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DATA ACQUISITION AND PROCESSING PLATFORM DESIGN FOR SHINE WIRE SCANNER*

J. Dong†, J. Chen, S. S. Cao, F. Z. Chen, L. Y. Yu, R. X. Yuan, SSRF, Shanghai, China

Abstract

The Shanghai High repetition rate XFEL and Extreme light facility (SHINE) accelerates electrons to 8 GeV with a high repetition rate of up to 1 MHz. For the transverse beam profile measurement in the high energy sections wire scanner is used as an essential part of the accelerator diagnostic system, providing the tool to measure small beam size in an almost non-destructive manner. The prototype of the data acquisition and processing platform of wire scanner is designed and installed at the Shanghai soft X-ray Free Electron Laser (SXFEL) for verification. The experimental results show that the platform can be used for the SHINE.

INTRODCUTION

Motivated by the successful operation of X-ray FEL facilities worldwide and the great breakthroughs in atomic, molecular, and optical physics, condensed matter physics, matter in extreme conditions, chemistry and biology, the first hard X-ray FEL light source in China, the Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE) is under construction. The SHINE will utilize a photocathode electron gun combined with the superconducting to produce 8 GeV FEL quality electron beams with 1 MHz repetition rate [1].

Wire Scanner is widely used for beam profile measurements. A fork equipped with thin wires passes through the electron beam. The wire interaction with the beam produces scattered electrons and showered particles downstream the wire scanner unit which are detected by photomultipliers [2-3].

At the SHINE, each wire scanner unit consists of two motorized forks (horizontal and vertical plane) driven by a linear servo motor. This 90° configuration of motors helps to avoid vibration influences. Figure 1 shows a wire scanner motion unit installed at the SXFEL. A set of three 90° tungsten wires (20, 20 and 20 μm) is mounted on each fork. The wire position is measured with a magnetic railings ruler which has a resolution of 1.0 μm. The Beam Loss Monitors (BLMs) downstream of the wire scanner motion units are used for detection of scattered particles.

DATA ACQUISITION AND PROCESSING SYSTEM

The PMTs and preamplifiers, which convert the BLM Cherenkov light pulse and LED heartbeat light pulse into a time-shaped voltage signal, are mounted on the signal conditioning board. The BLM and Beam Position Monitor (BPM) signals are digitized and processed with the system. The magnetic railings ruler is installed next to the linear motor track to measure the position of wires. The signal outputted by the magnetic railings ruler is collected and analysed by the data acquisition board. The wire scan processing software calculates the beam parameters by merging the beam loss data, beam positions and the wires positions.

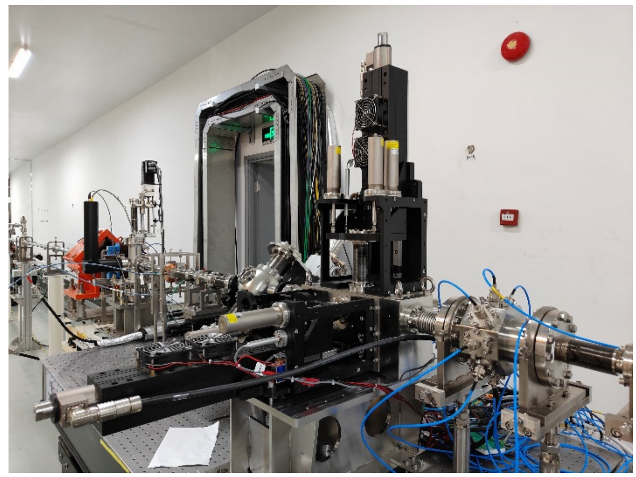

Figure 1: Wire scanner motion unit at the SXFEL.

Data Acquisition System

Figure 2 shows the structural block diagram of the data acquisition system. The analog signal acquisition module digitalizes the input signals and provides the trigger and clock interfaces. The operational amplifiers are used to convert the four input signals from single-ended to differential. The amplitude of the input signal can also be adjusted by changing the gain to maximize the ADC dynamic range. The buffers are used for external trigger signals and user-defined signals to improve their driving capabilities. The performance of operational amplifiers in the ADC front-end analog circuits directly affects the performance of the system. The fully differential amplifiers LMH5401 is selected. The LMH5401 device is a very high-performance, differential amplifier optimized for high-speed, ac or dc coupled, time-domain applications. The device is ideal for ac or dc coupled applications that require a single-ended-to-differential conversion when driving the ADC. The LMH5401 generates very low levels of second- and third-order distortion.

