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PROTOTYPE DESIGN OF WIRE SCANNER FOR SHINE*

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Abstract

SHINE is a high repetition rate XFEL facility, based on an 8 GeV CW SCRF linac, under development in Shanghai. In order to meet the requirements of measuring the beam profile of shine in real time and without obstruction, a new diagnostic instrument, wire scanner has been designed. This paper mainly describes the design of wire scanner in shine, and some simulation results are also shown and discussed.

INTRODUCTION

SHINE [1] has 3 undulator lines that consist of FEL-I, FEL-Il and FEL-Ill and 10 experimental stations in phase-I, it can provide the XFEL radiation in the photon energy range of 0.4 -25 keV. In SHINE, wire scanners will be used to monitor the transverse profile of a 10-300 pC eletron beam with a final energy of 8GeV and repetition of 0-1MHz. Providing a high resolution measurement of electron beam profile averaged over many shots is the primary purpose of the wire scanner (WSC). Profile measurements can also be used to determine transverse beam emittance and twiss parameters without changing the magnet settings [2]. Compared to view screens, WSC offer a non-destructive monitoring of the beam transverse profile, and avoiding secondary particle damage to superconducting cavity. At present, the preliminary design scheme WSC in SHINE has been completed. The specific equipment parameters, such as the material, diameter, scanning speed, scanning mode need to be determined according to simulation and performance. Now simulation based on MATLAB has obtained some results.

OVERVIEW

At SHINE, design of WSC includes wire scanner detector, PMT detector, data acquisition electronics, data processing module, and remote monitoring. General block diagram of the WSC is shown in Fig. 1.

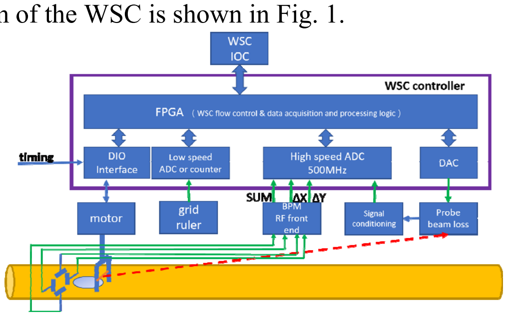

Figure 1: General block diagram of the system.

Wires in wire scanner detector driven by linac motor interacting with electron beam generates γ rays which are received by the PMT detector. Data acquisition electronics is to collect the PMT beam loss signal, wire position back-reading and BPM output. Data processing module is responsible for information extraction and Gaussian fitting, and remote monitor implements user interface and terminal control of WSC.

For reason of high repetition rate, slow scanning mode with step by step is more likely to cause damage to wire than fast mode. Therefore SHINE's WSC will apply fast scanning mode, in which wires will be swept fastly and smoothly through the beam pipe at one time to prevent large vibrations.

At present, WSC of SHINE is still in simulation of actual parameters and development of key technologies, and the hardware parts have not been assembled and coordinated to realize functions. Unsolved problems include heating damage of tungsten wire under high repetition rate beam [3], vibration of tungsten wire in fast scanning mode [4] which Influences system resolution, selection of PMT probe position which influences beam loss signal quality, unknown SNR of PMT beam loss signal which also influences system resolution, and optimization of data processing algorithm which influences on system precision and speed. In future, according to the theoretical analysis and simulation results, wire scanner device parameter will be configured which includes wire diameter, scanning speed, PMT requirements, ADC requirements, etc, and beam experiments will be carried out to observe its working state to evaluate the performance of wire scanner.

Wire Scanner Detector

The wire scanner detector will be installed along the beam line. When it needs to be used, commands generated by upper software is sent to control the motor to drive the wires to sweep through the beam. After the measurement, the wires will be moved out of the beam channel to avoid blocking the beam. Wire scanner detector is driven by linear motor, and encoder is used to feedback position. The motion of the wire scanner detector has high reliability, and there is no movement stuck fault, and repetition accuracy of the motion is better than 20 μm. The wire scanner detector mainly includes a vacuum chamber with flange, flexure, linear motor and magnetic grid ruler, 45 degree mounting seat, and independent adjustable supporting base as shown in Fig. 2. We use 10 μm and 20 μm tungsten wires for test recently.

