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THE CONTROL SYSTEM FOR THE NSF TANDEM

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1. INTRODUCTION

This paper describes the control system proposed for the Nuclear Structure Facility (NSF) at Daresbury. The project is based on a large vertical electrostatic generator and is designed to accelerate a complete range of ions throughout a terminal voltage range of 10 to 30 MV.

The accelerator is shown schematically in fig. 1.

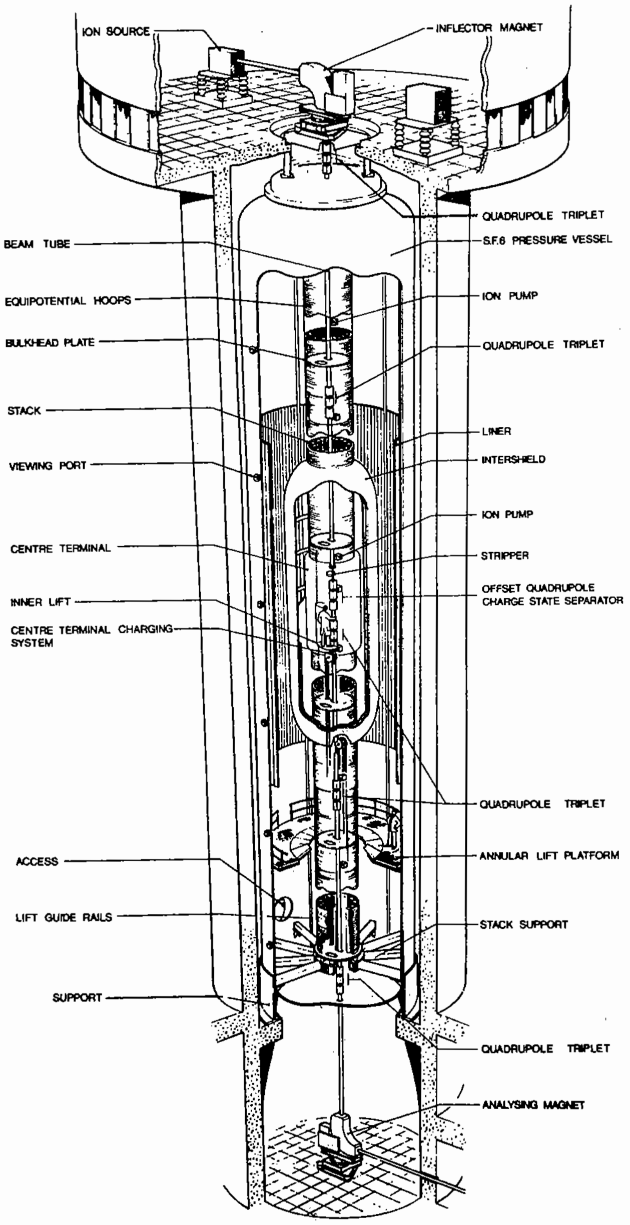

Fig. 1. Cut-away drawing of the NSF tandem.

The ion beam to be accelerated in the machine is produced by one of a number of ion sources located in the circular injector room at the top of the tower building. The source sits on an insulated platform together with the various power supplies needed to extract, focus and deflect the ion beam. Application of up to 400 kV to this platform allows the pre-acceleration of the ions before they pass through the 90° inflector magnet into the main accelerator. A modulated light beam is used to communicate with the power supplies on the injector platform.

The physical size of the machine has been mainly determined by the maximum voltage gradients that the stack and accelerator tube can sustain for continued reliable operation. As a consequence of this a long beam path through the machine is involved and the beam handling and vacuum equipment necessary to transport a wide range of ions at various energies through the accelerator is more complicated than in existing accelerators. Reliable and accurate remote control is needed for magnets, pumps, beam scanners, slits and other equipment located in field free sections of the stack, at many million volts electrical potential. Many of these components can be seen in fig. 1.

Table 1 gives some idea of the number of primary analogue and digital channels needed to control and monitor the apparatus inside the accelerator pressure vessel. This number would be sufficient to provide a fairly close control of the equipment but a large number of analogue channels would be needed if checks on temperature, vibration and suchlike were also to be included. Even for the basic provision of Table 1, it is clear that mechanical data transmission is not practicable. Some of the information to be transmitted across the large potential differences is rapidly varying analogue information, such as that needed in the centre terminal for stripper or down-charge modulation, or beam profile information. This can only be transmitted by some form of fast insulated data link. Such a link, using photodiodes and digital transmission, has been developed for the purpose at Daresbury and has been shown to work efficiently under the most rigorous electrical surge conditions. Indeed, prototypes of almost all the control elements and power supplies needed within the NSF machine have been successfully tested in this way, great

TABLE 1

Control Requirements within the NSF Tandem

	Digital Channels		Analogue Channels	
	Control	Monitor	Control	Monitor
DEAD SECTION A				
Vacuum Equipment	8	10	1	2
Beam Diagnostics	2	2	2	4
Stack and tube currents	0	0	0	4
Totals	10	12	3	10
DEAD SECTION C	10	12	3	10
DEAD SECTION B				
Vacuum Equipment	8	10	1	2
Beam Transport including cooling	19	32	15	33
Beam Diagnostics	4	8	4	8
Stack and tube currents	0	0	0	4
Totals	31	50	20	47
CENTRE TERMINAL				
Vacuum including cryopump	48	69	3	19
Beam Transport including cooling	30	48	30	58
Beam Diagnostics and gas stripper	23	37	18	29
Laddertron	9	15	3	6
Foil Stripper including heater	3	6	1	1
Cooling	8	12	0	6
Totals	121	187	54	119
DEAD SECTION E				
As dead section A	10	12	3	10
Foil stripper including heater	3	6	1	1
Laddertron	9	15	3	6
Totals	22	33	7	17
DEAD SECTION F				
As dead section B	31	50	20	47
DEAD SECTION G				
As dead section E	22	33	7	17
GRAND TOTAL	247	377	114	267

importance being attached to reliability.

The accelerator structure is located in a large pressure vessel containing sulphur hexafluoride (SF_6) insulating gas. A complicated gas handling system is used to empty and fill the pressure vessel and to circulate the gas for purification and liquefy it for storage. Control and monitoring facilities are needed for this system and for the cooling water and electrical services.

It has always been accepted that the accelerator would undergo continuous modification and upgrading as a result both of the R & D programme at Daresbury and of operating experience. For example the machine will almost certainly run initially at around 20 MV with a single stripper and without an intershield. The addition of a second stripper or the intershield will result in changes to the mode of stabilisation. It is thus essential to design a control system which will allow for such additions and modifications. At a later stage in the running of the Facility, a second stage accelerator may be added. Again, adaptability of the control system is essential if this is to happen without causing undue disturbance to the operating system. This adaptability can be achieved if the control system is based on digital electronic systems capable of high data rates. By using the types of computer now commonly available to handle this data, a reliable and extremely powerful control system can be developed at a cost which is comparable to that for a conventional system providing far fewer facilities.

A full costing of a conventional system has not been performed, but some idea of relative costs can be obtained by comparison of circular accelerators of comparable complexity. The cost of the control system for the 5 GeV electron synchotron NINA, without computer, was about £160k out of a total plant budget of £2.0M, i.e. 8% of the cost. The corresponding numbers for the 2 GeV SRS storage ring with a computer-based control system very similar to the NSF one, are £205k out of £2.4M, 8.6% of the cost. The comparison is a fair one in view of the similarity of layout and mode of operation of the machines, but is almost certainly weighted against the computer-based system as labour and cabling costs have risen disproportionately since NINA was built. The computer-based system proposed for the NSF is estimated to cost £326k out of a plant budget of £3.5M, i.e. 9.3% of the plant budget (March 1974 prices).

Reliability and adaptability of the computer-based system depend on the design and layout of the system. It is the main purpose of this report to describe our proposed system. The system can only be efficiently and easily used if peripheral equipment such as displays and controls are carefully designed. With this in view, a colour TV display with interactive capabilities has been developed at Daresbury.

Finally, before starting a more detailed description of the proposed control system, some remarks must be made about the use of computer control systems in general. Such systems are now in use controlling nuclear reactors like the PFR, medium and high energy particle accelerators such as Los Alamos Meson Production Facility and the Fermilab 400 GeV accelerator and on a number of industrial installations which involve the manipulation of large numbers of functions and variables. A system similar to ours has been proposed by Oak Ridge National Laboratory for their 25 MV electrostatic accelerator. In all these cases a number of clear advantages can be identified for the computerised control system.

1) It provides an automatic data logging system which can handle great quantities of data. In addition it provides the means to sift and sort the data as required to produce clear and concise information on plant performance.

2) Parameters can be easily controlled either manually or automatically. Automatic checks can be made on the values of these parameters and action taken if they move outside defined limits. In addition it can provide warnings in a form that can be readily and rapidly understood. In cases where a number of limits are exceeded simultaneously the control system can make a very rapid diagnosis and advise the operator.

3) It can set predetermined values which will often be very close to the final optimum ones. These values can be calculated, or based on previous runs. In addition if required they can be dynamically varied as the plant operates. Such a process can save a great deal of time and can later be developed into complete start-up and shut-down operations.

4) It can act as a selection facility in order to display or control only relatively small amounts of information at one time. The information to be displayed or controlled at a given time will be selected by the operator, as will the type of display or control, but the system can be arranged such that fault conditions or other urgent conditions can interrupt when necessary. This allows simplified operation for the operator, who only has to concentrate on a small number of variables at one time. A number of different types of display and control are available but the most powerful is the TV screen which can be made to provide mimic diagrams, a bank of strip indicators, a graphical display or a written display. The use of colour is particularly important in greatly increasing

legibility and visual discrimination, while a light pen or similar device allows direct interaction with the display.

One particularly powerful facility made available is the control of an 'imaginary' variable. For example a switch could be used to vary positive ion charge state at constant output energy, the focusing and selecting magnets and the terminal and injection potential being reset by the computer to new calculated values as the switch is operated.

5) All these functions are of an 'open loop' nature, but with a suitably designed system, 'closed loop' operation can be easily introduced at a later stage if it becomes appropriate. For example, consistent behaviour of the internal beam optical system could eventually lead to the focusing and bending magnets being set using beam position indicators without human intervention. Such a method of operation is greatly eased by the presence of computers.

6) Finally, a computer-based control system can be designed to be highly adaptable. The result is that there need be no significant interruption of the operation of the control system if further small computers are added to control a second stage machine or if the computer programs are modified or extended in response to changes to the present accelerator. Major changes to the facility might involve the addition of another small computer while changes to the tandem would require modifications to the computer programs, but in neither case would there be significant interruption to the operation of the control system.

2. SYSTEM DESCRIPTION

The design of the computer control system for the NSF is based on consideration of the nature and location of the plant to be controlled, and of the currently available techniques and equipment. In addition, the ability to maintain control of the accelerator under fault conditions in the control system, to give improved accelerator control and diagnostic information during faults in the accelerator itself, the ease of extension and modification of the control functions, and the problems of maintenance in a system of this size have all received full attention.

The following paragraphs give the reasons which lead to the chosen configuration shown in block diagram form in fig. 2. In this system the various areas of plant are connected by a distributed analogue and digital multiplex scheme to several inexpensive minicomputer systems. Each of these is itself connected by a high speed serial transmission bidirectional data link (750 kBits/s) to a single midi-computer system (midi) which forms the central node of a star configuration. Also connected to the midi are similar data links to the central laboratory computer, at present an IBM 370/165 (central computer) and the main control consoles for the accelerator. Extra local support for these consoles will be provided by a further minicomputer. Information transfer between the accelerator control system and the experimental users will also be by data link to the midi-computer.

2.1 Midi-Computer System

The midi-computer (fig. 3) forms the heart of the control system. It is the control computer and will carry out the more complicated and generalised functions necessary to provide the facilities outlined in the introduction. It will be required to perform:

i) System integration. To achieve this, executive control of all minicomputer systems will be required centrally, dictating the programs they run and the way they handle their data. This is necessary to allow the level of flexibility required.

ii) Organisation of data communications throughout the system. Many functions of the system, for example generation of displays or collection of historical data, require the transmission of data between different areas of the system. The midi-computer being at the hub of the system must be responsible for the organisation of their transmissions.

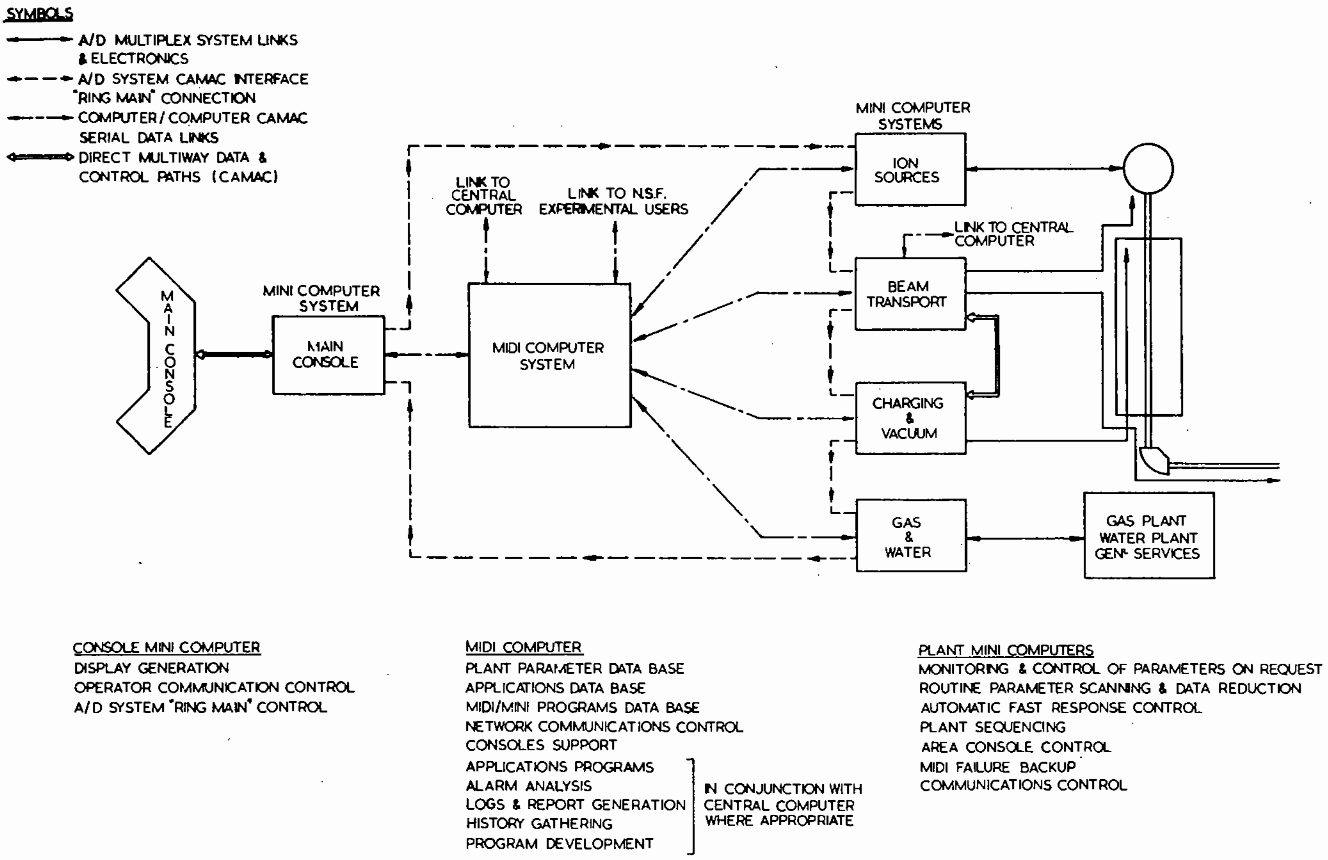

Fig. 2. Control system configuration.

