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SECTION 9
CONTROL SYSTEM

The control system for the Nimrod machine is now almost completed with the installation entering its final stages. Almost all items of equipment have already operated under local control conditions and some large sections of the plant, such as the injector, have been remotely controlled from the main control room.

The control system embraces all the main items of plant such as the magnet and its power supply, the injector, the vacuum system, the radio-frequency accelerating cavity and its power supply, and the cooling plant, and integrates them into a common functioning machine, adding such interlocking and sequencing as may be required for personnel and equipment protection.

This report will take as examples for more complete description, the control aspects of the injector, vacuum system, coolant temperature and flow monitoring, personnel and safety interlocking and the main control room, these items being representative of the complete control system.

9.1. Injector.

9.1.1. Introduction.

Since the injector may be regarded as a linear accelerator which is complete in itself and is required to operate as such, especially in the early commissioning stages of Nimrod, it was necessary to design the control system so that it could either operate independently or be integrated at will into the main Nimrod control system. With this end in view, a local control room was provided and all control functions on the injector may be carried out from this position. When required the essential control functions can be extended to the main control room by the operation of changeover switches. The injector local control room can remain manned during the operation of the injector alone but when high energy beams are achieved in the synchroton, the injector will need to be remotely controlled from the main control room.

Figs. 9.1.1(i) and 9.1.1(ii) show the layout and current appearance of the injector control room, which is situated in the injector hall adjacent to the H.T. platform and d.c. gun. Fig. 9.1.1(iii) shows a simplified block schematic of the injector control system.

The injector first operated successfully under local control in August 1961.

9.1.2. E.H.T. Supply, E.H.T. Platform and D.C. Gun.

A 600 kV d.c. supply is produced by an electrostatic generator. This supply feeds the d.c. gun which accelerates protons from the pulsed ion source into the linear accelerator. Since all the equipment associated with the ion source is at +600 kV with respect to earth, all control signals must be suitably isolated and accordingly compressed air is used to convey control signals through polythene tubes to the platform. Ion source trigger signals pass via light guides and photocells, and other control adjustments are carried out by reversible geared motor units with long insulated drive shafts. Electrical power to the equipment on the H.T. platform is provided by 115 V, 2000 c/s; 110 V, 50 c/s and 24 V d.c. generators mounted with their control equipment on the H.T. platform. The compressed air links provide control signals for sequence interlocking and protection; other controls comprise E.H.T. voltage level, d.c. gun operating parameters and monitoring.

9.1.3. R.F. Drive.

More than 1 MW of r.f. power, at a frequency of 115 Mc/s and a pulse length of 2.5 ms is available to provide the r.f. drive for the linear accelerator. This power is obtained from a large triode valve, either driven from a crystal oscillator or run as a self oscillator by feedback, coupled directly from the linear accelerator resonant cavity. A pulse modulator provides 30 kV pulses of 2.5 ms duration to the power triode via a pulse transformer and ignitron from a delay line accurately charged by a grid-controlled rectifier system. All aspects of r.f. valve and modulator operation are sequence controlled and interlocked to ensure correct operation, and full remote operating and monitoring facilities are available.

R.F. drive for the buncher and debuncher is obtained via pick-up loops from the linac. Monitoring and remote motorised control are provided for drive and phase adjustments.

9.1.4. Tuners and Tilters.

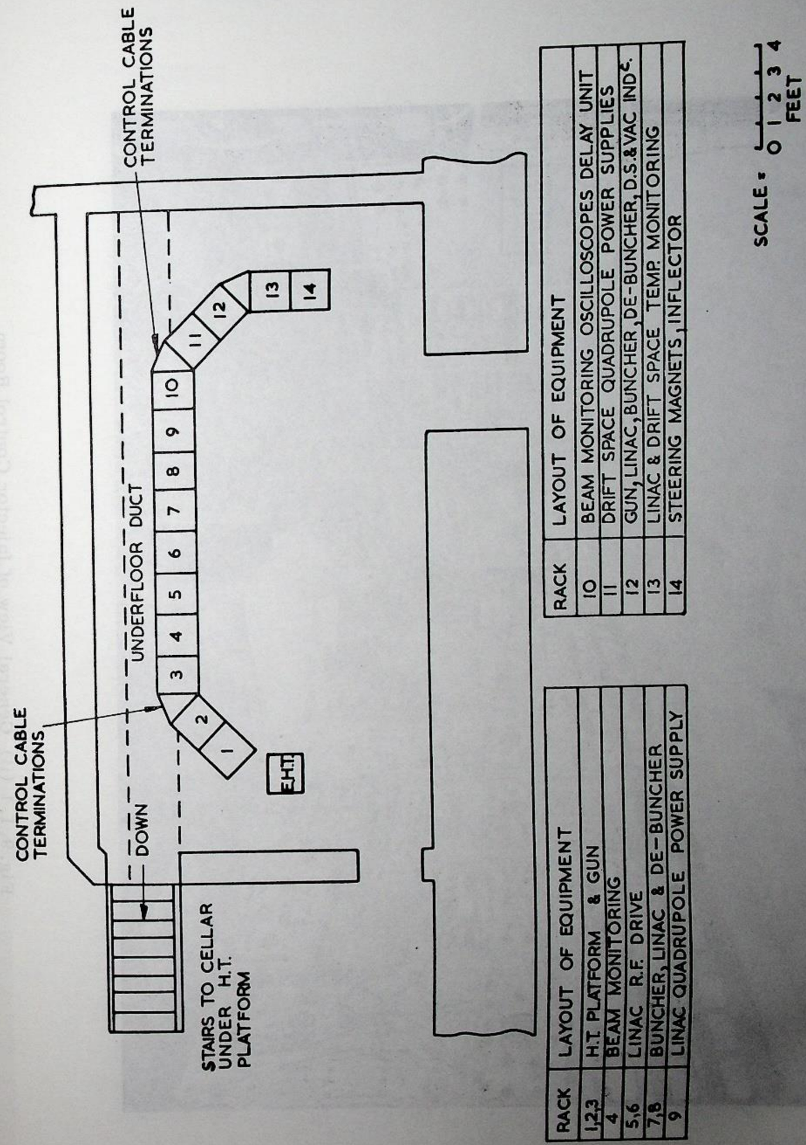
The buncher, linac and debuncher each form resonant cavities tuned to a frequency of 115 Mc/s. Sections of the r.f. liners of these vessels are arranged to incorporate flexibly mounted pads (tuners and tilters), movement of which modify the effective physical dimensions of the vessels and so the resonant frequency and the field configuration. In the case of the buncher this adjustment is made remotely by push button from the control room but for the linac and debuncher, motorised servo-controlled tuners are provided. Remote indication of pad movement, for both manual and servo tuners, is given by position indicators in the control room.

9.1.5. Quadrupoles and Steering Magnets.

The linac incorporates over 70 quadrupole focussing and beam steering magnets, the majority of which are water-cooled and contained within the vacuum space. The power requirements of these magnets varies according to their position and purpose, but in all cases the supply must be stabilised within close limits and the ripple voltage must be kept low. Voltage or current stabilisation via electronic regulators is employed for the control of the transductor-rectifier power units which vary in capacity from 2 kW to 150 kW. Fast response is attained in some cases by the use of flux-reset half-cycle transductor circuits, and stabilities vary from about ±0.5% in the case of the quadrupole magnets down to ±0.03% in the case of the inflector magnets. The voltage stabilised units employ precision potential dividers in the sensing circuits, while both shunts and d.c. current transformers have been used for the current stabilised power units. Most of the units incorporate some form of automatic current limiting or high speed short-circuit protection, and both selenium and silicon diodes are employed.

Where a number of magnets are grouped in series on to a common power unit, variable shunt resistor or transistorised networks are employed in conjunction with supply stabilisation in order to adjust the current in individual magnets.

Full remote control and monitoring of voltages and currents for the rectifier sets is available in the injector control room and main control room.



