INSTRUMENTATION AND OPERATION OF A REMOTE OPERATION BEAM DIAGNOSTICS LAB AT THE CORNELL ELECTRON-POSITRON STORAGE RING*

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Abstract

Accelerator beam diagnostics are being modified at the Laboratory of Elementary Particle Physics (LEPP) at Cornell University for remote operation at nearby Alfred University. Presently, a streak camera used for longitudinal dynamics measurements on the Cornell Electron-Positron Storage Ring (CESR) is operational and measurements have been made from Alfred University [1]. In the near future, photomultiplier tube arrays for electron and positron vertical beam dynamics measurements will be remotely operated as well. In this paper, we describe instrumentation and operation of the remote beam diagnostics.

INTRODUCTION

In the field of accelerator physics, the majority of physicists hold positions at large national laboratories where the accelerators exist. Therefore each accelerator is operated, maintained, and modified by physicists at the national laboratory. As a result, the instruction and research of accelerator physics mainly occurs at large national laboratories and remains an anomaly at most research universities.

This leads to several shortcomings in the field, such as a lack of exposure for prospective scientists and a lack of awareness of the interesting developments in the field outside of the major research laboratories. Consequently, there is a shortage of trained accelerator physicists. We have addressed these shortcomings through remote operation of accelerator equipment, thus increasing our level of collaboration.

In addition, the development of accelerator beam diagnostics from a remote location has an important place in the development of the International Linear Collider project, which is a collaboration of many national laboratories in Europe, Asia, and the Americas. The International Committee on Future Accelerators (ICFA) has formed an international working group, Remote Experiments in Accelerator Physics, to address the challenge of remote operation at the international level [2].

Alfred University is approximately 100 miles southwest of Cornell University, corresponding to a commute of 1 1/2 hours by car. Hence, performing research at Cornell consumes time and resources, justifying the utility of a remote lab.

The objectives of the remote operation of beam diagnostics at CESR are: i) to measure the longitudinal and vertical beam dynamics of single colliding bunches for luminosity optimization, ii) to expose undergraduate students to accelerator physics research, and iii) to explore the challenges of remote operation for future accelerators. Using the broadband internet enables the operation of sophisticated beam diagnostic equipment at CESR from Alfred University.

REMOTE OPERATION OF LONGITUDINAL BEAM DIAGNOSTICS

The capability of single bunch longitudinal dynamics measurements on CESR using a streak camera has existed for some time, but the apparatus was antiquated and cumbersome to use [3]. Now it is possible to operate the streak camera from a computer with a reasonable internet connection anywhere in the world. Remote operation of the streak camera hardware and software necessitated modifications to: (i) the synchrotron radiation beam line optics, (ii) the streak camera hardware and software, (iii) remote internet connections from Cornell and Alfred Universities, and (iv) a laboratory at Alfred University to operate and analyze the streak camera data.

Synchrotron Radiation Beam Line Optics

A diagram for the synchrotron radiation beam line optics is shown in figure 1. The optical elements that are located in the radiation area are: (a) a primary mirror, (b) an optical telescope, and (c) two periscopes. The radiation area optics are not remote controlled but the optical telescope and first periscope mirror can be adjusted locally from the laboratory in the radiation safe area. In the radiation safe area, the optical elements are: (d) actuator controlled mirrors, (e) a periscope with an actuator controlled mirror, (f) two focusing lenses on actuator controlled stages, (g) a neutral density filter wheel, (h) the streak camera, and (i) a web camera.

The primary mirror is located in the CESR vacuum chamber and is designed to reflect the visible synchrotron radiation from both electron and positron bunches simultaneously. We have no control over the incident angle on the synchrotron radiation or the primary mirror so we use the beam line optics in the radiation safe area to focus the electron/positron light into the streak camera.

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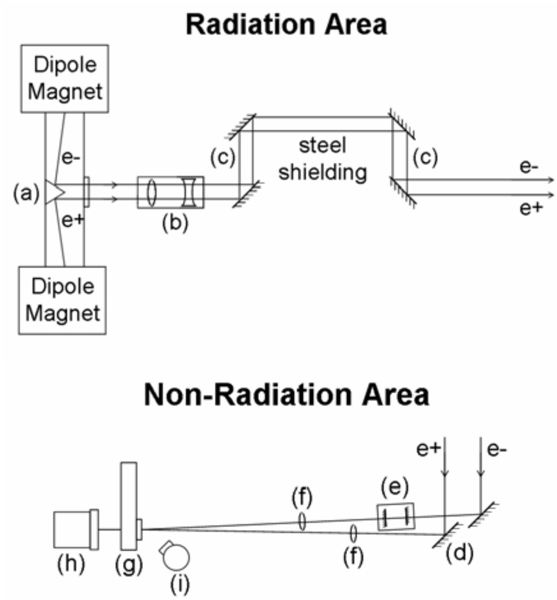

Figure 1: A schematic of the synchrotron radiation beam line optics which extracts the visible light from electron/positron bunches in the CESR vacuum chamber.

