Neutrino Beam line optics study

Ming-Jen Yang, September 3, 1996

Abstract

A study was done to understand the beam line optics from the beginning of Switchyard all the way to the end of Neutrino beam line. All available SWIC data were taken to get the beam centroid and width to be used in the analysis. The beam emittance and lattice function at the beginning of beam line can also be inferred from the study. The result indicated that the normalized 95% emittance to be around 15π -mm-mr for the vertical plane and about 28π -mm-mr for the horizontal plane.

Introduction

The study was conducted on August 16, 1996. Two sets of data for the horizontal plane was taken with H90 set at nominal current of 56.28 amp and with current set at 51.28 amp. For vertical plane data was taken with LAMD set at its nominal of -98.08 amp and at -125.4 amp. All SWIC profiles were taken at every set of data with the exception of SWIC V100 which was not working at the time.

The SWIC profile data contains both the centroid and the width information. To understand the beam line optics the centroid information is used in conjunction with the calculated Δ kick from the trim magnet used. The width information is used to estimate the beam emittance and the momentum spread, given the calculated beta and dispersion function at the SWIC locations. Since the twiss parameters of a beam line depends also on its value at the beginning it is also necessary to find the starting twiss parameter that best fit the width data.

The analysis of the Switchyard neutrino beam line was done entirely on the Excel spread sheet which calculates the orbit and lattice parameters used to fit the data. All calculation was done based on the magnets setting at the time data was taken. All the fitting reported here were done visually with the Excel plotting both the data and the calculated values.

Data analysis

There are three steps in analyzing the SWIC data. The first step is to fit for the beam centroid and beam sigma from the profile. The second step is to use the centroid information to verify the optics, or the quadrupole strength. The third part is to calculate the twiss parameters and fit for the emittance.

Figure 1. An example of profile data from MSEP SWIC. The curve is the fitted profile which consisted of a flat background, a Gaussian halo and the Gaussian beam distribution. The centroid and sigma shown are for the beam Gaussian distribution only. The vertical plane profile is shown in (a) and horizontal plane profile is shown in (b).

PROFILE

Currently the facility for doing off-line profile analysis does not exist. The analysis reported here was done by scanning the hardcopies of SWIC profiles into the computer. The wire-by-wire pulse height information is re-digitized, for a total of 48 per profile. This digitized data is then read into Excel spreadsheet to be fitted.

The beam centroids are calculated on-line and available as ACNET devices. It is compared to the off-line analysis when missing wire data is present or when profile is a bit messy and has to be resolved by human eyes. The width information is fitted visually on the Excel spread sheet. Because the on-line sigma calculation is susceptible to background influence all width information used in the analysis came from fitting done visually with Excel spread sheet, which calculates and plots the data and the fitted curve. Figure 1(a) shows an example of a horizontal profiles with the visually fitted results and in 1(b) the vertical profile.

Figure 2. Comparing beam orbit data with calculation. (a) is for horizontal plane and (b) for vertical plane. Orbit data is the difference between the excited orbit and reference orbit as measured and is displayed in open diamond. The calculation is shown in open circles.

ORBIT

For each plane there are two sets of orbits taken. One is the reference and the other the excited orbit. An upstream trim magnet is used to give the beam an extra

kick. This kick strength is used to calculate expected orbit difference. The data orbit difference is shown in Figure 2 along with the calculation.

A change of Q100 current from 52.95 to 51.55 amp substantially improved the agreement between data and calculation and the result is shown in Figure 3. The vertical trim device S:LAMD current was found to need an adjustment of about 10% in order to match the vertical orbit data. This is consistent with an previous study done for the Proton beam line. The trim device S:H90 kick strength calculation agrees well with data.

The beam position at PLAM can not be taken seriously because of a large background contamination in its profile data which renders position calculation difficult.

Figure 3. Orbit comparison as in Figure 2 but with Q100 current changed from 52.95 to 51.55 amps. In (a), the horizontal plane, the improvement is clearly substantial. In (b), the vertical plane, although the change is small but it is definitely in the right direction.

Further improvement at the end of beam line was achieved by modifying Q120 & Q121 current and is shown in Figure 4. The matching of calculation with data is significantly improved in the vertical plane while leaving the vertical plane un-changed.

Figure 4. Further improvement from Figure 3. This time the current at Q120 and Q121 were changed. In the horizontal plane (a) there is no appreciable change. In the vertical plane (b) the match in NLAM position was substantially improved.

TWISS PARAMETERS & EMITTANCE

The twiss parameters are calculated with optics as verified using the orbit data and with a given initial lattice function. The dispersion function η and η' are calculated as well. The initial value of η_x and η'_x are assumed to be 2.5 meters and -0.028 radian [1], with η_y and η'_y being both zero. The beam width data from all SWICs is visually matched for the emittance and σ_p/p , the sigma of momentum spread. A number of iteration was needed to see which initial set of twiss parameters fits the width data best.

Figure 5 shows the result of this iterated fitting procedure for the horizontal plane and Figure 6 for the vertical plane. The values of the initial beta and alpha that best fit the width data are also shown in part (a) of each figure. The change made to

[1] KTeV Beam Systems Design Report - Version 1.1, page 26.

Q120 and Q121 current setting also resulted in a better fit for the emittance and is used in the calculation for figures 5 and 6.

Figure 5. Result of fitting horizontal beam emittance. In (a) is the calculated horizontal beta function, (b) is the horizontal dispersion function, and (c) is the plot of beam width sigma. The calculated beam width using the fitted emittance is shown in open circle and the measured beam width data is shown in open diamond. The fitted emittance of 0.0115 π -mm-mr is un-normalized.

Figure 6. Result of fitting vertical beam emittance. In (a) is the calculated vertical beta function, (b) is the vertical dispersion function, and (c) is the beam width sigma. The calculated beam width using the fitted emittance is shown in open circle and the measured beam width data is shown in open diamond. The un-normalized vertical emittance is estimated to be .0062 π -mm-mr.

Conclusion

The modeling calculation matches well with data taken from the Neutrino beam line. The orbit data, which is the beam centroid information, is in particularly good agreement. The beam line optics is believed to be understood.

In fitting the initial twiss parameters and the emittance, the beam width is a source of uncertainty. The horizontal profiles, carrying the signature of the QXR slow extraction process, is visibly non-Gaussian. Fitting such profiles inevitably introduces error and bias. The estimated horizontal emittance of $0.0115 \pi\text{-mm-mr}$, or 27.6 normalized at 95% envelope, therefore should not be taken literally. The data for vertical plane is more credible because all profiles are fairly Gaussian-like. The estimated vertical emittance is $.062 \pi\text{-mm-mr}$, or 14.9 normalized at 95% envelope.