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MODIFIED BETATRON ACCELERATOR DATA ACQUISITION AND CONTROL SYSTEM

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I. Introduction

This article describes the planning and implementation of the NRL Modified Betatron Accelerator[1,2] (MBA) data acquisition and control system (DACS). The design goal of the MBA is to accelerate multi-kiloampere electron beam pulses to 50 MeV. It employs an applied toroidal magnetic field in addition to the rising vertical fields of a conventional Betatron.[3-5] Theoretical studies show that the toroidal field improves the stability and equilibrium properties of the device at high currents. The accelerator hardware consists of three capacitor banks, the precision injector accelerator, toroidal and vertical field coils, vacuum chamber and pumping system, and intense relativistic electron beam diode. The task of the DACS is to conduct the safe and efficient firing of the MBA and the data acquisition and archiving of accelerator function.

II. DACS Requirements

The DACS must perform three major tasks: (1) the control and shot sequencing of the accelerator, (2) the data acquisition of MBA shot data and (3) the archiving of the shot conditions, shot digitizer data, and oscilloscope data. There are several constraints that need to be met in the course of performing these tasks. An effective control system is one that minimizes the need for human direction and intervention. The data acquisition system must be able to prepare the digitizers and the other various data acquisition modules, log conditions before the MBA shot and coordinate the data retrieval after the shot. Display of data after each MBA shot should be convenient for the MBA operator. The archiving system should uniquely identify each shot and mark each set of data accordingly. Data should be easily retrieved and manipulated by users without confusion or delay. Finally, the control system must discourage and prevent dangerous and costly accidents which are control system caused, particularly those initiated by software bugs.

The hardware for the DACS should meet additional requirements. During shot sequencing, the MBA produces radiation and electrical transients. The DACS must provide for personnel and equipment safety in a noisy electromagnetic environment. Grounding, isolation, and shielding must protect low power digital circuits and sensitve diagnostic instruments. For the DACS to be cost effective, existing hardware such as oscilloscopes should be utilized as well as the incorporation of newer types. Manpower for design, fabrication and testing of diagnostics and controls are also limited. Thus, when possible, these newer DACS modules should conform to existing hardware standards making interfacing simpler. This also applies to the computer system hardware which has to interface not only to experimental diagnostics but also network to remote users other more powerful computers.

The DACS software has similar constraints. Principal among these is to minimize the development time as much as possible through the use of standard and/or existing software. In addition, the data should have consistent format for all of the various diagnostics despite originating from substantially different hardware. The computer system software must also serve "department level" computing needs for the NRL Advanced Beam Technology Branch when the MBA is not firing. These include word processing, scientific applications, computer aided design, and networking to other more powerful NRL computers. These functions must then be gracefully set aside during MBA shot sequencing.

III. DACS Hardware Implementation

The principal communications link of the DACS system is a CAMAC fiberoptic serial highway[6] (IEEE 583 and 595). The CAMAC serial highway system is connected through the use of a system CAMAC crate containing a pair of Kinetic Systems (KS) 3920 crate controllers and a KS 3992 serial highway driver. The KS 3920's are connected to a VAX 11/750 and a PDP 11/23 using UNIBUS and Q-bus boards, respectively. Each CAMAC crate is connected to the serial highway using a KS 3952 serial crate controller. There are four locations for the CAMAC crates and each of these are connected to the other locations using LeCroy 5211 U-port adapters and fiberoptic cable. The physical and logical layouts of the DACS system are given in figures 1 and 2. The "system crate" configuration was chosen instead of the more widely used rack mounted serial highway driver so that the PDP 11 could control the serial highway on a coequal basis with the VAX. The use of fiberoptics not only serves to minimize electrical pickup by these connections, but also allows the computer room to be placed on a completely separate ground from the experiment. The control racks outside the computer room house a pair of crates containing modules which interface to the manual control system. Capability for distributed control is provided by an in crate PDP 11/23 crate controller mounted in the control area. There are two diagnostic shielded rooms, one inside the eight foot thick concrete wall which encloses the MBA and another adjacent to the computer screen room. These rooms house crates containing CAMAC digitizers of various speeds (LeCroy 8828 and 8210) and an CAMAC module interfacing to GPIB[7] (IEEE 488) digitizers (Tek 7912 and 7612).

