DNPL 04

4 GeV ELECTRON SYNCHROTRON

Progress Report for the Half-Year ending 31st October, 1966

Daresbury Nuclear Physics Laboratory
Daresbury, Nr. Warrington, Lancashire

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CONTENTS

1. INTRODUCTION

The half-year to the end of October, 1966 has seen great progress towards the completion of NINA, the 4 GeV electron synchrotron. Indeed, during October, assembly was sufficiently far advanced for injection and inflection tests to be made into the completed ring.

The difficulties, reported in DNPL. 3, with the energy storage choke for the magnet power supplies have been overcome and at the end of October installation was complete and commissioning had commenced. The other major difficulty, the parasitic oscillations occurring in the R.C.A. triode amplifier which powers the accelerating cavities, is to be circumvented by the addition of plate modulation. However, this modification will not be ready in time for initial acceleration trials, which will, therefore use the output of the driver tetrode.

With the approaching completion of its main initial project, the Laboratory has been re-organised into different Groups. These are listed below with the names of the Group Leaders.

Administration	(Mr. H. Rothwell)
Applied Physics	(Mr. M. C. Crowley-Milling)
Electronics and Computer	(Dr. B. Zacharov)
Experimental Physics	(Dr. R. G. P. Voss)
Machine	(Mr. A. J. Egginton)
Services	(Mr. M. J. Moore)

The titles of these Groups are largely self-explanatory, but in connection with the Electronics and Computer Group, it may be mentioned that the Laboratory now possesses two computers, an IBM 360/50 and an IBM 1800. The latter is to be used as a data logger and control computer for the synchrotron.

This report gives further details of the physics experiments to be carried out when NINA becomes operational and also outlines the progress made in designing and assembling the necessary experimental equipment. Details are also given of a new experiment proposed by a combined team from Manchester and Lancaster Universities.

2. MAGNETS

2.1 Magnet Assembly and Test

By the beginning of August all magnets were assembled and correctly positioned in the ring. Two magnets had then to be removed to allow the energy storage choke, which arrived at that time, to be taken across the ring for installation in the Inner Hall. Following this the ring was again completed and the concrete shielding blocks, which cover the part of the ring which passes through the Experimental Hall, were arranged in their final positions with suitable channels for emergent experimental beams. This was completed at the beginning of September.

Tests with full a.c. power on the magnet windings started in October, and no difficulty with the magnets was experienced except that three of the pole-face windings burnt out. The fault was found to be due to displacement of some of the wires in the moulding, resulting in inadequate insulation between adjacent turns which failed due to the voltage induced by the high rate of change of magnetic field. The damaged windings were replaced immediately by spares, and replacements for these are now being manufactured. Vibration measurements made during these tests using an accelerometer have indicated that the levels are low. The maximum vibration of a magnet base plate was 0.002 in peak corresponding to an acceleration of 0.19 g.

2.2 Magnet Survey

The magnets were located finally in the ring using the survey techniques described in DNPL. 2. Two independent checks of this survey have been made. The first consists of measuring the offsets of three consecutive magnets from an optically defined chord between magnets at each end of the group of three. Using this method the offsets of eight groups of three magnets, uniformly distributed around the ring, have been measured. From the distribution in the magnitude of these offsets, the r.m.s. deviation of the radius from the mean has been calculated to be ± 0.0022 in. The second check was a measurement of the machine radius by measuring the distance from a ring magnet to the centre survey monument directly rather than by using a ring monument as an intermediate step. To do this, holes had to be drilled through the shielding walls to allow the Invar tapes to pass through. These measurements were made at seven points around the ring; the resultant r.m.s. deviation of the measurements from the mean was ± 0.0015 in.

The heights of the magnets were also checked independently of the survey monuments using one magnet as a datum and measuring heights of all other magnets with respect to it. The resulting r.m.s. deviation of the height of the magnets from the mean was ± 0.0012 in.

2.3 High Energy Beam Bumps

After the circulating electrons have been accelerated to full energy, it is necessary to steer the beam onto an internal target in order to produce bremsstrahlung photons. The target is so positioned in the F-type magnet vacuum chamber that the photon beam leaves the machine at the long straight section immediately following. It is also necessary to steer the circulating beam during electron beam extraction.

In order to deflect the beam, a localised distortion is made in the equilibrium orbit. This distortion is caused by passing a current pulse through windings situated on the back legs of several of the synchrotron magnets, and thus causing temporary magnetic field perturbations in the magnets.

A simple "beam bump" can be obtained by applying uniform field perturbations $-\Delta B$, $-0.15\Delta B$ and $-\Delta B$ on three consecutive F-type magnet units. This system gives a single radially outward beam bump with a maximum in the centre magnet of the triplet and with very little orbit distortion elsewhere. Removal of the excitation from the centre magnet increases these unwanted distortions but this simpler system is still usable. The field perturbations are now $-\Delta B$, 0, $-\Delta B$. Excitation of the beam bump windings is liable to induce transient oscillations in the main magnet power supply network. The amplitude of these oscillations can be reduced by employing a beam bump of such a type that the sum of the field perturbations is zero. (The amplitude would in principle be reduced to zero if all the perturbed magnets were within a single one of the 10 series-connected magnet groups). In the present case zero net field change is attained by superposing three beam bumps, the outer ones moving the beam radially inwards to half amplitude and the middle one moving it outwards to full amplitude. If the maxima are given a separation of two magnet periods the field perturbations are seen to be $+\Delta B/2$, 0, $-\Delta B/2$, 0, $-\Delta B/2$, 0, $+\Delta B/2$.

Either one or two turns of back leg windings are used on each magnet in the beam bump system. In order to allow for overlap of several systems, a total of six turns have been provided on each back-leg. The turns consist of 1 in $\times \frac{1}{4}$ in copper strip conductors insulated with $\frac{1}{8}$ in thick nylon. The windings are constructed in such a way that they can, if necessary, be installed on or removed from a fully assembled magnet.

The power supplies for the windings utilise a pulse forming network, which is charged up and then discharged through the windings to give an approximately rectangular pulse, variable in duration from 1 to 3 milli-secs. The shape of the pulse can be varied over a limited range by adjustment of the inductors which form part of the pulse forming network. It is hoped to use this adjustment to optimise spill time.

Four beam bump systems have been installed and testing of the associated pulse power supplies is well under way.

3. VACUUM SYSTEM

3.1 Vacuum in the Ring

The ring vacuum system was closed at the beginning of October in preparation for the "first turn" studies. All sector valves and the isolating valve for the injection flight path were opened and pressures ranged from 2×10^{-7} torr to 2.5×10^{-6} torr. Some vacuum difficulties have been experienced with the