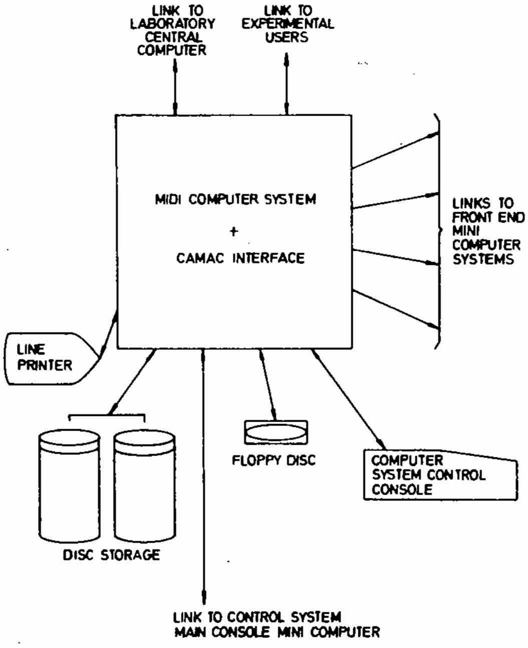

Fig. 3. Midi-computer system.

iii) Provision and support of system library and data bank facilities. For example, the main parameter data base, operational logs, and minicomputer core loads. These are essentially central services which must be available to all parts of the system.

iv) Analysis of alarm situations. When accelerator faults do occur they will often result in a number of system variables moving outside their normal operating range. Without suitable processing this would lead to a flood of warning messages being generated in which those of real importance are swamped. To avoid this situation the greater processing power of the midi-computer can be used to analyse fault situations in depth to ensure the correct weighting and information content of alarm displays.

v) Generation of multiple displays showing system operation. The quality of displays is of vital importance. Storage, selection and processing of information for these displays will be best done by the larger machines.

vi) Interpretation of operators' requests which involve complex processing. Although the generation of displays and communication with its operators is best handled at a high level by the midi-computer, there is also a more mundane level of computing required for the detailed organisation in both these areas. It is intended to provide a minicomputer system between the midi-computer and these functions for this purpose.

vii) History gathering and the production of logs and reports. A computer control system can amass operational data and produce logs and reports in far greater detail than can be assimilated by the operator. The problem here is one of ease of selection and presentation of data. This requires the large backing store and printout facilities of the midi system.

viii) Control processing. To allow control to be exercised over certain areas of plant, for example beam transport, considerable processing power and the availability of files of information and backing storage will be required. This requirement too will be handled by the midi-computer system.

ix) System development. As experience is gained and techniques advance, continuing development of the software of the computer control system will be necessary. Facilities must be available to achieve this in parallel with normal operation of the control system without jeopardising use of the accelerator for its experimental programme.

To carry out these functions the midi-computer must be capable of running a dynamic selection from a potentially large number of different programs. This will require a real time multi-tasking capability with fast access time to system files of both data and programs.

Communications with the central computer and the experimental users must also be supported. To enable printed information to be produced locally for plant management and system development a medium speed printing device (line printer) will be a necessity. Finally a control console device will be needed for control of the system itself.

These requirements can be met by a computer system consisting of a processor of medium power with typical characteristics:

i) Word length. At least 16 Bits will be necessary to offer the necessary performance. However, much of the newer equipment suitable for this application has a 32 Bit word length, at least on data manipulation.

ii) Random access memory. It is likely that a total of about 128 kbytes will be required for the operating system and applications programs. The access time is not likely to exceed 1 μs.

iii) Memory protection/management. To ensure the security of independent tasks in the system a hardware memory protection scheme will be present.

iv) Floating point arithmetic. Because of the level of processing required a hardware Floating Point Arithmetic capability can be expected.

v) Direct memory access (DMA). For efficient handling of all the different input/output connections a multi-channel DMA capability will be required.

vi) Backing storage
At least 2 moving head disc drives with a removable cartridge facility will be required. Access times of the order of 40 ms average and total on-line capacity of around 10 Mbytes can be expected. A smaller faster access device may form part of the system to improve response times for critical tasks.

vii) Operating system software. Because of the complexity of the requirements an excellent disc based real time operating system will be required. Excellence in this area will be a major factor in the selection of suitable equipment.

At the present time a number of computer manufacturers offer hardware/software packages which broadly meet the requirements.

The major disadvantages of such a system are that all the applications processing, much of it fairly undemanding, must pass through a single fairly powerful processor, and under fault conditions there is an inevitable deterioration in the level at which control can be exercised. (The use of front end minicomputers will ensure that control is not lost).

Alternative solutions using a number of processors for the control processing (e.g. 400 GeV SPS at CERN(1)) were examined but for the NSF for the reasons given below a single control computer solution was chosen.

1) It makes available a large amount of manufacturer supported software on which the application can be built. This will conserve use of laboratory manpower at a time when it is in the least supply.

2) It makes available a greater continuous computing capability, should this power be necessary in the future.

3) The total computing power required is not enormous. The facilities available from the computer system are very important. With only a medium requirement for both processing power and storage it becomes more difficult with lessening economic advantage to subdivide the requirements without jeopardising the available facilities.

4) The availability of a large central computer (IBM 370/165) further reduces the processing power and storage necessary whilst offering a partial solution to the single control computer fault situation.

5) There is considerable experience at Daresbury in using a single control computer for accelerator control. Thus fewer problems can be expected than if new disciplines of multiprocessor working and computer networks are introduced into this area.

6) A near identical system will be used for a second major project proposed for the laboratory - the Synchrotron Radiation Source. A high degree of resource sharing will thus be possible.

2.2 Use of the Central Computer

In a situation in which a very large data processing installation is already in existence (central computer) and is expected to remain so into the foreseeable future with an on-line capability and reasonable availability, it is unreasonable to expect the power of the NSF midi-computer to provide for the most demanding aspects which the NSF may require. On the other hand the central computer provides for a large number of users, situated both in the Laboratory and remotely, who submit a very mixed work load. Within this complex the NSF will be only one of many users who in total will demand a continuous service. It cannot therefore expect to dictate the operation of, or get quick response from, the central computer. In addition, although to date a high average availability (time facilities needed are available during the period they are required /time facilities are required x 100%) has been achieved (≈ 95%), experience of operating the existing accelerator at Daresbury has shown that to achieve acceptable performance a control system should attain availabilities in excess of 98% during scheduled operation.

In this light the NSF computer control system should be designed to provide a high standard of accelerator control without resorting to the central computer, but making maximum use of it where operational considerations allow. Loss of the central computer must not for example significantly affect the availability of the accelerator for producing experimental beams or require an increase in the total number of operators required. A loss of more peripheral activities such as software development or historical data analysis would be acceptable as would a temporary increase in operator work load or the inability to provide highly sophisticated beam transport optimisation. It is proposed therefore that connection should be made to the central computer from both the NSF midi-computer and the beam transport minicomputer, but the central computer will not be in direct control of essential operations. Examples of the use of the central computer are

i) Long term history file storage and the retrieval and processing of information from these.

ii) The generation, processing and storage of operating data for transfer to, and use by the NSF system.

iii) The generation, processing and storage of NSF system programs with possibly system simulation and other software production aids.

iv) Meeting the more extensive control requirements. As control and optimisation of the accelerator by computer is extended the computer power required can be expected to steadily increase. In many cases this type of control will be long term and will enhance rather than be essential for operation. In these cases the restrictions of using the central computer are more tolerable.

2.3 Front End Minicomputers

The most obvious characteristics of the accelerator from the control point of view is that it is composed of a number of separate sub-systems, which are then interconnected to provide an integrated system for the control of the complete accelerator. Each sub-system is to a large extent self contained particularly in the sense that for their operation they make most use of parameters, which are either completely internal or on their boundary with another sub-system, and very little use of internal parameters of other sub-systems. That this is so is no accident. It stems from the size of the project and the number of different disciplines involved. Work on the various plant sub-systems progresses in parallel right through from initial design to the completion of commissioning and beyond. The implication of this on the provision of computer control is that each area of plant as it progresses will need computer facilities for its commissioning and integration into the computer control environment. Thus a very important initial requirement for the use of computers will be for multiple simultaneous independent facilities.

A further characteristic of the accelerator is that it is of large physical size, that its sub-systems are distributed throughout this volume and that measurements and control points will be widely distributed. In some cases a functional sub-system can be fairly closely associated with a particular area. In others functions can be seen to be both distributed and merged throughout large areas.

Under normal operating conditions the purpose of the control applied to most of the plant is to maintain a desired equilibrium state of controlled variables by systematically varying other controlling variables. Most of this control is fairly simple and in many cases will be performed by electronics hardware. Provided the data show that these equilibrium conditions are maintained without resort to abnormal states of the controlling variables, much of it has served its purpose and is no longer required. A significant amount of data reduction is thus possible at a very early stage with a minimum of processing. The requirement here then is for simple repetitive processing of large amounts of simultaneously available data. Typical examples are to scan all measurement and status points, check measurements against predefined limits, detect unacceptable status conditions and perform simple equipment sequencing. Even under fault conditions the above is still true for all the data that does not display irregularities. For such operations as start-up or shutdown an additional requirement to carry out relatively simple predefined sequences is imposed but computing is necessary and is often required simultaneously in different areas of plant.

Turning to the currently available computer equipment, particularly at the small end of the range, minicomputers with appreciable performance are now available for a hardware cost comparable, for example, to a good general purpose oscilloscope. Thus the use of a number of them on a project the size of the NSF becomes the cheapest and most efficient system for achieving the required control functions.

There are several advantages in this approach. It matches the requirements for simultaneous simple operations on data direct from the plant. It matches the plants characteristic of large size with wide spatial distribution of measurement and control points. Processing power in smaller physically separate packages enables the processing to be moved out to the areas where the data is generated. Here it can be used to effect both data reduction and multiplexing. Whilst the cost of both computers and electronic circuitry in general has decreased over the last few years the costs of plugs, sockets, cabling and installation have increased to the point where the economics now favour the approach of data concentration local to the plant rather than centrally located electronics with long individual runs to measurement and control points. On the software side the organisational aspects of a small computer with a limited number of different tasks are much less complicated than a large computer capable of running large numbers of different tasks. A further major advantage in the characteristics of this configuration is observed under fault conditions. With the work load shared between several minicomputers, a fault in a single computer represents the loss of only a small proportion of the computer power of the total system. With suitable system organisation this need result in only a degradation of the level of computer control or the loss of control to only a limited section of plant. Reducing the capital value of a unit of computing equipment opens up a new and simpler approach to system maintenance. With a large expensive computer, faults must be fixed *in situ* by printed circuit board or electronic module replacement after, what can be, a lengthy procedure to localise the fault. The cost of a minicomputer allows a complete computer to be treated as a module of the system and faults rectified by complete machine replacement. There are two advantages here. First it is invariably easier and quicker to isolate a fault to a computer than to a lesser functional module. Secondly, because a computer's operation is defined by program and is thus variable the computer kept as a spare need not sit on a shelf but can be incorporated into a system with other spares equipment and can be programmed to continually monitor the serviceability of all.

In the light of the above discussion the front end minicomputer system has been designed so that, as far as is possible, each sub-system of the accelerator is under the complete control of a single minicomputer. Because of the variation in size of the sub-systems and the desire to keep the size of each computer system about the same to allow maintenance by replacement, in some cases a minicomputer system controls just 1 sub-system, in others 2 or more sub-systems (fig. 4). The advantages of this configuration during the evolution of both the plant and the control system itself are that development of the systems can proceed in parallel, and stand alone minicomputer systems can aid in commissioning of the plant itself.

Also, due to the nature and use of data in a system of this type, this configuration should offer a maximum capability for data reduction within the minis and thus minimum computer-to-computer data exchanges. In several areas of the accelerator, such as the ion source room and the gas and water plants, it is the obvious choice irrespective of other factors as the plant is concentrated in localised areas. The choice of a single midi-computer will result in maintenance by diagnosis and repair *in situ* and can result in relatively prolonged loss of service on occasions. Under these conditions continued control of the machine must be possible. To allow this, small minicomputer controlled secondary consoles will be provided. The alignment of minicomputer systems with accelerator sub-systems will ensure that meaningful control can be exercised from these minicomputer consoles.

