BEAM DYNAMICS OF THE 13 MeV/50 mA PROTON LINAC FOR THE COMPACT PULSED HADRON SOURCE AT TSINGHUA UNIVERSITY*

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Abstract

We present the start-to-end simulation result on the high-current proton linac for the Compact Pulsed Hadron Source (CPHS) at Tsinghua University. The CPHS project is a university-based proton accelerator platform (13 MeV, 16 kW, peak current 50 mA, 0.5 ms pulse width at 50 Hz) for multidisciplinary neutron and proton applications. The 13 MeV proton linac contains the ECR ion source, LEBT, RFQ, DTL and HEBT. The function of the whole accelerator system is to produce the proton beam, accelerate it to 13 MeV, and deliver it to the target where one uniform round beam spot is obtained with the diameter of 5 cm.

INTRODUCTION

For the spallation neutron source, the high-current proton accelerator provides one important platform for the multidisciplinary development of condensed matter physics, radiation physics, materials science, aerospace science and life science. One pulsed high-current proton Linac is being built for the Compact Pulsed Hadron Source (CPHS) project at Tsinghua University. With the proton beam bombarding a Beryllium target, the neutron will be generated for the Small Angle Neutron Scattering (SANS) and neutron imaging [1].

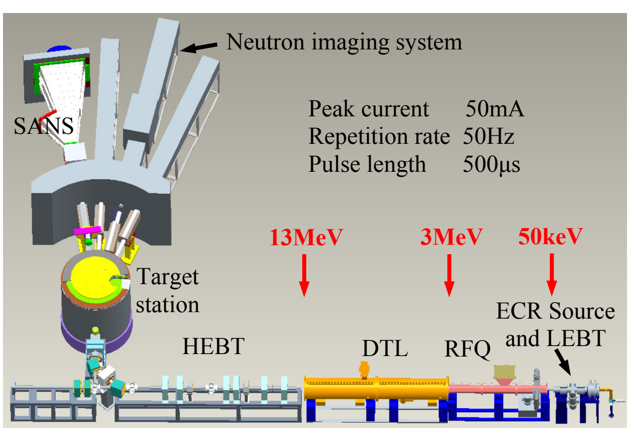

Figure 1: CPHS proton Linac layout.

The function of the whole accelerator system is to produce the proton beam, accelerate it to 13 MeV, and deliver it to the target where one uniform round beam spot is obtained with the diameter of 5 cm. To fulfil this requirement, various codes are adopted to design the Linac and carry out dynamics simulation. The layout of the CPHS proton Linac is shown in Fig. 1. The 13 MeV/50 mA proton linac contains the ECR ion source, LEBT, RFQ, DTL and HEBT. The beam dynamics simulation of the whole accelerator is presented in this paper.

ECR SOURCE AND LEBT

The Electron Cyclotron Resonance (ECR) ion source is adopted to produce the proton beam [2]. After passing through the LEBT, the 50 keV pulsed proton beam (50 Hz/500 μs) is matched to the RFQ (α=1.35, β=7.73 cm/rad). At the entrance of the RFQ, the designed proton beam current is 50 mA with the normalized RMS emittance not larger than 0.2 π mm·mrad.

The 50 keV pulsed proton beam (50 Hz/500 μs) is extracted by a four-electrode extraction system, which consists of the plasma electrode, mid-electrode, suppression electrode and extraction electrode. PBGUNS [3] is adopted for design and simulation of the extraction system.

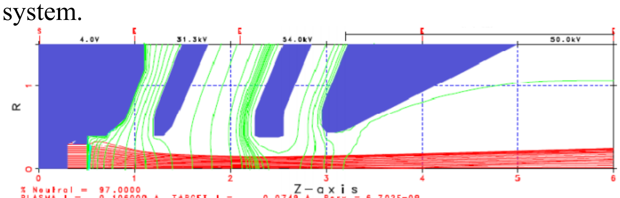

Figure 2: PBGUNS simulation for the LEBT extraction.

To shorten the length of the LEBT, steering magnets are placed inside the two Glaser solenoids. One cone structure (the cone, ACCT and electronic trap) before the RFQ entrance is expected to enhance the proton ratio larger than 85%. The LEBT is designed by PBGUNS and TRACE-3D [4], which agrees well.

