The large single-gap sonic spark chambers mounted in K12A beam line. (Experiment 1).

Instrumentation for High Energy Physics

The setting up of experiments requires considerable technical support. In this section of the Report, apparatus for particular experiments in the physics programme and general developments, including electronic instrumentation and targets for elementary particle scattering experiments are described. The Laboratory support groups are involved in the design, manufacture, installation and commissioning of apparatus not only for experiments at Nimrod, but also those carried out at CERN by research groups based on the Rutherford Laboratory.

APPARATUS FOR THE K12A EXPERIMENT

General Engineering Work

In experiment K12A (Experiment 9, Page 38) particle detectors were designed to define the incoming beam and detect the scattered particles within the spectrometer magnet and down stream of this magnet. The detectors (see figures 30 and 63) consists of:

(a) Magnetostrictive spark chambers and scintillation counters for beam definition in front of the magnet.

(b) Sonic spark chambers and scintillation counters within the spectrometer magnet aperture.

(c) Various scintillation counters within and around the target vessel.

(d) Sonic spark chambers and scintillation counter arrays behind the spectrometer magnet.

The new items in the beam line are the six magnetostrictive beam defining chambers. These chambers have an aperture of 16 cm diameter and the wire planes are mounted normal to the beam direction with relative wire directions rotated by 45° about the beam axis in consecutive chambers. The wire used is 0·1 mm diameter with 1 mm pitch between wires. As assembled in the beam line, the total length of the six chambers is approximately 60 cm. Downstream of the above chambers and close to the target are various veto scintillation counters; one of these is actually mounted within the target vacuum vessel. This counter is made from 6 mm thick by 60 cm wide sheet of plastic scintillator and is in the shape of a round-ended flask. It surrounds the target with its open end facing downstream towards the spectrometer magnet. Three light guide fish-tails transmit the light signals to the exterior of the vacuum vessel.

Placed within the spectrometer magnet poles is the first sonic spark chamber (C2, figure 30), this is a double gap unit 1·8 m long by 38 cm high, made completely from non-magnetic materials, and is of 'prestressed' design. Modules of PZT5H material (1969 Annual Report, page 85) are used for the sonic detectors.

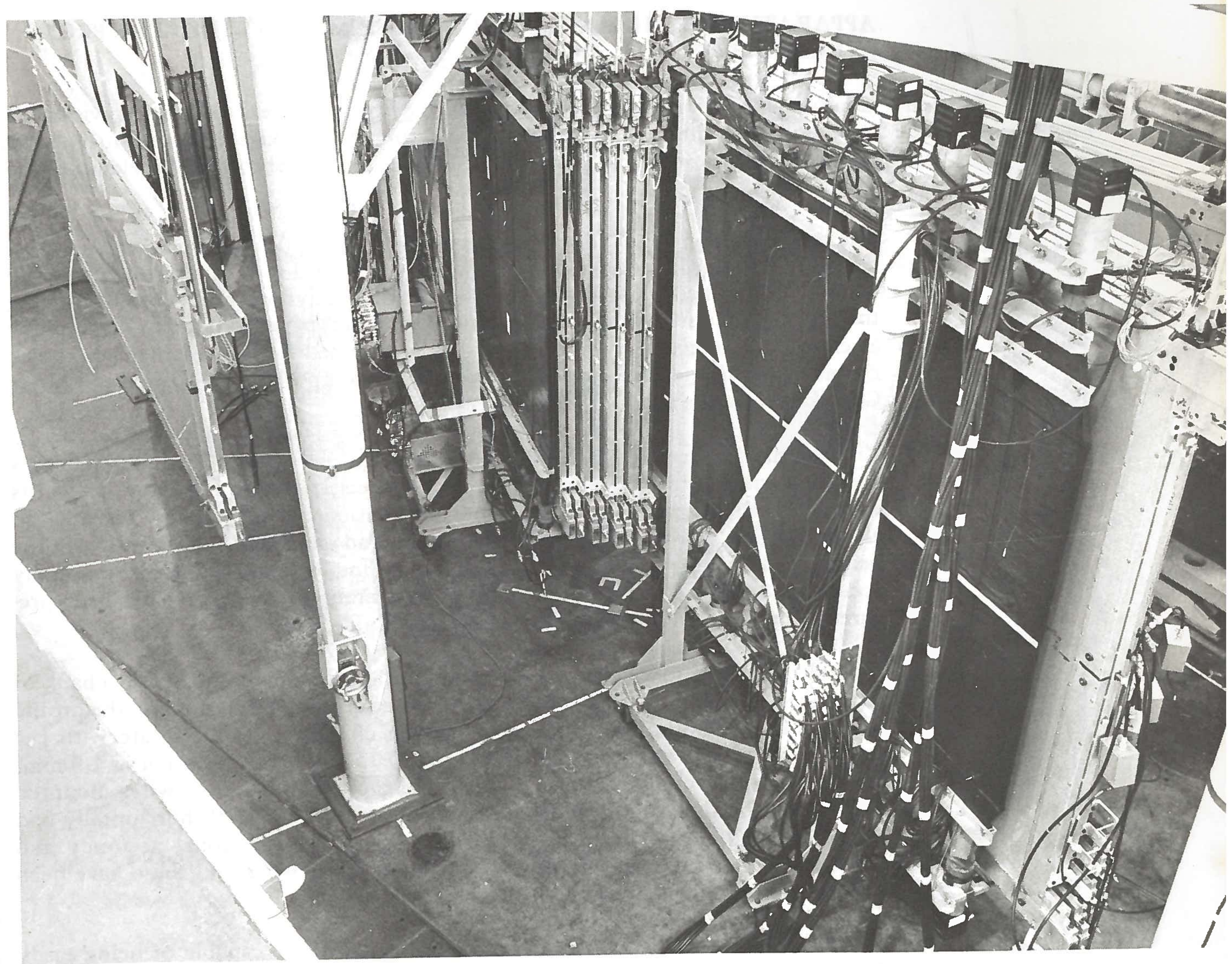


Figure 63. Large spark chambers and scintillator arrays for the K12A experiment.

Behind the spectrometer magnet are twelve very large single-gap sonic spark chambers in three groups of four. Four of these are 3·64 m long x 1·38 m high (C3, figure 30) and eight are 3·66 m long x 2·33 m high (C4). The latter are probably the largest spark chambers of their type in the world. The detector system for these spark chambers is a modification of PZT5H modules referred to above. It has been possible to achieve an accuracy of ± 0·5 mm in the relative positions of these large chambers.

Behind each group of C3 and C4 spark chambers is an array of scintillation counters totalling fifty units mounted on three mobile stands, the largest of which supports twenty-two assemblies covering an area of 5·9 m^2. The whole of the spark chamber system behind the spectrometer magnet is suspended from an open steel frame 3·9 m high x 7·2 m wide and 4·2 m long supported on six steel columns. This has been designed so that the chambers can be moved individually on rails to provide access for setting up and installation, and also permit mobility of other apparatus (e.g. the counter arrays above).

In addition a spark chamber test facility has been installed which moves these large chambers so that they can be scanned by a test beam with a positional accuracy of better than 1 mm, thus enabling the characteristics of each spark chamber to be precisely defined.

APPARATUS FOR THE ANTI-PROTON EXPERIMENT AT THE CERN PROTON SYNCHROTRON

General Engineering Work

Considerable effort has been spent during the past year on the provision of apparatus for the p̄-p experiment (Experiment 10, page 39) currently being installed in the South Hall of the CERN Proton Synchrotron Accelerator (see figure 64).

The main component of the apparatus consists of a 130 ton magnet, mounted on clusters of spring loaded ball castors, which is required to rotate through an angle of 55° about a fixed pivot above which is mounted a hydrogen target. Surrounding the magnet are arrays of wire spark chambers. Banks of scintillator and light guide assemblies are accurately and selectively positioned around each of the spark chamber arrays and the hydrogen target. Also incorporated are Lucite and Water Cerenkov counters and a beam hodoscope.

An essential feature of the experiment is that the arrays of wire spark chambers and the various scintillator assemblies move precisely with the magnet during its rotation with the minimum of positional variation between items. In order to effect rotation of the castor mounted magnet and apparatus, and to maintain the height of the magnet with respect to the beam line within ±1·0 mm, an especially accurately constructed floor, surfaced with armoured steel plates has been prepared. Movement is effected by means of a hydraulic ram.

A total of 38 wire spark chambers are used in the experiment, including a bank of ten placed upstream of the experiment for the purpose of determining the profile of the beam. The majority of the remaining chambers, which rotate with the magnet and have a working area of 2·75 m x 0·75 m with a wire pitch of 1·5 mm, are of two basic configurations:— (a) single gap, with planes of wires mounted diagonally, (b) double gap, with planes of wires mounted both horizontally and vertically. Particular attention has been paid to the positional accuracy and catenary of the 0·125 mm diameter beryllium/copper wires and these have been kept to less than 0·5 mm total variation.

All the chambers which are required to be gas tight, are capable of being easily dismantled for the purpose of maintenance. They are mounted individually and any chamber may be removed on a special loading trolley. Their required positional accuracy with respect to the magnet is ±0·5 mm.

In order to economise in the amount of high purity neon/helium gas mixture required to continually circulate through the chambers and to keep the impurity level within the chambers to less than 0·1%, three gas purification systems, designed and developed at the Laboratory, are employed.

The techniques leading to the successful construction of all the spark chambers were established at the Laboratory, and subsequently all double gap spark chambers were manufactured by commercial firms using wire winding machines also designed and supplied by the Laboratory. The manufacture of the single gap spark chambers with diagonally mounted wires was undertaken in the Laboratory. All the spark chambers are being tested (see below) prior to shipment in specially designed crates.

After trial assembly at the Laboratory, installation of the apparatus, including three control and plant rooms, front and rear rotating platforms and spark chamber support structures, and a large overhead service gantry, commenced December 1970 at CERN. Further installation will continue between running periods with beam particles, when apparatus already installed will be tested. The main magnet will be available to complete the installation in May 1971.