RACK	LAYOUT OF EQUIPMENT
1,2,3	H.T. PLATFORM & GUN
4	BEAM MONITORING
5,6	LINAC R.F. DRIVE
7,8	BUNCHER, LINAC & DE-BUNCHER
9	LINAC QUADRUPOLE POWER SUPPLY

RACK	LAYOUT OF EQUIPMENT
10	BEAM MONITORING OSCILLOSCOPES DELAY UNIT
11	DRIFT SPACE QUADRUPOLE POWER SUPPLIES
12	GUN, LINAC, BUNCHER, DE-BUNCHER, D.S.&VAC IND^c^.
13	LINAC & DRIFT SPACE TEMP. MONITORING
14	STEERING MAGNETS, INFLECTOR

Fig. 9.1.1 (i) Layout of Injector Control Room

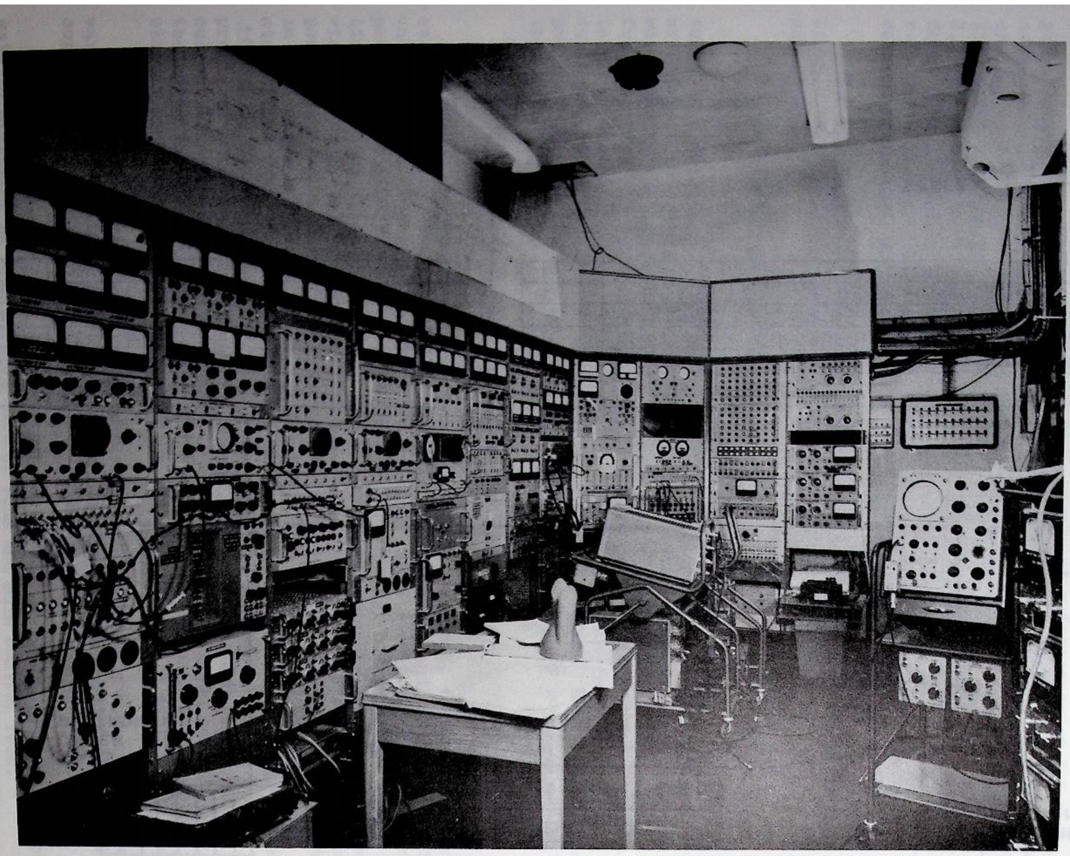


Fig. 9. 1. 1 (ii) General View of Injector Control Room

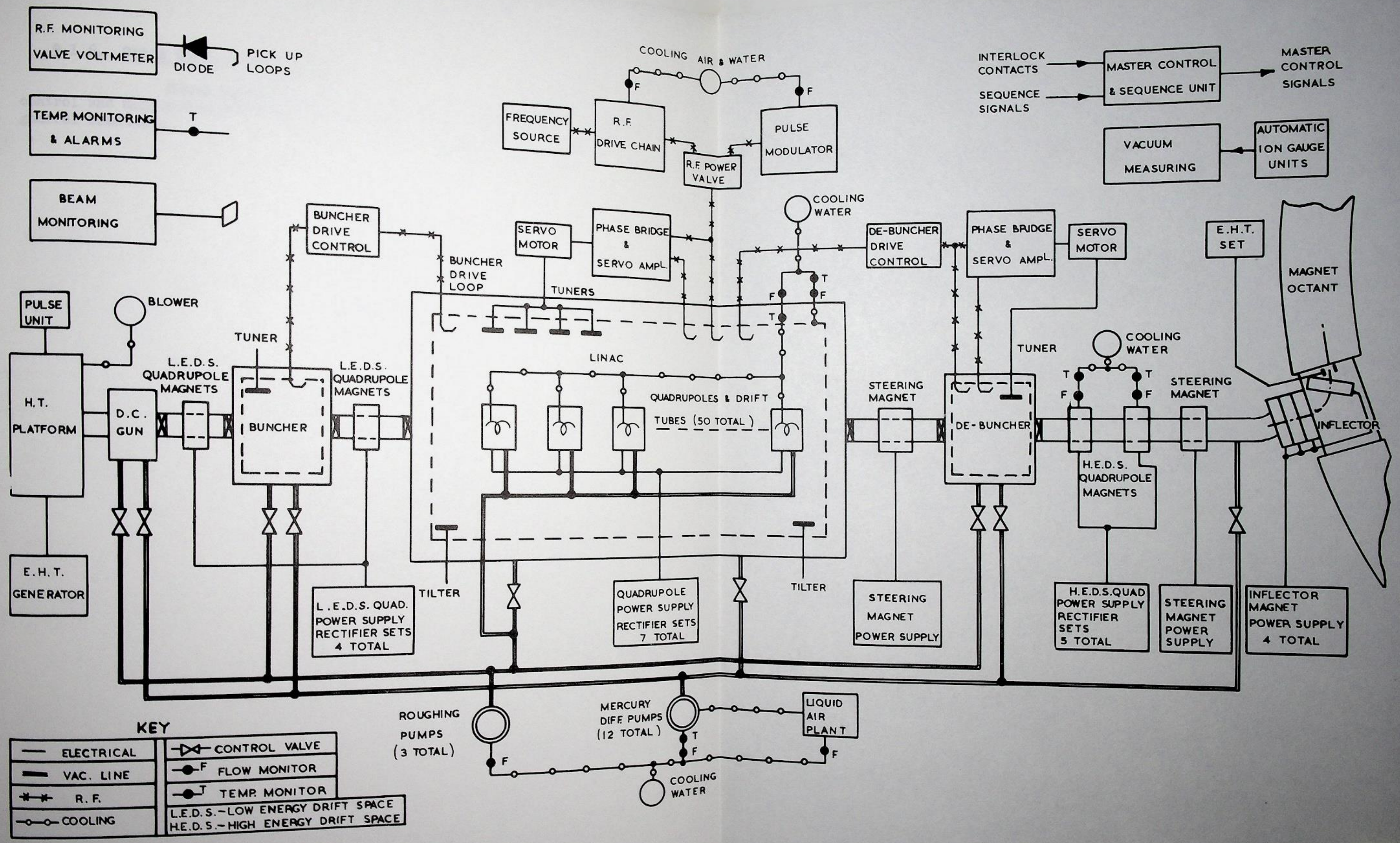


Fig. 9.1.1(iii) Block Diagram of Injector Control System.

9.1.6. Other Control Facilities.

Other facilities on the injector, such as vacuum, temperature control and monitoring and safety interlocking are dealt with below under these general headings.

9.2. Vacuum System

9.2.1. Introduction.

The Nimrod vacuum system is a large and important part of the machine. The vacuum pressure required for operation is approximately 10^{-6} torr and this has to be achieved over the length of the injector and throughout the synchrotron inner vacuum vessel (150 ft dia.).

