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ERROR STUDY OF CPHS DTL AFTER ASSEMBLY

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Abstract

The Compact Pulsed Hadron Source (CPHS) at Tsinghua University is one multi-purpose pulsed neutron source. The injector of the CPHS is a linac, which mainly consists of a source, a low-energy beam transport line (LEBT), a radio frequency quadrupole (RFQ) and a drift tube linac (DTL). The error study of the DTL for CPHS is presented in this paper. The error study can provide the field tolerances in the DTL cavity and the alignment tolerance between the RFQ and DTL.

INTRODUCTION

Compact Pulsed Hadron Source (CPHS) at Tsinghua University is a pulsed hadron-source scientific facility based on one high-intensity proton linac. The linac mainly consists of an electron cyclotron resonance (ECR) source, a low-energy beam transport line (LEBT), a radio frequency quadrupole (RFQ) and a drift tube linac (DTL). The construction was launched in 2009 [1]. In July 2013, the 3 MeV RFQ was built, the proton beam was accelerated to 3 MeV [2, 3] and the neutron beam was produced [4]. So far, the 13 MeV DTL cavity is assembled [5]. The DTL will be commissioned and the neutron beam will be produced by the 13 MeV proton beam bombarding the Beryllium target.

PARAMETERS OF DTL

The DTL will accelerate 50 mA proton beams from 3 MeV to 13 MeV to bombard the target [6, 7]. The permanent magnet quadrupoles (PMQs) are used to focus the beam downstream of the RFQ. The PMQs are mounted in the drift tubes with an FD lattice. Besides, no MEBT is used to match the beam between the RFQ and the DTL as the phase advance in the RFQ and DTL are optimized to be continuous.

The total length of the DTL is 4.4 m. The bore radius is 10 mm. The DTL cavity is presented in Fig. 1 [8].

The main design parameters of the DTL are listed in Table 1 [7].

BEAM DYNAMICS

The alignment of the drift tubes has been finished [5]. The alignment results of the DTL, including the displacements and the rotation around the z-axis of the PMQs, are presented in Fig. 2. The RMS value of the displacements of the PMQs is 0.13 mm (x)/ 0.10 mm (y), which is slightly larger than the required value (0.1 mm) [7].

The emittance measured is different from the designed value. According to the result of the emittance meter at the downstream of the RFQ, the normalized RMS emittance is 0.34 π mm·mrad (x)/ 0.35 π mm·mrad (y) [9], which is much larger than the designed value. We can assume that the normalized RMS emittance at the entrance of the DTL is the same on the basis of Liouville's theorem.

As the PMQs are difficult to rectify in the drift tubes, it is necessary to figure out the tolerances of other parameters after the alignment.

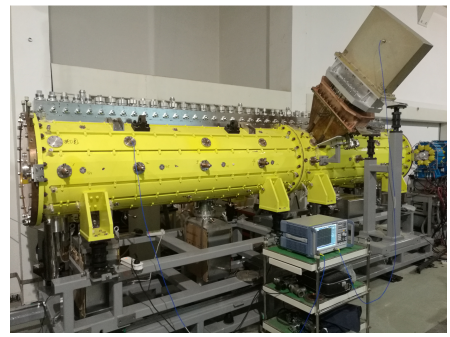

Figure 1: CPHS DTL cavity.

Table 1: DTL Design Parameters

Parameter	**Value**
Ion type	Proton
Input beam energy	3 MeV
Output beam energy	13 MeV
Input Norm. RMS emit.	0.25 π mm·mrad
Peak current	50 mA
RF frequency	325 MHz
Pulse length	0.2 ms
Pulse repetition rate	50 Hz
Cell number	40
Accelerating field	2.2 to 3.8 MV/m
Total RF peak power	1.2 MW
Total length	4.4 m

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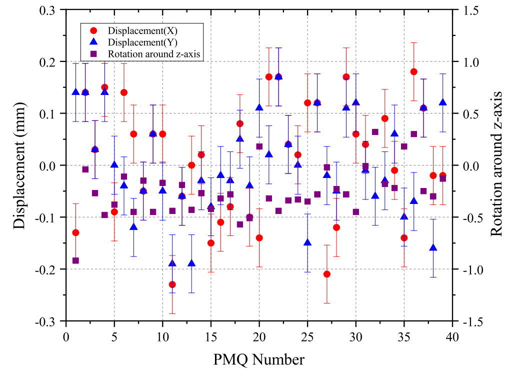

Figure 2: The alignment result of the DTL.