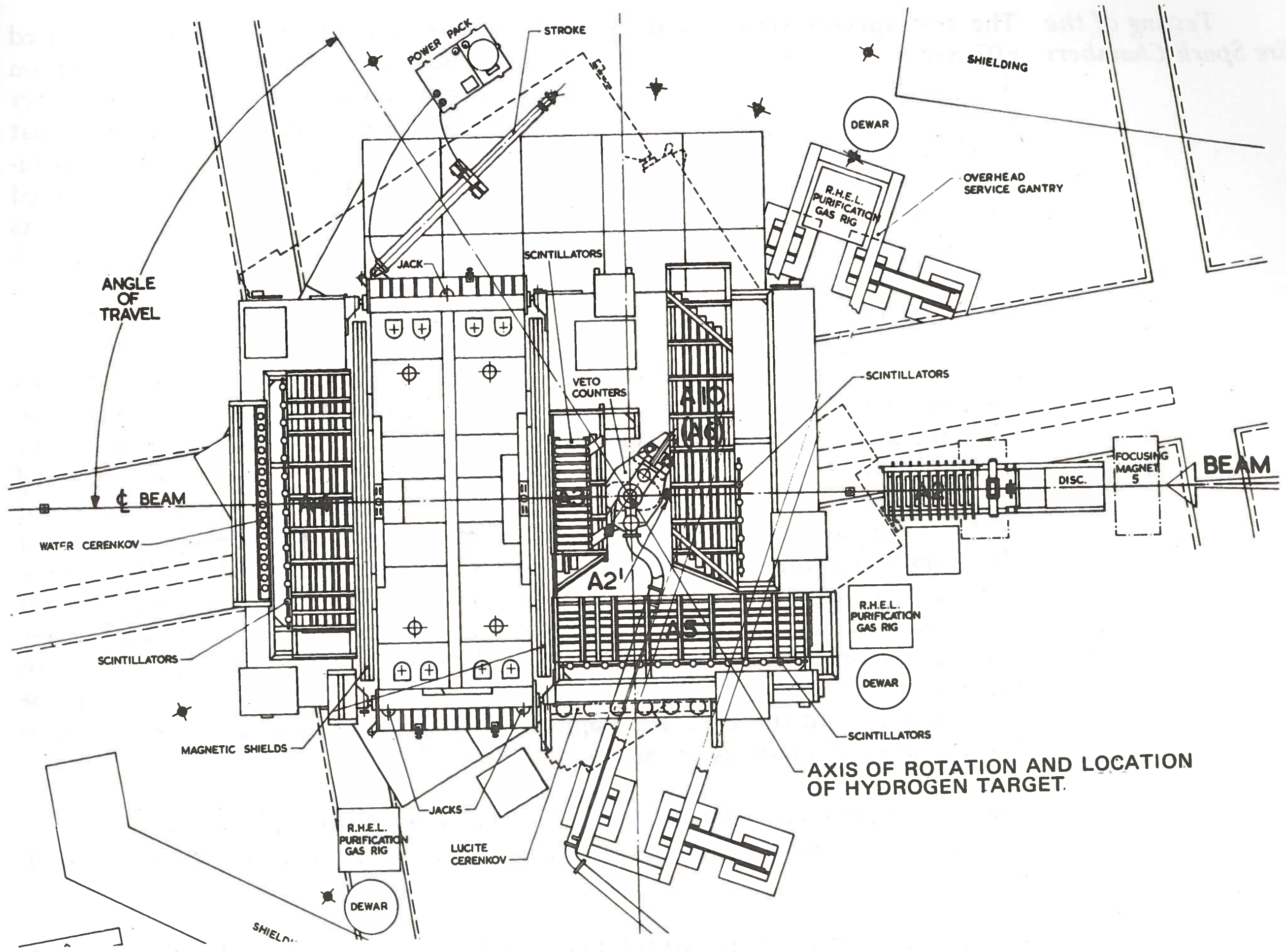


Figure 64. A plan view of the apparatus for the p̄-p scattering experiment. A2, A3, A4, A5 and A6 are banks of wire spark chambers. A hydraulic ram rotates the magnet and secondary particle detectors through an angle of 55°.

As a result of close co-operation with the experimental team during the testing of the prototype spark chamber, a test specification and test facility were produced to ensure that all wire spark chambers manufactured for this experiment would be delivered to CERN fully tested and with known characteristics.

The chambers are designed for use with a core read-out system, wire spacings are 1·5 mm pitch and the active area dimensions are 2·75 m x 0·75 m and 1·17 m x 0·384 m.

The chambers are of two main types:—

1. **Three frame chambers**, each chamber having two gaps, one gap having both planes of wires wound on the frame in the 'x axis' and the other gap having both planes of wires wound on the 'y axis'. Of this type 13 are large chambers having an active area 2·75 m x 0·75 m and 4 are smaller chambers having an active area 1·17 m x 0·384 m.
2. **Two frame chambers**, these are single gap chambers, both planes of wires being wound diagonally on the frames. Of this type 6 are large chambers with an active area of 2·75 m x 0·75 m and 2 are smaller chambers with an active area of 1·17 m x 0·384 m.

Testing of the Wire Spark Chambers

The test specification was designed to ensure that all the chambers operated efficiently over the whole of the active area without having too great a spread on the spark efficiency-EHT curve. It was also necessary to check that each chamber reached maximum operating efficiency at an electric field strength well below that at which spurious breakdown in the chamber became a problem. Operating parameters such as gas mixture, gas flow and clearing field voltage were determined during testing of the prototype and the performance of the manufactured units was established using these criteria.

Test Procedure

Each chamber was flushed with helium gas for 12-24 hours, and during this time the chamber was tested for leaks and the value of the feed capacitor was measured. After the initial flushing the gas was changed to 30% helium, 70% neon with 10% of the gas flow being bubbled through N-butyl alcohol, the chamber being flushed for a further 12-24 hours. At the completion of the flushing period a source of electrons (see page 96) and a counter telescope were used to trigger the chamber EHT supply and measure the spark efficiency versus applied volts at each of three positions of each gap. The area in which a spark should occur due to the passage of an ionising particle was tightly defined by using a scintillator of area 1 cm^2 in the telescope system and a finely collimated beam of electrons. Then, in order to obtain a set of spurious breakdown-EHT curves the source and counter telescope were removed and the EHT was applied to the chamber using an external trigger; this test being a purely visual one.

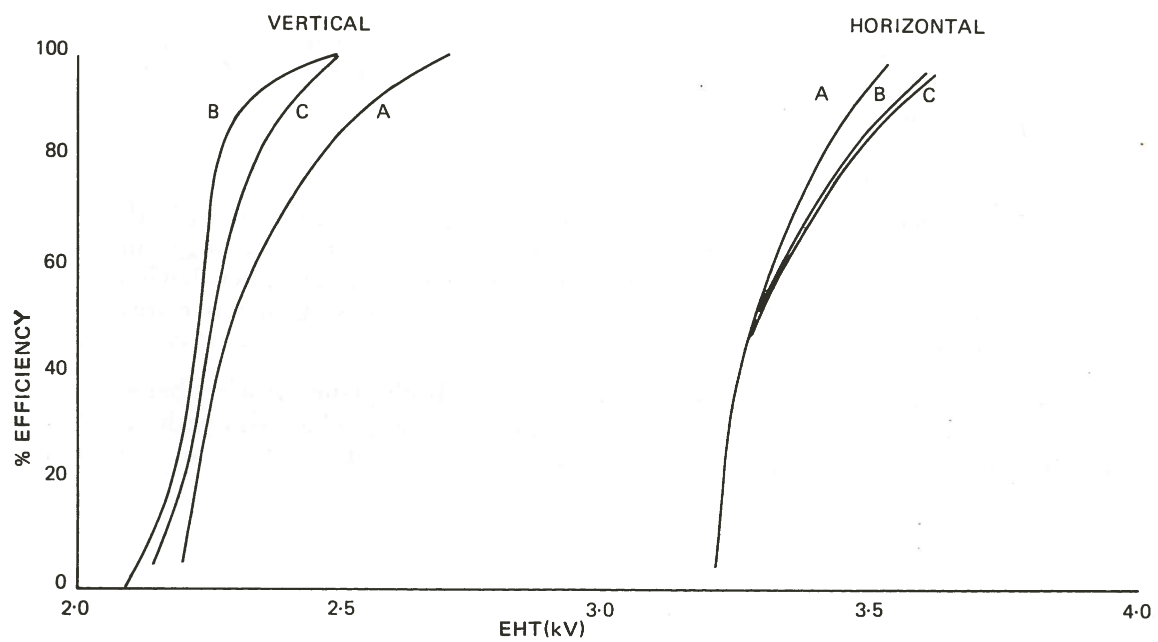
The double gap chambers were tested one gap at a time, the gap not in use having the wires of the read-out plane shorted together and earthed, the HT plane being allowed to 'float'.

The maximum number of wires which could be connected to the test core read-out at any one time was 250; all remaining wires of the read-out plane were shorted together with copper foil and connected to earth.

Results of Tests

Figure 65 shows typical spark efficiency curves as a function of HT voltage for a small three frame chamber at each of three positions. To ensure that the value of the power supply HT was accurately known, the voltage was monitored using a potential divider and the value read out on a digital voltmeter. The voltage could be set to an accuracy of 5 V over the range 0-10 kV and a continuous monitor of this value was maintained throughout. Although the spark efficiency-EHT curves were not identical, all the chambers of each type had similar characteristics.

Figure 65. Spark efficiency—EHT curves at each of three positions for a small three frame wire spark chamber.



