DESIGN OF THE BEAM DIAGNOSTICS SYSTEM FOR A NEW IR-FEL FACILITY AT NSRL*

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Abstract

A new IR-FEL has been designed at NSRL. This facility will provides electron energy from 15 to 60 MeV, beam bunch with a macro-pulse length of 5~10 μs and a general micro-pulse repetition rate of 238 MHz, pulsed radiation with up to 100 mJ at about 0.3%~3% FWHM bandwidth. So the diagnostics system is necessary to monitor the performance of the bunch and the character of the FEL radiation, such as the beam position and profile, emittance, energy spread, laser intensity, etc. The beam diagnostics system mainly consists of Flags, a diagnostics beam line, BPMs, pop-in monitors and a FEL monitor system. This paper introduces the construction of this diagnostics system.

INTRODUCTION

The National Synchrotron Radiation Laboratory (NSRL) is embarking on setting up a new infrared FEL facility to provide intense, pulsed laser radiation, continuously tunable from mid-infrared (MIR) to far-infrared (FIR). This facility is consist of an electron injector, linear accelerator, beam transport system, undulator, control system, beam diagnostic system and other auxiliary system. It is important to set up a reliable beam diagnostics system with completed function and high performance. So that it can provide various parameters of the electron beam in real time for the facility debugging and monitor the beam performance on-line during the operation stage. To meet these requirements, a complete diagnostics system should have the ability to measure the beam position and orbit, emittance, beam energy and energy spread, beam current intensity, beam parameters in the undulator and the infrared laser performance. Figure 1 shows the layout of the beam diagnostics system and Table 1 shows the main type and parameters of the detectors.

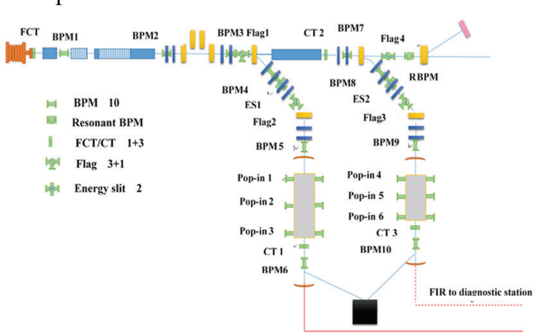

Figure 1: Layout of the beam diagnostics system.

Table 1: Summary of Essential Parameters of the IR-FEL

Parameter	**Value**
Electron energy	15-60 MeV
Energy spread	<0.4 %
Beam charge (I_{peak})	100 A
Radiation wavelength	2.5~50 , 400~200 μm
Emittance	<30 mm·mrad
Micropulse length	5~10 ps
Micropulse energy	20 mJ
Macropulse length	5~10 ms
Macropulse energy	<100 mJ
Bandwidth	0.3~3 %
Continuous tunability	300~400 %

BEAM DIAGNOSTICS SYSTEM

Beam Profile and Emittance Measurement

The measurement of the profile mainly used for calculating the beam profile and beam emittance. There are four Flags in the whole beam line. Each flag equips a fluorescent/OTR screen to image the beam spot. The fluorescent screen with high sensitivity is used for observing the size and position of the beam spot. And the OTR screen is used for measure various parameters such as beam profile size and beam emittance.

The emittance can be determined from a series of profile measurement by changing the focusing strength of a quadrupole [1], as schematically shown in Figure 2. For LINACs with a straight, non-dispersive transfer line, the transformation from a location S_0 to S_1 is given by a 2 × 2 transfer matrix **R**, which is related to quadrupole's focusing strength k and the distance l between S_0 and S_1. So the beam width x_1 is measured at S_1 and the equation for the element $\sigma_{11}(k_1)$ is given by:

$$x_1^2(1) = \sigma_{11}(1) = R_{11}^2\sigma_{11}(0) + 2R_{11}R_{12}\sigma_{12}(0) + R_{12}^2\sigma_{22}(0) \quad (1)$$

This is a linear equation for the unknown three beam matrix elements $\sigma_{11}(0)$ at location S_0.To get a solution, at least three different settings of the quadrupole strength k_i are needed. When $i \geq 3$, we can get a redundant system of linear equation with the different settings of focusing strength $k_1, k_2 \ldots k_n$:

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$$\begin{aligned}
\sigma_{11}(1,k_1) &= R_{11}^2(k_1)\sigma_{11}(0)+2R_{11}(k_1)R_{12}(k_1)\sigma_{12}(0)+R_{12}^2(k_1)\sigma_{22}(0)\\
\sigma_{11}(1,k_2) &= R_{11}^2(k_2)\sigma_{11}(0)+2R_{11}(k_2)R_{12}(k_2)\sigma_{12}(0)+R_{12}^2(k_2)\sigma_{22}(0)\\
&\cdots\\
\sigma_{11}(1,k_n) &= R_{11}^2(k_n)\sigma_{11}(0)+2R_{11}(k_n)R_{12}(k_2)\sigma_{12}(0)+R_{12}^2(k_n)\sigma_{22}(0)
\end{aligned} \tag{2}$$

