STUDIES OF THE LOW ENERGY PROTON BEAM HALO EXPERIMENT

Hongping Jiang#,Shinian Fu, Jun Peng, Tao Huang, Fang Li, Peng Li, Huachang Liu, Cai Meng, Ming Meng, Zhencheng Mu, Huafu Ouyang, Peng Chen, Linyan Rong, Biao Sun, jianmin Tian, Biao Wang, Shengchang Wang, Wenqu Xin, Taoguang Xu, Lei Zeng, Fuxiang Zhao
Institute of High Energy Physic, Chinese Academy of Sciences, Beijing 100049, China

Abstract

We report measurements of transverse beam phase-space properties and transverse beam halo in mismatched proton beams in 28-quadrupole FODO transport channel following the 3.5-MeV IHEP RFQ. Beam profiles in both transverse planes are measured using beam-profile diagnostic. The gradients of the first four quadrupoles can be independently adjusted to match and mismatch the RFQ output beam into beam-transport channel. We also compare the measured beam profile with the 3-D nonlinear macro-particle code IMPACT simulations in the beam halo experiment. Quadrupole scans were used to determinate the transverse properties of the RFQ output beam. The Gaussian distribution was chosen as the initial particle distribution, which is well fit with the measured beam-core profile. We match the beam using the least-squares fitting procedure that adjusted the first four matching quadrupoles to produce equal rms beam size in the last six wire scanners. Simulations had been fairly successful in reproducing the core of the measured matched beam profiles, but there are some differences in the mismatched beam profiles.

INTRODUCTION

The interest in understanding the formation of a halo distribution around an intense proton beam has increased in recent years with the development of new applications requiring such beam, because the beam halo is a major source of beam loss and radioactivation in high-power and high-current proton linacs. Beam mismatch have been identified as the major source of the halo formation [1], space-charge forces in mismatched beam are the main source of beam halo in high current proton beams. Having well matched beam conditions is a fundamental requirement for the operation of proton linacs. And the macroparticle simulation method is widely used in modern accelerator design and beam dynamics studies [2].

In this paper, we present measurements of transverse beam phase-space properties and comparisons of simulation results using the code IMPACT [3] with experimental measurements of the beam profiles in a high-current matched and mismatched proton beam. The beam profiles were measured by the wire-scanners. The transport line was installed after the radio frequency quadrupole (RFQ) accelerator designated for ADS study at the Institute of High Energy Physics (IHEP).

Jianghp@ihep.ac.cn

THE BEAM-CORE MATCHING EXPERIMENT TRANSPORT LINE

The 28-quadrupole beam transport line is installed at the end of the IHEP RFQ, which accelerates the proton beam to 3.54MeV and operates at the frequency of 352MHz. The purpose of this transport line is the experimental study of the beam halo formation and the comparison of the experimental data with the simulations. The block diagram of this transport lattice is shown in Fig. 1. In this line, the first four quadrupoles are independently adjustable to match the beam or to produce mismatches; the last 24 quadrupoles form an FODO lattice.

The transverse beam profiles are measured using beam profile scanners, which consist of wire scanners for measurement of the dense beam core and halo scrapers for measurement of the outer halo regions [4]. In the beam halo experiment, we use the wire scanner to measure the beam profiles, and the wire scanner can provide intensity measurement over a dynamic range of about 10^3. The philosophy of the scanner placement is the following: the first group of two scanners is placed after quadrupole 5 and 6, they separately measure the beam vertical and horizontal profiles which are used to characterize the proton beam output from the RFQ. To observe beam profiles of matched or mismatched case, another two groups of scanners with 6 scanners for each group are placed after quadrupole 17 to 28, covering about two mismatch oscillations.

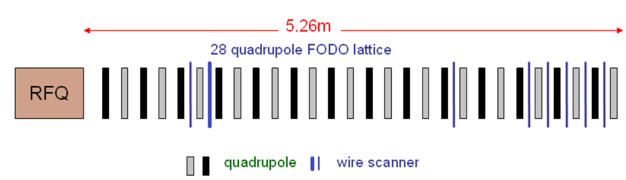

Figure 1: Block diagram of beam-core matching experiment transport line.

CHARACTERIZING THE PROTON BEAM OUTPUT FROM THE RFQ

In order to know the details of the beam, quadrupole scans and multi-wire scanner were used to characterize the transverse beam output from the IHEP RFQ [5]. In the scanning process, we kept the other three quadrupoles the same gradient 25.40T/m and obtained the Gaussian-like beam distributions with different rms radius compared with simulations shown in the Table 1 and Figure 2, the same with horizontal. Due to the lack of longitudinal measurements, the beam longitudinal Courant-Snyder parameters from the RFQ were predicted by the PARMTEQM [6] RFQ simulation code. Table 2 shows the results: the beam Courant-Snyder parameters and emittances. And the multi-wire scanner results will be show in the future, we can find the difference of parameters between the quadrupole-scan and the multi-wire scanners is about eight percent, which is acceptable in our experiments.