9.2.2. Injector Vacuum Controls.

The system is initially roughed by three two-stage mechanical pumping units, each comprising a Kinney pump, a Roots pump and refrigerated oil traps. These pumps are automatically controlled and pump the 45 ft long linac vacuum vessel and the auxiliary vessels down to a pressure of 10^{-2} torr. Twelve mercury diffusion pumps, mostly of 9 in and 24 in type, provide the high vacuum pumping capacity. Each pump has its own local control cubicle, with sequence interlocking, protective features and vacuum monitoring, which is capable of completely automatic remote operation. Fig. 9.2.2(i) is a schematic of the type of control circuit used for all the Nimrod diffusion pumps, there being only slight variations between mercury and oil pump circuits. In all cases, the equipment is so arranged that under a pump fault condition the respective gate valve is closed automatically, the pump is shut down and the appropriate fault indication is exhibited. The pumps are fitted with refrigerated baffles and traps cooled by liquid air. The liquid air is produced by four air liquefiers adapted for semi-automatic operation. The liquid air is dispensed to the traps on the diffusion pumps, via a reservoir and vacuum insulated distribution main, on a time-controlled basis and further controlled by liquid air level-switches on the pumps.

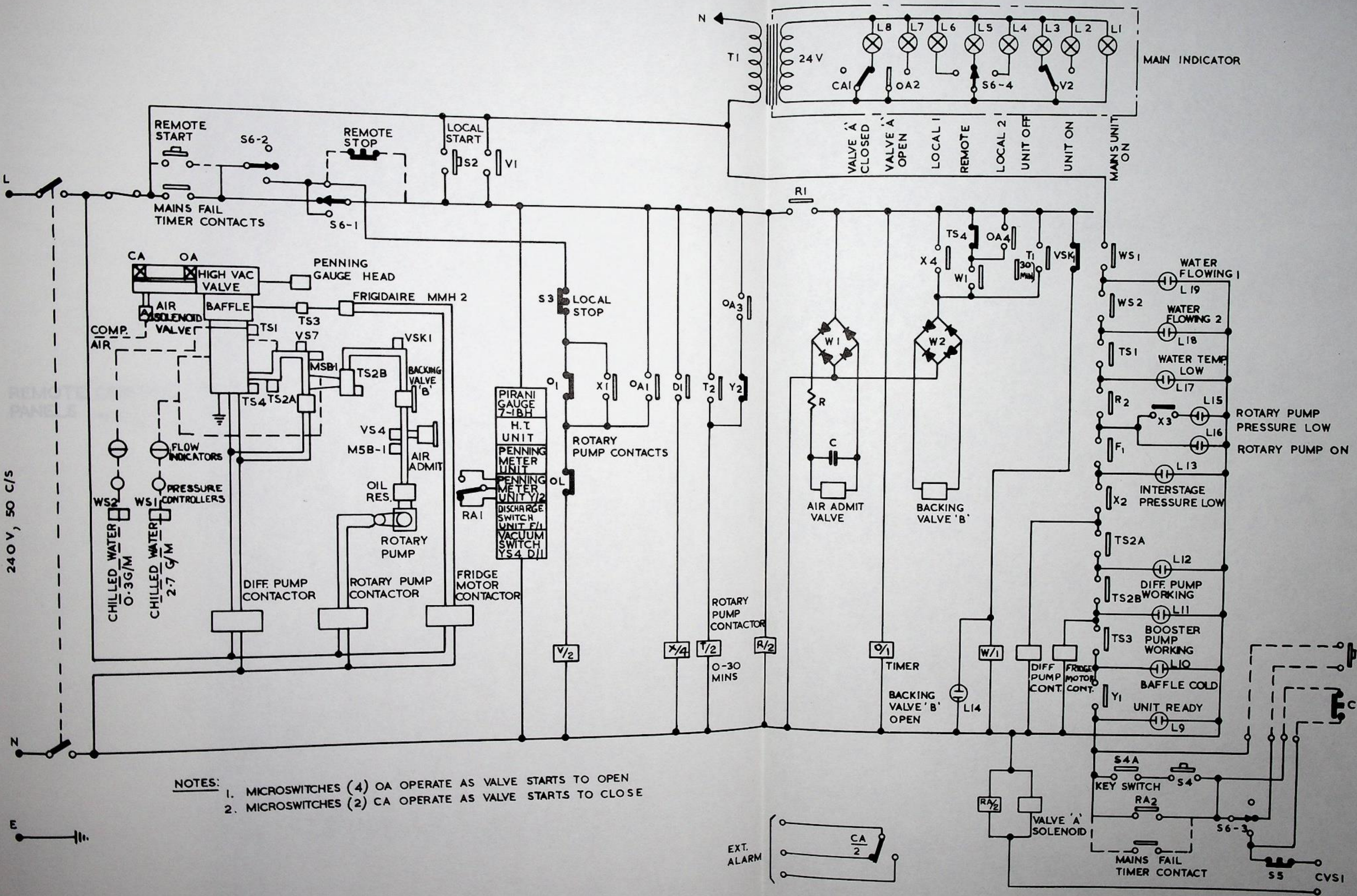
A combined "mimic diagram" and master control station in the injector room integrates the fifteen vacuum-pumping units, four air liquefiers, fifty solenoid-operated vacuum valves and numerous pressure switches into a single operational unit. This master control station indicates the status of the complete injector vacuum system at any time and gives control from a central position. Additionally, since both flexible and correct operation must be ensured, the entire system is selectively interlocked in such a way that only eventualities potentially detrimental to the prevailing operating conditions are prevented and a rigid operational sequence is not imposed. This gives the required flexibility.

Finally the injector vacuum system is integrated into the main synchrotron vacuum system, and control is extended to the main control room. Isolation of the two vacuum systems under fault conditions is achieved by incorporating a high speed shut-off valve in the linac high energy drift space.

9.2.3. Main Vacuum Vessel Controls.

The Nimrod main vacuum vessel is of double-walled construction. The vacuum required in the vessels for normal operation is about 10^{-6} torr for the inner vessel and < 1 torr for the outer vessel. The maximum differential pressure permissible at any time between inner and outer vessel is 2 torr.

Five 24 in oil diffusion pumps per octant and two 12 in oil diffusion pumps per straight section (i.e. a total of 56 pumps) comprise the high vacuum pumping capacity for the inner vessel which is initially roughed by eight two-stage roughing pumps of similar type to those employed on the injector. The outer vessel



NOTES:
1. MICROSWITCHES (4) OA OPERATE AS VALVE STARTS TO OPEN
2. MICROSWITCHES (2) CA OPERATE AS VALVE STARTS TO CLOSE

Fig. 9.2.2(i) Schematic Circuit Diagram of 24 in. Oil Diffusion Pump Unit.

