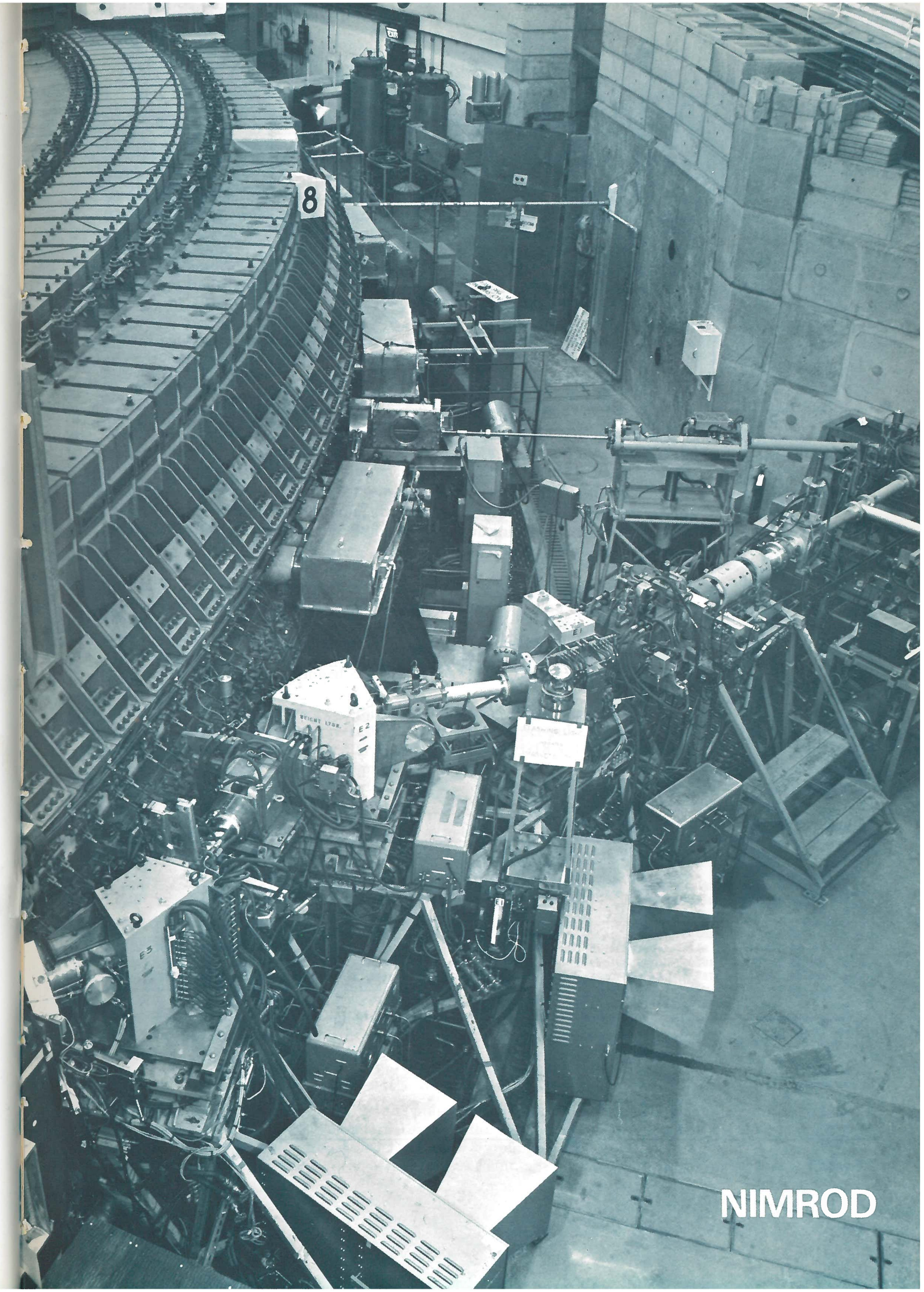
View of Nimrod Magnet Hall
showing the Inflector System used
to guide the protons from the
Linear Accelerator into the Synchrotron
Magnet Ring at the end of Octant 8.



Nimrod

OPERATION OF NIMROD 1970

During the period under review the beam intensity has been considerably increased, reaching a maximum of $3{\cdot}13 \times 10^{12}$ protons per pulse (average of 10 pulses), with an average beam intensity over the year of $2{\cdot}13 \times 10^{12}$ protons per pulse. This compares with an average beam intensity of $1{\cdot}66 \times 10^{12}$ protons per pulse in 1969. The total number of pulses with beam exceeded 6×10^{6}. Protons accelerated were $12{\cdot}88 \times 10^{18}$. This is another record and compares with $10{\cdot}45 \times 10^{18}$, in 1969.

Operation has continued in a three-week cycle, nominally 404 hours High Energy Physics research and 100 hours accelerator development and maintenance. The operating record is as follows:

Summary of Nimrod Operations for 1970 (Ref: 146, 147, 148, 149, 150)

HEP Research. Scheduled operating time 5297·64 hours. Good beam time 4708·01 hours. i.e. Beam on for 88·9% of HEP scheduled operating time. On the average there has been 4·4 experiments taking beam simultaneously during the year.

Accelerator Development. Scheduled operating time 1477·82 hours. Realised beam time 649·96 hours. Machine available time 996·59 hours. i.e. Machine availability 67·44% of scheduled operating time.

Nimrod is normally started up in the accelerator development period. This fact, together with the policy of switching repairs which can be postponed out of High Energy Physics research periods, is reflected in the somewhat lower availability of machine time in the scheduled accelerator development time compared with the High Energy Physics research figures. The operations record is detailed in the following table:

Table 14

Nimrod Operations January to December 1970.

Date From	To	Clock Time	Shut-down	Shed. Maint.	High Energy Physics Research: Shed. Beam Time	Beam On Total	Beam On EPB	Set-Up	*Exp. Off	Nimrod Off	Nimrod Avail.	Machine Physics and Development: Shed. Beam Time	Beam On	*Exp. Off	Nimrod Off	Nimrod Avail.
Jan 1	Mar 31	2160·00	600·00	132·73	1013·37	847·67	847·67	20·08	0·40	145·22	848·07	413·90	188·79	73·63	151·48	262·42
Apr 1	Jun 30	2184·00	89·85	141·95	1342·42	1195·50	1195·50	2·68	1·00	143·24	1196·50	609·78	238·53	220·31	150·94	458·84
Jul 1	Sep 30	2208·00	108·00	79·63	1718·40	1536·32	1529·80	7·23	2·10	172·75	1538·42	301·97	117·28	28·25	156·44	145·53
Oct 1	Dec 31	2208·00	783·50	48·88	1223·45	1128·52	1128·02		2·40	92·53	1130·92	152·17	105·36	24·44	22·37	129·80
Totals		8760·00	1581·35	403·19	5297·64	4708·01	4700·99	29·99	5·90	553·74	4713·91	1477·82	649·96	346·63	481·23	996·59
Percent Clock Time		100·00	18·05	4·60	60·48	53·74						16·87				
Percent HEP Scheduled Time					100·00	88·87		0·57	0·11	10·45	88·98					
Percent MP Scheduled Time												100·00				67·44

*Beam off at Experimenter's request.

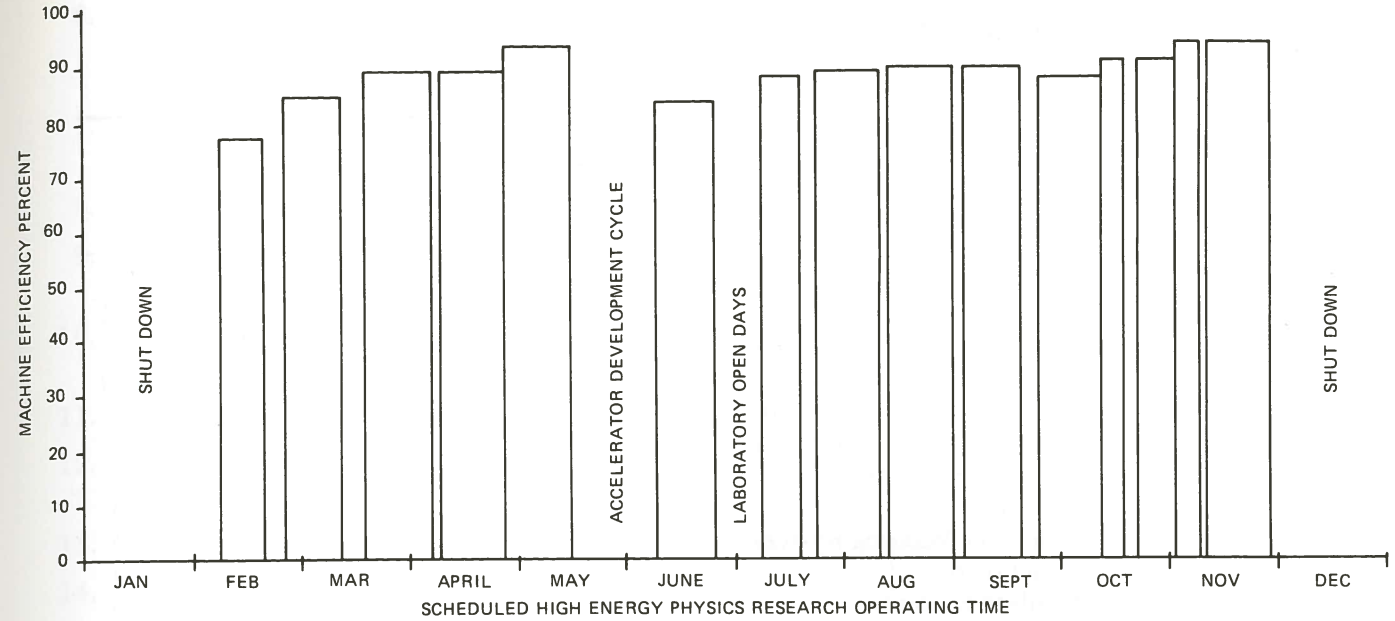


Figure 77. Nimrod operating efficiency during scheduled High Energy Physics research time. January to December 1970.

Out of a total scheduled beam time of 6,775 hours for Machine Physics plus HEP Research, beam was not available for 1,035 hours. The faults causing this loss have been categorised in Table 15. The machine efficiency during scheduled HEP research time has continued at a high level. This is summarised in figure 77.

Extracted proton beams were run throughout the year. Beam intensities measured at external targets have been a record with 10^{12} protons per pulse being measured in X2, which services secondary beams in Hall 1, and $1{\cdot}18 \times 10^{12}$ protons per pulse in X3 servicing secondary beams in Hall 3.

The general pattern of utilization is:—

1. X1/K9, the fast spill bubble chamber beam in Hall 1, has a share of every pulse.
2. Because X2 and X3 are mutually exclusive, one, (usually data-taking), has beam for four pulses out of five, with the other, (usually setting up), taking the remaining fifth pulse. In the main, this pattern is reversed on alternate cycles.
3. Scattered-out beams normally take beam every pulse, sharing being varied by the adjustment of target radii.

A new extraction system using a thin-septum magnet has been successfully tested for the X3 beam. This system gives an improved extraction efficiency of about 38% compared to 30% for the previous arrangement. Since early in June, the X3 beam has been extracted by this thin-septum energy-loss system during scheduled High Energy Physics research time, on a routine basis. It is planned to install a thin-septum magnet in the X1/X2 channel.

During the period January to August the pulse repetition rate was about 20 ppm. After the failure of No. 2 motor-alternator set of the Nimrod Magnet Power Plant in September, repetition rates varied between 9·6 ppm at 7 GeV to 22 ppm at 5 GeV using one half of the Nimrod Magnet Power Plant.

Table 15

The faults causing loss of beam time.

Fault Area	Lost Beam Time (hours)	% of Scheduled Op. Time	% of Nimrod Off Time
*Extraction Systems, Rotary Power Supplies	(88·48)	(1·31)	(8·55)
*Extraction Systems, excluding Rotary Power Supplies	(172·13)	(2·54)	(16·63)
*Extraction Systems, total	260·61	3·85	25·18
Nimrod Magnet Power Plant	166·30	2·45	16·07
*Vacuum Systems	91·89	1·36	8·88
Injector	90·86	1·34	8·78
Pole Face Winding Systems	63·47	0·94	6·13
Synchrotron r.f.	56·36	0·83	5·45
Coolant Systems	52·33	0·77	5·06
Targets and Target Mechanisms	39·43	0·58	3·81
Nimrod Magnet	8·19	0·12	0·79
Beam Control/Beam Spill Systems	5·51	0·08	0·53
Diagnostics	2·82	0·04	0·27
†Miscellaneous	46·41	0·69	4·48
Other Reasons			
Public Electricity Supply Mains Dips	22·65	0·33	2·19
Start-up	128·14	1·89	12·38
Totals	1034·97	15·27	100·00

* Includes routine inspection time.

† Miscellaneous includes such items as beam line elements, collimators and beam cut-offs inside the synchrotron hall, beam interlocks, wind and weather etc.

Shut-down December 1970-January 1971

A number of developments and installations are being undertaken in the scheduled annual shut-down, notably:

1. Replacement of the Mk 1 plunging mechanism with a Mk 2 system in Straight Section 2. This is associated with the X1/X2 extraction system.
2. Installation of a new shim magnet XHQ2/2 in the header vessel of Octant 3. This is in preparation for the change to a thin-septum energy-loss extraction system in the X1 beam line later in 1971. (Note that a corresponding magnet, XHQ2/3, is being manufactured for use with the X2 beam line).
3. Installation of a spare drive motor on the No. 1 motor-alternator set of the Nimrod Magnet Power Plant.
4. The re-installation of the repaired drive motor on the No. 2 motor-alternator set of the Nimrod Magnet Power Plant. (This motor failed on 1 September 1970).
5. Installation of a new solid pole motor and a new stator on the No. 2 motor-alternator set of the Nimrod Magnet Power Plant.

6. Installation of a spare Haefely EHT power supply for the pre-injector system. All components in the system with the exception of the rectifier stack will then be duplicated.
7. Commissioning of the No. 2 (stand-by) alternator system associated with the injector EHT platform.
8. Installation of a new debuncher ramper system.
9. The 250kW generator in the Magnet Hall has been re-positioned in order to allow installation of the new homopolar machine later in 1971.
10. A new target mechanism type 1c for the X1/X2 thin-septum extraction system has been installed in Octant 1.
11. Target mechanisms 5/14 and 4/21 have been removed.
12. The Mk 3 target mechanism in Octant 6, used for the π10 beam, is being re-positioned.
13. Target mechanism 3/21 in Octant 3 has been re-positioned slightly.
14. The water cooled cables associated with the 300kW rotary power supply in the chalk pits are being extended so that this power supply may be used to power other thin-septum magnets. At present it only supplies RX3, a magnet associated with the experimental X3 resonant extraction system.
15. The power supply which feeds XHQ2/1 has been removed from Catacomb 6 and re-installed in the chalk pits.
16. Installation of new undercarriage rails in Straight Sections 4 and 7.
17. Installation of a stiffened support structure on XHQ2/1.

