THE IUCF COOLER RING CONTROL SYSTEM*

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ABSTRACT

The IUCF Cooler Ring is an accelerator system capable of accumulating and storing light ion beams, cooling them with a localized electron beam and accelerating them (to about 500 MeV for protons). The commissioning phase for this device is nearing completion, including demonstration of all its basic functions. The architecture of the computer control system used by this machine is presented, with emphasis on software. The event timing, high-voltage control and the interface to the existing cyclotron control system are discussed. Operational considerations will cause the operator stations to be moved a large distance in the near future. The new system layout is presented.

INTRODUCTION

IUCF has been operating a system of three accelerators under computer controlled since 1976 to perform basic research in nuclear physics. The original control computer and the entire complement of software was replaced in 1985[1]. Addition of the Cooler Ring to the accelerator complex required a separate control system and control computer for a number of reasons. Physical constraints of the building and the desire for short diagnostic signal cable runs and quick access to the ring and its power supplies during the commissioning phase meant that the cooler operator controls had to be some hundreds of feet from the cyclotron control room and the existing control computer. The need to develop a large quantity of new software, the lack of a controls development system, the desire to operate the cyclotron and cooler independently and the anticipated ramp calculation load all argued for a new computer.

Since IUCF operates with the minimum sized controls software group (one fulltime person up until the beginning of this year plus various temporary people), the new processor has to run nearly the same software as DIANA, the cyclotron control system PDP-11/44. An LSI-11/73 system (PLUTO) was assembled as the best available option at the time of purchase (1984). As with DIANA, this is an efficient solution in that the controls bus (cooler DIO) is a 16-bit device and most controls operations are I/O rather than compute bound. But it was known from the beginning that this system alone would be inadequate at some stage of cooler development. The system admits several natural paths for expansion, some of which are discussed below. Two operator stations were constructed which are identical to those on DIANA. An eight color, medium resolution (768x574) graphics display was added.

I. STATIC CONTROLS

As a storage ring and beam cooling device, the Cooler may be viewed as a length of beamline, that is, a static device very similar to the cyclotrons for which IUCF has a trained operations staff, great experience and well honed control techniques. Therefore to evolve cyclotron control software to the Cooler was both natural and highly desirable. The basic control displays are identical for both cyclotron and cooler and allow cyclotron operators to concentrate on cooler-specific problems without having to learn a new interface. The assembly language codes providing acquire/control and SCD (Standard Cyclotron Device) and general display functions are conditionalized so that one set of source files treats the customized hardware on each computer.

The cooler places more stringent bounds on the tuning range for all devices, or, conversely, "tuning" one's way out of a volume of parameter space in which circulating beam cannot exist is nearly impossible. A Save/Compare/Restore program exists to save the complete state (all DAC and ADC values) of the cooler (hopefully a state that supports stored beam), restore all or selected subsets of those values and compare saved values to those in previous saves or to the existing cooler state, reporting all differences found

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which exceed preselected thresholds. While making permanent saves requires specific operator action, temporary saves are made automatically with an adjustable period. The latest 16 temporary saves are available to the operator to be made permanent or used in the compare or restore functions. This is the most heavily used application in the entire system.

The primary beam sensing device is the Beam Position Monitor (BPM)[2]. At present there are 36 BPMs accessible by PLUTO. At beam currents of a few hundred nA and above, these BPMs supply reliable beam position and intensity information which can be displayed on the color graphics display. The BPM software provides for scans of user definable sets of monitors to be done either continuously or in synchrony with the timing system via interrupts. Positions may be displayed in mm or in 'aperture units', i.e., divided by the square root of the beta function value at each monitor. In all modes, the software adjusts its delay between measurements to conform to the hardware sampling time, which varies inversely as the beam intensity. The resulting "realtime" display is one of the primary cooler tuning tools.

Control for the high-voltage platform for the cooling electron beam terminal is accomplished through a 52-meter fiber optic cable driven by Synchronous Mode Avionics Receiver Transmitter (SMART) chips[3]. Each cable end is connected to a shore or island computer containing a SMART and an M6809 MPU. The entire system is called LUCIFER and can be run in stand-alone mode from any RS232-linked terminal for testing. A FIFO for input commands and dual-ported memory supplying output, both connected to the cooler DIO, make LUCIFER appear to PLUTO as a set of normal DACs and ADCs, minimizing PLUTO programming. Internally, LUCIFER can transfer 64-byte messages over the optical link at about 100Hz, more than enough to satisfy all demands from PLUTO. LUCIFER works so well that we would like to retrofit all our high-voltage terminals with copies.

