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LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California

PRELIMINARY REPORT ON COMPUTER CONTROL OF
2XIIB NEUTRAL BEAM SOURCES

G. G. Pollock

March 17, 1975

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ABSTRACT

The computer control and monitoring system being built for the Neutral Beam Sources on the 2XIIB CTR project is discussed. The problems of neutral beam source control are described in general. The present and future capabilities of the system being developed are described. The specific hardware implementation and software algorithms for each control loop are given.

INTRODUCTION

The purpose of this report is to document the computer control system as it is presently being developed for the 2XIIB neutral beam sources. Although much of the equipment for the computer control system has not yet been delivered and much of the software remains to be written, the structure and functions of the system have been determined in detail. That has been a considerable task, since we knew little about even manual operation of these 50 A neutral beam sources when they first arrived. We have had to wait for experience with manual control to suggest the proper approaches for computer control. In reading the descriptions of control algorithms and operator interactions that follow, it should be remembered that these 50-A sources are the state of the art in such devices and their control is not easy. Actual control experience with the algorithms and techniques described may require changes from what is presently planned.

PURPOSE OF THE NEUTRAL BEAM COMPUTER

The purpose of the neutral beam computer is to perform control and monitor functions for the twelve 50-A neutral beam sources used on 2XIIB.

Computer control is done for several reasons. First, computer control will simplify control of the sources. Less human interaction will be necessary to operate the sources. Computer control and simpler operation will reduce the incidence of control error and thus lessen the chances for accidental source damage. The computer's constant level of attention to the control problem will advance sources at their maximum rate through their burn-in schedules. This will reduce the exposure of the source to accident situations and will increase the availability of the sources. With computer control of all twelve sources, eventual centralized high level control from a console operated by a physicist in the diagnostic room becomes possible.

Manual control operation will still be available for backup operation and for manual operation of troublesome sources. In the latter case, the computer will still function as an operator aid.

As part of the control function, the computer will produce an operations log to aid in trouble shooting and fault analysis.

The monitor function is done to provide data for the physicist and machine operator. The physicist basically needs to know the energy and current output of the source throughout the experiment pulse so that it can be correlated with the other diagnostic outputs of the experiment. The machine operator uses much the same information to assess the operation of the source and diagnose improper operation.

The sources are often fired at a calorimeter target to make a calibration between measurable source parameters (such as accel current) and source energy output. The calorimeter outputs also provide a measurement of source beam shape. The calorimeter outputs are also monitored and processed by the computer to aid the physicist and operator.

OVERVIEW OF NEUTRAL BEAMS

The 2XIIB Experiment

The 2XIIB machine is a magnetic confinement CTR experiment. Figure 1 shows a simplified diagram of the machine itself.

The experiment is pulsed in nature. At the beginning of the experiment cycle, the dc solenoid magnets are energized to provide the axial field and the plasma guns are fired to inject plasma down the length of the machine. The two gate magnets are energized in sequence to trap the plasma between them. The main compression magnet is then energized to compress the plasma. The experiment duration from the time of compression is approximately 10 ms. The entire experiment can be repeated at approximately 5 min intervals.

The Neutral Beam Sources are fired at an arbitrary time before or during plasma containment.

The experiment's diagnostic signals converge on the instruments and computer located in the diagnostics room. The various control signals that operate the experiment all originate in the control room. These two rooms are carefully kept isolated electrically so as to minimize the amount of electrical noise in the diagnostics room. Electrical signals that must pass between the two rooms are optically isolated.

The Neutral Beam Sources

The purpose of the neutral beam sources is to supply power to increase the energy of the plasma in the 2XIIB machine during the experiment pulse and to supply particles to maintain the density of the plasma. They do this by generating a high energy beam of neutrally charged particles (deuterium atoms) focused on the plasma. Since they have no electrical charge the atoms are not affected by the magnetic field of the machine and are able to penetrate into the containment region. Here, a large fraction of the neutral atoms are ionized by the plasma and are then trapped by the magnetic field. These trapped particles add energy and density to the contained plasma.