NIMROD MACHINE SYSTEM

Plunging Mechanism Improvements (Ref: 117)

The Mk II electronic control system was added to the existing Mk I plunging mechanism in December 1969. This has produced smoother control resulting in reduced stress on the mechanical parts. Since this time, swash pump failures have been greatly reduced and control faults virtually eliminated and the operational life has been increased from one to approximately five months i.e. from 1×10^6 to 3×10^6 cycles. The increased reliability has allowed a reduction in the frequency of inspection and hence improved the scheduled beam-time efficiency.

External Target Mechanisms

Modifications have been carried out on external target mechanisms resulting in a more reliable unit. The target arms of internal target mechanisms, which are subject to bearing failure, are now changed after 2×10^6 flips, or after receiving 10^{18} protons, whichever occurs first.

Magnet Pole-piece Bolt Failure

In February 1970 a Nimrod main magnet pole piece bolt failure, diagnosed as fatigue failure, caused concern. A special strain measuring device was developed by the workshop and a programme of measuring strain on the 1344 pole piece bolts was implemented. This bulk of this programme was completed by the end of the year. Some bolts have been removed and inspected, but to date no further evidence of fatigue has been found. Some 200 bolts are not readily accessible for measurement. It is intended to devise means to complete the measurements during 1971, without resorting to the dismantling of major components of the synchrotron.

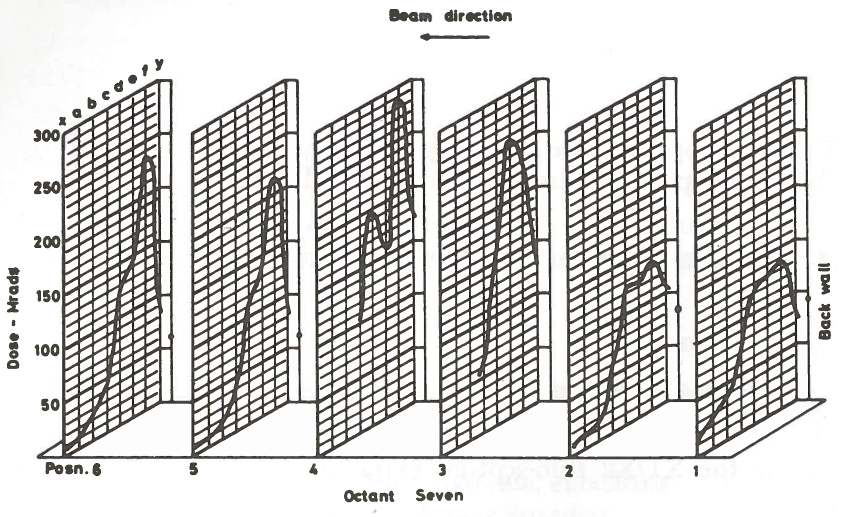


Figure 78. Radiation dose measurements for the inner vacuum vessel at Octant 7, A peak dosage of 290 Mrad was recorded.

Radiation Dosimetry

Radiation Dosimetry of the Nimrod vacuum vessels, beam lines and pressure bags has continued throughout the year.

The dose distribution does not appear to have changed significantly during this period and the regions of highest accumulated dose continue to be in Octants 1, 7 and 8. Figure 78 shows the dose distribution pattern for the inner vacuum vessel at Octant 7, where the peak dosage of 290 Mrad was recorded.

Resonant Extraction Tests

Resonant extraction tests, involving as they do much higher currents in the pole face windings, have highlighted radiation damage to the nylon tubes on pole face winding cooling pipes. Repair of these pipes was carried out at Straight Section 7 after modifications to the Straight Box support structure in order to allow access.

Nimrod Vacuum System

During the annual maintenance period this year, the injector vacuum system has been singled out for attention and, in particular, the liquid air system which supplies the diffusion pump traps. The liquid air system has been in continuous operation since 1964 since when it has produced over half a million litres of liquid air.

An investigation has been carried out with a view to increasing the reliability of the Nimrod synchrotron vacuum system. This has resulted in the development of a novel, all-metal, vacuum seal for the booster pumps to work at a temperature of 200°C. Although some improvement has resulted from changing the booster pump fluid from Arachlor to Apiezon G, further tests showed that an improved performance would result from a change to Apiezon 201, a recently developed fluid, and this has been done. Tests have shown that it is possible to run the Roots roughing pumps without refrigerated traps thus removing a particularly troublesome component.

NIMROD MAIN RING MAGNET POWER SUPPLIES AND ANCILLARY PLANT

The magnet has been pulsed for the greater part of the year using both motor-alternator flywheel sets and the complete convertor plant. However, at the beginning of September a failure occurred on No. 2 Drive Motor rotor and from then until the planned shutdown at the end of November the magnet was pulsed using half the power supply plant. The mercury-arc convertor plant has continued to operate reliably, the arc-back rate remaining very low at about one in every 435 hours of operation. Further progress has been made in the change over to the re-designed grid control gear and the static ripple filter has achieved an acceptable standard of reliability although further work remains to be done. The operational statistics for the year are as follows:—

Machine running time	$6{\cdot}4 \times 10^3$	hours
Machine pulsing time	$6{\cdot}1 \times 10^3$	hours
Total number of pulses	$6{\cdot}8 \times 10^6$	

No. 2 Drive Motor Failure.

The rotor of No. 2 Drive Motor failed at the beginning of September when an earth fault occurred immediately upon closing the stator circuit-breaker. Upon dismantling the machine it appeared that the origin of the fault was a breakdown of the insulation of a rotor bar in the region where the bar emerges from the core. This initial fault then seems to have involved a second rotor bar in a similar manner. A visual examination of the rotor showed a considerable amount of red dust, typical of the occurrence of fretting, in the region of one of the two composite keys which transmit the drive from the core to the shaft hub. That portion of the keyway which lies in the core laminations has been broached out to improve the profile and new oversize keys have been made. The rotor is being completely re-wound and will also be fitted with the new design of slip-ring and brush gear assembly produced for the new drive motor. Delivery is expected by the end of 1970. The stator suffered limited superficial damage and this has been repaired. Subsequently a whole series of tests, including loss angle and dielectric loss analysis, was carried out by the manufacturer in order to predict the life expectancy of the stator winding. The final report has not been received but degradation has occurred to a significant extent and consideration is at present being given to the interchange of the line and star point connections on the stator. This will reduce the stress levels on the most affected parts of the windings.

Operational Experience with the First Solid Pole Rotor

A solid pole rotor, acquired in 1969, is installed in No. 1 Alternator. During the 1969/70 shutdown, when the rotor was still within its guarantee period, a shorted turn was found to exist on No. 6 pole. The complete winding on this pole was removed and replaced by a spare, the faulty winding being repaired subsequently. During the dismantling of the bolted-on pole shoe assembly necessitated by this fault, it was found that virtually no slackening of the pole shoe retaining bolts had taken place and that the condition of the undersides of the pole caps and of the mating surface of the pole body was excellent. At this time the rotor had already performed about $4{\cdot}9 \times 10^6$ pulses. It has performed satisfactorily throughout the operational period this year.

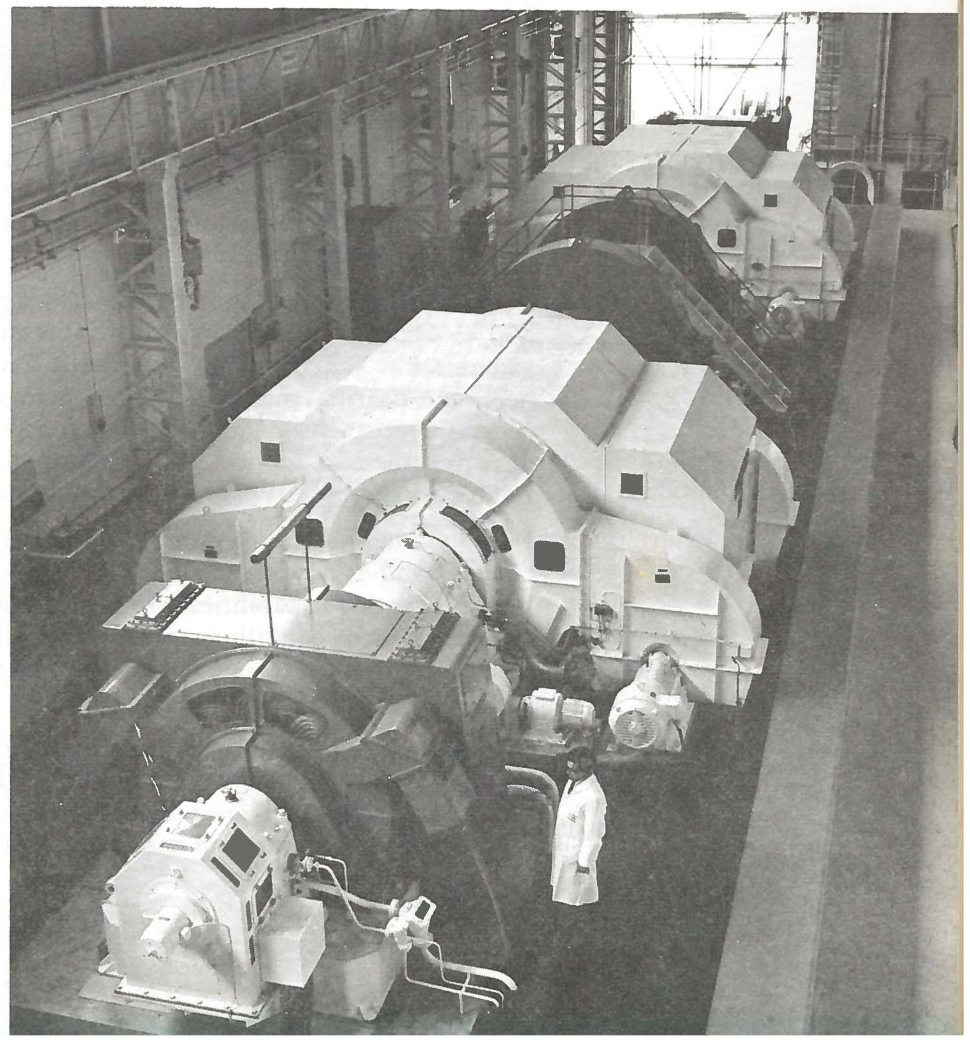


Figure 79. The two Motor Alternator sets which provide power for the Nimrod Magnet.

Spares for Magnet Power Supplies Rotating Plant

The new alternator stator, solid pole rotor and drive motor mentioned in the report for 1969 have been received. The two new flywheel assemblies are expected early in 1971. The new stator and rotor are being installed on No. 2 set and the new drive motor is to be fitted on No. 1 set. Tests will then be conducted to investigate the load sharing between the two alternators, each now with a solid pole rotor, when operating electrically paralleled but mechanically separate.

Electronic Analogue Wattmeters

Electronic Analogue Wattmeters will play an essential part in the tests referred to above. The wattmeter specification is now fully patented in the United Kingdom and provisionally so in the USA. The equipment was demonstrated at the 1970 Physics Exhibition, and several other organisations have also shown great interest.

Alternator Rotor Vee Coil Support Bolt Design

Fretting was found to exist between the bolt shank and its fibre-glass insulating sleeve as mentioned in the Report for 1969. It has now been confirmed by a series of investigations in a special test rig that the coating of the bolt shank with a 0·010 in layer of adiprene prior to the application of the fibre-glass appears to prevent damage from this cause. During early 1971 the opportunity will be taken to examine a limited number of Vee coil support bolts treated with adiprene which have seen one year's service in a rotor.

Drive Motor Rotor Resistors

A flashover occurred early in February on one phase of No. 1 Drive Motor fixed rotor resistor. This is believed to have been caused by contamination by airborn debris drawn in by the cooling fans. A spare unit for this phase was installed. The remaining units were cleaned, but only to a very limited extent owing to the very poor accessibility. It was decided that a complete new assembly of six units should be ordered and these are being installed during the 1970-71 shutdown. The units removed from service will be overhauled and kept as spares.

Mercury-Arc Rectifier Control System

Fifteen out of the sixteen operational grid control systems have been modified to permit access when the convertor plant is working.

Static Ripple Filter

A compressed air operated contactor has been developed and installed to replace the vacuum contactors which could not be made to operate consistently or reliably. Together with modifications to the protection circuitry, this has resulted in regular operation of the filter under normal pulsing conditions. Further development is proposed to improve the overall ripple reduction factor and the reliability of the installation.

Primary Ripple Filter

A prototype pre-amplifier of a new design has been operational on the A2 amplifier during the year and has been found to be much more trouble-free and consistent in performance than the originals. Two new pre-amplifiers have been constructed to this new design and are at present being installed.

Ancillary Plant

De-mineralised/Raw Water Heat Exchangers. The four heat exchangers for the No. 2 Magnet Circuit and the Experimental Area have been dismantled for examination and overhaul. The shells have been grit blasted to remove the old neoprene coating and then treated with epoxy resin paint. The tubes were in a generally satisfactory condition and after re-assembly and pressure testing the units were returned to service. A similar programme is to be carried out on the two Bubble Chamber heat exchangers during the 1970/71 shutdown.

Hall 3 Cooling Water System. The installation has been taken over from the contractors and is now in service. The loading so far has not been sufficient to test heat dissipating capabilities of the whole system and a load test, carried out under adverse ambient conditions, proved inconclusive. It is proposed that a further load test be carried out before the expiry of the guarantee period in June 1971 although the performance to date gives no cause for concern.

Instrumentation. A multi-channel alarm and annunciation system has been installed on the R4/R10 ancillary plant and it is planned to include the Hall 3 system at a later date. Indication is given in the alternator control room. A considerable amount of existing instrumentation has been overhauled and repaired.