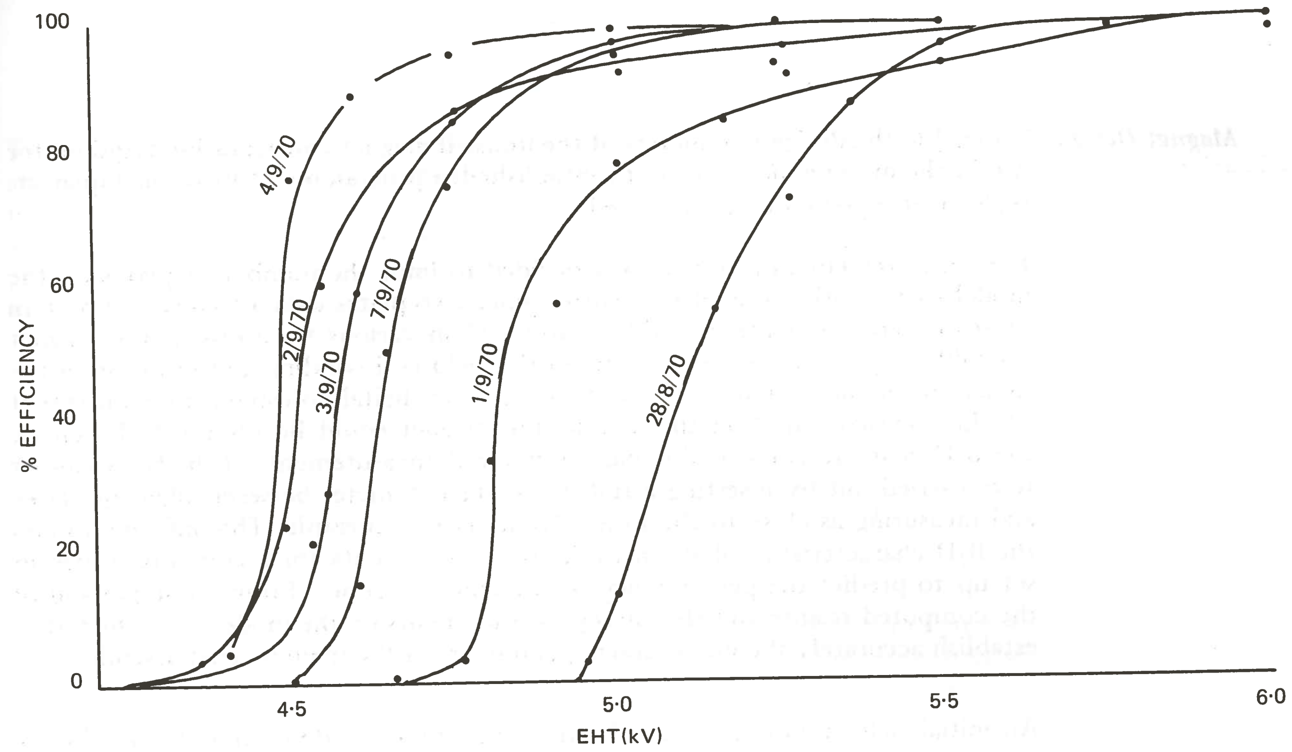


Figure 66. Spark efficiency—EHT curves, at a fixed point of a large wire spark chamber, showing variation with time.

Spurious breakdown for the small three frame chambers occurred only for values of HT above 5 kV. Although the other types of chamber were less impressive, tests showed that the spark efficiency-EHT curve plateaued well below the value of HT at which spurious breakdown became a problem. Preliminary analysis of the read-out data shows that a chamber operating at 100% efficiency was setting about 3 cores per spark. Whenever timescales allowed, additional tests were carried out and figure 66 shows typical results obtained in this case at one point of a large three frame chamber, where spark efficiency-EHT curves were plotted over a period of several days.

At the time of writing this report 20 out of the total of 25 chambers have been tested and shipped to CERN. It is anticipated that the remaining chambers will have been tested by mid-February 1971.

DESIGN AND CONSTRUCTION OF APPARATUS FOR THE MUON EXPERIMENT AT THE CERN INTERSECTING STORAGE RINGS

A new project during the past year was the design and construction of the apparatus for the muon experiment at CERN. (Experiment 18, page 51). The position in which the experiment is to be erected, Intersection II of the Intersecting Storage Rings, also houses two other experiments, and the requirements of all three have to be integrated into the overall lay-out. The major components of the muon detector, namely the absorber assembly, magnet assembly, thick plate spark chambers, scintillation counters, and optical system are in an advanced stage of design and construction.

The Absorber Assembly

The absorber consists of a lead mass approximately 80 in wide x 55 in high x 20 in thick weighing 12 tons contained in a steel casing supported centrally about the intersection region, and between the intersection region and the magnet. It is required to have an adjustment of 12 in under remote control and is mounted on trunnions slotted into bearings on a support frame, which is in turn supported on pivots bolted to the floor. The support frame is held upright by two supporting towers either side of the absorber assembly, and give reaction support for the adjustment. These towers are framed together to support other apparatus near the beam line, and are fitted with ladders to give access to this apparatus as the beam line is 13 ft from the floor.

Magnet Design

To enable the design parameters of the unusual magnet configuration required for use in the muon experiment to be established, a programme of work on a quarter-scale prototype model was initiated.

For measurement purposes it was decided to limit the number of plates on the model to give either side of the centre spine. Two plates were fitted with a pattern of search coils and these could be arranged in various positions in the magnet assembly. By reversing the current in the field coil winding and monitoring the signals from the search coils on an integrating digital voltmeter a measurement of flux density variation throughout the magnet could be obtained. To check the B/H characteristics of the magnet material, measurements of the H parameter were carried out by inserting a Hall Plate Magnetometer between adjacent plates and measuring as close to the iron-air boundary as possible. This information on the B/H characteristics of the material was used as data for a computer program set up to predict the performance of the magnet proper. From a comparison of the computed results and the survey measurements on the model it was hoped to establish accurately the major design parameters of the main magnet assembly.

An initial field survey was carried out on the model to determine the number of ampere turns required to produce a flux density distribution better than 15 kG ± 20% across the horizontal mid-plane in the magnet plates. Having established this value of ampere turns, measurements on the fringe fields around the magnet and the transverse fields existing between plates were made. These were found to be of the order of 10 G close to the magnet, dropping off to less than 1 G at a few feet from the magnet. As a result of these measurements it was decided to flatten the flux density distribution by increasing the ampere turns to approximately twice the previous value. Further survey measurements at this value of ampere turns were carried out and the flux density distribution across the horizontal mid-plane was found to be 15 kG within +10% and -5%. The fringe and transverse fields were also checked and in addition measurements on the vertical and horizontal fields existing along the circulating beam directions of the Intersecting Storage Rings were carried out. These were all found to be below the acceptable limit.

Data from both the model measurements and computer program have been incorporated in the design of the main magnet assembly.

The Magnet Assembly

The full-scale magnet consists of 26 steel plates 14 ft 6 in x 8 ft x 4 in thick arranged either side of a central spine at an angle of 15° (see figure 43, page 51) such that it forms a magnetised steel moderator. The energising coil is housed around the top half of the spine to produce an approximately circular flux pattern in the iron plates. It is important to the experimenter that the flux distribution is fairly constant across the plate, and also of the same value in each plate. As there are practically no air gaps, the main reluctance of the circuit is in the steel. To achieve the maximum uniformity of flux density across the plates, the steel has to be run at saturation (approximately 15 kG). It is also important that the stray field due to the magnet is low as the field tolerance at the intersection of the Intersecting Storage Rings is approximately equal to the earth's magnetic field and the magnet has to be sited very close to the intersection as shown in figure 43. These requirements have been checked in the quarter-scale model described above and the full-scale magnet is being assembled at the Rutherford Laboratory (see figure 45) for a final magnetic and dimensional check before being despatched to CERN.

Thick Plate Spark Chambers

The thick plate spark chambers are double gap optical chambers to be viewed from the side and the bottom. They will be located in the 4 in gaps between the magnet plates and have active areas which cover the majority of a 2 m x 4 m area.

To ensure that these chambers will record multiple events, the gap between the spark chamber planes must be held to 1 cm ± 0·05 cm. Several attempts were made to achieve this condition using various stiff materials such as 0·75 in thick aluminium plate, composite materials of aluminium and balsa and aluminium and plywood, but none of these were satisfactory, as they either presented extreme manufacturing difficulties or were not sufficiently flat. In these early attempts no spacers were used between the plates as these reduce the visible region.

As a compromise solution, aluminium sheet 0·1875 in thick, which meets the flatness specification, has been used. The plates are stiffened by a system of spacers which give a minimum of shadow. Twenty-four of these chambers are required, and they are being manufactured commercially using jigs and tools which have been designed at the Rutherford Laboratory.

Scintillation Counters

There are five banks of scintillation counters in the apparatus shown in figure 43. These scintillators are arranged in such a geometry that the spark chambers are only fired when a particle originates from the intersection region, thus reducing the number of triggers due to cosmic rays.

The B, C and D banks (see figure 43) are very large assemblies, the C bank being the largest and most complicated. It consists of 24 sheets of scintillation material, 20 mm thick x 1 m x 69 cm, with twelve sheets each side of the centre spine arranged 2 sheets wide x 6 sheets high to cover an area of 2 m x 4 m. The scintillators will be housed in light-tight aluminium casings together with acrylic light pipes. These assemblies are designed to hang in the 4 in gaps between the magnet plates in the same manner as the thick plate spark chambers.

The Optical System

Each of the 24 thick plate spark chambers and also 2 multi-gap foil chambers mounted between the absorber assembly and the magnet (see figure 43) are to be viewed directly from the side and the bottom and also at a 7·5° angled view from the bottom. To achieve this arrangement the side mirrors looking at both side and bottom views are required to be 21 ft long x 4 in wide. It is possible to split these into three 7 ft lengths, but even at this reduced length the only plant that is capable of producing front-aluminized glass with a protective coating is at the Rutherford Laboratory. The mirror system is arranged so that the spark chambers are viewed by a single camera which also records a considerable amount of other information by means of a data box. The camera is mounted at the rear of the apparatus.

Each spark chamber will be fitted with fiducial marks and calibration marks every 20 cm in both views, at the back and front of each chamber. These will be used to made spatial reconstruction of events and enable corrections to be made for any optical distortion due to spark chamber materials or mirror inaccuracies.

At the camera position will be a remote controlled indexing device, to enable 4 cameras, each loaded with 1,000 ft of film, to be used in turn. One position can also house a theodolite arranged such that it may be angled both horizontally and vertically to enable accurate checking of the optical system from the camera to the spark chambers.

The whole experiment will be covered with a light-tight igloo 37 ft long x 28 ft wide x 22 ft high. This structure will also be used to help support the mirror systems, provide support for the main cable runs and walk-ways and ladders to give access to the equipment.