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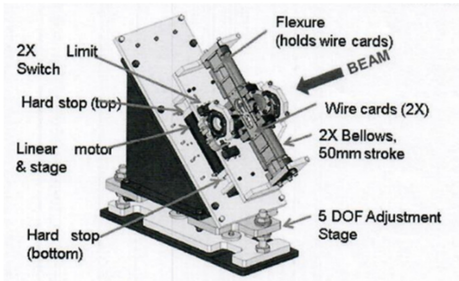

Figure 2: Structure of wire scanner detector.

We use LinMot motor as Mechanical actuator. The Control Panel of LinMot helps the user to access directly to the control and status word of the MC Software. The drive can be commanded from the PC through RS232 cable. A test for controlling motor has finished in which we use python to send control word nor MC software. This enables automatic reading of motor positions. Motor motion curve without loading is shown in Fig. 3.

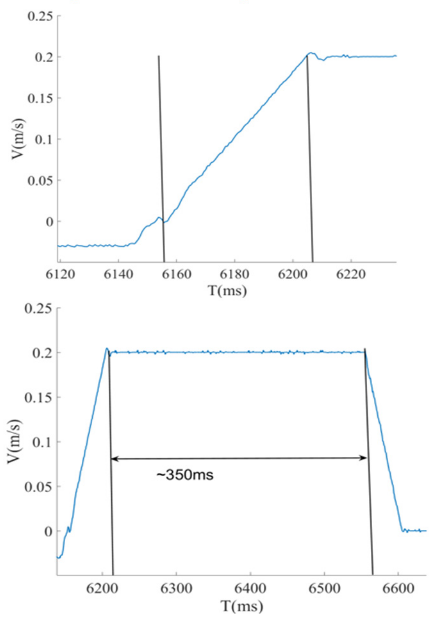

Figure 3: Test of LinMot motor.

However, reading position has two steps. First is that PC sends words to ask LinMot current position of motor, secondly LinMot receives and encodes its response and sends it back to PC, resulting in great uncertainty of response time up to milliseconds. If this scheme is used to measure position of wire at speed of 0.1 m/s, the position resolution will bad than 100µm and this is not acceptable. In this situation, grating ruler as a third party measuring device as shown in Fig. 4 may be helpful. Grating ruler is installed outside of the vacuum chamber. Its slider is connected to the Wire Card, so that slider can move along with motor and grating keep fixed. Considering that grating ruler is easy to be damaged under radiation environment, lead shielding device will be installed to protect grating ruler. When the grating ruler moves, we receive the square wave signal as shown in Fig. This signal can be used as a clock for a counter in FPGA, so that counter value can represent the relative position, and we can record the counter value when trigger from timing system arrive, the response time jitter is lower than 10 µs, equivalent to position jitter lower than 1µm at speed of 0.1 m/s, and the resolution of the grating ruler is 1µm, this is acceptable.

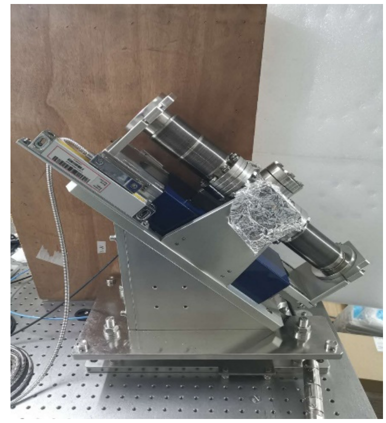

Figure 4: Installation of grating ruler.

PMT Detector

The duty of detecting gamma photons is accomplished by H10720-110. H10720-110 series are photosensor modules containing a metal package PMT as shown in Fig. 5 and a high-voltage power supply circuit.

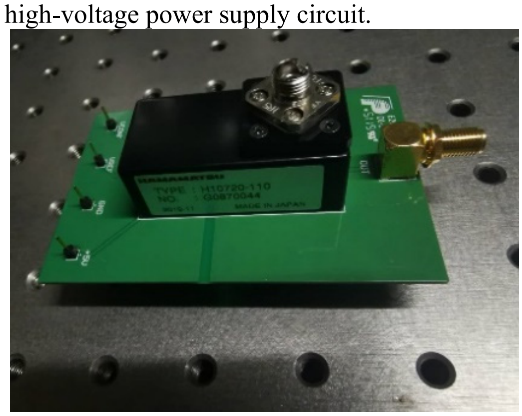

Figure 5: PMT detector.