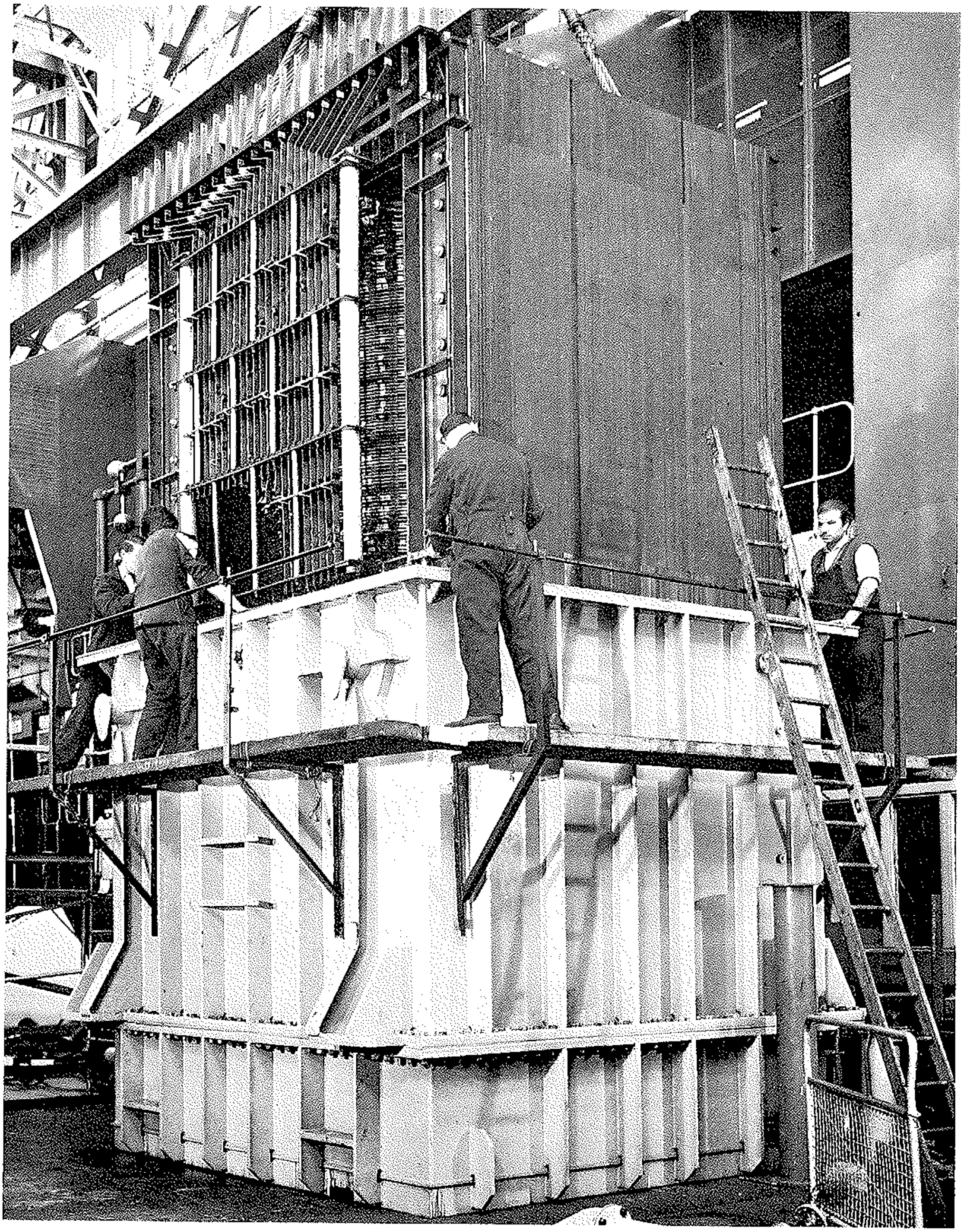

FIG. 1. THE ENERGY STORAGE CHOKE BEING LOWERED INTO ITS OIL TANK

r.f. cavities, especially at the seals on the ceramic rings used to isolate the cavities from the rest of the system. This has resulted in minor r.f. breakdown in some cavities. During trials with an injected beam at 40 MeV no appreciable pressure rises were observed even when all the beam was lost in the first vacuum vessel after the inflector. However, the beam current was much smaller in these tests than will be finally injected.

Ion pump currents are used for measurement of pressure and indications are available in the main control room either as selected readings on a digital voltmeter or displayed as separate vertical deflections on an oscilloscope, thus giving an overall picture of conditions in the ring. One reading from each sector is fed to the data logger. A pressure sensitive switch operating from a Penning gauge in each sector gives an alarm if the pressure rises above 10^{-5} torr and switches off the injector.

When magnets were excited with a.c., the temperature rise, due to eddy currents, in a vacuum chamber was only 3°C in agreement with results obtained on prototype tubes.

3.2 Vacuum Development

Consideration is being given to proposals from three interested companies for the procurement of ceramic vacuum vessels. A prototype short length, made by Ferranti Ltd., has been tested and showed a very low outgassing rate. When pumped down to a pressure of 6×10^{-9} torr at room temperature, the pressure rose only to 2×10^{-8} torr when the chamber was heated to 100°C.

Two rigs are now in use for measurements of outgassing rates of materials to assess their behaviour at pressures down to 10^{-9} torr. A Mass Filter unit is used in connection with these rigs to analyse the gas released.

4. MAGNET POWER SUPPLIES

4.1 Energy Storage Choke

DNPL. 3 gave an account of the troubles experienced with the initial assembly of the energy storage choke. The re-assembly of the coil stack in its iron mantle was completed by the middle of May and measurements were made, prior to the fitting of cleat bars, to see if the choke was now satisfactory. The settings of the auto-transformer in the primary circuits were determined and the number of secondary turns chosen to give the optimum performance. Fig. 1 shows the choke being lowered into its tank at the English Electric Co. factory.

On completion, the choke was shipped to site in early August, and was installed within the sound-reducing enclosure by the end of the month. Connections to the busbar system took a further month and the system was then tested at 30 kV d.c.

4.2 D.C. Bias and Pulse Power Supplies

The power supply system could not, of course, be completely tested in the absence of the choke. Preliminary commissioning of the d.c. bias power supply, up to 40% of full current, was carried out using a resistive load and the current stability found to be within the specified limits. However, the motor drive in the voltage regulator system showed a tendency to stall at slow speed operation on outputs below 15% of full load. This fault was rectified by the suppliers, Brentford Electric Ltd.

When final connections at the magnets had been made, at the end of September, continuity and polarity checks were made by circulating a small direct current through the network.

A temporary a.c. supply, rated at 16 kW, was used to power the network up to 20% of the normal excitation level during the first week in October. The losses at full rating could then be calculated so that the pulse power supply storage capacitors, filter choke and pulse choke settings could be adjusted to suit these losses. The tests also indicated that the network was well balanced and could be resonated close to 50 cycles per second.

When the energy storage choke installation was completed, commissioning of the pulse power supply commenced on 18th October. Initial checks showed that the pulse valve, hitherto untried, and its associated auxiliaries, operated satisfactorily. Checks were also carried out on all the high speed logic protection devices.

The capacitor banks were trimmed to resonate the magnets at 50 c/s, to minimise a.c. current at the d.c. bias connections and to minimise and also equalise the choke primary circulating currents. The a.c. excitation on the magnets was then increased in stages from 10% to 100% of full load (480 A r.m.s.), the latter being reached on 31st October.

5. R.F. SYSTEM

5.1 General

By the end of October, the system of waveguide and cavities had been energised from the high power driver amplifier intermittently for almost three months. During the early part of the period covered by this report, the waveguide system was tuned to ensure that all cavities would be energised in phase. As soon as all five cavities were under vacuum, it was possible to apply r.f. power and commission the automatic tuning. The 2041 driver amplifier had, by this time, been up-rated as mentioned in DNPL. 3, and will now give, with the drive available, an output of 85 kW peak. It has been run up to 30 kW average on rectangular pulses.

The master oscillator, phase-locked to a crystal, has provided a stable signal for the injector, as well as for the r.f. system, during most of the period. The frequency modulation facility is now being incorporated, together with a control for detuning the cavities by changing the frequency of the tuning pulses (which occur between acceleration cycles).

During the latter part of the period a start has been made on the investigation of the response of the waveguide-cavity system to both pulses and sine-waves and on the realisation of an amplitude feedback loop. Initially, the aim will be to achieve modest loop gain and band-width figures, to improve linearity and to make the cavity voltage more independent of changes in load impedance due to mistuning or beam loading.