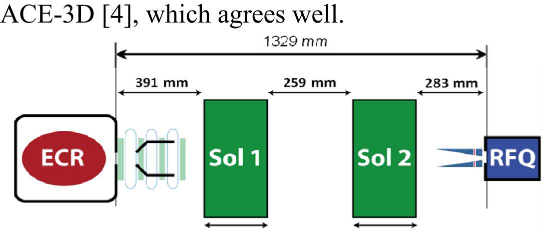

Figure 3: CPHS LEBT configuration.

The beam dynamics from the exit of the ECR source to the entrance of the RFQ is studied by TRACK [5] and TSTEP [6], which can both read the field distribution of

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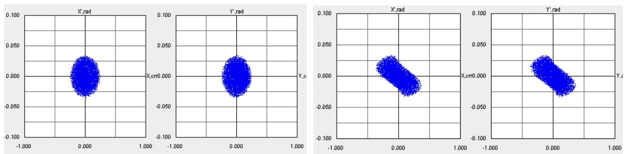
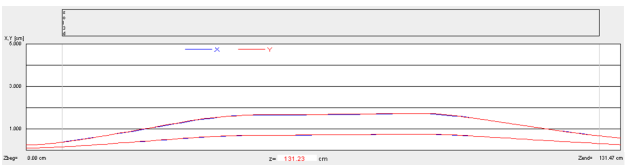
the solenoids generated by other codes to include the field aberration. Figure 4 shows the simulation result by TRACK, in which the space charge neutralization rate is chosen to be 97%. The field of the two Glaser solenoids is calculated by the POISSON/SUPERFISH code [7]. The Twiss parameters at the RFQ entrance can be adjusted by the currents of the two solenoids.



(a) Phase space at the entrance (left) and exit (right) of the LEBT.



(b) Beam envelop along the LEBT.

Figure 4: TRACK simulation result from the exit of the ECR source to the entrance of the RFQ.

RFQ

The 3-meter-long RFQ accelerates the 50 keV proton beam from the ECR source to 3 MeV. The transverse and longitudinal focusing at the high energy end of the RFQ and at the entrance of the DTL have been tailored to provide continuous restoring forces independent of the beam current. The inter-vane voltage is increased with the longitudinal position which is of benefit to producing a short RFQ. Detailed design result of the RFQ can be referred to [8]. The RFQ structure has been designed by PARMTEQM [9] and POISSON/SUPERFISH.

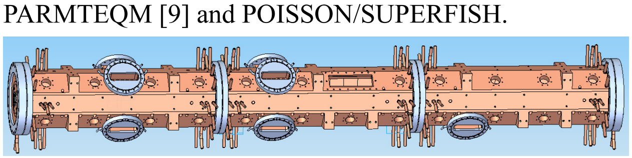


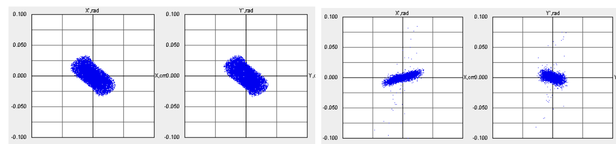
Figure 5: 3D model of the CPHS RFQ.

Simulation results of the RFQ starting from the 4D waterbag model by three codes (PARMTEQM, TOUTATIS [10] and TRACK) have been compared as in Table 1. The transmission rate difference between TRACK and the other two codes shall be further investigated.

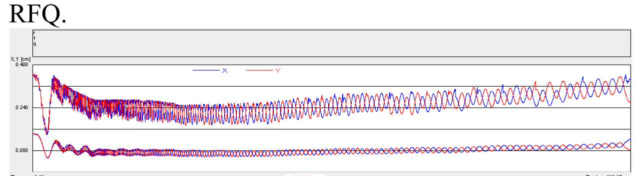
We also carried out the simulation from the LEBT to RFQ by two sets of codes: TRACK and TSTEP/TOUTATIS. In this way the beam matching can be considered between the LEBT and RFQ. Because of the space charge neutralization the currents in the LEBT and RFQ are different. Therefore TRACK simulation was done twice while reading the particle distribution from the LEBT to simulate the beam in the RFQ. TRACK gives the transmission rate of 84.0%, while the result of TOUTATIS is 85.3%.