The scintillator will be placed downstream of the wire target and outside the beam tube. The light generated by γ photon interaction with the scintillator is passed into the PMT through the optical fiber. The typical signal diagram of PMT is shown in Fig. 6 which signal length is around 100ns.

Figure 6: Typical signal diagram of PMT.

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Data Acquisition Electronics

Beam loss signal from PMT detector is sampled by the QT7135 data acquisition board. Test shows sampling rate of the ADC sub-board support range in 400Msps-1000Msps and effective number of bits is 11 and the bandwidth is at 500MHz. QT7135 can be connected to ZCU102 evaluation board developed by xilinx through FMC HPC. Data sampled by ADC will be saved to DDR4 on the PL side of the evaluation board through internal bus AXI. The 4 GB, 16-bit wide DDR4 memory system is comprised of one 256 Mb x 16 SDRAM and its part number is MT40A256M16GE-075E. When measurement start the beam diagnostic personnel sends out the command to start scanning on OPI. The command is input into arm in zynq which located in zcu102 through epics control network. Then the arm changes the FPGA pin level to make FPGA start recording data when the motor moves to default position. When the trigger comes, FPGA will record a group of PMT beam loss signal sampling values and record the wire position values, record signal from BPM to calculate the central position bunch by bunch. When sampling the PMT beam loss signal, the selection of specific sampling rate will depend on PMT signal length and DDR frequency. When collecting BPM signals, for beam repetition is 1MHz, sampling rate is no need to be very high and the bandwidth is at least 500MHz. For those reasons, we decide set sampling rate as 500MHz. Position signal generated by a grating ruler is a kind of square wave, we can use it as the clock for the counter generated within FPGA so that wire position can be read with low clock jitter. Final version of data acquisition electronics has not been established, we use these commercial board as test prototype to test the feasibility of the scheme.

Data Processing Modules

Arm on zcu102 board will install Linus OS and be used as EPICS IOC. When the scanning is completed, ARM will retrieve the sampling value of beam loss signal from DDR, extract the beam loss value corresponding to each collision between wire and beam, and call the value of the wire position corresponding to the beam loss signal which will be modified by bunch by bunch central position extracted from BPM data. Finally, position data will do Gaussian fitting with beam loss value and variance of this gaussian could be a measure of beam size.

Remote Monitoring

All the data in the embedded IOC are available as EPICS PVs and display on a Linux host.

SIMULATION RESULTS

When the wire interacts with the beam, the electron density at the location of the wire cannot be accurately represented by the measured beam loss due to the presence of the wire diameter. The wire diameter will cause the gaussian fitting function to be wider, which will lead to beam size measured value being larger. Eq.(1) is concluded by simulation in which beam size of σ measured by wire with diameter D is σ_t:

$$\left(1+\frac{e^{1.43}\left(\frac{\sigma}{D}\right)^{-1.998}}{100}\right)\bullet\sigma=\sigma_t \qquad (1)$$

Simulation based on MATLAB in which 10,000 different beam currents were measured by wire scanner, and the measured results were modified by Eq.(1). The result is shown in Fig. 7.

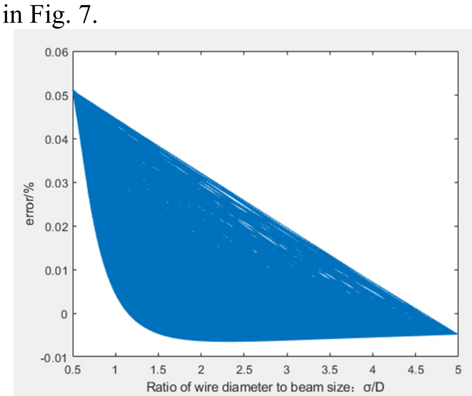

Figure 7: Test of correction formula.

Through another simulation based on MATLAB we also found that with the increase of white noise or wire diameter, the standard deviation of measurement error will increase. This indicates that the greater the noise or wire diameter is, the worse the measurement resolution will be.

CONCLUSION

We have described the system configuration, the content of subsequent test and optimization, present status of WSC in SHINE. This system will be extensively installed on SHINE for beam profile measurements with a resolution target of 10 µm.

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