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COMPUTER CONTROL OF THE ISX-3 NEUTRAL INJECTION BFAMLINES

P. C. Hanna

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COMPUTER SCIENCES DIVISION
at
Oak Ridge National Laboratory
Post Office Box X
Oak Ridge, Tennessee 37830

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COMPUTER CONTROL OF THE ISX-B NEUTRAL INJECTION BEAMLINES

ABSTRACT

A system of controls for the Impurity Study Experiment (ISX-B) neutral injection beamlines at the Oak Ridge National Laboratory is presented. The system uses standard CAMAC equipment interfaced to the actual beamline controls and driven by a PDP-11/34 mini-computer. It is designed to relieve the operator of most of the mundane tasks of beam injection and also to reduce the number of operators needed to monitor multiple beamlines.

1. INTRODUCTION

The ISX-B tokamak experiments at Oak Ridge National Laboratory (ORNL) are directed primarily toward investigating high-beta plasmas.¹ A fundamental part of these experiments is the neutral beam injection system,² which supplies additional heating to the plasma.

The ORNL beamlines duopIGatron ion source³ is shown in Fig. 1. Hydrogen ions are generated in the arc chamber floating at high voltage and are accelerated between the plasma electrode and the ground electrode. The ion beam next passes through a hydrogen gas cell neutralizer, followed by a high magnetic field region to remove any remaining ions. The neutrals then pass into the tokamak, where they reionize and thermalize, depositing their energy in the background plasma. Continuous conditioning of the arc chamber and grids, together with proper control of the source parameters are necessary to maximize the extracted beam power. These and other items, such as switching between conditioning (on the beamline calorimeter) and injection, and recording the current and voltage parameters after each shot, require the operator's total attention. It was decided that a computer-based system could be designed to handle most if not all of the above mentioned tasks. The results of current work on this system are presented here.

Fig. 1. Typical Ion Source Electrical Power Systems

2. DESIGN REQUIREMENTS

The beamline system at ISX-B consists of two beams which operate completely independently of each other with the exception of the relative sequencing of the beams. For this reason the computer has to be able to monitor and control each beamline separately. The two beamlines, designated West (W) and East (E), also react differently to the same parameter settings so that the system must be tailored for each beamline individually.

In order to have any control of the beamlines, monitoring and data acquisition must be done to provide a basis for decisions. Arc current, arc voltage, beam current and beam voltage comprise the basic information. Another facet of the data acquisition system is to record these parameters for every tokamak injection shot, along with the time and date and the corresponding tokamak shot number.

The parameters which govern the beamline and thus need to be controlled by the computer are the arc drive voltage, the source gas feed, the source magnet strength, and the accel voltage level. For safety, and efficient operation, the human operator must be able to effect changes in the values which the computer sets for these parameters or, if need be, switch from computer control to manual control very quickly. It is required that this system be able to automatically adjust these parameters in order to generate a beam with a specified power level. This includes gradual increases in parameters, and recovery from breakdowns (localized arcing) when they occur. Also the beam current and voltage are varied from the values which are optimal for beam optics (described by the perveance $I_b/V_b^{3/2}$) to clean the ion acceleration structure and prevent breakdowns.

The final requirement of the system is that it recognizes which beam or beams are to be injected and at the correct time moves the calorimeters⁴ and switches the timers to inject mode. This also involves switching back to conditioning (test) mode after a shot or a time-out (shot cancelled).

3. SYSTEM DESCRIPTION

3.1 Hardware

CAMAC modules are used for all of the data acquisition and control functions. All modules occupy a single CAMAC crate in the ISX-B control room. This crate is tied via the CAMAC serial highway to a PDP-11/34 computer with a Jorway 411 CAMAC interface.

An eight-channel analog-to-digital converter (ADC) with 8192 words of memory and running at 500 Hz provides 1024 data points for each of the desired voltage and current parameters over a 512 msec period spanning the actual beam shot. The beam trigger and a tokamak -5 msec trigger are both detected by a simple in-house trigger sense module. The tokamak shot number is provided by the tokamak computer system via a CAMAC data communication module.

To effect the controls needed, there were many tie-ins added onto the beamline circuitry. Most of the tie-ins are in parallel with a manual switch to choose whether the computer or the operator has control. The exception to this is the safety interlock for the high voltage power supply which is in series so that the supply will be on only when both the computer and the operator want it to be.

A digital to analog converter (DAC) gives the computer the ability to set the gas density and the magnet strength. Two reed relay modules provide on/off type switches for the high voltage interlock, calorimeter up or down, timer (trigger) enable or inhibit, condition or inject mode, and a failure alarm. These reed relays are also used in a timed on/off manner to pulse the motors which increase or decrease the arc drive voltage and the high voltage (beam) supplies.

The PDP-11/34 drives a CRT-type terminal for operator interaction.