APPARATUS FOR THE π 10 NUCLEAR STRUCTURE EXPERIMENT

Multi-wire Proportional Counter/Display Interface Unit

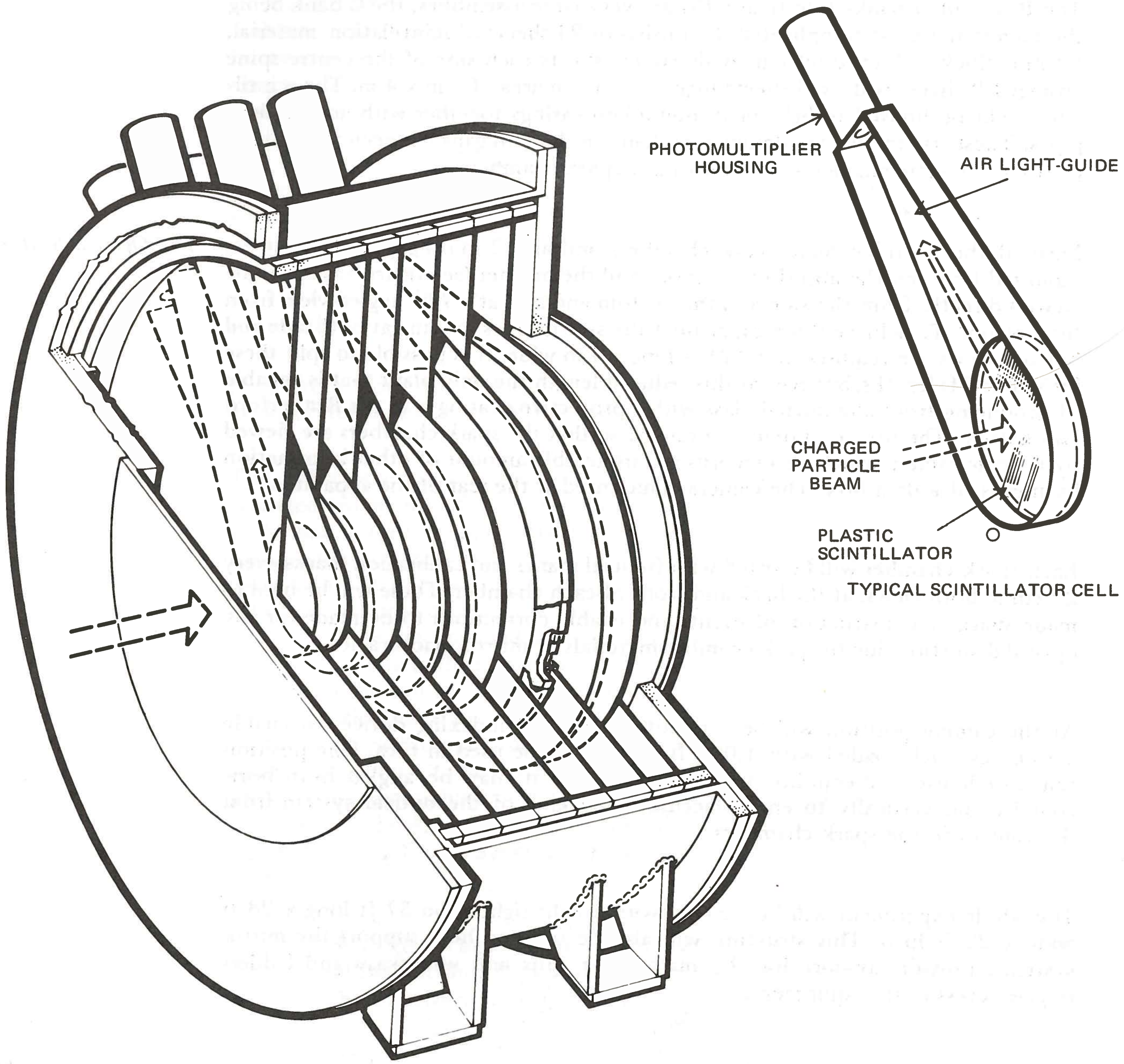
A portable beam-line investigation system, capable of displaying beam profiles and beam emittance data was required for the π 10 beam. (Experiment No. 32, page 68). This called for an interface between the particle detector, a multi-wire proportional counter with 36 wires, and the display device, a 'Laben' analyser.

A prototype interface has been developed which accepts the output pulses from the individual wire amplifiers of the counter. These signals are converted to BCD, then gated and modified so that the output pulses are compatible with the analyser address system in respect of pulse repetition frequency, amplitude and length. The 'Laben' analyser is an integral part of the beam diagnostic equipment for the experiment and is thus available for this additional function.

The Transmission Counter

The transmission counter is comprised of six light-tight cells mounted in a cylindrical vessel 42 in dia x 15·5 in long. Each cell is maintained concentric with the vessel's outer shell and contains an accurately positioned circular disk of scintillating material.

Figure 67. The Transmission Counter showing a typical scintillator cell.



The light-tight cells are formed from a series of circular hoops of 41 in dia x 2 in wide x 0·5 in thick, each with an aluminised melinex sheet 0·002 in thick bonded 'drum-like' across one end so as to make a light-tight membrane between each cell. Six scintillator disks, ranging from 7 in dia x 0·375 in thick to 23·25 in dia x 0·5 in thick, are bonded one to each side of alternate cell membranes and are accurately located in relation to a datum face at the front of the transmission counter vessel. The advantages of this method of assembling a transmission counter is that a minimum of unwanted material is in the path of the beam, and by mounting the scintillators on both sides of a melinex sheet, the assembly is mechanically balanced. To make an efficient air light guide from scintillator to photomultiplier a strip of aluminised melinex, of width equal to that of the cell, is wrapped around the edge of the scintillator disk and tapered to the photomultiplier aperture where it is retained in position by small plate clamps. The counter is shown schematically in figure 67.

LARGE GAS CERENKOV COUNTER

K15 Cerenkov Counter

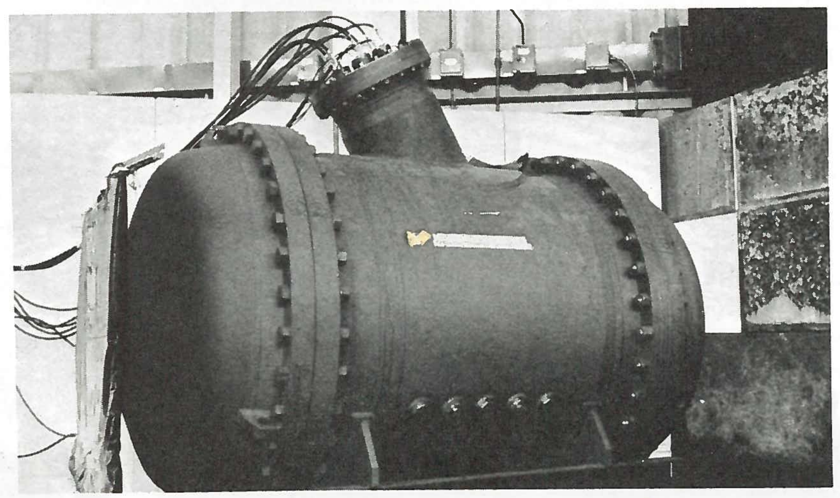
A 4 ft diameter by 6 ft long gas Cerenkov counter (figure 68) was installed in the K15 beam line. The vessel is constructed of carbon steel, having a 4 ft 6 in long cylindrical section with forged end domes. The vessel was designed to operate at a working pressure of 280 lb/in^2 gauge, initially using sulphur hexafluoride gas as the radiating medium.

A large aluminised perspex paraboloid mirror, mounted in the downstream end of the counter, focusses the Cerenkov radiation from charged particles passing through the counter on an array of seven photomultiplier tubes mounted in a branch on the top of the vessel.

The gas handling system has been designed to allow use of most radiating gases, either hazardous or non-hazardous. The equipment is built into a standard electronics console which contains and encloses the valves and pipework, also the electric heater and control systems. When used with a hazardous gas the console is ventilated and the containers for the electrical systems are purged with an inert gas. High pressure gas from storage cylinders is passed through a reducing valve after which the gas passes through a heater and a mass flow controlling nozzle. The heater is controlled by a sensing thermistor downstream of the nozzle to ensure that gas at the ambient temperature is fed into the Cerenkov counter.

A gas system has been set up specifically for the recovery of sulphur hexafluoride from the counter. Sulphur hexafluoride has a vapour pressure of about 310 lb/in^2 absolute at room temperature and is normally stored in liquid form. During the recovery process the gas is passed from the counter vessel through a 'Corblin' compressor into a water cooled vessel. There condensation of the high pressure gas takes place and the liquid gravitates into a bank of storage cylinders.

Figure 68. The large gas Cerenkov Counter (4 ft diam x 6 ft long) installed in the K15 beam line.



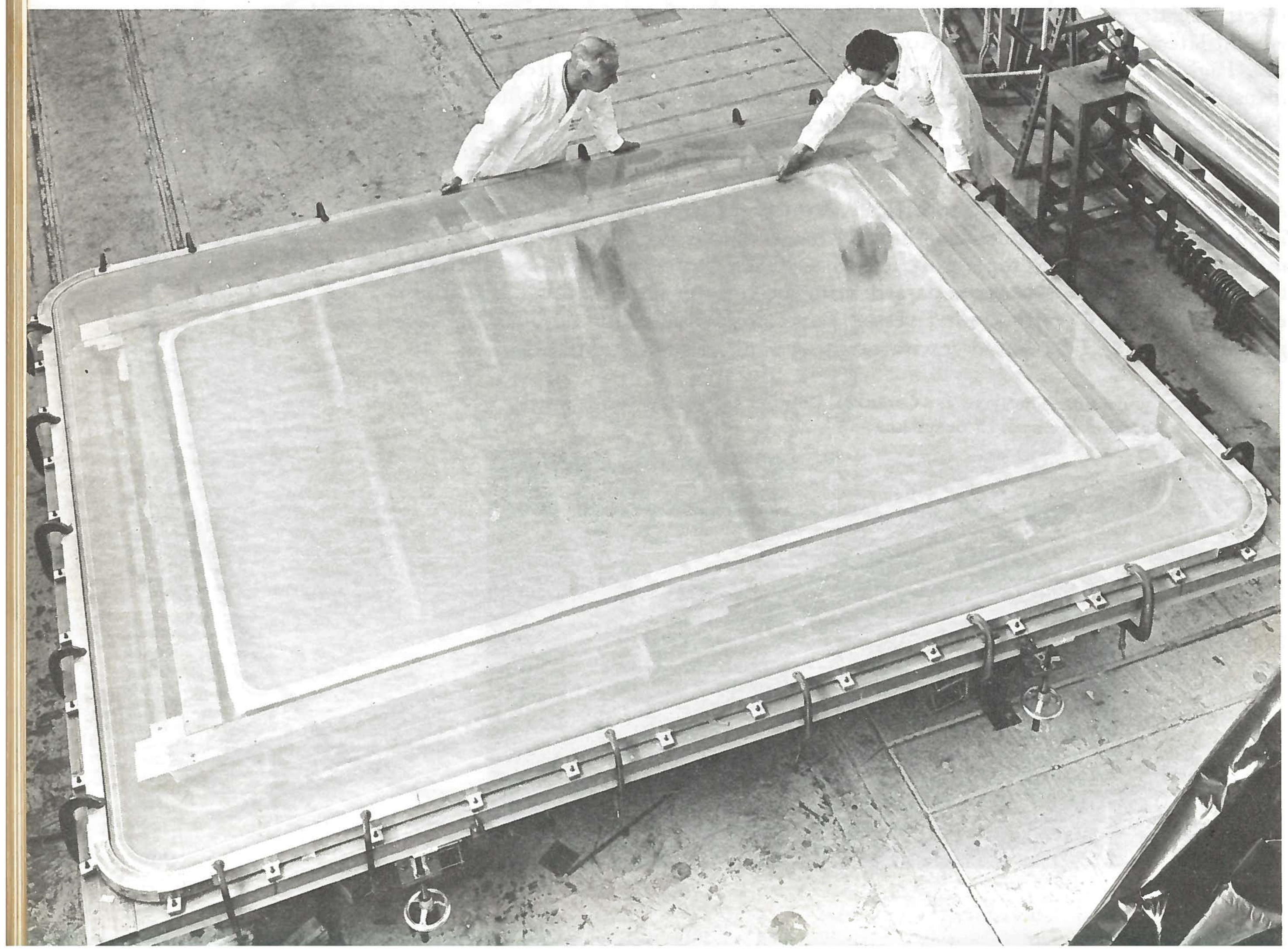
INSTRUMENTATION WITH GENERAL APPLICATIONS