The amplitude programme equipment which takes signals proportional to B and dB/dt and produces the correct cavity voltage waveform is complete and being installed. This and the phase diagnostic system will be described in a future report.

5.2 Waveguide

The r.f. accelerating system uses five equally-spaced cavities fed by means of waveguides connected by series-tee junctions to a waveguide ring in the lower tunnel (Fig. 2). This ring was made resonant by adjustment of phase-shifters between the risers. The electrical lengths of the waveguides between ring and cavities were also adjusted, such that, on detuning the cavity each side of resonance, the forward power in the waveguide feed falls off symmetrically.

By detuning four cavities it is possible to feed all the r.f. power into the remaining cavity, provided the matching into the ring is appropriately adjusted, and use has been made of this to assist in outgassing the cavities.

5.3 Cavities

Some r.f. breakdown has been experienced, possibly because of vacuum difficulties, on the installed cavities, but now only three of the cavities show any evidence of breakdown. The breakdown, which causes only a few per cent. reduction in cavity voltage, occurs after the first four milliseconds of a rectangular pulse and then only over a limited, fairly low range of power input. It is hoped this will clear up with further pumping and r.f. operation.

The automatic tuning system showed two defects, both of which have now been largely eliminated. The gating pulse, during which the error signal from the phase detector is fed to the servo drive, was originally longer than the r.f. tuning pulse. This meant that transients were included. These proved to be different in character in the ring system, compared with an isolated cavity, and disturbed the tuning. When the gating pulse was narrowed the effects disappeared. The other problem was drift, particularly with change of mean power level. Certain minor modifications have greatly reduced this.

5.4 High Power Amplifier

In July, R.C.A. stated that considerations of time, cost and technical uncertainty precluded further work on the 2054 amplifier circuit as a way of eliminating the parasitic oscillations. They proposed instead that the most certain way of overcoming the difficulties in a reasonable time was to build a plate modulator. It was eventually agreed that they should do this. Design is now almost complete and construction well advanced. Delivery is to be in February, 1967, and, by April, it is hoped the high power amplifier will be operational. Various other methods were considered, DNPL proposing either a cathode modulator or the use of a non-linear cathode bias resistor. In the light of the limited experiments which had already been done varying the cathode bias, however, it is felt that these approaches

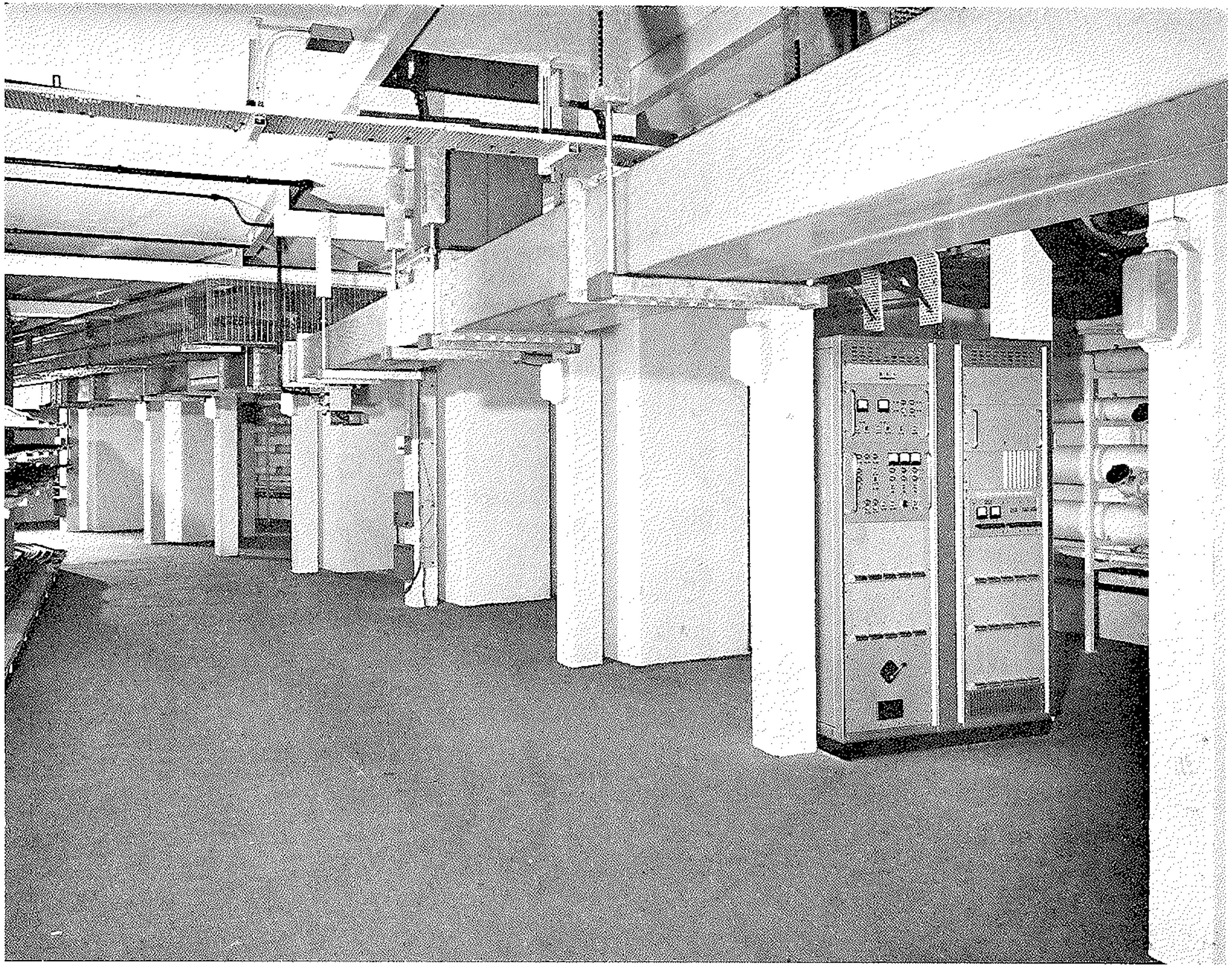

Fig. 2. The Lower Tunnel showing the Waveguide Ring and Cavity Control Racks

6.5 Beam Sensing System

The beam position sensing devices have all been manufactured. Vacuum tests on the first device indicated a high outgassing rate, caused by the dust core toroids used in the current transformers. The outgassing rate has been reduced sufficiently by vacuum encapsulation of the transformers, using the copper screening cans as a container for the epoxy resin. A resin with a low vapour pressure has been used, and it is expected to have reasonable resistance to radiation damage.

Four position monitors and two intensity monitors were used during the injection tests. Problems arose because of the large pick-up signal produced by the switch-off edge of the inflector pulse current. To overcome these problems, the inflector is being more effectively screened, the input connections to the amplifiers in the ring are being double screened and attempts are being made to obtain a single earth point for the whole beam sensing system.

6.6 Power Supplies

The pole-face winding power supplies were used during the inflection tests for correcting the remanent fields of the magnet. As a result of this operational trial, some modifications are being made to the control equipment and minor faults on the power units are being rectified.

Two of the pulsed power units for high energy beam bumps have been completely assembled and one set of back-leg windings has been successfully energised. The back-leg pulsing produces two unwanted effects, one due to magnetic coupling between the back-leg and pole-face systems, and the other due to the excitation of the 500 c/s transmission line mode of the magnet power supply system.

It is hoped that the first effect, which produces unacceptably high voltages at the pole-face winding power supply units, can be circumvented by using suitable filter circuits. The second problem may be solved by employing a longer pulse rise time.

