Calculated Emittances for Neutrino Muon Beamline

Version 0.3 11/22/2011

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Abstract

 Previously Switchyard was running 900 GeV protons and the beam was split to each individual beamlines by the way of Septa and Lambertsons. One of these lines was the Neutrino Muon Line, or NM Line. Around 2003 the Switchyard beamlines were redesigned and tuned for 120 GeV protons from the newly built Main Injector.

With these changes the Neutrino Muon line will have to be retuned with different beam functions. The measurements and the data presented are calculated to achieve proton beam to the NM3 target and absorber.

Introduction

 The E-906 beamline will be using the same enclosures that were used in 2000 when the beamline was running last. Because of the energy change there will be some changes to the elements. Not only are there some element changes but the beam envelope will be changed too. These element changes are:

* Conventional magnets of EPBs than the cryogenically cooled magnets
* The number of magnets for V100 critical device
* A doublet of Quadrapoles in place of the Muon Septa (MuSeps)
* A doublet of Quadrapoles in place of the string of seven (7) in NM2
* NM2Q1 (4)
* NM2Q2 (3)
* Reposition the Quadrapoles in the G2 enclosure
* Different settings for all bending and focusing elements

Beamline Measurement and Data

 In order to proceed with optical changes, accurate measurements of the beam functions present in the beamline are needed. To achieve these values, measurements were taken with a series of SWICs in the existing beamline. The general transfer matrix in Courant-Snyder parameters is: 1

$\left[\begin{matrix}β\\α\\γ\end{matrix}\right]\_{1}$=$ \left[\begin{matrix}C^{2}&-2CS&S^{2}\\-CC'&CCS^{'}+SC'&-SS'\\C'^{2}&-2C'S'&S'^{2}\end{matrix}\right]\left[\begin{matrix}β\\α\\γ\end{matrix}\right]\_{0}$

 As shown in Figure 1, three SWICs in a row with known distances between them, D1 and D2, and no Quadrapole correction between those SWICs in a beamline, the transfer matrix can be used to solve for the unknown functions $β\_{0}$ and$ α\_{0}$.

|  |
| --- |
| $ D\_{1}$ $D\_{2}$ SWICs.bmp |

Figure 1 Representative drawing of SWIC configuration

Solving for both $β\_{1 }$and $β\_{2 }$where$ γ\_{0} =\left(\frac{1 + α\_{0}^{2}}{β\_{0}}\right)$,

$β\_{1 = }C\_{1}^{2}β\_{0}- 2C\_{1}S\_{1}α\_{0} + \frac{S\_{1}^{2}}{β\_{0}}(1 + α\_{0}^{2})$ (1)

$β\_{2 = }C\_{2}^{2}β\_{0}- 2C\_{2}S\_{2}α\_{0} + \frac{S\_{2}^{2}}{β\_{0}}(1 + α\_{0}^{2})$ (2)

Using$ ε = \frac{σ\_{0}^{2}}{β\_{0}}$,$ ε = \frac{σ\_{1}^{2}}{β\_{1}}$, and $ε = \frac{σ\_{2}^{2}}{β\_{2}}$,

$β\_{1}= \left(\frac{σ\_{1}}{σ\_{0}}\right)^{2}β\_{0}$ (3)

$β\_{2}= \left(\frac{σ\_{2}}{σ\_{0}}\right)^{2}β\_{0}$ (4)

Substituting equation 1 and 2 into 3 and 4 and solving for$ α\_{0}$,

$α\_{0} =\left(\frac{1}{2}\right)β\_{0}Г$ (5)

where

$Г = \left(^{\left(\frac{σ\_{2}}{σ\_{0}}\right)^{2}}/\_{S\_{2}^{2}}\right)-\left(^{\left(\frac{σ\_{1}}{σ\_{0}}\right)^{2}}/\_{S\_{1}^{2}}\right)-\left(\frac{C\_{2}}{S\_{2}}\right)^{2}+\left(\frac{C\_{2}}{S\_{2}}\right)^{2}$ (6)

Direct substitution of equation 1 using equation 3, solving for $β\_{0}$

$β\_{0}= {1}/{\sqrt{\left({\left(\frac{σ\_{1}}{σ\_{0}}\right)^{2}}/{S\_{1}^{2}}\right)-\left({C\_{1}^{2}}/{S\_{1}^{2}}\right)+\left(\frac{C\_{1}}{S\_{1}}\right)Г-\left(\frac{Г^{2}}{4}\right)}}$ (7)

For a drift space of a known certain length$ D\_{1}$and $D\_{2}$,$ C\_{1}$=1 and $S\_{1}$ = $D\_{1}$,$ C\_{2}$=1 and $S\_{2}$ = $D\_{2}$.2 One hundred and thirty five pulses of beam were taken through three SWICs S200, S105, and S106. These three SWICs are at the beginning of the Neutrino Muon beamline, and have no Quadrapole effect on the beam. The distances between those SWICs and the measurements of the beam profiles are listed in Table 1 below.