What then will be the situation when the midi-computer fails? The minicomputer associated with the central consoles will quickly detect the situation and inform the operators accordingly. Further total control of the accelerator from these consoles will no longer be possible. Instead a degree of limited operation will be available as follows. The central console mini will re-configure (from floppy disc) and, via the analogue and digital multiplex system "ring main", will assume control of the on-line ion source thus maintaining control of that within the Main Control Room. The beam transport, charging system and vacuum system minicomputers will be resident within the Main Control Room and their respective local control consoles will be adjacent to each other and close to the main consoles. Control of each system will therefore be available from these. The gas and water plant and services control system is however in the main plant room and control will transfer to the local console within that area. The nature of this plant however makes this acceptable for a limited time. The loss of the midi-computer will inevitably result in the level of control being reduced. It is not possible

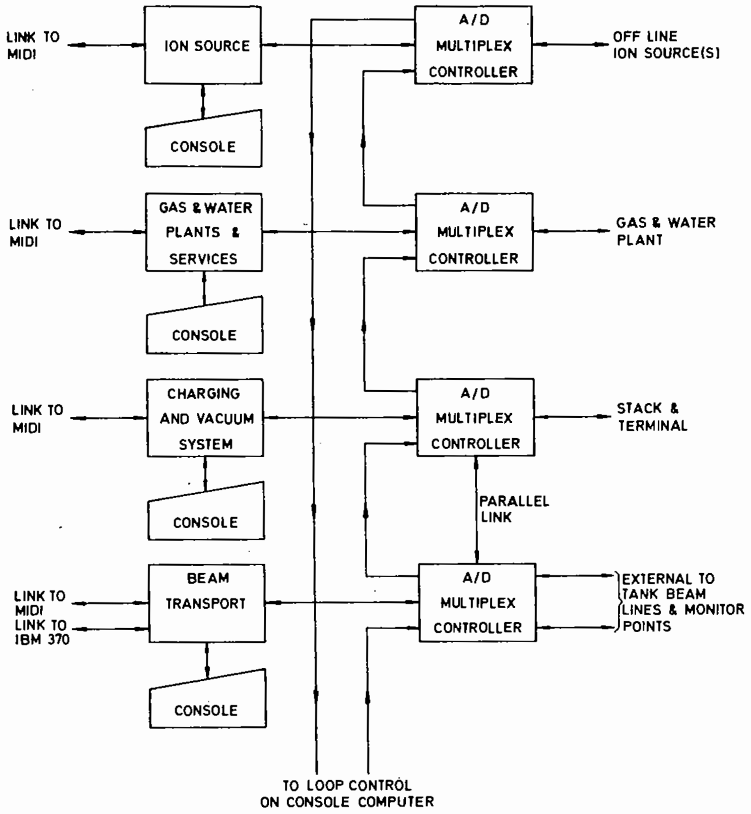

Fig. 4. Front-end minicomputer systems.

without providing redundant equipment to produce a system in which the loss of such a key unit does not significantly affect the system performance. Beam transportation will suffer most in this situation as it involves a large number of components, many directly interactive and requiring extensive computer/operator control. To reduce the loss of control facilities, even with the midi-computer absent, it is proposed to provide a data link directly from the minicomputer in control of the beam transport system to the central computer. Finally to keep these problems in perspective it should be pointed out that computer systems similar to the proposed midi-computer system are now in operation which are available far in excess of 98% of their scheduled running time. With modern equipment an improvement of this can be expected. In addition the choice of a 2 level system will guarantee that control system faults will only reduce the level of control, not cause loss of control.

The type of minicomputer suitable is a machine from the small end of the 16 Bit word range with 16k words of memory. A small floppy disc unit will provide a limited amount of local storage. Apart from this all peripherals will be for either the connection of points on the accelerator or use by the accelerator operators.

The number of minicomputers has been chosen so as to provide a rational sub-division of the system and to provide all the facilities needed. The configuration is such that more can be added later if needed, for example to control a polarised ion source.

Extensive use will be made of the CAMAC system for connecting equipment to the computers. This applies to the connection of both measuring equipment and operator peripherals such as displays, keyboards and control knobs.

2.4 System Parameters

Although more work must be done on both the control system and the accelerator before firm values can be established for the main characteristics of the system, an attempt is made below to give an indication of the likely numbers involved.

2.4.1 Accuracy

The analogue and digital multiplex system uses shared equipment for converting between analogue and digital signals. An accuracy of 12 Bits (1 part in 4096, or 0.025% of full scale) has been chosen as standard in this area. A standard has been set for analogue signals of -10 V to +10 V.

2.4.2 Parameter scanning rates

The system will automatically scan and check all parameters against acceptable limits. Depending on the individual parameter a rate of sampling of between once per second to once per minute will be used.

2.4.3 Parameters in automatic control loops

Any parameters which form part of an automatic control loop under computer control will be handled locally by the minicomputer in that area. Rates will be dependant on the characteristics of the particles system but can be many samples per second (e.g. ∿ 200 per second for laddertron control).

2.4.4 Parameters appearing on displays

To ensure operator confidence in displayed information all readings on displays should be updated at least once every 3 seconds.

2.4.5 Operator controlled parameters

When a parameter or parameters are under operator control through a control knob or knobs updating of both the parameters and the display of the controlled values of interest should be at such a rate as to appear continuously variable. To achieve this update rates of between 10 and 25 times per second will be necessary.

2.4.6 Maximum data rates

Although estimating data rates at this stage in the system development is rather hazardous some indication of maximum rates can be gained by considering the beam scanning equipment. Beam scanners generate data at a far higher rate than any other device yet proposed for inclusion in the computer control system and multiple units must operate simultaneously to produce displays at the accelerator control consoles. Each scanner collects information first in the X and then the Y planes making 256 measurements in each plane. Each measurement will result in the transmission through the system of a 16 Bit word of data. To achieve reasonable updating of displays every other scan should be taken from each scanner giving approximately 10 scans per second and 6 scanners could be used simultaneously. Thus the raw data rate passing through the system is given by

$$2 \times 256 \times 16 \times 10 \times 6 \quad = \quad 490 \quad \text{kBits/s}$$

Thus suitably formated for transmission over data link equipment a rate significantly in excess of 500 kBits/s will be necessary. At present a 750 kBits/s system is being considered.

2.5 Operator Facilities

2.5.1 General considerations

It is necessary to use minicomputers and other associated modular hardware to control an accelerator of the complexity of the NSF satisfactorily. The flexibility of a computer and its "accelerator" interface modules ensure that any changes or additions to the accelerator and/or its control system may be made with the minimum of overheads in terms of time and further design effort. To avoid the physical changes to operator control consoles that may have been associated with typical control system alterations, it is essential to provide "programmability" in the operator's control and monitoring facilities.

2.5.2 Computer driven displays and other interactive devices

Extensive use will be made of CRT colour display equipment in presenting information to operators. Computer generated displays have the advantage that they are dynamically variable and with an associated device such as light pen or rolling ball can accept operator input. They can thus be used instead of multiple special purpose racks and panels.

The particular features of the equipment to be used in the NSF control system which is based on an in-house design and make it particularly suitable are:-

i) It is built to the CAMAC standard and is thus processor independant.

ii) It contains its own memory and does not therefore place heavy demands for input/output on the controlling computer.

iii) It is organised in a 2 level manner with the screen displaying a matrix of 64 x 32 symbols where each symbol can be any one of 455, defined separately in a symbol definition memory. It is thus very suitable for written or mimic information display.

iv) Each of the 455 symbols is defined (9 x 7 dot matrix) at run time. This means that for written or mimic work it is extremely flexible. The availability of such a large number of symbols also allows it to be used for displaying graphs.

v) Each symbol is displayed in 2 colours associated uniquely with its position on screen. This provides both foreground and background colouring. Any one of 8 different colours can be specified in either case.

vi) A light pen is provided to allow the display to be used for interactive work.

vii) The display is produced on standard television type raster scan colour monitors. Thus displays are bright enough to be viewed under ambient light conditions, they are updated at a high rate (50 times/s) and it is possible to have further displays easily. Using standard monitors allows the same screens to be used for displaying C.C.T.V. pictures, mixed with computer generated information if desired.

An additional interactive device that can provide useful facilities for some purposes is the touch panel display. A CRT has a number of transparent touch panels attached to its tube face, and keywords are placed on screen, behind the touch panel, by the computer system. The operator, by placing his finger on the panel at the appropriate keyword, initiates the action defined by the keyword. Further pages of keywords can be called by the same process if required.

A keyboard is also required to enable the entry of alphanumeric data.

To effect changes to machine parameters that require rapid sequential analogue adjustment to be made by an operator, two digital shaft encoders, each fitted with a control knob, are needed.

Each control console will require a badge reader, through which the scope and depth of an operator's access will be determined. For example, the design engineer responsible for the gas plant would have access in depth to the gas plant but little or no control access to other areas of the accelerator. Similarly an experimental user would have only limited control of the accelerator although he would be provided with comprehensive machine status information.

2.5.3 "Hard wired" equipment

The previous section described the "programmable" control devices used by an operator at a control centre to interact with the accelerator control system.

In addition to these an intercom and PO phone extension will be required on all consoles. For diagnostic purposes a real time CRT display is required on each console, the waveforms under investigation by the operator being routed to it by the control system.

Hard wired indication of primary status information from all safety systems will be required on the console, and more detailed information may be called via the display system if needed.

Switches are also required to enable manual removal of power from selected equipment, including total power shutdown within a control area, leading to total removal from the accelerator of all electrical power if necessary.

2.6 Special Hardware Features and Environmental Considerations in Hardware Concepts and Design

2.6.1 Environment

Anyone who has worked closely with a large Van de Graaff accelerator must be well aware of the improvement in instrumentation on the machine that could be obtained by using modern electronic techniques. However, it is hard to imagine any other environment that is as hostile to solid state devices as that which exists inside the accelerator's pressure vessel during voltage breakdown conditions. In addition to this problem there can be enough energy from breakdowns or other electrical disturbances to cause the malfunction of electronic equipment external to the pressure vessel, such as computers and experimental instrumentation.

The NSF Division at Daresbury have taken these problems seriously from the beginning. The protective techniques briefly described in sect. 3.2.1 will be discussed in some detail in a further report and practical systems have been operated successfully in the Harwell tandem and the pilot machine at Daresbury. In this prototype equipment all information is transmitted by digital serial transmission methods using a phase encoded (DI Phase) technique, whether the transmission path be a coaxial cable, or a free space optically isolated data link (light link). At one stage in the tests on the pilot machine the light link system was driven using serial transmission by a small computer over 200 m of coaxial cable, which had toroidal transformer isolation at each end of the cable. No errors were detected by the computer, even during tank sparking.

Data communication between the minicomputers of the accelerator's control system will be made using DI Phase serial transmission, and will use toroidal transformer isolation techniques so that error free operation may be assured, in the presence of electrical transient activity from the accelerator.

2.6.2 Digital and analogue distributed multiplex system

The multiplex system is designed to meet the control needs of equipment and the monitoring requirements on the stack. All information is transmitted digitally in serial form across voltage gradients as in the prototype system used at Harwell and in the Daresbury pilot machine.

The multiplex system uses the most modern computer-compatible low cost techniques to translate parameters such as temperatures, pressures, speed, currents and voltages as well as digital control and status values into binary words for processing by the computer system. It is necessary to measure many such parameters from vacuum and beam handling equipment and other support systems in the accelerator's field free "dead sections", so that their short and long term performance can be assessed. In addition to the routine chores of operating the support systems, the multiplex system will play an important part in the energy stabilisation system of the accelerator. For this purpose autonomous channels are set up to provide high bandwidth links between external energy measurement devices and the down charge and stripper modulation equipment. This same capability will also be used to show real time displays of stack and tube currents for diagnostic purposes, enabling some fault conditions to be investigated.

A multiplex system data crate has a combined analogue and digital data highway into which multiplex system cards are connected. The inputs and outputs from these cards will directly accept most transducer inputs without any further signal conditioning being required (an important consideration where space is at a premium) with isolated drive for digital signal inputs and outputs.

It is essential that the multiplex system be highly reliable, as the loss of operating time would be considerable from each breakdown, due to the time that is necessary to empty and refill the pressure vessel with gas. The use of good quality components is not enough to ensure high reliability particularly where integrated circuits are involved and additional tests will be made.

The hardware design philosophy too is important, since if parallel or serial data buses are used it is highly desirable that the design should allow operation of other units on the common bus if one device fails, but perhaps accepting reduced facilities if this should occur.

It is normal laboratory policy to use CAMAC whenever possible. The limited space available and the need for double screening make it unsuitable for use in the high voltage column of the accelerator for data handling. Having developed for this purpose the serial link using optical transmission, it seemed appropriate to use a small additional number of the same modules with coaxial cable links outside the machine. Thus all the analogue and digital information is gathered and multiplexed by these custom-built modules. CAMAC is used however at the immediate interface between the multiplex system and the minicomputers, at which point a single CAMAC crate will also be located. We think it essential to use CAMAC at these points as so many driver modules are standard Daresbury equipment while a wide range of others are rapidly becoming available at Daresbury, CERN and other laboratories.

2.7 Safety Control

2.7.1 Access to radiation areas and the vessel

To attain the highest degree of reliability in this area will necessitate the provision of a "hard wired" system. In order to facilitate the display of diagrams showing the system state, spare contacts from interlocks will be available to the control system. The computer may then also be used to provide a further level of safety by enabling the identification of any faults that develop in the hard wired system.

2.7.2 Health physics monitoring

It is convenient for this equipment to make use of distributed multiplex system hardware for the connection to the control system.

To increase the reliability of the equipment, test features built into the monitor's electronics will permit automatic checking "on line", so ensuring a higher degree of confidence.

2.7.3 Safety in computer controlled heavy plant

The computer control system will sequence heavy machinery, when that machinery has been selected to operate under computer control.

It is essential that once a machine has been switched to local control this can only be returned to computer by a man operating a switch locally. Similarly the operation of a local emergency off, or a manufacturer's protective trip must also throw the machine into the local control mode. Automatic control can only then be re-established after an operator resets the unit to computer control near the machine in question.

2.7.4 Fire alarms

A hard wired system is necessary for reliability. Provision will be made to provide spare contacts to enable display of the system status on the control system colour displays.

3. ANALOGUE AND DIGITAL DISTRIBUTED MULTIPLEX SYSTEM

3.1 Introduction

Although the analogue and digital distributed multiplex system will find application in other areas of the NSF accelerator, the primary justification for developing a system of this type stems from the control needs on the accelerator stack itself.

Due to the length of time taken to gain access to the pressure vessel in order to investigate any fault, it is essential that rigorous designs are utilised in the multiplex hardware, to achieve a flexible and highly reliable system. Reliability is not just a question of sound electronic design, as steps will also have to be taken to eliminate sub-standard components. In particular equipment commissioning techniques will have to be carefully specified. The installation problems of double screening will need special design considerations, to remove as far as possible awkward and time consuming crate interconnection techniques.

A multiplex system using almost identical techniques to those considered necessary for the NSF is in operation on the pilot machine at Daresbury, to enable monitoring and control of equipment in the high voltage terminal. Similar equipment has been tested for some time in the Harwell tandem, and has proved to be reliable.

The experience gained from the prototype system has been considered along with other projected needs for the NSF, to produce a number of requirements to be fulfilled by the production equipment.