7. INJECTION EQUIPMENT

7.1 Linear Accelerator

The 40 MeV linear accelerator was operated for the first time at Daresbury on the 26th June, 1966, producing a beam of 600 mA. Since then the M.E.L. Equipment Co. Ltd. commissioning team has been working to improve the performance and reliability of the equipment. Tests to see whether the accelerator meets the performance specification have not been carried out, since throughout the period the temporary diode gun and modulator was in use. The final modulator and triode gun, originally expected in August, was not shipped from the factory until the end of October.

Flattening of the tops of the pulses applied to the high power klystrons has been completed. The variation during 1.5 microsec. was within $\pm 0.2\%$ the corresponding phase change between input and output being less than 5°. Flattening is achieved principally by selection of tapping points on the coils of the pulse forming networks. It was carried out with the klystrons operating at the 24 MW level with their heater powers set at the recommended level of 330 watts. This setting is important since it is found that the impedance of the klystron is somewhat dependent on heater power. The modulators have run for long periods with good reliability.

Attempts were also made to flatten the pulse applied to the drive klystron, an Eimac X3029. It was found, however, that with a reasonably flat voltage pulse, the phase across the tube varied almost linearly throughout the pulse by about 18°. The spare klystron was tried and was found to need 100 hours of conditioning before it produced a full r.f. pulse. The behaviour was then similar to that of the first tube. Similar behaviour has been observed at S.L.A.C. and attributed to gassiness. Clearly, it may limit the performance obtainable from the injector and steps are being taken to obtain a satisfactory replacement.

The chief limitation on the performance of the accelerator during the period has been the temporary gun modulator, since this does not produce a flat voltage pulse. The current from the gun varied during the pulse giving rise to energy variations of some $2\frac{1}{2}\%$. The current through a 1% energy slit, however, had peaks of 400 mA giving some hope that the specified current might be obtained if the new gun modulator works satisfactorily.

Some multipactor discharge occurs in the prebuncher cavity and this has persisted in spite of several changes of geometry. Experiments are in progress to see whether the trouble can be overcome by a suitable surface coating. There is a range of power level free from the effect and so the improvement in

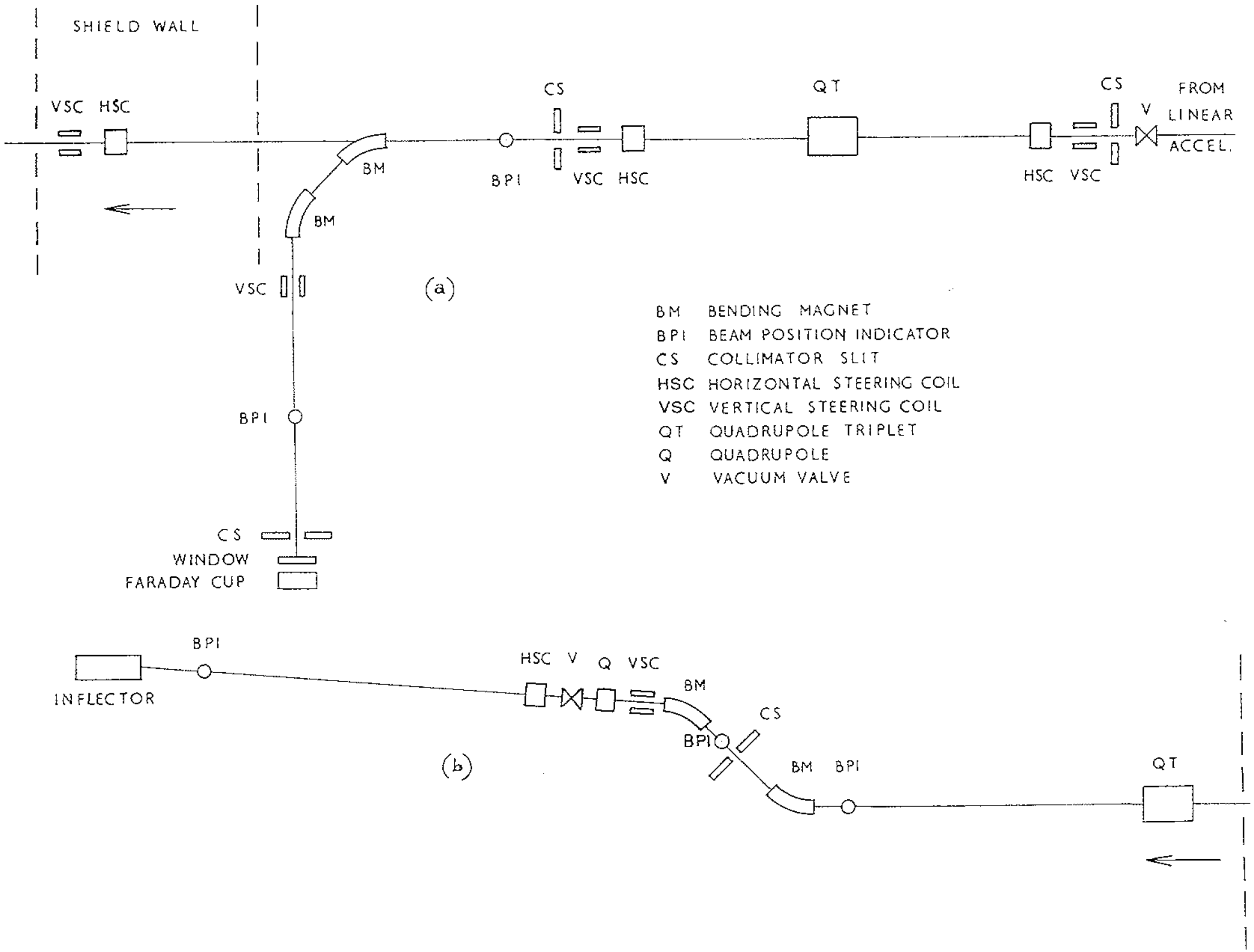

FIG. 3. SCHEMATIC LAYOUT OF THE INJECTION PATH
(*a*) IN THE INJECTOR ROOM (*b*) IN THE RING TUNNEL

performance of the accelerator by using the prebuncher could be assessed. It appeared to double the current in a 1% energy width for a given injected current from the gun.

Some delay and extra work in the commissioning programme arose due to the unsatisfactory design of the focusing coils, between the gun and the accelerator. These coils, were originally water-cooled and failed due to electrolytic action. They have been replaced by oil-cooled coils.

The accelerator was run for long periods during injection and inflection trials into the ring in October. Because of the variation of spectrum during the pulse the phasing of the accelerator was set to give a wide spectrum with an approximately constant, but low, current appearing in a 1% energy bite. Details of the tests are given in Section 8.

7.2 **Injection Path**

Some details have been given in DNPL. 3 of the injection path design as regards momentum and emittance matching of the injected beam to the synchrotron. A layout of the path showing the principal components is given in Fig. 3. It divides into a section within the linear accelerator tunnel, with emittance measuring equipment, spectrometer magnets and a beam dump area, and a section in the ring building where the momentum matching system and the inflector are situated. Between the two is a shield wall, 10 feet in thickness, to enable running of the injector on its own into the beam dump area, yet allowing access to the ring. In these circumstances, in order to ensure personnel safety in the ring, the spectrometer magnets must be energised and a beam stopper inserted in the path between the first spectrometer magnet and the ring before the injector can be switched on.

All the pipework is in stainless steel, but water-cooled aluminium blocks with relatively small apertures have been inserted at various points to prevent deflected beams from hitting the vacuum pipework. Where the latter is bent to form a path through bending magnets, water pipes have been brazed to the side walls.