Table 1: The rms Vertical Radius Compared with Simulations under Different Focusing Strength

Q 1 (T/m)	Measurements	Simulation
-21.04	2.96±0.06 mm	2.94 mm
-23.57	2.46±0.05 mm	2.50 mm
-25.19	2.20±0.08 mm	2.27 mm
-26.90	2.10±0.06 mm	2.10 mm
-29.34	1.96±0.06 mm	1.98 mm

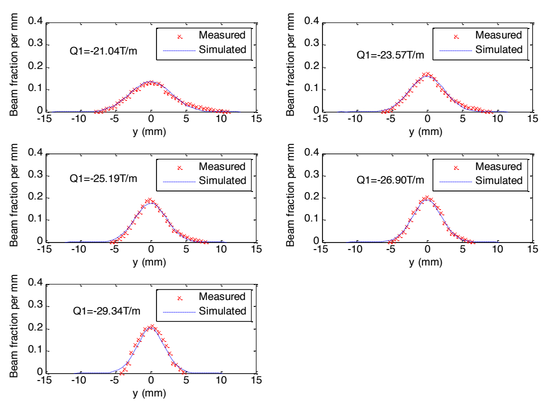

Figure 2: The beam measured vertical profiles compared with simulations under different focusing strength.

Table 2: Unnormalized Emittances and Initial Courant-Snyder Parameters from Quad Scan Analysis

	α	β (mm/mrad)	Emittance rms Unnormalized
Horizontal	3.443	0.42	3.66 mm-mrad
Vertical	-0.165	0.10	5.45 mm-mrad
Longitudinal	-1.564	3.16	0.32mm-mrad (normalized)

THE MATCHED BEAM

A least-squares-fitting procedure was used based on measurements of derivatives of rms sizes with respect to matching quadrupole gradients. Because the lack of vertical wire scanners at the end of transport line, beam was matched by adjusting the first four quadrupoles to produce equal rms sizes in horizontal position at the last 6 wire scanners. The measured results with different location equilibrium horizontal beam-core profiles were shown in Figure 3. As shown in the figure, the beam profiles with different locations have the similar distributions with an rms radius about 1.1mm.

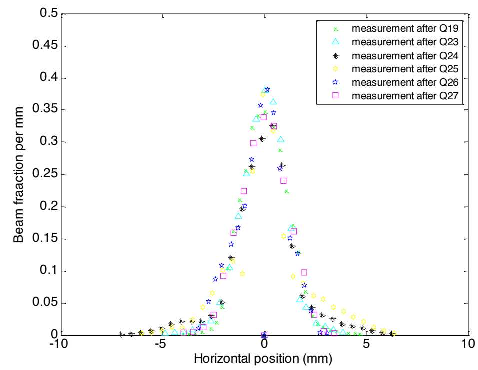

Figure 3: The equilibrium horizontal profiles measured at different locations.

Using the Gaussian distribution with a 24.7-mA beam current as the input distribution, we simulated the beam transported through the beam-core matching experiment. We have used 2×10^{8} macroparticles per bunch with a computation grid of 64×64×128. The rms beam size and emittances at the centre of each drift space as a function of distance is given in Figure 4 compared with experimental data. From the figure we can see the rms radius predict an oscillation following the FODO periodic focusing channel and the wire scanner rms radius is perfectly fitting with the simulation, and the emittances are nearly constant. Besides the rms sizes, we also measured the projected density distribution, i.e., beam profiles in horizontal projections at seven locations along the transport channel. Figure 5 compares the simulations with the measured beam horizontal profiles. Simulations are fairly successful in reproducing the core of the measured matched-beam profiles (about 3 rms radius), but there are some discrepancies in the scope larger than 3-rms radius in some locations.

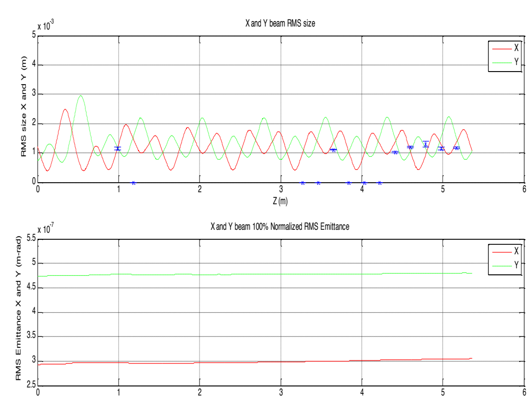

Figure 4: Results of beam rms radius and emittances as a function of distance for a matched beam.