Table 1: Simulation Results of the CPHS RFQ (Input Parameter: macroparticle number of 10^5, emittance of 0.2 π mm·mrad, current of 60 mA, Twiss parameter $\alpha_{x,y}$=1.35, $\beta_{x,y}$=7.73 cm/rad. All the emittances are rms normalized)

Parameters	PARMTEQM	TOUTATIS	TRACK
Output Trans. emittance (π mm·mrad)	0.246 (x) 0.248 (y)	0.258 (x) 0.263 (y)	0.259 (x) 0.262 (y)
Output Trans. α_O	-2.27 (x) 2.06(y)	-2.19 (x) 2.11(y)	-1.32 (x) 0.53(y)
Output Trans. β_O (cm/rad)	35.2 (x) 36.3 (y)	31.1 (x) 33.0 (y)	48.8 (x) 21.6 (y)
Transmission rate	97.2%	96.3%	91.5%



(a) Phase space at the entrance (left) and exit (right) of the RFQ.



(b) Beam envelop along the RFQ.

Figure 6: TRACK simulation result of the RFQ starting from the LEBT output (transmission rate is 84.0%).

DTL

Samarium-cobalt permanent magnets are adopted as the transverse focusing quadrupoles for the CPHS DTL. The field gradients are designed to be almost constant (84.6 T/m), as shown in Fig. 7. The gradients of the first four quadrupoles are adjusted to match the RFQ directly. The lattice structure is FDFD, which ensures small envelop of the beam. The average accelerating field increases almost linearly from 2.2 MV/m to 3.8 MV/m. The maximum Kilpatrick factor is 1.6.

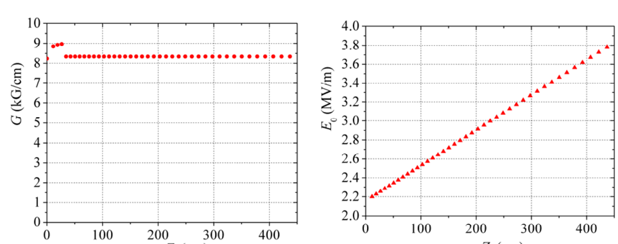


Figure 7: Field gradients of the quadrupoles (left) and average accelerating field (right) of the DTL.

The DTL is designed by PARMILA [11]. The beam dynamics from LEBT to DTL is carried out by TSTEP/TOUTATIS/PARMILA. While TOUTATIS shows the transmission rate of 85.3%, the transmission rate for the accelerated particles in the DTL is 99.9%.

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Most of the particles shifting from the RFQ but out of the bucket are lost in the drift and first four cells of the DTL. Figure 8 gives the beam profile and the longitudinal phase space at the exit of the DTL. The simulation will be cross-checked by the TRACK code.

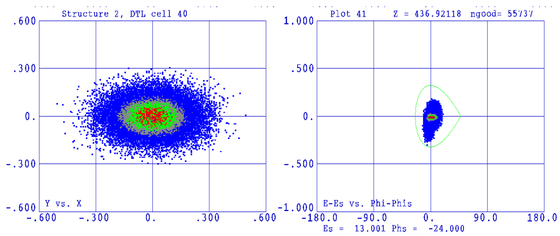

Figure 8: Beam profile and the longitudinal phase space at the exit of the DTL.

HEBT

The HEBT is to deliver the 13 MeV proton beam accelerated by the DTL to the target station, with minimum beam loss, and obtain one uniform round beam spot with the diameter of 5 cm on the Be-target. To decrease the influence of the recoil neutrons on the DTL, the proton beam is deflected before it bombards the target.

Three octupoles are adopted in the HEBT to obtain the uniform round beam spot on the target. The code of TRANSPORT [12] is used to design the basic parameters of each element (nine Quadrupoles and two Dipoles), and determine the optimal position of the three octupole magnets, as shown in Fig. 9.