|  |  |  |  |
| --- | --- | --- | --- |
|  |   | Measurement |  Error |
| Vertical (mm) | σ0 | 2.888 | 0.076 |
| σ1 | 2.713 | 0.119 |
| σ2 | 3.427 | 0.121 |
| Horizontal (mm) | σ0 | 2.307 | 0.048 |
| σ1 | 2.302 | 0.064 |
| σ2 | 2.918 | 0.073 |
| SWIC Distances (m) | D1 | 60.045 | 0.076 |
| D2 | 101.245 | 0.076 |

Table 1 Sigma measurements and SWIC distances

Substituting these values into equation 6 and using equations 7 and 5 yields $β\_{0}$ and$ α\_{0}$. With a measured value of $σ\_{0}$ and calculated$ β\_{0}$, ε can be calculated using$ ε=\left(\frac{σ\_{0}^{2}}{β\_{0}}\right)$. Knowing the value for $ε$ at one sigma measurements, we can calculate the Normalized 95% emittance, for 120 Gev/c protons of mass 0.938 Gev/c^2.

|  |  |  |  |
| --- | --- | --- | --- |
|  |   |  Calculation | Error |
| Vertical | $$β\_{0}$$ | 92.400 (m) | 0.256 |
| $$α\_{0}$$ | 0.490 | 0.032 |
| $$ε$$ | 0.090 | 0.002 |
| $ε$n | 21.983 (π mm mr) | 0.489 |
| Horizontal | $$β\_{0}$$ | 89.047 (m) | 0.200 |
| $$α\_{0}$$ | 0.392 | 0.030 |
| $$ε$$ | 0.060 | 0.001 |
| $ε$n | 14.656 (π mm mr) | 0.244 |

Table 2 Calculated optic functions and error

Magnet Setpoints

|  |  |  |  |
| --- | --- | --- | --- |
| Quads | Current (Amps) | Type | Type of Focusing |
| Q104 | 34.0 | 3Q120 | QF |
| Q105 | 34.0 | 3Q120 | QD |
| Q424 | 21.7 | 3Q120 | QF |
| Q420 | 22.4 | 3Q120 | QD |
| NM2Q1 | 386 | 4Q120 | QD |
| NM2Q2 | 387 | 4Q120 | QF |

Table 3 Quadrapole Set points

 Table 3 shows the three Quadrapole Doublets in the beamline, and their set points. Table 4 displays the major bending elements along the beam line. Table 4 also shows the type of magnet that each power supply is connected too; In addition to that it shows the Critical Devices of V100 and MuLam.

|  |  |  |  |
| --- | --- | --- | --- |
| 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 |  |
| 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 |  |
| NM1U-1 | 338 | EPB |  |
| NM2EU-A | 721 | B2 |  |
| NM2EU-B | 721 | B2 Mod |  |
| NM2D1 | 790 | B2 |  |

Table 4 Major Bending Elements

Beamline Design

 The beamline has been designed using existing EPB designs. Newly reconstructed, refurbished, and tested dipoles have been placed for the V100, MuBend, and NM1U strings. The first two Doublets of Quadrapoles are 3Q120 style Quadrapoles that have been tested. The last Doublet will be using the 4Q120 style magnets already located in the NM2 enclosure. The optical structure of both planes has been plotted in Figure 2.

The starting change begins in Enclosure C. This is where the beam envelope is affected by the first of three Quadrapole Doublets in the beamline. The first Doublet is in place of the MuSeps. During the previous run, the MuSeps would split the beam creating two beam lines; one for the Muon Line and another for the rest of the Neutrino area. Currently this Doublet will focus the beam in both planes when traveling through to the G1 stub approaching the Muon Lambertson (MuLam).

Figure 2 On-Momentum half-width beam sizes 1 sigma and 6 sigma (95%)

 Enclosure G2 Quadrapoles are stationed more upstream to compensate for the new beam envelope created by the Doublet in Enclosure C. This new positioning has two main purposes. One was to make the beam envelope pass through the restrictive aperture created by VT420, a small vertical trim magnet in G2. The second purpose was to match the beam envelope to the Doublet in the NM2 enclosure. Shown in Figure 3 and 4 is the Beta and Alpha functions of the beam line.

Figure 3 Optical functions from Enclosure C to the NM3 target

Figure 4 Optical functions from Enclosure C to the NM3 target

References

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[2] D. A. Edwards and M. J. Syphers, *An Introduction to the Physics of High Energy Accelerators*, J. Wiley, & Sons, Inc., New York 1993