Certain aspects of the system were determined by the monitoring and control requirements of equipment located in field free sections (stack dead sections), where both analogue and digital data was concerned. Due to the 'mixed' nature of the data to be handled, and the limited communication paths between dead sections and ground, there were advantages in using a time division multiplex system, with some form of serial pulse code modulation for transmission of the original digital and analogue information.

Special features are also required to enable analogue closed loops to be formed between equipment on the dead sections and external equipment, so that the energy of the beam from the accelerator may be stabilised. It is not expected that the bandwidth required for these loops will exceed 400 Hz, but during machine commissioning or for fault diagnostic purposes bandwidths of a few kilohertz will be required on occasions.

The digital transmission of information between data crates in the multiplex system needs at least one analogue to digital convertor (ADC) to digitise an analogue voltage, and one digital to analogue convertor (DAC) to reconstruct a voltage from the digital word per crate. Input multiplexers are then required to expand the number of analogue input channels to the ADC and a sample and hold decommutator may be used to expand the number of analogue output channels from the DAC.

If full advantage is to be taken of the potential throughput of the system, it is necessary to make further provisions in the hardware. Programmable sampling rates for the multiplex channels, and the use of local digital memory for storing current ADC and DAC values for all channels, offer further operational advantages. The local memory enables the use of simple low cost sample and holds, and frees a driving computer from timing problems, as information between crates can be made from memory-to-memory.

The use of memory-to-memory techniques in the multiplex system is important for the fast transfers of information needed to support channels having a large bandwidth. However, if a computer is used to directly participate in the exchange of all information between crates the potential bandwidth of the system would be greatly reduced.

Optimum performance may be achieved by using the computer in a routing capacity to set up autonomous channels which would then run at high speed, with normal transfers involving direct computer participation, interleaved with them.

This autonomous capability is further utilised in implementing the control system for the NSF, to enable the display of real time information on any control console. In this arrangement the driver module for each sub-multiplex system is linked by a "ring main" connection to the central contole console. Autonomous channels can then be set up to link one sub-multiplex system with another when required.

3.2 Environmental Considerations

3.2.1 Operation at high voltage relative to ground

The stack structure has a number of field free dead sections including the terminal, where equipment must be powered and controlled.

In each dead section electrical power is provided by an alternator driven from an insulated shaft, by a motor, which is at ground potential. Due to the physical characteristics of the grading structure on the stack, terminal discharges or other voltage breakdowns can result in the propagation of high frequency electromagnetic fields. These fields contain sufficient energy to damage or destroy unprotected electrical equipment and in particular any equipment that utilises solid state devices in the design.

The use of double shielded screening enclosures and the filtering of power and low frequency signal leads, gives adequate protection from the effects of a surge. High frequency signal entries to such an enclosure must use fibre optic techniques or free space light transmission through a honeycomb type entry to act as a waveguide and attenuate frequencies below cut off, the "light frequency" passing through with little attenuation.

As the NSF is more complex than any existing electrostatic accelerator, the traditional methods of remote control of equipment in dead sections using rods and strings are unsuitable because of the high data rate required. An electronic system using modulated microwave or near infra-red light link is required. The practicalities of the screening situation made the use of a "light link" preferable.

3.2.2 Equipment operation under pressure and vacuum

Control equipment situated inside the accelerator pressure vessel must withstand pressures from rough vacuum to 7 bar. It is unlikely that the alternators will be permitted to run much below atmospheric pressure because of the reduction in voltage hold-off caused by the reduced pressure, but the components used in any equipment must not deteriorate as a result of such pressure changes.

None of the components used in the electronic assemblies are expected to be troublesome due to these pressure changes, with the exception of large electrolytic capacitors. The large area forces experienced on such a component may cause it to collapse.

This situation could occur as a result of a typical operational cycle of the accelerator, where it is pressurised for a number of months, and then returned to atmospheric pressure in a few days for access. Under pressure gas may seep into the capacitor. A subsequent evacuation of gas from the pressure vessel would produce a pressure reversal on the case of the electrolytic so that an explosion might then occur. Alternatively, failure may occur after a number of such pressure cycles due to fatigue.

In this respect there is some advantage in using direct off line switching regulated supplies for the multiplex system. Energy is stored in the power supply at approximately 200 V in supplies of this type, therefore the physical size of capacitor is considerably smaller than that needed in a conventional power supply, with a corresponding reduction in "area" forces due to pressure.

The prototype light link utilised such a switching supply. As yet there have been no problems with the main reservoir capacitor, but all production power supplies will need to be individually pressure tested as an important step in their acceptance testing.

There is also the slight risk of personnel being injured by the explosion of an electrolytic and agreed safety procedures will need to be followed when doing any maintenance on a power supply that has previously been in a pressurised environment.

3.2.3 Space available on the stack

The space available for control equipment on the stack is strictly limited, particularly in the small dead sections. Positions for control system crates have been allocated between the eight support legs of each dead section. Access to these crates is available from the outside of the dead sections only and under these circumstances intercrate wiring must be carried through double screened conduits and across the back of the inside crate of each double screened enclosure.

It will be necessary to produce a standard double screened crate for the accelerator, the crate itself being available in three heights. The width and depth being identical for each type. The crates will accept control cards or may be used to house magnet power supplies or other high power electrical equipment. The preferred arrangement for such a crate is shown in fig. 5.

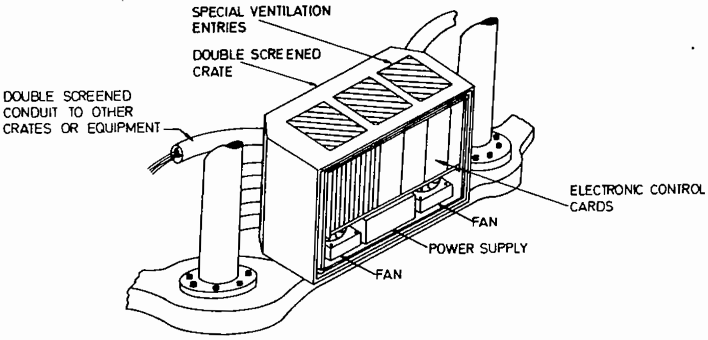

Fig. 5. Arrangement of double screened crate within dead section. Front panels removed.

3.3 Preliminary Design of the Analogue/Digital Multiplex System

3.3.1 Introduction

The main support systems on the stack comprise of beam transport, charging and vacuum equipment. In each of these areas digital values (ON-OFF states) have to be set and monitored. In addition analogue control and monitoring is needed, with some diagnostic channels requiring bandwidths in excess of 1 kHz.

Some information carried over the multiplex system will be used in the closed control loops that stabilise the machine. An autonomous channel capability is required from the multiplex system to implement the closed control loops. The autonomous channel will also be utilised for transmitting information for diagnostic purposes, for display on oscilloscopes.

It has been decided to use a free space modulated light link using infra-red emitting gallium arsenide diodes, for information transmission to and from dead sections. It has further been decided to transmit information digitally and in serial form, with time division multiplex being used to provide the necessary channel capacity. A system of this type is flexible in application and simple to interface with a digital computer, which may then be used in both a routing capacity for autonomous channels or to directly participate in information transfers on lower data rate channels.

3.3.2 Determination of serial data rate for the multiplex system

3.3.2.1 Arrangement of light transmission paths

There are advantages in running the light link path longitudinally up the Van de Graaff stack structure requiring that each control crate must retransmit the serial message, forming a ring main system as shown in fig. 6.

The alternative would have involved a radial light path to the tank wall from each dead section, requiring a hole in the dead section skin and with the additional problems of alignment and pressure breaks for the receiver and transmitter on the tank wall, opposite the dead section. A radial light path would have also been more liable to interference both from reflected light from a tank spark, and also by the resultant pressure wave in the gas, the stack helping as a shield in the longitudinal case.

The two disadvantages of the longitudinal arrangement, are that the data rate needs to be higher because all crates become part of a serial ring main and that the failure of power in one section would prevent the closing of the "ring main". None of these deficiencies are considered significant compared with some of the practical problems of implementing a radial system for the NSF. There are no technical problems in achieving the data rates for the "ring main" system as TTL logic will be used as standard. Further light link

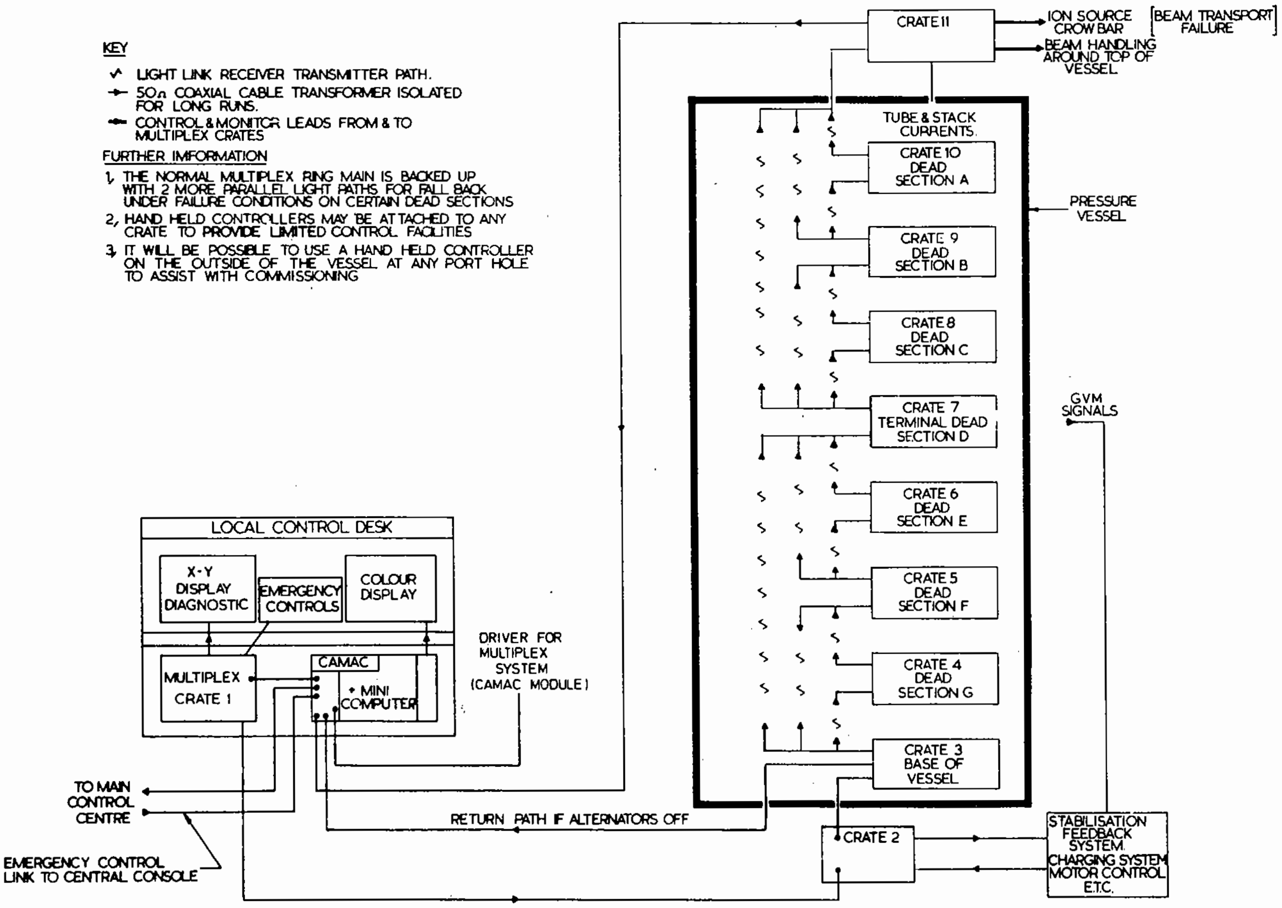

Fig. 6 Arrangement of light link paths on accelerator.

paths will also be arranged to form an additional safeguard in the event of a loss of power in less critical dead sections.

3.3.2.2 Design data rate

It has been estimated that a data rate of 300 kBits will be sufficient for the ring main system to meet the needs of the NSF accelerator.

However, the standard technology to be used will permit operations up to 10 MBits, so that operating the system at 5 MBits will allow sufficient margin for further expansion, or enable the extra capacity to be used for diagnostic purposes.

The prototype light link used in the pilot machine utilises similar technology to that proposed for the NSF. A typical communication path over 10 m with a 4 MHz bandwidth has a signal-to-noise ratio greater than 150:1. In view of the satisfactory operation of the prototype in SF_6, the same transmitter/receiver arrangement will be suitable for the NSF.

3.3.3 Multiplex system electronics

3.3.3.1 Introduction

Due to space limitations in the accelerator stack it was necessary to develop a special system. The organisational methods of CAMAC were considered for application in this system. However, the CAMAC philosophy makes much wider modes of operation possible than is required, with the consequence that the design of autonomous controllers becomes much more complex, as does the electronics of any module in the system.

For our purposes an autonomous capability is required for the following reasons:

1) Automatic computer independent control loops can be implemented.

2) Higher bandwidth continuous data can be taken for the production of live diagnostic displays.

3) It was not wished to reduce capability on what will be a developing machine in order to adopt the CAMAC protocol, which in our application would be wasteful in terms of true data rate, so reducing analogue channel capacity or bandwidth. An efficient purpose-designed message structure was therefore required.

4) To enable certain aspects of computer control and monitoring to be simplified.

5) To attain the reliability that is required in the stack the complexity of the equipment should be kept to a minimum to achieve the performance required.

A system was therefore designed to meet the unique situation found in the stack of the accelerator. However, the principles and requirements for monitoring outside the stack are similar to those inside and therefore the system can be directly applied elsewhere.

A prototype system using the techniques envisaged has been operating reliably in the pilot machine at Daresbury and in the Harwell tandem. This system uses low cost techniques and costs considerably less than an equivalent CAMAC system for this application. The multiplex system makes use of the best features of CAMAC by providing its main control module in CAMAC standard.

3.3.2 Arrangement of the data highway

The type of card to be used has two 48-way edge connectors on one side. One of the edge connectors is used for inputs and outputs whilst the other connects to the analogue and digital data highway (see fig. 7).

The analogue signals to be "bussed" are listed as follows:-

1) Six wires for use as a 4/6 wire system for enabling the multiplex of temperature transducers (4 wire) or enabling the multiplex of full bridge type transducers (6 wires).

2) Two wires for a common input line for two analogue-to-digital converters.

3) Two wires for a common output line from two digital-to-analogue converters.

