DNPL 3

4 GeV ELECTRON SYNCHROTRON

Progress Report for the Half-Year ending 30th April, 1966

Daresbury Nuclear Physics Laboratory
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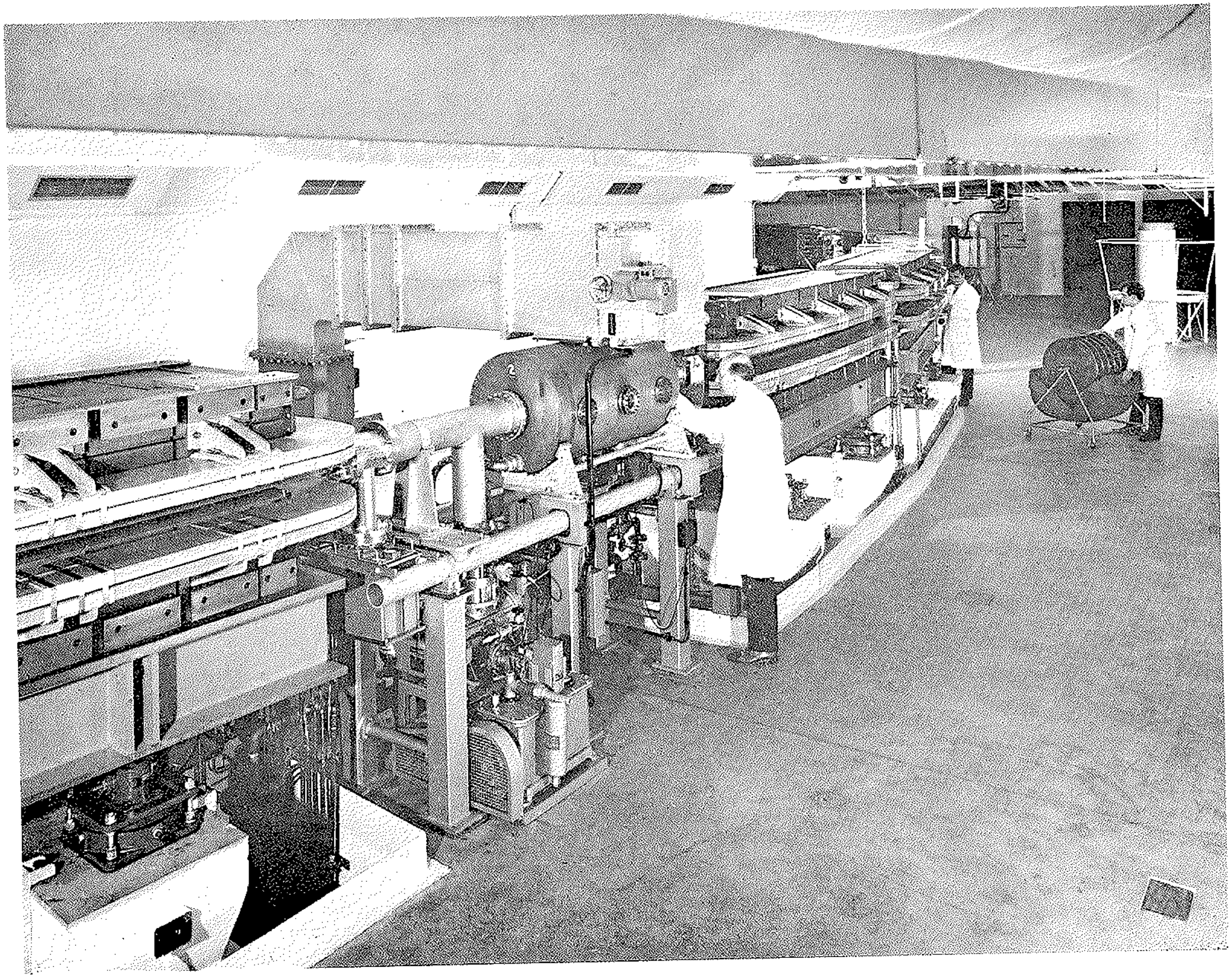


Fig. 1. Sector of the Ring with Accelerating Cavity

4 GeV Electron Synchrotron Progress Report for the Half-Year ending 30th April, 1966

1. INTRODUCTION

The Daresbury Nuclear Physics Laboratory is constructing a 4 GeV electron synchrotron (NINA). An account of the layout of the site and the main parameters of the accelerator was given in DNPL 1 and a subsequent report (DNPL 2) outlined the progress made towards completion of the project at the end of October, 1965. The present report shows the considerable further progress made during the half-year since then.

There have, however, been some difficulties in connection with the choke for the magnet power supply and also with the main power amplifier for the r.f. system, which have entailed a considerable revision of the installation programme. Details of these difficulties are given in the report. It is still hoped, however, that a high energy beam will be produced in autumn 1966, as originally planned.

The first experiments to be carried out using NINA have been approved and brief details are given of these experiments, together with the progress in designing and procuring the experimental equipment needed for their realisation.

2. MAGNETS

2.1 Magnet Assembly

The delivery of various components of the NINA magnets is nearly complete. As mentioned in DNPL 2, all magnet blocks, including spares, are on site. Oerlikon have delivered 148 of the 160 coils needed, and the remainder of the contract, including spares, is expected by the end of May. The manufacture of the coils has continued to demand the closest inspection in order to achieve and maintain a satisfactory standard. A.E.G. have completed the delivery of all pole face windings.

There is now a total of 27 magnets fully tested and accurately positioned in the ring. Four magnets are awaiting positioning and a further four are complete apart from the coils. A sector of the ring with installed magnets is shown in Fig. 1.

2.2 Magnet Survey

Considerable progress has been made in the various problems associated with the survey. Detailed analyses have been made of the sources of the various errors in the measurements of lengths and heights. These have led, in turn, to the development of a certain amount of equipment in the Laboratory to replace that from commercial suppliers.

The use of invar tapes, calibrated by the National Physical Laboratory, in conjunction with an air bearing, developed here, enables lengths to be measured to an accuracy of one part in a million and a half. It now appears that the distances between the magnet survey movements in the ring vary slightly from one survey to the next and this is correlated with external temperature conditions. Though the movement is small, an alternative method of survey, independent of this effect, is being developed.

