MACROPARTICLE SIMULATION STUDIES OF A BEAM-CORE MATCHING EXPERIMENT

Hongping Jiang#,Shinian Fu, Peng Chen, Tao Huang, Fang Li, Peng Li, Huachang Liu, Cai Meng, Ming Meng, Zhencheng Mu, Huafu Ouyang, Jun Peng, 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 compared the 3-D nonlinear macro- particle code IMPACT simulations with the measured beam-core profiles obtained by the wire-scanners in the beam-core matching 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 matched 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.

INTRODUCTION

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]. 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 comparisons of simulation results using the code IMPACT [3] with experimental measurements of the beam core profiles in a high-current proton beam. The beam core profiles were measured by the wire-scanners, which were interspersed in a 28-quadrpole beam transport line. The scope of the wire-scanner is about 3-rms beam radius. The transport line was installed after the radio frequency quadrupole (RFQ) accelerator designated for ADS study at the Institute of High Energy Physics (IHEP). Through this experiment, we have a comprehensive understanding of the beam matching conditions.

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 matching and 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 with the zero current phase advance of 90°per period to provide transverse strong focusing.

The lattice is spatially periodic with a focusing period length of 38.0 cm. The quadrupoles are spaced every 19 cm so that beam diagnostic devices can be mounted between the magnets. 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-core matching experiment, we only use the wire scanner to measure the beam-core profiles, and the wire scanner can provide intensity measurement over a dynamic range of about 10^2. 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 matching case, another two groups of scanners with 6 scanners for each group are placed after quadrupole 17 to 28, covering about two mismatch oscillations.

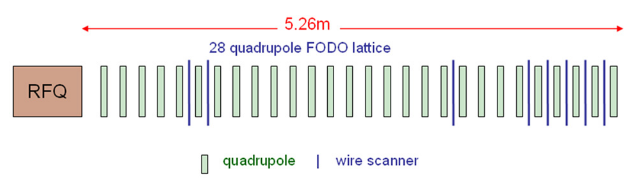

Figure 1: Block diagram of beam-core matching experiment transport line.

CHARACTERIZING THE PROTON BEAM OUTPUT FROM THE RFQ

In order to know the details of the beam, quadrupole scans 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-core distributions with different rms radius shown in the Table 1 and Figure 2, so we only addressed the rms properties of the distribution [6,7] and chose the Gaussian distribution as the initial beam distribution. The analysis of the original scan data utilized simulation code IMPACT, the 3-D PIC code with nonlinear space charge. Due to the lack of longitudinal measurements, the beam longitudinal

Jianghp@ihep.ac.cn

ISBN 978-3-95450-122-9

Courant-Snyder parameters from the RFQ were predicted by the PARMTEQM [8] RFQ simulation code. Table 2 shows the results: the beam Courant-Snyder parameters and emittances.

Table 1: The Rms Radius with Different Focusing Strength

Q 4 (T/m)	Horizontal	Q 1 (T/m)	Vertical
23.79	1.45 mm	21.30	3.11 mm
25.40	1.65 mm	23.79	2.49 mm
26.96	1.97 mm	25.40	2.19 mm
29.18	2.15 mm	26.96	2.03 mm
31.26	2.37 mm	29.18	1.95 mm

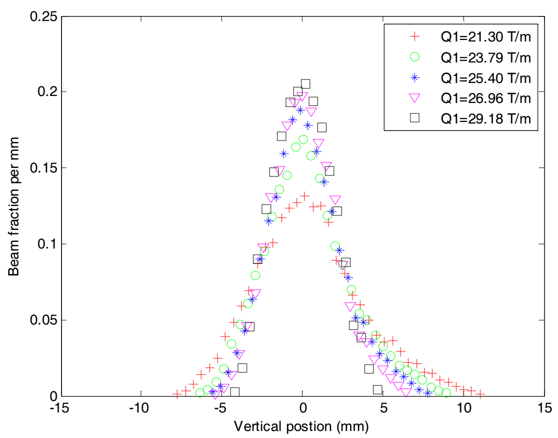

Figure 2: The beam vertical profiles measured with different focusing strength.

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

	α	β	Emittance rms Unnormalized
Horizontal	3.13	0.378(mm/mrad)	4.769(mm-mrad)
Vertical	-0.11	0.112(mm/mrad)	3.029(mm-mrad)
Longitudinal	-0.27	1.03(deg/KeV)	2.877(deg-KeV)

COMPARISON BETWEEN SIMULATION AND EXPERIMENT

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. A least-squares-fitting procedure was used based on measurements of derivatives of rms sizes with respect to matching quadrupole gradients. Under matched conditions, the beam is expected to be transported along a linear transport channel with minimal emittance growth, and no significant change in the equilibrium distribution [9]. 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.