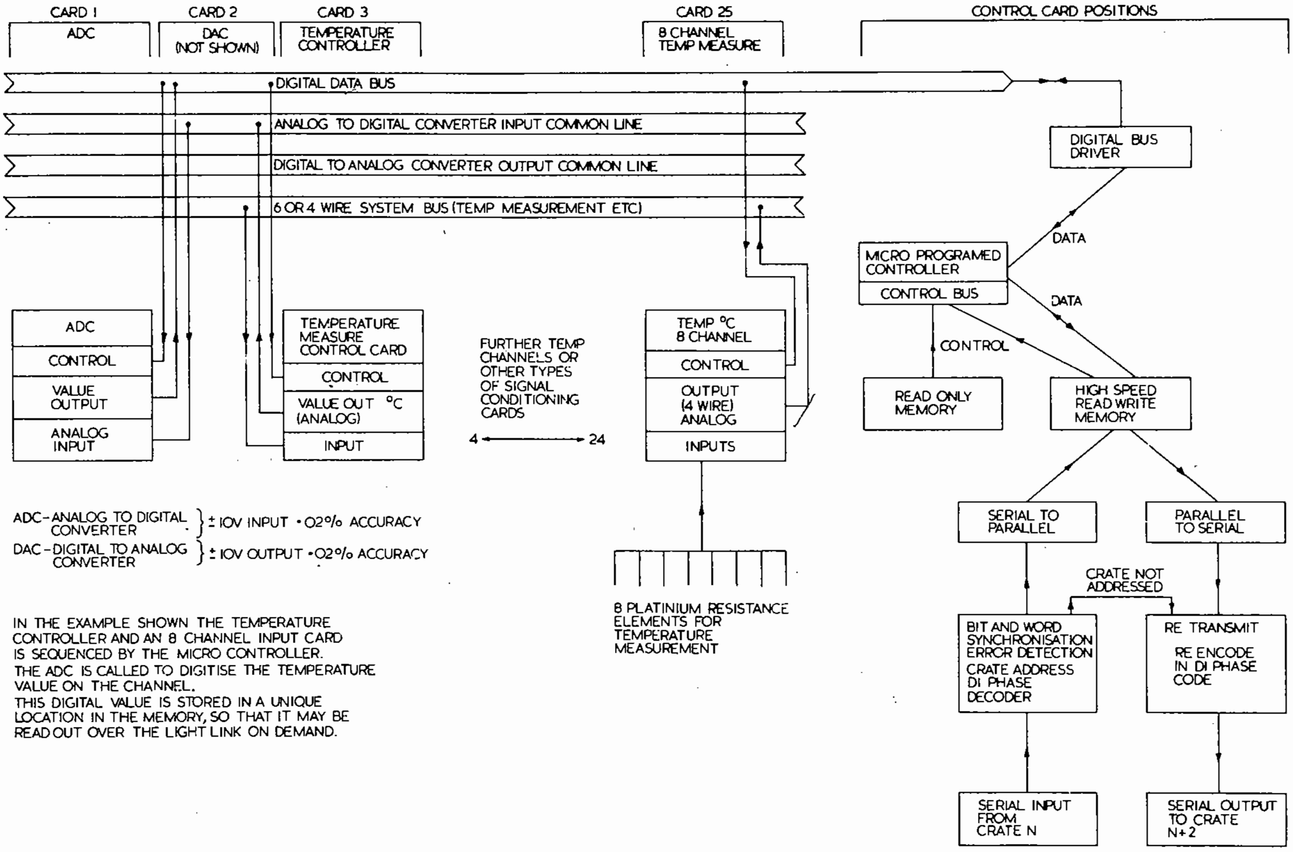

Fig.7 Data highway in multiplex system crate.

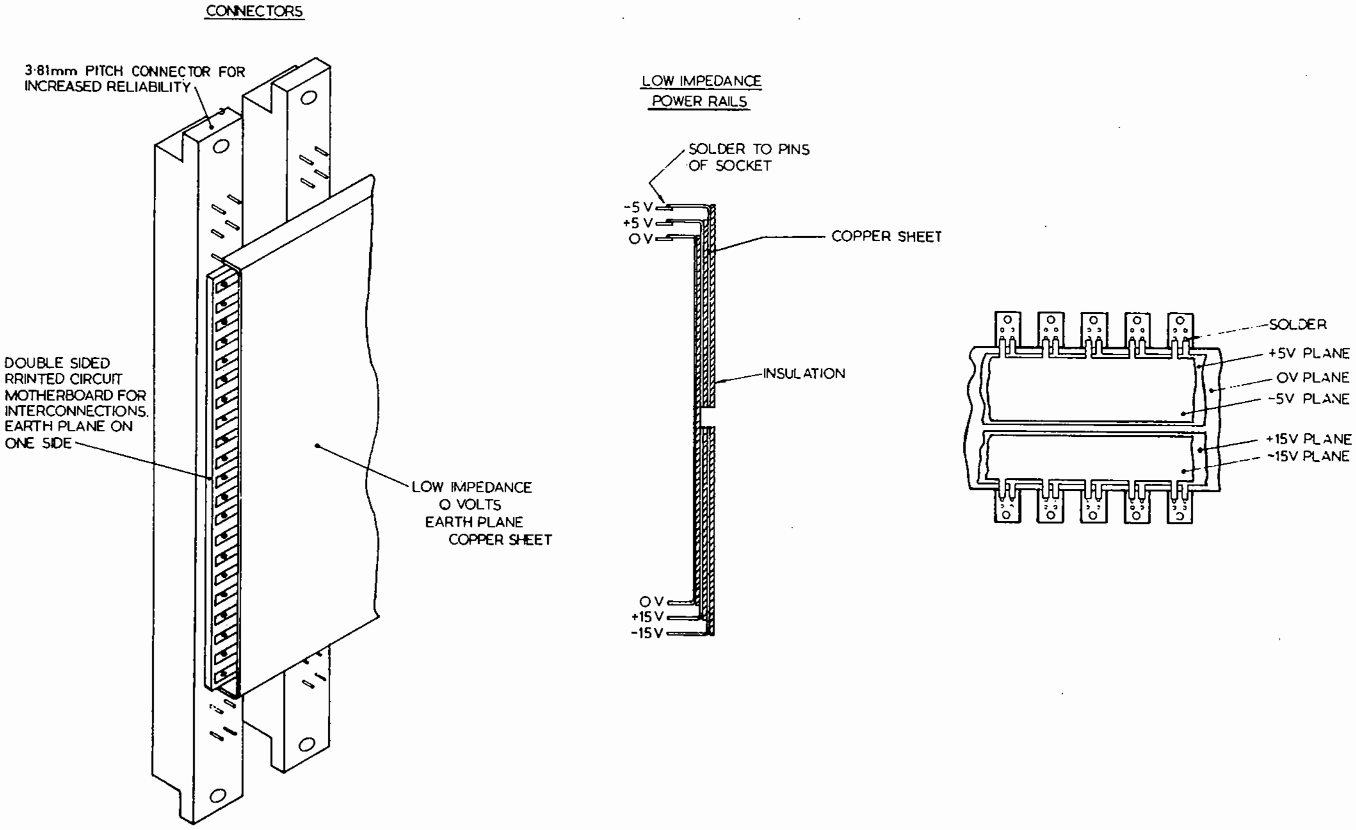

Fig.8 Low impedance power planes.

The rest of the signals on the common highway are digital data or control lines and power lines.

In any combined analogue digital system particular attention must be given to low impedance power and earth planes, if a satisfactory performance is to be attained. The method to be employed for the production system power planes is shown in fig. 8.

A standard crate will have twenty-eight card positions of which three will be crate control cards for control of the highway. They will also convert to and from serial code to enable transmission over light links or coaxial cable, to other crates and the multiplex driver CAMAC module.

A further three positions will be taken up by an analogue-to-digital converter card, digital-to-analogue converter and temperature scanner controller. This leaves a further twenty-two positions which will give a large input/output capability (264 temperature channels for example).

3.3.3 Operation of the control cards

It will be possible for diagnostic purposes to transmit information with a bandwidth of 10 kHz and the ability to change analogue channel sampling rates on demand.

Such features are best implemented using micro-programmed hardware techniques in the control cards instead of random logic, to enable a systematic approach to be made to the design. Documentation, commissioning and maintenance will be considerably simplified by this approach, and operating changes may be made simply by changing the micro-program. This may occur dynamically as a result of an operator demand that effects a change in analogue sampling rates, or to effect a reconfiguration of signal paths in the crate. (For example, if one analogue-to-digital converter fails, its load could be passed on to a second one, enabling measurements still to be made but at reduced bandwidth).

Approximately 512 words of memory will also be required on one of the control cards to store the current values of analogue values monitored and set. Memory-to-memory techniques may then be used for inter-crate data transfers.

3.3.4 Multiplex system CAMAC driver

The driver module enables a number of multiplex crates to be driven from a computer via CAMAC. Design features are required in the module to enable autonomous channels to be set up for higher data rate channels when necessary.

A further autonomous port on the driver module is necessary to enable high rate information to be transferred to the main control centre, for diagnostic purposes, in some instances for display on an oscilloscope.

A block diagram of the driver module is shown in fig. 9.

3.3.5 Reliability of electronics components

3.3.5.1 Testing of components

All electronic components prior to assembly will be subject to elevated temperature tests to accelerate the failure of "freak" components. This test will be available as a standard option on components from some integrated circuit manufacturers.

Following assembly and commissioning of complete electronic systems, the assembly will be run for a minimum of 10 days at an ambient temperature of 70°C. This will be followed by at least 5 pressure cycles of rough vacuum to 7 bar.

It is expected that the previously outlined tests will eliminate the vast majority of faulty components.

If time permits, the equipment may then be powered for further bench tests for a time not exceeding 500 hours, prior to final installation in the machine.

3.3.5.2 Commissioning and preventive maintenance

Most of the commissioning and testing of electronic cards will be done with computer assistance. To facilitate this operation and to keep a check on the life histories of control cards, provision will be made to enable the card type number and serial

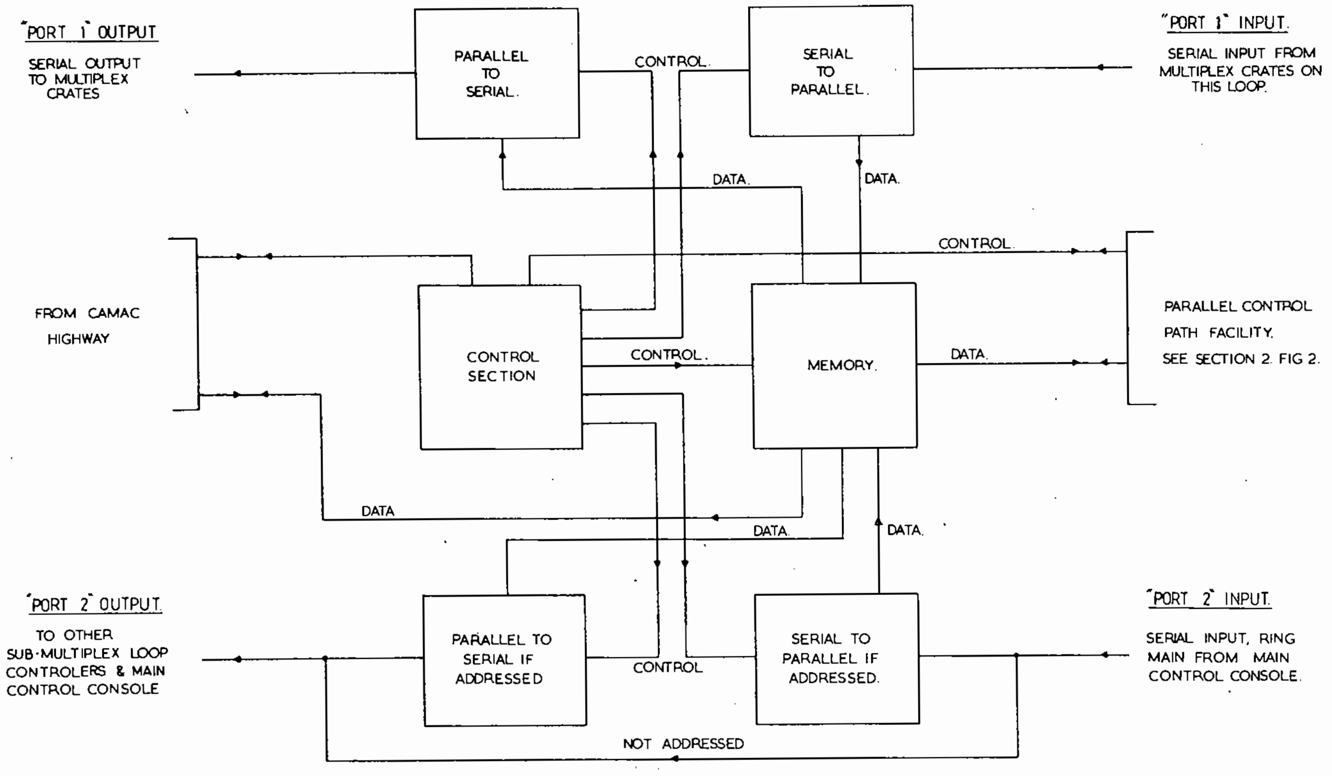

Fig. 9. Simplified block diagram of multiplex driver module.

number to be read out electronically over the multiplex system data highway on the command of a standard function code. Such a feature will also enhance the long term reliability of the multiplex system electronics, enabling hours run by individual cards to be logged. The results of on line tests may be compared with the original values at equipment commissioning; slight changes of any characteristics may be investigated at the next machine shutdown, perhaps preventing the inconvenience of an operational failure at a later date.

4. COLOUR DISPLAY SYSTEM

4.1 Introduction

The NSF control system will make extensive use of colour display units as an operator interface for monitoring and control of the machine. A computer interfaced colour display system for use with a PDP11 computer has been developed to a prototype stage. A CAMAC version of this system is now being developed(2) commercially and it is this unit that will be utilised in the NSF control system.

4.2 Colour Display Organisation

The organisation and operation of the basic colour display is described in Appendix A.

The CAMAC version of this unit(3) requires that 2048 words of memory are available to support the picture, to avoid the overheads that would have been incurred when using a direct memory access channel on a CAMAC system.

Further advantage has been taken of recent developments in high capacity semiconductor memory technology to store symbol shape information in read-write memory, permitting a user to define or change a set of symbols at will. Apart from the convenience of this facility, more detailed graphical information may then be presented on screen as a result of this addition.