The solution of this system are the values of the beam matrix $\sigma_{ij}(0)$ at the entrance of the quadrupole magnet. Then the absolute emittance is calculated as following:

$$\varepsilon = \sqrt{\det \sigma(0)} = \sqrt{\sigma_{11}(0)\sigma_{22}(0)-\sigma_{12}^2(0)} \tag{3}$$

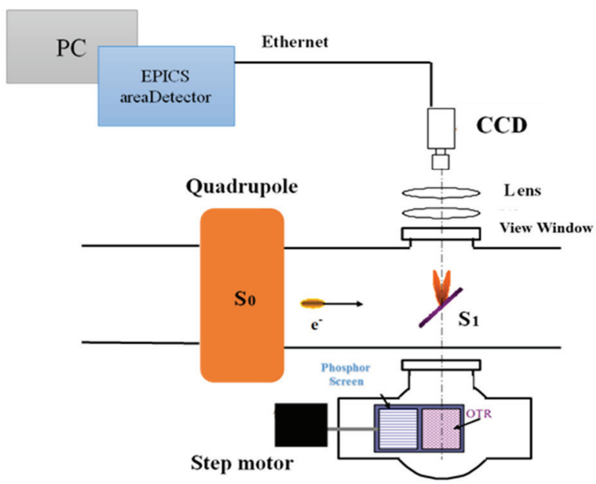

Figure 2: Emittance measurement system.

Beam Position Measurement

The beam position measurement system is consist of BPMs, signal processor, data communication network and monitoring computer. By considering the limitation of the installation space in the longitudinal direction, the button BPM is a suitable choice. In order to avoid the flange hole, the electrodes of the button BPM are placed into 60° symmetry. Figure 3 shows the sectional views of the button BPM. The parameters of the electrode structure are decided by simulation result [2].

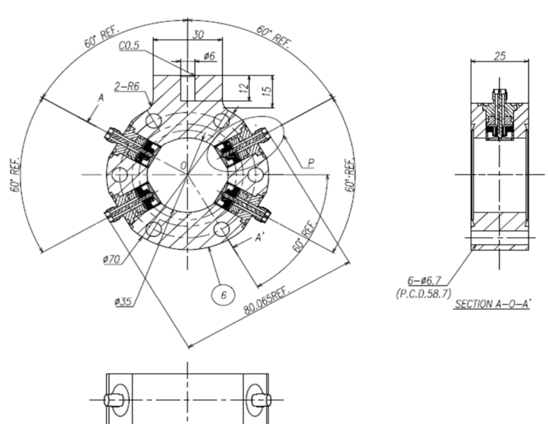

Figure 3: Sectional views of the button BPM.

To process the signals picked up by button BPMs, the Libera Single Pass E digital processor, which is produced by Instrumentation Technologies, is a reliable solution [3]. It is an all-in-one solution that enables trouble-free commissioning, high precision beam position monitoring, and local and global feed forward or feedback building. Each Libera Single Pass E goes through the acceptance tests. So we built a testing platform to check the performance of the Libera Single Pass E. Figures 4 shows the acceptance testing setup block for analysing the RMS noise. The pulse generator generates series of pulses with 5 V peak and 1 ns width to simulate the beam signals.

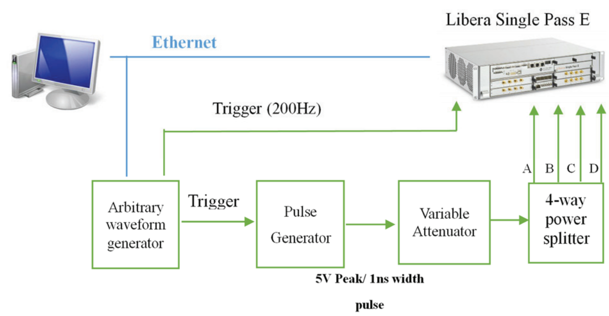

Figure 4: Testing setup block for RMS noise.

Then Libera Single Pass E obtains these signals and processes them to get the beam horizontal and vertical positon (x and y) information. We acquire these data and calculate the RMS values of x and y. Figures 5 shows the RMS curves measured compared with the required. The testing result satisfies the requirement very well. And the simulation result of the button BPM indicated that the resolution of signals is nearly 8 μm in all conditions. So the Libera Single Pass E has the ability to process the BPM signals.

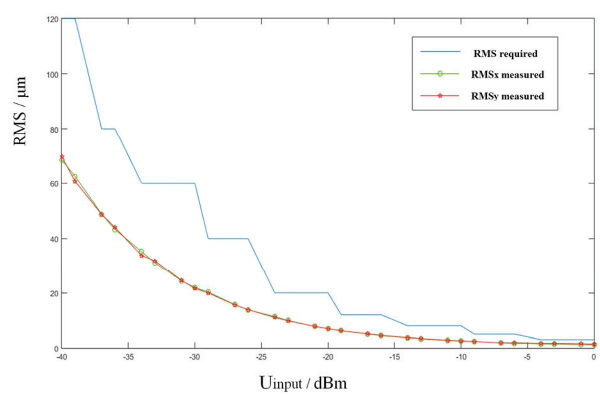

Figure 5: Curves of RMS values along with different input power signals.

