Control System of the Superconducting X-Ray Lithography (SXLS) at Brookhaven*

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Abstract

The design and implementation of a distributed real-time control system for a compact synchrotron will be discussed. Graphic generation of accelerator device control logic, CAMAC device interfaces and operator display screens is presented. Beam digitization techniques and results of beam position and profile measurements is presented. Methods for automation of routine operator procedures will be discussed.

I. INTRODUCTION

The SXLS machine is being developed as a prototype of an industrial X-Ray Lithography facility. As such the control system is required to provide for the flexible demands of a research machine and yet provide the foundation for an industrial control environment. Such a control system must easily adapt to the changing requirements of commissioning and the machine studies period. The industrialization requirements demands a system that is easy to learn and use and yet is sophisticated enough to provide automated sequencing of routine operator procedures, and meaningful diagnostics. In addition, the control system has to provide monitoring of system status, fault detection, alarm display, logging and plotting of data and a high degree of reliability. The decision was made early in the development cycle to adapt an existing control system rather than to build our own. This decision was based on our own manpower constraints while being mindful that the control system will become part of a commercial product. The CEBAF accelerator control system, developed at Newport News, Va was chosen as most closely meeting our needs [1].

II. MAJOR FEATURES

The control system features a set of graphic tools for configuring the computer system and hardware interface as well as for building control logic and operator display screens. Utilities are available for logging and plotting data, and defining state transitions for sequenced operation. The control system runs on Hewlett Packard workstations running the UNIX operating system. Machine hardware is interfaced to the control system through CAMAC interfaces. Diagnostic and measurement instrumentation is controlled via a GPIB interface. All code is written in C.

III. SYSTEM ARCHITECTURE

The control system is divided into a supervisory and a control layer. The supervisory layer consists of HP workstations networked together via ethernet. This layer supports the operator display screens and is the main operator interface. This layer of workstation also maintains the central database. The supervisory level computers are connected via a separate ethernet port to diskless workstations which constitutes the local layer. These computers are connected to the CAMAC crates through which the accelerator hardware is controlled. These local computers repeatedly read all the CAMAC crate modules, execute the previously downloaded set of control logic functions, write out new setpoint values to the CAMAC crates and update the system database with new

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values. Our present configuration consists of 2 supervisory level computers and 2 local computers controlling six CAMAC crates. The CAMAC crates have been generally configured by function with one crate each controlling the magnets, RF, vacuum, frame grabber, diagnostics and motor systems. The present hardware configuration is shown in Figure 1.

SXLS PHASE I CONTROL SYSTEM

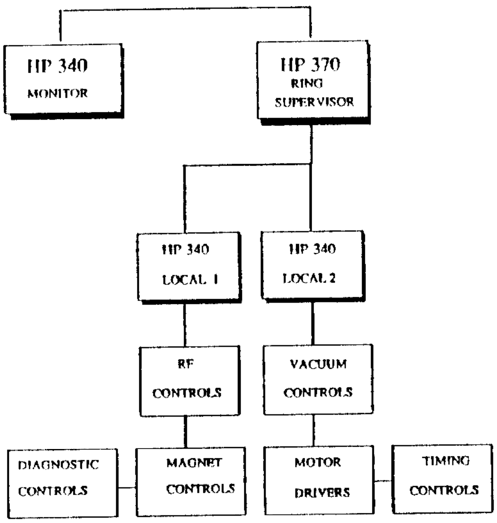


Figure 1

IV. OPERATOR INTERFACE

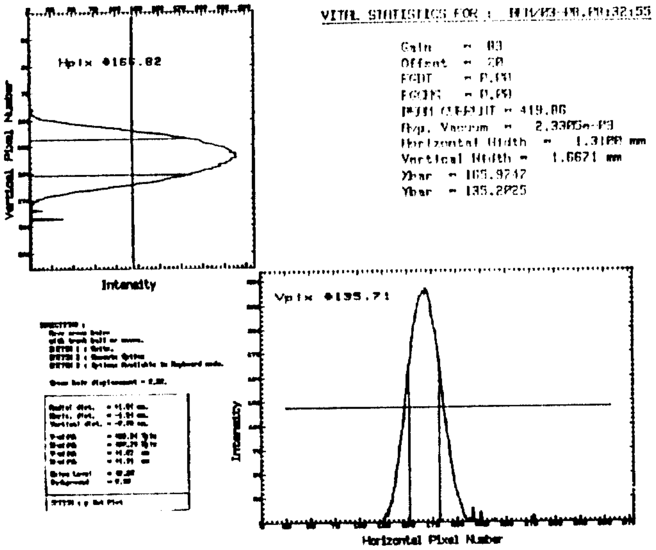
The operator interface consists of a workstation display screen along with a mouse and knobs for display screen control. A display screen typically depicts a subsystem of the accelerator and contains user defined icons which when clicked on with a mouse, can control individual accelerator components or can activate entire control sequences. At present we have built approximately 20 display screens for machine control. The display screens and icons are built with the aid of a graphic editor. This tool allows custom icons to be designed, built and assigned to machine devices in a few hours time. A standard set of display devices such as bar graphs and dial indicators is also available.