The cyclotron control system has used pseudo-devices, combinations of real devices treated as a single device, since its inception. However, cooler operation exploits this feature quite heavily and has required extensive expansion of its treatment. A COMBO is a linear combination of an arbitrary number of real devices with adjustable coefficients. Incremental COMBOs multiply a specified change in the COMBO pseudo-DAC by each coefficient to obtain a change for the corresponding real DAC; absolute COMBOs do the same using DAC positions instead of increments. The new DAC positions of all components of a COMBO are checked against the appropriate limits before any DAC is updated. The COMBO control algorithm is also recursive, allowing COMBOs of COMBOs. The cooler has about 75 COMBOs defined, using most of the 160 ring devices. Most COMBOs are composed of steerers to produce local horizontal or vertical angle or position changes in each of the six corners and straight sections. Because all ring quads have multiple coils and shared power supplies, COMBOs also exist which allow single quadrupoles to be excited for beta function measurements. The operator may change the composition or coefficient values of any COMBO at any time and can archive and restore all COMBO data.

II. TIME-DEPENDENT CONTROL

Even when operating as a storage ring, the cooler is not really a static machine, but rather requires a number of precisely timed, repetitious events to occur for injection, if nothing else. The master timing system at present consists of a number of Jorway 221 CAMAC modules driven by an external clock at 1MHz and controlled through a home-built coincidence box to ensure synchronicity between modules and with 60Hz power. Database maintenance and timing server tasks exist so that operators or other programs may read, modify or create time events and the repetition period of the total timing cycle. The ramping and stacking injection programs mentioned below both utilize this facility to set timing events according to their own requirements. The operator may also define or change timing signal names, archive and restore sets of events and toggle between two "online" event sets. While this system is inexpensive and functions quite well, it has neither the flexibility nor length of cycle (maximum of 16 2/3 sec) to meet known future cooler requirements. We are presently examining options for a new system.

The ramping hardware and software have been described in some detail elsewhere[4)5)]. In brief the system allows the calculation and use of up to eight separate ramp segments of 256 endpoint-slope data pairs each for 90 ramping devices. At present two ramp segments are used routinely: one for the ramp-to-run-level, which is carefully divided into vectors of equal duration and corrected for dipole supply filtering, and one for the ramp-to-fill-level, which is a single vector, get-me-there-now, ramp. Ramp archives are of little use, since it is the present machine state, dependent on operator tuning activity, that is ramped at any time. However, it is very useful to archive and reapply previously successful modifications after recalculating ramps. Now that long-lived accelerated beams are becoming common, the ability to modify ramps on the fly by tuning at the run level will be added. The program controlling ramp execution uses the timing server task to define injection and ramp-to-run-level events, while it retains control of reset and ramp-to-fill-level operations.

Stacking injection[6)] requires programmable waveform generators to supply precisely timed changes to RF amplitude, phase and frequency. The amplitude and phase are controlled with Jorway 221 CAMAC modules driving a ganged pair of 8-bit DACs yielding a settling time of 0.1% full scale in 1 usec for full scale values from -0.2 to -10.0V. The frequency is set from a synthesizer driven by a standard IUCF ramp DAC card modified to output eight BCD digits, instead of the normal 16-bit word, at a maximum rate of 250kHz. A program provides the operator with control of these devices in terms of voltages, frequencies, start times, durations and repetition period and count. It makes heavy use of the timing system to repeat the complex stacking cycle up to 75 times, limited by the memory capacity of the Jorway. Use of the timing server task also allows stacking and ramping tasks to execute independently and yet "co-operate" to produce a stacked, ramped beam.

III. INTER-COMPUTER COMMUNICATIONS

All IUCF control and data acquisition computers are tied together by a common Ethernet/DECnet system. PLUTO and DIANA each use it to provide transparent remote access to devices defined on the other control computer via existing library calls, i.e., with no recoding of application tasks. This service, originally intended to be provided by an independent Ethernet line, is implimented by a FORTRAN task doing task-to-task DECnet data transfers over the common Ethernet and allows full control of all remote devices as if they were local. While involving a noticable delay, SCD response for controlling remote devices is fast enough not to bother most operators. The data acquisition VAXen use a separate system which allows them to read all, but control only a very limited set of, devices on either DIANA or PLUTO.