Saddle coils are clamped to the vacuum pipes at a number of points along the path to give vertical and horizontal beam steering. Also inserted at various points are beam position and total current monitors, which use coils wound on mumetal cores surrounding the beam path. Four coils are arranged in pairs to feed differential circuits which give signals when the beam deviates from the axis. Summation to give total current is also made. Another similar monitor is also mounted near to the inflector. In this case a rectangular B1 ferrite frame with four coils on it is mounted inside the vacuum box.

A trim coil on the second bending magnet, together with vertically deflecting saddle coils and a horizontal steering coil, enable the beam to be steered into the inflector. This combination can be used to explore the acceptance of the synchrotron.

Collimator slits in the injection tests system are arranged to traverse across the beam path by remote operation. When they have served their purpose for emittance measurement, they will be converted to enable the width of the slits to be adjusted remotely about the central position, thereby giving control of the amount of beam current passing. A slit system, converted in this way, has also been placed between the two bending magnets to give some control of the energy spectrum of the beam being injected into the synchrotron.

The first section of the injection path was completed in June ready for initial linear accelerator tests and the subsequent section, in the ring building, was completed in time for the first injection trials into the ring in early October. The chief delays proved to be in the procurement of vacuum pipes and vessels promised delivery dates being exceeded by several months.

7.3 **Inflector**

The design and construction of the inflector has been described in previous reports. The assembly was completed in August and installed in its vacuum box in the ring. A photograph of the assembly with the lid of the vacuum housing removed is shown in Fig. 4, which also shows some details of the modulator.

The inflection modulator, constructed by Staveley-Smith Limited to an A.E.I. design, was completed and delivered to site by early July. This equipment consisted of the modulator, the control cubicle and panels for the injector and main control rooms. The modulator itself had to be assembled immediately adjacent to the inflector in order to minimise the circuit inductances and this involved a good deal of assembly and wiring on site. However, the modulator was ready for testing by the middle of August

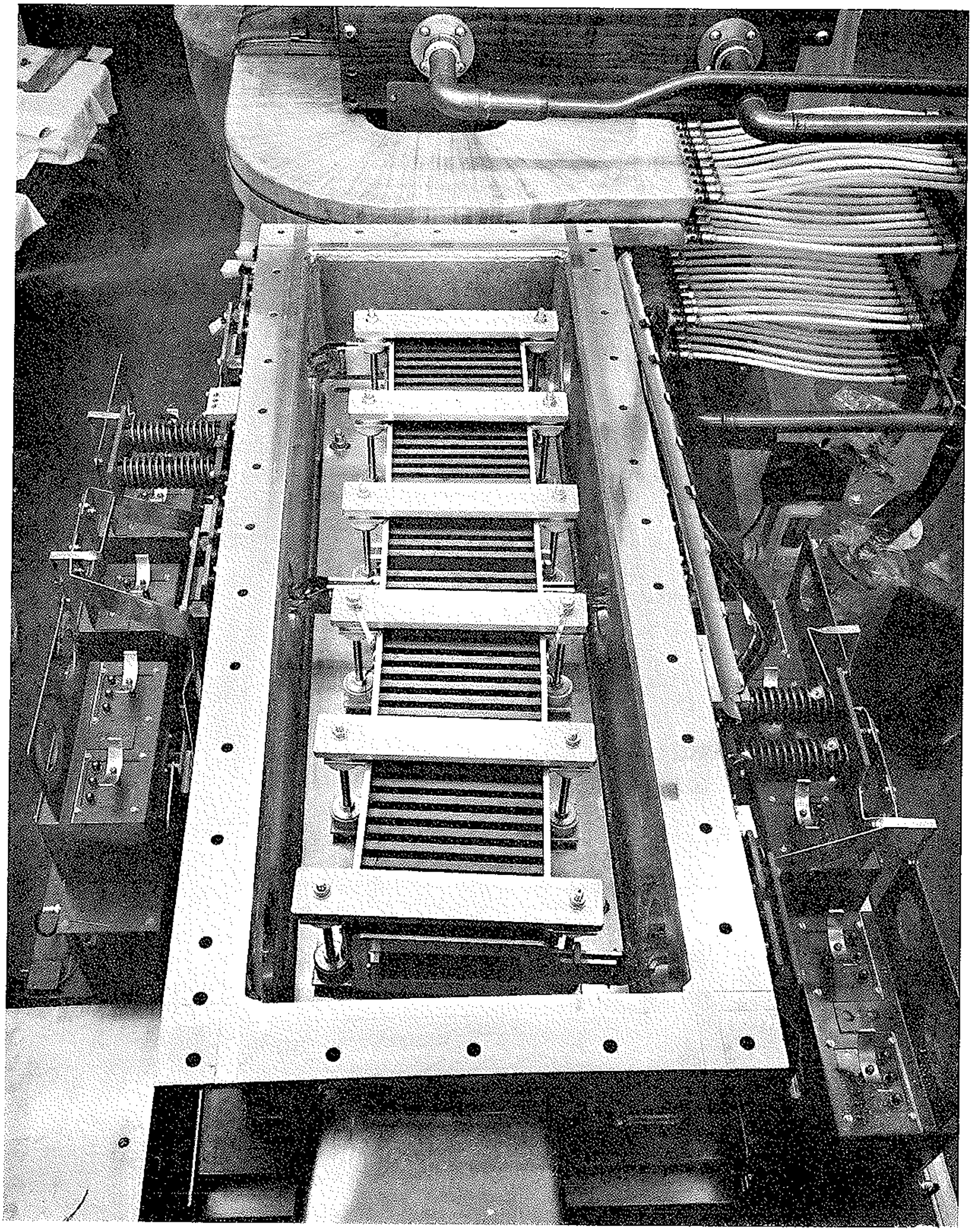

FIG. 4. THE INFLECTOR ASSEMBLY IN ITS VACUUM HOUSING

10. SERVICES

10.1 Design and Drawing Office

Work on the experimental equipment for NINA has been intensified to meet the requirements of the Experimental Groups. Manufactured items are now arriving in the Laboratory and are being assembled in the experimental area.

10.2 Mechanical and Electrical Sections

The work on installing NINA is drawing to a close and more emphasis is being placed on experimental equipment. The work load on the mechanical shop has increased considerably over the last six months and continues to be diversified. Assembly of spectrometer arms, quantameters and other gear continues both in the workshop and Experimental Hall.

The small group working on liquid hydrogen targets has tested successfully the first of a series of targets. Fig. 6 shows the reservoir and target for the Manchester University experiment. This group will shortly move into the new extension to the workshop where the conditions are more favourable for the type of work involved. Testing will, of course, be carried out in the Cryogenic Test Area.

The Electrical Workshop is fully extended on numerous projects for the Experimental Groups and the major item in this category, the 4 MW d.c. distribution network for experimental magnets is making good progress and will be finished by the end of the year. Approval has been given for the second phase of the supply of a.c. to the new plant room and work is in hand to place orders for the plant at an early date.

10.3 Building Development

The Computer Laboratory was finished in June and has proved satisfactory in use, whilst the Cryogenic Test Area was completed in July.

Building Contracts have been let for the new Laboratory and Office Block and for the Experimental Hall extension. The latter should be ready for occupation in January, 1968 and the programme for the completion of the former has been phased as follows:—

Electronics Section	August, 1967
Main Laboratory Section ...	April, 1968
Lecture Theatre Section ...	August, 1968

11. COMPUTER

11.1 Introduction

As part of the reorganisation of the Laboratory a new group has been formed with responsibilities both in computing and electronics. At the present time, the scope of the group is to provide a computing service, both on and off line; to develop and maintain electronic equipment used for fast logic, interface systems and controls; and, finally, to develop the computer synchrotron-control system. Some of this work has been described in Section 6.