Infrared FEL Diagnostic System

The infrared FEL diagnostic system is aimed at measuring the infrared laser intensity. The detector is the key of the system. It should have a fast response to measure the rising edge of macro laser pulse and a wide response range of wavelength. The QS5-IF pyroelectric detector manufactured by Gentec-EO can meet the measurement requirement.

Figure 6 shows the measurement block diagram of the infrared laser diagnostic system. The laser through the coupling aperture could be seen as the Gaussian beam. It will be focused by a 90 degree off-axis parabolic mirror, then be adopted by the detector. The focused laser can still

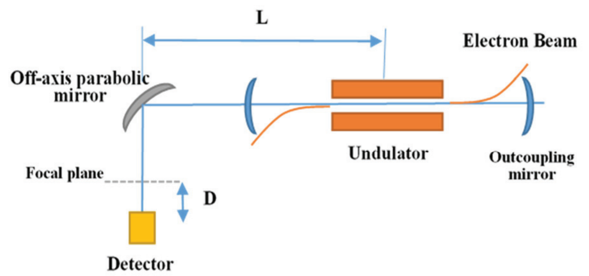

Figure 6: Block diagram of IR FEL diagnostic system.

be treated as the Gaussian beam, whose waist is close to the focal plane. So the detector should be installed nearby the beam waist to receive the beam within effective area. According to the parameters of the FEL cavity (shown in Table 2) and Gaussian beam model, we simulate the relation between L and D, where L is the distance from the 90 degree off-axis parabolic mirror to the centre of cavity and D is the distance from beam waist to focus plane.

Table 2: Parameters of the FEL Cavity

Parameter	MIR	FIR
Cavity length /m	5.04	5.04
Cavity mirror radius /m	2.756	3.018
Coupling hole diameter /mm	1.0~3.5	1.0~4.0
Rayleigh length /m	0.77	1.12
Beam waist radius /mm	0.78~3.5	3.77~8.44
Far field divergence angle /mrad	1.0~4.55	3.37~7.54
Radiation wavelength /μm	2.5~50	40~200

The simulation result is shown in Figure 7. The focal length of the 90° off-axis parabolic mirror is chosen as 152.4 mm. The simulation curves will offer a reference when the detector and off-axis parabolic mirror be installed.

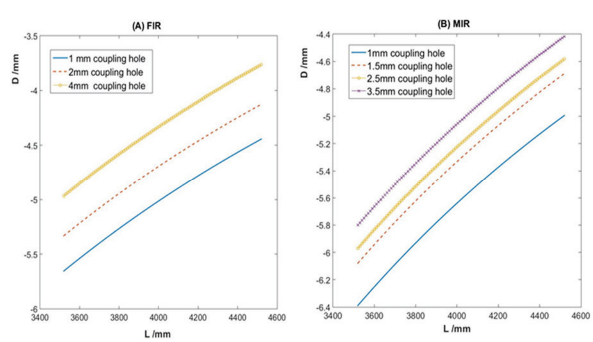

Figure 7: Simulation curves of the location relation between detector and 90° off-axis parabolic mirror for FIR and MIR FEL cavity, with the different size of coupling hole.

Pop-in Monitors

The pop-in monitors have been used in many same-type FEL facilities [4-5]. The main applications of the pop-in are helping aligning the FEL resonant cavity and observing the profile and position of the beam in the undulator. To achieve these targets, the vacuum chamber within the undulator comes equipped with three monitors, each with a 1 mm hole and a 2 mm hole, which can be viewed by CCD cameras, as shown in Figure 8. To align the optical cavity, we adjust the position of the monitors to make the laser goes through the holes in the pop-in. If the cavity is not aligned, the laser beam will deviate the axis of the cavity and be reflected by the pop-in monitor, then be viewed by the CCD. The YAG target installed in the monitor can image the electron beam to measure the profile parameter and position in the undulator. The pop-in monitors should be withdrew from the undulator gap.

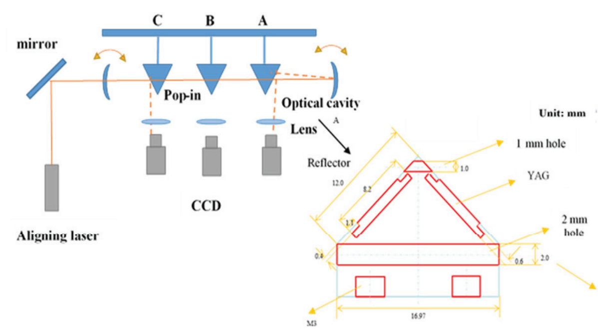

Figure 8: Schematic diagram of the pop-in monitors.

CONCLUSION

The beam diagnostics system design has been basically determined, also some details need a further discussion. Several months later, these components of beam diagnostic will be assembled and installed into the IR-FEL facility. More works are going to do in the future such as testing the diagnostics devices and optimizing the design, in addition, developing the hardware and software as required.

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