A simplified schematic of a neutral beam source is shown in Fig. 2. The filaments are energized a few seconds before the experiment pulse. A small quantity of deuterium gas is introduced into the arc chamber and a plasma is created by a discharge in the gas between the anode and the filaments. The voltages applied to the extractor, accelerator (accel) and decelerator (decel) grids extract and accelerate an ion beam from the arc

Fig. 1. Plan view of the 2XIIB.

Fig. 2. Neutral beam source (adapted from LEA 73-4057-01 B sheet 1).

chamber plasma. The ion beam is neutralized by electron capture as it passes through deuterium gas in the neutralizer region and then passes into the 2XIIB machine as a beam of deuterium atoms.

THE NATURE OF THE CONTROL PROBLEM

The Existing Manual Control System

The controls for the neutral beams were designed for manual operation with future computer capability. A brief look at the number of controls required to operate the 12 neutral beams on 2XIIB (close to 250 individual switches, pots, and buttons) will give an indication of the complexity of the control situation.

The presently existing manual control system has 15 separate controls for each of the 12 neutral beams plus over 19 general mode and timing controls, all of which are manually operated. For each source, the following controls are provided: accel regulated voltage is set by a multi-turn pot and monitored by a 4-1/2 digit digital panel meter. Accel bank voltage is increased or decreased by two push buttons and monitored by a panel meter. Arc pulse line voltage is set by a multi-turn pot and monitored by a 3-1/2 digit digital panel meter. Filament voltage is increased or decreased by two push buttons and monitored by a 3-1/2 digit digital panel meter. A timing chassis produces controls for adjustment of gas fire delay, interval between shots, arc delay, and accel duration. Each source also has several on-off switches and limit indicators associated with the controls.

The operation of the source during the shot is observed on a multi-channel storage scope and by the data output by the monitoring function of the neutral beam computer. Depending on the condition of the particular source, the operator may select signals from the following list to indicate source operation: accel voltage, accel current, arc voltage, arc current, decel voltage, decel current, or plasma probe voltage. Normally, due to the limited number of storage scopes available, at most only four signals and more usually only two signals per source are observed. The present computer monitoring of four signals per source at a 300- μ s resolution produces 2400 words of data per shot. The new equipment now on order will expand to an eventual total of at least nine channels per source at a 200 μ s or better resolution and will yield 8100 words of data per shot.

Manual Control Techniques

Accel regulated voltage is used as the independent variable in operating the source. The operator uses graph data from previous sources to determine a first trial value of arc pulse line voltage to correspond with the desired accel regulated voltage. The accel bank voltage is set at a constant offset above the desired accel regulated voltage. After the trial shot, the operator interprets the accel current and arc current waveforms on the storage scope and determines which way to vary the arc pulse line voltage for the next trial. After a few iterations, the best value will have been found. By this procedure, the operator has compensated for the individual characteristics of the source. In future operation of the same source, the difference between the theoretical and actual value of arc pulse line voltage determined in this procedure will be used to select better first trial settings at other values of accel regulated voltage. The operator seldom bothers to plot the actual relationship between accel regulated voltage and arc pulse line voltage since that relationship is not only unique by source but also may change during

the running life of a source. Instead, the operator generally relies on an acquired skill of "tuning" the source. More will be said on the characteristics of this particular control relationship later in this report.

The operator sets the value of accel bank voltage simply to a constant offset above the value of the accel regulated voltage to account for the drop in the regulator and the voltage sag in the capacitor bank during the shot proper. If the offset is not large enough, a drop off will be seen in the accel current waveform toward the end of the shot. This is a relatively simple control to operate.

The filament voltage is periodically checked and set to its correct value. This is another unique-by-source parameter since the voltage measured is the open circuit voltage between shots and the actual voltage under load will depend on the filament resistance of the source. As individual filament loops burn out in a source or when filaments are replaced, the relationship between open circuit and full load voltage changes and the correct value for the operator to use will change. Changes in power line voltage and the temperatures of filament supply components cause changes in the filament voltage sufficient to require re-setting as often as several times per hour. Equipment is presently being developed to measure the actual filament voltage during the shot (not simple since both sides are elevated to the extraction potential of as much as 20 kV during the shot) and this should simplify accurate control of this parameter.

