A NEW BEAM PROFILE DIAGNOSTIC SYSTEM BASED ON THE INDUSTRIAL ETHERNET

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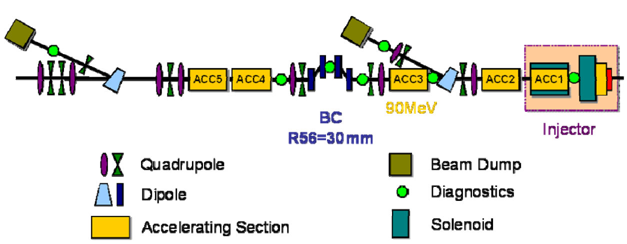
Abstract

A new beam profile diagnostic system based on industrial Ethernet has been installed in Shanghai Deep Ultraviolet Free Electron Laser (SDUV-FEL) facility recently. By choosing GigE Vision cameras, the system provides better image quality over a long distance than before. Beam images are captured from the beam profile monitors which are controlled by air cylinders or step motors. In order to fit for the system expansibility and curtail the cables, all devices are operated through the Ethernet and distributed along the FEL facility. The approach to the design of the hardware and software will be described in this paper. Applications and experiment results will be shown in this paper as well.

INTRODUCTION

The goal Shanghai Deep Ultraviolet Free Electron Laser (SDUV-FEL) project is to provide a high-brightness coherent deep ultraviolet source (DUV)[1]. The SDUV-FEL facility is about 100 meters long, and 27 profile or Pop-in monitors[2] have been installed at various positions along the facility. A new beam profile diagnostic system based on industrial Ethernet has been designed to acquire the beam image from the profile or Pop-in monitors. Figure1 shows the layout of the SDUV-FEL facility.



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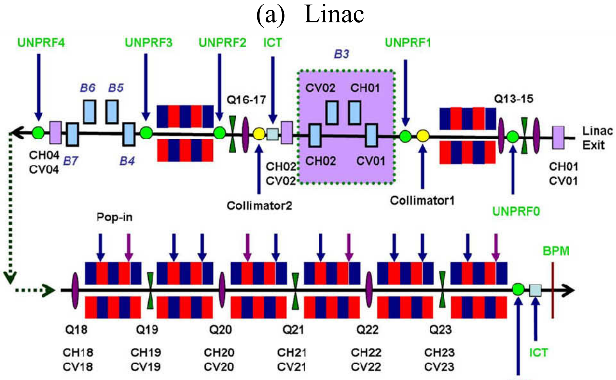

(b) Unduator

Figure 1: Layout of SDUV-FEL.

Comparing to the former design, the GigE Vision cameras replaced the analog cameras. This solution has two major advantages. First, digital system does not suffer from pixel jitter, and digital signals can be transmitted much more stably than analog signals. Second, unlike analog cameras, GigE Vision cameras do not require the frame grabber. The image data could be received by the computer directly from the Ethernet.

SYSTEM STRUCTURE

In this system, 27 GigE Vision cameras have been installed for SDUV-FEL beam profile diagnostics. All of these cameras are distributed over a long distance, therefore five to seven near-by cameras are grouped and connected to a field controller for profile measurement[3]. The controller not only transmits the acquired image data from the cameras to the control room, but also fans out the trigger signal from the control room to the cameras. Furthermore, the air cylinders of the profile monitors are controlled by the controller. The structure of the beam profile diagnostic system is shown in Figure 2.

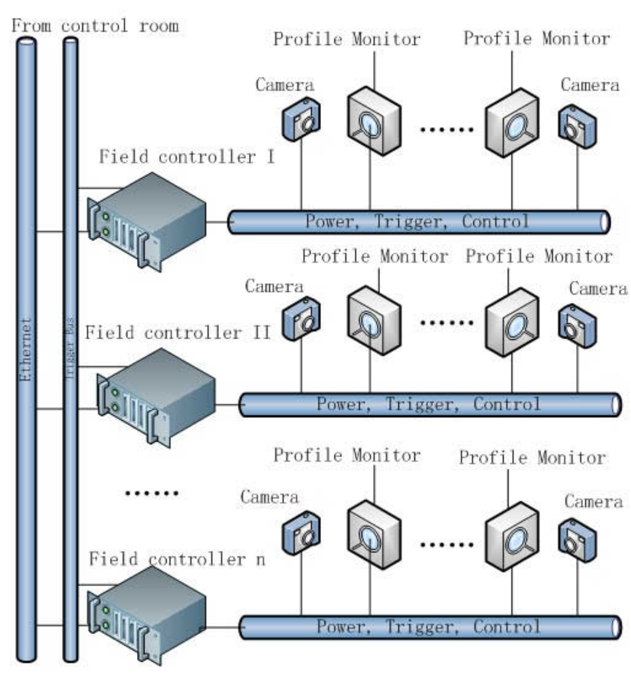

Figure 2: Structure of the beam profile diagnostics system.