A description of the beam line optics follows. After the light is reflected off of the primary mirror, it passes through a series of optical elements over a 17m path, where it is focused into a streak camera. A variable optical telescope, located just outside the CESR vacuum chamber, focuses the electron/positron light onto two actuator controlled mirrors. Each mirror has two Newport NewStep (model NSC200) micrometer actuators for two-dimensional control (up to 11mm) and high resolution positioning [4]. The actuators have a serial RS485 communications link, converted to a USB adaptor that allows all 4 actuators to be controlled in parallel. In addition, the actuators come with windows based software for remote positioning by the streak camera PC.

Two lenses, mounted on horizontal stages, are used to focus the electron/positron light on the streak camera slit. Each stage has a Zaber (model KT-LA60A) linear actuator, with 0.1mm resolution and up to 60mm of travel, which is computer controlled to adjust the lens to the focal point of the light [5]. The actuators are daisy chained through a RS-232 computer link that is converted to a USB adapter. Windows based software is provided with the actuators for remote positioning by the streak camera PC.

To avoid light saturating the streak camera, a Finger Lakes Instrumentation neutral density filter wheel with varying filter attenuation is used [6]. The filter wheel has eight filter slots. Seven of the slots have neutral density filters and the eighth slot has a light position target aligned with the streak camera slit. The computer link between the filter wheel and streak camera pc is made through a USB connection. Windows based software is provided by the vendor that operates the filter wheel. A web camera, positioned to view the light position target, is used to steer and focus the light along the optics beam line.

Streak Camera Software and Hardware Upgrades

The dual axis synchroscan streak camera is manufactured by the Hamamatsu corporation [7]. In its original state, the streak camera was controlled by a PC with a 386 processor, operated by primitive data acquisition software, and the CCD camera was water cooled with a vacuum pump to eliminate condensation. A major upgrade to the streak camera operational interface was needed to achieve remote operation, including: i) an air cooled Hamamatsu Digital CCD camera (model C4742-95) for data acquisition, ii) an Intel Pentium-IV PC, and iii) HPD-TA streak image acquisition software. Now up to 230 streak images can be acquired at a rate of ~1.5Hz.

In addition, the streak camera is a pre-General Purpose Interface Bus (GPIB) device. Therefore, basic setting changes such as the multichannel plate gain, streak speed, and tuning on the camera, must be done manually. To overcome these shortcomings the following modifications have been made: (i) the streak speed adjustment is now controlled by the CESR control system, (ii) the surge protector for the camera is remote controlled, using Smarthome Manager, by the streak camera PC [8], and (iii) the multichannel plate gain of the camera is not remote controlled, so the neutral density filter wheel is used to avoid saturation.

Remote Internet Connection

Since the beam line optics and streak camera data acquisition software are controlled by the streak camera PC, remote operation of the streak camera is done with Virtual Network Computing (VNC) [9]. VNC, the desktop sharing system that allows remote control of another computer, is used to control the streak camera PC from Alfred University. A secure shell (SSH) client in windows, PuTTY, is used for the remote connection protocol into the Cornell computer system, and VNC viewer is used to remotely control the streak camera PC [10]. Streak images are downloaded to the Alfred computers using VNC.

Occasionally for machine studies video/audio conferencing between Alfred and Cornell is necessary. Virtual Room Videoconferencing System (VRVS), using a web camera and audio headsets with microphone, is used in these circumstances to communicate easily between the two locations [11].

Alfred University Laboratory and Data Analysis Software

A laboratory at Alfred University, outfitted with two PCs with a T3 internet connection, is used to operate the streak camera. Each PC has two monitors to allow multiple windows to be opened for monitoring beam parameters of CESR while measurements are being made.

Data analysis of the streak camera experiments are done at Alfred University.