The manual control racks contain hardware which is sufficient to operate the MBA with or without computer control. The controls for each major subsystem component is mounted on a separate rack. The interlocking logic both for the safety of the accelerator and its operating personnel are implemented in relay logic. Our reasoning is that the MBA software is more likely to be the source of safety problems than the hardware because the hardware will not be modified as often and because the knowledge of interlocking hardware safety systems is greater. As a result, the MBA can be fired without any computer assistance at all, since the

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computer control system operates in parallel with the manual controls. The manual control switches and sense lights have separate computer control lines which allow it to fire the MBA in the same way that human operators do. The principal advantage of computer control is that the routine button pushing and indicator light sensing and their recording can be automated. The software is set up to record shot conditions such as background vacuum gauge pressures automatically. Manual controls have the advantage of simplicity during testing phases. Thus, the implemented system has the advantages of both types of controls. The switching between manual control and computer control is accomplished as follows. While the DACS is under manual control, the computer actuates a given set of switches and signals the operator by lighting a "computer ready" indicator lamp on the control rack. The operator then directs the computer to take control of the MBA. The computer asks to be switched into remote mode, and at the discretion of the MBA operator, the local/remote switch is toggled. At that point, the manual control switches will not operate except for the "all systems dump" switch which automatically brings the DACS to manual control.

Manual control for the MBA is based on 120 volt AC relay logic. All primary control circuits incorporate normally open intelock contacts and momentary contact switch actuators to insure that: (1) for the majority of probable failure modes, a "disabled" quiescent state will result and (2) interlock relays must be deliberately energized to provide a closed circuit control path. Potter and Brumfield four-pole socket mounted relays and heavy-duty microswitch PM type controls are used throughout.

A typical manual control circuit consists of a normally closed (OFF) and normally open (ON) switch pair in series with an interlock chain and the end item to be controlled, e.g. motor starter or solenoid valve. Manual operation is accomplished by pressing and maintaining the normally open switch to send control power to the end item. A feedback signal (e.g. limit switch) is used to energize a control response relay which: (1) latches the control circuit in the ON state by short circuiting the switch contacts, (2) illuminates the appropriate status lamps on the control panel and (3) provides additional interlock contacts for dependent or subordinate circuits. An OFF state is achieved by momentarily pressing the normally closed switch to interrupt control power to the end item. As soon as the feedback signal no longer indicates the ON state, the latch is disabled and the entire circuit is left in the quiescent OFF state.

When the system is transferred to computer controlled operation, relay contacts are used to disconnect the manual controls/latches and substitute a parallel set of computer controlled CAMAC switching modules. In this mode, the ON/OFF functions are reduced to "switch closed" and "switch open" indicators, repectively. The computer, however, monitors the feedback lines directly to determine if the intended control function has taken place. The manual mode interlock chain is retained in computer mode to provide a fail-safe backup for the normal computer switch sequencing.

As was stated above, the computer control system software operates computer switches and sense lights in parallel with the manual controls. Each switch or sense light has a corresponding bit that can be read and/or written on a register of a CAMAC module. Standard Engineering Co. CAMAC modules are used for this purpose as well as for digital to analog controls and analog to digital senses. When possible these connections to the CAMAC modules are made through optically isolated termination blocks.

IV. DACS Software Implentation

The software for the MBA was constructed as a multilayered product. The serial highway software driver for our hardware configuration was purchased from Kinetic Systems Corp. This driver provides a QIO level access to the CAMAC system. It appears to the VMS operating system as a normal system level device allowing multiple users to access the CAMAC system while preventing multiple processes from accessing the same module simultaneously. Of course, access conflicts between the VAX and the PDP 11 are not resolved by the hardware or the software. The driver also has interrupt capability for CAMAC LAMs which is not presently utilized. Provided with the driver were subroutines having CAMAC standard FORTRAN calls which we use with minor modifications allowing for high level access to the status bytes. Above this level are routines which handle generalized digital sense, digital switch, analog sense, and analog control functions. A block data common block database allows the same subroutines to be called for these functions regardless of the specific hardware used.

The MBA control system software was entirely written in VAX FORTRAN at NRL. It can be divided into four different modules reflecting the different phases of MBA operation. First, the "shotset" program queries the MBA operator as to the parameters of the upcoming shot. Next, these parameters are verified and saved by the "verset" software module. Program "shotfire" prepares the MBA hardware for the shot and after given the go ahead signal from the operator the shot sequence is initiated concluding in either an "all systems dump" error condition or successful MBA firing. In the future, some of this "autosequencing" function will be delegated to the in crate PDP 11. The standalone PDP 11 system will be used as a development system for creating this autosequencing software. After each shot the diagnostic data is acquired from the digitizers and cataloged by program "datacq".