These four controls, accel regulated voltage, accel bank voltage, filament voltage, and arc pulse line voltage generally occupy most of the operator's attention. He may occasionally change one of the timing controls, usually at the request of the physicist, to fire the source at a different time relative to the 2XIIB experiment timing.

Decel voltage is presently changed when necessary by moving jumpers in the source power supplies themselves. Remote control of this parameter by switches in the control room is presently being implemented. Like accel bank voltage, its relationship to accel regulated voltage is simple and relatively easily controlled.

The manual control function is sufficiently complicated and demanding that we normally use one operator for each three sources.

CONTROL AND SOURCE CHARACTERISTICS

Individuality and Time Variance

As has been mentioned earlier, each source has highly individual characteristics which may change with time. The individual and time variant principal characteristics are the relationship between accel regulated voltage and arc pulse line voltage, the relationship between open circuit and full load filament voltage, the maximum energy that a source will be able to achieve, the rate at which the burn-in process will progress, and the spatial energy distribution (focus) of the resulting beam. All of these characteristics are affected by manufacturing tolerances and source individuality appears immediately. As the source is burned-in and operated, its characteristics will change. Filament loops may burn out. Grids will be affected by arcing during burn in and by temperature stresses. Impurities and filament metal boil off and evaporate and deposit elsewhere. If a source is idle for an extended period or if the experiment vacuum is released, the source characteristics may change, especially the maximum achievable energy. This means that the computer control system, like the human operator, must "learn" the characteristics of each source it is operating by trial and error and be adaptive to follow changes in

these characteristics. The computer control system has an advantage in this process since it can quickly use mathematical formulas of almost any required complexity to empirically determine equations that relate the characteristics of the source. It can also easily keep comprehensive histories of source operation and derive information or performance trends that will be useful in operation and control.

Burn-in

One of the important characteristics of neutral beam sources is that they must be burned-in. This consists of starting operation at a low energy level (determined by accel regulated voltage) when the source is first installed, and gradually progressing to higher energy levels. At each increase of energy level, the source will go through a period when there are many interrupts on each shot. An interrupt takes place when protective circuits in the source determine that there is an arc between grids. To avoid dumping all the source energy into such an arc with the accompanying damage to the grids, the extraction potential is momentarily interrupted to allow the arc to extinguish. As the source is operated, these individual arc occurrences tend to remove their own causes, such as microscopic burrs or other imperfections. After a time at a particular energy level, only a few interrupts will be seen. The voltage is then increased and the process repeats. Often a point is found at less than the maximum possible energy beyond which the source cannot operate.

When the burn-in first begins, the source will be fired at one minute intervals. When the energy levels become substantial (10 kV or so), the interval is lengthened to 5 min to allow the grids to cool between shots.

The time required for a source to reach its maximum energy is on the order of a week. If the experiment vacuum is released, or the source is allowed to idle for a long period, or a serious arc event occurs, the burn-in process may be set back by hours or days. In the case of a serious arc event, the maximum energy that the source will eventually reach may be reduced.

The burn-in process is one of the more important applications of computer control. When depending on human operators, it is not possible to burn-in the sources as rapidly as possible. This is because it is not practical to have enough trained operators available to run all twelve sources 24 hours a day. It is also difficult for a human operator to maintain the high level of attention required to advance each source at its maximum (and, of course, individual) rate during the long periods of burn-in. The process of learning the characteristics of each source is repeated as shifts change and different sources are exercised. A few minutes inattention by an operator during the long and tedious burn-in process can result in damage to the source due to drifts in filament voltage and the like. Computer control during the burn-in process is expected to bring more sources to their maximum energy in less time and with fewer casualties.

Source Damage By Control Error

One of the most important aspects of neutral beam source control is the possibility of damaging a source by improper operation of its controls. As described earlier, there is a specific relationship, individual to each source, between accel regulated voltage and arc pulse line voltage. If the arc pulse line voltage is set much above the correct value, damage to the grids may result, lowering the maximum energy achievable with the source. If the energy level of the source is raised too much above its present capability, the grids may be damaged by excessive

arcng. The filaments are susceptible to damage due to overvoltage conditions. Their life is shortened when run only a few percent above the proper value.