The quality of the sampling clock is one of the key factors determining the performance of the data acquisition system. The jitter of the sampling clock leads to the aperture error which affects the signal-to-noise ratio of the ADC and decreases the system performance. The clock of the ADC front-end analog circuits generated by the onboard crystal oscillator or external clock is used for the sampling clock, synchronization clock of ADC, and the FPGA high-speed serial transceiver. The HMC7044 is

* Work supported by the NSFC (Grant No. 12105346)
† email address: dongj@sari.ac.cn

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selected which is the industry's highest performance clock conditioner with JEDEC JESD204B support. The 14 clock outputs from PLL2 can be configured to drive seven JESD204B converters or other logic devices with clock jitter of only a few tens of fs.

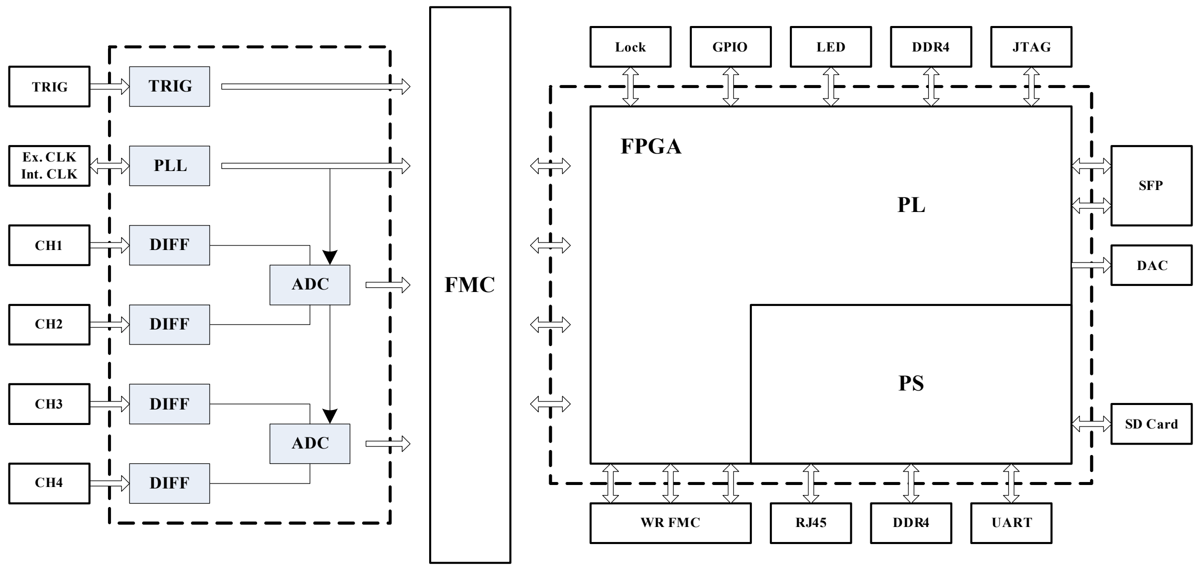

Figure 2: The structural block diagram of the data acquisition system. The carrier and mezzanine card design is adopted to meet the requirements of subsequent upgrades and updates.

