TRANSVERSE PROFILE EXPANSION AND HOMOGENIZATION FOR THE BEAMLINE OF XIPAF

Z. Yang, S.X. Zheng, X.L.Guan, H.J.Yao, C.T.Du, M.W.Wang, X.W.Wang, Department of Engineering Physics, Tsinghua University, Beijing 10084 , China

Abstract

For the Xi'an 200 MeV Proton Application Facility (XiPAF), one important thing is to produce more homogenous beam profile at the target to fulfill the requirements of the beam application. Here the beam line is designed to meet the requirement of beam expansion and homogenization, and the step-like field magnets are employed for the beam spot homogenization. The simulations results including space charge effects and errors show that the beam line can meet the requirements well at the different energies (from 10 MeV to 230 MeV) and different beam spot size (from 20mm to 200mm).

INTRODUCTION

To fulfill the need of the experimental simulation of the space radiation environment, especially the investigation of the single event effect, the project of Xi`an Proton Application Facility (XiPAF) is under construction in Xi'an City, China [1]. The facility is mainly composed of a 230 MeV synchrotron with a 7 MeV H- linac injector and two experimental stations. A proton flux of 10^5~10^8 p/cm^2/s with the uniformity of better than 10% on the sample in the range of 1 cm×1 cm ~ 10 cm×10 cm is designed. Table 1 lists the main specifications of the synchrotron.

Table 1: Main Specifications of Synchrotron of XiPAF

Parameter	Synchrotron
Ion type	proton
Output energy (MeV)	60(10)~230
Repetition rate (Hz)	0.1~0.5
Beam pulse width	1~9 s
Maximum average current (nA)	30
Flux (p/cm^2/s)	10^5~10^8

There are 2 beam transport lines in whole accelerator system, which are MEBT and HEBT. The main function of the MEBT is to transport H- beam from DTL to synchrotron, while the HEBT is to expand proton beam and transfer the beam to the target station uniformly.

Accelerated by the synchrotron, the energy of the exacted beam can be changed from 60 MeV to 230 MeV, while we are trying to make it low to 10 MeV. By changing the magnet field of the quadrupoles and the length of the long drift region, the diameter of proton beam can be expanded to nearly 300 mm on the target.

In this study, step-like field magnets are used to meet the very strict requirements at the XiPAF target. Step-like field magnets (SFMs) were initially proposed for the beam spot uniformization at the ESS targets [2], which were also applied to the China Spallation Neutron Source [3], IFMIF project [4] and China-ADS project [5] for the same purpose. They are considered to be more effective and cheaper than conventional standard multipole magnets in this kind of applications.

DESIGN OF THE DUMP BEAMLINE

According to the multiple-phase development plan of the XiPAF, in the first phase one beamline is built to focused on the beam with the energy from 60 to 230 MeV; in the second phase it is to transport the low beam energy from 10 MeV to 60 MeV, as shown in Fig. 1. Therefore, the 2 beamlines has been designed to fit the beams with different characteristics.

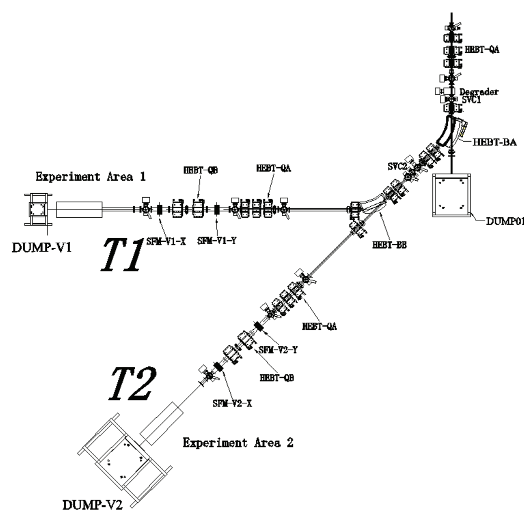

Figure 1: Schematic layout of the HEBT beamline for XiPAF.

Design Goals and Constraints

The HEBT beamline is designed with the following guidelines:

- To facilitate the application requirement, the transverse beam profile at the experiment area entrance should be more-or-less rectangular, the footprint are required to be adjustable from 20 × 20 mm^2 to 200 × 200 mm^2.
- The homogeneity of the beam power density on the experiment area entrance or so-called the target should be as good as possible, which is determined by the application requirement, about 10% in rms here.