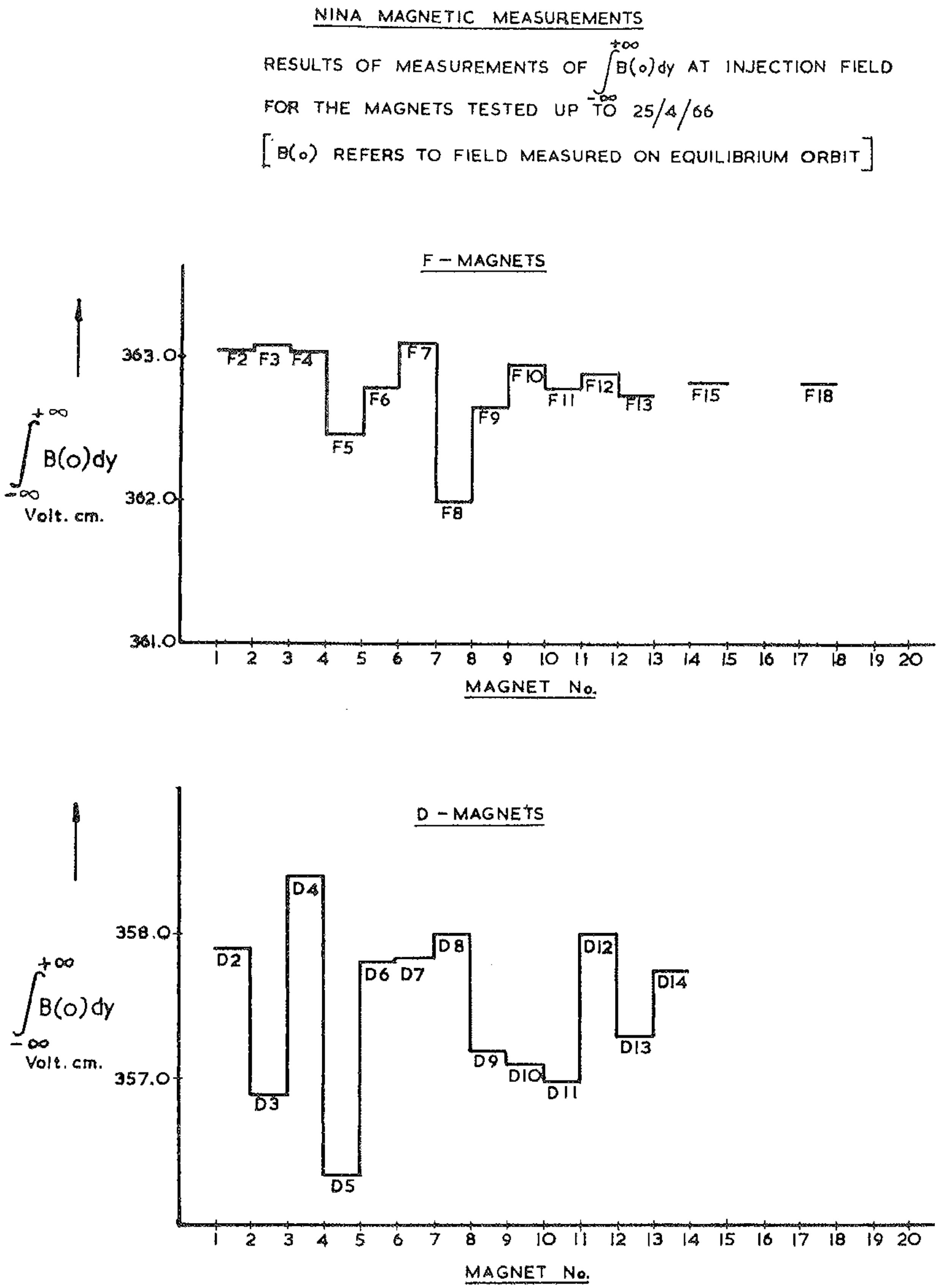


FIG. 2. INJECTION FIELD MEASUREMENTS ON RING MAGNETS

Large aluminium tubes, suitably lagged, have been installed between the 8 survey monuments in the magnet tunnel to reduce the effect of air turbulence on height surveys. These have reduced the closing errors considerably.

2.3 Magnetic Measurements

Measurements on the NINA production magnets commenced in September, 1965, and by the end of April, 27 magnets, comprising 13 D magnets and 14 F magnets, had been measured and subsequently installed in the ring. Progress on measurements was halted for a period of about 10 weeks due to a strike by the men employed by the contractor responsible for magnet assembly. Finally this contract was terminated and since then good progress has been made using the Laboratory workshop staff. It is expected that the measurement programme will be completed by mid-June. The magnetic measurement equipment has worked very well and, in particular, the data logging system has proved extremely useful.

As stated in DNPL 2, the "B-lengths" of the magnets are measured as a function of radius. From these measurements the parameter $\int_{-\infty}^{\infty} B_0 \, dy$ can be evaluated, where B_0 is the field on the equilibrium orbit and y is the azimuthal position. This quantity is a measure of the influence of the magnet on the electron beam and differences from magnet to magnet will result in electrons deviating from the equilibrium orbit. The position at which magnets are placed in the ring are chosen on the basis of this parameter so as to make deviations negligibly small when the field is at injection level. The parameter can be measured with a reproducibility at injection field of 5 parts in 10^4. Fig. 2 shows the variation in the integrated injection field from magnet to magnet for the F and D magnets so far measured. The maximum variation is about 0.3% for F magnets and 0.6% for D magnets.

It has been found that the mean value of B_0 at peak field is about 0.2% lower in D magnets than in F magnets, but no reason for this has yet been determined.

Apart from the routine measurements carried out, measurements have been made of the magnetic field in the presence of pole face windings and vacuum chambers. The quadrupole and sextupole windings were tested and found to give the desired field distributions, whilst the effect of vacuum chambers on the magnetic field distribution was found to be negligible.

3. MAGNET POWER SUPPLIES

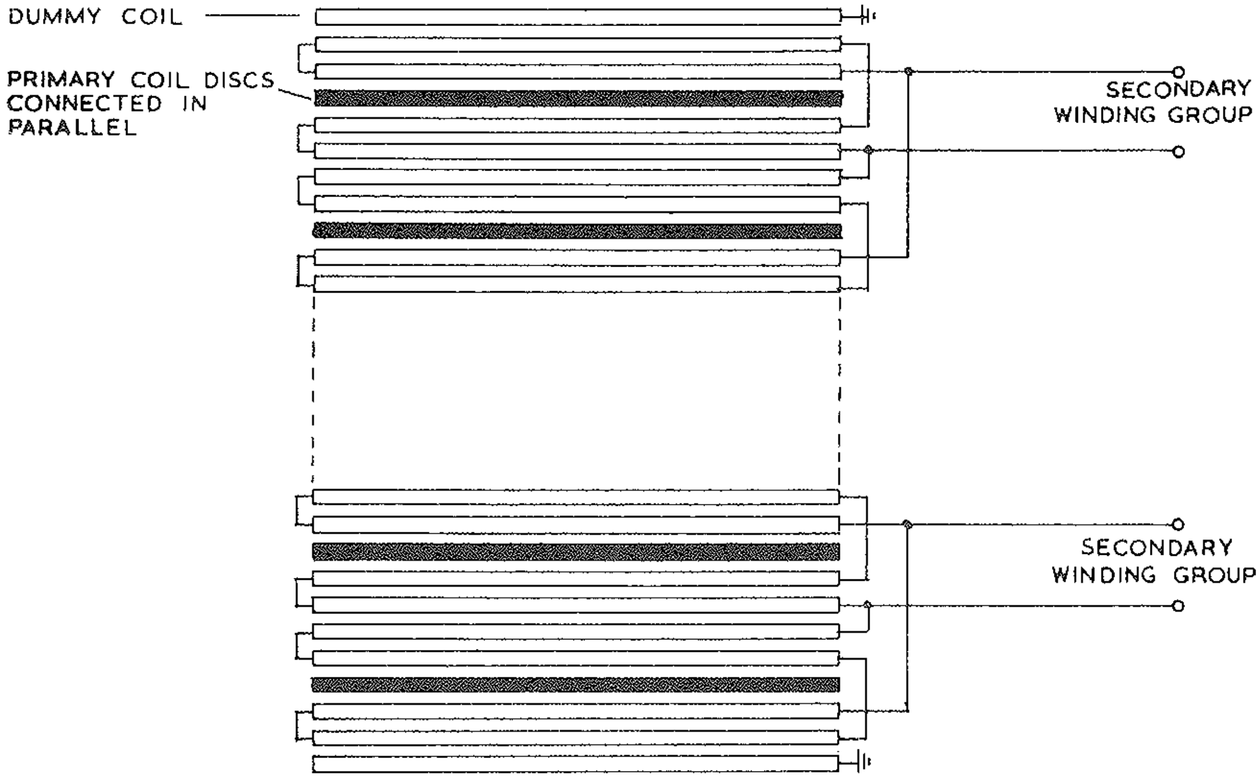
3.1 Energy Storage Choke

The assembly of the coils within the iron mantle was completed at the Stafford works of the English Electric Co. Ltd. in November, 1965. Low power measurements were carried out prior to assembly of the cleat bars. These tests indicated that, with the primary windings connected in parallel, the variation in inductance between secondary windings was within the specified tolerance of 1%. However, the primary equalising currents were extremely high and in some windings would have been higher than the rating of the copper if the choke had been operated at full power.

