CONTROL SOFTWARE COMPONENTS FOR THE CEBAF SYNCHROTRON LIGHT INTERFEROMETER PROJECT*

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Abstract

The first Synchrotron Light Interferometer (SLI) has been built at Jefferson Lab. The SLI is a valuable beam diagnostic instrument for the CEBAF accelerator. It is a non-invasive, multi-element measurement device consisting of a CCD video camera, a video image processing system, and a set of stepper-motors to adjust the positions of optics parts and diffraction slits. The main functions of the SLI elements are automated with the use of new distributed control software. The paper describes the structure of this software and its performance.

Figure 1: The experimental Hall A beam line at Jefferson Lab with the installed Synchrotron Light Interferometer.

INTRODUCTION

The Synchrotron Light Interferometer (SLI) technique was developed in KEK, Japan [1] to measure very small (down to a few μm) electron beam sizes. This beam diagnostic technique is completely non-destructive and has successfully been implemented in several accelerator laboratories all over the world.

The SLI design at Jefferson Lab is a "classic" wave front division interferometer that uses polarized quasi-monochromatic synchrotron light. It has a 3-D structure, with major elements placed on two horizontal levels that are parallel to the ground plane (see Fig.1). Limited space and relatively high radiation in the accelerator tunnel strongly influence the SLI design and implementation. More details on physics and mathematics of the Synchrotron Light Interferometer at Jefferson Lab can be found in paper [2].

SLI AND ITS BASIC ELEMENTS

The synchrotron light generated by the electron beam in a dipole magnet (the left blue element in Fig.1) is extracted through a quartz window by a mirror installed in a vacuum chamber. Two additional adjustable mirrors guide the synchrotron light through the SLI optical system. One of them is remotely controlled. The main task of this mirror is to send light on the CCD head through a long (~5 m) plastic pipe, diffraction slits, and all SLI optical components (a narrow band pass filter, a polarization filter, and a video camera objective lens), in the direction opposite to the direction of the electron beam. The CCD and optical components are placed in an optical box. A double slit assembly with a predefined set of distances between slits and small slit openings is located right in the front of the camera objective. The assembly is moved in horizontal and vertical directions by two remotely (RS-232) controlled stepper-motors.

The SLI video camera is the STV digital integrating video system from the Santa Barbara Instrument Group [3]. The camera has its own control box with the RS-232 interface to an external computer. Its quantum efficiency is more than 60% and the pixel size is very small (7.4μm×7.4μm). An electronic cooling system keeps CCD dark currents extremely low. The exposure time of the camera can gradually be changed from 0.001 seconds to 10 minutes. The CCD camera is connected to an image processor. The SLI image processor is Datacube's Maxvideo MV200 board [4] that is the basic video image processing system for beam diagnostic applications at Jefferson Lab.

In the SLI, the synchrotron light generated by the electron beam produces an interference pattern. With a Gaussian beam profile approximation, we can easily calculate the RMS beam size from the visibility (contrast) of the interferogram [1]. The main problem is to measure this visibility as accurately as possible. To solve this problem, new SLI control and data processing software has been created at Jefferson Lab. The software automates the main functions of the SLI and performs all necessary mathematical calculations.

SLI CONTROL AND DATA PROCESSING SOFTWARE

The accelerator control system at Jefferson Lab is based on the EPICS toolkit [5]. With its very powerful set of tools, EPICS allows easy system extensions at all control levels. Based on EPICS, a new automated SLI control system was created in a very short period of time (several weeks). The system is built up from the SLI control and data processing software. It is easily extendable to

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accommodate new SLIs that could be installed in the accelerator tunnel any time in the future.

SLI control and data processing software consists of two basic modules (see Fig.2): the SLI Control Module (CM) and SLI Data Processing Module (DPM). It is distributed software running on several computers connected to the accelerator control network. The communication between software components is based on the standard EPICS Channel Access (CA) network communication protocol.

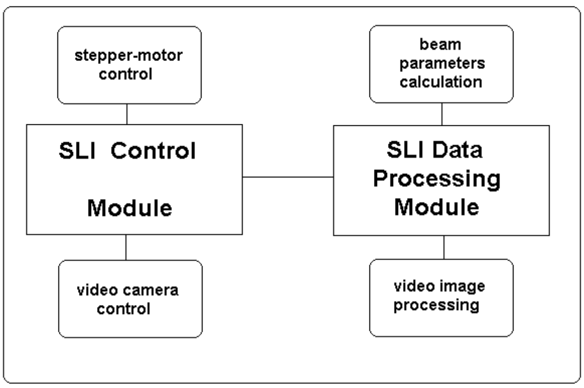

Figure 2: SLI control software structure.

SLI Control Module

The CM provides the automation of the main SLI functional elements. It has a stepper-motor and a video camera control sub-modules. Both sub-modules use Jefferson Lab's serial (RS-232) software library [6]. With the use of this library, the serial device control is straight forward.

The device is connected to a serial port that is handled by a control computer (IOC). Each serial port is served by a separate control task that exchanges messages with the EPICS database records referencing this port. The serial port control task reads and writes data into and out of the serial port. It also handles the hardware operation timeouts.