11.2 Computing Services

After a period of intensive test running, the IBM 360/50, which was installed in the new computer building in July, was finally accepted by DNPL, on schedule, on 1st October. A general view of the computer room is given in Fig. 7.

The IBM 360/50 configuration at present installed has a control processor with 64×10^3 words storage. The peripheral equipment attached includes three disk-pack units, each of 2×10^6 words capacity, and four magnetic tape units with ability to read and write both seven and nine track tapes. Also installed is a high-speed paper-tape reader for five to eight hole tape.

Starting off with day-time shift running only, after one month the IBM 360/50 was used on weekdays for an average of about twelve hours per day.

11.3 Data Preparation

A new data-preparation room is now ready, next to the computer room. Equipment has been installed in this room for card punching and reproducing, and there are also interpreting and sorting facilities. Some space has been made available to users for card storage, and a room has been provided

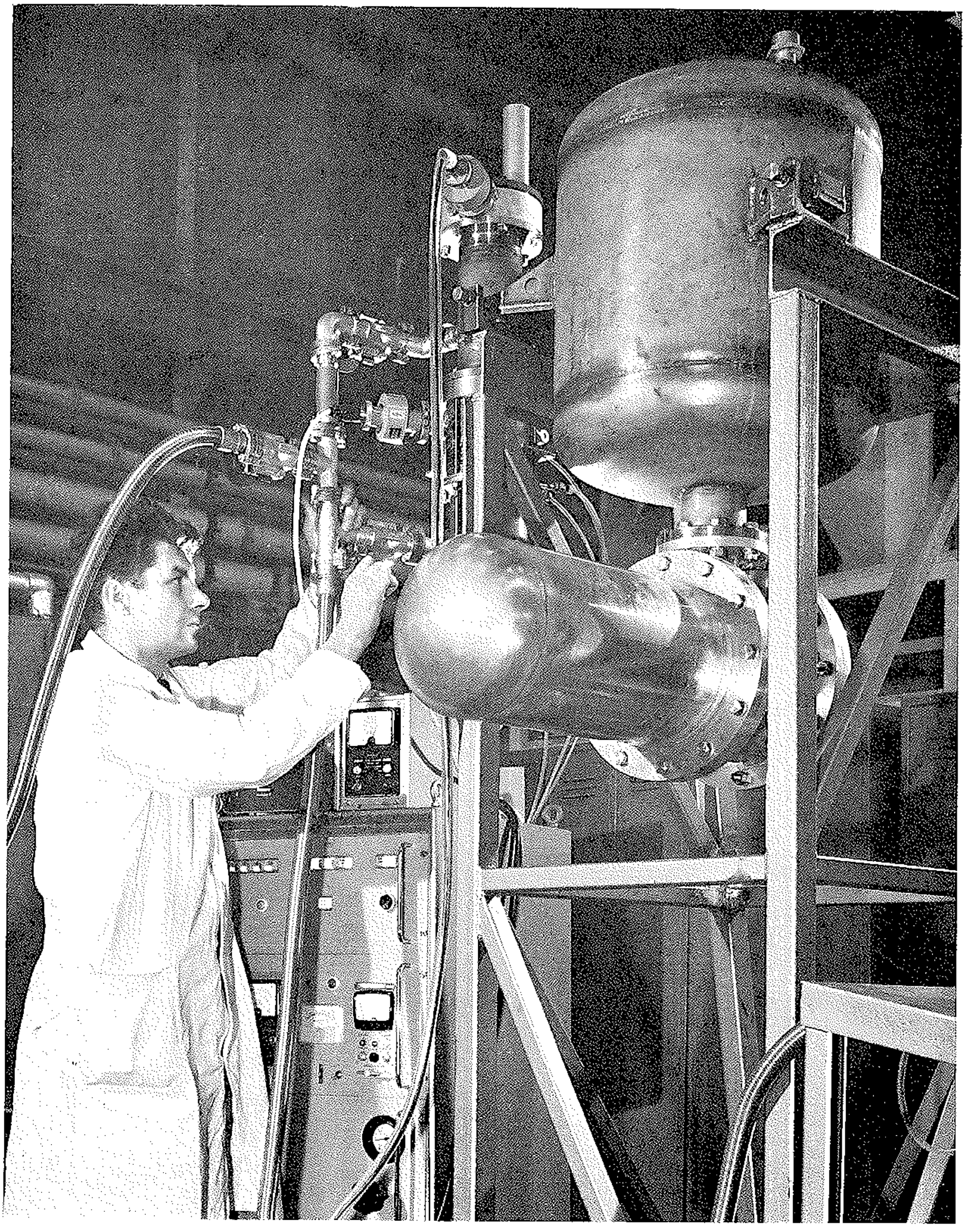

Fig. 6. Liquid Hydrogen Target and Reservoir

12.3 Quantameters and Integrators

During the first phase of the experimental programme at Daresbury, photon beam intensities will be measured by means of Wilson type quantameters. Four of these are to be provided, and all the components are now being manufactured. Delivery of the final batch of copper absorption plates and of one complete set of stainless steel components is expected by the first week in November. A unit will then be assembled.

Four sets of U.K.A.E.A. type 3008 integrators, for use with the quantameters, have received extensive tests to assess their long term stability and accuracy on all ranges. The units have been calibrated on the 10^{-5}, 10^{-6} and 10^{-7}; coulombs/cycle ranges using a test current source accurate to $\pm 0.2\%$. The absolute accuracy and the stability of the source when set for the 10^{-8} and 10^{-9} coulombs per cycle ranges were not as good. Long term tests indicate that, on all except the 10^{-9} coulombs per cycle range, the units are stable to $\pm 1\%$.

12.4 Counting Systems

The first contractual period for the supply of fast logic modules by E. G. & G. has ended and negotiations for the extension of the contract are under way. During the twelve month period about 630 modules were bought and distributed among the groups intending to carry out experiments at NINA.

Deliveries of photomultiplier housings were recently completed and nearly 200 housings have been issued. A contract for the supply of an additional 200 units is under discussion.

Negotiations with Ferranti have resulted in an improved packaging of the XP20/21 fast light source. The new package, the EXP548, as supplied to the Laboratory, is easier to connect to external drive circuits and lends itself well to being embedded in scintillation counters.

13. BREMSSTRAHLUNG SPECTRUM MEASUREMENTS

An experiment is being prepared to measure the bremsstrahlung spectrum from an internal target in order to provide data for experimenters using photon beams. The apparatus consists of a magnetic pair spectrometer using a W.17 bending magnet. The photons in the beam will be allowed to strike a thin foil located in the magnet and a known proportion of them will convert into electron-positron pairs. Symmetrical pairs in a known energy band at a given energy will be registered in two scintillation counter telescopes located symmetrically at about 18°, on either side of the beam line, about two metres downstream of the magnet. The energy of the pairs will be determined by the magnetic field strength in the magnet. By counting the number of pairs registered in coincidence it will be possible to estimate the number of photons at that energy in the given energy band. The spectrum can be plotted by counting the pairs as a function of field strength in the magnet.

The counters and their associated electronics will soon be ready, together with the necessary hardware for mounting them and the converter foil. It is hoped to make a start on this experiment at the end of the year. The whole experiment should not take more than about 3 months to complete.

14. EXPERIMENTAL PHYSICS PROGRAMME

14.1 The Photo-production of π° and η mesons (Liverpool Group)

Experiments of pion-nucleon scattering have revealed a complex situation in the baryon mass region around 1690 MeV. There seems to be good evidence for four resonant states whose energies almost coincide. Since it will certainly be important to ascertain the proportions in which these states are excited by photons we intend, as a first step, to make accurate measurements of the π° photo-production angular distribution as a function of photon energy between about 900 MeV and 1150 MeV.