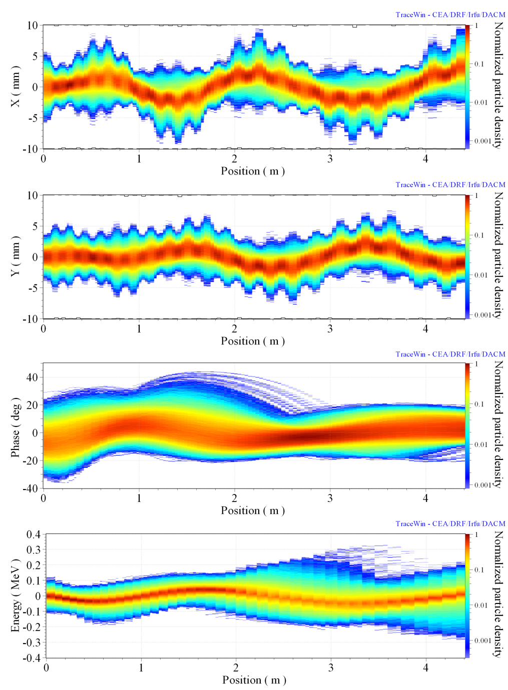

Figure 3: Beam dynamics in the DTL after assembly.

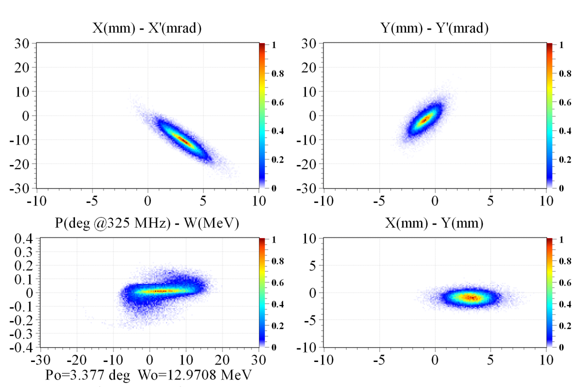

Figure 4: Phase space at the exit of the DTL.

The beam simulation with the alignment results is performed by the TraceWin code [10]. The displacements of the PMQs strongly affect the beam envelope of the DTL, which is shown in Fig. 3. The transmission rate of the DTL given by TraceWin is 99.9%. The phase space at the exit of the DTL is given in Fig. 4.

ERROR ANALYSIS

As the alignment of the drift tubes has been finished, error analysis is now to give a guide to the tuning of the DTL and the alignment between the RFQ and DTL. The process of error analysis is as follows [11, 12]. First, the acceptance will give the allowable range of the input beam. Second, the undetermined errors are checked with error sensitivities. Then the error sensitivities and the practical abilities are used to determine the undetermined error. At last, with all the errors, simulations are carried out to check whether the tolerances need to be modified or not.

Acceptance

The acceptance of the DTL can give a reference to the input beam tolerances. With the displacements of the PMQs, the acceptance of the DTL can be obtained. We also find that the beam center of the acceptance is not in the center of the pipe. The normalized RMS acceptance (see Fig. 5) is 2.19 π mm·mrad (x)/ 2.78 π mm·mrad (y). The center of the acceptance is (1.15 mm, 6.29 mrad) and (-0.53 mm, 3.06 mrad) in *x-x'* plane and *y-y'* plane separately. The acceptance is large enough even though the PMQs are misaligned and the real emittance is larger.

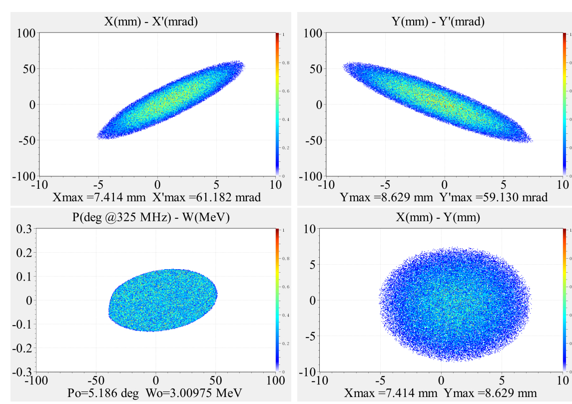

Figure 5: Acceptance of the DTL.

Undetermined Errors

Undetermined errors consist of 1) input beam errors: position and divergence of the beam center, emittance change of the beam, phase and energy jitter, mismatching of the Twiss parameters, current jitter; 2) quadrupole errors: rotation and gradient and 3) RF field errors: field distribution and phase, field and phase of the RF source, field amplitude tilt. Tilt error is introduced in the tuning process as the slope error of the accelerating field [13]. A tilt error of 3% means $0.97E_{0,low}$ at low energy end, $1.03E_{0,high}$ at high energy end, where $E_{0,low}$ and $E_{0,high}$ are the designed values of accelerating field at low and high energy ends.