Image acquisition subsystem

Considering the resolution, the cost, and the upgrade of our system, Basler scA640-70gm CCD cameras were chosen as the major devices in image acquisition subsystem. The CCD sensor size of this camera is

659*494 by 7.4μm square pixels. With a 1:1 lens, the spacial resolution could be 14 microns. The range of grayscale could be 0 to 4095 because the camera has a 12 bits ADC. External trigger mode is important for the system, because the action of capturing the beam images must synchronize with the timing signal of the entire system.

This kind of camera is fully compatible with GigE Vision standard which is proposed by Advanced Imaging Association (AIA). The data output type can be either Fast Ethernet （100Mbps） or Gigabit Ethernet (1000Mbps). Apart from the hardware interface, the GigE Vision standard also includes the communication protocol which can be utilized for controlling and communication with the cameras.

As mentioned above, the cameras should work in the trigger mode. There are 27 cameras in total, so that a circuit to transmit and fan-out the trigger signal from the timing system was designed. The timing system gives out a TTL signal synchronizing with the electron bunch generated by an electron gun at the rate of 2 Hz. When the trigger signal transmit controller receives the TTL signal, it converts the signal to differential signal, then transmits to profile measurement controller through shielded foiled twisted pair (SFTP). Transmitting by differential signal and using SFTP can reduce the noise efficiently, so that the furthest camera (over 100 meters away from the control room) can receive a correct trigger signal. The fan-out circuit in every profile measurement controller fans out the signal received from the SFTP. Each fan-out circuit can trigger eight cameras at most. If the timing system does not work, the signal generated by wave generator circuits which is built in the trigger signal transmit controller can be used to test or debug the machine vision system independently.

Pneumatic control subsystem

Most of the profile and Pop-in monitors are controlled by air cylinders, and the air flow of the cylinders was switched by the solenoid valves. There two solenoid valves in each profile monitor with four positions, and three solenoid valves in each Pop-in monitor with three positions. Each solenoid valve needs an output channel to drive, while each position needs an input channel to feed back the state of the monitor. The power for the illumination of each profile or Pop-in monitor is given by an additional output channel. Five to seven near-by cameras share a controller, so each controller should have 10 output channels and 15 inputs channels at least.

The Ethernet based I/O module in the system is MOXA E2210, which includes 12 channels 24 VDC digital inputs (DI) and 8 channels 24 VDC digital outputs (DO). It supports RS-485 modules for expandable I/O, and MOXA R2110 was chosen as the expanded I/O module. The MOXA R2110 also has 12 DI and 8 DO channels, so that the I/O channels can meet the demand of each controller.

By using the MXIO API, we can drive the solenoid valve and get the position of the air cylinder conveniently and remotely.

Step motor control subsystem

Some of the beam profile diagnostic devices, like the slit and scrapers, are controlled by step motors. Since the step motor controller requires remote controlling as well, Galil's DMC-21x3 Ethernet motion controller has been adopted. The position of the beam profile diagnostic devices can be adjusted continuously by the step motor, and the linear scale feeds back the position. The motion is simple, just going forward and backward. The forward limit switch (FLS) and reverse limit switch (RLS) are used to control the place where the devices can go. Software development is calling the API provided by Galil Company, and sending the instructions to the motion controller.

SOFTWARE DESIGN

Virtual instrument technology was adopted to drive the devices, and to develop the measurement software. The virtual instrument development platform is National Instruments LabVIEW™. According to the structure of hardware system, the corresponding pneumatic control, motor control, image acquisition and processing modules are included in the software system.

We have had previous experience with LabVIEW™ in imaging applications. However, it is much different this time, and NI-IMAQdx driver software is in demand because we use GigE Vision cameras. The NI-IMAQdx driver is fully compatible with GigE Vision standard camera. The image data can be easily acquired and display with this driver. The cameras may operate at different resolutions and frame rates, depending on the camera capabilities and the bandwidth of the networks.

Figure 3 shows the operator interface of beam profile diagnostic system in LabVIEW. The image was grabbed in triggered mode and 8 bits/pixel monochrome format. We made the beam image display in pseudo-color, looking more visually intuitive. In addition, both the horizontal and the vertical distributions of the beam image were displayed in the panel.

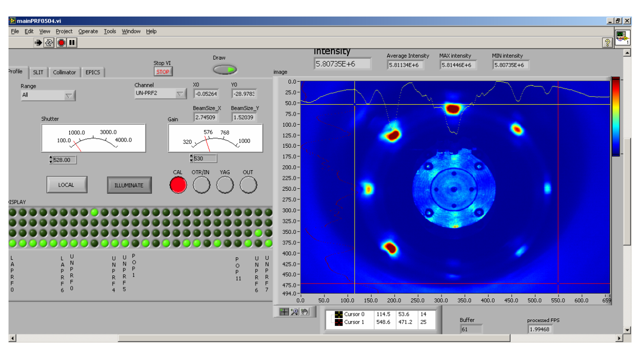

Figure 3: Beam Profile Diagnostic Control Panel in LabVIEW.

Moreover, the virtual instrument development platform LabVIEW and the control system for accelerator and large physics experimental facilities EPICS are connected through Shared Memory technology, in order to achieve cross-platform operation. Figure 4 shows the operator interface of beam profile diagnostic system in EDM. It has the same function with that in LabVIEW.