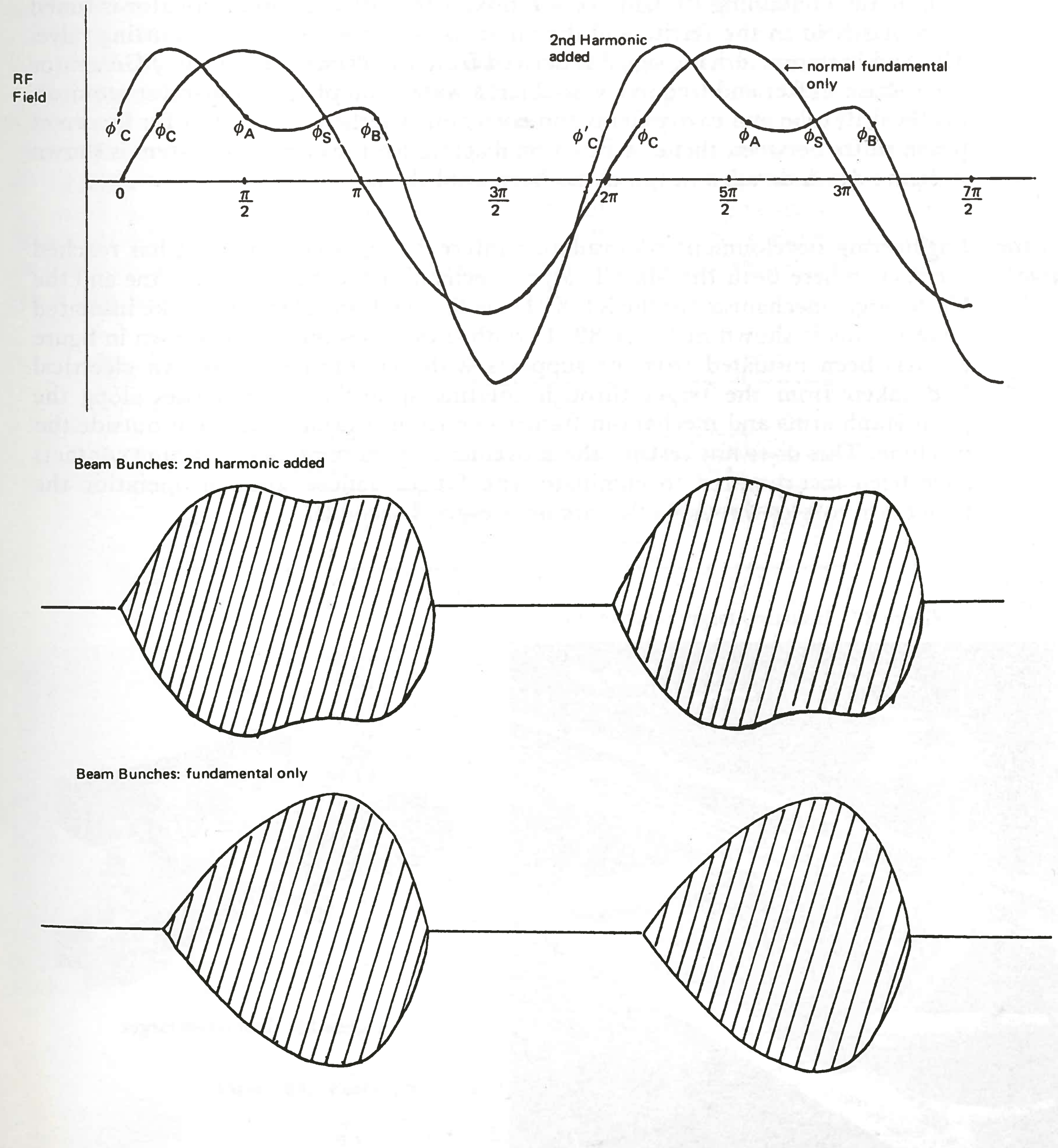
ACCELERATOR DEVELOPMENT

Proposal for a 2nd Harmonic R.F. Accelerating System

The present maximum working beam intensity in Nimrod is about 3×10^{12} protons per machine pulse. It has been confirmed that the limitation at this intensity is due to the space charge forces on the particles at the outside of the beam bunches. These forces are defocussing forces which counteract the focussing forces due to the magnet field gradient and, in the limit, lead to beam loss through radial and vertical betatron resonances. If the bunches could be lengthened and their maximum height reduced, more particles could be accommodated in them for the same space charge limit.

To examine this possibility, a design study was carried out assessing and costing the feasibility of installing an additional accelerating stage in Nimrod. Its function would be the addition of a 2nd harmonic r.f. field at eight times the orbital frequency. With such a field in the correct phase and amplitude the acceleration field is modified from its normal sinusoidal form to that shown in figure 80. The accelerated particles receive the same synchronous energy gain per turn but there are now two stable phase angles ϕ_A and ϕ_B and two unstable phase angles, ϕ'_C and ϕ_S, compared with the normal case where the synchronous energy gain occurs at ϕ_S (stable) and ϕ_C (unstable). The effect is to lengthen the phase stable area, and reduce its maximum height in the desired manner. An increase of 40% in beam intensity is possible.

Figure 80. Effect of 2nd harmonic r.f. accelerating field on beam bunches.



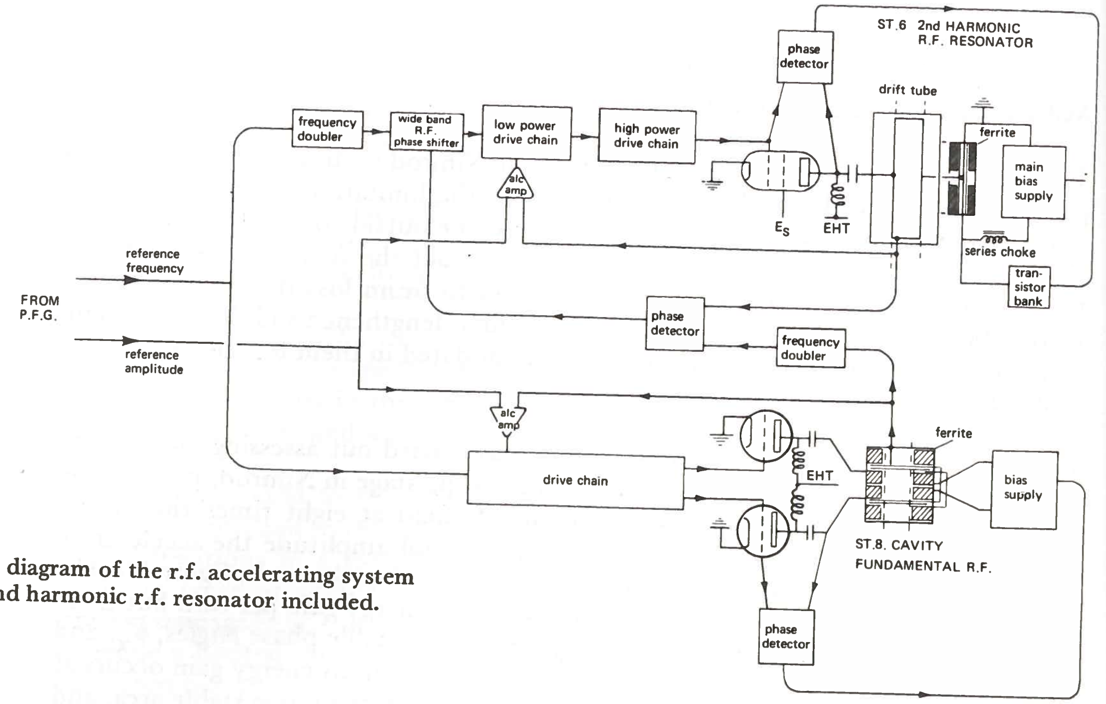


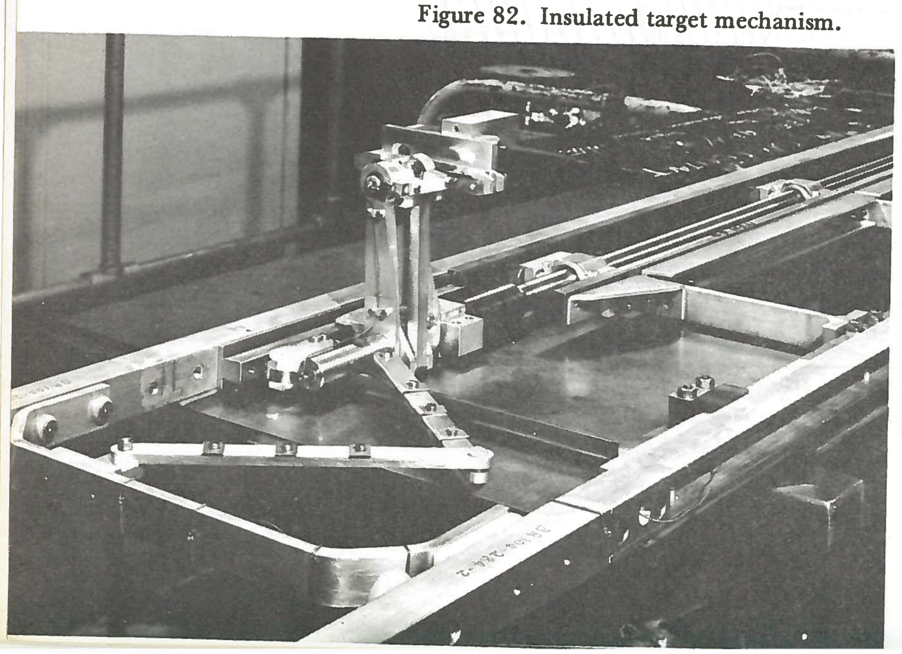
Figure 81. Function diagram of the r.f. accelerating system with the proposed 2nd harmonic r.f. resonator included.

Of the possibilities examined the most promising comprises a drift tube installed in Straight Section 6 tuned by a pair of ferrite-loaded resonators mounted on each side of the containing straight section box. The drift tube and resonator is tuned by a bias field in the ferrite and driven at r.f. by a high power transmitting valve. The 2nd harmonic driving signal is derived from the Primary Frequency Generator via a phase shifter and frequency doubler, a wide band phase comparator monitoring the drift tube and cavity fields and correcting via the phase shifter for incorrect phase shifts between them. A function diagram for the complete system is shown in figure 81. A detailed proposal has been published.

Target Mechanisms for Insulated Targets

Engineering development on insulating internal targets continues. It has reached the stage where both the Mk III target mechanism for the π10 beam line and the Mk Ic target mechanism for the X1/X2 beam line has been adapted to take insulated targets. This is shown in figure 82. In both these cases the target, shown in figure 83, has been insulated from its supports with ceramic insulators. An electrical lead taken from the target through rotating sprung contacts passes along the pantograph arms and mechanism framework to measuring equipment outside the machine. This does not restrict the movement of the target. The sprung contacts have been incorporated to eliminate wire fatigue failure since in operation the target arm rotates through a 90° arc once every 3 seconds.

Figure 82. Insulated target mechanism.



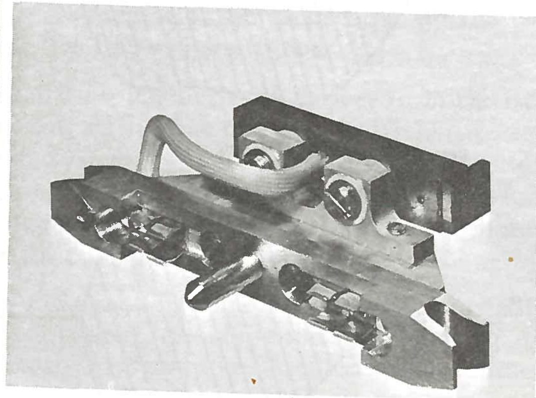


Figure 83. Insulated target

The circulating beam on hitting the insulated target induces a current which is measured and calibrated to indicate the proportion of proton beam taken by the target. The insulated target can also be used as a beam monitor. This design of insulated target with monitoring will be fitted to all internal target installations in Nimrod as time permits.

Time Structure Analyser of Synchrotron Beams

The measurement of time intervals in the sub-microsecond region is often necessary in nuclear physics experiments. In a typical measurement the first event detected triggers a time to amplitude converter, TAC, with a second event stopping the converter. The output of the converter, a pulse or d.c. level, proportional to the time interval measured is stored in a pulse height analyser.

This same technique is used in beam diagnostics when studying the time interval distribution or "structure" of a beam of particles. Beam intensity may be measured by means of counting secondary events, e.g. scintillations produced by secondary particles on a target monitor, with a TAC being used as above. This method is necessarily slow as after each measurement the TAC must be reset and the analogue placed in store before the next measurement can commence. Even in the fastest systems several microseconds may be lost between measurements.

This disadvantage is overcome in the instrument described below in which time measurement is a continuous process and the necessary time lapses for storage and resetting are catered for by employing a trio of binary counters, only one of which is in the read mode at any one instant. The arrangement is shown in figure 84. It is based on a three stage shift register or ring counter, ABC, and a 100 MHz oscillator. The pulses derived from the scintillation counter are fed to the clock line of the shift register, moving a previously loaded logic 1 from stage to stage as each pulse arrives. Each stage controls an AND gate steering the 100 MHz oscillator into one of the binary counters. When counter A is operating, counter C is being read and counter B is being reset. In this way no time is lost between pulses and all consecutive time intervals are measured and stored in the analyser. An integrating store is employed in the counter read-out circuits. Each binary number is then decoded and stored as a unit of charge in one of 256 capacitors. Each capacitor, termed a 'bin', stores the number of time intervals occurring within its range; each bin width is 10 nanoseconds.

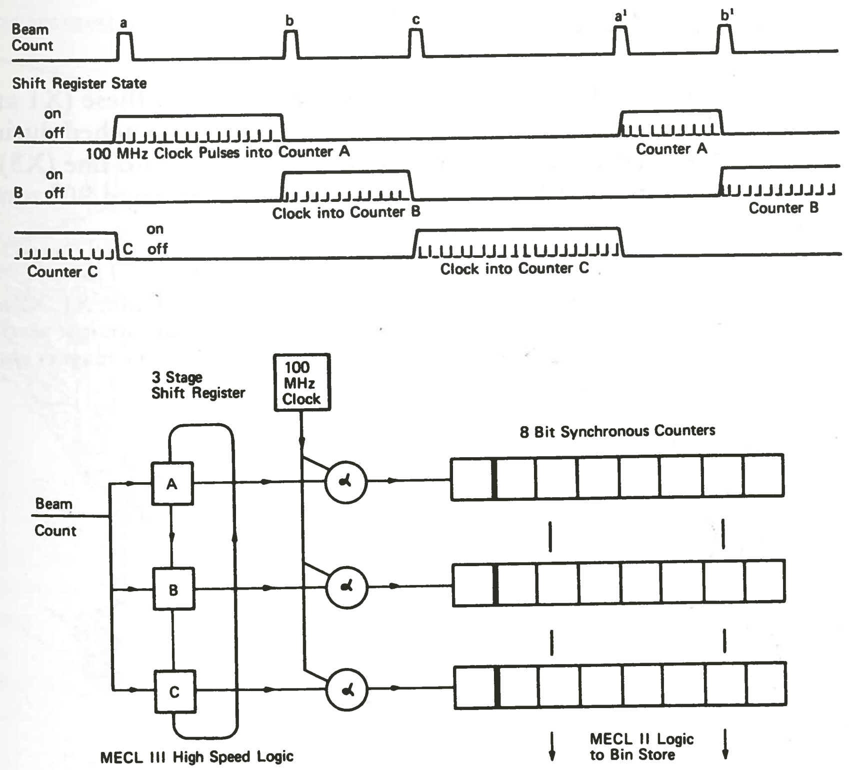


Figure 84. Fast digitizer for the time structure display.