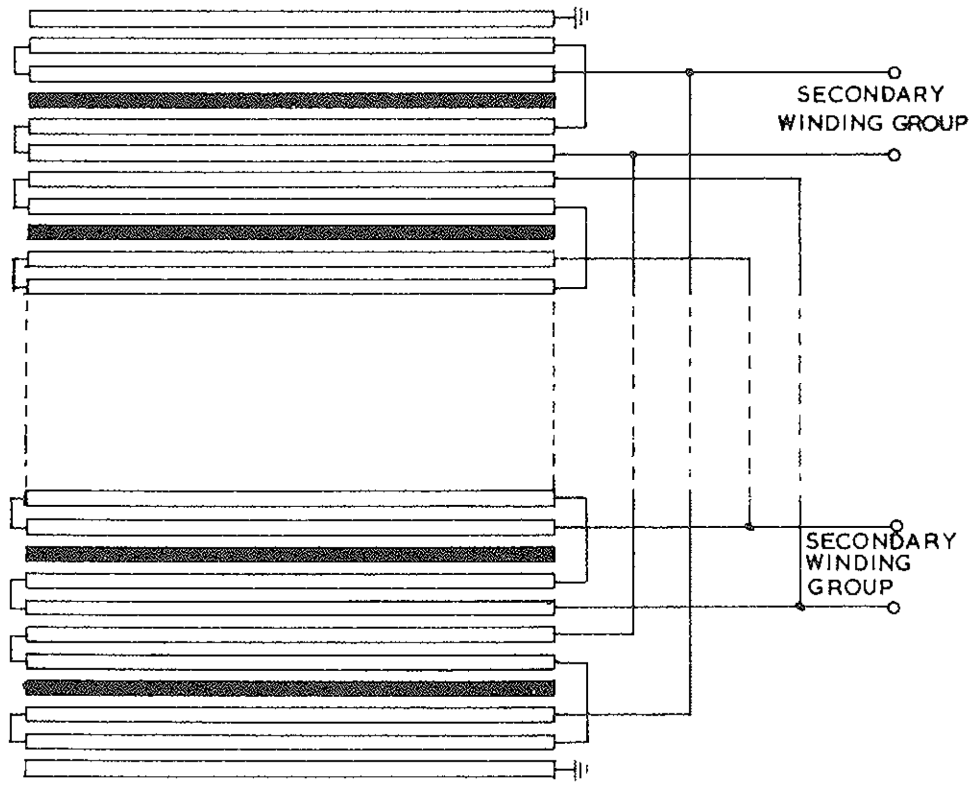
A series of tests were carried out at Stafford by Daresbury and E.E. Co. personnel and also at Daresbury on the $\frac{1}{10}$ scale model choke. The results of these tests have been issued in the form of a technical memorandum.

To explain the causes of the excessive circulating currents it is necessary to examine the choke design. Forty double disc secondary coils, interleaved with twenty primary coil discs, are arranged vertically within a laminated steel mantle. A dummy coil is positioned at each end of the coil stack to minimise capacitive leakage currents from the end windings. With this arrangement the inductance per turn is not uniform because of leakage flux, and so it is necessary to grade the number of turns throughout the coil stack to achieve equal voltages on secondary windings. Each coil disc is wound with one additional turn above the nominal number of turns to provide some adjustment during testing. The number of turns chosen varied from 31/32 turns on coil discs near the centre of the stack to 35/36 turns on coil discs at the ends.

The secondary coil connections were arranged so that each winding group consisted of two parallel circuits, each with two double disc coils connected in series. The top two double discs were connected in series and paralleled with the next two double discs and so on (Fig. 3 (*a*)). The twenty primary coils were connected in parallel.



(A) ORIGINAL SECONDARY CONNECTIONS



(B) REVISED SECONDARY CONNECTIONS

FIG. 3. ARRANGEMENT OF CHOKE SECONDARY CONNECTIONS

The tests carried out indicated that a number of factors contributed to the excessive primary circulating currents.

(i) The grading of the turns was too coarse. It seemed that the revised distribution should be from 32/33 turns at the centre of the stack to 34/35 turns at the ends.

(ii) The arrangement of connections of secondary coils (Fig. 3 (*a*)) made it impossible to maintain the flux-turns product constant in each parallel circuit of the secondary coil groups because of the coarseness of one turn adjustment. A more symmetrical arrangement was tried in which the top pair of coil discs were paralleled with the bottom pair, and so on throughout the stack (Fig. 3 (*b*)).

(iii) Difficulties experienced in lowering the top beam of the iron mantle during assembly led to the omission of some insulated spacers from the top of the coil stack and this resulted in a mechanical asymmetry of the stack in relation to the mantle. This led to excessive circulating currents in the end winding groups even with the re-arrangement of secondary connections described above.

(iv) The turns ratio between primary and secondary is 1:4, so that a one turn change in a secondary winding would have required a fractional change in the primary. It is proposed to overcome this by use of tapped auto-transformers across the outer turn of each primary coil.

It was necessary to dismantle the choke to enable the winding turns to be altered and to ensure symmetry in positioning the coils within the iron mantle. Dismantling commenced at the end of January. The turns on the various coil discs have now been modified in accordance with the computed values and an additional turn has been added to the end coil discs for further adjustment.

The auto-transformers for primary winding fractional turn adjustment have been designed with 8 tap positions and with a low leakage inductance to maintain a high primary to secondary coupling co-efficient. Each transformer is adequately rated for connection across the end turn of a pair of primary coil discs. Nine auto-transformers will be supplied for connection to nine of the ten primary winding groups so that optimum adjustment can be achieved with a whole number of turns on the tenth. All transformers are now in the final stages of assembly and should be completed about the middle of May.

At the end of April all the coils had been assembled within the iron mantle and the laminations of the top beam were being fitted. Measurements and tests on the re-assembled choke are expected to commence on the 10th May and delivery to site should be made in the middle of July. Assembly and connections on site will take about 4 weeks, so it will be well into August before testing of the whole magnet power supply system can start.

3.2 Resonant Capacitors

Erection and site testing of the ten resonant capacitor banks was completed in November, 1965. All units withstood an overvoltage test of 31 kV d.c. for one minute and the measured capacitance of each capacitor bank, in an ambient temperature of 20°C, was within 0.3% of the nominal value. Additional oil impregnated capacitor units, to provide 1% and 0.5% trimming during resonating of the choke and magnets, were delivered to site in February. These trimmers are interchangeable with the oil impregnated capacitors fitted on each of the racks.

3.3 Pulse Power and D.C. Bias Supplies

All the plant installation and inter-connections for the Pulse Power and D.C. Bias Supplies were completed in February, after which acceptance tests were carried out. High voltage and insulation tests, secondary injection tests on protection circuits and equipment and functional tests on the main rectifiers and all auxiliary equipment were performed, including extensive tests on the pulse valve cooling system, ignition, excitation and arc drop. The grid firing jitter was found to be less than 0.1 microsec. In general the systems were found to be satisfactory, though a few minor faults were discovered and are being corrected.

Final commissioning of the pulse power and d.c. bias supplies can only be carried out when the energy storage choke and magnet network are available. A dummy resistance load, rated at 75 kW, has been connected across the d.c. bias to permit some setting up and checking of the bias servo equipment. The resistance has been arranged to match the network resistance of about 1.5 ohms and allow the d.c. bias to run at about 33% of maximum output voltage, or, by changing links, the resistance can be arranged to run the equipment at full voltage with 10% maximum current output. These preliminary checks will be carried out in May.

3.4 Busbar System

The tubular copper busbars and polythene insulated cables at the magnets are installed. Flexible cable for terminating at the magnet connections will be delivered during May. Erection of protective screening around the busbar system is progressing but final completion of the system can only be achieved after delivery of the energy storage choke.

3.5 Fire Protection Equipment

Because of the potential fire hazard in the Inner Hall resulting from oil-filled electrical equipment, a contract for the supply and erection of an automatic high pressure water fire protection system was placed with Mather and Platt Ltd. in July, 1965. Installation of this equipment has commenced.

4. VACUUM SYSTEM

4.1 Vacuum Assembly in the Ring

By the end of April, three of the ten sectors into which the ring is divided had been fully erected and commissioned and a fourth was expected to follow shortly. After it had been ensured that no detectable leaks remained, the pressure in the three commissioned sectors ranged between 2×10^{-7} torr and 6×10^{-7} torr. The pump-down time was reasonably short; 25-30 minutes to 10^{-4} torr, the starting pressure for the ion pumps, and 2 hours to 10^{-6} torr. Subsequent pump-down times are shorter still as the system cleans up. Although the programme appears to be slightly late, the sectors assembled so far have all contained r.f. cavities which add to the complexity of assembly. The lost time should, therefore, be made up in assembling the 5 sectors without accelerating cavities, and the complete ring should be under vacuum by mid-July.

Work is continuing on the production of internal targets for photon beams and designs are being produced for various exit windows and evacuated beam tubes for carrying the external photon and electron beams into the experimental area.

4.2 Vacuum Chambers

An investigation is being made into the possibility of using a high density alumina to produce vacuum vessels with much greater radiation resistance. Ferranti Ltd. are carrying out a small development programme in conjunction with the ceramics firm of Andermann & Ryder to produce a short length of "D" type cross section with a number of typical joints and end flanges. It is only possible to make this alumina in short lengths to maintain tolerances after firing and, in order to make a complete vacuum chamber, sections of length 12 in. will be joined by cupro-nickel connections attached to the ceramic by metal sealing techniques. The short cupro-nickel rings will then be welded together (Fig. 4). The inside surface will be metallised to prevent beam distortion by electrostatic charge build-up, the metallising being connected by lead-through conductors to earth. Alternatively, if the upper and lower portions of the metallising are separate, a clearing potential can be applied for ion removal. This prototype work is going well and we hope to have the first jointed tube in June or July. If this ceramic work is successful, it should improve the reliability of the system by reducing the need for vacuum chamber repair. It will also result in a cleaner system with smaller out-gassing rates and hence lower working pressures.