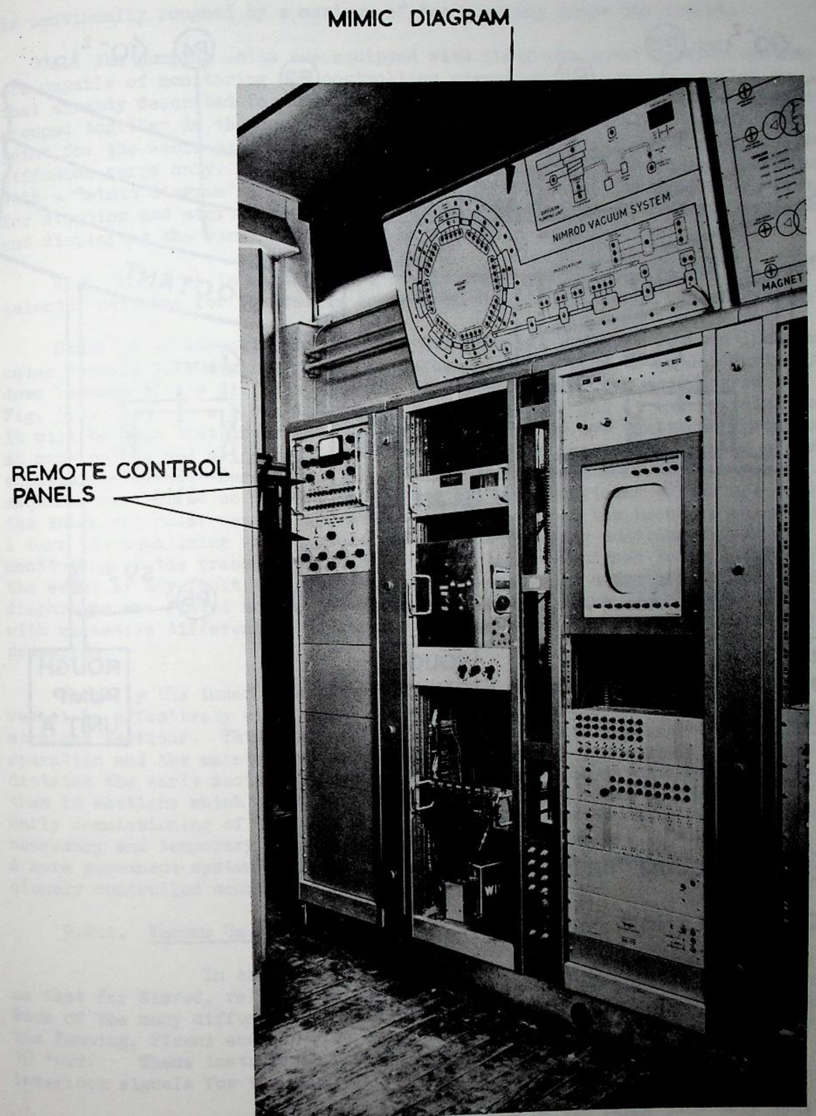


Fig. 9.2.3 (i) Vacuum System Mimic Diagram and Control Panels (in Main Control Room)

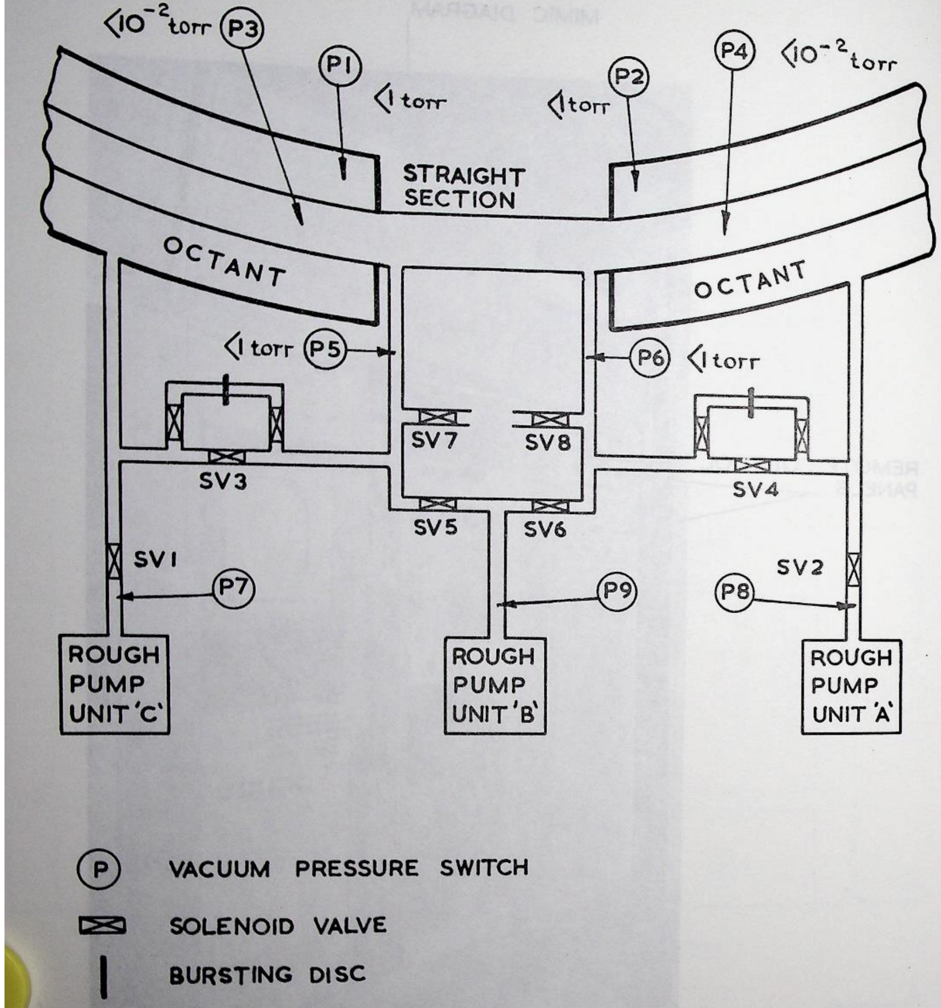


Fig. 9.2.3 (ii) Block Diagram of a Straight Section Interlock and Roughing System

is continually roughed by a maximum of two roughing pumps per octant.

All the pumping units are equipped with their own local control systems which are capable of monitoring and controlling operation in a manner similar to that already described for the injector pumps. These local controls are then grouped together in the magnet room to provide a single control and indicating point for the whole vacuum system. Finally, a minimum number of controls, for the diffusion pumps only, is taken back to the main control room where, in conjunction with a "mimic diagram" and associated selector switches, facilities are provided for stopping and starting any diffusion pump, opening or closing its gate valve, and displaying the working status of any selected pump in detail.

Fig. 9.2.3(i) is a photograph of the main control room "mimic diagram" and selector switches for the remote control of the entire Nimrod vacuum system.

Since it is essential to keep the differential pressure between inner and outer vessels to a minimum at all times considerable care is needed during pump down because of the different pumping speeds and impedances encountered. Fig. 9.2.3(ii) is a block diagram of the system employed at each straight section. It will be seen that inner and outer vessel pressures are continually monitored at many points and any excess differential pressure causes the opening of pressure equalising valves. During initial roughing the operation of the various valves is sequence controlled so that at this stage all the equalising valves are open and the inner and outer vessels are pumped together. When the pressure has reduced to 1 torr the equalising valves close and separate pumping continues under the monitoring of the pressure switches. The system is designed to fail-safe and in the event of any fault the equalising valves open. As a further safeguard bursting diaphragms are fitted across the equalising valves; these are designed to rupture with excessive differential pressure and so equalise the inner and outer vessel pressures.

Normally the inner vessel is a continuous vacuum space, while the outer vessel is effectively eight separate vessels since there is no double wall at the straight sections. This has involved considerable interlocking to ensure safe operation and the maintenance of minimum differential pressures at all times: it also dictated the early decision to operate the system as an integrated whole, rather than in sections which could be out-of-step in a vacuum sense. However, for the early commissioning of the vacuum system, single-octant working has been found necessary and temporary modifications have been carried out to achieve this. A more permanent system to permit sections to be pumped separately under certain closely controlled conditions has been worked out.

9.2.4. Vacuum Gauges and Switches.

In order to ensure effective control of a vacuum system as large as that for Nimrod, reliable methods are required for measuring a range of pressures. Each of the many diffusion pumps is equipped with pressure gauges and switches of the Penning, Pirani and hot wire type, operating over the range 10^{-6} torr to 10 torr. These instruments provide local indication of pressure and also interlock signals for the control circuits of the pumps.

Approximately 100 vacuum switches operating in the range 10^{-2} torr to 1 torr are used for the monitoring of the pressure in various positions in the injector and main vessel. These switches, which are of thermistor-transistor type, have been specially developed for this work and are fully described in Section 8.

The units give local indication of pressure and incorporate a relay coming into operation at a fixed pressure. Since the head amplifiers and switching units are transistorised, they are installed in the cellars under the magnet room to minimise radiation effects.