The production of η in both the processes $\pi^- + p$ and $\gamma + p$ shows a large peak in the cross-section just above threshold ($E_\gamma = 720$ MeV) attributed to an S-state resonance which decays to η rather than to π. Measurements of angular distributions will be made, looking for evidence of other resonances decaying to η in the range of incident energies up to 2 GeV.

The apparatus consists of a range telescope to detect the protons and a lead glass Cerenkov counter to detect the γ-quanta from the decay of the π° or η. The proton telescope has 9 scintillation counters with copper absorbers between them and is placed at the focus of a quadrupole triplet. This serves to increase the solid angle and also focuses protons of a particular angle to a point in the horizontal plane where they are detected by a hodoscope of 10 angle counters in front of the range telescope.

This telescope has been tested and calibrated in the proton beam of the Liverpool synchrocyclotron over the energy range 80 to 380 MeV. The correction for nuclear absorption and scattering amounts to 54% at the higher energy and this has been determined to an accuracy of ±2%.

The γ-detector consists of an array of 49 lead glass blocks 8 cm ×8 cm ×35 cm in size, each one viewed by a 2 in photo-multiplier. The outputs from these can be either added linearly or taken separately to analogue-digital converters.

When a $p-\gamma$ coincidence occurs the state of the proton and gamma counters is recorded on bi-stable circuits which are then scanned by a highway system which transfers the information either onto paper tape or into a PDP8 computer.

The experiment will be controlled from two portable laboratories (30 ft ×8 ft) which will be situated just outside the hall. These have been delivered, one to Liverpool and one to Daresbury, and electronic equipment is being installed in the former. The highway system has been designed and built by the electronics group at Liverpool and is at present being tested. The analogue-digital converters are also being built by them. The rest of the electronics consists mainly of standard E. G. & G. modules and most of it is to hand. The computer will be delivered early in 1967.

The state of the other parts of the equipment is as follows: the two platforms for the proton and gamma systems are fabricated and the centre pivot arrangement will be ready by the middle of November. The vacuum chamber for the proton quadrupole system is almost complete. Fifteen of the lead glass blocks and 25 photo-multipliers have been received with the remainder of both promised in a few weeks' time. The parellel-sided liquid hydrogen target has been designed and construction will start shortly.

14.2 Manchester University Experiment on K° Photo-production

Work has continued on design and setting-up for an experimental study of the photo-production of K° mesons, to be carried out at Daresbury. A magnetic tape unit, a fast paper-tape reader and a display unit have been connected to a PDP 8 computer. These units have been tested with appropriate programmes. An interface system for reading data into the computer from up to 16,000 magnetic cores in an array of wire spark chambers has been constructed and tested. Three of the wire spark chambers, each 60 cm by 120 cm with 22 wires per inch, have been constructed. Magnetic core systems have been constructed and are now under test with the spark chambers, using cosmic rays and β-sources. The mechanical layout of the experiment has been designed and setting up work at Daresbury is in progress. The electronic system consisting mainly of E. G. & G. units is being set up. Special circuits for fast pulses and for deriving information about the NINA r.f. phase have been constructed. A large amount of computer work, using the Daresbury IBM computer, has been done in preparation for the analysis of the experiment. It is expected that the apparatus will be ready to run by the time a beam is available from NINA.

14.3 Glasgow University Experiment

In this experiment the polarisation of the recoil protons from elastic e-p scattering will be measured at values of the square of the four-momentum transfer, q^2, between 25 and 50 fermi $^{-2}$. A brief description of the experiment has been given in DNPL 3.

The protons will be momentum analysed by a magnetic spectrometer consisting of two Q29 quadrupole magnets and a W17 bending magnet, mounted on a rotating platform. These items are all under construction, the magnets are due for delivery shortly and the platform early in February, 1967.

The analysed protons pass through a liquid hydrogen target 4 cm in diameter and 60 cm long. The design of this target is complete and construction will commence shortly. Protons from elastic p-p scattering events in the hydrogen target will be detected by two sheets of plastic scintillator, each 28 in long by 10 in high, placed on either side of the target. The light from these scintillators is carried by sixteen shaped perspex strip light guides to a single 5 in photo-multiplier placed below the hydrogen target. These light guides have been successfully constructed and the whole system will shortly be tested. The tracks of the incident proton and the two scattered protons will be detected in four wide gap spark chambers, which have a gap width of 6 in and which are pulsed to 150 kV by Marx generators. These spark chambers and their pulsers have been manufactured and have been tested individually on cosmic rays. Further tests will be made shortly with high energy electrons from the Glasgow synchrotron to check their operation in higher fluxes of particles and also their efficiency and track luminosity as a function of track angle relative to the electric field direction.

Each chamber is viewed in two orthogonal directions by a mirror system which has been designed to fit these eight views onto the format of a 35 mm camera. The supporting structure for these mirrors and for the spark chambers themselves has been constructed at Glasgow and when optical tests are complete it will be transported to Daresbury. It is planned that the film will be measured and the track co-ordinates digitised on the automatic c.r.t. digitiser at the Rutherford Laboratory. Close contact is being maintained with the Rutherford group to ensure that the film format is compatible with their machine.

In order to ensure that only protons associated with elastic e-p scattering at the primary target are recorded it is necessary to detect the scattered electrons in coincidence with the recoil protons. For this purpose a half quadrupole magnet, type HQ29, focusing in the vertical plane, will be mounted on a second rotating platform. A shower counter will be used to detect the electrons. The design of this small platform is complete and a contract for its manufacture will be placed shortly. The shower counter, consisting of sixteen sheets of plastic scintillator, interleaved with an equal number of lead plates, each one radiation length thick, is almost complete and will shortly be tested in a beam of 300 MeV electrons.

The fast electronic logic which will be used to trigger the spark chamber system, when appropriate signals are received from the scintillation detectors, has been assembled and tested at Glasgow. Because it is desirable to minimise the delay between the time of an event and the time at which the spark chambers are pulsed, this fast logic will be mounted in racks situated on the floor of the experimental hall. The remainder of the electronic equipment, such as the photomultiplier power supplies, scaled for monitoring various counting rates, magnet controls, etc. will be situated in the counting room.

14.4 **Daresbury Laboratory Experiment**

The initial proposal by this group to study symmetric wide angle electron pair production in carbon has now been modified as a result of the recently reported experiment performed at DESY, Hamburg by a DESY-Columbia group. Their results show that Quantum Electrodynamics correctly predicts the electron pair yield in contradiction to the earlier results of the Harvard group, which gave a large deviation between theory and experiment.

The Daresbury Group is proposing to measure electrons and muon pairs to test Q.E.D. down to 0.1 fermi and also to provide a sensitive test of the equivalence of the electron and muon propagator. The accuracy of the comparison between theory and experiment is limited by the presence of additional Compton pairs and nucleon form factor uncertainties. The Compton pair process can be measured by studying the distribution of asymmetric pairs and the uncertainties in the form factors minimised by measuring the symmetric pairs in hydrogen.

Charged particle pairs which are produced at small angles to the incident photon beam direction are momentum analysed by two identical magnetic spectrometers situated on either side of the photon beam line. The spectrometer bends the particles in the vertical plane, which allows the use of a long target without any loss of angular definition in the horizontal production plane—an essential property when measuring the strongly angular dependent pair production process in hydrogen. A general arrangement of the spectrometers illustrating the counter detection system is given in Fig. 8.

