DESIGN OF BEAM MEASUREMENT SYSTEM FOR HIGH BRIGHTNESS INJECTOR IN HLS*

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Abstract

A high brightness injector has been developing in HLS (Hefei Light Source), and the design of beam parameter measurement system is presented in this paper. The whole system will measure beam position, beam current, emittance of beam, bunch length, beam energy and energy spread. For the beam position, we have designed three types of BPMs: stripline BPM, with the resolution of 20 μm; cavity BPM, with the resolution of 10 μm, and resonant stripline BPM. The beam position processor Libera will be used. The beam current will measured using the ICT and FCT. When going out of the gun, the energy of the beam is about 4MeV ~ 5MeV, and the emittance of the beam is charge-dominated, so we use a set of slits with the width of 90 μm to split the beam to beamlets. The bunch length is measured using OTR and streak camera. Before entering the bending magnet, the beam will go pass a very narrow slit, with the width of 90 μm, and the resolution of energy spread will be improved.

INTRODUCTION

The operation of short wavelength Free Electron Lasers (FELs) requires the usage of electron beams with extraordinary beam quality [1]. Besides this demand for very low transverse emittance of electron beams with medium-high bunch charges, the technology choice for the linear accelerator driving the FEL might place additional requirements on the time structure of the electron bunches. The RF photocathode injector in HLS is designed to produce high brightness beam with the transverse normalize emittance of 6mm mrad for a bunch charge of 0.3 nC. The longitudinal FWHM of each bunch is about 8 ps. The RMS energy spread is less than 0.5%, with the energy of 4 MeV ~ 5MeV at the exit of the RF photocathode gun. As these beam parameters have been improved, many new methods and new technologies in beam diagnostics should be in research.

BEAM MEASUREMENT SYSTEM SETUP

A detailed layout of the current beam measurement system in HLS is shown in Fig. 1. This low energy diagnostic section is used after the electrons produced from the RF gun.

This section consists of different view screens, BPMs, charge measurement components, beam energy measurement device and longitudinal bunch length measurement device. Fig.2 (a) shows two kinds of view screens: OTR screen and YAG screen. Compared to YAG screen, the OTR screen has higher spatial resolution and faster temporal response, but lower intensity [2]. At each position, two screens are both used. The charge per bunch can be monitored non-destructively using ICT and FCT at the Position B and Position E, and it can also be monitored destructively using Faraday Cup. BPMs are mounted at Position C, Position F and Position K. Slit in Position A and OTR/YAG screen in Position D are used to measure emittance, so are slit in Position D and OTR/YAG screen in Position G. Beam energy and energy spread can be measured using slit in Position H, bending magnet in Position I and OTR/YAG screen in Position J. Additionally, the bunch length can be measured using OTR and streak camera.

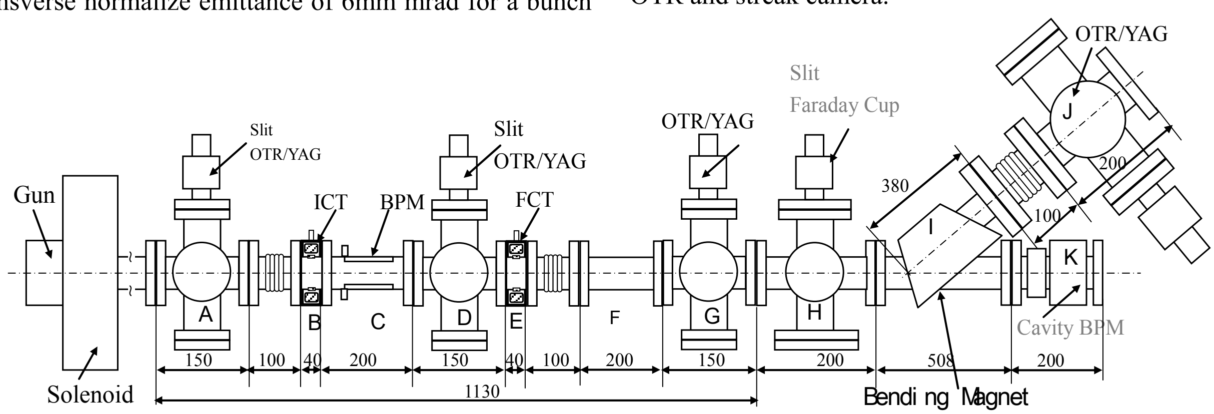

Figure 1: Layout of Beam Diagnostic for High-Brightness Injector in HLS.