Investigational work is also proceeding on the existing vacuum chambers, described in DNPL 2, to ensure that they are post-cured and outgassed in the best way to give satisfactory performance at the expected running temperature of 80°C.

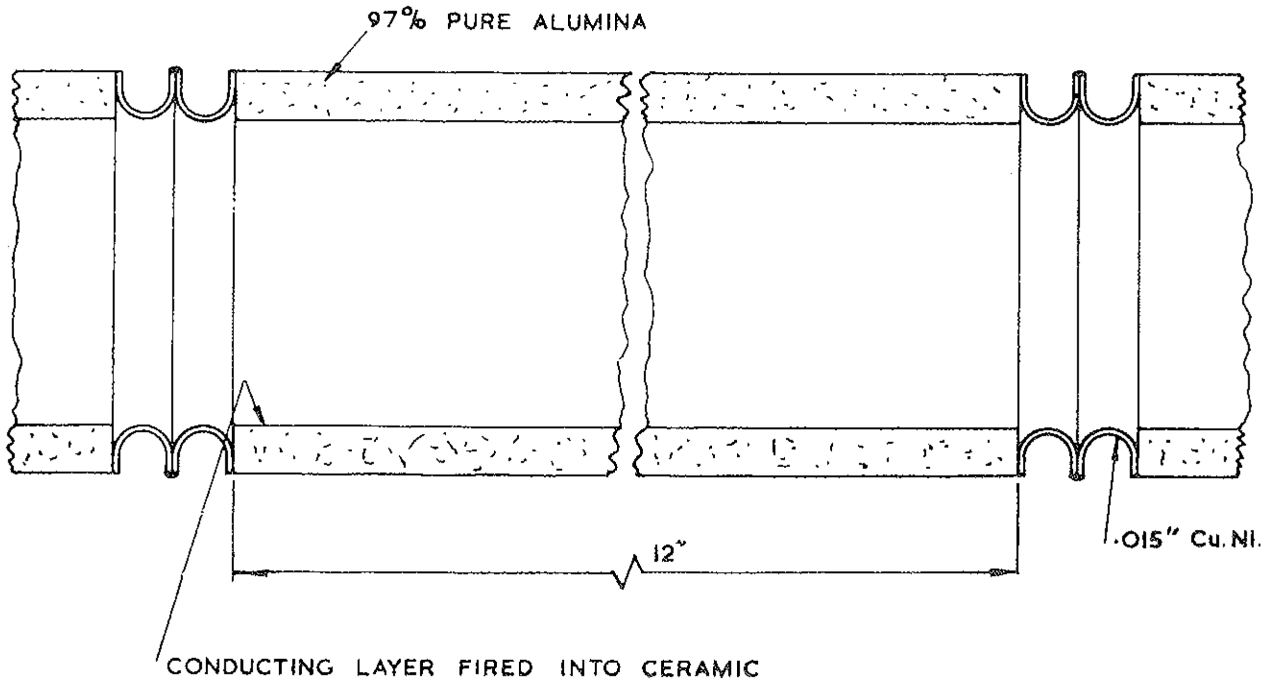


FIG. 4. SECTION OF PROPOSED CERAMIC VACUUM CHAMBERS

5. R.F. ACCELERATING SYSTEM

5.1 Introduction

Apart from the problem of the amplifier output stage, which will be described below, the completion of the r.f. system is running about six weeks behind the time-scale envisaged six months ago. This is due partly to installation delays early in the period and partly to manufacturing delays mainly affecting recent work. However, with the exception of parts of the modulation and control circuits, it is expected that the basic r.f. system, consisting of master oscillator, amplifier, waveguide ring, cavities, cavity tuning system and monitoring equipment will be complete by mid-June. System commissioning will then start.

5.2 Power Amplifier

The parasitic oscillations in the 2054 stage, mentioned in the previous report, proved to be not easily overcome, and on 23rd November, 1965, the tube and cavity were shipped back to the R.C.A. works at Lancaster. The basic problem was as follows:

Although all "super-power" triodes show a tendency to oscillate when operated at high plate voltages and with low grid drive, it had been shown that the 2054 was stable in our cavity up to the highest plate voltage envisaged, with no drive. During commissioning, however, it was found that oscillations occurred immediately after the removal of the drive pulse under conditions of d.c. plate voltage, and later it was also found that oscillations occurred during the pulse when the drive was between certain levels. Since then R.C.A. have put in a lot of work investigating this phenomenon, and have established that the amplifier will oscillate in this way, in many modes, at frequencies between 1,000 and 2,300 Mc/s depending on the electrode voltages and circuit configuration. No circuit configuration has so far been found in which the tube did not oscillate with the possible exception of one so asymmetric that the amplification efficiency at 408 Mc/s was quite unacceptable.

The line of attack has recently switched to using an equivalent tube with a matrix oxide cathode. A tube of this type has been tried and appears to meet the specification. Tests of this tube are to be witnessed in early May. If these tests are satisfactory, the amplifier may be returned to Daresbury in the near future, though tube evaluation will not be regarded as complete.

Commissioning of the r.f. system, and even of the synchrotron, could start using the driver stage. To obtain the maximum power from this stage the 2041 tetrode is being converted to an A.2548 by installing a new water separator and adding water cooling to the plate circuit jacket. These modifications will be complete by mid-June.

Partly because of concern about the possibility of a parasitic oscillation at any time damaging the amplifier, the crowbar circuits have been improved. Originally the tube was protected only against a flash-arc by means of the circuit shown in Fig. 5. Here the smoothing capacitor, C, of the power supply is connected to earth via a small resistor, R_1, enabling the current pulses drawn by the amplifier to be monitored. If an arc occurs in the amplifier tube, the voltage across R_1 exceeds a preset fault level and operates a transistorised trigger circuit, this in turn fires the crowbar tube which is a type CX.1140 hydrogen thyratron, and the fault current is immediately diverted from the amplifier tube because the isolation resistor, R_3, has a much higher impedance than the crowbar tube in conduction. The current pulse through the crowbar is monitored across R_4 and used to trip-off the power supply, after which C discharges through R_2 and the crowbar tube.

This protection circuit operates in 1 microsecond after the detection of a fault. An interesting feature is the use of a tetrode thyratron in which the first grid is permanently ionised and the grid current operates an interlock relay to ensure that the circuit is always in a state of readiness. This circuit is used to protect the anode and screen grid of the 2041 driver amplifier, but the power levels in the final amplifier are 10 times greater, so the hydrogen thyratron is used as a trigger device for a BK.178 ignitron which is used as the crowbar tube. This has a firing delay of several microseconds but the circuit still satisfies the protection test requirements. The protected power supply is connected to a test spark gap of which one electrode is a sheet of 0.001 in. thick aluminium foil. If the protection circuit is operating correctly the spark produced does not puncture the foil.

Because of the possibility of parasitic oscillation a second detector circuit has now been added to compare the r.f. output from the final stage with the anode current waveform. If at any time these differ significantly, the same trigger circuits are tripped. A dead zone and small time delays are built in to ensure that error signals due to the non-linearity and the rise time of the amplifier do not cause the crowbar to be tripped.