ISBN 978-3-95450-138-0

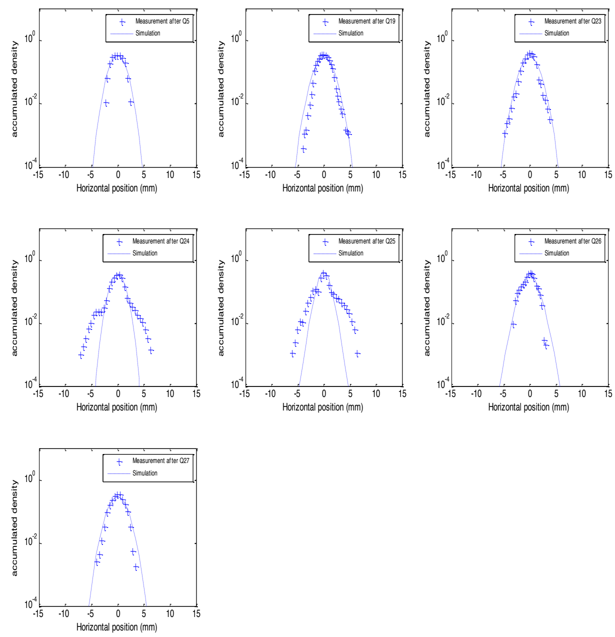

Figure 5: The horizontal profiles from measurements and simulations after Q5 Q19 Q23 Q24 Q25 Q26 Q27 for a 24.7 mA matched beam.

THE MISMATCHED BEAM

After we found the matched case, we adjusted the matching quadrupoles to obtain the mismatched beam. We measured the beam profiles and compared with simulations. The results were shown in Figure 6.

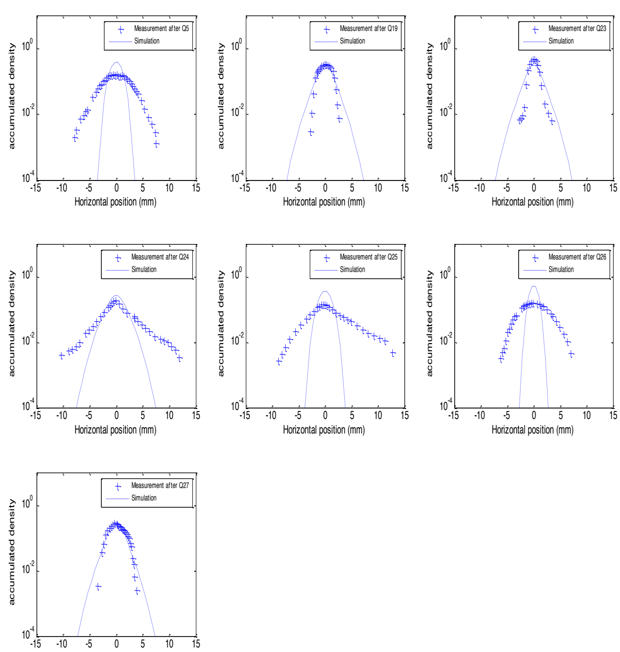

Figure 6: The horizontal profiles from measurements and simulations after Q5 Q19 Q23 Q24 Q25 Q26 Q27 for a 24.7 mA mismatched beam.

From the Figure 6 we can find only three locations beam profiles agree well with the simulations, the others have big differences. The simulation shows that the beam distribution is also a Gaussian distribution, but the measured beam profiles show the beam halo has formated. We need do further study to understand these questions.

CONCLUSIONS

We have used quadrupole scans and multi-wire scanner to determine the RFQ output beam Courant-Snyder parameters and emittances. In the simulation, we choose the Gaussian distribution with the obtained Courant-Snyder parameters as the initial beam-core distribution. We have compared the macroparticle simulations with the measurement data in a matched beam at 24.7mA. Simulations are fairly successful in reproducing the rms properties of the measured matched-beam, and the beam profiles in horizontal projections at the six locations shows that the beam is well matched, but for the mismatched case there are some discrepancies in the beam profiles in some locations. For explaining this phenomenon, we think there are more simulations with errors about the mismatched beam and beam offset to be analysed.

ACKNOWLEDGMENT

We thank Mr Ji Qiang for providing the IMPACT code and for help associated with its use.

REFERENCES

[1] Allen C K, Chan K C D, Colestock P L, et al. Beam-halo measurements in high-current proton beams [J]. Physical review letters, 2002, 89(21): 214802.
[2] J. Qiang, R. D. Ryne, B. Blind, J. H. Billen, T. Bhatia, R. W. Garnett, G. Neuschaefer, and H. Takeda, Nucl. Instrum.Methods Phys. Res., Sect. A 457, 1 (2001).
[3] J. Qiang, R. D. Ryne, S. Habib, and V.Decyk, J. Comput. Phys. 163, 434 (2000).
[4] Yu-Fang, Ruan, et al. "Design and simulation of a wire scanner for the CSNS linac." Chinese Physics C 34.10 (2010): 1655.
[5] Schulze M E, Allen C K, Colestock P L, et al. Characterization of the proton beam from the 6.7 MeV LEDA RFQ[C], PAC 2001, IEEE, 2001, 1: 591-593.
[6] K. R. Crandall et al.,"RFQ Design Codes", Los Alamos National Laboratory report LA-UR-96-1835 (revised February 12, 1997).

.