In keeping with the minimization of software development costs, we adopted the data acquisition and analysis system used by the University of Maryland Laboratory for Plasma and Fusion Energy Studies. This software consists of a program to acquire the data from CAMAC and other types of digitizers, a program to display them numerically and perform elementary calculations on them and a third program to plot the results. It was originally written in FORTRAN IV for the PDP 11 running RT-11, so some development time was spent transporting the code to VAX/VMS. The second of these programs uses the CSI command interpreter which was not available on the VAX and such a parser had to be written. During that process, the code compatibility was checked using the standalone PDP 11 system.

Another data acquisition and analysis problem was how to translate oscilloscope data to the same format as the digitizer data. This was necessary because of a sizeable existing inventory of expensive wideband oscilloscopes. Moreover, these fast oscilloscopes are the most cost effective means of recording signals with bandwidth >100 Mhz. To this end, we acquired a Hamamatsu C-1000 video camera system and

Austin Research Associates software to digitize oscilloscope photographs. The software was modified to produce data files in the Maryland format. The stand alone PDP 11 is used to acquire and preprocess the photographic data. The resulting files are then transferred to the VAX using DECnet.

It is also a requirement of the DACS that communication with other computers at NRL be available to facilitate post-processing and interaction with numerical simulations. Shielding of the computer screen room presents an obstacle to normal wire connection of terminals to the VAX. High speed fiberoptic modems are used to connect terminals in offices and locations outside the computer screen room to the VAX. Installation of a fiberoptic version of Ethernet (IEEE 802.3) connecting to other NRL VAXes and NRL CRAY XMP/12 is in progress. Since in the design of the DACS, the computer is primarily a replacement for a human operators, microsecond or even millisecond response times are not required. Thus during periods of MBA shot sequencing, the relative priority of other tasks such as terminal and network activity is lowered, guaranteeing adequate computer response for the DACS. In this way, processes in progress during MBA firing are not aborted, but only delayed.

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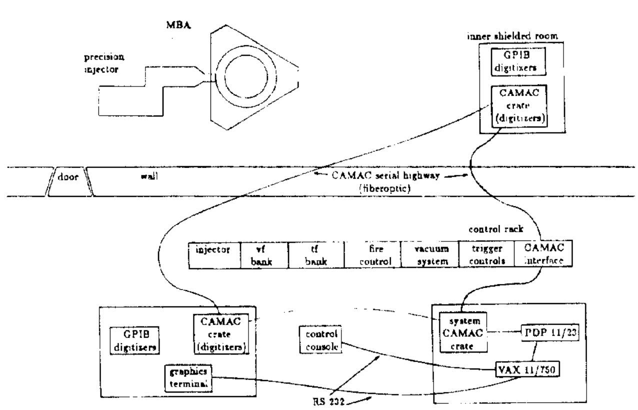

Figure 1. Modified Betatron Accelerator physical configuration.

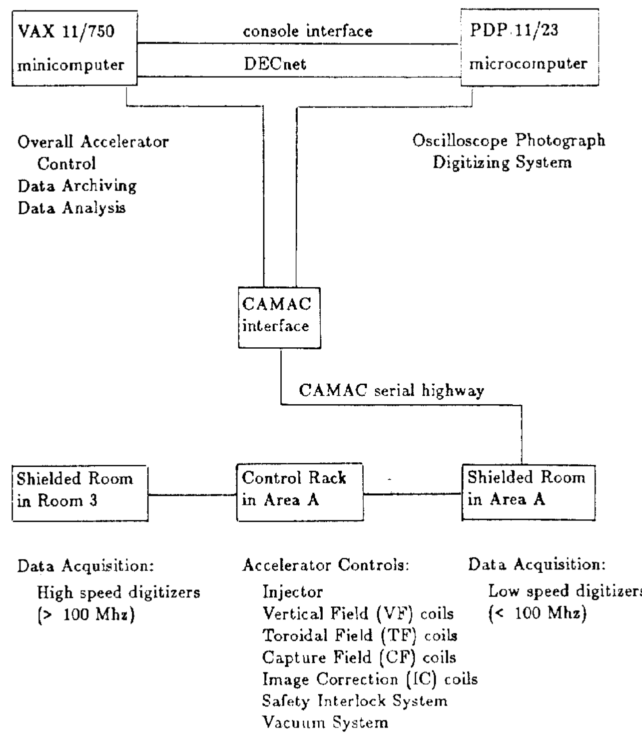

Figure 2. Modified Betatron Accelerator logical configuration.