Indication of high vacuum in the range 10^{-3} torr to 10^{-8} torr is provided by specially developed ion gauges. These provide local indications of vacuum over a wide series of ranges chosen by selector switches. A further position on these switches provides a logarithmic output covering the range 10^{-4} torr to 10^{-7} torr. The outputs from the ion gauges are applied to three multi-channel recorders remotely situated in the main control room, so providing a continuous record of the vacuum conditions in the various parts of the machine. A further single-point recorder capable of being switched to any of the ion gauges and fitted with a repeater slide-wire is used to provide vacuum measuring facilities in the main control room, both at the control rack and on the main desk.

Provision is made, at the racks in the main control room, for remote switching to a standby ion gauge head.

9.3. Cooling Plant, Temperature Monitoring and Flow Monitoring.

9.3.1. Introduction.

Nimrod has many components, such as magnets and power supplies, which dissipate large quantities of heat. In most cases this heat is removed, via a closed-circuit cooling water system, to the main cooling towers. Advantage has been taken of this water cooling to reduce physical dimensions to a minimum and to increase current densities in conductors to a practical maximum. These factors indicate that if a complete or even partial water flow failure occurs, dangerous increases in temperature would probably result, causing damage to insulation or resulting in unacceptable changes in the length of magnet conductors.

Some impression of the scale of the problem is conveyed by the fact that on the main synchrotron magnet and associated pole face windings alone there are respectively 672 and 512 separate parallel water circuits and the peak pulse power dissipated in the main windings is about 12 MW, with a mean dissipation of a quarter of this.

Continuous temperature monitoring together with water flow monitoring is employed to ensure the detection of faulty conditions.

9.3.2. Temperature Monitoring.

There are two types of temperature monitoring currently in operation on the Nimrod cooling systems. The first of these is of the simple thermostat type which is employed on individual water circuits, especially where these are scattered. A high degree of accuracy is not required and the alarm condition is for a change in temperature in one direction only. Many hundreds of thermostats are used in this way, e.g. each of the 68 diffusion pumps is fitted with at least 4 thermostats for monitoring the operating temperature of various parts of the pump. The thermostats are fitted with contacts which perform interlocking and/or alarm and indication duties. No actual measurement of temperature is possible with this system.

The second type is considerably more sophisticated and permits sequential monitoring of large numbers of points for both high and low deviations of temperature, alarm and/or trip indications and local and remote measurement of temperature as required. It is installed in two separate designs: the earlier was installed about 4 years ago for the injector, and the later was recently installed for the synchrotron magnet and pole face windings. Both designs employ thermistors as the temperature sensing element.

Thermistors are available in a wide range of physical shapes (discs, rods, pellets, beads, etc.) and a range of resistances varying from less than 10 Ω to 1000 M Ω. The permissible temperature range is about -60°C to +400°C (reduced for some types). They were chosen in preference to thermocouples or resistance thermometers because of overall advantages when cost, size, robustness and performance for the particular duty (e.g.long leads with the risk of pick-up, etc.) were considered.

The chief disadvantage of thermistors is the non-linear relationship between the resistance R_T and the absolute temperature T, this being of the form $R_T = a \exp (b/T)^T$ where a and b are constants. However circuits can be designed which minimise the effects of this non-linearity and this has been done.

In the case of the injector temperature monitoring system the thermistors, many of which are inside the vacuum space and specially encapsulated, are sequentially scanned by uniselectors, which place each thermistor in turn across a Wheatstone Bridge circuit where they are compared with a standard resistor. The bridge is initially balanced for nominal temperature and any deviations, either high or low, cause resistance changes in a thermistor, creating unbalance conditions in the bridge. The unbalance of the bridge is detected in this design by a sensitive moving coil relay. This system has worked well over a period of several years, and its performance is limited only by the operating speed of the moving coil relay and the acceptable cycling rate for the uniselectors. The present cycling rate is 1 point/2s which is about the maximum rate for the moving coil relay. This is thought to be a little too slow and work is in hand to redesign the error detector circuit. The thermistors are individually trimmed for variations in resistance due to manufacturing tolerance and differing lead lengths, and the system is capable of an accuracy of ± 0.5°C over the working range. Alarm and trip points operate at the nominal temperature ± 2°C or ± 5°C depending on the application. Fig. 9.3.2(i) is a photograph of this equipment.

The basic design used for the injector was reconsidered when the much larger systems required for the synchrotron magnet were being produced. The same basic thermistor sensing element was retained but the sequencing uniselectors were replaced by specially developed 100 way transistorised switching units. These switching units are completely static in nature and are driven by 10 way gas-tube counters of commercial design, and also provide indication (in the main control room) of the actual points being measured. This system is capable of an extremely high speed of operation (e.g. each 100 way unit could cycle, if required, at 2000 points/s) and is economical both in equipment cost and cabling. As with the previous scheme, facilities are provided for remote manual selection of thermistors and individual temperature measurement. During normal monitoring, any error signals detected by the bridges are fed to low-drift transistor amplifiers before operating alarm or trip relays. A cycling speed of 10 points/s has been adopted with sixteen 100 way units running in parallel, so that 1600 points can be completely surveyed every 10 s.

Owing to the large number of ways involved, it was decided to dispense with individual trimming for the thermistors, and accordingly types with a manufacturing tolerance of ± 2% on resistance were chosen, together with circuit values sufficiently high to swamp variations due to different lead lengths. This has resulted in a minimum of components and has considerably reduced the setting-up time required, without increasing the maximum error over the operating range to greater than ± 1°C. This error could be reduced to about ± 0.5°C if individual trimming of each point were added to the current design.

Figs. 9.3.2(ii), 9.3.2(iii) and 9.3.2(iv) show various elements of this transistorised version of the temperature monitoring system as applied to the synchrotron magnet and pole-face windings. It has been installed and is currently being commissioned. A report (NIRL/R/48) describes the system in greater detail.

9.3.3. Coolant Flow Monitoring.

In addition to temperature monitoring, continuous water flow monitoring is also carried out on all important circuits.