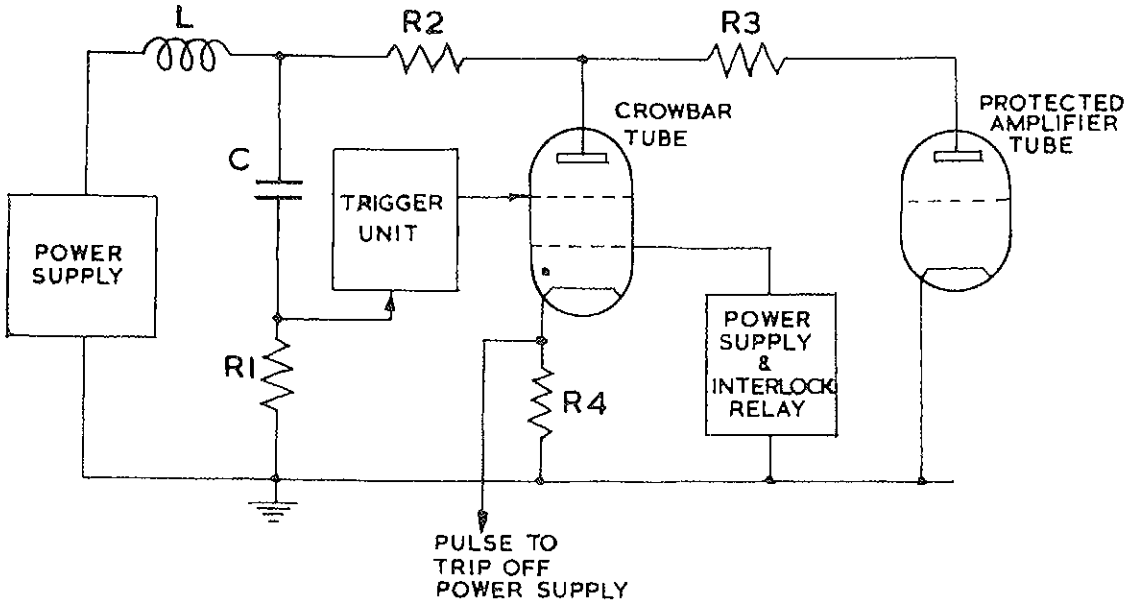


FIG. 5. BASIC "CROWBAR" CIRCUIT FOR FLASH ARC PROTECTION

5.3 Master Oscillator

This is now complete. Since the injector, which operates on the 7th harmonic of the synchrotron frequency, must be phased-locked to the synchrotron, it is logical to derive the linac r.f. from a frequency multiplier which is driven by an output from the synchrotron master oscillator. In this way proper synchronism should be obtained between the two systems without the need for any extra special equipment. This will of course only be true once temperature equilibrium has been established in all tuned circuits. For the injector, a frequency stability of 1 part in 10^5 has been given as the maximum acceptable tolerance. The synchrotron frequency tolerance is however more stringent and if one takes as a criterion the tolerance of 5° for the cavity phase at injection then it follows that the frequency stability must be 3 parts in 10^6 when the cavities are lightly loaded.

There is a further special requirement for the master oscillator, namely that it shall be capable of being frequency modulated during the acceleration cycle without affecting the frequency stability at injection, at which time the f.m. control signal will be removed. It had been hoped that a commercial frequency synthesiser would have fulfilled the role of master oscillator, but no such instrument met all the requirements. However, suitable commercial oscillator stabilisers are readily available in the U.S.A. so it was decided to employ such a unit in conjunction with a Laboratory designed voltage-controlled oscillator. The stabiliser operates as follows:

A high frequency reference is derived from a crystal oscillator whose stability is somewhat better than the final requirement. This high frequency reference is heterodyned with a sample from the oscillator to be stabilised. The difference frequency is chosen to be 30 Mc/s. This difference frequency and the signal from a low frequency reference oscillator, which is nominally 30 Mc/s, are fed to a phase comparator which can provide a high level output. The phase comparator output operates directly on the voltage control of the oscillator to be stabilised. If for some reason the phase lock should fail, or not establish itself, for example, soon after switch-on, an automatic search routine is called into play to sweep the frequency range of the oscillator to be stabilised and hence pull it into lock. The circuit of the complete master oscillator is shown in Fig. 6.

It was thought advisable to design the master oscillator for an output of 5-10 W, thus eliminating the need for some extra power amplifiers outside the feedback loop. The voltage-controlled oscillator therefore took the form of a 3-stage self-excited amplifier with 18 dB gain, with a varactor phase shifter in the feedback path. The amplifiers were constructed with emphasis given to stability of circuit parameters and were provided with their own stabilised h.t. supply. The phase shifter had a range of about 90° and the voltage range was about 10-90 volts for the full phase shift. Tests of the complete assembled unit showed that the original specification had been met, and in particular the speed with which the f.m. deviation of 2 parts in 10^4 could be made was of the order of 10 microseconds, limited only by the f.m. signal generator's speed of response. The oscillator would stay locked on over deviations of several hundred kc/s, and the purity of output, i.e. freedom from parasitic modulation, seemed to be excellent in comparison with the earlier scheme using a frequency synthesiser or with a quartz oscillator followed by a frequency multiplier. This particular test was made with a high Q cavity where the effects of parasitic modulation would have been very pronounced.

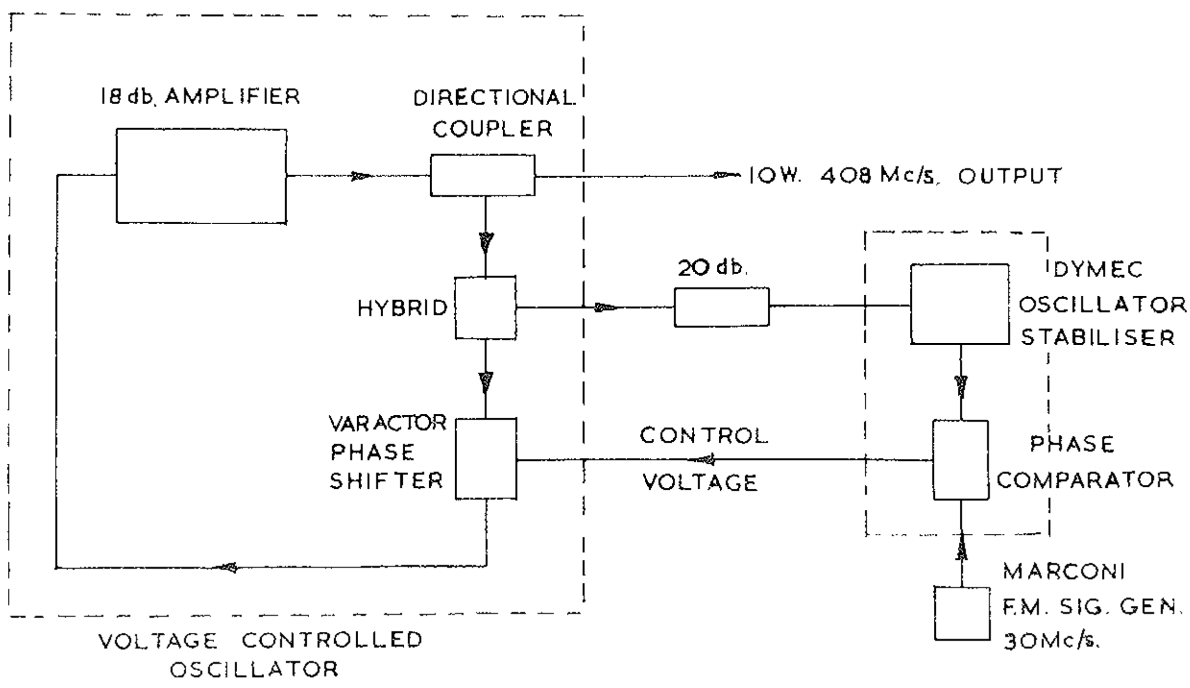


FIG. 6. MASTER OSCILLATOR BLOCK DIAGRAM

5.4 Waveguide and Cavities

The waveguide has all been manufactured and the ring has been installed together with the feeder from the amplifier. Tuning each section of the ring between tee junctions to be an exact number of wavelengths has started and should be complete during the next few weeks. Four of the six cavities ordered (which will include one spare) are on site and vacuum tight and have been r.f. tested to power levels of 20 kW c.w. and 50 kW peak with a 40% duty cycle; they are all now being installed in the ring. For the last two cavities, a metallurgical fault in the input flange material has held up production but both are expected on site during May. The cavities have not proved easy to manufacture; with the first ones the dimensional distortions which occurred during brazing necessitated mechanical deformation of the ends to bring the cavities on tune. Though later cavities are better, there have been cases where vacuum leaks appeared at brazed joints during shipment, and we have established a repair procedure using hot water for heating the cavity, and low melting point solder used with a flux which is non-contaminating from the vacuum point of view. Such a repair can be done *in situ* in the ring if necessary.

All equipment for the automatic tuning system and monitoring circuits for the cavities has been manufactured and is being installed; it is described in some detail below. The r.f. circuits made considerable use of specially designed stripline components and some remarks concerning these are also made below.

5.5 Cavity Automatic Tuning System

A simple servo system is used to keep each of the five accelerating cavities on tune during long periods of operation. Basically the system consists of an r.f. phase detector which monitors the cavity tuning by comparing the phase of the cavity voltage with that of the input wave, and sends a proportional error signal to transistor amplifiers which feed a d.c. servo motor which drives adjustable tuners in each cavity cell. A separate system is used for each cavity.

Because of the reactive effect of beam loading on the cavities the cavity tuning must be monitored in the period between acceleration pulses. During this time a short pulse of r.f. power is fed into the cavity and the output from the r.f. phase detector is gated so as to give a signal corresponding to the tuning error during this pulse. This, after amplification and conversion to d.c., drives the motorised tuners.