Magnetostrictive Wands for Wire Spark Chambers

A programme of work on magnetostrictive wands is in progress to produce units suitable for use in the wire spark chamber arrays currently being manufactured for experiments at the CERN Intersecting Storage Rings. In all a total of approximately 100 units will be required in lengths ranging up to 2·5 m. In addition to the long spans covered by the wands, they will also be required to detect multi-spark events and to meet these requirements development work has been carried out to improve the acoustic damping and amplifier performance. Due to the restricted access of the spark chamber printed circuit board active areas, the cross sectional dimensions of the wands are severely limited and this together with the long spans involved has entailed special attention being given during design to ensure structural rigidity of the complete assembly. This has involved modifications to the wire clamping and the mounting arrangements for the coil and bias magnet. These now form an integral part of, or are mounted directly from, the wand spine. This minimises the effect of flexing between the spine and end cover assembly and simplifies the alignment procedure during assembly of the wands.

Improvements in acoustic damping have been achieved by providing a two stage damping system at the receive coil end. In this arrangement the acoustic pulse is channelled first through a soft damping pad consisting of a trough filled with wax and then through a graduated damping pad formed by a sandwich of synthetic rubber and tape. Modifications to the pre-amplifier include changes in the MA702 differential amplifier circuit and the provision of additional stages to increase the gain (approximately 500) and improve discrimination. Prototype testing of the wands is now completed.

Figure 69. Construction of a large thin foil spark chamber.



Development of Large Spark Chambers with Thin Foil Planes

The large spark chambers used in the K12A experiment required the development of special construction techniques because of their weight, 68 kg, and size, 3·64 m x 2·34 m. (See figure 69).

The spark chambers consist of pairs of matched frames, each frame supporting a single composite foil (an aluminium alloy membrane mounted in polyester film), and a polyester film pressure window. The large foil areas are prepared on a stretching frame; in the case of the largest chambers, two pieces of 0·025 mm thick aluminium foil 1·65 m wide x 4·2 m long, are placed side by side and bonded at a simple overlap joint of 15 mm. The frames are constructed from a specially developed aluminium extrusion with a high strength to weight ratio. The extrusion is hollow, thus allowing the horizontal members of one frame to be used for the helium gas distribution. The frames are pre-stressed so that the sides bow outwards. Prior to applying the foil, the sides are clamped so as to bow inwards. Then, after the foil has been bonded to the frame, the clamps are removed so that the frame tension compensates for 'adhesive creep' between bonding and final cure and maintains foil tension during dimension changes resulting from thermal cycling.

A Thyratron Pulser for Large Spark Chambers

A thyratron pulser has been designed to energise the large acoustic spark chambers used on the K12A experiment. The largest of these chambers measures approximately 3 m x 2 m, the active gap being 1 centimeter. These chambers operate on pulse voltages in the 10 to 15 kV range. At the high voltages and short pulse rise-times required to operate these chambers at high efficiency, heavy demands are made on the peak current capability of the pulsing device. Both the triggered spark-gap and the thyratron may be used to produce high voltage pulses of high peak current at a fast rate of rise. The thyratron, an English Electric CX1157, was chosen for this application because, unlike the spark-gap which suffers from spark erosion of its electrodes, it requires no servicing and will give trouble-free operation for long periods; up to 10,000 hours service has been claimed in some cases. In addition this valve has other advantages over the spark-gap. It will give extremely accurate and reliable firing at any voltage within its range without adjustment to the circuit being necessary and it requires a relatively low trigger voltage. Against these merits must be set the considerably greater cost of this type of thyratron compared to a spark-gap.

The circuit of the pulser has been designed using as few components as possible, consistent with efficient operation, in order to obtain maximum reliability. The firing circuit makes use of only two active components, an avalanche transister and a small special quality thyratron. It will operate from a 'type 2' standard pulse or any similar negative-going edge and produces an output pulse having a positive-going amplitude of 500 to 600 V, with a rise time of 12 to 15 ns. The delay time, input to output, varied from 35 to 50 ns over the 15 firing circuits tested. The delay time due to the thyratron pulser itself is variable, depending as it does on such factors as heater and reservoir voltages, but the measurements made suggest the overall delay through the pulser should not total more than 80 ns. The rise time of the output pulse is dependent to a large extent on the load circuit.

As supplied to K12A, the firing circuit was arranged for use with a standard power unit in the 2000 series and is contructed as a plug-in module, mounted close to the thyratron. The thyratron anode circuit is housed separately. This permits greater flexibility of use since the circuit can be designed to suit operating voltage, size or type of spark chamber, pulse repetition rate and so on. Operational experience with the pulser is limited thus far to a few hundred hours use of the prototypes on routine chamber testing, however the results suggest a high degree of reliability.

Electroluminescent Lamps for Spark Chamber Fiducials and Data Board Displays

Development work on the use of electroluminescent materials for reference marker and data display applications has continued during the year and has been directed mainly towards finding a more reliable material and to minimising the cost of power supply requirements.

Several British manufacturers can now supply material in standard sheet sizes and using a front masking technique the pattern can be defined to the accuracy required. However, although this approach solves the problem of material supply conveniently, it makes the cost of the power supplies prohibitive due to the additional area to be excited. Attempts to define the pattern required, by employing masking techniques during the manufacturing process thus limiting the excited area to a minimum, have met with only limited success. In the case of the inorganic ceramic type materials, the high temperature firing process involved during manufacture produces distortions in the finished product. Although it is quite feasible to obtain high definition patterns using screen printing techniques in the manufacture of the plastic and glass organic type of materials, the initial development costs are high, and for small quantities the cost is excessive. At present a compromise procedure is in use where high definition patterns are required. The material, in the form of a sheet, has a gross pattern printed during manufacture and the final definition is obtained by a front mask, produced either by machining a metal panel or by photographic techniques.

Equipment of this type is now being produced for the ISR and K10S experiments, and results obtained on prototype units are most encouraging. It is hoped that further developments in this field will enable extremely sophisticated data displays to be incorporated in future experiments.

Gas Recirculating Rig for use with Spark Chambers

Development work on gas recirculating systems has continued during the year and a modified version of the prototype unit reported previously has now been produced. This Mk II unit has been designed as a standard rack-mounted equipment which can be incorporated easily into the normal control room arrangements. The unit is self-contained, requiring only a mains electrical supply and a source of liquid nitrogen to replenish the purifier vacuum flasks. Special attention has been given in this design to providing a high level of protection both in respect of interlock circuits to ensure correct operating sequences being carried out and in the fault alarm circuits to allow continuous operation with minimal supervision.

The performance of this equipment has been most encouraging and at present two units are being used by experimental teams. The results obtained from this operational experience will be incorporated in the second stage of manufacture and it is hoped to have a total of six units completed and in service by mid-1971.

A Light Pulser for testing Photomultipliers

In order to fulfil the requirement for a standard light pulse for testing the performance of photomultiplier tubes, work was initiated to produce a unit comprising an alpha particle source in contact with a disk of plastic scintillator. Monoenergetic alpha particles of kinetic energy 5·5 MeV from an isotope of Americium, Am^{241}, are totally absorbed in the scintillator, thereby producing light pulses of constant intensity. The whole assembly is sealed in epoxy resin to provide for safe handling. Initially a unit employing a source of 18 μ-curies on a 0·125 in thick scintillator disk was tested. This produced good pulses but radiation damage in the scintillator was such as to reduce the output by 50% within a 2 to 3 week period. Work is continuing and it is hoped to produce a light pulser with a useful life of about one year.

Solid State Light Emitting Diodes for testing Scintillation Counters

Work on evaluating the performance of solid state light-emitting diodes has been carried out to decide upon a suitable diode for on site testing of scintillation counter arrays. The performance of several types has been evaluated in terms of light output and its variation with temperature, pulse rise time, price and reliability. Comparisons were made by pulsing the diodes using a Hewlett Packard 215A pulse generator and measuring the light output by means of an RCA 8575 photomultiplier tube. A green light emitter would be most suited to the spectral response of the photomultiplier (peak response at 4,500 Å), but the two types of green emitter tested were not found suitable. The most practical device so far tested is the Monsanto MV1 which emits light in the amber region.

In application, a hole is drilled in a scintillator at an appropriate point and filled with optical grease. The diode is inserted into this hole and is secured in position with epoxy resin. In event of failure the diode can be broken away and replaced.