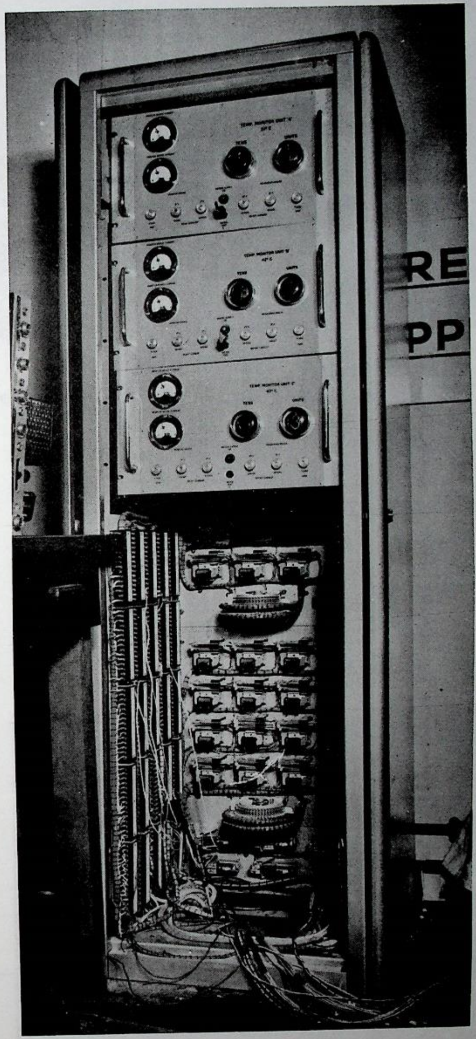


Fig. 9.3.2 (i) Temperature Monitoring Equipment for the Injector

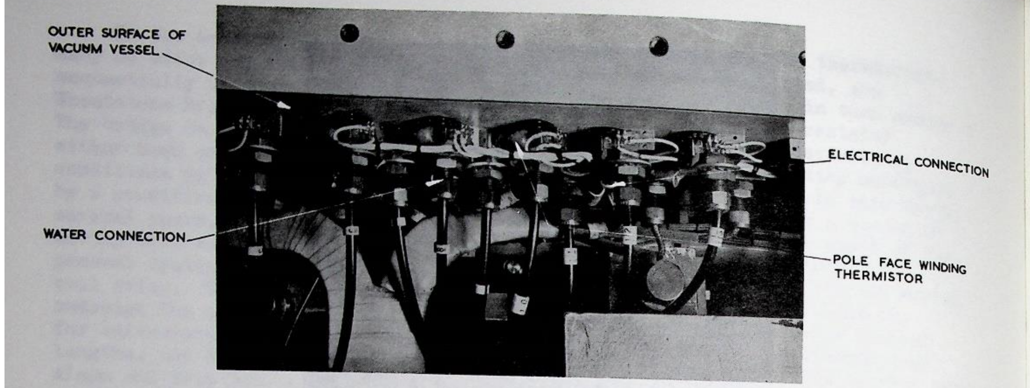


Fig. 9. 3. 2 (ii) Thermistors Mounted on Pole Face Winding Connections

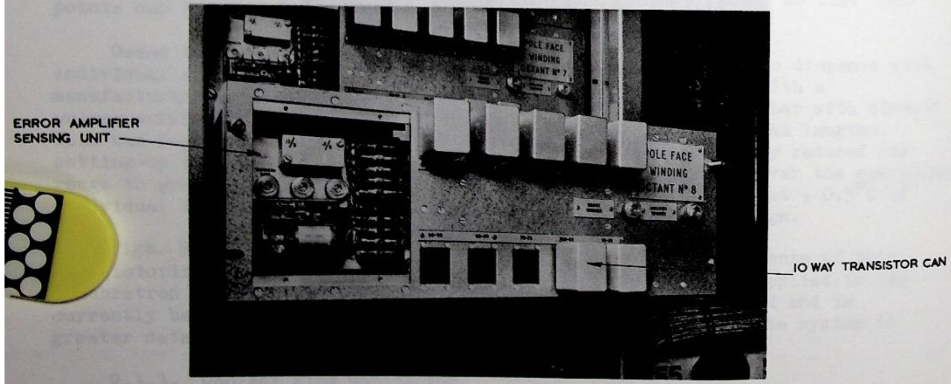


Fig. 9. 3. 2 (iii) Transistorised Gating and Error Sensing Equipment for 1600 Way High Speed Temperature Monitoring System

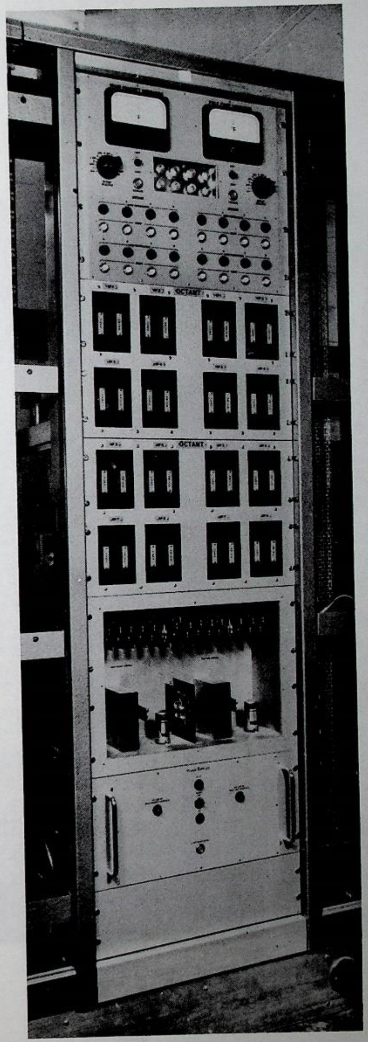


Fig. 9. 3. 2 (iv) Temperature Monitoring Control Panel (in Main Control Room)

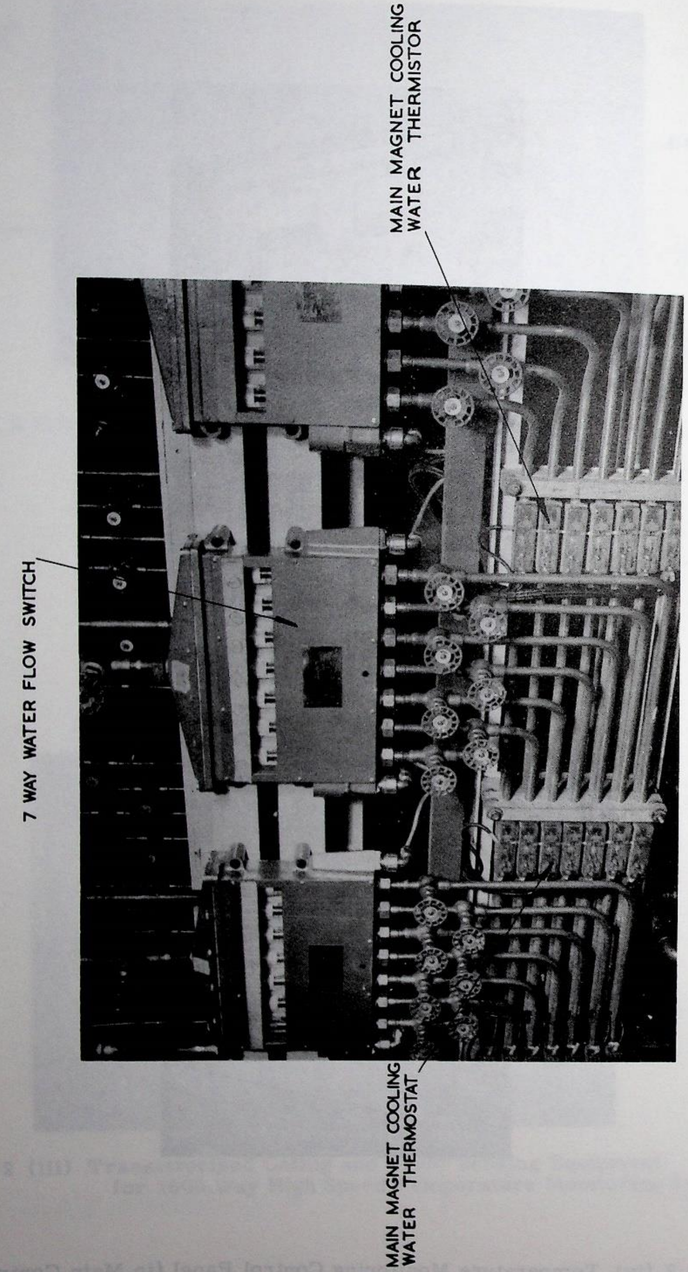


Fig. 9.3.3 (i) Seven-way Water Flow Monitor

Two main types of water flow relay have been used. The first of these, employed for the monitoring of single circuits, is of standard commercial design and is available in a wide range of flow rates. In this type a diaphragm communicates with the opposite sides of an orifice through which the cooling water flows. A reduction in flow causes the pressure differential across the orifice to fall and the diaphragm deflects, so operating a micro-switch.

A seven way flow switch, working on the stainless-steel float/tapered glass tube principle, has been especially developed for the magnet circuits, where large numbers of parallel water circuits are grouped together. The tapered part of the tube has flow graduations and the lower parallel portion of the tube corresponds to the trip setting. It is thus possible to match flows to accurate limits in adjacent conductors. Two different flow-rate settings are obtained by using floats of different weights.

Fig. 9.3.3(i) is a photograph of one of these units capable of monitoring seven flow circuits simultaneously. A flow rate above the set minimum raises the seven floats in the unit clear of a beam of light passing through all seven tapered glass tubes which are carrying the cooling water. The spacing of these tubes allows the light to refocus on adjacent tubes (i.e. each tube acts as a lens) thereby achieving maximum output from the cadmium sulphide photo-cell at the end of the unit. A number of such seven way units are grouped together in an alarm circuit. Water failure in one or more circuits causes a float to drop, so interrupting the beam of light in a unit and causing the alarm circuit to operate. Release of an alarm relay stops the magnet power supply pulsing and also raises an alarm and indication signal. This system has worked very reliably for about two years.

9.4. Main Control Room

Fig. 9.4(i) shows a layout of the main control room and Figs. 9.4(ii) and 9.4(iii) are photographs taken during construction.