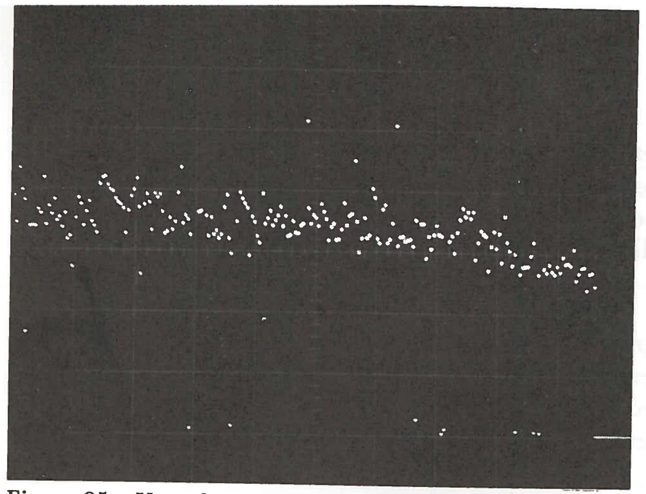


Figure 85. Use of the Time Structure Analyser Instrument showing beam structure minimised during ejection by detuning the accelerating cavities. Counting conditions: 44,000 Counts per burst length of 400 ms. Oscilloscope sweep rate 250 n sec/large division.

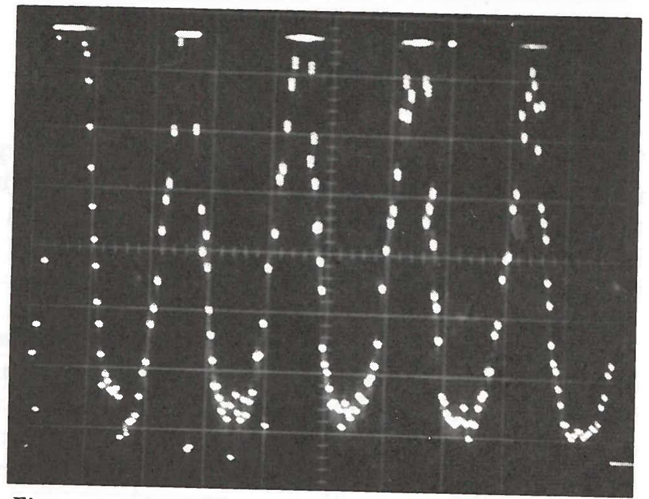


Figure 86. Beam structure during ejection with cavity detuning 'off'. Conditions otherwise as in figure 85 with same oscilloscope gain setting.

The full range of the instrument is thus 2·56 microseconds. A multiplex switch couples the complete bin store to a CRT for visual display. The complete instrument, apart from its power supplies, is housed in a single CAMAC crate. A prototype instrument has been built and is currently in use on the CERN PS, with a further model presently being constructed for use on Nimrod.

The instrument is capable of monitoring and displaying the high frequency components of beam structure encountered on the CERN PS and because of its capacity for acquiring and storing data can be used to observe pulse to pulse structure variations.

The analyser may be used when setting up the PS on slow-ejection. To keep beam structure to the minimum value it is necessary to detune the accelerating cavities, which, although not energized during ejection, can have a profound effect on the beam through resonating interaction. Figure 85 shows the display when beam "structure" has been minimised. This may be compared with figure 86, which clearly exhibits pronounced structure of about 2.5 MHz period, occurring with the r.f. accelerating cavities "detuning" off. The first 2.5 microseconds of the time interval spectrum is displayed.

EXTRACTION TECHNIQUES AT NIMROD

Extracted Proton Beams (Ref: 118)

Nimrod has three extracted proton beams (figure 87). Two of these (X1 and X2) derive from a single extractor magnet, whose current may be switched during flat-top to provide a fast spill for X1 and slow spill for X2. The third line (X3) serves the Experimental Hall 3 and is fed from a magnet which is situated 90° round the ring from X1.

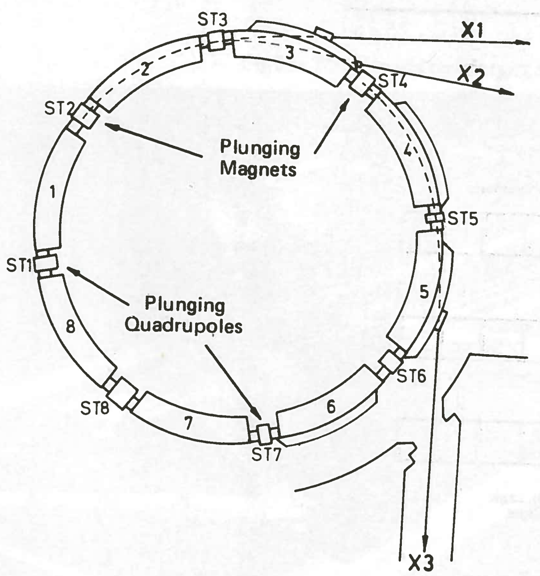


Figure 87. Extracted proton beams at Nimrod, X1, X2 and X3. The magnet octants are labelled 1 to 8, and straight sections ST1 to ST8. The proton beam is injected into the magnet ring at ST1.

Until June 1970 the achromatic energy-loss extraction method was used for both channels, the extraction efficiency being typically around 30%. Each channel required a plunging quadrupole in addition to its 6 cm septum extractor magnet. Since over 80% of the circulating beam is used for extraction purposes, plans were made to test two further methods of extraction with the aim of increasing this efficiency.

The first of these methods, called Thin-Septum Piccioni, was commissioned in January 1970 and has been in use with the X3 beamline since June 1970. The second, Resonant Extraction, has also been tested but further studies are required before it can become an operational system.

Thin-Septum Piccioni Extraction System

As its name implies, this method requires the use of a plunged extractor magnet having a thin-septum, which in practice is 11 mm thick (figure 88). The beam is steered on to a beryllium energy-loss target 1·85 cm in length, in which the most probable energy loss is 5·1 MeV. Because of the sudden change in closed orbit, most of the beam enters the extractor magnet just over one turn later and is deflected towards XHQ2, a pulsed half-quadrupole situated in Nimrod's fringe field (figure 89). In this quadrupole the large radial divergence introduced by the fringe field is partially overcome, after which the protons enter the first elements of the standard beamline. An important operational feature is that there is no need for a plunged quadrupole.

The thin-septum scheme was successfully commissioned in X3, using the computer control system introduced 6 months earlier. At this time, the extractor magnet, XM9, was in use, having a vertically laminated septum which behaved very well magnetically, but which, by virtue of its construction, was not sufficiently reliable for operational service. This was later replaced by a modified extraction magnet XM10.

From the outset it proved possible to accelerate normal beams with XHQ2 energised in a d.c. mode at the current required for 7 GeV. However, because the magnetic forces on XHQ2 caused it to move excessively each time Nimrod was pulsed, it was not possible to make full use of the range of adjustment provided, until additional strengthening was added to its support structure. The beam was viewed by means of scintillators placed upstream and downstream of XHQ2, enabling immediate diagnosis of beam misalignments as they arose.

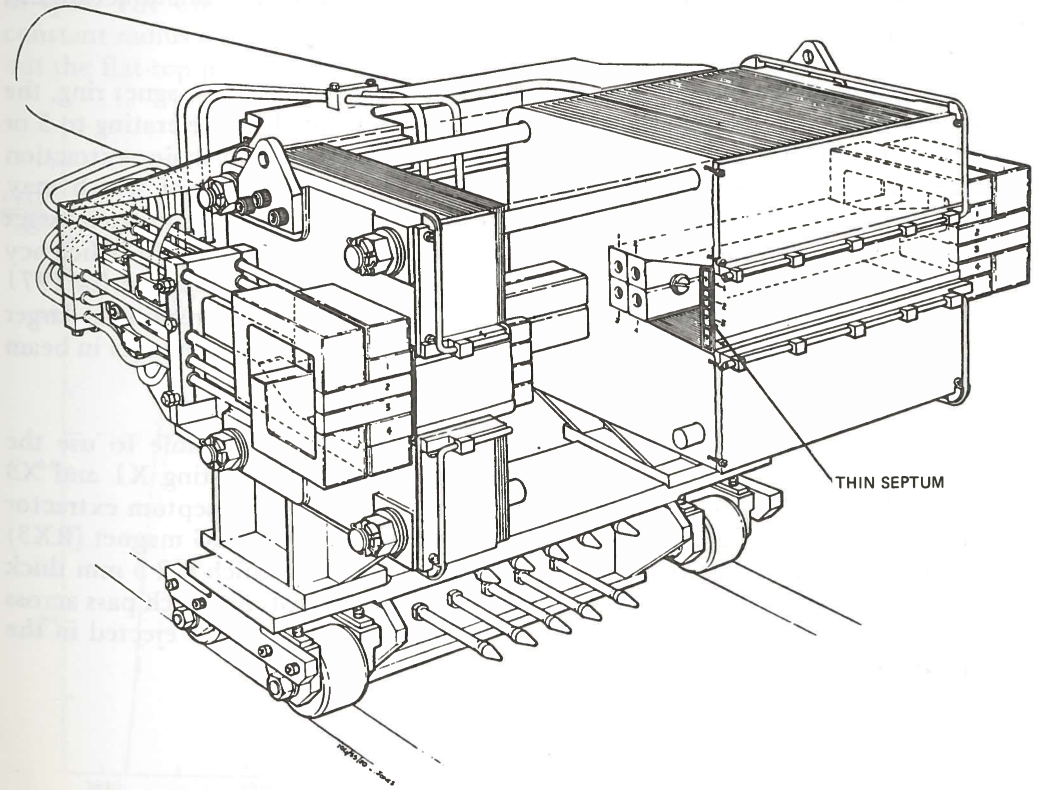


Figure 88. Thin-septum extractor magnet (XM type) with 4 stack septum.

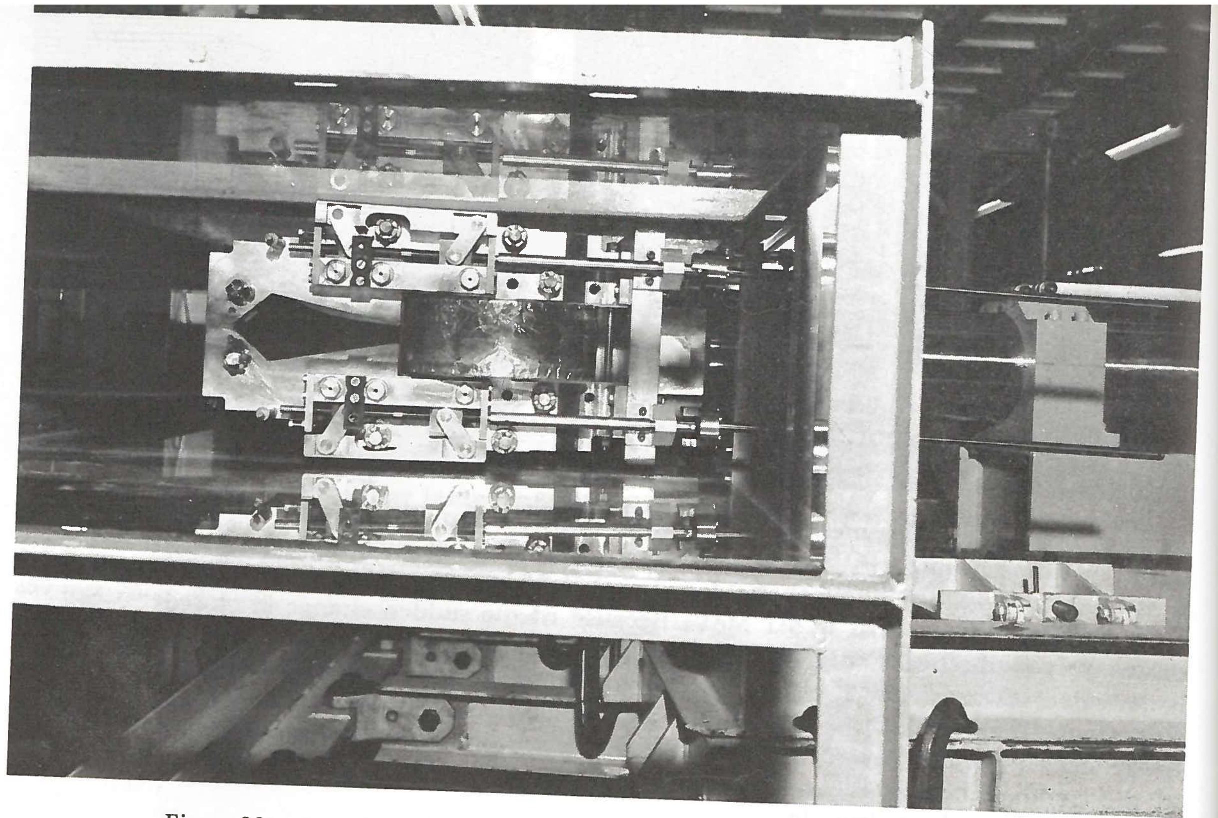


Figure 89. The half-quadrupole shim XHQ2. This is now installed in Octant 5 Header Tank as part of the thin-septum extraction system.

Extraction Efficiency of the Thin-Septum Energy-Loss System

After optimising the energy-loss target length, 10^{12} protons per pulse were extracted from Nimrod for the first time, representing an efficiency of about 45%. A foil exposed at the entrance to XHQ2 showed the beam to be of the expected shape and to contain 66% of the circulating beam. The transmission factor of the beamline, including XHQ2, was therefore 76%.

It is known that XHQ2 introduces a bend of $\sim$ 3 m-radians which another quadrupole, XHQ3, was to have counteracted in addition to providing further focusing. Since XHQ2 appeared to offer adequate focusing alone, a small bending magnet has been installed in the X3 beamline to deal with the excess bend at XHQ2, and to avoid the disruption of installing the extra quadrupole in the machine header vessel. More recent calculations show that an increase in efficiency of about 10% may be achieved by including XHQ3, but it is not proposed to manufacture this magnet at present.

While one alternator only has been available to power the Nimrod magnet ring, the synchrotron has been operated at near full repetition rate by accelerating to 5 or 6 GeV, rather than 7 GeV. This has entailed re-optimisation of major extraction parameters and exposed certain phenomena, a full examination of which may lead to higher extraction efficiencies. For example, considerably increased target radii and extraction magnet plunged radii were required to restore the efficiency to an acceptable level after the change in energy. Investigations planned for 1971 will indicate whether this is due entirely to the improved field regions at larger radii, or whether it is a consequence of alterations in the abrupt changes in beam direction at octant ends, requiring angled targets.

Resonant Extraction

Theoretical and experimental studies have shown that it is possible to use the radial Q_r = 2/3 resonance to extract the beam down the existing X1 and X3 lines: this has been made easier by the introduction of the thin-septum extractor magnet for the modified Piccioni scheme. A vertically plunged 2 kG magnet (RX3) is situated one octant upstream of XM10, having a septum which is 2·5 mm thick (figure 90). Once the resonance has been created those protons which pass across the RX3 septum are diverted into the mouth of XM10 and then ejected in the normal manner.