V. CONTROL LOGIC GENERATION

The control logic is executed through ladder logic. Ladder logic is implemented as an array of logic functions which are executed column by column. Control sequences are built out of a set of discrete logic functions which are graphically pasted onto the logic array to form the appropriate control sequences. The logic functions available include boolean, mathematical and user defined operators. A complete set of editing functions is available to modify existing logic arrays. Hardware devices are controlled by associating a name with individual hardware channels. A graphic utility is available to create the signal name to hardware connectivity.

VI. BEAM DIAGNOSTICS

The beam diagnostics on the SXLS machine is obtained through seven flags and six sets of pickup electrodes distributed about the ring and the transfer line. The flags are phosphorescent screens which are inserted into the beamline for beam position and profile measurements. Beam profile measurements are made through a synchrotron port located at the exit of the first dipole. The position and profile measurements are made by digitizing the video image of the electron beam. The video image is obtained through a set of Sony XC-77 CCD cameras. The cameras are positioned at each of the flags and at the synchrotron light port. The camera video signals are multiplexed to a Data Design Corporation AC100 frame grabber which digitizes the video image. The resulting 380 by 240 by 8 bit pixel array is read by the console computer where it is color mapped by pixel intensity before being displayed on the operator console. The digitized video image may be saved on disk along with the beam current and vacuum pressure for later analysis. Offline utilities have been written to calculate the average position and the rms width of the beam density distribution [2]. A sample display of data taken from the synchrotron light port is shown in Figure 2. The horizontal bar is the half maximum intensity. The two vertical bars show the rms beam width.



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VITAL STATISTICS FOR :  01/03-98,00:32:55

Gain     =  03
Offset   =  20
FGDT     = 0.00
FGON     = 0.00
BEAM CURRENT = 419.06
Avg. Vacuum  =   2.3305e-09
Horizontal Width  =   1.3100 mm
Vertical Width =   1.6671 mm
Xbar   = 165.9747
Ybar   = 135.2025
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Figure 2

Beam Orbit Measurement

Beam orbit measurements are calculated from readings of six sets of pick-up electrodes (PUEs) within the synchrotron ring. Each set of PUEs in the two straight sections provides horizontal and vertical beam position information with the aid of RF Receivers [3]. Receivers in the two dipoles provide horizontal position information only. The PUE signals are read approximately four times per second. To avoid the display of jitter due to orbital variations, a time-averaged value is displayed along with the standard deviation. The beam position was found to depend on both the horizontal and vertical components in a non-linear way. A method of nonlinear reconstruction was used and a noniterative algorithm was developed to account for this [4]. Transport line and first turn beam position measurements were made by multiplexing processed PUE signals to a LeCroy 7200 oscilloscope. The processed PUE signals yield a difference and a sum signal of the individual PUE button. The LeCroy oscilloscope was programmed to calculate the beam position from a calibration constant and the processed PUE signals. This is done for the horizontal displacements according to the formula:

$$X = ((B + D) - (A + C))/\text{Sum}\,(A + B + C + D)$$

where A,C are pickup electrode buttons for the inside and B,D for the outside of the ring respectively [5].

Timing System and Beam Position Measurement

The septum and kicker magnets are synchronized to the LINAC electron bunches by triggering a Stanford Research Systems DG535 pulse delay generator with a synchronization pulse. The DG535 also provides a high precision pulse to the LeCroy 7200 oscilloscope for proper triggering on the electron beam bunches for the first turn beam position measurements. The DG535 was programmed to receive setpoint commands from the control system through a GPIB interface.

Quadrupole Magnet Positioning Control

The quadrupole magnets in the 2 straight sections are motor driven to provide independent horizontal and vertical positioning. The motor drive system consists of eights motor assemblies (including stepper motors, stepping motor controllers and translators), and eight high precision multi-turn potentiometers. The control system reads the voltage from all eight potentiometers, converts them into positions and displays these values in terms of millimeter to the user display screen. It also compares the magnet positions with the user setpoint values. If the magnet position is not within the 5 microns tolerance limit, the program calculates the new displacement, taking into account any gear backlash, converts the displacement to microstepping motor pulses, along with optimum speed and acceleration curve setpoints, sends the new value to the motor controller.

Special Features

Automated sequencing of routine operations is accomplished with state machine utility. This utility allows the definition of actions to be executed at given states and the transitions rules to pass from one state to another. The transition rules take the form of mathematical and logical operations on signal values in the system database. The state machine has been used to ramp the XLS ring magnets (Dipoles, Quadrupoles, Sextupoles and Trims) for low energy injection, beam orbit and beam lifetime studies.

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VI. REFERENCES

[1] R. Bork, private communications, 1990.

[2] S.L. Kramer and R. Rose, "XLS Video Beam Profile Measurement System," NSLS Technical Note SLK-4 (18 Feb. 1991).

[3] R. Biscardi and J.W. Bittner, "Switched detector for beam position monitor", *Proc. of the 1989 IEEE Particle Accel. Conf.*, March 1989; pp 1516-18.

[4] E. Bozoki, J.W. Bittner, J-Y. Huang; "Calculation of the orbit from PUE measurements using nonlinear reconstruction", NSLS Technical Note 355 (20 Sept. 1989).

[5] E. Bozoki, J.-Y. Huang, J.W. Bittner, "A noniterative method for calculating beam position from induced electric signals," *Proceedings of 1989 IEEE Particle Accelerator Conference,* Chicago, Illinois, Vol. 1, p. 470, 1989.