The colour display system will be available with a light pen as the standard interactive device. However, a rolling ball or touch wire system may also be used if required, as CAMAC interfaces for such units are already available.

5. MINICOMPUTER SYSTEMS

The minicomputer systems provide the interface to the plant. When the complete system is operating normally they will concentrate the various data sources and perform a first level of data reduction. Under system fault conditions they will provide sufficient facilities to allow adequate accelerator control for the duration of the fault. Because of their relative cheapness a faulty mini will be corrected by complete processor replacement.

The functions of the mini systems are in many ways similar. It is possible therefore to design a generalised system on which each can be based, fig. 10. In practice this means configuring the CAMAC and A/D multiplex systems to provide the actual facilities required. Standardisation on processor type, core size and available options, is needed so that a policy of maintenance by replacement can be adopted. The system is based on a 16 Bit word machine. This meets the requirements for measurement accuracy, normally 12 Bits with up to 16 Bits in special cases. In addition it allows the choice of a processor of appropriate capability from a wide range of models and manufacturers.

A core size of 16k words has been arrived at by consideration of the total program and data area requirements. For data storage particular attention has been given to the manipulation of system variables and the generation of displays (Appendix B). It is the intention to use CAMAC as the sole means of communication between the processor and the system. The use of a computer-independent and closely defined standard makes available a continually expanding range of suitable modules from commercial sources, other groups within the Laboratory and other laboratories engaged in similar work. The almost complete standardisation within the Laboratory as a whole on the CAMAC system over the past few years has resulted in the accumulation of considerable expertise in its design and application and the establishment of specialised maintenance facilities. On the software side, coupled with the use of machine independent languages, CAMAC offers the possibility of developing transportable software to a level greater than it has been possible to achieve hitherto. CAMAC does have its disadvantages and is not particularly suitable where multiple analogue and digital signals must be handled from a distributed plant generating an electrically and mechanically hostile environment. Within the NSF control system the 'plant' will be connected to the various minicomputer systems by distributed analogue and digital multiplex equipment, see fig. 10. Briefly this provides further data concentration local to the plant. Analogue and digital data is then transmitted by Time Division multiplexer and pulse code modulation techniques to and from the local minicomputer systems. Using commercially available standard components it is possible to obtain from this equipment a high performance in terms of accuracy and measurement rate. In general this will be used by the computer system to achieve a fairly moderate sampling rate from a large number of channels. It also makes possible a fast sampling rate from a smaller number of channels. In practice if the system is designed to allow variable sampling rates a mixed system is possible. With present techniques the sampling and transmission rates that can be achieved allow measurements to be taken resulting in an output signal of several kilohertz bandwidth. Many of the signals from the NSF fall within this range and it is possible to use the multiplex system to produce live real time oscilloscope displays, a feature of great benefit for assessing machine behaviour. To allow the computer system to control these transfers whilst not requiring it to actually handle the data, it is proposed to cater for up to two computers to access each A/D multiplex system directly, and to include all A/D multiplex systems in a "ring main" under autonomous control supervised by the main control console minicomputer.

5.1 Module Function

The function of each of the modules in the proposed system is dealt with separately in the following paragraphs.

5.1.1 Colour display system

This part of the system comprises the display driver(3) and display store CAMAC modules. The prototype colour display and the light pen are described in detail in Appendix A. In the minicomputer system this equipment will be the major

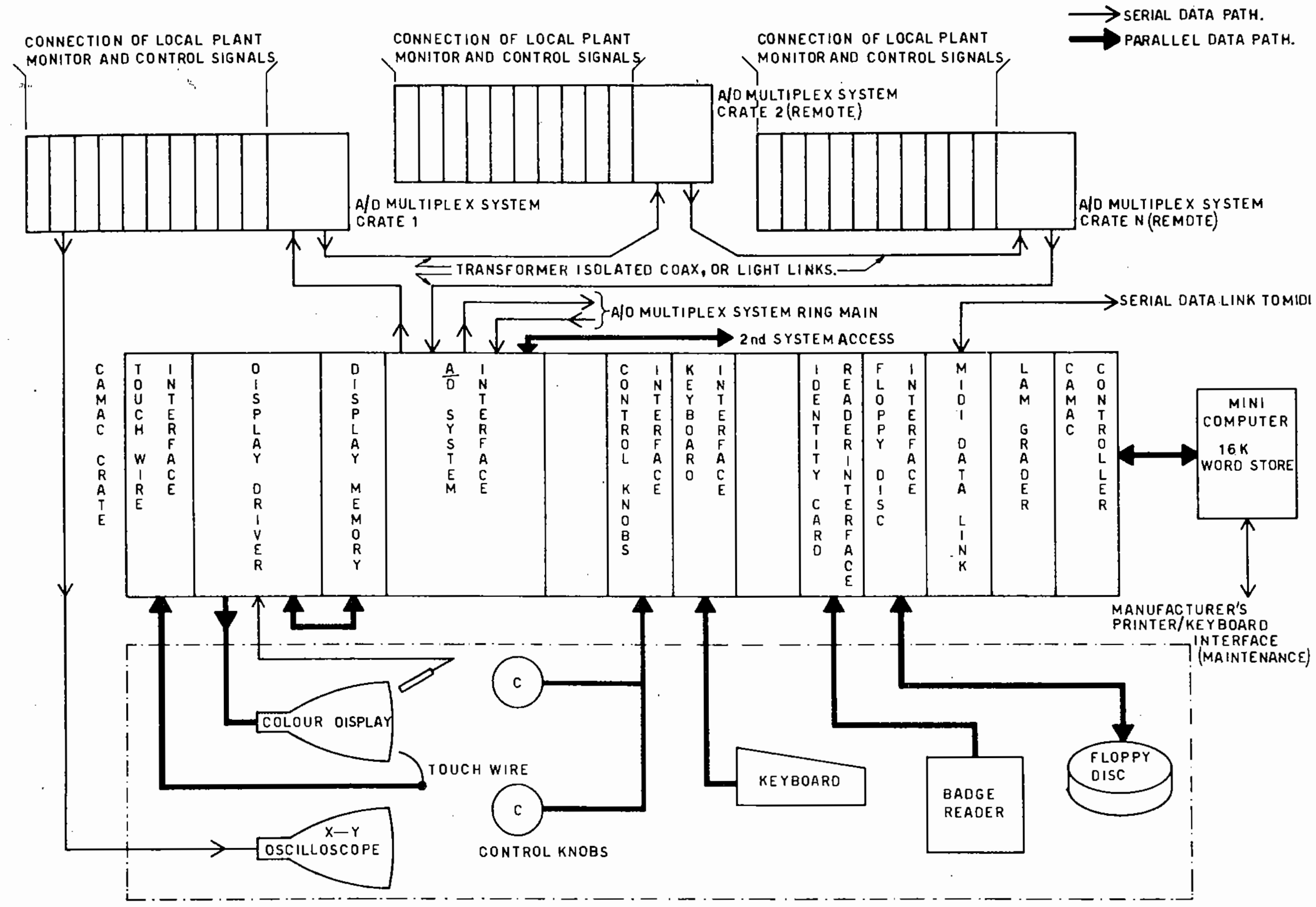

Fig. 10. Basic minicomputer system.

device for providing output information to the operators. As such it will be used for display of plant information local to the minicomputer system and act as a control console for the computer system itself. Under fault conditions which result in the loss of the central computing facilities it will be the sole means of displaying data from that part of the plant which is controlled by its minicomputer system. The light pen feature is provided to allow operator interaction with the control system.

5.1.2 Control knobs facility

Two incremental shaft encoders, together with a controlling CAMAC module will provide a means for continuous control of selected variables by operators. The selection of the variables and the feedback of their actual varying values to the operator will be through the colour display system.

5.1.3 Keyboard

A keyboard with full alphanumeric capability and extra number pad will be available, interfaced directly to the CAMAC system via a suitable module. This will be used to allow operators to enter data requests and commands to both the systems and applications programs. Again in practice the keyboard will be used with the display system.

5.1.4 Identity card reader

With so many operator control positions and the multipurpose nature of these, such a wide range of control becomes possible from each position that it is important that the interaction of operators with the system and with each other is organised in an orderly fashion. To aid in preventing indiscriminate operator intervention either by accident or design an identity card reader will be provided at each control console. This will accept an identity card, in appearance very similar to the common credit card but containing a pattern of holes. Such a card will be issued to all persons authorised to operate sections of the accelerator. The card will uniquely identify the operator to the system and will allow him to perform operations on those parts of the system that he has been given the authority to control. Any control console without such a card in the card reader will appear either inoperative or will only accept requests for display of information.

5.1.5 Touch wire system

This facility is provided to give the operator a function key facility.

5.1.6 Floppy disc

The data requirements of the minicomputer system particularly for operation in a stand-alone mode will far exceed the size of direct computer memory that it is economical or necessary to provide. Full data on all system variables, display formats and alternative systems programs are examples of this information. A floppy disc will give the necessary quantity of storage required and the access time of these devices should be adequate for their application.

The ability of the floppy disc systems to accept discs produced on other disc drives will enable this device to be used for data and program loading. For stand-alone operation of the minicomputer system particularly during the commissioning of the accelerator and the control system, this feature will be extremely important and will remove the requirement for special peripherals to be provided solely for this purpose.

5.1.7 Data link

Under normal operating conditions control of the minicomputer system, the production of operator information, logs,histories etc. will be from the main consoles and midi-computer. The CAMAC interfaced data link equipment is the means by which the mini/midi intercommunication is achieved. Using modern design techniques and standard components a data rate of several hundred kBits can easily be achieved. This will be more than adequate for the NSF requirement.

5.1.8 Analogue and digital multiplex system

All signals between the plant and the control system will be made using analogue and digital multiplex systems (sect. 3). The control of these systems and the transfer of data between plant and computers will be via the CAMAC to A/D multiplex system, interface module.

5.1.9 Computer system modules

The remaining CAMAC modules, the LAM Grader and the CAMAC controller are system modules necessary for the operation of the computer system itself. The LAM Grader is required to enable efficient handling of "Look at Me" requests (Interrupts) from the CAMAC modules. The CAMAC controller is the interface between the computer and CAMAC system itself.

Past experience with minicomputer systems where CAMAC is used to interface all peripheral activities has shown that it exhibits a serious practical weakness. To the outside world the computer and CAMAC system becomes one and under many fault conditions it can be impossible to deduce where the fault is located, or load diagnostic aids into the computer system which would help determine this. Because of the large number of individually replaceable modules involved, this situation often seriously impairs the maintenance procedures and is completely unsatisfactory in practice. It is essential therefore that each minicomputer is provided with the necessary facilities to allow the temporary speedy attachment of sufficient peripheral equipment to allow the effective use of diagnostic software so that the location of faults within a CAMAC/minicomputer system can be quickly established. For computer repair these same peripherals must be available in any case. The lack of any manufacturers peripherals renders most of the diagnostic software produced by him useless. The production of high class diagnostics is both specialised and time consuming and is an area of considerable investment by any worthwhile minicomputer manufacturer. The loss of these facilities within a system where high availability is a primary aim is unthinkable and any attempt to modify them to fit misguided.

The provision of a manufacturers basic printer-keyboard unit may well prove useful for the early stages of software development. Again it makes available for use manufacturer's software, in this case the range of utility programs for program production and debugging.

5.2 Functions of the Minicomputers

The functions required of the minicomputers are dependant on the status of the midi. Under normal situations (well over 90% of the time) the midi will be fully operational, and the main consoles will be used for NSF control.

In these circumstances the minicomputer systems will collect data and perform a first level of data reduction, the midi-computer being in executive control, providing the required flexibility of operation. Under these conditions programs in the minicomputers will be called on for:-

a) Monitoring of measurement and status channels.

b) Setting of measurement and status channels from information supplied by the midi-computer.

c) First level data reduction by checking against tightest measurement limits and accepting or rejecting status information.

d) Allowing a local operator to enter commands which will be routed to, and processed by the midi-computer.

e) Producing information displays on the local control console from data supplied by the midi-computer.

f) Performing any simple automatic control which requires high speed response.

g) Generating and transmitting messages to the midi-computer, where for example:-

   i) out of limit measurements or unacceptable status is detected,

   ii) measurement or status information is specifically called for by the midi. This may be either once or on a repetitive basis,

   iii) the minicomputer requires data from the midi-computer files,

   iv) a local operator has entered a command (see d) above).

h) Accepting messages from the midi-computer which for example:-

   i) request measurement or status information,

   ii) change measurement or status point settings,

   iii) update data files within the mini to effect changes in operating conditions or as the result of a previous mini request,

   iv) are new or updated programs for subsequent operation,

   v) are requests to the mini operating system to control the running of programs within the mini,

   vi) will result in displays on the local control console.

Should the facilities of the midi-computer become unavailable or a decision be made to operate a minicomputer in a "stand alone" mode then the requirements for the minicomputer operation change. If the situation is caused by a fault condition then initially the minicomputer must ensure that the *status quo* is maintained. In order that the operating state may subsequently be changed a reduced capability to achieve this under operator control will be provided from the local control console. Under these circumstances programs within the minicomputers will be required to

i) Monitor measurement and status channels.

ii) Vary control and status points under manual control, from the local console.

iii) Check data against tightest limits and accept or reject status information.

iv) Inform the local operator of any data exceptions.

v) Accept commands from an operator at the local control console of a level sufficient to allow the operator to maintain control over the plant.

vi) Produce displays for the local operator in keeping with v).

vii) Perform simple automatic control which requires a high speed response.

viii) Carry out simple sequences to aid the operator in start-up or shutdown of sections of plant.

The ability to change operation, produce displays, accept operator commands and produce messages will require more information to be stored for both programs and data than it is either economical or necessary to provide as main memory. This storage will be provided by a floppy disc unit. The capacity is estimated to be adequate as is the access time. Most accesses will be as a direct result of the actions, and to satisfy the demands of a single local operator.

5.3 Individual System Descriptions

Each of the actual computer systems is based on the above generalised model. The following sections deal with each system in turn.

5.3.1 Ion source system

Functions:

1) To provide control and monitoring for the on-line ion source and other miscellaneous functions within the ion source room. Under normal operation overall control will be from the midi-computer via data link.

2) To provide local control and monitoring facilities for setting up and testing ion sources.

Measurement and Control Point Estimates:

For each ion source table with 4 sources -
100 measurement monitoring points
30 measurement control points
230 status monitoring points
90 status set points
Other points in the ion source room -
60 status monitoring points
20 status set points

Location: Ion Source Room.