- For the reasons of the hands-on maintenance and the device protection, the beam loss rate along the beamline should be controlled to be as low as possible.
- The beamline should be designed to adopt different beam characteristics at different energies. The devices remain the same but the relative positions can be adjusted slightly.

Although the beam energy is not high, a few quadrupoles with quite large apertures are applied to produce very flat beams at the positions of the SFMs. The optimizations are made to reduce the requirements on the quadruple strengths.

Design Methods

As mentioned before, to control the beam homogeneity in both horizontal and vertical planes, two SFMs are applied in the beamline.The aspect ratio of the beam cross-section at the SFMs should be large enough to decouple the nonlinear field in the two phase planes, e.g. larger than 6. At the same time, the phase advance between the SFMs and the target should be designed to be slightly different from π or 2π. Thus, to adjust the beam optics flexibly, one needs at least five quadruples, three of which are put before the 1^{st} SFM, and the other two are located between the two SFMs.

Two 45^{o} bending magnets are introduced, one of them is used to do the particle energy analysis and selection; the other one is to transport the beam to the experiment area 1 or 2.

TRANSPORT [6] codes are used to set up the preliminary beam optics without applying the SFMs, while TRACEWIN [7] code is used to optimize the optics including space charge effects and the nonlinear fields of the SFMs. Usually, several iterations need to be carried out for the optimization of the linear optics and the SFMs.

For the multi-particle tracking by TRACEWIN, different initial beam distributions for 10 MeV, 60 MeV and 230 MeV at the beam line entrance are from the synchrotron dynamics design and contain 100000 macro-particles at the exit of septum magnet.

At 230MeV

Because of the 3^{rd} integer resonated slow extraction, the emittances of the horizontal-axis and the vertical-axis are significant different. The linear beam optics is designed to have flat beams at the SFMs and an enlarged beam profile at target with an initial emittance of 8.5π mm.mrad on x-axis and 15π mm.mrad on y-axis which contains 99% particles.

The multi-particle tracking at the target entrance with 60mm beam envelope has been made and for comparison, the design result by using octupoles in the places of the SFMs was also carried out, whose homogeneity looks very close at target. The mean square root homogeneity of the beam power density on the flat top is about 22% by using the single SFMs, while it is about 24% for the case of octupoles. With the given total macro-particles, there are statistical errors of a few percent in the homogeneity calculations that are due to relatively small numbers of macro-particles in each grid, and here 2×2 mm^2 size grids are used. 2 collimators are located at the end of the beamline to cut the beam halo, which make the homogeneity down to the 11% by using the single SFMs. The beam orbit correction shows that no beam loss is observed for the case of SFMs.

Situations of different beam envelopes are also made. The result with 120mm beam envelope is shown in Fig. 2. To get bigger beam profile on the target, the experiment table is moved upstream by 2.0 m from the setup 60mm beam envelope. The mean square root homogeneity of the beam power density on the flat top is about 19.6% by using the single SFMs, and 10.2% by using SFMs and collimators.

At 60MeV and 10MeV

At lower beam energy, the y-axis beam emittance is much larger than x-axis, while the space charge effect is stronger.

In order to obtain a better control on the beam halo and beam uniformity, beam compensations on the transverse plane are made by using the code TRACEWIN. From the simulation result, it shows that the homogeneity on the lower energy could reach as well as 230MeV. The beam spot distribution at the target after applying the SFMs

