BEAM DIAGNOSTIC OF THE LINAC FOR THE COMPACT HIGH-PERFORMANCE THz-FEL

T.N. Hu, B. Qin, P. Tan, K.F. Liu, Y.Q. Xiong, J. Yang, Q.S. Chen, W. Chen,
State Key Lab. of AEET, HUST, Wuhan 430074, China
Y.J. Pei[#], Z.X. Tang, J. Liu, NSRL, USTC, Hefei 230029, China
Z.M. Wang, Chinagray, Hefei 230088, China

Abstract

With the aim to obtain short-pulse bunches with high peak current for a terahertz radiation source, an FEL-based LINAC is employed in HUST THz-FEL, and the LINAC consists of an EC-ITC RF gun, a disk-loaed waveguide structure with a constant gradient and collinear absorbing loads with focusing coils surrounded and so on. To achieve a balance between compactness and high performance, beam diagnostic system should be simple and high-precision. So that a cost-effective measurement scheme for the high-brightness beam extracted by the LINAC is needed. This paper will describe the beam line and beam diagnostic system of the LINAC in the HUST THz-FEL in detail and give corresponding assembly scheme. In addition, online monitor system is introduced.

BEAM LINE OF THE FEL-BASED LINAC

To achieve a balance of high performance and compact layout for a THz-FEL facility, HUST and USTC are cooperating to construct such a machine and perform corresponding experiment researches. And the facility is under commissioning right now. This facility is mainly composed of a novel EC-ITC RF gun, 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.

Table 1: Main Specifications

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

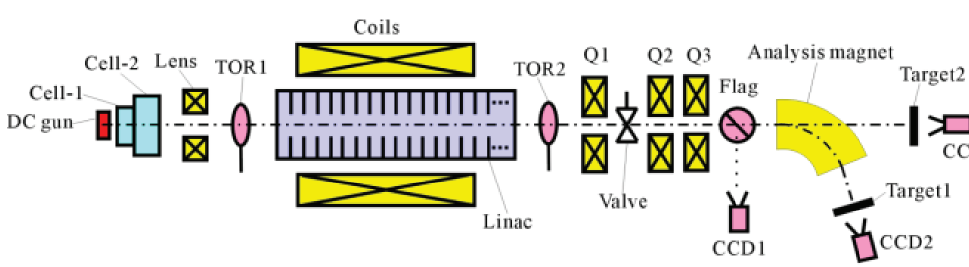

Figure 1: Layout of the HUST THz-FEL LINAC.

As the most important element, the EC-ITC RF gun plays a role of transfer DC beam to short bunches, and determines beam properties of the LINAC such as energy spread, transverse emittance, bunch length. In addition, by using velocity bunching of the standing-wave cavity, this type of gun can realize energy spread self-compensation, so that it helps to achieve the purpose of compressing the facility sizes.

Previous researches shown that, high quality bunches with ~0.3% energy spread, ~10mm mrad emittance, 201pC charge and ~2ps length can be generated by the EC-ITC RF gun[2,3]. However, in the process of dynamic calculations, a 5A DC beam are adopted as the input beam of the EC-ITC RF gun by means of parallel injection. In the actual situation, the DC electron gun has been designed to generate 4A DC beam, and it would be injected to the EC-ITC RF gun by negative angle. To press close to the actual situation, a 4A beam with negative angle is imitated, which can be shown by Fig. 2.

By adjusting power and phase parameters of two cells of the ITC cavities, the optimal results can be obtained. Dynamic results calculated by Parmela are shown in Fig. 3, meanwhile, detailed specifications of the bunches generated by EC-ITC RF gun with negative angle injection are listed in Table 2.

ISBN 978-3-95450-168-7

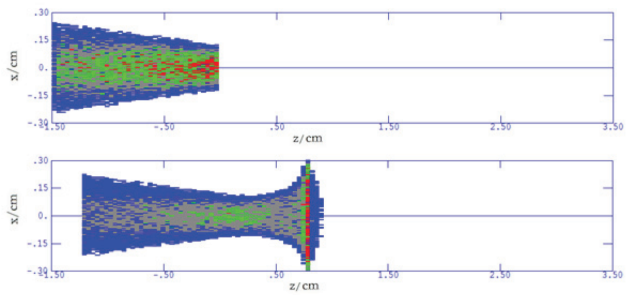

Figure 2: Longitudinal profile at different time of the DC beam with negative angle injection.

Table 2: Main Specifications of the Bunch Generated by the EC-ITC RF Gun with Negative Angle Injection

Parameter	Unit	Value
Energy	MeV	2.6
Width	ps	1.0 (Micro pulse)
Energy spread	%	0.14
Nor. emittance	mm mrad	8.0
Effective charge	pC	245 (Micro pulse)

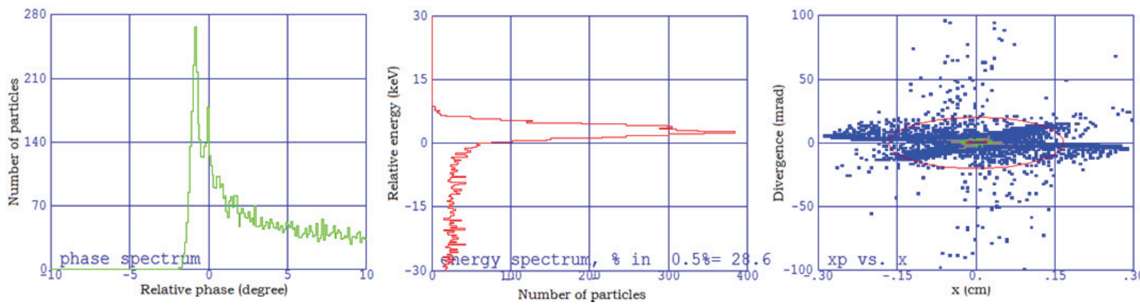

Figure 3: Phase spectrum, energy spectrum and transverse phase space of the bunch extracted from the EC-ITC RF gun.