3.2 Software

The software was developed completely in FORTRAN with calls to existing CAMAC subroutines. It is broken up into a number of small tasks which are outlined below. These tasks all access a FORTRAN common area so that data can be shared.

AUTOBM - Initialization.

Initializes variables and CAMAC modules. Also displays initialized variables to the operator and allows changes to be made.

BLC - Operator interaction routine.

Allows the operator to change control parameters which the computer has set. The operator also uses this routine to inhibit or enable a beamline and to signal that a beamline should inject when the tokamak fires.

WATCHT - Watches for triggers.

Waits for the proper triggers to occur and starts the digitization of the parameters. When the ADC is finished, WATCHT signals the appropriate processing routines that the data is valid. (See Flowchart 1.)

SAVDAE or SAVDAW - Save data.

After a tokamak shot with beam injection these tasks are started in order to save the parameters from that shot to disk.

RECALE or RECALW - Recall data.

These tasks are run by the operator when he wants to see the data on the disk. Data can be accessed by shot number or by the date of the shot and can be displayed or printed.

Fig. 2. Flowchart 1 - WATCHT

INITE or INITW - Initialize the arc current.

More of a safety feature than anything else. This routine waits for WATCHT to signal that the data is valid and then looks for a good arc current. It verifies that an arc is established before the arc voltage exceeds 100 volts; otherwise it shuts down. If the arc current is established, this routine starts CONDE or CONDW and exits. (See Flowchart 2.)

CONDE or CONDW - Condition arc and beam.

This routine brings the arc up to a specified current and then turns on the beam and brings it up to the specified current level. It handles all breakdowns, as well as high voltage sweeping, waiting to clear up numerous breakdowns, and switching between test and inject modes. (See Flowchart 3.)

Fig. 3. Flowchart 2 - INITE or INITW

Fig. 4. Flowchart 3 - CONDE or CONDW

4. CONDITIONING ALGORITHM

Getting the arc current (I_a) up to the specified level is fairly easy. It involves holding the gas and magnet at their initialized levels and increasing the arc drive (thus increasing the arc voltage (V_a)). If breakdowns occur, the arc drive is decreased until the breakdowns go away and then increased again.

For the beam current (I_b) the high voltage (V_b) interlock is closed in order to generate the beam. The arc drive is still the main tool used to increase I_b . The gas level is adjusted after each shot to try to maintain a certain relationship between I_a and V_a . This relationship is expressed as follows:

$$I_a = k_1 V_a - k_2$$

where k_1 and k_2 were found experimentally for each beamline.

This I_a is adjusted slightly for changes in the magnet level. The magnet level is set such that a certain magnet level corresponds with a certain I_b .

The high voltage is adjusted so that I_b and V_b remain close to a predetermined perveance curve approximated by:

$$V_b = (2.88 I_b)^{.68}$$

The high voltage sweeping consists of holding I_b constant and sweeping V_b in an arc which goes 20% above and below this perveance curve. This sweep is done from time to time to improve beam optics.

Breakdowns are handled by decreasing the beam parameters until the beam stabilizes and the parameters can again be increased.

5. OPERATING EXPERIENCE

During the first stages of testing it was found that the software would have to handle the tremendous amount of electrical noise in the system. Most of the noise problems were overcome by reading triggers multiple times and averaging over a large sample of data using methods which discard very irregular points.

The computer operated the beamlines quite effectively with a minimum of operator input for a period of approximately one month prior to the ISX-B shutdown in early October 1981.

Operation has been very successful with beam current up to about 65 amps. Both the east and west beamlines on ISX-B have been operated separately and together in many combinations of injecting and conditioning. The main problems encountered during this time were computer problems due to bad disk drives.

During the last week of operation, some attempts were made to reach much higher power levels (I_b - 65 to 100 amps). It was determined that the control system as it stands could not handle the excessive electrical noise generated and manual operation had to be resumed.

The existing operator interface was very tedious in that the display was difficult to interpret with both beamlines going. The operator also had to invoke a new task in order to make any changes in the parameters. The worst problem seemed to be that the terminal would be "busy" for one reason or another and the entire system would stop while waiting to write to the terminal.

6. FUTURE IMPROVEMENTS

The first priority seems to be more electrical noise immunity. This may involve work on both the computer software and the existing beamline controls.

The operator interface is being redeveloped to include a display with lightpen interaction. This display is updated automatically and the operator can make changes by simply touching the screen with the lightpen.

The existing calorimetry system which provides power measurement will be incorporated into this system so that these values will be available to the operator.

7. CONCLUSIONS

A control system for neutral injection beamlines has been designed, implemented, and used with much success. Despite the problems with very high power levels, this system is very successful in relieving the operator's burdens of slow conditioning, data recording, and mode switching. The use of computer control with multiple beamlines now appears very promising.

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