COMMISSIONING AND FIRST PERFORMANCE OF THE LINAC-BASED INJECTOR APPLIED IN THE HUST THz-FEL

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Abstract

The construction of a compact high-power THz source based on the free electron laser(FEL), which is constructed in HUST, is undergoing. Before the end of 2014, we have installed most of the key components, completed conditioning of the LINAC-based FEL injector, and performed first beam experiment. During last 5 months, we have established a high efficient beam diagnostic system with a reliable online monitor platform and precise data processing methods. At present, longitudinal properties such as the micro-pulse width and the energy spread are kept to a reasonable level, while transverse emittance compensation by adjusting focusing parameters is still undergoing. In this paper, we will give the summary on the commissioning schedule, detailed commissioning plan, the development of the commissioning and first performance of the LINAC, etc.

INTRODUCTION

Brief Descriptions of the FEL-based LINAC

The THz-FEL facility is mainly composed of a novel EC-ITC RF gun (which consists of a DC electron gun and two independent standing-wave cavities), constant gradient travelling wave structure with a collinear absorbing load and an input coupler which makes the electric field be symmetry, and its focusing coil, beam diagnostics system, microwave power system, vacuum system, control system and so on [1]. The layout and main parameters of the LINAC are given by Fig. 1 and Table 1 respectively, and beam diagnostic equipments are sketched by Fig. 1 either.

By applying the EC-ITC RF gun as the pre-LINAC, and adopting the elements already exist these methods, the length of the whole beam line can be compressed into 2 m, which contributed to a more compact layout for the whole facility.

Beam Diagnostic System

For the sake of compactness, the beam diagnostic system should use the elements which already exist in the facility as far as possible [2]. As Fig. 1 shows, the online beam testing system contains two Toroids, one Flag with a fluorescent screen and a OTR screen, energy analysis system, two fluorescent targets, and three CCD(Charge-Coupled Device) cameras.

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Table 1: Main Specifications

Parameter	Unit	Value
Energy	MeV	4-15
Current	A	0.571(Macro pulse)
Width	us ps	1-5(Macro pulse) 1-10(Micro pulse)
Energy spread	%	0.2-0.5
Nor. emittance	mm mrad	<15
RF frequency	MHz	2856
Input power	MW	20

In order to measure the beam length, we will adopt a method which is by means of a relation of electron energy and its phase in the Linac. When beam located at the "0" phase, the energy spread will change less. If the beam phase located in φ which is different from the "0", their energy spread will change and larger than initial energy spread. This change depend on beam length, so measuring these energy, energy spread and their phase, we can get pulse width [3].

Obviously, we will use quadrupole scanning technique perform normalized emittance measurement [4]. Since the beam matrix at Target2 can be written as Σ_1. And the beam matrix at the entrance of the Quadrupole chosen to be scanned is Σ_0. So that the two beam matrixes can be connected by the transmission matrix of the Quadrupole M, $\Sigma_1 = M\Sigma_0 M'$, If we change the current of the Quadrupole three times, three different beam spot sizes $\sigma_{11}(1)$, $\sigma_{11}(2)$, $\sigma_{11}(3)$ will be obtained on Target2 by CCD3, then we can obtain the following equation set,

$$\begin{pmatrix}\sigma_{11}(1)\\ \sigma_{11}(2)\\ \sigma_{11}(3)\end{pmatrix} = \begin{pmatrix} m^2_{11}(1) & 2m_{11}(1)m_{12}(1) & m^2_{12}(1)\\ m^2_{11}(2) & 2m_{11}(2)m_{12}(2) & m^2_{12}(2)\\ m^2_{11}(3) & 2m_{11}(3)m_{12}(3) & m^2_{12}(3)\end{pmatrix}\begin{pmatrix}\sigma_{11}(0)\\ \sigma_{12}(0)\\ \sigma_{22}(0)\end{pmatrix} \quad (1)$$

By solving above equation set, parameters used to calculate the normalized emittance can be determined, and the following formula should be used,

