ADVANCED BEAM ENERGY SPREAD MONITORING SYSTEMS AND THEIR CONTROL AT JEFFERSON LAB*

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Abstract

Two Synchrotron Light Interferometers (SLI) have been in use at Jefferson Lab for more than one year. Each SLI is an absolutely not invasive beam diagnostic device routinely monitoring the transverse beam size and beam energy spread in a wide range of beam energies and intensities with a very high accuracy. The SLI are automated with the use of distributed, multi-level, and multi-component control software. The paper describes the SLI configuration, the structure of the SLI control software and its performance.

Figure 1: The CEBAF accelerator site at Jefferson Lab.

INTRODUCTION

With the use of the superconducting RF technology, the CEBAF accelerator (Fig. 1) provides nuclear physics experiments at Jefferson Lab with powerful continuous (CW) electron beams of a very high quality.

High quality means not only a small transverse beam size that sometimes is about 50 microns on experimental targets, but also an extremely small relative energy spread (better than $2*10^{-5}$). The smaller the energy spread, the better the resolution of the experiment and physicists can see more details inside nuclei.

A growing number of experiments at Jefferson Lab require 5 GeV, 100 μA CW beams with their transverse size and energy spread continuously monitored. The beam size measurement methods based on such popular devices as wire scanners and optical transition radiation (OTR) monitors simply do not work at these requirements. The wire scanners are destructive for the beam (or invasive) even at small (~10 μA) currents. The OTR monitors are less invasive but at high beam currents produce a significant radiation background and increase the beam energy spread to a level that is not acceptable by accelerator users.

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With an extremely small beam energy spread available at Jefferson Lab, even at critical high dispersion locations of the CEBAF accelerator, the beam size is smaller than 80 microns. One such high dispersion location is shown in Fig. 2. A set of the standard CEBAF dipole (bending) magnets (blue elements) is seen in this figure right before and after this area.

Figure 2: High dispersion location 3C12 (experimental Hall C beam line).

High dispersion locations have the next very important properties:

- if we know the beam size at these locations, then the energy spread is defined there automatically because it is approximately equal to the beam size divided by the dispersion;
- to measure the beam size at these locations, we can relatively easily use synchrotron light generated by the beam in dipole magnets.

BEAM DIAGNOSTICS BASED ON SYNCHROTRON LIGHT

Direct beam imaging devices based on the synchrotron light are known as Synchrotron Light Monitors (or SLM). Many accelerator laboratories in the world use such devices for beam diagnostic applications. The main idea of the SLM is transparent. Right after a dipole magnet a view port is created to get the synchrotron light out of the beam pipe (see Fig. 3). Then a conventional optical system (a telescope, if you will) is built to direct the visible part of synchrotron light through all its components and to form the beam image on a screen or a video camera. The transverse beam size is easily calculated as a product of the beam image size and the magnification factor of the optical system. It is obvious that the SLM is absolutely not invasive but its resolution is limited, mostly by diffraction effects [1].

At high dispersion locations of the CEBAF beam transfer lines this resolution is not better than 80 microns and, of course, it is not enough to resolve smaller beams.

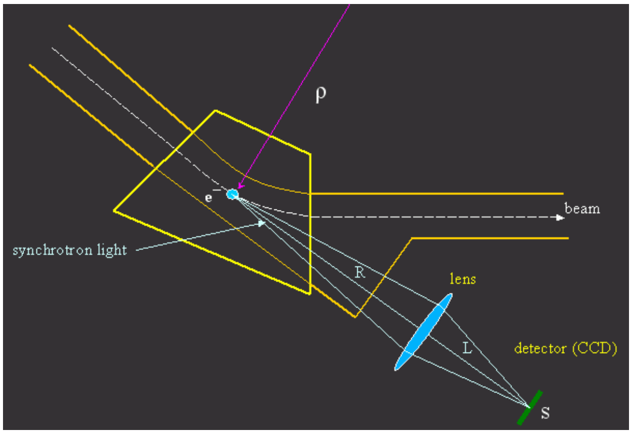

Figure 3: Synchrotron Light Monitor (SLM).