One of the main advantages of the serial library at Jefferson Lab is that it typically does not require any software coding for connecting a new serial device to the control system. If the device communication protocol is relatively simple and consists of only the data requests from the computer site and the data provided by the device site, all that has to be done is to create and run the EPICS database handling this device. This was the case of the SLI stepper-motors. The video camera control protocol is more complicated. The IOC and device must provide not only control commands and requested data but also some additional information including command headers, data headers, checksums, etc. To handle this case, a video camera state machine control application was created. This application is responsible for the device communication protocol and acts as a data translator between the serial library and video camera control box software.

SLI Data Processing Module

SLI video image processing and data analysis are performed by the DPM. The DPM has a video image processing and beam parameters calculation sub-modules.

The synchrotron light interference pattern is captured by the CCD camera and analyzed by the image processing software running on the MV200, its host computer (a Motorola PowerPC based IOC), and a workstation connected to the accelerator control network. As a part of the distributed real-time EPICS database, the digitized images from the video camera and the information about the calculated beam parameters are available for the accelerator control computer network and can be used for various beam diagnostic applications.

The MV200 continually processes a large volume of pixels corresponding to the video frames from the CCD camera using parallel pipeline technology. This technology makes it possible for the MV200 not only to routinely perform such important operations for visual data processing as masking the pixels outside the interferogram region and subtraction of a background image but also to estimate RMS beam size from the interference picture contrast at a high rate (up to 10 Hz in the multiplexed version of the software).

The SLI data analysis software runs on a workstation. This software takes the estimated beam size from the IOC and calculates the necessary corrections due to the image noise levels, the field depth effects, and imbalance between intensities of the two modes of light illuminating the double slit. The software fits the measured interference pattern using several multi-parameter, non-linear SLI data acquisition and processing models.

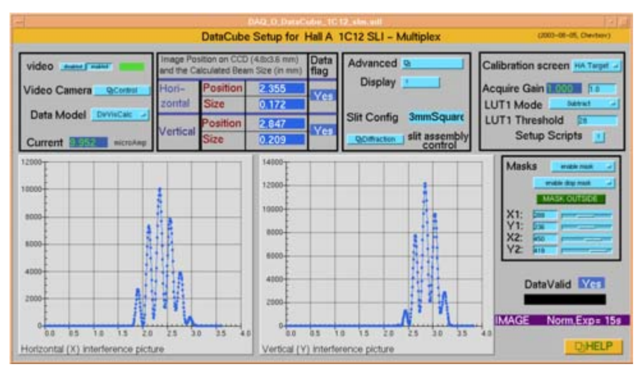

Figure 3: Main SLI control screen.

SLI CONTROL SCREENS

The control of all SLI components can easily be done with the use of the main SLI control screen (EPICS MEDM, Fig.3). This screen contains the information about the beam (current, energy, calculated size), SLI (the diffraction slit configuration, video camera exposure time), Maxvideo parameters (the data pipeline, mask configurations), as well as the image processing models for the beam size calculations. It also has the synchrotron light interference pictures in x and y directions, the detailed description of SLI control functions activated by pushing the HELP button, and the links to the stepper-motor and video camera control screens. The last one looks almost like the camera control box front panel and is shown in Fig.4.

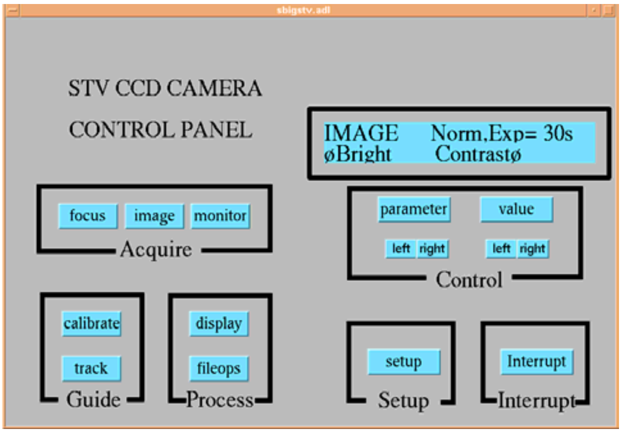

Figure 4: SLI video camera control screen.

CONCLUSIONS

The new SLI control software at Jefferson Lab has successfully been working for more than one year. It has been providing a very simple and extremely reliable handling all SLI components.

The fully non-invasive nature of the interferometer makes it possible to develop and test all software components with the use of the real data from the accelerator, without a risk to interrupt beam delivery to experimental end stations. This significantly simplifies the work on various data processing models that is extremely important for the right interpretation of the data obtained from the SLI. The performance of the image processing software is very high. In the conditions of the experimental Hall A beam line, to obtain the synchrotron light interference picture that is optimal for the mathematical data analysis, the video camera exposure time has typically to be set in the range from one to five seconds. This is absolutely enough for the software not only to estimate the beam size directly from the interference pattern but also to fit the data with the use of at least two image processing models and compare their results.

The main technical achievement of our first SLI project is that Jefferson Lab has designed and created a prototype of a completely automated modern beam diagnostics device together with its data processing software. On the basis of this prototype the work on the future SLI projects for the CEBAF accelerator will be relatively easy.

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