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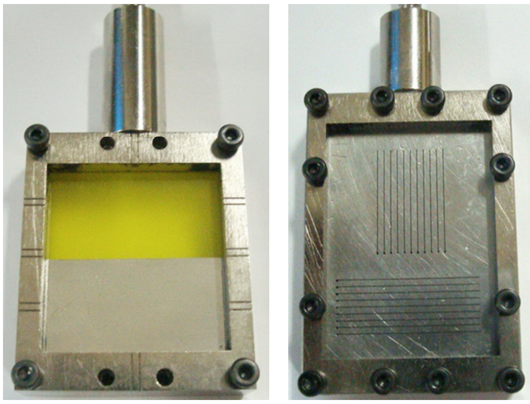

(a) YAG/OTR Screen (b) Multi-slits

Figure 2: Outline of YAG/OTR Screen and Multi-slits. (a) Top of Left Photo is YAG Screen; While Below is OTR Screen. (b) Top of Right Photo is for Vertical Emittance Measurement; While Below is for Horizontal Measurement.

Emittance Measurement

The slits reduce the dominated space charge incoming beam into some emittance-dominated beamlets that drift up to a YAG/OTR screen, as it shows in Fig. 3. If the screen response is linear, the intensity of beamlets spots on the screen are directly proportional to the number of particles in the beamlets which hit the screen and the RMS un-normalized emittance value can be retrieved by the formula [3].

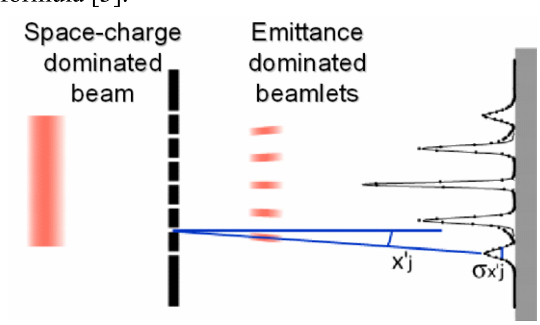

Figure 3: Schematic Diagram of Space Charge Dominated Beam Separated into Beamlets by Multi-slits

A set of multi-slits has been made, as it shows in Fig. 2 (b). The material is stainless steel; the thickness is 2 mm; the width of each slit is 90 μm; the distance between adjacent slits is 1 mm and the distance between multi-slits and screen is 490 mm. The multi-slits in Position A and the screen in Position D are a pair, so are the multi-slits in Position D and the screen in Position G.

We know whether the beam is charge-dominated or emittance-dominated can be judged by R_{sc}:

$$R_{sc} = \frac{I\sigma_x^2}{2I_A\gamma\varepsilon_n^2} \tag{1}$$

Where, ε_n is the normalized emittance, I is the peak beam current, and I_A = 17 kA is the Alfven current. When R_{sc} is far less than 1, the space charge effect is neglectable, and the beam is emittance-dominated, where linear theory can be applied.

If there is no multi-slits, the parameters are I=35A, σ_x =2mm, γ =8, ε_n =6mm mrad, and R_{sc} will be 14, which means the beam is absolutely charge-dominated. If the multi-slits is inserted in, the parameters of the beamlets are σ_x =0.09mm, γ =8, ε_n =6mm mrad, and R_{sc} will be 0.028, so they are emittance-dominated.

Beam Energy and Energy Spread Measurement

Bending magnet and screens are usually used in Linac beam energy and energy spread measurement, as it shows in Fig. 4 [4].

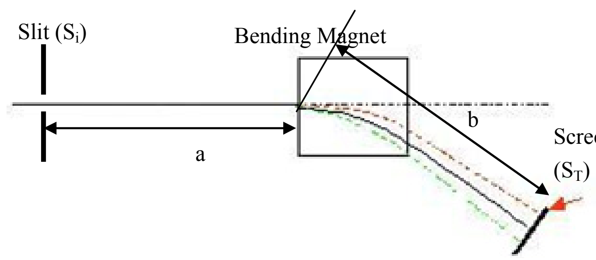

Figure 4: Schematic Diagram of Energy and Energy Spread Measurement

The transmission matrix from slit (S$_i$) to screen (S$_T$) can be described as following:

$$M_0^T = \begin{bmatrix} m_{x11} & m_{x12} & m_{x13} \\ m_{x21} & m_{x22} & m_{x23} \\ m_{x31} & m_{x32} & m_{x33} \end{bmatrix} \tag{2}$$

The particles hit in the screen is

$$x_T = m_{x11}x_i + m_{x12}x_i' + m_{x13}\frac{\Delta E}{E_0} \tag{3}$$

We change the distance between slit and bending magnet, which is a, and the distance between bending magnet and screen, which is b, to make m_{x12} be equal to zero. And we add a slit with the width of 90µm to minimize the affection of m_{x11}.