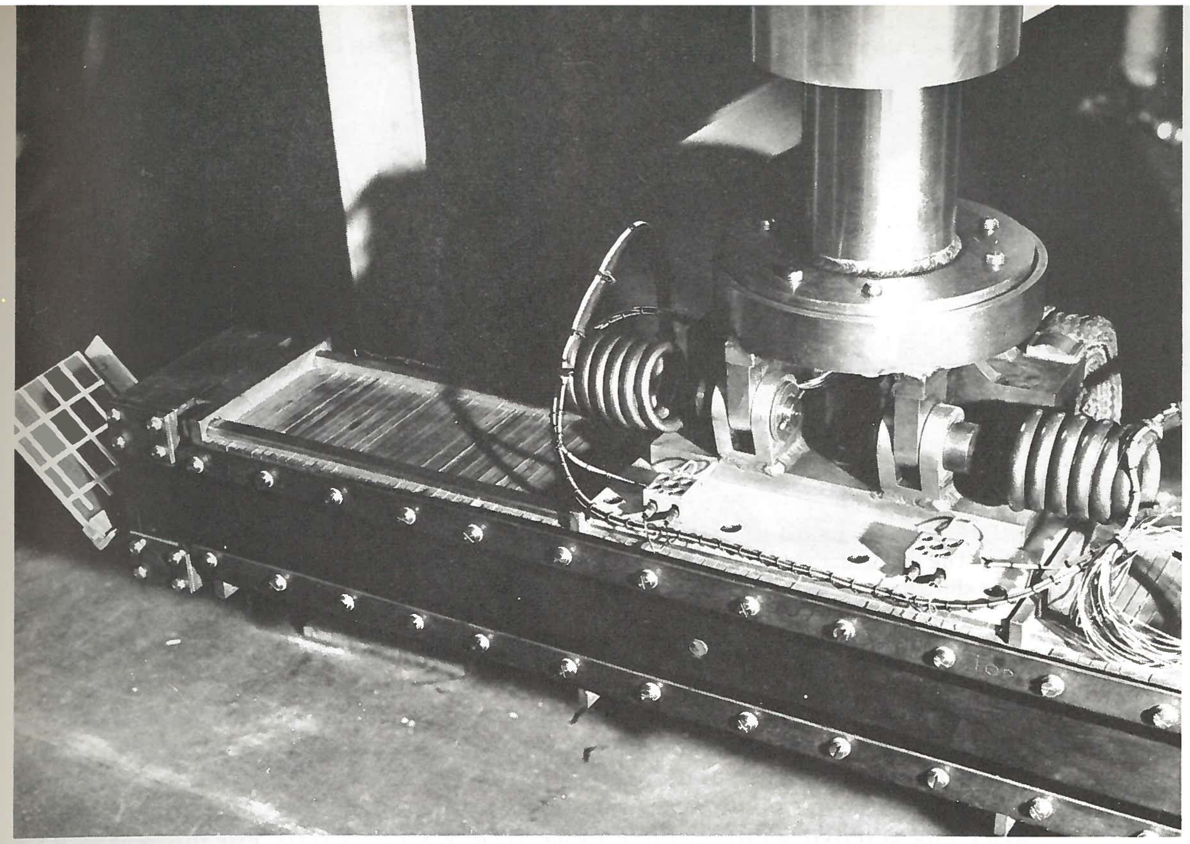


Figure 90. The vertically plunged kicker magnet, RX3, looking towards the face of the 2·5 mm septum. This magnet is used for resonant extraction. An adjustable scintillator can be seen on the left of the photograph.

The Nimrod pole-face windings are used to adjust the field gradient and to produce the necessary second harmonic sextupole component. Nimrod's field gradient across the aperture at 14 kG is shown in figure 91. On R_o the field index n is equal to 0·7, considerably higher than the resonant n-value, $n_{2/3}$ = 0·647. If the resonance were approached from the higher n-value the amplitude growth would become limited by a large octupole field component: for this reason n has to be moved to about 0·6 before extraction begins (see broken curve on figure 91). Approaching the resonance from this lower n-value, the protons see an average field gradient which gets closer to $n_{2/3}$. Their amplitude begins to grow, as shown on figure 92. The gradient is further depressed towards the outside radii using another pole-face winding, with the intention of providing a small net sextupole component: this allows the beam to be steered into the unstable region as one possible method of spill. The other principal method of spill envisaged is to hold the beam at a constant radius and to increase the n-value to $n_{2/3}$ in a controlled manner throughout the flat-top period.

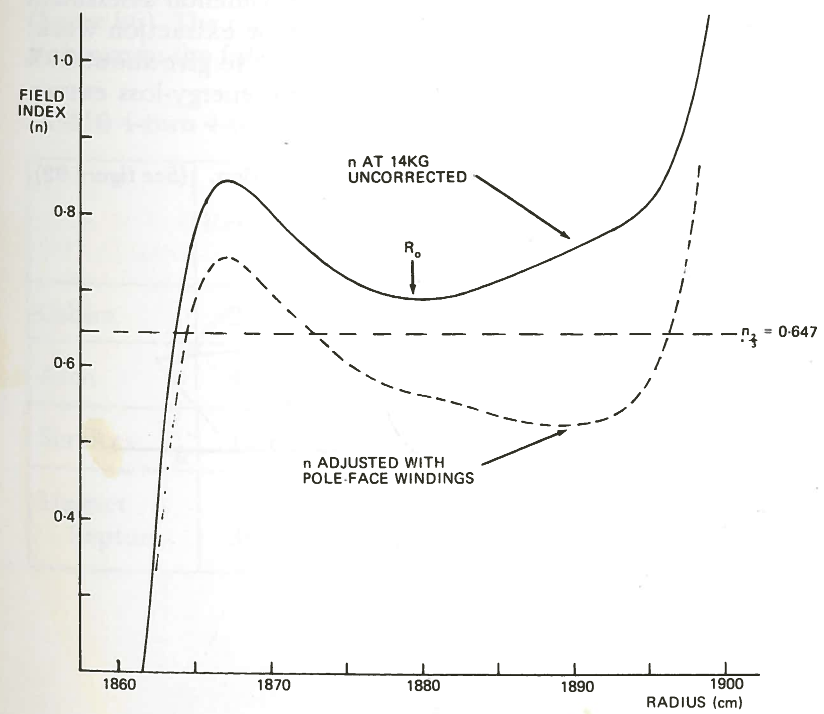


Figure 91. Nimrod magnet field gradient index, n, at 14 kG (corresponding to 7 GeV). n is defined by $\frac{dB}{B} = -n \frac{dR}{R}$ where B is the magnet field strength and R the radius.

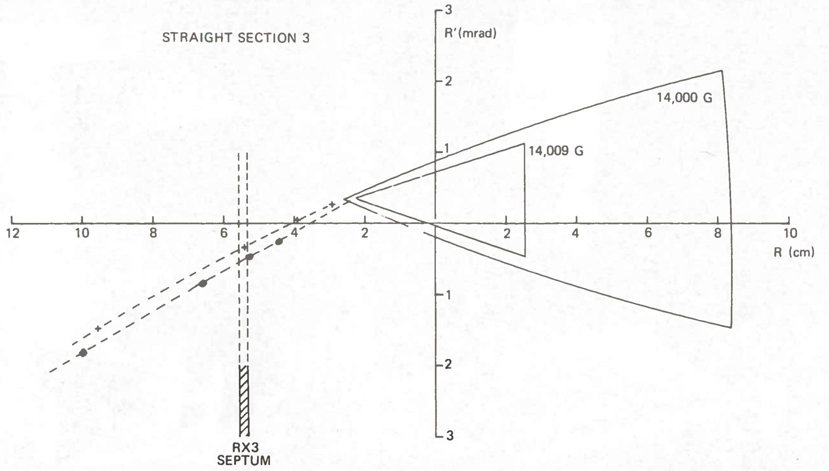
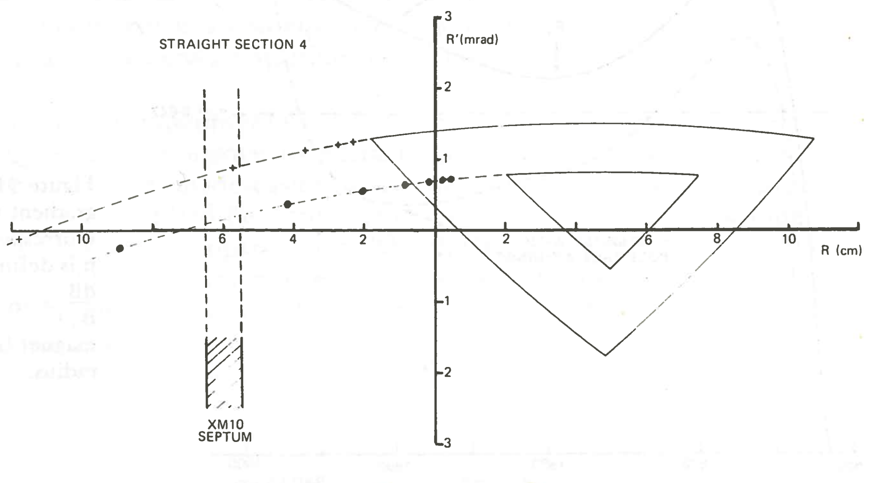


Figure 92. Radial phase diagram at Straight Section 3 during resonant extraction. The triangular shape indicates the stable particle region. This shrinks as indicated during extraction due to the small 'flat-top' magnetic field variation and particles are "peeled-off" from the periphery. Successive particle positions after every three orbits of the magnet ring are indicated.

The width of the circulating beam is between 12 cm and 15 cm, and because the good field region measures only 20 cm at most, there is little room for manoeuvre. Furthermore, protons cannot be allowed to penetrate too far into the first magnet (RX3) because the non-linear guide field at these small radii will distort the phase space characteristics during the passage from RX3 to XM10. For this reason RX3 is placed close to the inside edge of the beam; as a result the jump per three turns at the septum radius varies widely throughout the spill as the stable region shrinks in size (figure 92). A further disadvantage is that there is a large change in divergence of the emergent beam during the spill (figure 93).

The first trials of this scheme have been moderately encouraging. The method of spill was to hold the beam at constant radius and to increase n through $n_{2/3}$. The spill time was about 100 msec. As anticipated, it was difficult to steer the beam on to flat-top without premature loss, but between 50% and 60% of the circulating beam was transported to the external target, where the spot was of good quality and measured only a few mm in both dimensions. A foil which was irradiated at the entrance to XHQ2 registered 70%. At this stage commissioning studies were halted by failures of the pole-face windings, due to the unusually high currents demanded in them and to radiation damage which has occurred at their end connections. These mechanical faults will take some time to overcome. Moreover, compared with the thin-septum energy-loss scheme, resonant extraction requires an additional plunging mechanism, involves difficulties in beam sharing with internal targets, and has the known disadvantage of spill modulation due to field ripple. Further theoretical and experimental assessment is under way to determine the future course of the resonant extraction work: the current philosophy is that, unless the system can be shown to give about 80% efficiency, Nimrod will continue to operate with thin-septum energy-loss extraction.

Figure 93. Radial phase diagram at Straight Section 4 during resonant extraction. (See figure 92).



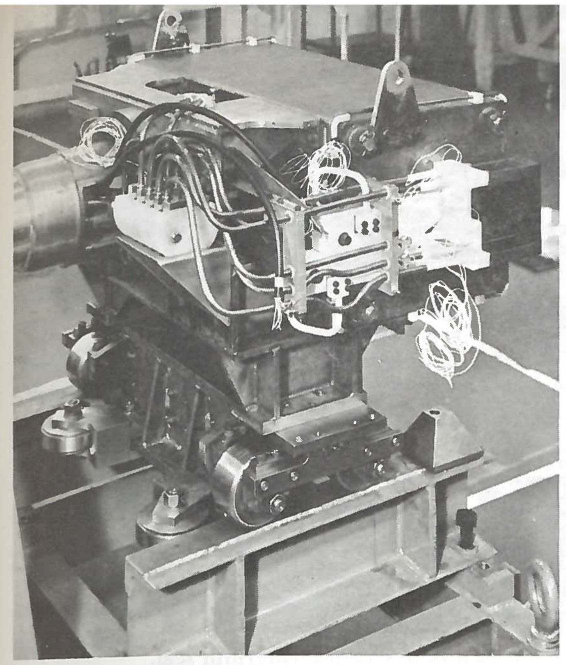


Figure 94. Extractor magnet, with 4-stack septum, and undercarriage.

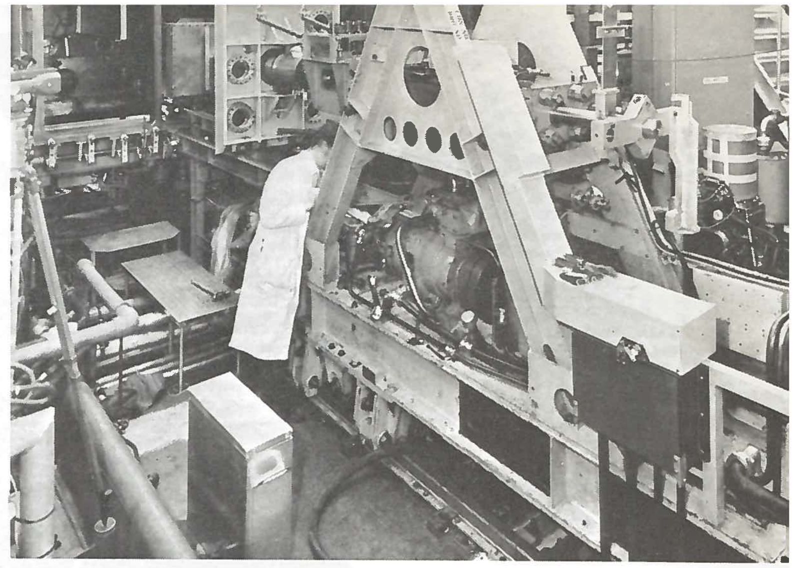


Figure 95. Mk II plunging mechanism installation at Straight Section 2.

EXTRACTED PROTON BEAM COMPONENTS

Septum Magnets

The XM type magnet with 4-stack septum, figure 94, has been running in Nimrod Straight Section 4 during the past year. A similar magnet is fitted in Straight Section 2 attached to the newly installed Mk II plunging mechanism, (figure 95), which provides the power to move the magnet (weight about 1500 lbs) about 20 inches in and out of the beam each Nimrod magnet pulse.

The 4-turn 4-stack septum, about 1 cm thick (figure 88), was designed to improve reliability and to reduce the manufacturing time of the vertical type septum. The 4-stack septum can be manufactured from readily available flat copper bars and plates suitably drilled and brazed together. Each turn is wrapped in 0·0035 in thick glass tape impregnated with epoxy resin, with the 4-turn assembly encased on three sides with a 0·03 in thick stainless steel channel. The rear conductors are coated with 0·01 in thick nylon to provide the necessary insulation. The final brazed joints connecting the nylon coated rear turns to the resin bonded glass fibre front turns was made possible by using special jigs, water cooling baths and high conductivity, low temperature, relatively high tensile strength silver braze.