In the process of burning-in and operating the sources, some damage is inevitable simply because these units are state of the art and their components are highly stressed. In fact, when a source fails to achieve the maximum energy level, it is difficult to say whether accidental damage is responsible or whether the source simply failed to meet our expectations. But we do know of more than a few instances when a source was damaged by control error due to operator inexperience, inattention, or judgement error. Related to this is the matter of exposure. The longer it takes to burn a source in, the longer the source is exposed to the hazards of control error and the greater the likelihood of damage.

We expect that the uniformity and consistency of computer control will reduce the number of source damage events.

Data Characteristics and Their Implications

One of the principal problems in computer control of the neutral beam sources is the interpretation of the data from the preceeding shot. Since the sources are pulsed devices involving the discharge of energy banks in a short time (10 ms), control consists of using the data from the previous shot to determine the set-up parameters for the next shot. While a theoretical waveform can be drawn for the signals of interest, in practice they almost never resemble it. Instead, they are poorly behaved, full of interrupts and spikes and odd shapes. The computer program has the problem of taking the 50 to 75 data points which represent, say, accel current and deriving a few descriptive parameters from them, such as average amplitude, peak amplitude, duration, etc. This is a key process, since the values of other controls will be based on these derived values and errors due to misinterpreted waveforms are not tolerable. Some examples of typical accel current waveforms are shown in Fig. 3.

It should not be hoped that the situation will ever improve, either. The waveforms will not become more sanitary in the future. They are the result of pressing state-of-the-art devices to their limits, which is normal operation. Our experiment demands the maximum beam energies and currents attainable, so if 50-A beams ever become ordinary, these will surely be replaced with whatever is then the state of the art.

The program that examines these data points must be carefully designed to account for as many of the bizzare situations as possible and must also have the option to request assistance from a human operator if it cannot evaluate a particular data set.

COMPUTER MONITOR AND CONTROL SYSTEM DEVELOPMENT

The Original PDP-8/I System*

The original system, which is the one in use at this time, is based on a PDP-8/I with a high-speed A/D converter and peripherals (Fig. 4).

* Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable.

This system provides monitor capability for four signals per source plus eight calorimeter channels. The control hardware is used for off-line development of the various control loop algorithms. Output of the system is graphic and tabular. The graphic output, intended for use by the machine operator, is the re-creation of the waveforms presented to the high-speed A/D converter, grouped by source. Tabular numerical data is also available. The calorimeter data is also available in both graphical and tabular forms. An algorithm analyzes the accel current wave form of each source to derive characteristic parameters such as average current, duration, interrupt count, etc. A summary tabulation of this data is provided along with related derived quantities.

Current Development

The successor to the original system is presently in development. It functionally differs from the original system in that the monitor function is expanded and the control function is fully implemented. To support this increase in scope, a new computer with increased capabilities is being purchased, along with a new high-speed A/D converter and peripheral equipment with which to interface with the existing source controls (Fig. 5).

The monitor function is expanded by the new high-speed A/D converter to allow faster monitoring (approximately 160 μ s per data set vs 300 μ s previously) of all the signals of interest during the experiment pulse. Accel current, accel voltage, arc current, arc voltage, decel current, decel voltage, and plasma probe voltage will be monitored for each source, with sufficient spare channels to allow secondary electron probes or other signals of interest to be added in the future. A new medium-speed A/D converter function will monitor control parameters between shots and provide increased resolution for processing calorimeter data. In addition to the calorimeter channels, open-circuit filament voltage, full-load filament voltage, arc pulse line voltage, accel bank voltage, and accel regulated voltage will be input from each source. Through other inputs, the computer will also monitor the setting of various mode select and source enable switches on the source manual controls.

Interface equipment will allow full computer control of filament voltage, arc pulse line voltage, accel bank voltage, and accel regulated voltage. A source fire enable control will be provided to prevent source operation unless all parameters are within required tolerances.