Fig. 5 shows the relations between a, b, m_{x11} and m_{x13}. We choose a proper distance, a=174.66 mm, and b should be 970 mm, then m_{x13} is equal to 938, and m_{x11} is equal to -3.4.

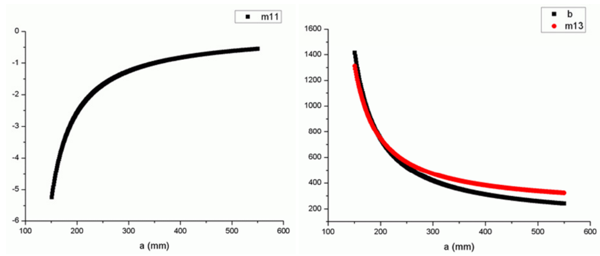

Figure 5: Simulation Curves between Different Parameters When M_{x12} is Equal to Zero.

BPMs

Fig. 6 shows a stripline BPM which will be mounted at Position C, with the resolution of 20μm [5]. The length of the strip line electrode is 26.26mm; just a quarter wavelength of centre frequency of 2856 MHz, with one end is shorted. The angle of the electrode is 45 degrees, and the feedthroughs are connected to 50-Ω coaxial connectors. A cavity BPM is being manufactured, with the centre frequency of 2448MHz, resolution of 10μm [6], and it will be placed at the Position K. The resonant stripline BPM is in simulation and Position F is prepared for it [7]. The centre frequency is designed to 1836MHz, which can be mixed with half of 2856 MHz to 408 MHz.

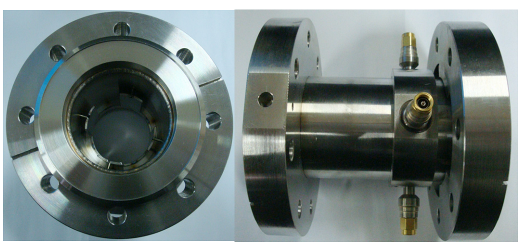

Figure 6: Photograph of Stripline BPM.

The signals picked up from BPMs will be sent into Libera or Log-Ratio Position Signal Processing Module to calculate the beam parameters. As the frequency Libera works at is just 408MHz, we are developing a new hardware with a higher work frequency.

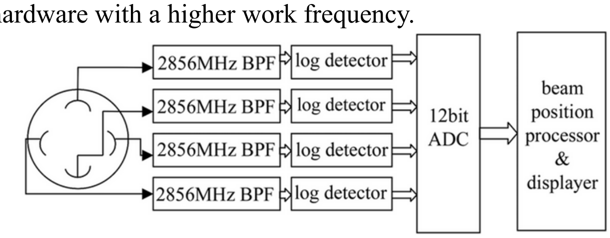

Figure 7: Block Diagram of Log-Ratio Position Signal Processing Module

In Log-Ration Processing Module [5], the signals will pass through a set of BPF, which centre frequency is 2856 MHz and bandwidth is 10 MHz. Then the power of the signals will be detected by the log detectors and sent into a 12-bit ADC to produce the digital signals which are needed for upper processor, as it shows in Fig. 7.

Beam Current Monitor

The beam charge or current can be monitored by using integrating current transformer (ICT) and fast current transformer (FCT) manufactured by Bergoz. The FCT is a passive AC transformer and used to measure peak current, as it shows in Fig. 8. The ICT stretches a beam bunch of a few picoseconds to an output pulse of a few nanoseconds to measure beam charge.

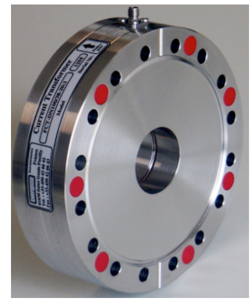

Figure 8: Beam Current Monitor.

FUTURE WORKS

Most of the works have been done are just in simulation or in offline testing. Several months later, these components of beam diagnostic will be assembled and installed to the high-brightness injector. And then, we will optimize the beam diagnostics system step by step according to the new situations, developing the hardware and software depending on the needs.

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