The magnet is powered through flexible water cooled cables up to the plunging mechanism over the arch, through the junction box and ram tube to the septum, (figure 96). The estimated total resistance, power, water flow and temperature rise is shown in the following summary:

XM10 4-turn 4-stack septum, (Peak current 14,000 amps, Average current 7,000 amps)

	Resistance $\mu\Omega$		Peak Power	Average Power	Water Flow gpm	Peak Temp. Rise	Average Temp. Rise
Cables	250						
Arch	420	790	154·8 kW	38·7 kW	12·0	74·0°F	18·5°F
Services	120						
Magnet Septum	390		76·4 kW	19·1 kW	3·6	120·4°F	30·1°F

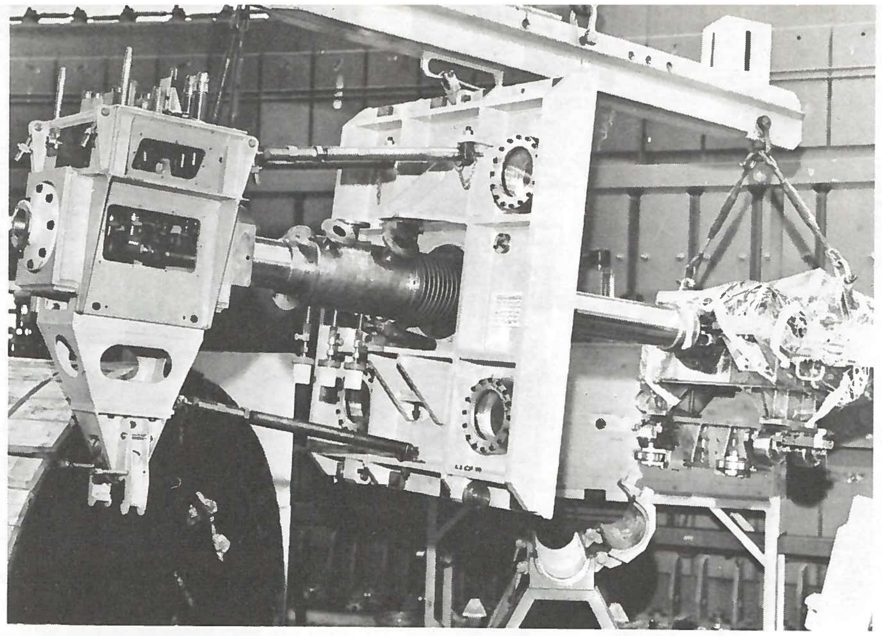


Figure 96. Assembly of junction box, ram tube services, labyrinth seal, cover plate and extractor magnet being lifted into position.

The magnet undercarriage operates in high vacuum and in high levels of radiation which presents serious problems of lubrication and wear. A reasonably satisfactory life has been achieved by mounting each wheel between two torsion bars, which permit independent twist and lift of each wheel thus ensuring that full contact is achieved between each wheel and rail throughout every stroke. The rails are made from EN24 steel, burnished with dry molydenium powder and bolted into an accurately positioned cradle.

Mk I Plunging Mechanism

A strengthened swash plate and modified control rods have been tested for $2{\cdot}5 \times 10^6$ cycles. Further investigation into the location of the slipper plate is in hand.

Mk II Plunging Mechanism

The Mk II mechanism with the V6S type swash pump was tested for 2×10^6 cycles and the control system optimised to give smooth running with accelerations of less than 4 g. Throughout the year there has been a reasonably trouble free period of running of these mechanisms.

The buffer arrangement of spikes and metal membranes, used to absorb the energy in stopping the magnet assembly if it overruns its specified distance, was tested. The finalised number of plates and spikes stopped the overrun magnet assembly in about 2 inches.

Further development continues on swash plate lubrication and bearings. A Mk IA mechanism which consists of a Mk I mechanism main frame fitted with the Mk II control system, components, hydraulic circuit and flexible pipes has been designed and will be built in 1971.

8-Stack 8-Turn Septum

This septum, shown in figure 97, is manufactured from copper tube 0·375 in square with a 0·15 in square hole. In this system improved mechanical reliability is possible since there are no joints in the vacuum system. The water pressure drop across this septum is much higher than the 4-stack septum. The eight turns are arranged to form a curved septum, bonded together with 0·003 in thick glass tape and epoxy resin and are encased on three sides with 0·03 in thick stainless steel.

Development of Thin Septum Magnets

Beam extraction efficiency can be improved by using an extraction magnet with a thinner septum and a higher magnetic field.

Basically, these conditions require a higher rate of heat transfer between the septum and its cooling water, and this has been effected by increasing the ratio of surface area to volume of the cooling channels and by using a high water velocity.

However, the improvement is limited by the increase in the ratio of length to diameter of these channels and boundary layer effects at the cooling water - copper septum surfaces. Tests have shown that the Darcy equation for calculating the pressure drop in pipes is valid when applied to extremely small bore capillary tubing.

Investigations are in progress to optimise the septum size, water pressure drop and current density. In addition transversely cooled septums are being considered and testing of possible septum profiles is in progress.

Inorganic Insulation

As a corollary to the work on thin-septum magnets some research is necessary on inorganic insulation. This is because the thin-septum will run at a temperature above that permitted for the type of epoxy resin now used for coil insulation. This type of insulation will give far greater radiation resistance than epoxy resins, and will also allow a greater margin of safety in the time taken to turn off power in the event of a water flow failure.

The forces involved on the coils of the septum magnets are considerable and techniques have to be evolved to make the septum construction sound both mechanically and electrically. A number of alternative materials have been considered, but work will be restricted to aluminium oxide, with which experience exists on other applications.

Following the construction of the first concrete insulated magnet, a second improved design has been constructed and demonstrated at the 1970 Physics Exhibition. This magnet has a resistance to earth of over 20 MΩ and withstood a 5 kV flash test.

Undercarriage Development

A rig designed for testing rails and various combinations of undercarriage wheels (loaded from 1 to 500 lbs) in a high vacuum has been in use throughout the year.

The results to date show that:

(a) EN 24T tyred wheel running on a EN 24T rail burnished with dry molydenium powder – satisfactory after $2{\cdot}13 \times 10^6$ cycles with only slight markings on burnished rail.

(b) Tyre coated with 0·05 in polyurethane – unsatisfactory. Polyurethane coat stripped off after 10 hours running.

(c) Solid polyurethane wheel – satisfactory after $2{\cdot}08 \times 10^6$ cycles, no measurable wear on the wheel diameter. Irradiation tests not complete.

Further tests are continuing using other materials.

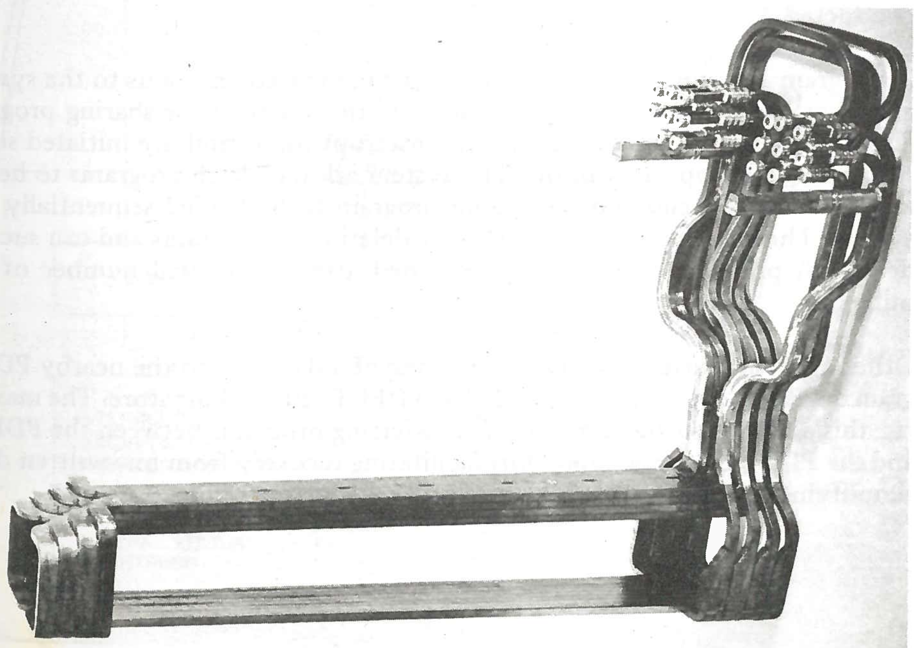


Figure 97. 8-stack, 8-turn septum.

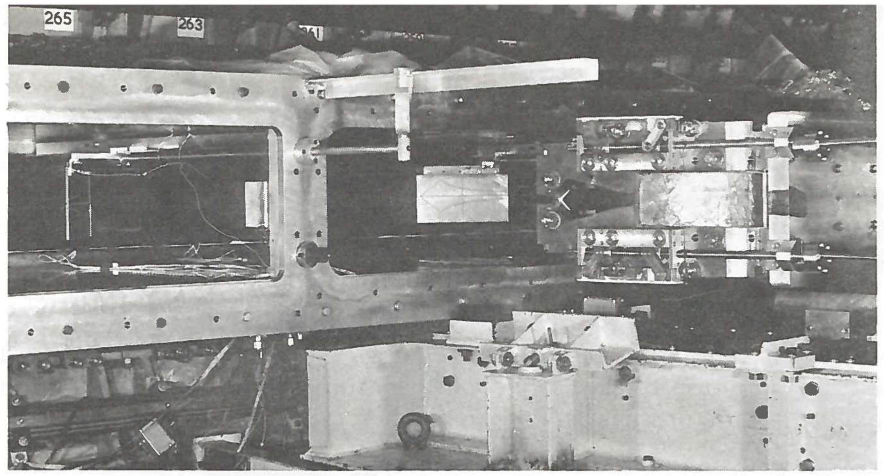


Figure 98. XHQ2/2 half-quadrupole magnet with upstream and downstream diagnostic scintillators.

Powered Shim XHQ2/2

During the December 1970 shutdown the second header vessel quadrupole magnet was fitted in Octant 3 for use with X1 beam. Figure 98 shows XHQ2/2 with its upstream and downstream diagnostic scintallators. Future scintallators will be attached direct to the magnet apertures.

Powered Shim XHQ2/3

The XHQ2/3 magnet and support structure has been designed for the X2 beam. Since it is in very close proximity to the X1 beam the whole support structure has been designed as an integral unit with the beam line quadrupole magnet and stand. This will limit movement of XHQ2/3 to ± 2 in radially and to ± 1 in azimuthally. Access is limited and removal of XHQ2/3 will necessitate removal of the X1 quadrupole magnet.

COMPUTER CONTROL OF BEAMS

Computer Control of X3 Extracted Beam Line (Ref: 139)

Commissioning of X3, the extracted proton beam for Hall 3, was made easier by the computer control system for beam line elements. The system has control over magnet current settings and collimator jaw positions.

Experience with this system early in 1970 quickly revealed two limitations. The first was that the maximum of 63 disk-stored files allowable in the PDP-8 Monitor System was rapidly being reached and this rather than the capacity of the disks (2 x 32K words) would limit the storage available.

The second limitation arose when it was realised that certain of the user programs would be better run as a time-shared activity, thus being executed each Nimrod pulse as well as, rather than instead of, one of the main programs. Notable in this category were programs dealing with presenting data, such as digital displays (nixie tubes), and target monitoring programs.

Extra disk and core storage has recently been incorporated in the computer to overcome these limitations and the first trials of the time-sharing system have been conducted.

A program for controlling the linking of time-shared programs to the system program has been tested successfully, and the first of the time-sharing programs has also been tested. They are run in the interrupt mode and are initiated soon after the end of flat-top on Nimrod. The system allows 7 such programs to be run and also permits 7 versions of the same program to be loaded sequentially into the system. The linking program controls the deletion of programs and can successfully deal with programs which have self-ended after a specified number of Nimrod pulses.

Other activities have been the engineering of a data link to the nearby PDP-5 program development computer, which has a DECTAPE backing store. The main reason for this was to provide a means of transferring programs between the PDP-8 disks and the PDP-5 magnetic tape, thus facilitating recovery from mis-written disks and simplifying updates of the disk-stored files.

The scope of the data acquisition and control equipment has been extended to include some of the X1 and X2 extracted beam instrumentation, and various quantities concerned with the operation of Nimrod, such as beam radius, data from insulated internal targets, and pole-face winding currents involved in resonant extraction.

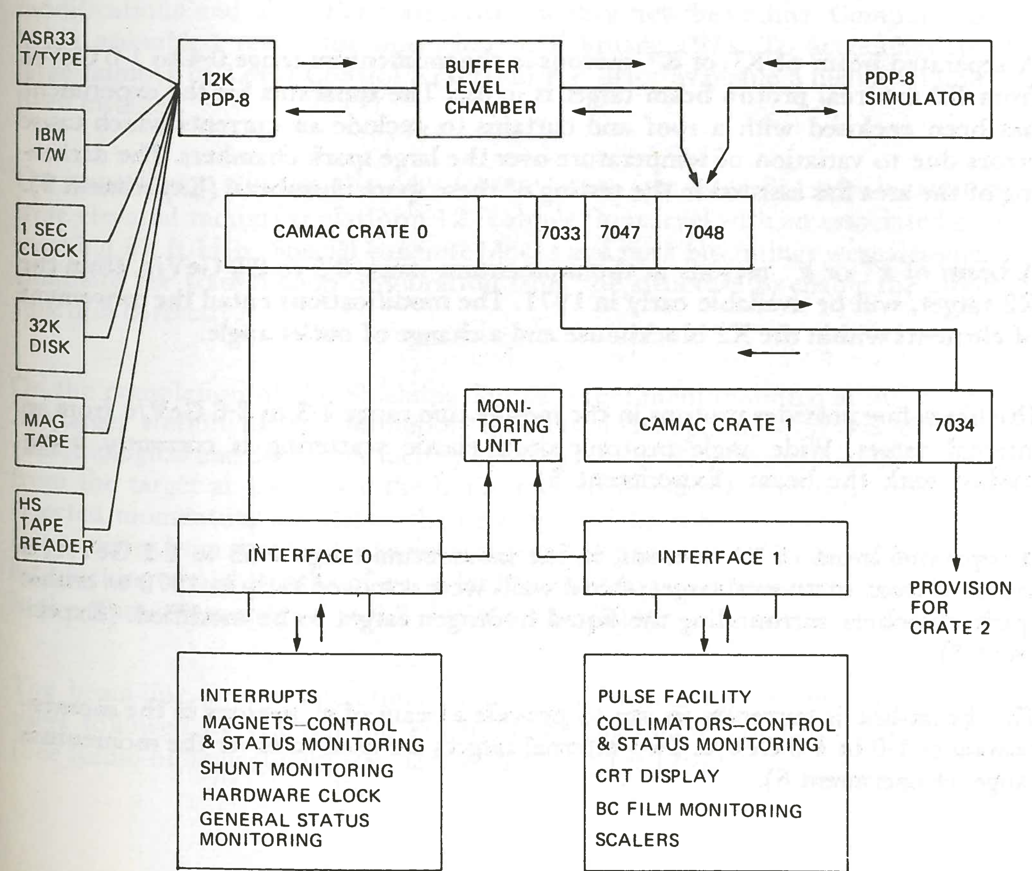
Preparations have been made for enlarging the system to accommodate the extension to X3, which is being installed during the Winter shut-down.