5.3.2 Gas and water plants and services

Function:

To provide monitoring and control over the whole of the gas and water plant and general services. A control console will be provided with display facilities for local display of system information. Under normal operation the link to the midi-computer will allow control to be exercised centrally from the main consoles.

Measurement and Control Point Estimates:
460 measurement monitoring points
100 measurement control points
1490 status monitoring points
270 status set points

Location: Main Plant Room.

5.3.3 Charging and vacuum systems

Function:

To monitor and control within the stack and beam line analogue and digital multiplex systems those points which are relevant to the charging and vacuum systems together with a number of other miscellaneous points. Under fault conditions of the beam transport computer system because the A & D multiplex systems have access to all beam transport measurement and control points, reconfiguration of the tasks of the system under midi-computer control will enable beam transport control to be continued. For local control purposes when loss of the central facilities occurs a small control console with colour display will be provided.

Measurement and Control Point Estimates:
540 measurement monitoring points
140 measurement control points
940 status monitoring points
560 status set points

(these figures assume that miscellaneous measurement and control is split between this system and the beam transport system so as to balance the total load).

Location: Main Control Room.

5.3.4 Beam transport system

Function:

To control and monitor the beam transport system parameters through the stack and beam lines, analogue and digital multiplex systems plus a number of further miscellaneous points within these systems.

To back up the charging and vacuum systems control under fault conditions in a reciprocal manner to that systems beam transport back-up capability, as described in the last section.

Measurement and Control Point Estimates:

540 measurement monitoring points
140 measurement control points
940 status monitoring points
560 status set points

(see note in last section).

Location: Main Control Room.

5.3.5 Main control consoles

Function:

To off-load from the midi-computer those functions which will be necessary for the operation of the main control consoles but which can be more conveniently handled by a dedicated smaller machine. Examples of functions which fall into this category are

a) translation of problem orientated display data for both display generation and display updating into memory image format for the display hardware. Local display manipulation such as window control by rolling ball, and light pen requests.

b) Assembly and editing of operator keyboard requests.

c) Handling of other operator devices for example control knobs, touch display system and identity card reader.

d) Supervising functions with A/D multiplex systems "ring main" controller.

Location: Main Control Room.

6. MIDI-COMPUTER SYSTEM

The functions of the midi-computer system were listed in sect. 2.2. This section gives details of the proposed hardware and software to handle these functions.

A block diagram of the proposed system is shown in fig. 11. Again where applicable it is proposed to make full use of the CAMAC system. The various modules shown are provided for the following functions.

6.1 CAMAC System

6.1.1 Computer system modules

The LAM Grader and CAMAC controller modules perform the same functions as in the minicomputer systems (5.1.9).

6.1.2 Floppy disc

This is identical equipment to that to be used on the minicomputer system. It will allow discs to be written for eventual use on the minicomputer systems. This facility will allow program development whilst the system is in operation which would result in for example alternative mini system discs for say later off-line use, or system enhancement.

6.1.3 Data links

The midi-computer is situated at the node of the complete control system. The actual communications with the other parts of the system are provided by CAMAC data link modules. Modules are provided for communicating with each minicomputer, with the IBM 370/165 and with the experimental users.

6.1.4 Printer

A local facility will be required to produce hard copy print-out of reports and logs as and when required. For this application a device capable of printing several lines per second will be necessary.

6.2 Midi-computer

The requirement here is for a hardware and software package, in that medium power computer hardware and a real time disc operating system will be necessary, and will most likely be obtained as a complete package from a single supplier. For this to be possible in a rational manner the use of CAMAC to interface all peripheral devices is no longer the best solution. In particular, the mass storage and control typewriter should be standard manufacturers peripherals interfaced to the midi-computer in his standard manner. In the case of the mass storage there should be two independent drives.

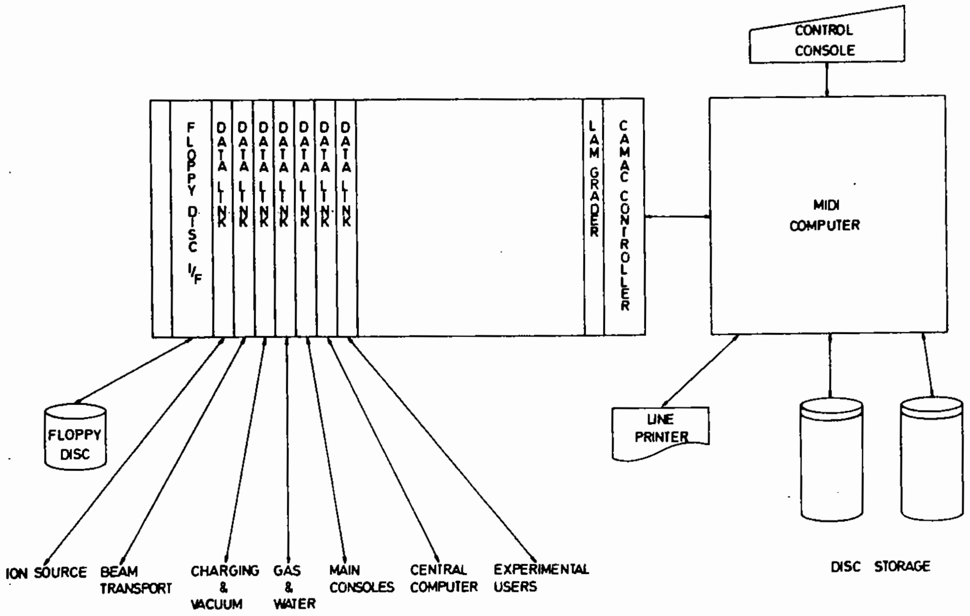

Fig. 11. Midi-computer system.

Their access times should allow the operating system to provide adequate system response times. As both the characteristics of the backing storage and the core store required are bound up closely with the operating system software and a fuller knowledge than is available at present of the midi-computer work-load and data rates, actual details of these parameters will be left until negotiations take place with possible suppliers. It is possible however to outline the characteristics expected from the midi-computer hardware/software system.

i) The system will be expected to run a selection of tasks simultaneously, chosen dynamically from a large number available on backing store. The execution of these tasks will be to satisfy on-line demands to the system which will generally need a response within relatively short times.

ii) There should be the ability to tailor the operating system facilities supplied by the manufacturer to fit the special requirements of this application. In addition it should ideally be possible to add user defined modules if required and modify manufacturers modules if necessary.

iii) It must be possible to meet the special requirements of the operating system imposed by the use of CAMAC as the major user interface and the extensive use of front end minicomputers connected via data links.

iv) Facilities should be provided for generating and handling files as required by the user on the backing storage.

v) It must be reasonably quick and easy to re-load the system.

Further information on the software aspects of the system as a whole are presented in sect. 7.

7. SOFTWARE

The limited availability of manpower and the necessity to provide computer control facilities within timescales dictated by considerations other than the control system itself mean that careful thought must be given to the production of software for the NSF. It is essential therefore that a policy be adopted to simplify and standardise the software requirements so that programs become simpler to write and more widely applicable. The price which must be paid for this is that the resulting software will in general be both larger and less efficient, requiring an increase in both computer power and memory. At a time when technology is still reducing the cost of computer hardware whilst the cost of human effort is continually increasing, the special needs of the NSF lead to a course of action completely consistent with the results of wider considerations.

These objectives can be achieved by ensuring that a sound basis is chosen from the outset in the following aspects of software production.

7.1 Language

The majority of applications of this type have until recently usually been programmed completely in the assembler language of the machines used. This was argued to lead to more efficient, smaller programs and in any case give the programmer a level of control over the machine not offered by the high level languages then available. This was not surprising since these languages had been designed for different types of application. The situation has now changed and a number of high level languages are available aimed specifically at this type of real time problem. A recent survey carried out by the Computer System and Electronics Division of the Laboratory concluded that the language RTL/2 originally developed by ICI is the best choice at this time and this language will be used wherever possible within the NSF control system.

The use of RTL/2 should considerably simplify the actual job of writing the programs. The language allows the programmer to concentrate his efforts on solving the direct problem without frequently being forced into solving the additional problems found at assembly language level, of driving the hardware. The result is that programs are easier to write, can be more efficient from the point of view of solving the application problem and are more easily understood by other programmers or the originator at a later date. Additionally the choice of a procedural language encourages and facilitates a modular approach to program writing both within single programs and between programs.

7.2 CAMAC

A major area of difficulty in enabling the complete use of high level languages including RTL/2 is that found at the interface between the computer and the outside world. The conditions here vary greatly from machine to machine making the definition of an all embracing standard language difficult. So difficult in fact that many of the standard languages, including RTL/2 side step the issue, only making provision for interface programming to be done in the machine's assembly language by subroutines or code inserts. The use of CAMAC solves the interface problem at the hardware level. From the software aspect CAMAC's closely defined command and addressing structure enables machine-independent input-output commands to be defined for all possible interface operations. These features can be made available by means of a pre-processor through which the program source is passed prior to entering the RTL/2 compiler. By this means all the programs produced for the NSF system can be machine-independent. This will further help in understanding the code produced by others. In addition the adoption of RTL/2, CAMAC and standard CAMAC commands throughout the Laboratory will improve the possibilities of exchanging software between the various systems on site. It will also ensure that programmers employed in other Divisions of the Laboratory will have minimum difficulty producing programs for use on the NSF system.

7.3 Modular Software

Three factors must be borne in mind when considering the software for the NSF system. Firstly, the system will use a number of minicomputers whose programs have many common characteristics but which in total are unique to their application. Secondly, the work-load and timescale are such that the programs will of necessity be produced by more than one person with parts inevitably being produced by programmers not connected with the NSF directly but from other Divisions of the Laboratory or possibly on contract from outside. Thirdly, extensions and improvements throughout the life of the system must be easily accommodated. The solution of these problems is to produce software in a modular form, where the interface and relationship with the rest of the system for each module is closely defined and controlled. Different systems with common characteristics can then be generated by configuration of a suitable set of modules, a number of programmers can work independently on different modules for the same system, and changes or addition become changes to or additions of modules. The disadvantage of course is that modules must be reasonably general purpose and will thus be both larger and slower in operation than could be achieved by programming for each particular application directly.

7.4 Real Time Executive

The modularity described above must be achieved within the real time environment of the NSF computers. In this situation a system is required to react quickly to the unpredictable demands of the real world. Programs must run at varying times and with varying degrees of priority. To fully utilise the machine at any one time may require several modules to be in varying states of execution, processing the various demands apparently in parallel. To achieve this type of operation whilst still enabling modularity requires the use of an overall control program to organise the scheduling and running of the different modules in response to external interrupts. This control program is generally called an executive. Other systems modules can be added to the executive to provide other essential general purpose functions such as loading, debugging and control of memory to produce an operating system.

Each computer within the NSF system will use a real time operating system. In the case of the minicomputer systems this will be fairly simple and will be core resident with limited facilities. It will be either produced internally or if a suitable commercial package is available will use or be based on that. For the midi-computer a more complex operating system will be required. This results from the large number of modules which must be catered for and the requirement for a mass storage file handling system. In this case it is envisaged that a complete operating system will be purchased together with the hardware of the midi-computer from a single supplier.

7.5 Evolution of the Control System

As the Van de Graaff accelerator is built and commissioned so the computer control system must evolve from providing at first local facilities to allow operator control of individual areas of plant to ultimately giving a fully integrated control system as the final stages of Van de Graaff commissioning are completed. To keep in step with these requirements the minicomputer systems must be the first to be operational in a stand-alone mode. These will be available first and software effort directed towards producing a working operating system. This will be followed by the production of those modules necessary to give a level of control over the various peripheral devices which will satisfy and ease the burden on the applications programmer. Finally sufficient applications programs will be produced to allow control of plant from the minicomputer control consoles. Following this, the task of system integration using the midi-computer will be undertaken together with the provision of more sophisticated control using the main control consoles.

Throughout this period all programming will be done on the IBM 370/165 computer using the TSO facility through VDU terminals within the NSF area. The availability of an IBM 370 RTL/2 compiler should help significantly to produce working code directly on the 370. However steps should be taken to provide, as early as possible, direct on-line facilities to an NSF minicomputer development system. This should be capable of loading directly into the minicomputer memory, programs written in RTL/2 or assembler language and processed on the 370.

8. EFFICIENT USE OF ELECTRONICS EFFORT

8.1 Introduction

The amount of time required to provide moderate quantity production of any electronic equipment is not just a function of basic design time. Frustrating delays may be caused during the assembly and commissioning stages, because the designer failed to take proper advantage of production techniques, to simplify assembly, or has not organised circuitry into functional sub-assemblies that would facilitate testing by lesser-skilled personnel.

The responsibility for most efficient use of all resources, needed to provide reliable production hardware on time, ultimately lies with the designer. He must therefore appreciate the production and commissioning problems when designing equipment (this also includes the mechanical aspects of the design), asking specialist advice where applicable.

8.2 Electronic Design

To achieve uniformity in more complex design work, micro-program type techniques will be used as far as possible. Not only will this simplify the design work in many cases, compared with random logic, but it will facilitate commissioning and documentation in that circuit operation can be easily understood by reference to a truth table. As an additional bonus most prototype design errors may be corrected at the commissioning stage by a change of the micro-program.

The general approach to design work with micro-program type technology permits the efficient use of functional sub-assemblies in the design, which will assist in commissioning and maintenance.

Similar advantages may be obtained by applying the same philosophy for the construction of analogue sub-assemblies that will be used in the distributed multiplex system.

8.3 Production Considerations

The equipment designer must design out "skill" in the production or assembly process, if potential problems are to be eliminated.

In general the following guidelines will apply.

1) Worst case component design tolerances will always be used in design.

2) Designs will eliminate the need for any adjusting devices (such as potentiometers) if possible.

3) Printed circuit connectors of 0.15" pitch in preference to 0.1" pitch will be used as far as possible for increased reliability, and to allow an increase in tolerances for PCB manufacture.

4) Where applicable printed circuit interconnection techniques will be used, for reliable, simple and low cost assembly.

5) Circuit designs will incorporate standard ranges of integrated circuits and components, to ensure the availability of alternative sources of supply.

6) Metalwork for electronic systems will be made from proprietary parts where possible.

8.4 Prototype Equipment

It is essential to produce prototype equipment as quickly as possible.

Wire wrap techniques will be used, for digital integrated circuits, along with "hard wired" printed circuit earth plane boards for combined analogue and digital circuitry. It is however intended to provide all production equipment in printed circuit form.

8.5 Commissioning

The majority of commissioning work will be on the distributed multiplex system electronics, which will include the light link system for the stack.