A typical data set consists of 200 streak camera images written in 1024x1024 .tiff image (figure 2). Each image needs to be analyzed quickly to allow conclusions regarding accelerator operational techniques to be updated. An efficient analysis software package was written in Matlab. Streak camera images are read into Matlab as a 1024x1024 matrix, where each element represents pixel intensity. By summing the columns of the matrix, thus producing a 1x1024 vector, the program locates the maximum intensity values in the matrix, and thus the bunch locations (figure 2). Within the region of each bunch, the pixel intensity, representing the longitudinal distribution of the bunch, is χ^2 fit to a Gaussian curve. The fit variables and their respective errors are returned for each bunch distribution. The data analysis software can fit a single train of 5 bunches up to 40 trains of bunches on a single image [12].

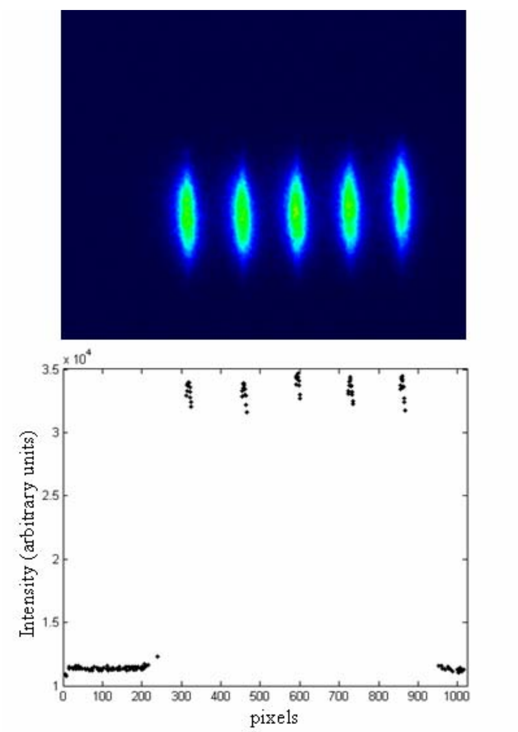

Figure 2: A streak camera image (top) and the vector intensity.

REMOTE VERTICAL BEAM SIZE MEASURMENTS

This past year, two photomultiplier tube (PMT) arrays have been installed and commissioned on CESR for electron/positron vertical beam size measurements [13]. The PMT array is manufactured by the Hamamatsu Corporation and has a 32 channel linear anode with an effective area per channel of 0.8 by 7mm [7]. The PMT signal has a sub-nanosecond rise time that provides the ability to measure the individual vertical beam size of all 45 bunches in CESR on a turn-by-turn basis. Hardware and software modifications are being made to allow remote operation of the PMT arrays in the near future.

SUMMARY

We have built a laboratory at Alfred University for remote operation of longitudinal beam dynamics measurements using a streak camera at Cornell University by: i) instrumenting a synchrotron radiation transport line with optics operated by a PC, ii) upgrading a streak camera's operational interface, iii) remotely operating the streak camera and transport line optics using VNC, and iv) writing data analysis software for fast analysis of streak images. Remote operation of the streak camera for parasitic measurements during CESR-c and CHESS operation are routinely made.

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REFERENCES

[1] R. Holtzapple *et al.,* "Longitudinal Beam Stability for CESR-c," EPAC 2006, Edinburgh, June. 2006.

[2] The website for the Beam Dynamics Panel Working Group on Remote Experiments in Accelerator Physics is: http://www.lns.cornell.edu/public/icfa/REAP/

[3] R. Holtzapple and M. Billing, "Measurements of Bunch Motion Due to the Longitudinal Dipole-Coupled Bunch Instability at the Cornell Electron-Positron Storage Ring," Phys. Rev. ST Accel. Beams 5, 054401, 2002.

[4] Newport Corporation-Corporate Headquarters 1791 Deere Avenue, Irvine CA 92606, USA.

[5] Zaber Technologies Inc 2891 Steveston Hwy., Richmond, British Columbia Canada, V7E 2J1

[6] Finger Lakes Instrumentation, LLC 7298 West Main Street PO Box 19A Lima, New York 14485.

[7] Hamamastu Corporation, 360 Foothill Rd, Bridgewater, NJ 08807.

[8] Smarthome, 16542 Millikan Avenue, Irvine, CA 92606.

[9] The website for VNC is: http://realvnc.com/.

[10] The website for PuTTy is: http://www.chiark.greenend.org.uk/~sgtatham/putty/.

[11] The website for VRVS is: http://www.vrvs.org/.

[12] P. Stonaha, "Acquisition and Analysis of Longitudinal Bunch Images at the Cornell Electron Positron Storage Ring," Senior Honors Project, Alfred University, Alfred, NY, April 2006.

[13] M. Palmer *et al.,* "Studies Using a Multibunch Turn-by-turn Vertical Beam Profile Monitor in CESR," EPAC 2006, Edinburgh, June. 2006.