The software for the monitor function will reduce the data gathered by the high-speed A/D converter to the parameters of the wave forms, and present these together with derived quantities in a summary form for use by the physicists. An operating log will be kept by the program of the control settings, shot summary results, and messages to the operator for each source on each shot.

The software for the control function will be developed in two phases. In the first phase, the computer will monitor the various parameters and signals and perform its control calculations. The results of these calculations will be presented as messages to the operator, who will be asked to make the indicated control adjustments. During this phase, the operator acts as a buffer between the control system and the experiment. The control system, messages, and the operator's observed responses will be logged by the computer. The operator will cause the computer to make a diagnostic data dump in any case where he believes the computer has made an incorrect request. These diagnostic data dumps and the normal operations log will be used to refine the data analysis and control algorithms.

When all concerned have acquired sufficient confidence in the control system through experience in the open-loop mode described above, the software will progress to a full closed loop mode of control.

Ideal

Ideal

Interrupt

Interrupt prematurely terminates
pulse at high energy

Interrupt

Fig. 3. Representative decel current waveforms (resolution to $400 \mu\text{s}$). Each horizontal unit on the grids is equal to 2 ms. Each vertical unit is equal to 25 A.

(a)

(d)

(b)

(e)

(d - e) Premature turn-off.

(c)

(a - c) Burning in at less than 10 kV
(multiple interrupts).

(f)

Immediate turnoff. No measurement
possible.

Fig. 3. (continued)

Fig. 4. 2XIIB neutral beam computer (original system).

Fig. 5. 2XIIB neutral beam computer (the system is currently in development).

In full closed loop control, the only control used by the operator will be the accel regulated voltage control when running the sources with 2XIIB. All other controls will be operated by the computer.

In both open and closed loop phases of development, the control software will have two principal modes of operation. The first will be a source burn-in mode, where the source will be operated at increasingly higher energy levels as rapidly as the source can accommodate them. In open-loop control, this is accomplished by messages to the operator. In closed loop control, the accel regulated voltage will be directly controlled by the computer.

The operator terminal will be fully developed with this system. It consists of a text and graphics output CRT driven by the computer, with a limited number of dedicated-function buttons and a number entry facility. This capability will allow the operator to have a two-way communication facility with the computer, separate from the computer system console, and specifically designed to match his task. Even in full closed loop control, an operator must be present to supervise the operation of the computer control function. It is recognized that the computer cannot resolve every conceivable combination of situations that may arise, and the program will be designed to recognize such situations and request help from the operator. An example could be the case where the algorithm which reduces the all-important accel current data is not able to derive satisfactory parameters from the data due to the characteristics of the data. The operator may be requested to examine the recreated wave form and input his judgement of the correct value. To aid the operator in supervising the control operation, he will be presented with graphical data for each source on each shot as was presented in the original system. He will have the ability, through his operator terminal, to request a complete set of all wave forms for a particular source if necessary for troubleshooting.

The manual control facility is entirely preserved and operative in this approach. Any source or sources may be removed from computer control for manual operation if desired. In the event of a computer system malfunction, the sources may be operated manually as they are now. The full manual control backup is a very necessary requirement for the 2XIIB neutral beams. 2XIIB is such a complex experiment that bringing the entire facility to operating status is a large and expensive task and single subsystem failures cannot be allowed to render the whole facility inoperative.

With the new computer, a "distributed system" network will be formed with the other two computers (control room computer and diagnostic computer) on the 2XIIB experiment. This will allow programs, data, and control to be exchanged between these computers and will allow sharing of their peripherals. For the current development, this will make program development simpler by making the extensive peripherals of the diagnostics computer available to the neutral beam computer. More use will be made in the future configurations, described later.

The Future Objective System

As was described in the previous discussion of the system currently in development, the three computers involved in 2XIIB will be connected together as a "distributed system" network. This will be accomplished by means of the manufacturer's proprietary software. The diagnostics computer will be the central unit with the neutral beam computer and control room computer as satellites. The network has the ability to exchange programs, data, and control between computers and provides a means for computers to share peripherals. In addition, the programs on the central computer will run under a "real-time executive (RTE)," also a proprietary software

package. RTE allows foreground-background execution of multiple programs and access to the system by multiple user terminals. Figure 6 illustrates the resulting network.