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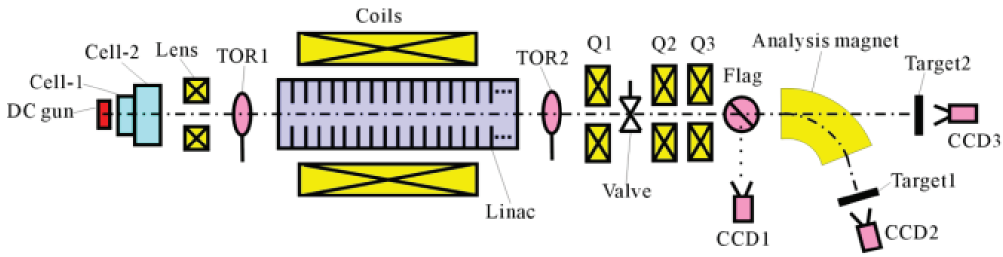

Figure 1: Layout of the HUST THz-FEL LINAC.

$$\varepsilon_x = \beta\gamma\sqrt{\sigma_{11}\sigma_{22} - \sigma^2_{12}} \tag{2}$$

where, β and γ are the relative velocity and relativity factor, respectively. Observed from Fig. 1, we apply an analysis magnet for the energy spread measurement. The whole energy analysis system can be expressed by Equation 3,

$$\begin{pmatrix} x_1 \\ x_1' \\ (\frac{\Delta p}{p})_1 \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix} \begin{pmatrix} x_0 \\ x_0' \\ (\frac{\Delta p}{p})_0 \end{pmatrix} \tag{3}$$

Under designing, by choosing suitable parameters, m_{12} is set to 0, and m_{11} should be designed close to 0 as far as possible. Then, by observe the beam spot on Flag and Target1, beam radii at these two position can be obtained, so that the energy spread can be calculated by Equation 4.

$$\frac{\Delta p}{p} = \sqrt{\sigma_1^2 - (m_{11} \cdot \sigma_0)^2} \,/\, m_{13} \tag{4}$$

BEAM COMMISSIONING

Commissioning of the Electron Gun

Before performing the beam commissioning for the LINAC, the vacuum of the whole system must have a stable level which is better than 5×10^{-6}Pa, and the conditioning work for the pre-injector and the travelling-wave accelerator must be completed. In addition, we must activate the DC electron gun. Table 2 shows the technical parameters of the gun.

Apparently, the calculate value of the perveance 2.10uP by using experiment results, is very close to the designed value 2.17uP.

The cathode activation can be conducted by following four steps,

- ***Cathode Disintegration:*** Under the vacuum condition of 1×10^{-5}Pa~1×10^{-4}Pa, add the filament current from 0 to 6.5A gradually.
- ***Thermal activation and low-voltage activation:*** make the filament current a little higher than the rated value (6.3A) and stay for a while; under the rated filament current, add the anode voltage from 0 to 10kV gradually.
- ***HV conditioning:*** reduce the filament current to 0, and add the anode voltage to 20kV gradually.
- ***Electron activation:*** under the rated filament current, add the anode voltage gradually, then test the emitting current and calculate the perveance, shown in Fig. 2. The electron gun activation is completed if the perveance matches with the designed value.

Table 2: Technical Parameters

Parameter	Rated value	Maximum value
Anode voltage	15kV	20kV
Emitting current	4.0A	
Perveance	2.17uP	
Waist radius	1.0mm	
Beam range	8.5mm	
Pulse width	4us	
Duty ratio	0.04%	
Filament voltage	6.0V	6.3V
Filament current	6.3A	6.5A

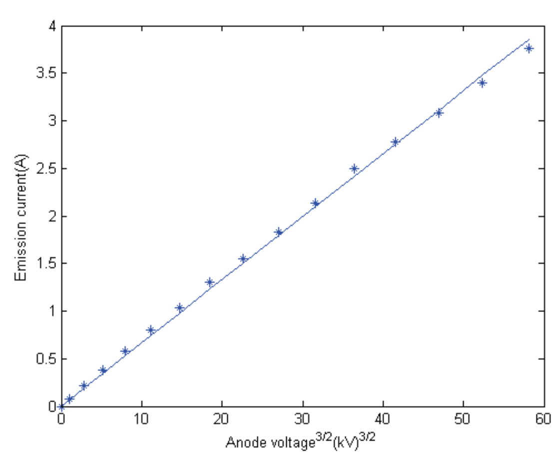

Figure 2: Measurement results for the perveance.

