ERROR ANALYSES OF THE PEFP 20/100-MEV BEAMLINES*

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Abstract

The proton engineering frontier project (PEFP) 100-MeV proton linac has two main beamline systems to extract and deliver the proton beam to the user. The one is designed to extract 20-MeV proton beams at the medium energy transport system of the linac and to deliver them to five target stations through a beam switching system. The other is able to extract 100-MeV proton beams at the end of the linac and to deliver them to another five target stations through a beam distribution system. We have completed the detailed beam optics designs of the beamline system and performed intensive error analyses to set the marginal limits of engineering errors of the beamline components by using a dedicated beam transport code. The paper presents the error analysis results of the PEFP beamline systems along with their characteristics and beam optics designs.

THE PEFP 100 MEV PROTON LINAC AND ITS BEAMLINES

The proton engineering frontier project (PEFP) is developing a 20-mA, 100-MeV proton linac, which consists of a 50 keV injector, a LEBT, a 3-MeV RFQ, a 20-MeV DTL, a MEBT, and a 100-MeV DTL, as shown in Fig. 1. The low energy part of the linac, up to 20-MeV DTL, has been developed in the first phase. The high energy part of the accelerator is under development. Detailed descriptions of the PEFP 100-MeV proton linac can be obtained elsewhere [1].
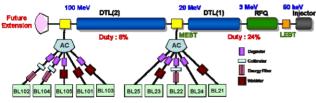

Figure 1: Layout of the PEFP 100-MeV proton linac and its beamline.

To provide proton beams with low to medium energies efficiently, two beam extraction systems are to be implemented: one at the end of the 20-MeV DLT and the other at the end of the 100-MeV DTL. The schematic of the 20-MeV beamline facility is shown in Fig. 2. The proton beam is extracted by a dipole magnet and delivered through a common beamline to a AC magnet, which is operated by a programmable AC power supply and distributes the proton beam into five individual beamlines. The 100-MeV beamline facility has similar

features. More detailed descriptions of the beamline facilities can be found elsewhere [2].
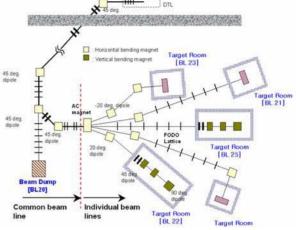

Figure 2: The PEFP 20 MeV beam line facility.

THE ERROR ANALYSIS CODE

We have developed a dedicated error analysis code, kTrace [3], which is able to trace the beam through a given lattice based on the matrix algorithm at the first order. In addition, we developed the code to account for the misalignment or field fluctuation of the lattice element based on the algorithm discussed in Ref. [4].

The kTrace is designed to share the same input file as TRACE3D [5] because it is widely used to design a beamline lattice. First, the kTrace reads in the input file and trace the beam through a perfectly aligned lattice. Then it generates an imperfect lattice with optional displacement and rotational errors and with optional global and local field fluctuations within the pre-specified limits, through which the input beam is being traced. The evolution of the beam centroid and envelope are investigated at pre-determined interval and compared to them calculated through the perfect lattice. For a given lattice, any number of imperfect lattices can be generated and analyzed to gather a large data sample which can provide marginal alignment limits of the lattice element and/or fabrication limits of the elements. The function of the kTrace is schematically shown in Fig. 3.
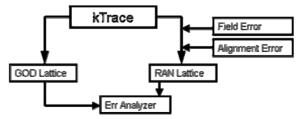

Figure 3: The schematic function of the kTrace.

BEAMLINE ERROR ANALYSES

We have investigated the effects of magnet misalignment errors, which can be assessed combined or separately. Unlike the linac, the beamline contains a number of dipole magnets, we need to carefully choose the marginal limits of misalignment errors of the dipole magnets because they introduce more serious effects. In the analyses, we set the marginal limits of displacement errors and rotational errors as listed in Table 1.

Table 1: Marginal limits of the misalignments.

