# DESIGN OF THE LOW ENERGY BEAM TRANSPORT LINE FOR Xi`an PROTON APPLICATION FACILITY

R. Tang, Q.Z. Xing, L. Du, Q.Z. Zhang, T.B. Du, H.Y. Zhang, X.L. Guan, X.W. Wang, C.X. Tang*,
Department of Engineering Physics, Tsinghua University, Beijing 100084, China
also at Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Ministry of Education, Beijing 100084, China
W.Q. Guan, Y. He, J. Li, NUTECH Co.Ltd, Beijing 100084,China

*Abstract*

Xi`an Proton Application Facility (XiPAF) is a new proton project which is being constructed for single-event-effect experiments. It provides proton beam with the maximum energy of 230MeV. The accelerator facility of XiPAF mainly contains a 7MeV H- linac injector [1] and a proton synchrotron accelerator. The 7MeV H- linac injector is composed of an ECR ion source, a Low Energy Beam Transport line (LEBT), a Radio Frequency Quadrupole accelerator (RFQ) and a Drift Tube Linac (DTL). The 50keV 10mA H- beam (pulse width of 1ms) extracted from the ion source is expected to be symmetric transversely with the Twiss parameters $\alpha$=0 and $\beta$=0.065 mm/mrad. With an adjustable aperture and an electric chopper in the 1.7m-long LEBT, the beam pulse width of 40μs and peak current of 6mA can be obtained. The H- beam is matched into the downstream RFQ accelerator with $\alpha$=1.051 and $\beta$=0.0494 mm/mrad. This paper presents the detailed design process of the LEBT and the beam dynamics simulation result with the TRACEWIN code.

## LEBT STRUCTURE

In general, Low Energy Transport line (LEBT) is used to match the H- beam between the Ion source and RFQ accelerator. For the linac injector of Xi`an Proton Application Facility (XiPAF), the beam which is expected to be symmetric transversely is extracted from an ECR ion source. A two-solenoid structure is capable of matching the beam in usual. The RFQ accelerator is expected to accelerate the beam with the pulse width of 40μs and input peak current of 6mA, while the Ion Source is designed to produce the beam with the pulse width of 1 ms and peak current of 10 mA. Thus a square aperture and a chopper are inserted into the 1.7m long LEBT. Figure 1 shows the layout of the LEBT. Those elements are related to the beam dynamics. The beam diagnostics devices like faraday cup, ACCT and emittance scanner are included in the design.

With the operation experience of the Compact Pulsed Hadron Source (CPHS) at Tsinghua University, it is difficult to manipulate the beam for the field of the solenoids is overlapped with the field of the steering magnets [2]. The rotating of the beam caused by the solenoids couples with the offset of the beam caused by the steering magnets. Therefore, at XiPAF`s linac injector, those two kinds of magnets are set at different position. The beam is focused and steered separately. It is much easier to match the beam in LEBT. The aperture is set after the steering magnets. The off-axis of the beam is avoided at the position of the aperture.

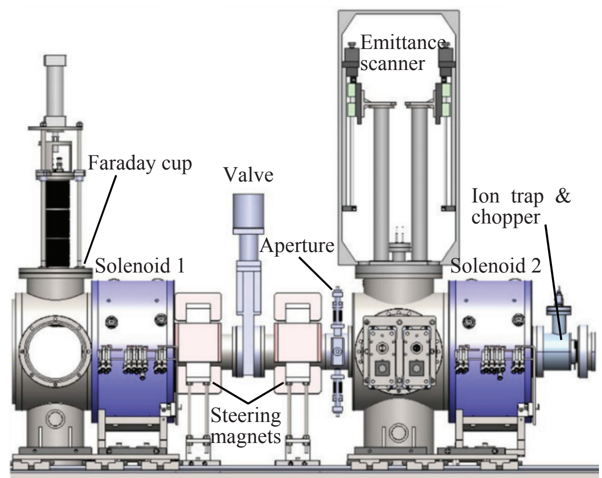


Figure 1: Layout of the Low Energy Beam Transport line (LEBT) of XiPAF.

## DESIGN AND SIMULATION PROCESS

There are four steps in the LEBT design and simulation process. The first step is matching the beam without the chopper and the aperture. The appropriate magnetic field strength of the solenoids are found out. Secondly, insert the square aperture into the LEBT and adjust its size, that decreases the peak current of the beam from 10mA to 6mA as the RFQ required. Thirdly, insert the electric chopper, that chops the pulse width from 1 ms to 40 μs. At last, consider the space charge compensation destroyed after the ion trap, then obtains the final beam parameters at the entrance of the RFQ.

The design purpose of the LEBT is to match the beam from the ion source to the RFQ accelerator with the simulation code. Table 1 shows the symmetric beam parameters at the exit of the ion source and the acceptance at the RFQ entrance. The Twiss parameters at the exit of the ion source are estimated to be $\alpha$=0 and $\beta$=0.065 mm/mrad. The detailed design and simulation results will be presented in the following sections.