In practice, the cavities require to be off-tune at injection to assist the trapping process, and, once this is completed, the frequency may be varied to tune the cavity-beam combination. The initial cavity detuning required varies with the beam current, and adjustment is achieved by means of a voltage-controlled varactor phase shifter in the feed to the r.f. phase detector in each cavity tuning circuit.

The automatic system keeps the cavities on tune to $\pm 1^\circ$ of phase and tuning errors are corrected within a few seconds. The speed of response of the system is limited by the maximum speed of the d.c. motors and associated gearing. The tuning system may be switched to either automatic or manual control and normally the three tuners are ganged together. However, in order to flatten the field in the three cells, the tuners may be driven singly under manual control using magnetic clutches. Various over-run and system alarms are incorporated. The tuning system associated with each cavity is housed in a double-bay rack unit in the lower ring tunnel, immediately below the cavity. This rack also houses motor controls for waveguide, phase shifters and matching units, monitors from cavities and waveguide, etc. These controls and monitors are duplicated in the inner hall adjacent to the main amplifier and in some cases also in the main control room.

5.6 Strip-Line Components in the R.F. System

A number of r.f. components have been specially designed for the r.f. system in strip-line form, a technique which is now well established and which offers, amongst other features, simplicity and cheapness of manufacture compared with the coaxial realisation of these components. The development and design work was carried out in the Laboratory and manufacture undertaken by Microwave Instruments Limited.

The type of strip-line adopted uses a copper strip sandwiched between two slabs of low-loss insulating material with earth plates at each side. The chosen geometry and parameters are briefly as follows.

Two $\frac{1}{8}$-in. sheets of aluminium are fitted together with two $\frac{3}{16}$-in. sheets of polythene between them. The inner conductor is 0.005 in. thick and the width of the strip is chosen to give the required impedance; for example the width to give 50 ohms impedance is 0.280 in.

Bandwidth of components was not a prime consideration and this has led to simplification of design and construction. For instance, although at first sight edge launching would seem preferable to avoid discontinuities, it has been found that matching is easily obtained if type N connectors are attached to one of the earth plates provided that two of the four fixing bolts form a short-circuit between the earth plates. The v.s.w.r. is never worse than 1.05, and construction is clearly much simpler than with edge feeding.

Passive components that have been made include edge and broadside directional couplers, hybrids with 3/2 wavelength path lengths, 4-way power dividers, low-, high- and band-pass filters. The hybrids and the directional couplers have been run at 500 W c.w. which is almost the safe limit for the connectors. For high power use, air-spaced units have been made. Active components have included solid-state phase shifters using varactor diodes, whose theoretical limit is 180°; in practice 80-90° is readily achievable for power levels up to 1 W with a v.s.w.r. not worse than 1.1. Another active unit is a thermionic detector using an EA.52 diode. This detector is so constructed that it can be used in conjunction with an external load and will handle powers up to 70 W though, in practice, the load is generally restricted to 10 W. In conjunction with standard emitter-follower units, the detector forms a peak power meter which will also read c.w. power correctly. The detectors are generally arranged in pairs with associated directional couplers, and are widely used on the r.f. system. A higher power phase shifter has also been developed for use with stepping motor control. Yet another interesting component is an infinitely variable directional coupler whose coupling can be altered externally by alteration of a coaxial cable: This component is merely a pair of folded hybrids with one internal connection and one external connection, and it is by altering the latter that the alteration in coupling or power division is obtained.

Experience to date with this type of transmission line is satisfactory and it will normally replace coaxial components except where these are unavoidable such as in high power transmission lines of long length, or where the circuit must fit in with a definite coaxial component such as a high power tube. The ease of development and manufacture for frequencies up to 1 Gc/s is quite remarkable, and the miniaturisation of the components by folding up the circuits on a flat plane, which is possible due to the rapid attenuation of fields edgewise to the strip, is very convenient.

6. INJECTION EQUIPMENT

6.1 Linear Accelerator

The 40 MeV linear accelerator made by M.E.L. Equipment Ltd. was delivered to Daresbury at the end of March. Installation work is proceeding. The equipment delivered is to the Stage I design, that is, there is at present no provision for beam chopping at 408 Mc/s. A system for doing this is still under development by M.E.L.

The gun modulator used during works testing and also to be used during early commissioning on site is a temporary equipment. The original intention was to use a triode gun with a d.c. potential on the anode. However, tests at Mullard Research Laboratories, Salford, where the electron gun development is being carried out, showed that it would be difficult to avoid flash-over troubles in the gun at its rated voltage of 80kV, even after prolonged conditioning periods. Accordingly a decision was taken early this year to pulse modulate the anode supply. The new modulator has been designed and is now being manufactured. Completion is expected in August this year.

Beam tests on the accelerator at Crawley showed that it was possible to load each section of the accelerator until zero r.f. power emerged into the output waveguide during the current pulse. The current at which this occurred was approximately 1A, and from this it could be deduced that the accelerator sections were behaving much as could be expected from design considerations. It was agreed to allow shipment of the accelerator to site without any spectrum measurements having been made in order to avoid further delay.

One cause of delay during the testing programme was the investigation of a phenomenon occurring in the high power klystrons (C.S.F. Type F 2049). It was found that at certain drive levels the r.f. pulse output became unstable whilst a large reflection of power occurred at the input cavity. When running at 30MW under recommended conditions, the drive level at which the instability occurred proved to be very close to saturation drive. At lower output powers the klystrons had to be overdriven before the phenomenon occurred, and at the output for which the accelerator had been designed (25 MW), the instability drive level was sufficiently different from saturation drive as to cause no practical worries.

However, C.S.F. were informed of the discovery and have carried out investigations both at Crawley and at Orsay. They formed the theory that the klystrons were not correctly matched to the external load at the 30MW level so that, under high drive conditions, the voltage occurring across the gap in the output cavity could be sufficient to cause some electrons to be turned back. These, on passing through the input cavity, interacted with the drive signal in such a way as to cause instability. Accordingly, C.S.F. altered the output coupling of the klystron by inserting an iris in each output waveguide, and were able to demonstrate that this effectively cured the trouble. Lengths of waveguide with appropriate irises are to be supplied for installation at Daresbury.

Another puzzling result of measurements on high power klystrons is a big discrepancy in perveance measured on the same tubes by C.S.F. and M.E.L. The difference is about 20%, although there is agreement on tube efficiency. Check calibrations are to be made to try to resolve the discrepancy.

It is expected that commissioning of the accelerator at Daresbury will commence during May, leading to the production of a 40 MeV beam before the end of the month. The injector test system for emittance and spectrum measurement has all its main components in position and connected up. Assembly of the vacuum pipework is proceeding.

6.2 Injection Path

As mentioned in the previous report, the injection path components have been designed for the large aperture and momentum spread of a positron beam, such that ideally each particle is placed on an orbit in the synchrotron appropriate to its momentum and emittance.

Two bending magnets are used, one with an angle of 32.77° and the other 28.52°. The bending radius is 1.478 m and the required beam aperture is 12.5 cm horizontally and 2.5 cm vertically. The magnets, made by Mullard Ltd., have poles 7 in wide with a 2 in separation. Measurements have recently been completed at the Laboratory to determine the necessary shims in the gap and the end contours of the pole pieces, to give the required field distribution and correct effective length over the desired aperture. Positioning of these magnets in the ring area is about to be carried out.

A single quadrupole with 10 cm aperture and a gradient of 60 Gs/cm was also made by Mullard Ltd. for use between the second bending magnet and the inflector. The remaining matching element, a quadrupole triplet with 12.5 cm aperture and a gradient in the centre quadrupole of 220 Gs/cm has now been specified and will shortly be ordered. Since this triplet is required primarily when positrons are to be injected, its early installation is not essential.

A beam position indicator situated between the two bending magnets will provide a signal to drive the energy servo system of the linear accelerator. Correction is achieved simply by controlling the output power of the second klystron.

Vacuum pipework for the injection path is in manufacture and is expected to be on site by the end of May.

6.3 Inflector

The inflector consists of two aluminium strip conductors, spaced apart a distance of 14 cm, and surrounded by 1 cm thick frames of Mullard B_1 ferrite. The internal contour of the frames has been determined by experiment to give a field gradient of 2% per cm across the portion of the aperture occupied by the injected beam. The reason for the gradient, as explained more fully in the previous report, is to limit the horizontal aperture of the injected beam through the momentum matching system.