The control equipment is housed in about 70 racks which are of standard type except for minor modifications to the design of the top covers which provide a 5 in wide interspace between the racks when they are butted together. All incoming multi-core control cables are terminated in these interspaces, and then looped into the actual control panels mounted in the racks. All terminations in the interspaces are of the crimped ferrule type and the control room floor is of hollow construction to permit the control cables to be fed from the cable trenches into the bottom of each rack. The control racks accept panels of standard 19 in G.P.O. type.

One of the main features of the Nimrod control system is the use of local control stations for almost every item of plant, with facilities for extension of control to the main control room. Thus nearly all plant can be run locally before being switched through to the main control room.

The main control room represents the focal point for operation of the machine and it is the only place where the operational status of all important parts of the machine are assembled and can be assimilated.

The quantity of information displayed is formidable since it is necessary to provide the operating staff with all the controls required to run the machine and adjust its important parameters, which in most cases must be done remotely since most of the machine is inaccessible during pulsing.

In order to assist staff to interpret the information displayed on the control panels, a number of "mimic diagrams" have been provided. These "mimic diagrams" are mounted on the top of the racks and display, by means of lamps, symbols and block diagrams, the state of various parts of the machine. In most cases these "mimic diagrams" operate in conjunction with an alarm annunciator equipment and take the place of the facia display units usually provided on these systems. In most cases the "mimics" are for display only but in the case of the vacuum system and personnel safety system the mimics form integral parts of the control equipment. "Mimics" have been completed for the vacuum system, the magnet and its power supply and the cooling water system. Others are to follow for the r.f. system, the personnel safety system, the extraction system and the beam handling system.

It is intended in the early commissioning stages of the machine to operate the necessary controls at the control racks and not to provide extensive facilities on the control desk. The framework of this desk has been installed, but only a minimum of controls, such as those for the public address system, are fitted. Further controls will be extended to the desk from the racks as dictated by operating experience.

RACK	LAYOUT OF EQUIPMENT
1	S.A.M.E.S. GUN AND H.T. PLATFORM
2 - 3	L.E.D.S. AND LINAC POWER SUPPLIES
4 - 7	MAGNET POLE FACE WINDINGS
8 - 10	DRIVE CHAIN, LINAC AND MASTER TIMER CONTROLS
11	BEAM MONITORING AND MEASURING
12	INFLECTOR AND H.E.D.S. POWER SUPPLIES
13	VACUUM MONITORING SYSTEM
14 - 15	BEAM MONITORING
16 - 17	MAGNET POWER SUPPLIES AND P.F.W'S.
18 - 19	R.F. POWER AMPLIFIER AND CAVITY
20 - 22	R.F. BEAM SERVO
23	SPARE
24 - 27	BEAM EXTRACTION AND TARGETS
28	SAFETY INTERLOCKS
29 - 31	HEALTH MONITORS
32	RECORDERS, HYDROGEN AND AIR CONDITIONING
33 - 43	BEAM TRANSPORT
44 - 50	P.F.G.
51 - 53	BEAM CONTROL
54 - 55	DATA LOGGING
56 - 57	GENERAL PURPOSE CO-AX SYSTEM
58	GENERAL PURPOSE MULTI - CORES
59 - 62	SPARE
63	L.V. SUPPLY
64 - 66	ALARM ANNUNCIATORS
67 - 69	TEMPERATURE AND FLOW ALARMS AND MONITORING
70	SPARE
A	PATCHING LEAD HOLDER
B	P.A.X. BATTERY AND CHARGER
C	DATA LOGGING CONTROL
D	MIMIC DIAGRAM

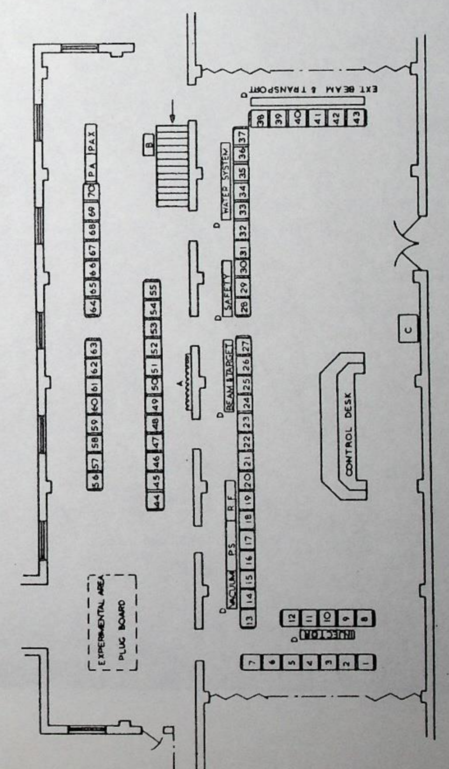


Fig. 9.4.(i) Layout of Main Control Room.