*tang.xuh@tsinghua.edu.cn


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Table 1: Beam Parameters at the Exit of the Ion Source (up) and the Acceptance of RFQ (down)

| **Exit of the ion source** | |
|---|---|
| Particle species | H- |
| Particle energy | 50keV |
| Peak current | 10mA |
| Pulse width | 1ms |
| α | 0 |
| β | 0.065 mm/mrad |
| Normalized RMS emittance | 0.2π mm• mrad |

| **Entrance of the RFQ** | |
|---|---|
| Particle species | H- |
| Particle energy | 50keV |
| Peak current | 6mA |
| Pulse width | 40μs |
| α | 1.052 |
| β | 0.0494mm/mrad |
| Normalized RMS emittance | 0.2π mm• mrad |

## SOLENOID

Solenoids are used to focus the beam. The strength of the focusing force is proportional to the square of $B_z$ (the magnetic field strength along the beam line). In avoid of introducing a nonlinear force to the beam, a uniform field distribution will be perfect. However, the space charge force of an intense H- beam is much bigger, comparing with the nonlinear force caused by the field. Two simple solenoids are capable of matching the beam as well as they can be easily manufactured. Figure 2 shows the magnetic field of one solenoid calculated by the SUPERFISH code [3].

There is no permanent magnet in the solenoid, which is different from the CPHS LEBT [2]. The magnetic field strength is proportional to the current. By adjusting the field strength and importing the field distribution into the TRACEWIN code [4], the matched Twiss parameters of the beam at the entrance of the RFQ is achieved. Two max Bz of the solenoids on the beam axis are 2.39 mT and 2.95 mT respectively. The space charge compensation degree of 85% is assumed throughout the whole LEBT. The phase space of the beam at the RFQ entrance is shown in Fig. 3.

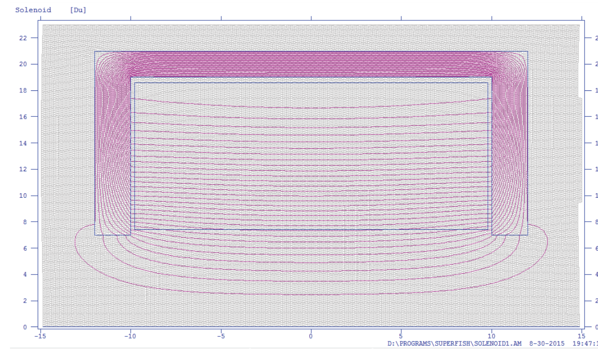

Figure 2: Magnetic field distribution of the solenoid calculated by the SUPERFISH code.

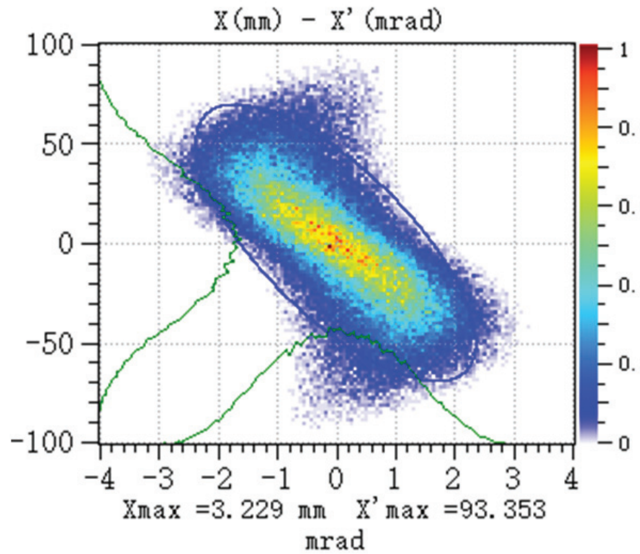


Figure 3: Phase space of the beam at the entrance of the RFQ (y direction is the same with x direction).

## APERTURE

The Aperture is adopted to decrease the beam peak current. The hole of the aperture is a square. Considering that the beam extracted from the ion source may not be exactly 10mA in reality, an adjustable aperture is necessary. And a square aperture is easy to be manufactured. The aperture is composed of four 3 mm-thick molybdenum plates. The primary structure of the aperture is shown in Fig.4. And the range of the aperture is 15~32 mm.

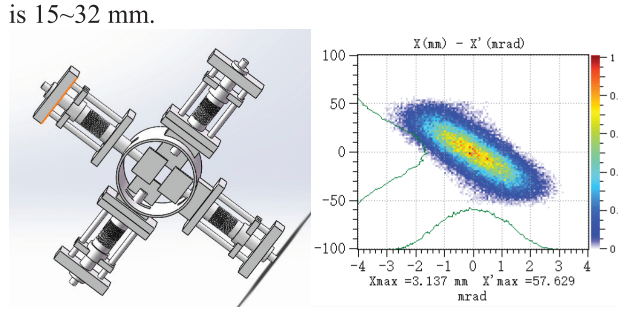


Figure 4: Primary structure of the aperture (left) and particles distribution at the RFQ entrance with the Aperture (right).