Housing for the RCA 8575 Photomultiplier

This device has been developed in collaboration with the experimental physics groups currently working on the K12A and π 10 experiments. The outer housing is made from mild steel tube. Each end is flanged, one flange carrying the light guide clamping ring and the other supporting the base assembly. (See figure 70).

A primary consideration in the mechanical design is to provide good accessibility to the electrical components. This has been achieved by making the photomultiplier together with its associated electronics removable as a complete assembly separate from the outer shell. Electrical connections are made through sockets on a common base plate. The dynode resistor chain was chosen specifically for the RCA 8575 phototube. This chain operating at a tube current of 300 μA will produce a constant 2V output at up to $3{\cdot}5 \times 10^5$ counts/second. A further derivating using ancillary HT can maintain output at 107 counts/second. Units to this design are now being manufactured commercially.

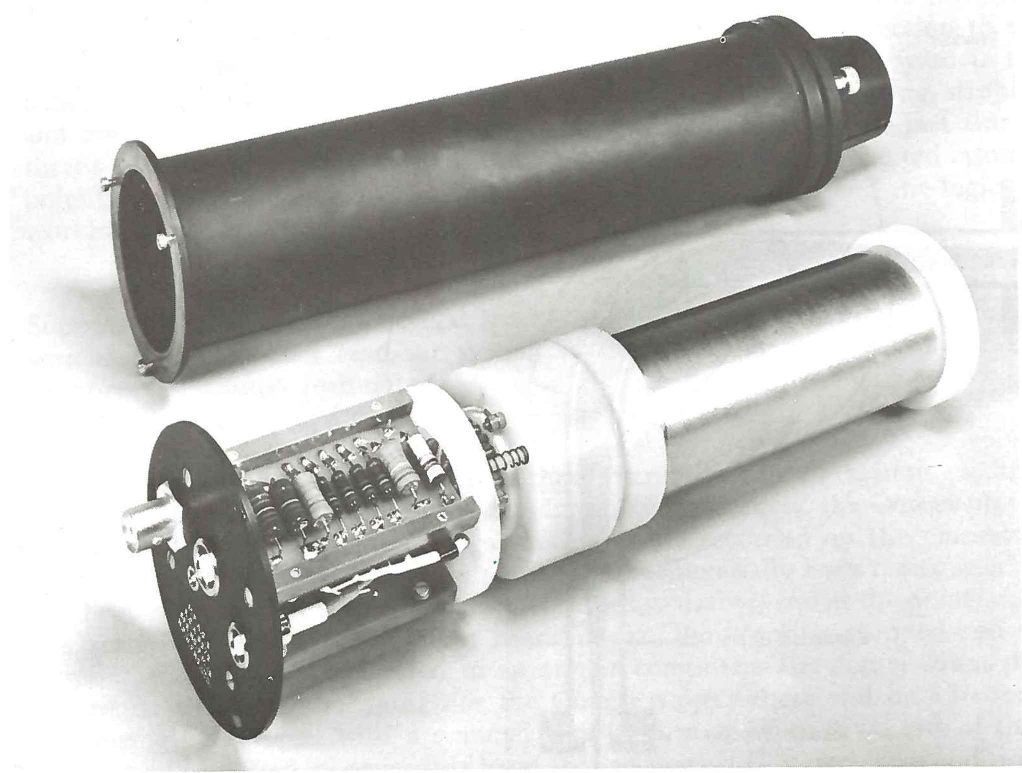


Figure 70. The RCA 8575 photomultiplier and housing.

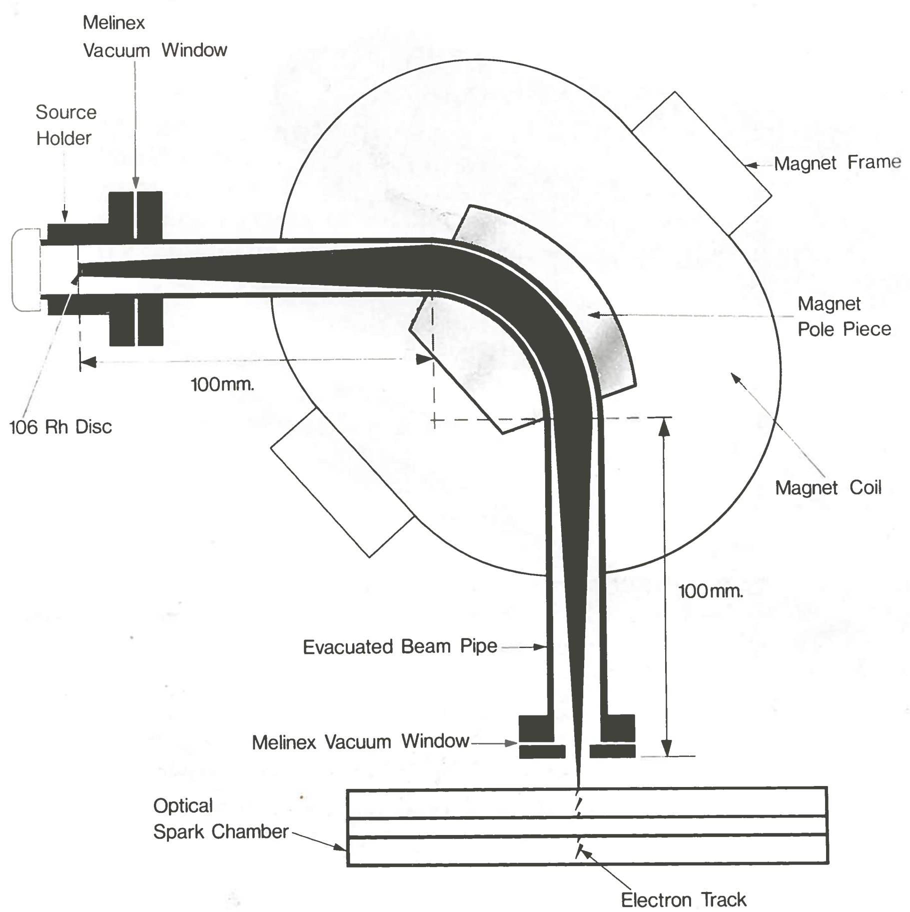
A Mono-energetic Electron Source for testing Particle Detectors

Many of the tests and calibration measurements made on nuclear physics apparatus such as scintillation counters, spark chambers and proportional counters can best be carried out using energetic particles independent of an accelerator. An instrument has been developed to provide a convenient source of electrons in the form of a well defined beam having good energy resolution and a high count rate for use in such applications. The device is portable.

It has three main elements; a radio-active source of energetic electrons, an evacuated beam transport pipe and a double focussing spectrometer magnet. Electrons emitted by the source are collimated and transported through the magnet section in the evacuated beam pipe. In the spectrometer magnet section, electrons of the required energy are selected from the primary beam, by adjusting the field strength in the gap, and brought to a focus. (See figure 71).

In the unit constructed the radio-active source used is an isotope of Ruthenium, Ru^{106}. This decays with a relatively long half-life to an isotope of Rhodium, Rh^{106}, which subsequently decays rapidly, yielding electrons with a maximum energy of 3·5 MeV. The activity of the source is 0·8 milli-curies and this produces several hundred counts per second at electron energies near the peak of the spectrum. The spectrometer section is an electromagnet having a bending radius of 5 cm. For the high energy electrons this corresponds to a magnetic field requirement in the gap of 2·7 kG. The gap length is 15 mm and the field coil power required to produce this magnetic field is 5A at 10V which can be easily provided using a portable power unit. The magnet pole face is shaped to produce a double focussing effect on the beam and the image of a point source placed 10 cm from the entrance pole face is located 10 cm from the exit pole face. The beam transport pipe is a vacuum system with Melinex entrance and exit windows which can be evacuated and sealed thus maintaining the portable facility of the instrument.

Figure 71. Schematic diagram illustrating the use of the mono-energetic electron source for testing particle detectors.



ELECTRONIC INSTRUMENTATION

The CAMAC System. (ref: 162)

During 1970 CAMAC has become firmly established as a world wide standard for modular electronics instrumentation associated with data acquisition. Much of this success is due to the thoroughness of the specifications issued by the ESONE working parties on which the HEP Electronics Group is represented. Specifications have been issued on the basic dataway (the crate) and on the branch highway (an assembly of up to 7 crates). Now consideration is being given to the possibility of standards at higher levels of CAMAC, the control of CAMAC systems and special purpose software.

More and more standard CAMAC,modules are becoming available on a commercial basis. However, it is evident that the 'data density' associated with high energy physics experiments is such that new modules still have to be designed for our applications. This is often done in collaboration with industrial firms, thus increasing their commercial potential. Though there is still work to be done at module level, it is at the higher level of system control where most effort is being expended.

Co-operation with CERN and Saclay has resulted in a common method of modular construction of controllers for CAMAC systems. It is expected that a controller containing a computer interface, an autonomous display and a link to the new terminal computer will become standard for most experimental teams at the Laboratory. It is proposed that the two Rutherford Laboratory collaborations at the Intersecting Storage Rings Project will link up with CERN equipment through such a system.

Counter Electronics

Development has been concentrated on a range of CAMAC modules for direct connection to counter hodoscopes and having direct output connection to the computer via the CAMAC highway. This marks a valuable step forward in the concentration of the various electronic operations – fast discriminating, strobing and coincidence logic, and the final gating of wanted events – into just two or three basic CAMAC units. By way of the CAMAC highway data can be fed into the units from the computer, to check that all parts of the system and the logic are working correctly.

Spark Chamber Read-out

Support has been given to several spark chamber groups in the construction of various spark chamber read-out systems including magnetostrictive, sonic and proportional counter read-out.

The Plumbicon System

A new effort which is being mounted is the construction of a TV scanning system, using plumbicon camera tubes, for the data taking system at the Omega project at CERN. In this system the images of sparks are recorded on the plumbicon photo-conductive surface, and are scanned out sequentially by a raster scan. At the beginning of each scan line a 90 mc/s clock is started, and at the point where the scanned electron beam hits a spark image, the clock is stopped and the number of counts is transferred to an on-line computer. The digital count then represents the spark position. For the Omega project there will be 110 spark chamber gaps to scan, with a scanned area of 3 m x 1·5 m. Two sets of three cameras will be used to cover this large area and give 17° stereo. Two additional cameras may be used in conjunction with a downstream chamber to improve momentum accuracy for high momentum particles. The principle of operation of the plumbicon system is shown in figure 72.