Obviously, by using negative angle injection, the most important parameter, effective charge is improved by 20%, while other targets such as energy spread and emittance are not deteriorated. At a certain content, the dynamic results are encouraged us to perform experiment researches for the HUST THz-FEL LINAC.

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. As Fig. 1 shows, the online beam testing system contains two Torrids, one Flag with a fluorescent screen and a OTR screen, energy analysis system, two fluorescent targets, and three CCD(Charge-Coupled Device) cameras. Correspondingly, beam parameters we need measure and corresponding testing methods are simply described as the following,

- ***Macro pulse current:*** TOR1, TOR2.
- ***Beam energy:*** Analysis magnet, Target1, CCD2.
- ***Energy spread:*** Flag, CCD1, Analysis magnet, Target1, CCD2.
- ***Normalized emittance:*** Quadrupoles (Q1, Q2 or Q3).
- ***Micro pulse width:*** Linac, Flag, CCD1, Analysis magnet, Target1, CCD2 and phase shifter.

The online monitor system is showed by Fig. 4 clearly.

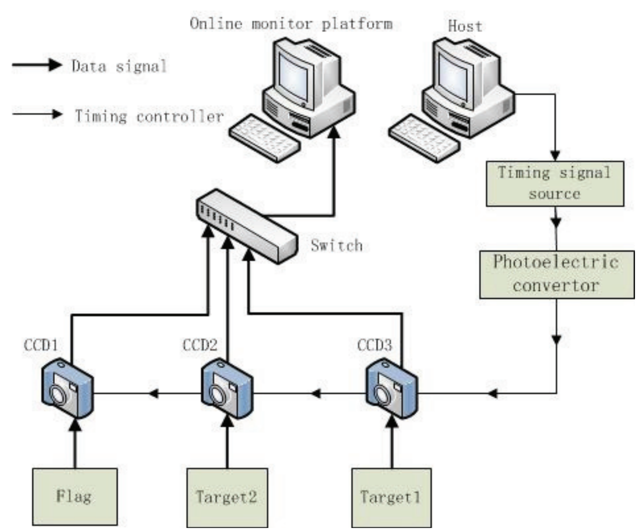

Figure 4: online monitor system

Micro Pulse width Measurement

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[4].

Normal Emittance Measurement

As mentioned above, we will use Quadrupoles in the beam line to perform normalized emittance measurement. And the well-known quadrupole scanning technique is widely used in the accelerator physics community[5]. However, the common method of thin focusing lens approximation is not suitable for the HUST THz-FEL LINAC. Because our case cannot satisfy $\sqrt{k}L_Q \to 0$ by considering facility compactness during previous designing process. Where, k and L_Q are the focusing constant and the effective length of the Quadrupole adopted to measure the emittance, respectively. Therefore, we will use transmission matrix to solve equation set directly.

Apparently, 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, $\Sigma_1 = M\Sigma_0 M^t$, which can be expressed in detail as the following,

$$\begin{pmatrix} \sigma_{11}(1) & \sigma_{12}(1) \\ \sigma_{12}(1) & \sigma_{22}(1) \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} \begin{pmatrix} \sigma_{11}(0) & \sigma_{12}(0) \\ \sigma_{12}(0) & \sigma_{22}(0) \end{pmatrix} \begin{pmatrix} m_{11} & m_{21} \\ m_{12} & m_{22} \end{pmatrix} \quad (1)$$

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,

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

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

$$\varepsilon_x = \beta\gamma\sqrt{\sigma_{11}\sigma_{22} - \sigma^2_{12}} \quad (3)$$

Where, β and γ are the relative velocity and relativity factor, respectively.

Energy Spread Measurement

Observed from Fig. 1, we apply an analysis magnet for the energy spread measurement. The whole energy analysis system can be expressed by Equation 4,

$$\begin{pmatrix} x_1 \\ x_1' \\ (\frac{\Delta p}{p})_1 \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix} \begin{pmatrix} x_0 \\ x_0' \\ (\frac{\Delta p}{p})_0 \end{pmatrix} \quad (4)$$

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 5.

$$x_1 = m_{11}x_0 + m_{13}\frac{\Delta p}{p} \quad (5)$$

CONCLUSION

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 2m, which contributed to a more compact layout for the whole facility.

ACKNOWLEDGMENT

The authors would like to thank Professor Kuanjun Fan, Lei Shang, Kai Jin and Ping Lu for consultations.

REFERENCES

[1] Y.J. Pei, et al., “Design of 14MeV Linac for THz source based FEL”, Proceedings of IPAC2013, Shanghai, China. 2181-2183 (2013).

[2] T.N. Hu, et al., “Physical design of FEL LINAC based on performance-enhanced EC-ITC RF gun”, Chinese Physics C, 38, 018101 (2014).

[3] T.N. Hu et al., "Study of beam transverse properties of a thermionic electron gun for application to a compact THz free electron laser", Review of Scientific Instruments, 85, 103302 (2014).

[4] Y.J. Pei, et al., "R & D on a compact EC-ITC RF gun for FEL", Proceedings of IPAC'10, Kyoto, Japan. 1737-1739 (2010).

[5] H. Wiedemann, Particle Accelerator Physics: Basic Principles and Linear Beam Dynamics (Springer-Verlag, New York, 1993).