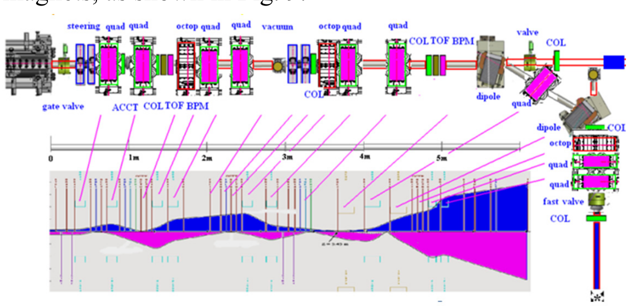

Figure 9: CPHS HEBT layout and TRANSPORT calculation.

The beam dynamics from the DTL output to the end of HEBT is carried out by TURTLE [13] to determine the optimal parameters of the three octupoles. The simulation will be cross-checked by TRACK, which shows the beam envelop in Fig. 10.

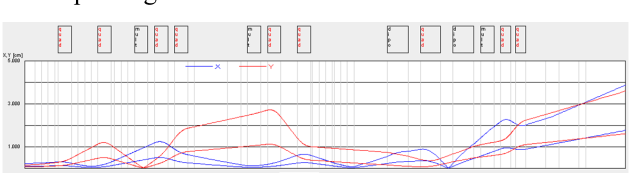

Figure 10: Beam envelop along the HEBT given by the TRACK code starting from the DTL output parameters.

The beam distribution on the target given by the TURTLE code is shown in Fig. 11. The flatness of the distribution is expected to be better than 90%.

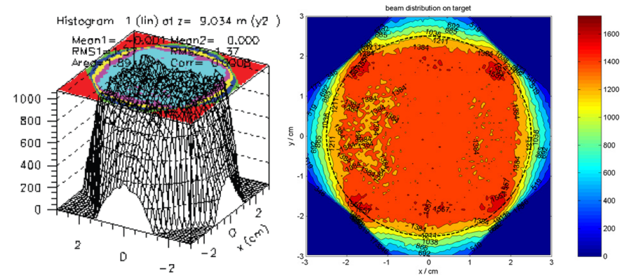

Figure 11: Beam distribution on the target by the TURTLE code.

CONCLUSIONS

The simulation shows that the field aberration of the solenoids is responsible for the mismatching between the LEBT and RFQ. With the particle distribution from the LEBT as input, the transmission rate in the RFQ decreases to about 85%. Moreover, the transmission in the DTL will be almost 100% for the accelerated particles.

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REFERENCES

[1] J. Wei, et al., "The Compact Pulsed Hadron Source Construction Status", IPAC'10, Kyoto, May 2010, MOPEC071, p. 633 (2010), http://www.JACoW.org
[2] Z. Feng, et al., "Design of the 2.45 GHz ECR Proton Source and LEBT in CPHS (Compact Pulsed Hadron Source)", LINAC'10, Tsukuba, September 2010, THP113, p. 1001 (2010), http://www.JACoW.org
[3] J.E. Boers, "An Interactive Version of the PBGUNS Program for the Simulation of Axisymmetric and 2-D, Electron and Ion Beams and Guns", PAC'1995, p. 2312 (1995), http://www.JACoW.org
[4] K.R. Crandall, et al., "TRACE 3-D Documentation", LA-UR-97-886
[5] V.N. Aseev, et al., "TRACK: The New Beam Dynamics Code", PAC'2005, Knoxville, May 2005, p. 2053 (2005), http://www.JACoW.org
[6] http://tstep.lmytechnology.com/TSTEP.html
[7] J. Billen, et al., "Poisson/Superfish", LA-UR-96-1834
[8] Q.Z. Xing, et al., "Design of the CPHS RFQ Linac at Tsinghua University", IPAC'10, Kyoto, May 2010, MOPD047, p. 792 (2010), http://www.JACoW.org
[9] K.R. Crandall, et al., "RFQ Design Codes", LA-UR-96-1836
[10] R. Duperrier, Phys. Rev. ST Accel. Beams 3, 000000 (2000).
[11] J. Billen, "Parmila", LA-UR-98-4478
[12] PSI Graphic Transport Framework by U. Rohrer based on a CERN-SLAC-FERMILAB version by K.L. Brown et al.
[13] PSI Graphic Turtle Framework by U . Rohrer based on a CERN-SLAC-FERMILAB version by K.L. Brown et al.

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