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As the beam center out from the RFQ is measured by the emittance meter, with an accuracy of ±0.2 mm, the beam position tolerances should be larger.

The error sensitivities of the undetermined errors are studied and the main error tolerances of the DTL are listed in Table 2. "Coupled" and "uncoupled" values in Table 2 correspond to the tolerances of the field of the RF source and field distribution.

Table 2: The Main Error Tolerances of the DTL

Input beam tolerances		**RF field tolerances**	
Position	±0.55 mm	Amplitude (uncoupled)	±3%
Divergence	±5.5 mrad		
Mismatch	15 %	Phase (uncoupled)	±3°
Energy	±0.04 MeV		
Phase	±2°	Amplitude (coupled)	±2%
PMQ tolerances			
Gradient	±3%	Phase (coupled)	±2°
Rotation around x,y	±3°	Amplitude tilt	±3%

Combined Errors

After the error tolerances are given, the comprehensive error study of the beam transmission rate is performed with combinations of all the undetermined errors listed above, including the input beam errors, the quadrupole errors and the RF field errors. The displacement values of the PMQs are the alignment results with an error bar of ±0.056mm. The measured value of emittance is used as the emittance at the entrance of the DTL. The beam center is in the center of the pipe.

The simulation is performed for 1500 times with 50000 macro-particles in each run. The errors are uniformly random distributed within the tolerances. The simulation results are shown in Fig. 6. Beam transmission rate is larger than 98% with the probability of 99%. The beam center is within the range of ±6 mm and ±20 mrad.

FIELD AND BEAM REQUIREMENTS

The field tolerances are guidelines for the tuning, the field distribution error should be smaller than ±3%, the tilt error should be smaller than ±3%. With 20 kHz perturbation, the required tilt sensitivity is less than 150%/MHz.

Also, the proton beams which come out from the DTL probably are not in the center (see Fig. 6), steerers are needed in the HEBT. If the input beam center is the required value, (1.15 mm, 6.29 mrad)(x)/(-0.53 mm, 3.06 mrad)(y), the simulation result with the same tolerances in Table 2 is shown in Fig. 7. Beam transmission rate is larger than 99% with the probability of 99%. Fewer particles are lost in the DTL, which is beneficial for the radiation protection.

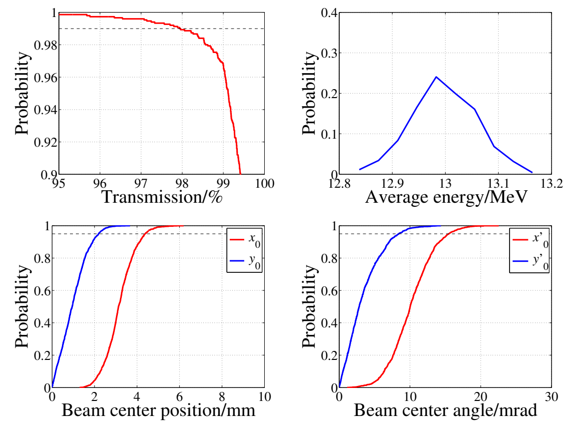

Figure 6: Probability of the transmission rate (top-left), the average energy (top-right), beam center position (bottom-left), beam center angle (bottom-right) at the end of the DTL.

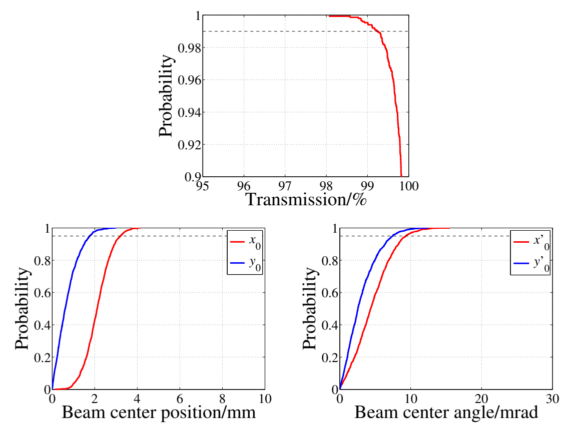

Figure 7: Probability of the transmission rate of the DTL (top), beam center position (bottom-left), beam center angle (bottom-right) at the end of the DTL after changing the input beam.

CONCLUSION AND FUTURE WORK

The error study of the CPHS DTL after collimating has been presented. The error study provides the field tolerances in the DTL cavity and the alignment tolerance between the RFQ and DTL, which guides the tuning and aligning work. Under varies of the errors, the DTL can still perform well, with low particle losses.

The tuning of the DTL has been finished, which meets the demand of the above field tolerances. The DTL will be aligned downstream the RFQ and the beam test of the DTL is expected.

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