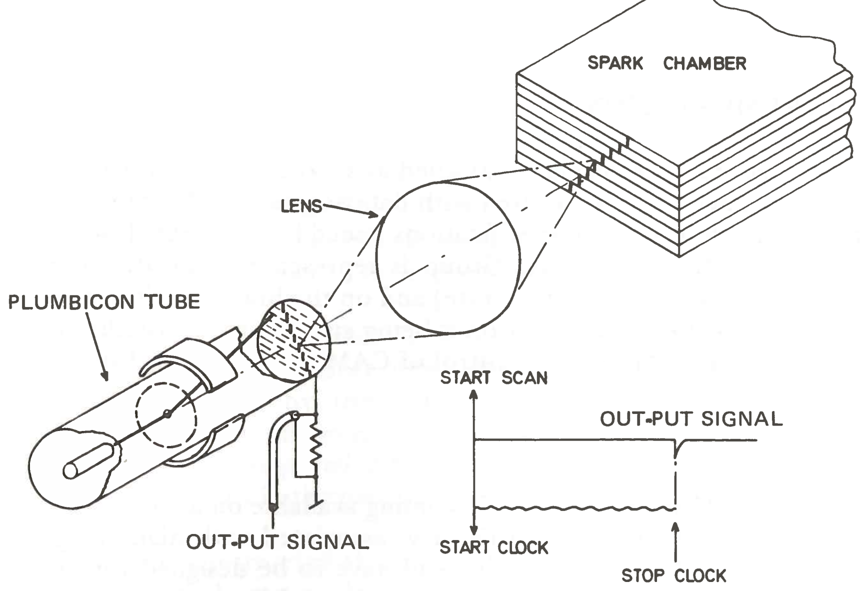


Figure 72. Principle of operation of the plumbicon system.

A careful study of the properties of plumbicon tubes has been completed and has shown that they should be very suitable for the proposed Omega scheme, having a fast recovery time and sufficiently good accuracy. A collaboration is being set up between HEP Electronics Group, Rutherford Laboratory Group A, Westfield College London, University of Birmingham, Ecole Polytechnique and CERN to build the fast data taking system for the Omega project.

Targets for High Energy Physics Experiments

POLARIZED PROTON TARGETS

A polarized proton target used on a π^+p scattering experiment (No. 4, see page 31) gave polarizations consistently greater than 65% in a Lanthanum Magnesium Nitrate crystal. The overall accuracy of the measurement was ±4% with a relative accuracy within ±1%. Very good agreement was obtained between polarization measurements made using nuclear scattering techniques and measurements made using a nuclear magnetic resonance spectrometer. An example is shown in figure 73 for a beam energy of 735 MeV, where a comparison is also made with results obtained by other workers. The experiment has been completed satisfactorily.

The New Polarizing Process. (ref: 50, 51, 63, 81, 93, 119, 128, 154, 156, 172, 174, 175)

Construction of a new type of polarized proton target for use in a charge exchange experiment $\pi^- + p \rightarrow n + 2\gamma$ is well advanced. The outstanding feature of this target is the large solid angle of free access to the target, exceeding 70% of the 4π steradian maximum. In this new system the hydrogen-rich target material is first polarized under optimum conditions for polarization at a temperature in the 0·8°K region and in a magnetic field of strength 50 kG. Under these conditions proton polarizations in excess of 60% have been achieved in organic target materials at the Rutherford Laboratory. The target is then cooled rapidly to about 0·3°K in order to reduce greatly the rate of depolarization from spin relaxation. In this frozen state the target is moved out of the uniform magnetic field used for establishing the polarization and into one of lower uniformity but providing the desired large angular access to the target.

To avoid excessive heating from eddy-currents during movement of the target from polarizing to holding positions the metal content of the cavity containing the target is made small. The resonant cavity, which contains the sample to be polarized is constructed from 12 micron thick foil supported by carbon fibre reinforced material. This construction has the added advantage of giving a target of low mean atomic number which is important in a charge exchange experiment.

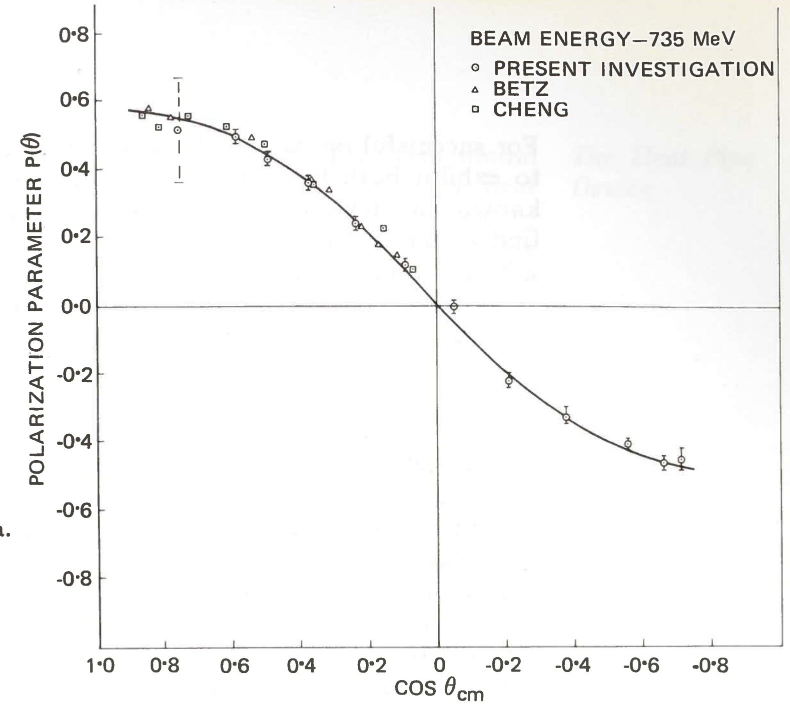


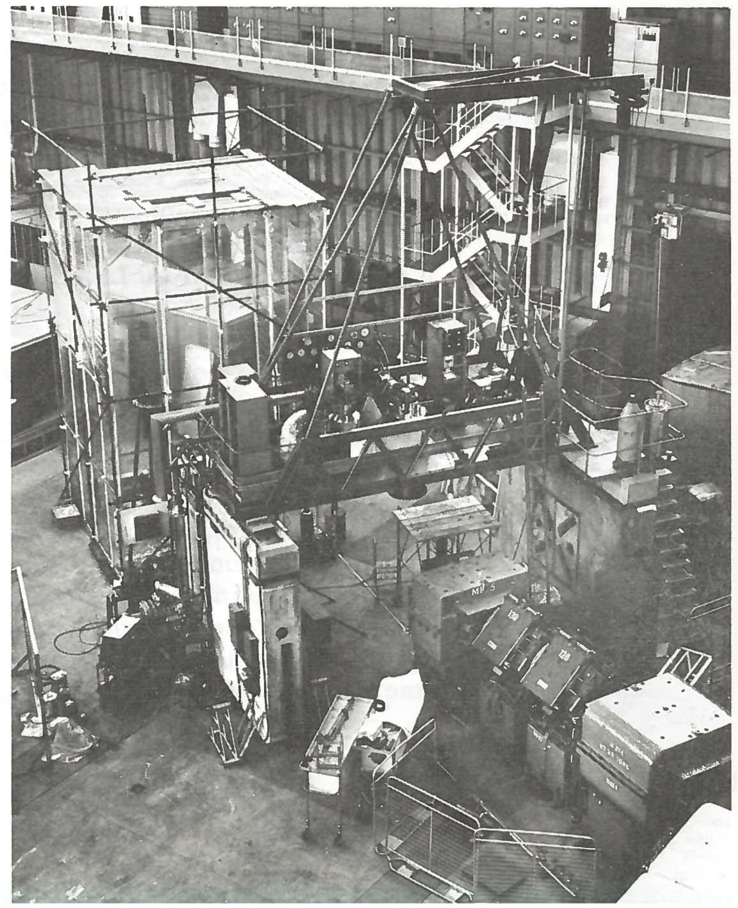
Figure 73. Comparison of polarization data.

The Refrigerator System

Experience gained in the use of a He^3 refrigerator operated during the last year in the temperature range of 0·9°K to 0·28°K has enabled simplification to be made in the design of the new frozen target. In particular, the target material now is to be cooled by direct contact with the He^3 refrigerant fluid. Using this refrigerator, extensive measurements of the main parameters of various possible target materials were carried out. These include polarization, proton relaxation rates, and polarization build-up times; the measurements were carried out over a range of temperatures and magnetic fields.

A continually operating absorption pump using activated charcoal is being developed for the frozen target. The principal advantage of such a pump is the extremely high pumping speed that can be achieved at low temperatures. In principal two absorption blocks, designed to have a rapid thermal repsonse time and small mass hold-up of the working fluid, are sequentially cycled thermally between about 4°K and a higher outgassing or release temperature. As one block is heated to release its gas content the other is absorbing gas at a low temperature. Figure 74 shows the frozen target being installed in the beam-line.

Figure 74. Installing the frozen polarized target in the $\pi 9$ beam line.



For successful operation of the frozen target it is necessary for the target material to exhibit both high achievable polarization and low rate of depolarization. No known target material was satisfactory. Research was undertaken, therefore, to find a suitable material. Research was mainly carried out on porphyrexide dissolved in 95:5 butanol-water and in 50:50 glycerol-water. Particularly long relaxation times and good polarization were found in glycerol-water and in this material the values obtained are adequate for operation of the frozen target.

Extensive measurements were made down to 0·3°K and over the field range 20 to 50 kG. During the year polarization work was extended to 2 mm microwaves and 50 kG yielding polarization of $\sim$ 70% as against $\sim$ 40% with 4 mm microwaves. Preliminary work was carried out on other materials (at 25 kG and higher fields). These were solutions of Fremy's salt in glycerol-water and of Chromium-V ion in ammonia. One would expect these to be very good materials for polarized targets but so far the polarizations obtained have been less than with porphyrexide. Other materials have been studied at low magnetic fields (3 kG). High enhancements have been obtained in several alcohols containing Chromium-V ion complexes and further measurements have been made for pinacol, which looks promising for higher field work.

The electron relaxation mechanisms of the free radicals have been investigated by measurement of the relaxation time. Measurements at 1°K and 25 kG were started during the year, and concentration and temperature dependences gave evidence of relaxation through pairs and higher clusters.