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The aperture scraps the beam from 10mA into 6mA as well as decreases the emittance of the beam. Without the aperture, the normalized RMS emittance of the beam at the RFQ entrance in both x and y direction is 0.232 π mm•mrad. After the aperture is inserted, the normalized RMS emittance of the beam at the RFQ entrance is 0.139 π mm•mrad. Fig. 4 also shows the beam distribution at the RFQ entrance with a square aperture with the width of 26.8 mm.

## CHOPPER

A chopper is used to chop the beam pulse width from 1 ms to 40μs in the XiPAF LEBT. Depending on the operation experience of CPHS, a static electric chopper with two parallel plates is enough. The size of the two plates is 70mm (longitudinal direction)*50mm. The distance between the two parallel plates is 60mm. The voltage between the two plates is designed to be 8 kV. Fig. 5 shows the particle distribution at the RFQ entrance after the beam is chopped. The minimum position of the beam in y direction is 7.11 mm. While the radius of the hole on the RFQ entrance flange is 6.92 mm, the chopped beam is lost entirely before entering the RFQ. The electric field produced by the chopper is calculated by the CST code [5]. The simulation is done by the TRACEWIN code after importing the field of the chopper. Because of the field distortion of the chopper near the plate with a high electrical potential, the circle beam spot is distorted. Fig. 5 shows the electric field of the chopper in y direction, and the chopped beam spot at the LEBT exit.

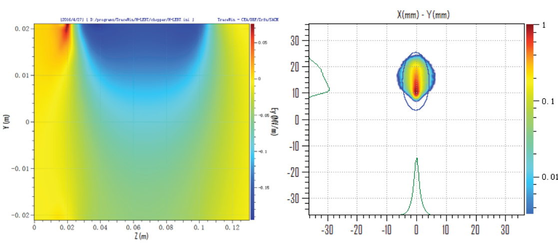


Figure 5: The electric field of the chopper in y direction (left), chopped beam spot at the LEBT exit (right)

## SPACE CHARGE COMPENSATION DESTRUCTION

The previous simulations are carried out with the estimated space charge compensation degree of 85% throughout the whole LEBT. Due to the electric field of the chopper and the RF field near the RFQ entrance, the space charge compensation is destroyed after the ion trap. Considering this in the dynamics simulation of the LEBT, the magnetic field strength of the solenoids is adjusted slightly, and the matched beam is achieved. Fig. 6 shows the beam envelop (y direction) in the whole LEBT with and without the chopper. Fig. 7 shows the matched beam distribution at the RFQ entrance.

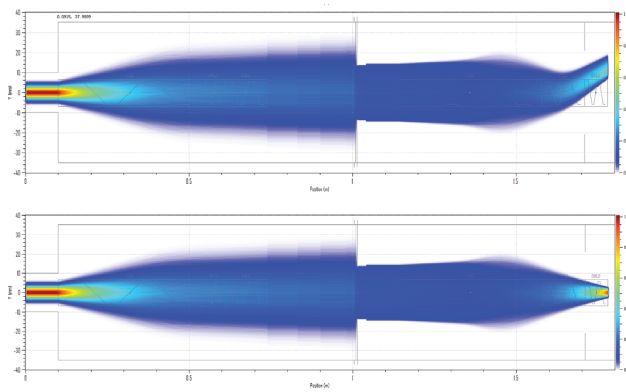

Figure 6: Beam envelop in y direction with chopper (up) and without chopper (down).

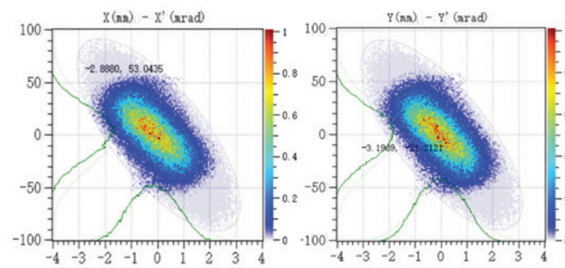


Figure 7: The matched beam distribution at the RFQ entrance (The RFQ acceptance is shown in shadow).

## CONCLUSION

This paper introduces the design process and the simulation results of the LEBT for Xi`an Proton Application Facility. The LEBT is mainly composed of two simple solenoids, an adjustable square aperture and a chopper with the ion-trap. It is capable of delivering a H- beam to the downstream RFQ with the peak current of 6 mA and the pulse width of 40μs. The chopped beam is lost before entering the RFQ. At the RFQ entrance, the parameters of the unchopped beam are $\alpha_x/\alpha_y \approx 0.818$, $\beta_x/\beta_y \approx 0.50$ mm/mrad, $\varepsilon_x/\varepsilon_y \approx 0.14$ π mm•mrad which is consistent with the RFQ acceptance.

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