Computer Control of K9 Bubble Chamber Beam Line

The basic details of the control system to be installed in K9 Local Control Room are as shown in figure 99. It was decided to interface the K9 devices with CAMAC, and the initial system will be contained in two crates of CAMAC modules, probably enlarging later to three. The computer is a PDP-8 with 12K words of core store, one disk of 32K words capacity, a single drive unit for magnetic tape and a fast reader, but no fast punch. Programmed transfer of single or double precision data between the CAMAC system and the computer is possible. The system has control over magnets and collimator jaws in a way similar to X3, and data is acquired concerning magnet currents, separator voltages, collimator jaw positions, beam counters and detailed status of the beam line. The system differs in many details from that of X3; one worthy of note is the multiplexing of the collimators, which will allow simultaneous control of any number of stations. This system will ultimately be applied in X3 and its extension.

There are also some differences in the philosophy of the control system. Much more emphasis is being placed on the day-to-day running mode of K9 beam, as opposed to the tuning of it, and there are two distinct ways in which the software will operate, the RUN and TUNE modes. 'TUNE' resembles the initial form of the X3 system, with, for instance, scanning and setting programs. 'RUN' consists largely of data collection, fault reporting and analysis, and gathering of statistics.

Figure 99. Block diagram of computer control system for the K9 beam-line.



BEAM LINES AND ASSOCIATED EQUIPMENT

The year commenced with the major effort being concentrated in Hall 1: two beam-lines ($\pi 7\gamma$ and K14) were removed completely and four beam-lines were modified (K12A, K13B, K10S, K9).

During the summer the beam-line in the northern section of Hall 2 (K8) was re-arranged and re-named $\pi 10$.

For the remainder of the year, with the exception of a quick change round, during November, of components of K9 for a neutron experiment, the main effort was concentrated on planned maintenance and activities in Hall 3.

The arrangement of beam-lines at the end of 1970 is shown in the two pull-outs at the end of this Report.

X2 Blockhouse (Hall 1) With the dismantling of K14A, the last of the three beam lines were taken away from the end of X2. The blockhouse roof has been removed to allow extraction of all redundant elements. With the removal of these elements a beam stop has been specially built to allow the Radiation Protection Group to take measurements at various depths of shielding. The opportunity has been taken to add a second personnel access point and modify the front end of K13. Additional shielding has been placed around the blockhouse and a more homogeneous roof is envisaged.

K9 (Hall 1) This beam-line is the continuation of the X1 external proton beam and transports beams of π mesons, K mesons or protons to the 1·5 m Bubble Chamber. A 20 ton lifting beam with electric hoists has been installed over the tilting platform section of the beam. For safety reasons this section is inaccessible to the Experimental Hall overhead crane unless the Bubble Chamber is emptied. The beam-line was temporarily modified for a neutron experiment and magnets and collimators have been prepared for the introduction of computer control of the beam-line components.

K12A (Hall 1) A separated beam of K^+ or K^- mesons in the momentum range 0·4 to 1·0 GeV/c from X2 external proton beam target is in use. The apparatus for the experiment has been enclosed with a roof and curtains to exclude air currents which cause errors due to variation of temperature over the large spark chambers. The darkening of the area has assisted in the testing of these spark chambers. (Experiment 9).

K13C (Hall 1) A beam of π^+ or π^- mesons in the momentum range 0·5 to 2·0 GeV/c, from the X2 target, will be available early in 1971. The modifications entail the movement of elements within the X2 blockhouse and a change of outlet angle.

P71 (Hall 1) The beam-line provides protons in the momentum range 1·3 to 3·6 GeV/c from an internal target. Wide angle proton-proton elastic scattering is currently being studied with the beam (Experiment 5).

K10S (Hall 1) A separated beam of K^- mesons, in the momentum range 0·65 to 1·2 GeV/c, is provided from an internal target; shield walls were removed early in 1970 to enable spark chambers surrounding the liquid hydrogen target to be modified. (Experiment 3).

$\pi 7$ (Hall 2) This beam-line is currently in use to provide a beam of π^- mesons in the momentum range 1·0 to 4·0 GeV/c. Two internal targets are used to cover the momentum range. (Experiment 6).

$\pi 10$ (Hall 2) In the latter half of the year, $\pi 10$ beam-line was set up to provide π^+ or π^- mesons in the momentum range 0·7 to 2·0 GeV/c for a nuclear structure experiment. This beam-line is a modification of K8. (Experiment 32).

Extension of the X3 Beam-Line (Hall 3 Phase II) The X3 beam line has now been extended to a second target station. This extension has been designated X3X and the new station will serve the new beam line $\pi 9$. It also has the facility to be extended to a third target station, or provide a 0° beam.

The installation was carried out in two stages. Stage 1 from the existing target station to the beam cut-off unit (approximately half way to the second target station), and the remainder in stage 2. In this way it was possible for X3 to run and provide beam for $\pi 8$ and K15 with minimal interruption.

It also provided the opportunity for radiation experiments to be carried out in the vicinity of the beam cut-off unit as a result of which two design modifications were carried out. (i) Due to the increased efficiency of the extraction system a second beam cut-off had to be installed. (ii) With the new radiation knowledge the design of the beam stop for the second target blockhouse was modified thereby saving approximately 380 tons of steel. The whole installation used 4,263 tons of steel and 2,571 tons of concrete.

$\pi 8$ (Hall 3) The beam-line is set up to provide π^+ or π^- mesons, in the momentum range 0·5 to 1·7 GeV/c, from X3 target. (Experiment 16). Under normal operating conditions it has been found necessary to provide temperature control of all environments housing the videcon cameras. Further development work has now achieved the high accuracy demanded for the successful operation of these units. A new beam-line safety barrier and interlock system was commissioned.

$\pi 9$ (Hall 3) A π^- meson beam in the momentum range 0·4 to 4·1 GeV/c is being set up. This beam-line, one of the beam-lines from the X3X target station was first laid out early in 1970. Throughout the year the design has continued embodying all the modifications and alterations associated with a new beam-line. Components are being assembled ready for operation in February 1971. To accommodate the large number of Local Control Rooms in the space available a high level unit has been installed.

The experiment will use the new frozen target (see page 98) which requires a large elevated mounting platform 12 ft above floor level with an associated gantry reaching 32 ft high. Special concrete blocks and cork mountings were designed to eliminate the transmission of vibration from the structure to enable the target to function correctly.

$\pi 11$ (Hall 3) On the completion of the Shielding Tunnel experiment mounted at 90° from the X3 target station for the Radiation Protection Group, approval was given for a radiobiological and dosimetry facility at this position. The beam-line takes particles from the target at 15° above the horizontal plane and then bends particles of the selected momentum parallel to the floor at a height of 8 ft. This is the first beam-line to differ from the standard height of 6 ft 3 in and assists the radiation shielding by blocking straight paths of particles from the target. Beams of π^+ or π^- mesons in the momentum range 0 to 0·2 GeV/c are available.

The beam-line is now operational and AERE Health Physics will be the initial users followed by teams from either St. Bartholomew's or Churchill Hospitals. (See Radio-biological Pion Irradiation Facility page 179).

K15 (Hall 3)

This beam originates from X3 target. Separated beams of $\pi^{\pm}$ and $K^{\pm}$ mesons in the momentum range 1·0 to 2·0 GeV/c are available. A light tight igloo for testing large spark chambers has been added to the beam-line (Experiment 8).

Collimators

Development of collimators has continued. Modifications include a new centre position indicator, a digitizer unit required for computer control of the collimator and a new drive system incorporating an electric clutch and torque limiter.

Work is in hand to facilitate easy and expeditious removal of collimator jaws from collimators installed in a beam line. This is desirable so that irradiated jaws can be removed before handling becomes difficult due to high induced radioactivity.

Consideration is being given to adapting the early Mk I collimator so that it can, when necessary, be used as a beam spoiler.

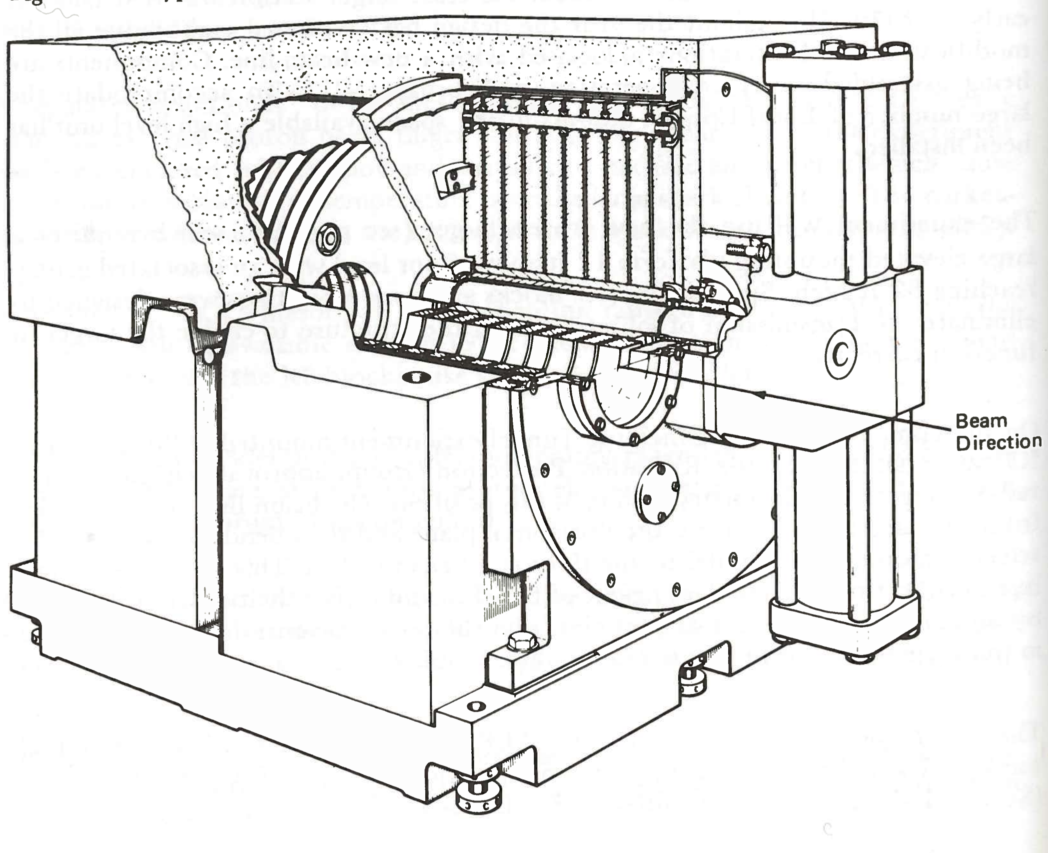
Beam Cut-off Unit

A 'type VI' version of beam cut-off unit, figure 100, has been developed and two of these units have been installed in X3X, the extension of Hall 3 external proton beam.

The unit consists of two thick steel disks mounted on a shaft parallel to the beam direction. Each disk has an 8 in dia beam hole off-set from the axis of rotation and by rotating the disks the holes can be aligned to transmit the beam. The system is pneumatically operated and, in the event of a failure of either air supply or electric power, will fail safe. The disks rotate under influence of gravity and are linked so that the holes are displaced relative to each other, thus making maximum use of shielding material.

The disks are enclosed in a vacuum vessel so as to form a continuation of the evacuated beam pipe and the external dimensions of the vessel match the shielding block module size.

Figure 100. Type VI beam cut-off unit.



Electrostatic Air Filters

Filter systems have been installed in K13 and π8 light tight igloos to protect the surfaces of the spark chamber mirrors from the very small dust particles which are normally present in the atmosphere.

Air-Conditioning of Experiment Control Rooms

Alterations and additions to control and diagnostic equipment in LCR's during the winter months has resulted in an increase in control room ambient air temperatures. This increase has had no immediate detrimental effect but it is calculated that if no action is taken beam line computers in particular will be in trouble, because of excessively high temperatures, during the summer. Additional air conditioning plant has therefore been installed in π8, K12A, K13B, and K14A, LCR's.

Beam-Line Magnets and Power Supplies

During the year, in addition to beam-line installation work, 40 magnets have been overhauled. Six 5 kW d.c. power supplies stabilized to ± 0·5% have been ordered. The first of these units has been delivered and tests indicate that stability is well within the specified figure of ± 0·5% over the range 15 to 150A. They will be used to power the M3 and Q7 range of beam-line magnets, where only low field levels are required.

NIMROD BEAMS–DESIGN STUDIES

Low-Momentum K-beam for 1·5 m Chamber, (K9)*

Using the track-sensitive hydrogen target in the 1·5 m bubble chamber, there is considerable interest in the interactions of K-mesons below 1 GeV/c momentum.

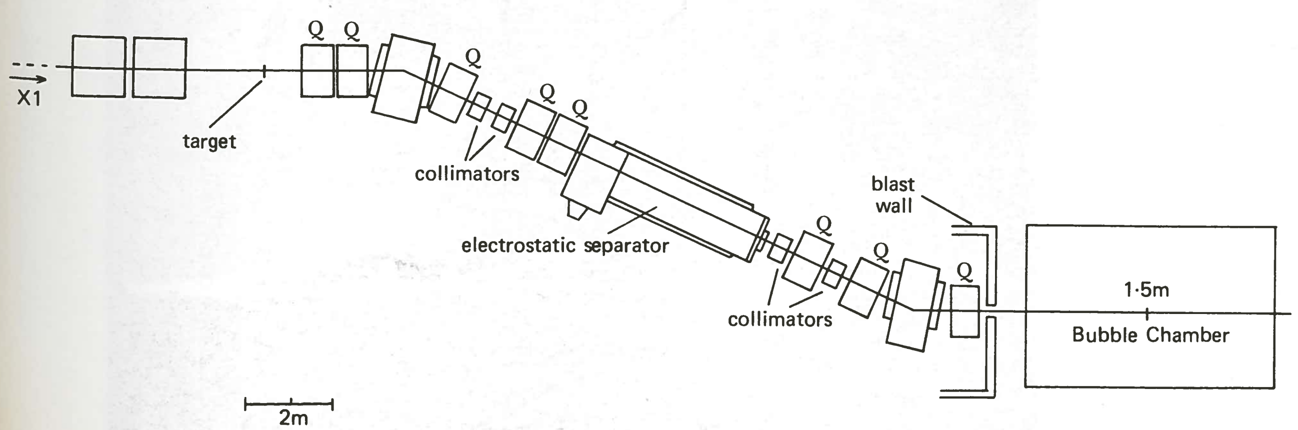
A preliminary design for a 600-800 MeV/c kaon beam has now been completed, and is illustrated in figure 101. Outside this momentum range, muon contamination presents severe problems.