One way of expanding the capabilities of the control system is to make use of an idle VAX. For example, DECnet is used to transmit BPM data to a VAX for analysis. In the past, hand calculations of steerer effects were done from BPM data sets manipulated by a VAX. We are now attempting to use a program running under VMS to calculate steerer changes from these data to correct the closed orbit in the cooler. From time to time new tunes are calculated for the cooler, using VMS codes such as MAD or COMFORT, which significantly change the beta function around the ring, requiring changes to steerer COMBO coefficients. The process of calculating and applying appropriate changes to all steerer COMBO coefficients is automated. Testing the "locality" of steerer COMBOs is a good test of one's knowledge of ring optics and magnet performance.

IV. FUTURE DEVELOPMENTS

This year the primary cooler control area will be moved from its present location to the cyclotron control room to facilitate routine operation now that commissioning is essentially complete. This move involves implimenting HADES, an 11/83 with 2MB of memory and an RA81 disk, and two operator stations. The cooler DIO will be dual-ported with contention arbitration giving priority to HADES. As mentioned above, the timing system will be redesigned, with signal distribution over long distances now being important. PLUTO will be retained as a development system and to supply direct cooler control for experimenters. A software interlock will be established between PLUTO and HADES to prevent operators and experimenters having simultaneous control of devices. See Fig. 1 for system layout. As with PLUTO, all low-level codes will be conditionalized to treat the unique hardware environment of HADES so that the single set of source files is retained.

Finally, we have numerous diagnostic devices which contain IEEE-488 (GPIB) ports. This summer these will be connected to HADES to automate parameter setting and

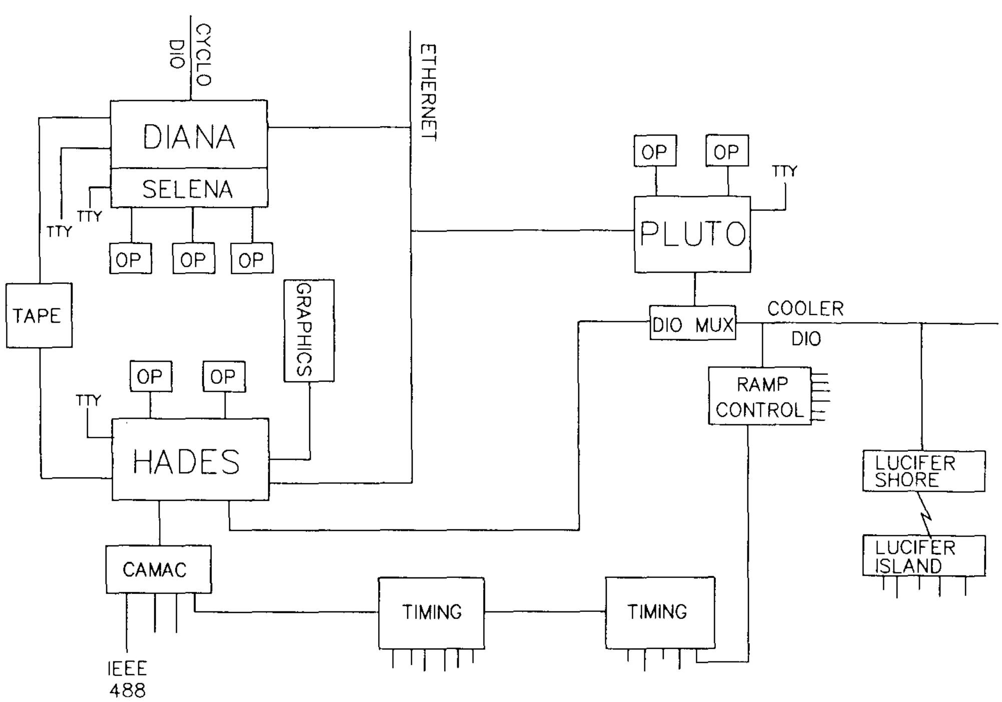

Figure 1. Schematic layout of IUCF control computers.

analyze measurements, part of the process of transferring cooler ring running from beam physicists to operators.

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