A d.c. and a.c. test will be given to all integrated circuits following an elevated temperature test. The d.c. test is particularly applicable in detecting some TTL fault conditions that usually appear as an intermittant fault (the worst kind), on operational equipment.

Such tests can be made by non-skilled personnel, on an accept and reject basis, using a small computer system and CAMAC to control the operation of the test rig. The saving in commissioning times and the improvement in long term reliability of the electronic systems will justify a 100% test, which will take approximately 10 seconds per device; allowing for component insertion and extraction time.

Following assembly of cards or sub-modules these units will be tested by semi-skilled personnel on an accept and reject basis, utilising a test rig driven by a small computer via CAMAC. Due to the component screening prior to assembly, any rejects at this stage would suggest a production problem, and would have to be immediately investigated by an engineer.

After the acceptance of individual cards, complete systems will be assembled and tested, again with the aid of a small computer system. At this stage in the acceptance testing an engineer will be responsible for the tests as trouble-shooting at this point will require technical knowledge. Following the commissioning of the complete system an elevated temperature test of 70°C ambient will be conducted, again "on line" to see if there are any further component "drop outs".

Most of the CAMAC equipment used in the control system will be of commercial design and manufacture. It is therefore unlikely to have been subject to the same rigorous testing of components, when compared with the multiplex system.

Although the CAMAC equipment will not be used inside the pressure vessel it is essential to ensure a high standard of reliability in all areas of the control system. Unless there is a problem with the distortion of the printed circuit board when heated (which may cause mechanical damage to an integrated circuit) elevated temperature tests will be made, with a final functional test at 70°C ambient.

8.6 Maintenance

Maintenance will be by replacement. Features will be designed into equipment to enable rapid identification of a faulty card. This will then be returned to the commissioning rig, where the faulty sub-assembly will be identified and replaced. The card will then go through the rest of the acceptance procedure before being accepted as an operational spare.

Operational spares including CAMAC, multiplex system parts and a minicomputer will be kept in the computer control maintenance area. This "spares" system will be powered continually to ensure that spare equipment is functional prior to it being required for the replacement of a faulty unit.

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APPENDIX A

Prototype Colour Display System

Prior to the availability of low cost minicomputers most major control systems still utilise conventional indication methods. This usually involved lamps, meters and push buttons, that were positioned on a custom made mimic diagram in the control centre, to assist an operator in determining the state of the plant. Any modifications to the plant meant that the mimic diagram had to be modified which caused a considerable upheaval in the control centre, with a corresponding loss of operating time.

A modern computer based control system may be used to give considerably improved mimic displays on closed circuit TV monitors. Numerous control diagrams can then be called by an operator for display. Modifications to the plant only require software changes to alter control centre displays, software which may be developed and tested prior to the plant being modified. This can result in less down time, and no hardware changes in the control centre.

Displays which are only in one colour tend to lead to operator fatigue, particularly if full advantage was to be made of the system, by presenting on screen information in high density.

The use of a colour display overcomes these problems and assists the operator to assimilate the information presented.

The prototype colour display has many possible applications in process control, power distribution and communications fields, as a monitoring or interactive display device.

Basic Format

A simplified block diagram of the colour display is shown in fig. A1.

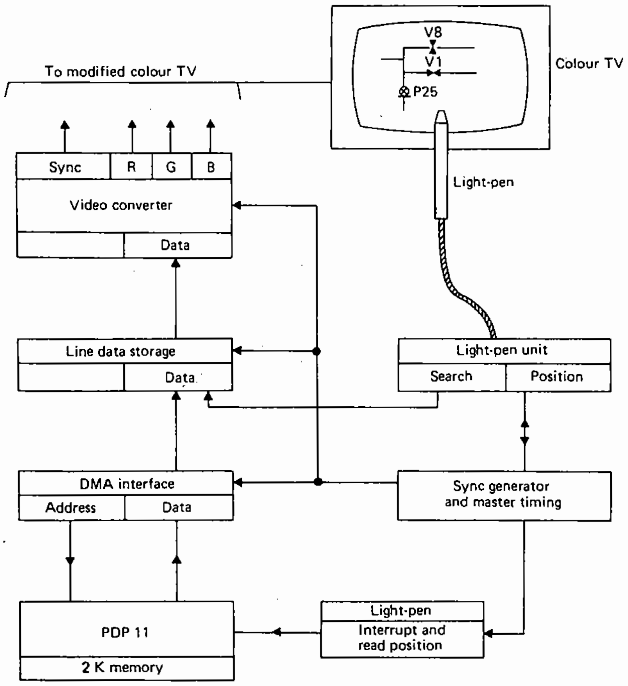


Fig. A1. Simplified system block diagram.

Referring to fig. A2 the picture viewed on the TV screen may be considered as a page of text having 32 lines (0 to 31) of symbols, with 64 symbols (0 to 63) to a line. Each symbol position on the screen has a unique location in computer memory; the top left would be location 0, top right location 63 and the end of the page, bottom right, would be location 2047.

The Bit pattern stored in one location is interpreted by the colour display generator as symbol shape and colour information for the location of a unique image on the TV screen.

A symbol-sized area is 7 elements horizontally by 9 rows vertically. An alphanumeric character only uses 5 elements by 7 rows, the rest of the symbol-sized area forming the space between one alphanumeric character and another. A symbol may use all of the 9-by-7 matrix, and placing the appropriate symbols adjacent to one another makes possible the drawing of flow diagrams (see fig. A2).

Some typical symbols are shown in fig. A3. In the prototype up to 192 symbols and 64 alphanumeric characters may be available, with 8 different colours for symbol foreground or background.

Operation of Colour Display Generator

The master timing (fig. A1) generator produces a sync. signal for the TV timebase and sets up computer DMA requests to locations in computer memory corresponding to the position on the screen.

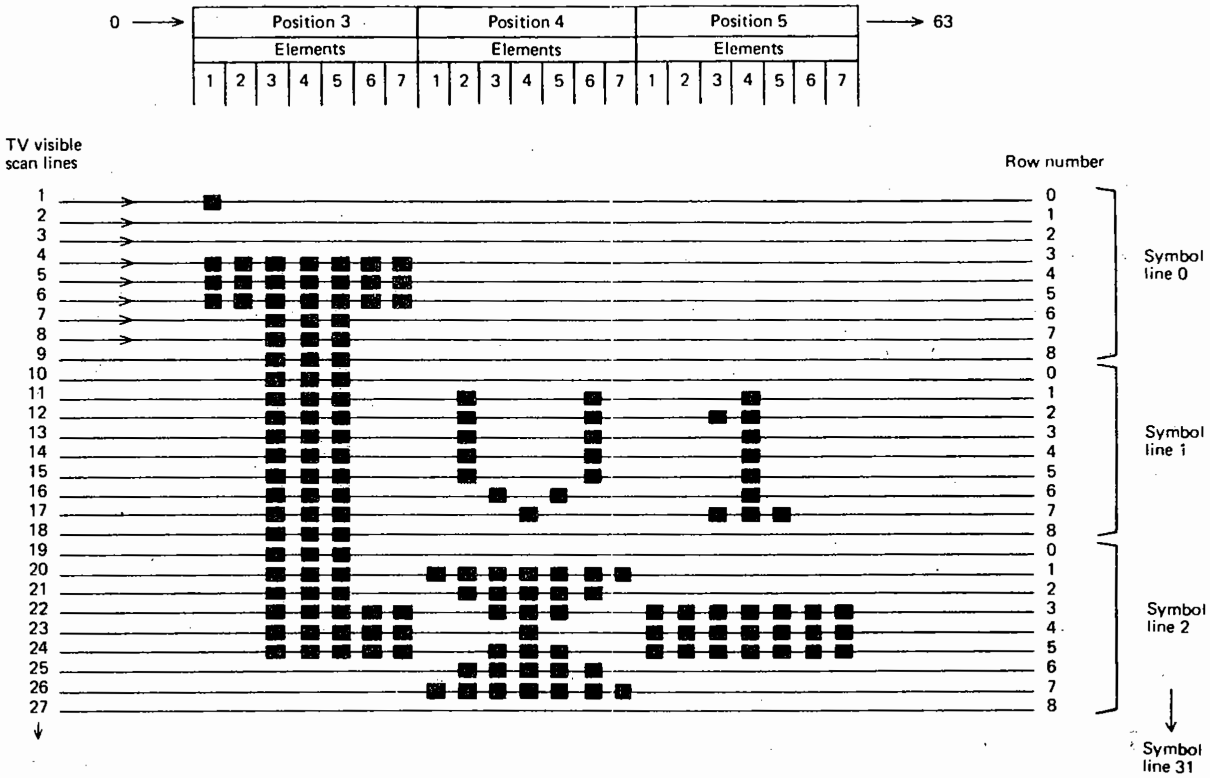
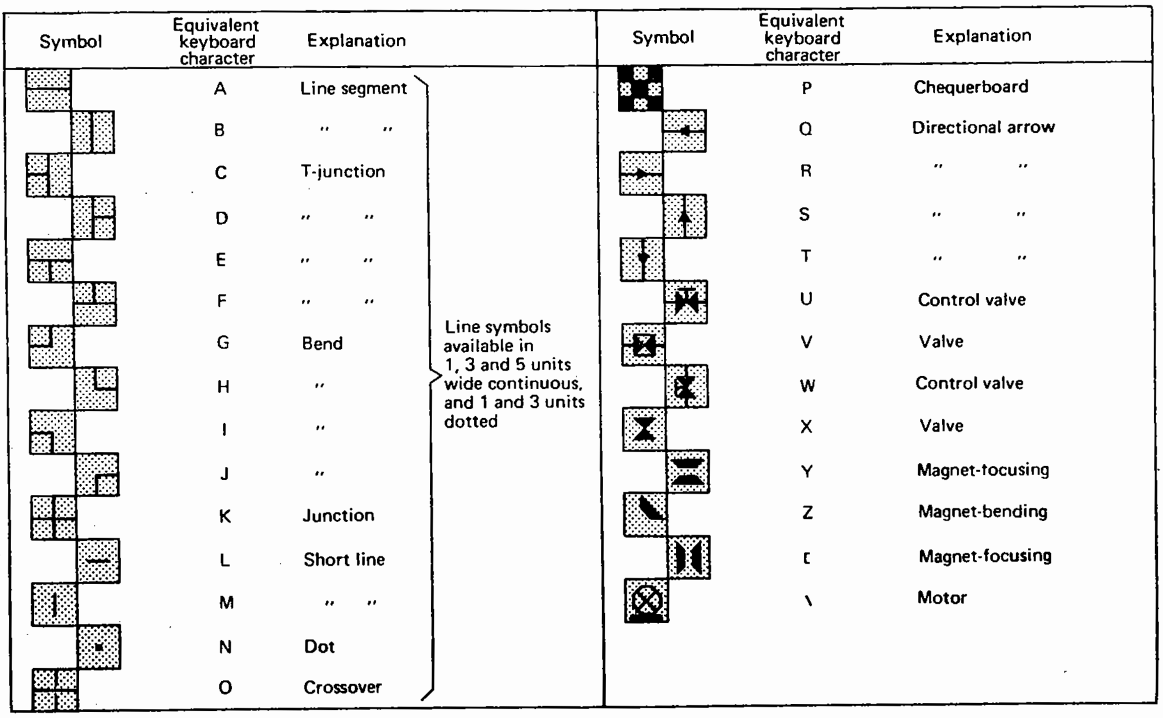


Fig. A2. Scanning of symbols.



Symbol	Equivalent keyboard character	Explanation		Symbol	Equivalent keyboard character	Explanation
	A	Line segment	Line symbols available in 1, 3 and 5 units wide continuous, and 1 and 3 units dotted		P	Chequerboard
	B	" "			Q	Directional arrow
	C	T-junction			R	" "
	D	" "			S	" "
	E	" "			T	" "
	F	" "			U	Control valve
	G	Bend			V	Valve
	H	"			W	Control valve
	I	"			X	Valve
	J	"			Y	Magnet-focusing
	K	Junction			Z	Magnet-bending
	L	Short line			[	Magnet-focusing
	M	" "			\	Motor
	N	Dot				
	O	Crossover				

Fig. A3. Typical symbols.

Data codes for a complete line of symbols are held in a single line circulating store and circulated 9 times (9 rows to a symbol). These codes pass in sequence to the video converter, where an electrically programmable read-only memory draws the symbol corresponding to the data code.

The light-pen is of high sensitivity and has a rise time of 100 ns to enable the fast-moving CRT spot to trigger an effective position on screen of a symbol being "picked" by the pen.

The Computer

The display is directly supported from the minicomputer, stealing processor time for refreshing the picture from memory. As this operation utilises DMA, therefore no timing co-ordination is required in PDP 11 programs, and data is just deposited in the display memory area to appear on screen. Having this effective random access to the display store permits rapid dynamic modifications of the picture, making animated diagrams possible for showing flows, etc.

The low cost of the system and the visual impact of colour make it a particularly attractive means of displaying control information in computer-based control systems. There are already indications that this technique will find many applications in the next few years.

APPENDIX B

Data Storage Requirements in the Minicomputer System

The minicomputer system with the highest number of measurement and control points is that handling the gas and water plant and services. In this case the numbers of each type of point are approximately

460	measurement monitoring points
100	measurement monitoring and control points
1490	status monitoring points
270	status monitoring and set points

It is estimated from programs written for the pilot machine that the number of 16 Bit words of information required to perform a simple check of each point of each type are

measurement monitoring points	6
measurement monitoring and control points	7
status monitoring points	3 for every 16 points
status monitoring and set points	5 for every 16 points

The total number of words of information involved is thus:-

measurement monitoring points	2760
measurement monitoring and control points	700
status monitoring points	280
status monitoring and control points	85
Total	3825

For most points the scanning rates required are such that transmission of the data periodically as required down the data link, or under fault conditions from floppy disc is possible. Even so to keep these transfers to a minimum approximately half of the above figure (2k) as a core requirement would seem reasonable.

The worst case core requirements will be met when the system is required to operate in the stand alone mode. An estimate of core load under these conditions taken from work done on the pilot machine extrapolated to try to anticipate the effects of the final software being more generalised and written in a high level language, RTL/2 gives

executive	3 k
RTL/2 control routine + maths package	2 k
scanning routine	0.3 k
limit checking routine	0.3 k
error analysis and message generation	1 k
operator command handling	1 k
display driver	1 k
disc driver	0.5 k
parameter tables	2 k
current display data	2 k
Total	13.1 k

Thus assuming main memory to be available as is usual in 4k word modules a memory size of 16k words is proposed.