An alternative design, based on 2-stage separation, is being studied at present: greater beam purity over a wider momentum range would be achieved at some cost in kaon flux.

Superconducting RF Separated Beam

Design of this beam, referred to in the 1969 Annual Report, was completed during 1970. However, in the K^{-} momentum range 2·0-3·5 GeV/c, the final flux estimates are below the requirements for the proposed experiment: only by going to zero-degree production, implying sole use of an EPB target, could the required fluxes be obtained.

Figure 101. Preliminary design layout of the low momentum K beam for the 1·5 m bubble chamber.



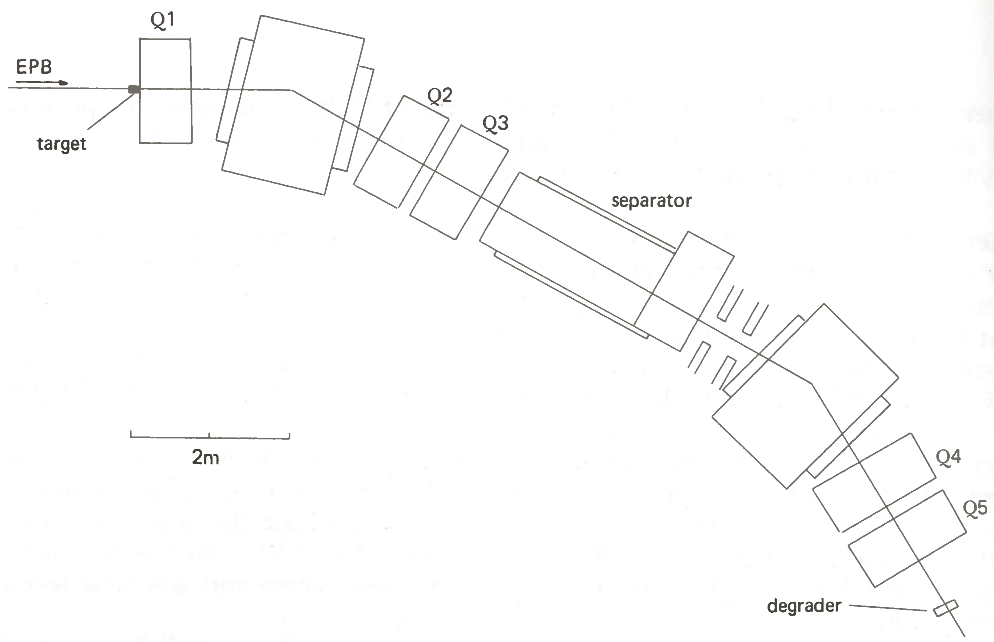


Figure 102. Design layout for a Stopping-Kaon beam.

Stopping K-Beam

Layout design for a "Stopping-Kaon" beam is shown in figure 102, and its optics is illustrated in figure 103.

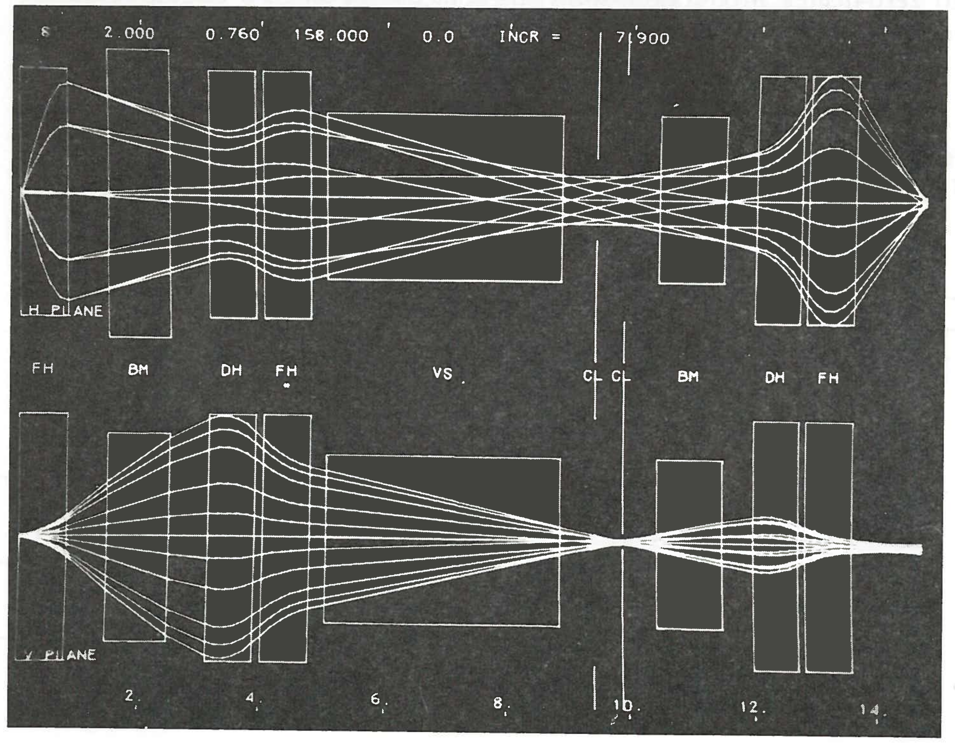
About 18,800 K^- per pulse of 10^{12} protons, transported and separated at 600 MeV/c should be focused on to a "degrader" at the final focus; (i.e. a block of material which would bring them to rest in the detector). The contamination by μ^- and π^- would be about 30:1, and the efficiency of the degrader would be about 10%.

The beam requires 5 large aperture (30 cm) quadrupoles, and would be the sole user of an external beam target—for example, a third target in X3.

Beam Design Programs

Beam designs and beam-tuning procedures are being developed with the aid of interactive visual display computer techniques. (See page 172).

Figure 103. Optics of Stopping-Kaon beam. An example of computer produced graphic output.



ELECTROSTATIC SEPARATOR OPERATIONS AND DEVELOPMENT

There has been a total of seven separators in operation in Nimrod beam-lines during 1970. The year has seen the final elimination of oil diffusion pumps from separators and their replacement by turbo-molecular pumps. The decision last year to complete the change over as quickly as possible has already been justified by the superior performance and increased reliability of the turbo-molecular pumps.

Wire Mesh Electrodes (Ref: 95)

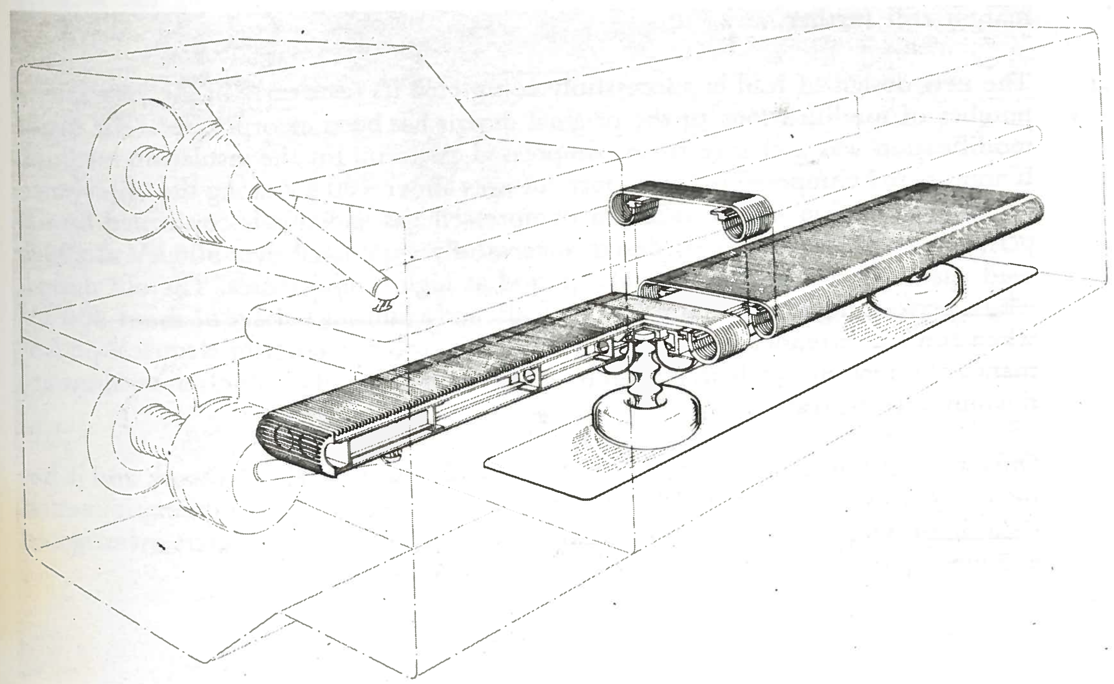
Following the discovery at the end of 1969 of the outstanding performance of a wire mesh electrode used as the anode of an electrostatic separator, effort has been devoted in 1970 to the design of a version suitable for use in an actual beam line.

Mechanical Design

The problem is to construct an electrode of an open screen of wires with a screening ratio (the ratio of the open area to the entire area) of about 0·8 and yet still retain sufficient mechanical stiffness to maintain the required degree of geometrical accuracy under the action of the electrostatic attractive forces, which are in the region of 160 Nm^{-2}. A prototype was produced, based on preformed wires, in order to test the electrical performance of the arrangement. This turned out to be even better than that of the early, rather crude, mesh electrode, giving a performance equal to that of the glass electrodes used hitherto, namely a peak performance of 7·2 MVm^{-1} and a working performance of at least 6·0 MVm^{-1}. These figures are for a 100 mm gap.

A more rigid mesh has now been constructed. The electrode is an array of flattened stainless steel tubes mounted so that their edges are presented to the electric field. Electrically this is equivalent to an array of round wires of diameter equal to the length of the minor axis of the flattened tubes, but mechanically it is much stiffer. Each electrode, which is 150 in long, requires 368 tubes. In the construction and alignment procedure groups of 12 to 14 tubes are assembled into jig drilled retaining blocks, set level on a bench and securely locked in position. This group of tubes is then mounted onto a rigid box beam and aligned as a group to adjacent assemblies. This method allows easy replacement of tubes in the event of electrical or mechanical damage. Figure 104 shows the arrangement of the wire mesh electrodes and figure 105 shows an actual assembly.

Figure 104. General arrangement of the wire mesh electrodes showing modular method of construction.



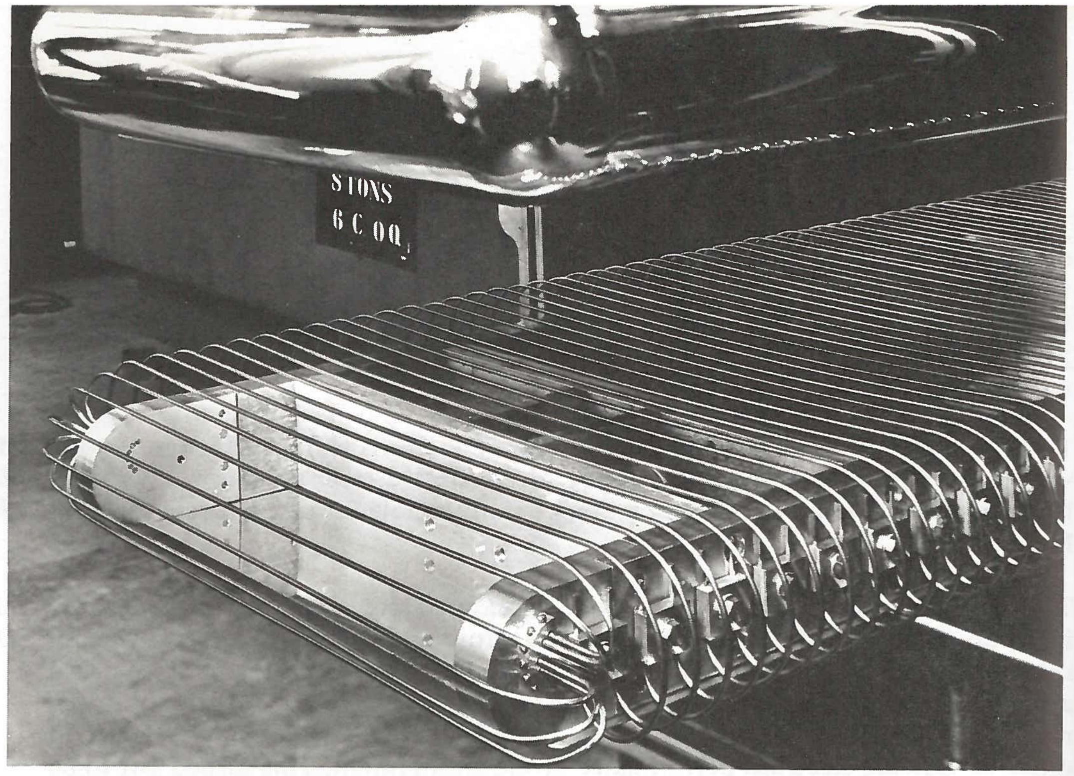


Figure 105. An assembled wire mesh electrode.

Advantages of Wire Mesh Electrodes

The advantages of wire mesh electrodes over heated glass electrodes are:—

1. The conditioning time is reduced from over a week to about 24 hours.
2. They do not require to be heated, thus saving the complication of heater controls and giving a further saving of start-up time of about 4 days.
3. They are insensitive to contamination of the vacuum system, which means that the expensive to run liquid nitrogen trap is no longer required and also that there is far greater immunity against vacuum failures, and services interuptions. Delivery of the final prototype is awaited for testing before ordering enough wire mesh electrodes to equip all separators in current use.

Electrode Support Insulators

The new insulators, described in the 1969 Annual Report, which withstood accelerated life tests so successfully, did not perform so well in service due to certain mechanical problems. These problems have recently been overcome and a further accelerated life test is currently in progress. The opportunity has been taken to introduce some electrical modifications with a view to increasing the security margin still further.

High Voltage Lead-in Insulators

The new design of lead-in successfully completed its tests early in the year after a number of modifications to the original design has been incorporated. The major modification was a change from compressed gas to oil for the insulation medium. It appears to be impossible to support voltages above 400 kV along the unscreened termination region of the cable in compressed gas and this is confirmed by experience elsewhere. The new design successfully supported over 500 kV at a high load sparking rate for an extended period at high temperatures. The old design, whilst performing very well for short periods, had a limiting voltage of about 360 kV when run for extended periods. As well as having a much better electrical performance the new design is much simpler to assemble. Final production versions are now undergoing tests.

Basic Vacuum Breakdown Research (Ref: 96)

Only a limited amount of time has been available this year for this work and it has been spent on consolidating the previous rarher hurriedly acquired experimental data, improving the accuracy, extending the range of the parameters investigated and investigating certain anomalies in the previous results.