Misalignment	Quadrupoles	Dipoles
Displacement error	± 50 μm	± 50 μm
Rotational error	± 15 mrad	± 2.5 mrad

We investigated the misalignment effects in three steps. First, we investigated the effects of the quadrupole misalignments assuming the dipoles are perfectly aligned. Typical evolutions of the beam centroid for a 20-MeV and 100-MeV beamlines are shown in Fig. 4 and Fig. 5, respectively. The deviation of the beam centroid from the designed beam trajectory is found to be within acceptable range of ± 5 mm, which means that we may require a marginal alignment or fabrication error limits on the quadrupole magnet.
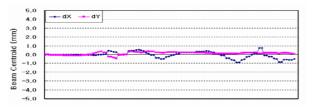

Figure 4: A typical evolution of the beam centroid through the 20-MeV beamline with the random misalignments of quadrupole magnets.
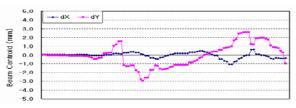

Figure 5: A typical evolution of the beam centroid through the 100-MeV beamline with the random misalignments of quadrupole magnets.

Secondly, we investigated the misalignment effects of the dipole magnets assuming all the quadrupole magnets are perfectly aligned. We learned that the displacement error introduces almost the same effects to the evolution of the beam centroid as the quadrupole magnet. However, we learned that the rotational misalignment introduces severer effects. Therefore, we required much tighter marginal limits on the rotational misalignment. Typical evolution of the beam centroid caused by the

misalignment of the dipole magnets for the 20-MeV and 100-MeV beamlines are shown in Fig. 6 and Fig. 7, respectively. It should be noted that the marginal limits on the rotational errors was set to be ± 2.5 mrad without displacement errors. The effects are about an order of magnitude larger than quadrupole case even though we imposed a much tighter error bounds.
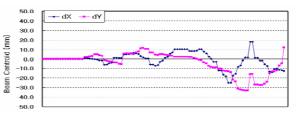

Figure 6: A typical evolution of the beam centroid through the 20-MeV beamline with the random misalignments of quadrupole magnets.

Figure 7: A typical evolution of the beam centroid through the 100-MeV beamline with the random misalignments of quadrupole magnets.

Finally, we fully investigated the misalignment effects considering all the magnet elements in the beamline, in which we set the marginal limits on the displacement errors of the quadrupole and dipole magnets to be ± 50 μm and the rotational errors of the quadrupole and dipole magnets to be ± 15 mrad and ± 2.5 mrad, respectively. Typical evolutions of the beam centroid for the 20-MeV and 100-MeV beamlines are shown in Fig. 8 and Fig. 9, respectively. The average deviation of the beam centroid from the designed trajectory was found to be about ± 20.0 mm, which is an order of magnitude larger than the typical deviations found in the similar analysis for the PEFP 100-MeV linac by using the same analysis code [6].

Considering the beam radius and the size of beam pipe designed for the PEFP 20-/100-MeV beamlines, the deviation of the beam centroid is unacceptable.
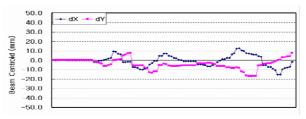

Figure 8: A typical evolution of the beam centroid through the 20-MeV beamline with the random misalignments of quadrupole magnets.
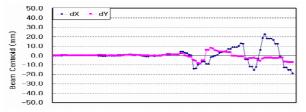
Figure 9: A typical evolution of the beam centroid through the 100-MeV beamline with the random misalignments of quadrupole magnets.

RESULT AND DISCUSSSION

We have developed a beam trace code for the detailed analysis of the misalignment effects of the linac and beamline. Using the code, we performed a detailed error analysis for the PEFP 20-/100-MeV beamlines and set the marginal alignment limits on the quadrupole and dipole magnets. From the study, we found that the rotation alignment of the dipole magnet requires extremely careful attention to make the beam under control without serious beam loss. Furthermore, another method to control the beam centroid, such as corrector magnet, should be considered.

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