transitions. Since the deflection is a function of the length of the pipe, we will take the worst case transition, the 60 foot transitions.

For fixed ends on a pipe the equation to calculate deflection along the pipe is:

Where q is a uniform force, x is the distance from the end of the pipe, E is the Modulus of Elasticity, I is the Moment of Inertia, and L is the length of the pipe. However the transitions are not a fixed pipe at either end. They have the ability to rotate on the fulcrum located at each end where the 16” pipe and the 30” pipe meet. For pipes with supported ends the equation changes to:

When using either equation for the possible deflection in the middle of the pipe where the deflection will be the greatest, worst case scenario the pipe deflects .495 inches; best case scenario the pipe deflects .099 inches. In the worst case scenario, having the aperture reduced from 13.25 inches to 12.75 inches is very manageable.

Figure 5 Plot of 12" steel sleeve, empty transitions and new beam trajectory

Sleeving with HDPE

In finding alternative materials to sleeve the berm pipe HDPE material was also considered. HDPE could stand long term radiation damage while supplying the proper vacuum conditions for transporting beam.[[2]](#footnote-2)[[3]](#footnote-3) The HDPE sleeve would just follow the bottom of the berm pipe, due to its low Modulus of Elasticity. However in the transitions, grout has been installed to raise the pipe to reduce the creep and sag of the HDPE pipe.[[4]](#footnote-4)

Figure 5 shows the projected aperture and layout of the HDPE pipe once all three transitions are filled to the lowest elevation level with grout. Included is the HDPE inner diameter wall (Red), and a projected 4” beam pipe (Green). This plot is also for the worst case scenario; meaning that when the HDPE pipe is hanging off of the edge of a transition it immediately falls to the bottom of the steel pipe, or bed of grout.

Figure 6 Plot of 14" HDPE sleeve, grouted transitions and new beam trajectory

New Beam Trajectory

The trajectory will have to change from the previous 800 Gev trajectory but the position in NM1 is difficult to change. Since the magnets in NM1 are fixed to the ground with very little room to move downward, the beam position is relatively the same as before.

However with different incoming beam trajectory towards NM1 and the outgoing beam trajectory remaining the same, magnet set points in NM1 will have to change. Horizontal trajectory doesn’t change; therefore all of the changes are in the vertical magnets.

Table 2 displays the major bending elements down the beam line. In addition to that it shows the Critical Devices of V100 and MuLam and the dogleg in the G2 enclosure to achieve this new trajectory. Trims are not listed in the table.

|  |  |  |  |
| --- | --- | --- | --- |
| Bends | Current (Amps) | Type | Misc. |
| V100-1 | 608.8 | EPB | Critical Device |
| V100-2 | 608.8 | EPB | Critical Device |
| Mulam-1 | 192.5 | LAM | Critical Device |
| Mulam-2 | 192.5 | LAM | Critical Device |
| Mulam-3 | 192.5 | LAM | Critical Device |
| V420 | 268 | EPB | Dogleg |
| MuBend-1 | 809 | EPB |  |
| MuBend-2 | 809 | EPB |  |
| MuBend-3 | 809 | EPB |  |
| MuBend-4 | 809 | EPB |  |
| MuBend-5 | 809 | EPB |  |
| MuBend-6 | 809 | EPB |  |
| V424 | 367 | EPB | Dogleg |
| NM1U-1 | 338 | EPB |  |
| NM2EU-A | 721 | B2 |  |
| NM2EU-B | 721 | B2 Mod |  |
| NM2D1 | 790 | B2 |  |

Table 3 Magnet current setpoints

Conclusion

When beam ran through this berm pipe it had a smaller beam size at 800 Gev. Aligning berm pipes was a daunting task. Improvements in technology have given us the ability to track the small trajectory changes of a 760 foot pipe from various distances away. With better data, we can provide better maximize performance, while decreasing the error in the measurement.

Knowing with better accuracy, we can properly target the end of the berm pipe and transport beam with reduce losses by ways of proper optics and beam trajectory. Even though the aperture of the berm pipe will decrease in diameter, properly directed beam should have the same results as the past.

1. Beams Document 4000 V 3 Optics [↑](#footnote-ref-1)
2. Beams Document 4000-V6.Irradiation [↑](#footnote-ref-2)
3. Beams Document 4011-V1 Vacuum [↑](#footnote-ref-3)
4. Beams Document 4010 V1 Creep of HDPE [↑](#footnote-ref-4)