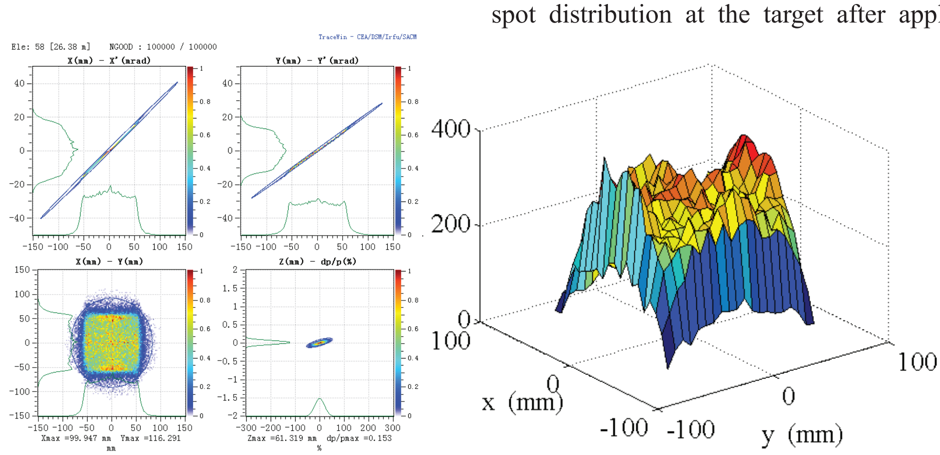

Figure 2: Beam distributions at the beam target at 230 MeV with 120mm beam envelope (left: 2D; right: 3D).

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along the HEBT at 60 MeV is shown in Fig. 3. The mean square root homogeneity of the beam power density on the flat top is about 17.4% in rms with only SFMs, and 9.8% with SFMs and collimators.

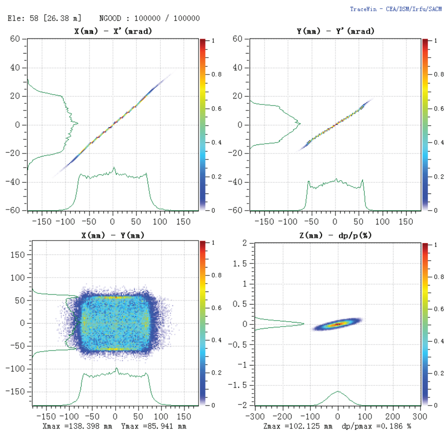

Figure 3: Beam distributions at the beam target at 60 MeV with 120mm beam envelope.

Error Simulation

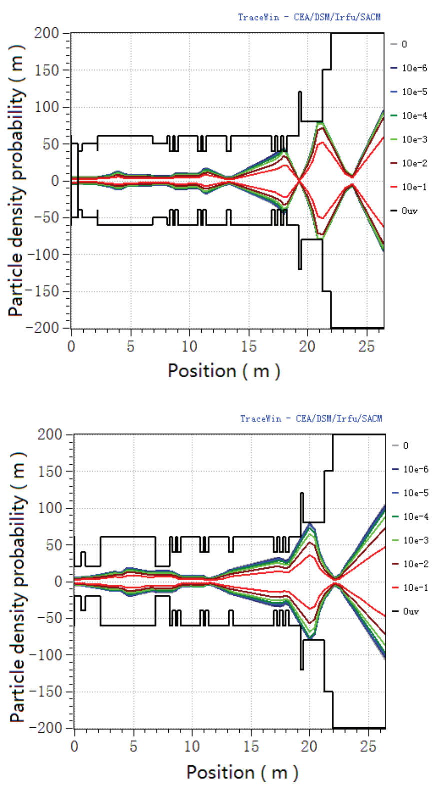

Figure 4: Beam distributions at the beam target at 60 MeV with 120mm beam envelope.

The error studies at XiPAF-HEBT have also been carried out (see Fig.4). The results show that the beam loss is acceptable in the beam transfer line if we design the apertures appropriately. Most of the beam loss happens between the last 2 quadrupoles because of the strong focussing, and one should take care about the possible beam loss there.

Summary of the Designs

For all the 3 different energies, the beam losses along the beamline and the beam power distributions at the target are summarized in Table 2.

Table 2: Beam Losses Along the Beam Line and the Beam Power Distributions at the Target

	10-MeV	**60-MeV**	**230-MeV**
Loss without errors (W)	No loss	No loss	No loss
Loss with errors (%)	<1	<0.5	No loss
Homogeneity across the flat top (%, rms)	16.5	17.4	22
Homogeneity with collimator (%, rms)	9.8	9.8	11

CONCLUSIONS

To fulfill the research request of the space radiation environment, a multi-energy beamline together with the experiment table is designed, which uses the SFMs and collimators to produce homogenized beam footprints at the target. The beam dynamics simulations show that the designed beamline can work very well at different energies (from 10 MeV to 230 MeV), which meet the requirements on the beam profile at target and the beam losses in the beamline.

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