LIQUID HYDROGEN TARGETS

Two further targets, using the Type II mechanically refrigerated condensing system, have been commissioned during 1970. The K15 target has a capacity of approximately one litre and has operated satisfactorily for 5,000 hours. The K12A target shown in figure 75 was installed and commissioned, using deuterium, during the December shut-down. This target has a capacity of 4 litres and a target mass of approximately 3 lb, the cool down and liquefaction time being 48 hours.

The beam entry end of the target flask incorporates a separate gas pocket within the liquid container. This pocket is connected to the liquid container at a point above the liquid level to ensure pressure equalisation. This allows the incoming beam particles to first encounter the liquid at a point well downstream of the metal support structure. The overall length of the flask is 70 cm and the liquid filled portion is 50 cm long.

The design and manufacture of the liquid hydrogen target components for the $\bar{p}$-p experiment was carried out during 1970. This experiment will be conducted at CERN by Rutherford Laboratory personnel.

One of the main problems encountered on the Type II system has been associated with the inability of the low power refrigerator to produce liquid at a reasonably high rate. This means that any excessive liquid evaporation taking place during an experimental data taking run involves the team in a period of lost time during which the evaporated liquid is recondensed to completely fill the flask.

Such an evaporation occurs when the target flask is emptied for protracted background measurement runs, and then refilled. The flask while in the empty conditions rises in temperature and therefore the refilling liquid has to remove the increased heat energy at the expense of some evaporative loss. Up to this time this restriction has dictated that the target empty runs are reduced to short periods of time such that the target flask temperature is not allowed to rise appreciably.

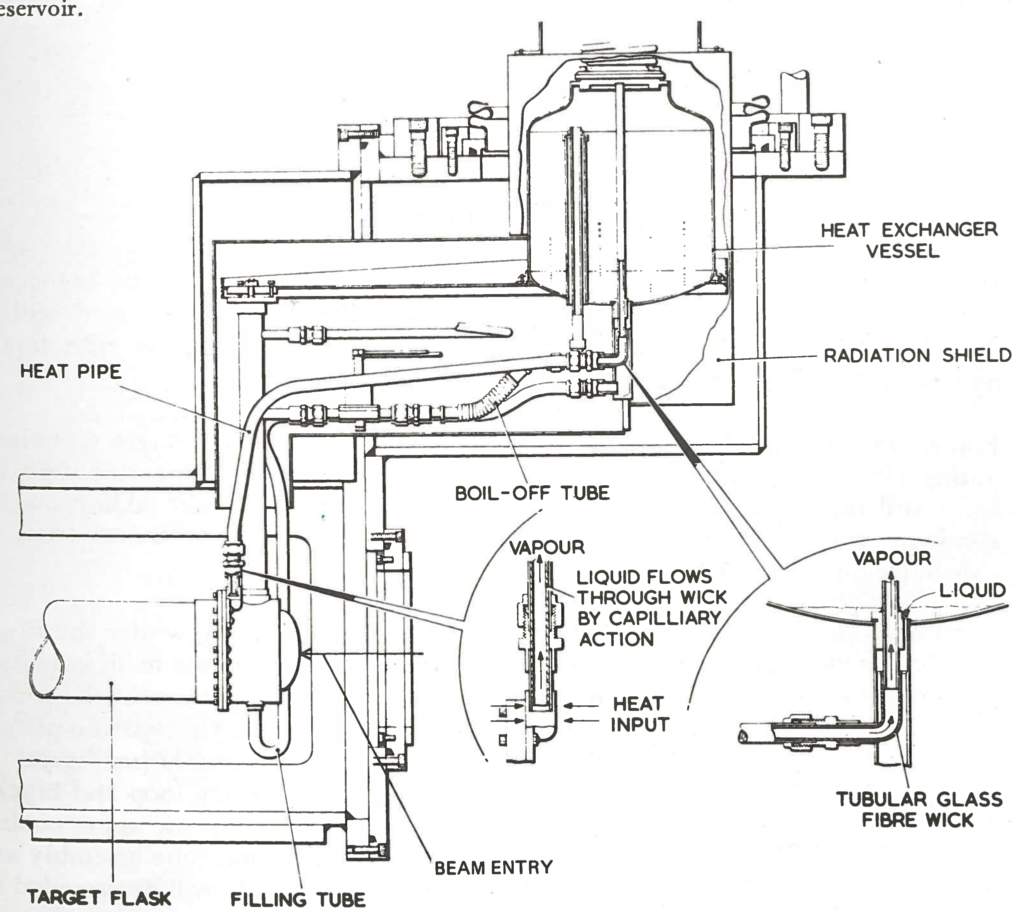
The Heat Pipe Device

For the K12A experiment, one of the requirements was that the flask should operate in the empty condition for many hours. For this requirement a 'heat pipe' was considered and a series of tests carried out using liquid nitrogen to investigate the possibility of using this device to provide an isothermal link between the refrigerator and target flask. The results of these tests showed the suitability of the heat pipe for this application.

Basically the device is a closed tube, lined with a wick material and containing a volatile fluid. Heat is removed from the external source by vaporisation of liquid within the tube of the evaporator end. This creates a slight pressure rise which assists the transport of vapour to the other end of the tube to which a refrigerated heat sink is attached. The heat sink removes heat which recondenses the vapour into the wick, the liquid being returned to the evaporator through the wick assisted by capillary action. The combination of vapour heat transfer and capillary action produce an extremely simple self-contained isothermal conduction device, having an effective thermal conductivity many hundreds of times greater than the best metallic conductors. The closed system was adapted to the K12A target (see figure 75). The condenser end of the pipe is opened into the heat exchanger vessel to allow the target liquid to soak the wick material as the target is emptied.

A test carried out during the K12A commissioning indicated a temperature rise of less than 2°K at the target flask over a 'target empty' period of 12 hours. The temperature increase took place during the first 10 minutes that the flask was empty and the flask temperature was completely stable for the remaining period. The satisfactory operation of this heat pipe has led to its inclusion in both the $\pi 8$ and K15 target systems.

Figure 75. The K12A target system showing the target flask, heat pipe and liquid hydrogen reservoir.



Vent System

A vent system is provided to contain the large amount of gas which would be evolved from the escaping liquid hydrogen in the case of a burst target. The vacuum vessel in which the target is located is connected through a low pressure relief valve to an evacuated volume of sufficient capacity so that the maximum pressure reached in such a failure is less than one atmosphere absolute. Two simulated flask failures have been performed when the flask was mechanically punctured and the liquid hydrogen contents allowed to spill out into the vacuum vessel. Pressure transducers measuring the pressure rise at various points in the vent system indicated an acceptable pressure fluctuation, which at no position rose to greater than one atmosphere absolute. The results of these tests have proved the suitability and safety of this type of vent system.

Two new targets, for K13C and K16 experiments are being designed for operation with the Type II condensing system for installation on Nimrod in 1971. The proposed K13C target has a flask volume of 0·2 litres and the K16 target has a volume of 4 litres.

Cryogenic Valve

A remotely operated valve for use with fluids in the temperature range 3°K to 500°K has been designed and is used on all current Type II Liquid Hydrogen Target systems. Made from stainless steel with a PTFE plug, it is actuated by helium gas at a low pressure acting on a sealed bellows assembly. The valve is very compact and can be operated in any orientation and may safely be used in a high vacuum or immersed in a cryogenic liquid. It has a fully open flow area of approximately 0·1 in^2 and functions as a combined stop and relief valve, (e.g. while positively closed against a pressure in one direction it will act as a relief valve in the opposite direction). Typically an operating helium gas pressure of 25 lb/in^2 absolute is used. At this pressure the leak rate across the seat is better than 5×10^{-2} lusecs at 15 lb/in^2 differential pressure. The standard valve has 0·375 in diameter ends and is suitable for 'in line' mounting. Alternatively it is possible to remove the actuator portion for use on any special body or manifold arrangement.

THE 1·5 METRE CRYOGENIC BUBBLE CHAMBER

Operations Summary

During the year, 1·066 million pictures were taken in the 1·5 metre cryogenic Bubble Chamber. Of this total, 528 thousand pictures were obtained with a deuterium filling and for the remainder, the chamber was filled with liquid hydrogen. Four high energy physics experiments were completed.

Following the encouraging results obtained with the sensitive target technique during 1969, three months were devoted to work in this field. Unfortunately, no successful running was achieved and further development work is taking place to eliminate the problems that were encountered during the technical trials in collaboration with CERN.

Chamber Modifications

Modifications to the chamber which are taking place over the winter shutdown are aimed at improving the pressures that could be obtained in the main insulating vacuum vessel. The existing chamber top plate and the lower portion of the expansion tubes and their heat exchanger loops are being replaced. The new top plate is of stainless steel and is welded directly to the new expansion tubes (see figure 76) which contain the inner heat exchangers and the lower cooling loop and blocks. The existing assembly will have the tubes cut through just below the upper cooling loop, these stubs being then entered into the new expansion tube assembly and welded. The seal between the top plate and the chamber body will be provided by an inflatable gasket pressurising indium seals.

Research and Development

Two main areas of development have occupied this section during the year. The PDP8-I computer system has been brought into operation, logging data from the 1·5 metre chamber. Further developments are in hand which will be aimed at improving the usefulness of the system by implementing a more sophisticated OPERATOR/COMPUTER interface. The other main area of activity has been the new liquid phase expansion system. Most components are now delivered and the prototype assembly is being built up to allow proving trials to commence in early 1971.

Track Sensitive Bubble Chamber Target

Research is continuing in the design of a flexible walled track sensitive target. Investigation of possible materials and model testing is in progress. The system will have sufficient flexibility to withstand malfunctions of operation which would normally burst the present type of perspex target. The aim of the design is such that it will be suitable for a variation of shapes and mounting dispositions, with the object of providing a basis for future targets.

Neon-Hydrogen Filling Technique

Use of the sensitive target for particle physics research will require an homogeneous mixture of neon and hydrogen in known proportions in the chamber region surrounding the target. This condition has been checked experimentally by stopping protons in the chamber filled with various neon-hydrogen mixtures. See Experiment 31, page 67.

Figure 76. The new expansion tubes and stainless steel top plate for the 1·5 m Cryogenic Bubble Chamber.