Each spectrometer consists of two half-quadrupole lenses (HQ 35) and a bending magnet (W. 17). The complete magnet and counter system is mounted on a 15 m long platform pivoted at the target and supported at three points along its length on ball castors which run on hardened steel plates attached to the floor. Each platform has a load capacity of 100 tons. At present, one of the platforms has been completely assembled and work is in progress on the second platform. It is expected that the platforms will be positioned on the floor by the end of November and sufficient spectrometer magnets will be available to build up one arm at the end of the year.

The energy and production angle of each particle of the pair is determined by placing scintillation counter hodoscopes at the exit of the spectrometer. Electrons are distinguished from the large background flux of pions, etc. by a 2 metre long threshold gas Cerenkov counter and shower counters of the lead/lucite sandwich type. Each Cerenkov and shower counter combination is expected to have a combined rejection for pions, the largest source of background, of 0.01% per channel. Muons are distinguished by their range in iron absorber, since all the strongly interacting charged particles are absorbed before reaching the end of their range. Approximately 2% of all the muons from pion decay

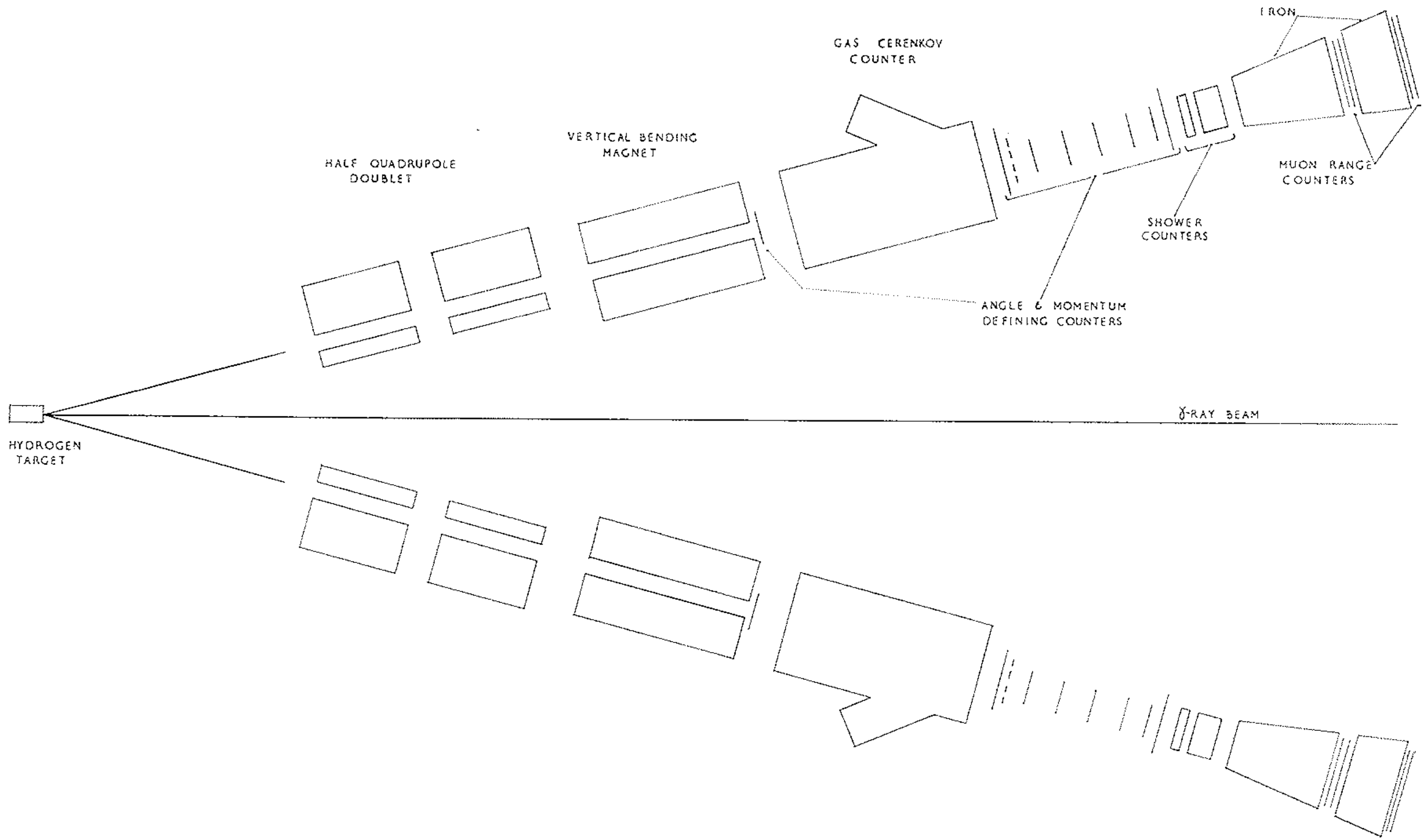

FIG. 8. LAYOUT OF THE WIDE-ANGLE PAIR PRODUCTION EXPERIMENT

in flight are expected to be recorded in the range counter. Most of these decays are produced after the bending magnet, which removes all the "out-of-channel" decay muons.

Construction of all the scintillation counters except for the muon range counters is complete, and each counter has been individually tested and calibrated with cosmic rays. The counter stands have been manufactured and the method of alignment of the counters is presently being examined. The components of the Cerenkov and shower counters have been manufactured, and are being assembled. One shower counter is now complete and is undergoing preliminary tests with cosmic rays to estimate the light collection efficiency. The efficiency of the Cerenkov and shower counter for rejection of pions will be determined when NINA becomes operational. A fast light source, the EXP. 548 (Ferranti Ltd., England) is incorporated in each counter of the experiment. This allows the stability and timing of the counters and electronics to be easily checked.

The output of each counter is taken to the fast electronics and data acquisition system in the counting room, a distance of approximately 90 m. Installation is nearing completion of the 200 data links and other cables linking the counting room to the Experimental Hall. Analogue and digital information from the counters will be transferred from scalers to paper or magnetic tape for later analysis by the IBM 360/50 computer. The paper tape "highway" is operational and delivery is expected shortly of the interface unit, which will allow faster rates of data transfer from the experiment onto an IBM magnetic tape unit (7330).

14.5 **Lancaster/Manchester Experiment**

A group from the Universities of Lancaster and Manchester proposes to study electron-proton inelastic scattering and in particular the electro-production of nucleon isobars. It is assumed that the electro-production process is dominated by one photon exchange and thus can be regarded as photo-production by polarised virtual photons. The multiple analysis of the angular distribution of the decay products of the isobar is more complex than for real photo-production, but contains more information. Since peripheral mechanisms are less important, and since it is experimentally more convenient, it has been decided to study the process $ep \to ep\,\pi^0$ rather than $en\,\pi^+$. The electron and proton will be detected in coincidence.

The experiment will be carried out using a 4 GeV/c extracted electron beam incident on a 7.5 cm long hydrogen target. The inelastic electrons will be detected with a magnetic spectrometer consisting of two half-quadrupoles and a bending magnet mounted on a platform pivoted at the target. A lead/lucite shower counter will discriminate against negative pions. A similar magnetic spectrometer will detect the protons and, in order to separate the contributing multipole amplitudes, the spectrometer is being designed to move between 25° and 70° in the horizontal plane, and from 0°-30° vertically. Both spectrometers contain scintillation counter hodoscopes to measure the particle momenta and angles. A small computer will be used to monitor and display the information from the 70-80 scintillation counters and the shower counter.

It is planned to make measurements around an N* mass of 1500 MeV/c^2 at four-momentum transfers of $q^2 = 0{\cdot}4$ GeV^2 and 1.0 GeV^2, but investigations into the 1238 resonance region may be made as an initial experiment.