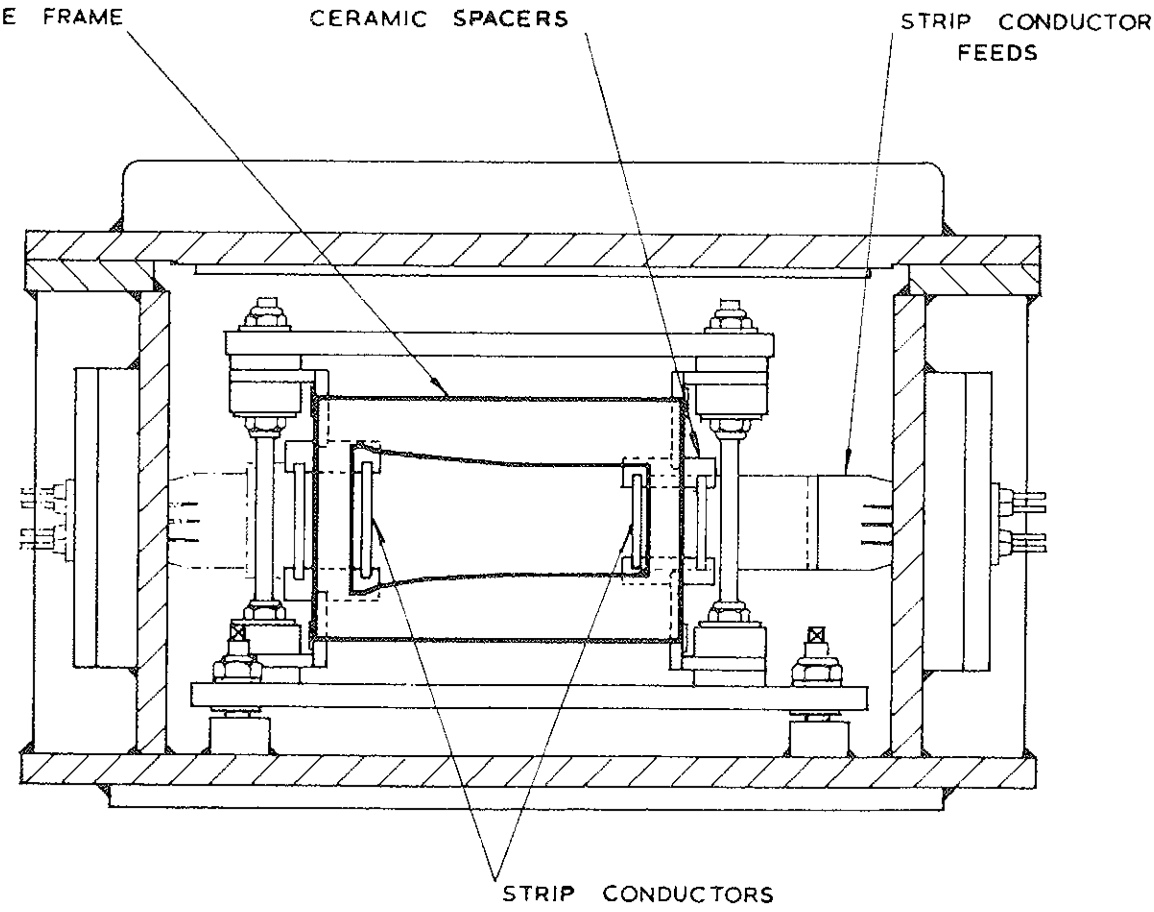


FIG. 7. CROSS-SECTION OF INJECTOR ASSEMBLY

A cross-section of the inflector assembly is shown in Fig. 7. The 50 ferrite frames are supported in slotted aluminium strips to give equal mark/space ratio. The strips are curved on a radius of 12.5 m so as to be parallel to the inflected beam trajectory. The conductors are also supported from these strips by means of alumina spacers at suitable intervals. The whole assembly, clamped together by tie-bars, is mounted on a base plate which is supported from the base of an aluminium vacuum box. Means of adjustment are provided so that the assembly can be positioned correctly inside the box.

Connections from the conductors are brought out at the middle and ends of the assembly to four vacuum windows on the sides of the box. The inflector pulses are to be brought in through 8-pin glass/metal seals made by English Electric, each conductor end being flexibly connected to four of the pins. The requirements for these seals are that they must be able to carry 1000 A, 1 microsec pulses and be capable of withstanding 5kV continuously and up to 25kV for periods up to 0.1 microsec.

The present position is that the vacuum housing is on vacuum test prior to being inserted in the ring. All components for the internal assembly are to hand and assembly work has started.

The inflector modulator, being manufactured by Staveley-Smith Controls Ltd., has taken longer to make than originally expected. However, completion is now planned for the end of May and commissioning by the A.E.I. design team will commence during June.

will be seen connecting the sensing device to the top plate. This plate is the lid of the enclosing vacuum vessel and its upper surface is provided with mountings for a survey target. By means of optical devices fixed to the datum points on adjoining magnets it will be possible to adjust the electrical zero of the sensing device to coincide with the correct orbital beam position. It will be necessary to remove each sensing device for this adjustment and place it in an external rig in which the beam current will be simulated by pulses of current in a wire. This rig has now been assembled and is undergoing commissioning tests.

Two further devices are being constructed for the purpose of measuring total beam current. They will be installed in two of the long straight sections, and are essentially a single-turn air-cored toroid encompassing the beam. The current induced in the toroid will be measured by means of similar "current transformers" to those used on the position sensing devices.

The electronic equipment associated with these devices is, on the whole, nearing completion of manufacture, but a few of the less important units are still at the development stage.

(*b*) *Timing Pulse systems*

The equipment for these systems is now under construction with some parts of it being given final bench tests.

(*c*) *Multiple display systems*

The system for displaying the vacuum pump currents has been completed.

(*d*) *Beam steering power supplies*

Most of these units are to hand and being given bench tests.

(*e*) *Pulsed power supplies*

The high current sections of 5 power supply units are now in the course of manufacture. They are designed to generate pulses of up to 400 amps of current lasting for up to 3 milliseconds, and can be connected directly to magnet back leg windings. Pulse transformers are being constructed to increase these current to 8,000 and 6,000 amps for a duration of about 1 millisecond to provide power for the kicker magnet and current strip of the electron extraction system.

(*f*) *Position controller/indicators*

There will be quite a number of mechanical features around the beam orbit which need control and indication of position relative to the orbit. They comprise targets, collimator slits, and extraction systems. It has been possible to standardise the electric motors giving the mechanical movements. Also the required accuracy of position indication can, in all cases, be obtained by means of linear potentiometers. Standard controller indicator modules for installation in the control room are therefore possible, and these are now being developed.

It is expected that the motor to be employed will be capable of stepping action as well as continuous running. Inching operations should, therefore, be easily controlled. It is proposed to make pairs of units capable of joint control either in the same or opposite directions. A simple indicating meter display of position will be associated with each control, but provision will be made for external connection to a more accurate display. It has been found that a simple modification to a "Digitec" voltmeter can provide this, and good accuracy is ensured by employing a ratiometer principle.

8. ACCELERATOR DEVELOPMENT

8.1 Beam Instrumentation

The aim at Daresbury is to accelerate a much higher current of electrons than has been achieved so far in similar synchrotrons and since the reasons for the limitations on the current in existing machines are not known, it is necessary to provide instrumentation to determine as fully as possible what is happening to the beam in the synchrotron.

Initially, it is planned to provide the following instrumentation:—

(*a*) *Beam position indicators*

Beam position indicators will be mounted in each of the 20 short straights. Some details regarding these have already been given in Section 7.7. They are a modification of a C.E.A. design, which uses a cubic framework of bars, through which the beam passes (Fig. 8). Voltages are induced in the longitudinal bars by the passage of the beam, the voltage in a bar varying with the distance of the centre of charge of the beam from that bar. The current in the transverse bars vary as the difference between the voltages induced in the longitudinal bars and thus they vary with the beam position. Ferrite core transformers on the bars are used to feed out this information to the indicators. The signal varies with beam current as well as beam position and so it is necessary to feed a signal proportional to beam current into the indicators to apply the necessary correction. The beam current signal will be obtained from the beam current indicators below. The information from each indicator will be stored and the indications presented in the form of a histogram showing the variation of beam position from the equilibrium orbit round the machine.

Beam position indicators of the toroid type will be fitted in the injection path. These also give an indication of beam current.