The future objective system will be an extension of the system currently in development. For normal operation, the system will take advantage of the capabilities of the distributed system and RTE.

The monitor function will utilize the data file transport capability of the distributed system to contribute data from results and conditions of each shot to the experiment diagnostics results tape. This tape, which is prepared by the diagnostics computer, is used by the physicists for further analysis on one of the large LLL computer systems and for archival storage of experiment results.

Using the capabilities of the RTE software, a terminal function will be implemented for use by the physicists, who normally occupy the diagnostics room (as opposed to the control room) during the operation of the experiment. This terminal will make summaries of source results and control settings available to the physicists, and allow high level control decisions to be made from the diagnostics room. The physicist will be able to simply indicate the number of beams he would like to operate at various energy levels. The software in the neutral beam computer will perform the task of selecting the specific beams to be fired and adjusting their controls to produce the desired energy levels. This control capability most closely matches the physicist's controls to the way in which the physicist thinks of the sources in relation to the experiment.

The actual capabilities of the final system may, of course, be quite different than described here. It is the nature of this type of physics research that plans and objectives are constantly changing and the requirements may be different when this version is implemented.

CONTROL LOOP IMPLEMENTATION

The hardware and software implementation of the principal control loops is described in the following sections.

Arc Pulse Line Voltage

This parameter is the most important and most difficult to control. Its proper value is based on the value of the accel regulated voltage plus the value of the decel voltage. That sum is referred to as the extraction potential.

The arc pulse line voltage determines the density of plasma in the arc chamber, which in turn varies the focus of the multiple electrostatic lenses in the extractor (the so called "grids"). Thus, overdense or underdense plasmas in the arc chamber cause the beam to diverge more than at optimum density. At best, the increased divergence results in less beam reaching the contained plasma in 2XIIB; at most, the source components may be damaged.

The difficulty of control is due to the fact that the relationship between extraction potential and arc pulse line voltage is individual from source to source. In mathematical terms, the form of the relationship is known and the same for all sources, but the coefficients vary from source to source. Additionally, the coefficients may change from causes such as accidental damage or changes in operating temperature.

Fig. 6. 2XIIB distributed system.

The accel current measurement made during the shot allows the arc pulse line voltage to be controlled. Its proper value can be calculated from the value of the extraction potential and the error between the calculated value and the actual measurement used to correct the arc pulse line voltage. The relationship between accel regulated voltage and accel current is also somewhat individual, and the exact relationship for optimum source output will be determined by calorimeter experiments early in the life of the source. The measurement of accel current itself is not simple. Some 50 to 75 data points are taken during the experiment pulse. Together, they define the accel current pulse waveform. This waveform is normally very irregular in nature, with the desired measurement confused by interrupts, spikes, and other extraneous events. The algorithm to extract the proper value from this confusion is a very critical part of this and other control loops. The present developmental version converges on a value by an iterative process of discarding data points that lie outside a tolerance interval and re-forming the resulting pulse. Properly, there must be three possible results from this algorithm. First would be the correct value of accel current. Second would be a recognition that a particular set of data points was unsolvable and the computer would request operator assistance in evaluating them. Last is the decision that the shot essentially failed altogether, indicating that the arc pulse line voltage is so far from the proper value that a radical adjustment is needed and a request will be made for operator assistance.

The value of accel current provided by the algorithm described above will be compared with that calculated from the accel regulated voltage. The error will be incorporated in an adaption factor in the equation which is used to calculate the value of arc pulse line voltage. After a few shots, the individual coefficients unique to this source will have been determined. The adaptive process will always be operative, so changes in the source characteristics will be accommodated automatically. A mechanism will be provided to preserve the individual coefficients on paper tape or on the diagnostic computer disk via the distributed system at the end of each operating period.

Having calculated the arc pulse line voltage required to achieve the desired accel current, the algorithm must take one of two branches to reach that value. The first branch, for a source already burned-in at the given accel voltage, is to converge as rapidly as possible on that value, probably in one to three shots.