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Commissioning of the LINAC

For the sake of compactness and cost-effectiveness, we only reserved sufficient space for key components and inevitable measurement tools on the beamline during the designing process, so that a more compact layout were obtained as described in Fig. 1. However, unavoidable difficulties and complications were induced in the beam commissioning process for the HUST THz-FEL LINAC. In order to fix these problems and pursue high-effectively commissioning methods, a simplified technology road-map is summarized based on many experiments and dynamic simulations, which is shown in Fig. 3.

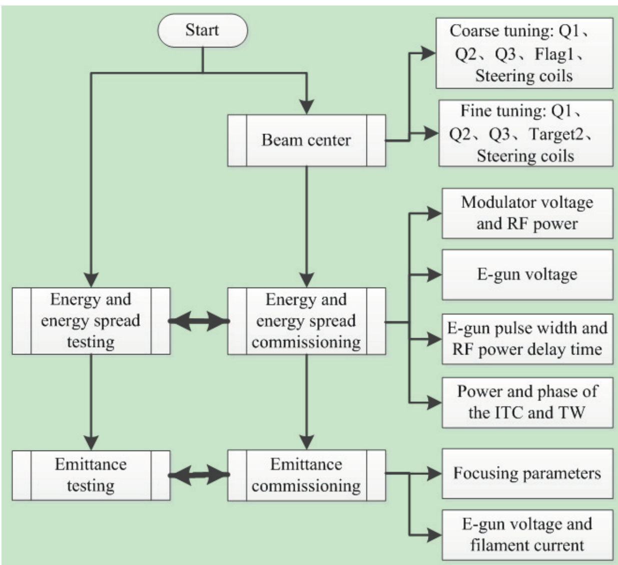

Figure 3: Technology Roadmap for beam commissioning.

FIRST BEAM EXPERIMENT

As mentioned above, we have established a high efficient beam commissioning scheme and beam diagnostic system. At present, several beam parameters such as energy spread, beam current, beam energy, etc. are tuned to a reasonable level, corresponding measurement results are listed in Table 3. Additionally, beam spot information of the energy analysis system is acquired by online monitor system, which is given in Fig. 4.

Table 3: Measurement Results

Parameter	Unit	Value
Energy	MeV	13
Current	A	0.744(Macro pulse)
Width	us	4(Macro pulse)
Energy spread	%	0.5
RF frequency	MHz	2856
Input power	MW	20

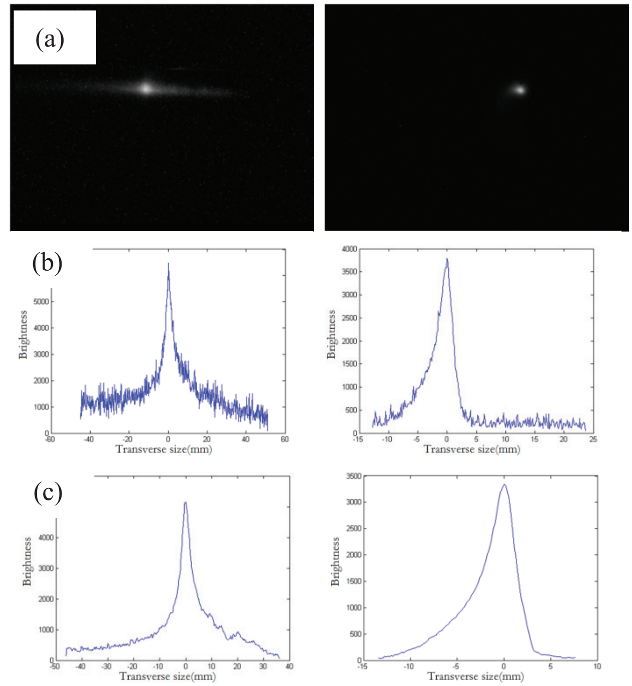

Figure 4: Beam spot information of the energy analysis system. (a) Beam spots on Target1 and Target2, (b) Brightness distributions of the Beam spots on Target1 and Target2, (c) Brightness distributions after picture processing.

CONCLUSIONS

Though some key parameters of the extracted beam from the HUST THz-FEL LINAC are tuned into a acceptable range by adopting a high efficient commissioning method, transverse emittance compensation by adjusting focusing parameters is still undergoing. And the stability of the whole system must be considered in the future commissioning .

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