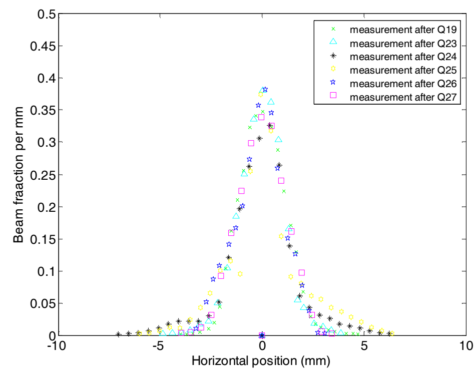

Figure 3: The equilibrium horizontal profiles measured at different locations.

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 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 oscillations following the FODO periodic focusing channel and the first wire scanner rms radius is perfectly fitting with the simulation, and the other six locations have a small difference. Besides the rms sizes, the experiment also measured the projected density distribution, i.e., beam profiles in horizontal projections at six 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.

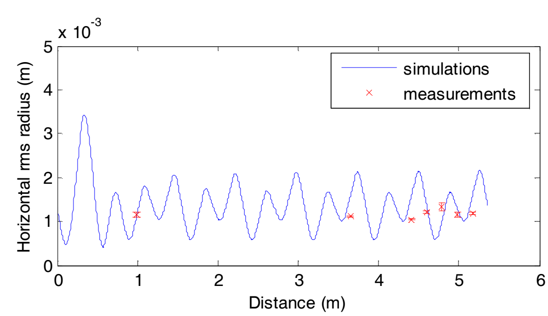

Figure 4: Horizontal rms beam size as a function of distance at a 24.7 mA matched beam.

ISBN 978-3-95450-122-9

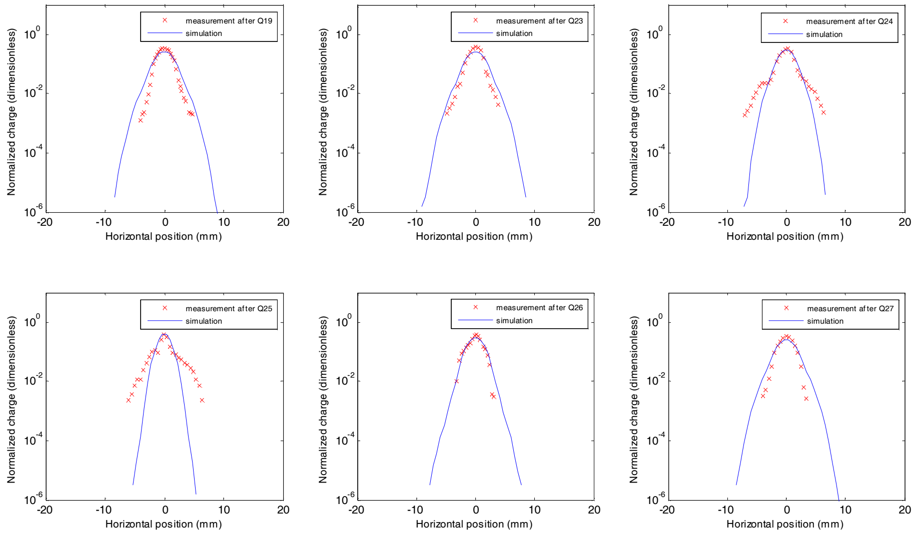

Figure 5: The horizontal profiles from measurements and simulations after Q19 Q23 Q24 Q25 Q26 Q27 for a 24.7 mA matched beam.

CONCLUSIONS

We have used quadrupole scans and the IMPACT code fitting to determine the RFQ output beam Courant-Snyder parameters and emittances. In the experiment we have found the Gaussian distribution is a good approximation for the initial beam-core distribution, so we only addressed the rms properties of the profiles. In the beam-core matching experiment, we find the obtained beam rms parameters is well fitting with the experimental data from the first wire scanner.

In the macroparticle 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-core is well fitted, but there are some discrepancies in the scope larger than 3-rms in some locations. For explaining this phenomenon, we think there are more simulations 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],Particle Accelerator Conference, 2001. PAC 2001.Proceedings of the 2001. IEEE, 2001, 1: 591-593.

[6] Lysenko W P, Gilpatrick J D, Rybarcyk L J,et al., Determining Phase-Space Properties of the LEDA RFQ Output Beam[J]. arXiv preprint physics/0008186, 2000.

[7] Lysenko W P, Gilpatrick J D, Qiang J, et al. Characterizing proton beam of 6.7 MeV LEDA RFQ by fitting wire-scanner profiles to 3D nonlinear simulations[C],Particle Accelerator Conference, 2001. PAC 2001.Proceedings of the 2001. IEEE, 2001, 4: 3051-3053.

[8] K. R. Crandall et al.,"RFQ Design Codes", Los Alamos National Laboratory report LA-UR-96-1835 (revised February 12, 1997).

[9] M. Reiser, Theory and Design of Charged-Particle Beams (Wiley and Sons, New York, 2nd edition 2008).