The second branch, for a source being burned-in, is to approach the desired voltage in many incremental steps. The decision to move up one step will be made on a basis of whether the number of interrupts is smaller than a given number. The second branch will frequently be required for sources which have not been operated in some time. The switch to branch two may be made either by the operator or by the algorithm.

Arc pulse line voltage is directly controlled by the computer by outputting the desired value to the arc pulse line charging control, which contains the circuitry to regulate the voltage to the desired value. The computer will use an A/D converter to monitor the voltage to insure that the control process has worked properly before allowing the source to fire. An A/D converter channel is also used to measure the accel regulated voltage. The accel current is measured by the high-speed A/D converter during the shot pulse. Decel voltage is controlled directly by the computer and the value commanded is used as the true value in these calculations.

Accel Bank Voltage

The accel bank voltage is calculated by simply adding a constant to the value of the accel regulated voltage. The accel bank voltage is not particularly critical as long as it is offset far enough above the accel regulated

voltage. This allows a fortunate simplification of the control procedure, since an energy bank is being charged and if it is charged to a value above that desired, there is no mechanism provided to lower its voltage.

The accel bank voltage is monitored by an A/D converter channel. The computer controls the accel bank voltage by operating raise and lower relays which control a motor-driven Variac. If the bank voltage is lower than desired, the raise relay will be closed to achieve the desired voltage. If the voltage is too high, the lower relay will be closed for an arbitrary time interval. This will have no effect until the pending shot discharges the energy banks and they begin to charge again. The generous tolerance on the parameter provides a large dead zone in this control and prevents hunting.

Decel Voltage

The decel voltage is calculated simply as a fraction of the accel regulated voltage. It is a relatively coarse control, having only 16 possible values. The value desired is output directly to the decel control chassis.

Due to variations in decel voltage output caused by variations in loading, the decel voltage may not be the value requested. The high-speed A/D converter monitors the decel voltage during the experiment pulse and if the actual voltage is much different than the desired voltage, the value output by the computer will be adjusted to compensate.

The operator will be allowed to change the decel voltage from the calculated value to adjust for variations in source behavior.

Filament Voltage

Two measurements of filament voltage are used for control. One, available continuously between experiment shots, is the open circuit output voltage of the filament supply. The other, available only for a few milliseconds immediately after the experiment shot, is the actual filament voltage under load measured at the source itself. It is this last measurement that must be kept constant. The control software will note any error between this measurement and its desired value, translate this into a change in the open circuit voltage, and adjust the open circuit voltage to that value.

The computer controls the filament voltage by operating raise and lower relays which in turn operates a motor-driven inductive voltage regulator. The two filament voltage measurements are made by A/D converter channels.

Accel Regulated Voltage

The accel regulated voltage is the basic independent variable in the control system and its desired value is determined by the energy level at which it is desired to operate the source. This value is determined in the burn-in process by incrementing the value each time the source interrupt count shows that it is operating satisfactorily, beginning at first with a low initial value. In operation with 2XIIB, the desired value will be manually entered by the operator.

The computer monitors the accel regulated voltage with an A/D converter channel. The computer controls the accel regulated voltage by providing raise and lower contact closures which operate a precision motor-driven potentiometer.

Source Fire Enable

One of the miscellaneous controls worthy of discussion is the source fire enable relay.

One of the concerns in implementing computer control is that one of the control loops will malfunction or the computer itself will halt, loop, or malfunction, and that the sources will fire with improper control settings resulting in serious damage. The source fire enable relay does much to reduce the possibility of such an incident.

With the exception of decel voltage, all of the parameters controlled by the computer can also be observed by the computer via its A/D converter prior to the shot. The control software, having completed the process of setting up the parameters for the next shot, will make a final check of the values of these parameters. If they are all within their proper tolerances, the computer will output the command to close the source fire enable relay. This relay enables the sources to be fired by their timing circuits. It is a characteristic of the relay circuit used for the source fire enable relay that the close command must be issued periodically in order to keep the relay closed. If the computer halts or loops and fails to issue the periodic command to keep the relay closed, it will open by itself and prevent the sources from firing.

NOTICE

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MSG/gw