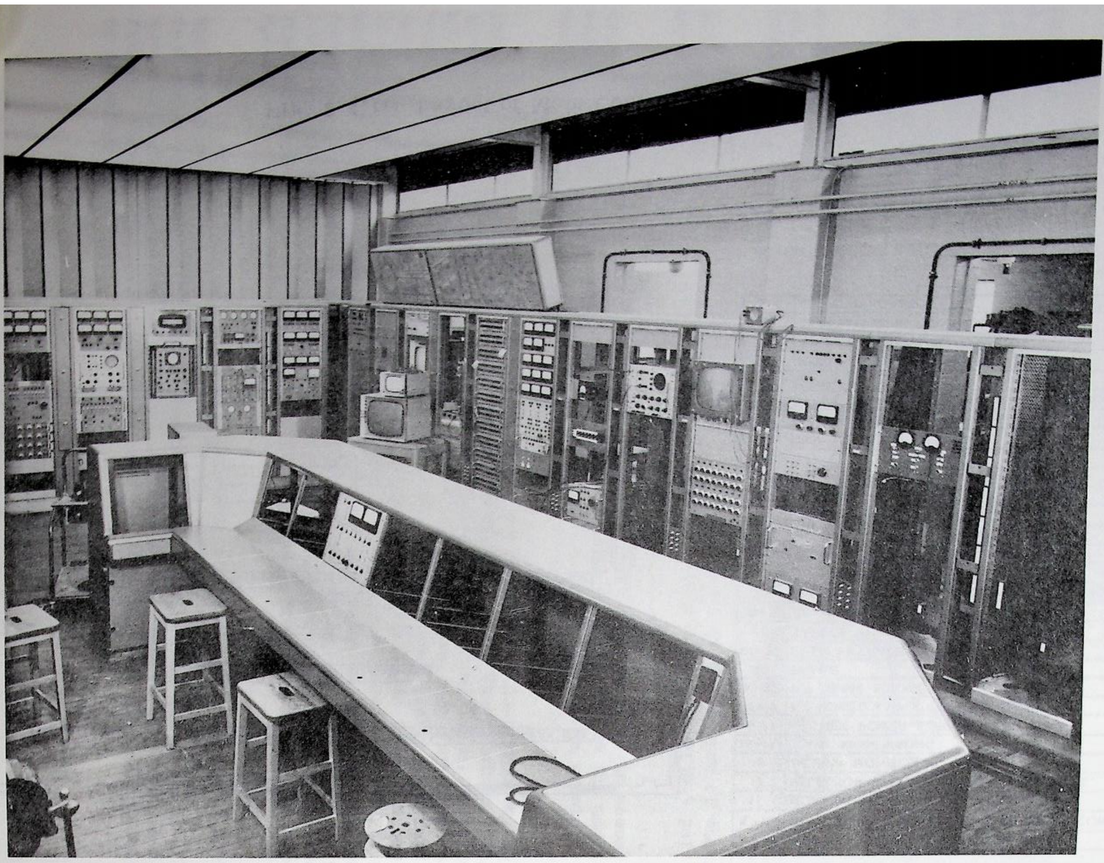


Fig. 9.4 (ii) General View of Main Control Room During Installation

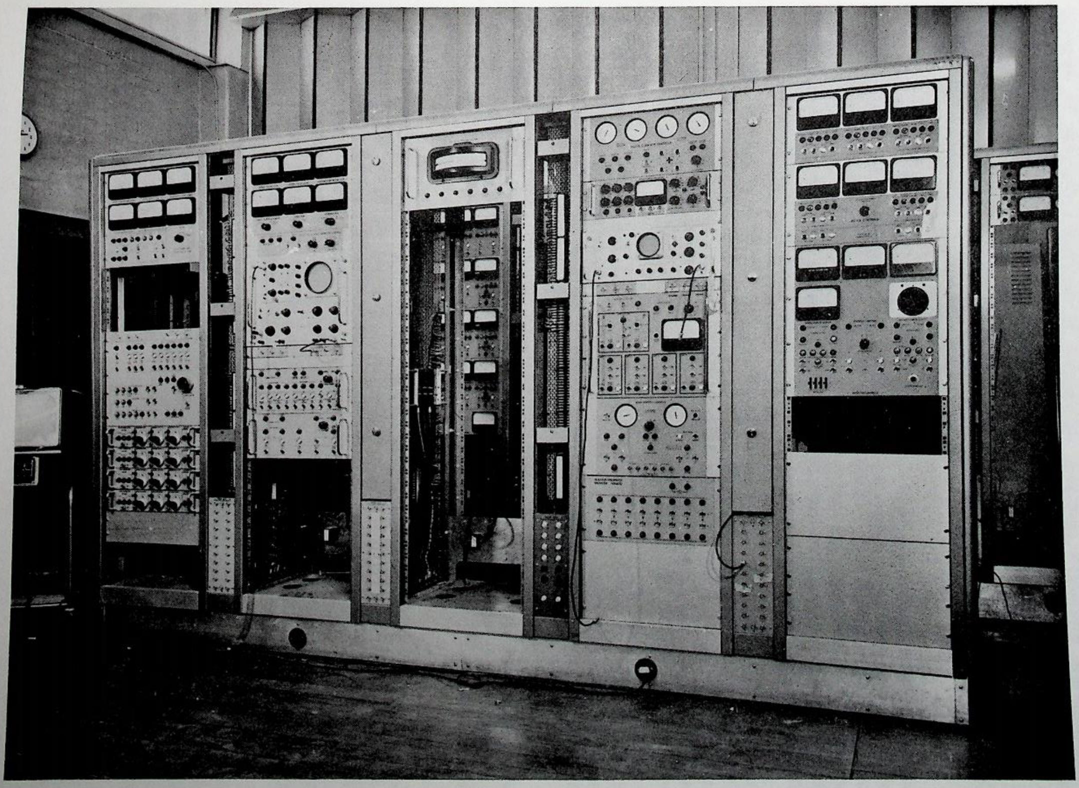


Fig. 9.4 (iii) Control Racks Installed in the Main Control Room

9.5. Personnel Control and Safety Interlocking.

When Nimrod is operating most of the machine and surrounding areas must be cleared of personnel because of radiation hazards; rigorous control procedures are required to ensure the necessary safety of staff and visitors. It is extremely difficult to devise a personnel control system which cannot fail under any combination of circumstances and yet still be sufficiently flexible to permit the effective commissioning and operation of the machine. All systems must rely to some extent on staff discipline and this is usually where the chief difficulties arise.

During the machine commissioning stages various temporary interlocking schemes have been employed. In the main these have been necessary to protect personnel in local areas, such as the injector room, where radiation and E.H.T. hazards have existed for several years prior to the completion of the magnet ring. These temporary systems have provided useful operating experience for the design of the permanent overall scheme, in addition to fulfilling their primary function.

The system chosen for the permanent personnel control installation will shortly be installed and it combines the simultaneous use of visual and audible warnings of impending machine operation with doors or barriers which are mechanically interlocked by a key system and electrically interlocked with door switches. Entrance is restricted by these systems but the doors are arranged so as to permit an easy exit at all times by any person trapped within an area. A closed-circuit television system covers certain of the access doors and large areas such as the magnet room so that temporary entrance to the machine by individuals and under closely controlled conditions can be permitted by the release of electric door locks remotely operated from the main control room.

The visual warnings are provided by a series of flashing indicators sited around the machine and associated with emergency beam-off push buttons, operation of any one of which stops machine pulsing. The level of lighting in the machine areas is also reduced (see below).

The audible warnings are provided by a public address system. The amplifier equipment for this is situated in the main control room and is operated from the main control desk. In addition to the normal public address facilities the system includes two tape machines for the transmission of repetitive pre-recorded warning announcements, four of which are normally available for selection. An oscillator produces three distinctive audible notes, any one of which may be selected for distribution over the loudspeaker network.

A possible way of using the facilities which are being provided is now described; the exact arrangement will be determined after experience in operating the machine. Machine start-up and running conditions are catered for in the interlocking and control procedure by four defined conditions or states of preparedness, namely: (a) Machine off (White), (b) Beam off (Green), (c) Beam temporarily off (Yellow), and (d) Beam on (Red).

In the "White" condition the machine is regarded as off for an extended period, certainly greater than 12 hours. During this period persons may enter at will, using a tally-board to indicate their presence.

In the "Green" condition the beam is off for a period exceeding half-an-hour but not exceeding 12 hours. Entrance to the area during this condition is normally restricted to authorised and semi-authorised persons only. Each person entering must take a key from a key-exchange box and return of all the keys is necessary before the machine can operate again. When the "Green" period is within half-an-hour of the beam-on time, audible warning announcements will be made using the pre-recorded tapes and people will be told to leave. After a further 5 minutes those persons still outstanding (i.e. according to tally or key) will be warned over the loudspeaker system by name. As soon as all the keys and tallies have been recalled the machine condition will change to "Yellow".

The "Yellow" condition denotes that the beam is off but expected to come on within half-an-hour. During this period a thorough search will be made of all relevant areas and loudspeaker announcements and audible warning notes will be transmitted at frequent intervals. Entrance to the machine will be limited to a few doors and any semi-authorised person entering must be accompanied by an authorised person. This reduced number of doors will be controlled remotely from the main control room. After all the checks of the areas are complete, final warnings to leave the areas are given, all keys are returned to the key exchange boxes and all interlocks are closed. A "one-minute" warning is given over the public address system, followed by an interrupted 1000 c/s note. Half the main lights are turned off and the machine condition changes to "Red".

The "Red" condition does not necessarily signify that a beam is actually being produced but that all conditions and interlocks are correct for the production of a beam. The red flashing lights around the machine occur for 1 minute before the machine can be switched on and any person left in the area under these conditions must immediately operate an "Emergency Off" push button.

The safety interlocking and radiation protection system for Nimrod is more fully described in a Nimrod Design Note (NDN/600/1).

SECTION 10

ANCILLARY PLANT

10.1 Introduction

The Nimrod ancillary plant provides the services of water and air for Nimrod. Many of the main components of Nimrod generate heat and require cooling, for example, the heat generated in the magnet is dissipated by cooling the conductor coils with water and by passing air between the magnet sectors to give forced convection. The cooling water must, of necessity, be of low electrical conductivity and, before use, the raw water from the mains is treated in a special plant to demineralise it and give it a low oxygen content. For most items of Nimrod equipment, the cooling water also needs to be temperature controlled; in some instances this involves the use of refrigeration plant. Where low electrical conductivity is not important, the water used for cooling purposes is only softened to reduce scaling.

The magnet room temperature is controlled to ensure that the magnet does not tilt beyond the acceptable limit due to differential temperature gradients across the foundation monolith. The relative humidity is also controlled to reduce electrical breakdown and to minimise condensation. This is effected by means of a large air conditioning plant employing refrigeration units and steam heaters.

Commissioning and development of much of this ancillary plant has of necessity proceeded in parallel with the commissioning of the main machine, rather than preceding it. One reason was because of the impracticability of simulating the heat loads put out by Nimrod and associated experimental equipment. The ancillary equipment is now functioning reasonably well, but a full knowledge of component plant capacities and reliabilities is not yet known.