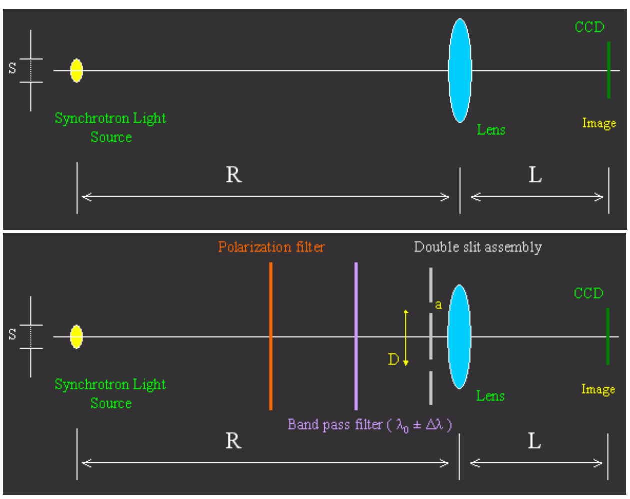

Figure 4: SLM (the upper picture) and SLI optics.

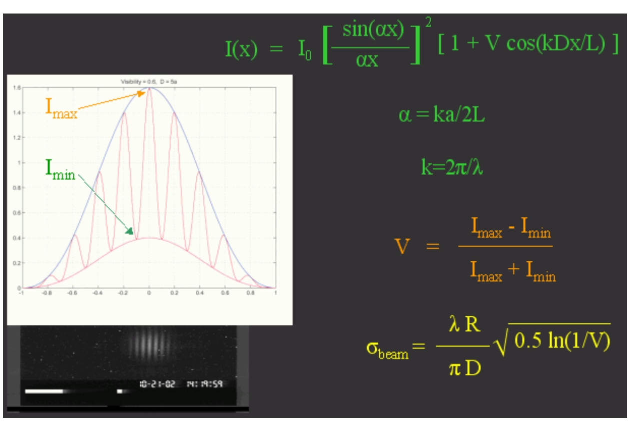

Figure 5: SLI image and beam size calculation model.

Let us modify the optical system of the SLM (see Fig.4) to increase its resolution. In front of the main focusing lens we put a double slit. We also use a band-pass filter and a polarization filter to make the synchrotron light generated by the beam pseudo coherent.

As a result, instead of the SLM with its relatively low resolution we get a Synchrotron Light Interferometer (SLI) the resolution of which can be made much better because it mostly depends on the distance between slits D. For example, with a standard configuration of the diffraction slits used at Jefferson Lab this resolution is about 30 microns.

At the same time, instead of the SLM beam image that is very easy to understand and use, we get a SLI interference picture that usually looks very similar to one shown in Fig. 5. How to obtain the beam size from this picture? The answer follows from the results of van Cittert, Zernike, and Mitsuhashi [2]. The definition of the visibility (contrast) of the interference pattern V and the basic formula to calculate the beam size are represented in Fig. 5.

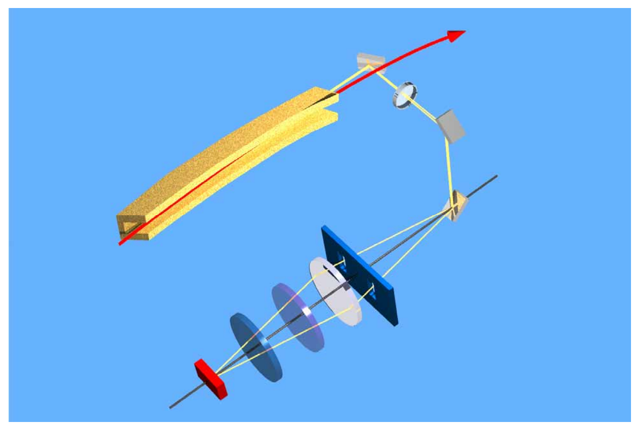

Figure 6. SLI structure.

The structure of Jefferson Lab's SLI is shown in Fig. 6. The synchrotron light generated by the electron beam in a dipole magnet is extracted from the beam pipe with the use of one "in-vacuum" mirror and a view port. Two additional mirrors direct light through the optical system on the CCD video camera. And, of course, all of this system is shielded from the external light.

SLI CONTROL AND DATA PROCESSING SOFTWARE

So we have the Synchrotron Light Interferometer and want to control it remotely. We use stepper-motors to position one of the mirrors outside the vacuum system and diffraction slits, the video camera control box, and the image processor that is a Maxvideo 200 board [3] at Jefferson Lab. All these elements, except Maxvideo, use a serial (RS-232) communication interface.

Now we need the SLI control and image processing software.

The SLI control software consists of the stepper-motor, video camera, and Maxvideo control modules (see Fig. 7). And all this is built around a distributed EPICS database.