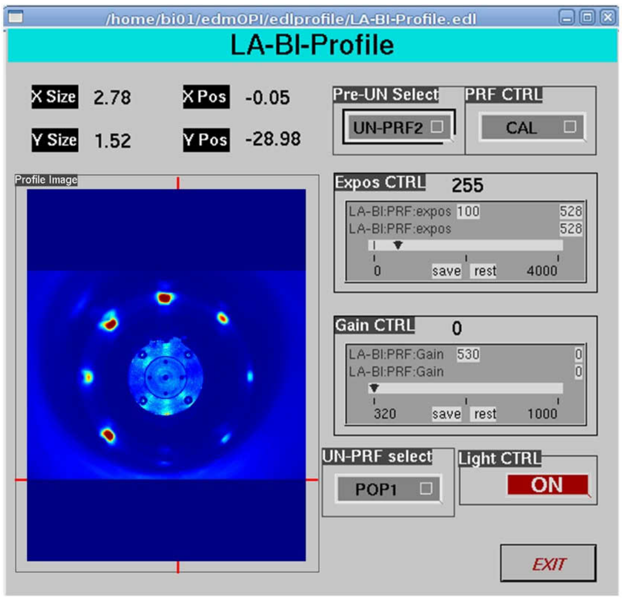

Figure 4: Beam Profile Diagnostic Control Panel in EDM.

COMMISSIONING RESULTS

Operators select different CCD cameras to see the beam images from the corresponding diagnostic devices. The beam size, relative position and the intensity could be got by processing the beam image. According to the information from the beam profile monitors, other physical parameters of the SDUV-FEL facility can be adjusted in order to get the expected result.

Figure 5 shows two different beam images. The left one was got from the Pop-in monitor, and its resolution could be 14 microns. The right one is from the profile monitor at the exit of the undulator.

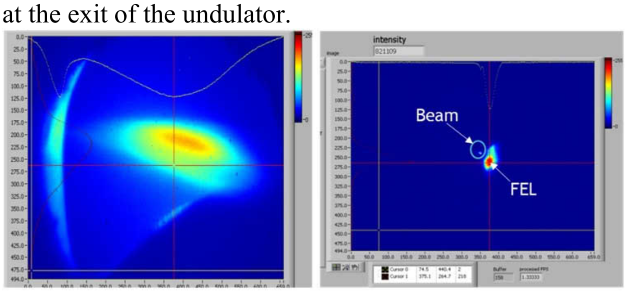

Figure 5: Images from the Pop-in monitor and the profile monitor.

By adjusting the quadrupole between undulators, let the beam scatter, so that the beam can be controlled to go through a certain number of undulators, and different intensity of FEL can be acquired as well. The exponential growth curve of the FEL intensity is shown in Figure 6.

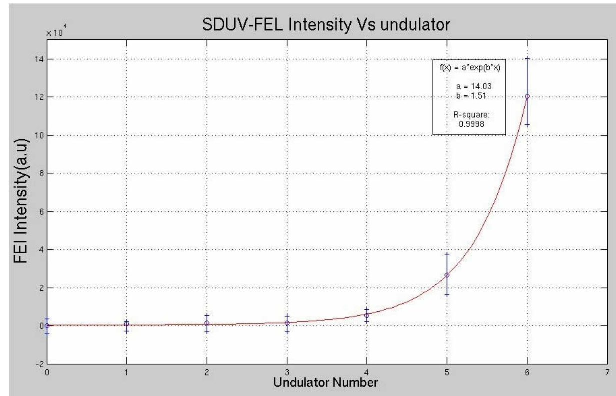

Figure 6: SDUV-FEL intensity vs. undulator.

CONCLUSION

The SDUV-FEL beam profile diagnostic system is commissioning from August 2009, and the results have shown that the beam profile diagnostic system for SDUV-FEL works well. One of the running field controllers is shown in Figure 7 The SDUV-FEL beam profile diagnostics take advantage of the new high-quality GigE Vision cameras and these cameras can be easily configured, even if they are numerous and distributed over a long distance. The use of industrial Ethernet based devices simplified the design of the system, especially relaxing the cabling.

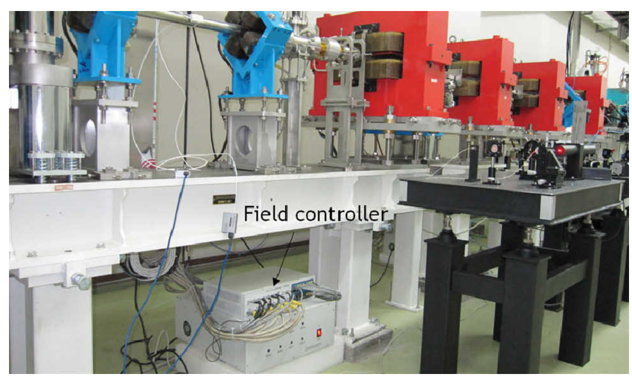

Figure 7: Beam profile diagnostics controller in the field.

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