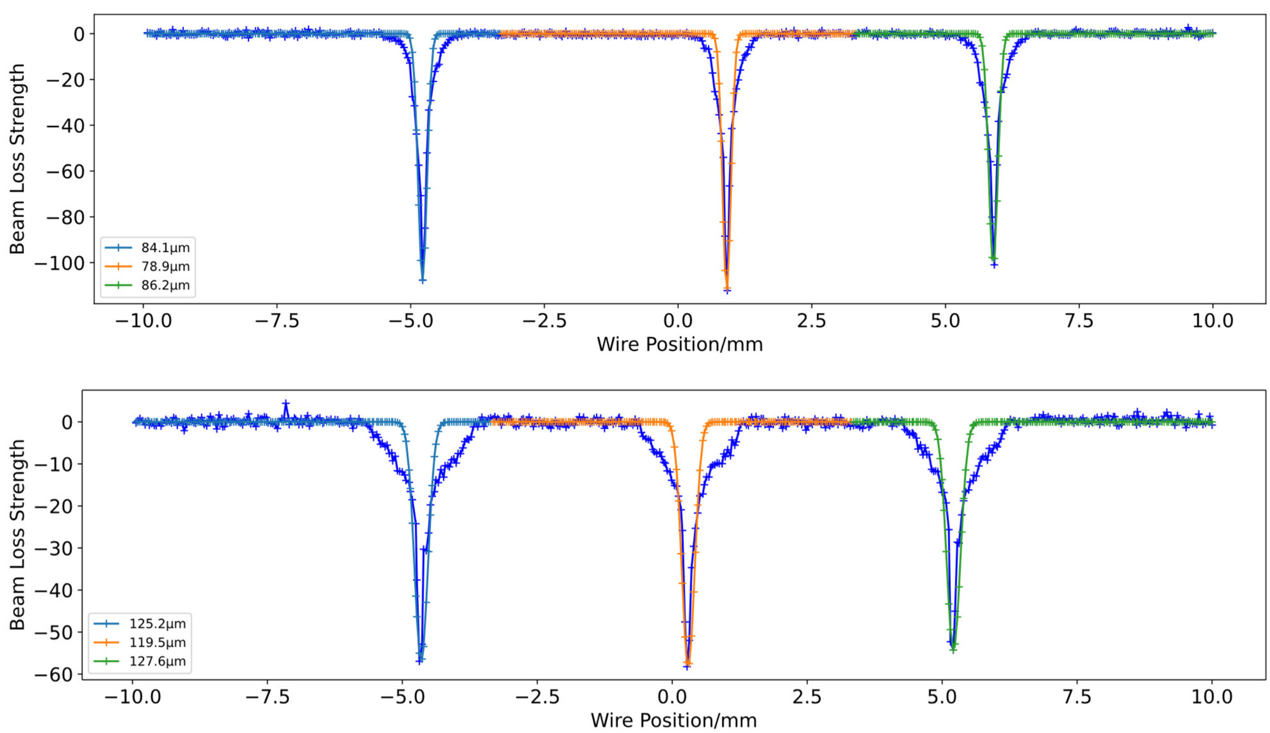

Figure 3: The first wire scanner measurement result at the SXFEL. The above and below figures show the measurement results in the horizontal and vertical directions, respectively. The variance of the fitted gaussian function is shown in the bottom left corner of each figure.

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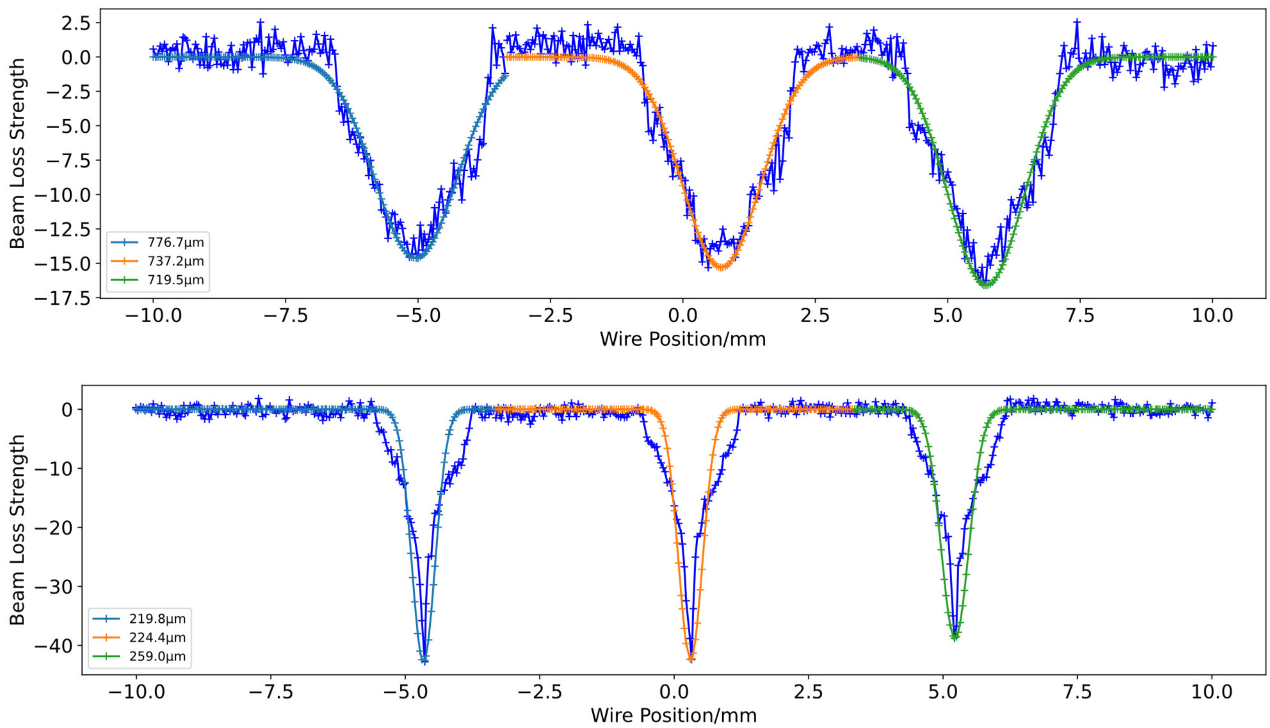