Serial devices are controlled with the use of Jefferson Lab's Common Serial Driver/Device Library and the

Device Configuration Handler [4-5]. The control is based on the device configuration files, which completely define the used communication channels and protocols.

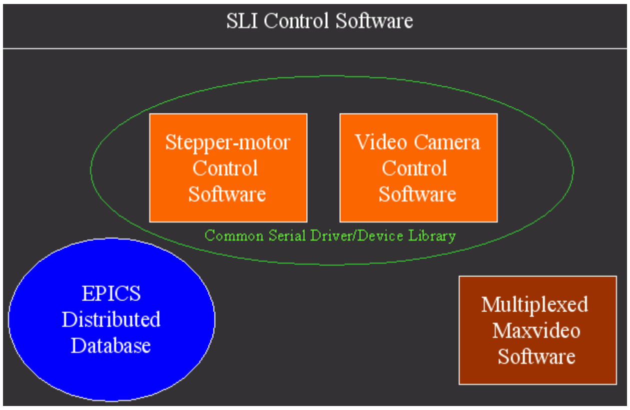

Figure 7: Components of SLI control software.

Preliminary image processing is done by Maxvideo. The multiplexed software created at Jefferson Lab [6] makes it possible for Maxvideo not only to routinely perform such important operations as masking the pixels outside the region of interest and subtraction of a background but also estimate the beam size from the interference picture contrast at a high rate (up to 10 Hz).

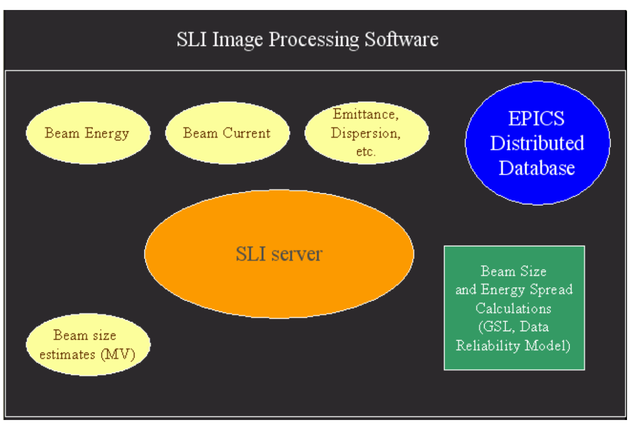

Figure 8: Components of SLI image processing software.

The basic and more accurate image processing and data analysis are done by a SLI server. The server runs on a workstation connected to the control system network. This is a typical configuration for a Jefferson Lab high level application with very powerful modeling and calculation engines. The server takes the information about the parameters of the beam, SLI components, and the Maxvideo beam size estimates from the accelerator control system and fits the interference pattern with the use of a multi-parameter, non-linear SLI model. One of the results of this fit is the visibility V that is used to calculate the beam size and the energy spread. Mathematics is based on the GNU scientific library (GSL). And again, all this is built around a distributed EPICS database (see Fig. 8).

The control of all SLI components can easily be done from the main SLI control screen. The screen contains information about the accelerator parameters, the SLI components, Maxvideo, as well as the beam size and the energy spread. It also has the horizontal and vertical interference patterns and links to the control of the SLI components. The images are typically processed once a second making the SLI a real time beam energy spread monitoring system at Jefferson Lab.

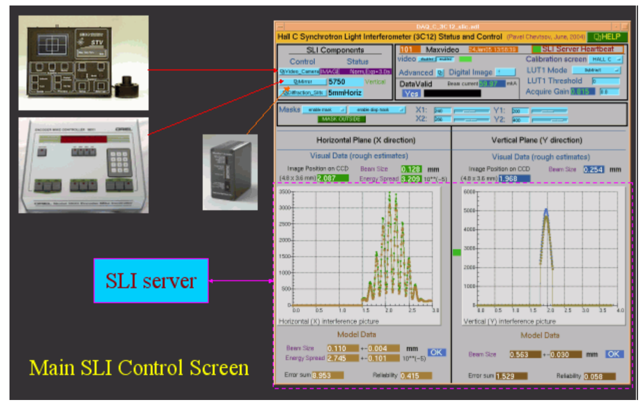

Figure 9: The details of the main SLI control screen.

CONCLUSION

We have created a prototype of a fully automated, non-invasive beam size and energy spread monitoring system that can successfully work in conditions of relatively small beam currents of accelerators, which are not synchrotron radiation facilities. A very high resolution and the ability to monitor beam energy spread in real time make these systems valuable beam diagnostic tools for current and future nuclear physics experiments at Jefferson Lab.

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