Figure 4: The second wire scanner measurement result at the SXFEL. The above and below figures show the measurement results in the horizontal and vertical directions, respectively. The variance of the fitted gaussian function is shown in the bottom left corner of each figure.

The FPGA of the digital carrier board adopts the ZYNQ UltraScale+ MPSOC architecture which includes the Processing System (PS) and Programmable Logic (PL), and provides flexibility for complex multitasking designs. The digital motherboard contains a variety of interfaces, such as RJ45, GPIO, SFP+, etc. In order to meet the requirements of subsequent upgrades and updates, the FMC+ standard interface has been adopted to connect the ADC daughter board and the White Rabbit board.

Data Processing System

The beam profile density distribution is gaussian distribution. Therefore, the signal of wire scanner can be thought as superposition of three gaussian distributions. The three gaussian peaks from left to right represent the beam density distribution in vertical or horizontal directions individually. The signal strength can be expressed as Eq. (1). In Eq. (1), Y_0 is a constant due to background noise; A_1, A_2, A_3 are amplitudes of three gaussian peaks; μ_1, μ_2, μ_3 are centre positions of gaussian peaks; σ_1, σ_2, σ_3 are beam profile sizes in three directions; μ and $Y(\mu)$ are the position and the signal strength of the wire scanner. Using the detected signal data, an equation related to μ and $Y(\mu)$ could be established, then the vertical and horizontal beam profile sizes will be got by solving the equation with nonlinear least squares method.

$$Y(\mu) = Y_0 + A_1 e^{-\frac{(\mu-\mu_1)^2}{2\sigma_1^2}} + A_2 e^{-\frac{(\mu-\mu_2)^2}{2\sigma_2^2}} + A_3 e^{-\frac{(\mu-\mu_3)^2}{2\sigma_3^2}} \quad (1)$$

In order to make the measurement procedure automated and easily accessible to all operators, wire scanner processing software is developed by Python.

BEAM MEASUREMENTS AT THE SXFEL

Beam size measurements have been performed using the wire scanner. The beam charge was ~500 pC. Two wire scanner measurements were performed. The first measurement result is shown in Fig. 3. The measured beam sizes have been compared with the measured beam sizes by the scintillating screens installed on the same stages. The measurement results in the horizontal and vertical directions of the scintillating screens are 178 μm and 98 μm. There is a discrepancy in the beam size measured by the wire scanner and the screen. The beam size measured by the wire scanner is less than the size measured by the screen. The screen is affected by the thickness, angle, and the point spread function, causing the measured size to be larger than the wire scanner measured size. Therefore, the wire scanner measured beam sizes are more reliable than the screen. The second measurement result is shown in Fig. 4. The beam size was changed by the quadrupole magnets. The two wire scanner measurements show that the data acquisition and processing system can collect and process signals under different beam conditions.

SUMMARY AND OUTLOOK

The design of the data acquisition and processing system has been completed. The beam experiments have been

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performed at the SXFEL. The results show that the system supports the slow scan mode. In the future, the system will be installed at the SHINE and tested for fast scan mode. Wire scanner usage will be moved from export-only usage to operators and scientists in daily use.

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