(*b*) *Beam current indicators*

Beam current in the synchrotron will be indicated by means of a conducting toroidal surface which forms the single turn primary of a pulse transformer. This indicator will respond to the modulation in the circulating beam current introduced by the inflector. The phase monitor, mentioned below, will also give an indication proportional to the 408 Mc/s component of the circulating current.

(*c*) *Q measurement*

Measurement of the betatron frequencies in the vertical and horizontal plane will be made by exciting coherent oscillations by means of a local transverse r.f. magnetic field in the appropriate plane. The frequency and amplitude of the r.f. field will be adjusted for maximum amplitude of betatron oscillation detected by a pick-up electrode a quarter of a betatron wavelength away. The r.f. field will be provided by an oscillator-amplifier combination, which produces 100 microsecond pulses of r.f. in a single turn winding in a rectangular ferrite core. By varying the timing of this pulse, the Q can be measured at various points during the acceleration cycle.

Separate coils will be provided for deflection in the two planes. Experiments with the ferrite frames show that a field uniformity of $\pm 5\%$ can be achieved over the whole useful aperture.

The ferrite frames and vacuum box have been ordered from Mullard Ltd. and Lintott Engineering Ltd. respectively and the r.f. drive system is being developed in the Laboratory.

(*d*) *Bunch length measurement*

Measurement of the effective bunch length can give information on the amplitude of synchrotron oscillations. At low energies, where this is of greatest importance, this measurement is most difficult to make, although some indication can be obtained from the measurement of the 408 Mc/s and harmonic frequency components in the circulating current. At high energies, where the bunch length is likely to be shorter, a method similar to that used with one of the electron storage rings at Novosibirsk will be tried.

The collimated synchrotron light (from one of the machine magnets) is focused on to the cathode of an image intensifier. The photo-electrons resulting are deflected by means of a rotating electrostatic field produced by two sets of plates at right angles fed in quadrature with r.f. at the synchrotron frequency or a sub-multiple of it. For continuous radiation, a circle would be drawn on the screen of the image intensifier, but since the source of radiation is bunched, the light will be modulated by the bunching factor, and only a portion of the circle illuminated. Measurement of the length of the arc gives an indication of the bunch length, subject to the resolution obtainable, which at Novosibirsk is claimed to be 10^{-11} second.

A suitable image intensifier has been obtained and the associated equipment is being designed.

(*e*) *Beam width measurements*

The horizontal dimension of the beam at or near injection can be estimated by the use of a low energy beam bump and a collimator. A heavy adjustable collimator and high energy beam bump are to be provided to allow the beam width to be estimated at higher energies. Suitable collimators are being designed.

(*f*) *Phase measurements*

A pick-up cavity in one of the straight sections will provide a signal of amplitude proportional to the 408 Mc/s component of the beam and in phase with the centre of charge of the bunch. Comparison of this with the phase of the r.f. in the cavities will give the average synchronous phase of the electrons.

8.2 Beam Ejection

As reported in DNPL 2, the basic principle of the beam ejection system is the same as that used at C.E.A. and D.E.S.Y., but it has been shown possible to fit the current strip and "kicker" magnet in the same long straight. By suitable choice of the field in the kicker magnet, and use of a correcting magnet, it should be possible to match the line of emergence of the electron beam to that of the photon beam from the same straight. In this way a beam of photons or electrons can be made available through the same channel through the shield wall.

A computer study was carried out to investigate the effects of the current strip and beam bump parameters on the spill-out time, efficiency of extraction and emittance of the emergent beam. An optimisation of the current through the current strip, for example, represents a balance between a long spill-out time and a high efficiency of extraction; similarly it was found that the greater the current strip width the smaller the spill-out time and the smaller the vertical emittance. A spill-out time of the order of 0.5 milliseconds is predicted under the proposed scheme with emittances of 1.0 and 0.35 cm-mrads for the horizontal and vertical planes respectively. It was found from the computer study that a longer spill-out time may be obtained if a second current strip is placed at the same azimuthal position as the first but on the inside edge of the beam. Spill time up to 1.5 milliseconds may be possible by this method although an increase in emittance is likely. The layout of the system is shown in Fig. 9 which also shows cross-sectional diagrams of the current strip and kicker magnets.

The design of the system is at present nearing completion. Some parts are under construction and the current strip, which is a modification of that used at C.E.A., is being made in the Laboratory workshop (Fig. 10). The majority of the parts are out to tender. Power supplies for the beam bumps, current strip and kicker magnet are scheduled for completion by the end of July and the system is expected to be tested out and installed in readiness for the first operation of the machine. Two 10 cm aperture quadrupoles and their power supply for use in the external beam transport have been ordered and delivered, and a bending magnet is being ordered. A ceramic vacuum vessel is to be used for that part of the beam line through the fringe field of the synchrotron magnet. Provision has been made for the addition of a second current strip to verify the theoretical predictions.

The first extraction system will be tested in straight 4 (that following magnet 4) and will then be transferred to straight 8 for experimental use. Later it is proposed that a second system will be built, incorporating any modifications found necessary from experience with the first and placed in straight 10.

9. SERVICES GROUP

9.1 Design and Drawing Office

The work of the Group Design and Drawing Office has gradually changed as the construction of the synchrotron approaches completion. Less design effort is required on the machine and the emphasis is now on equipment associated with the various beam lines. These are being laid out and the associated equipment, such as platforms, stands, quantameters, Cerenkov counters and collimators, designed and manufactured.

9.2 Mechanical and Electrical Workshops

During the past 6 months the workshop has continued to give active support to NINA Installation Group and other Laboratory groups. Staff recruitment has progressed steadily but some difficulty is being experienced in obtaining the type of skilled craftsmen required for the Laboratory. The work which is now being handled is becoming more demanding as evidenced by the current strip shown in

Fig. 10. The machining capacity has been increased recently by the acquisition of a large milling machine and lathe and with the machine tools now installed, the workshop can undertake most of the specialised types of work placed with it. A small group has now started specialising in low temperature work and they are now building the first phase of hydrogen targets.

The Electrical Workshop has been actively engaged with the installation of additional distribution equipment for the various Laboratory groups. The first phase of the installation of the 4 M.W. of d.c. power supplies has commenced with the installation of the main contactor switchgear and this will be closely followed by the building of the main d.c. link boards in the Electrical Plant Room. Work is in hand by M.A.N.W.E.B. to increase our incoming supply to 10,000 kVA and at the same time to install a second incoming feeder, thus increasing the reliability of the supply. This work is programmed for completion in August, 1967.

9.3 Building Development

The Computer Laboratory is on programme and will be available for the installation of the IBM 360/50 Computer in June. Progress on the small Cryogenic Test Building and on the Stores extension is running a few weeks late. Design studies have been completed on the new Laboratory and Office Block and on an extension to the Experimental Hall. A separate Plant Room is associated with the latter. The new Laboratory Block, which will have a floor area of approximately 41,000 sq ft, includes a Lecture Theatre to hold 150 persons. The extension to the Experimental Hall will provide a sorely needed additional 16,500 sq ft and this increases by about two the area available for experiments.

10. PHYSICS APPARATUS

10.1 Experimental Magnets and Power Supplies

A range of quadrupole and bending magnets, described in DNPL 2, will be available for the first phase of the experimental programme. The contracts for these magnets were placed with three manufacturers— A.C.E.C., Charleroi, Lintott Engineering Ltd., Horsham, and Oerlikon Engineering Co., Zurich, in September, 1965. The manufacturing programme is well under way and the contract date of September of this year for initial deliveries should be realised. All the magnets have vacuum chambers which form part of the magnet assembly and each magnet will have a separate adjuster stand for accurate location.

In addition, a contract has been placed recently with Lintott Engineering Ltd. for a modular magnet which consists of two C-magnets which can be butted together to form a large aperture window-frame magnet.

The power supplies for energising the magnets consist of six 400 kW units, four 200 kW units, six 100 kW units and four 25 kW units and are required to have a stability of 0.01 % over a 12-hour period. The contract for these supplies was placed with Brentford Electric Co., Crawley, in September, 1965. The first of the 400 kW units has been completed and is undergoing tests at the manufacturer's works. Delivery to the Laboratory is expected to commence in June, 1966.

10.2 Collimators and Sweeping Magnets

Collimators which are placed in the incident photon beam to define the incoming beam dimensions have been designed to cover a wide range of rectangular and circular apertures. Twelve collimator units have been delivered to the Laboratory, where the central inserts will be manufactured.

Permanent magnets, approximately 30 cm in length, have been designed to remove charged particles from the photon beam. A contract was placed with Mullard Ltd., Mitcham, in October, 1965, for ten 3 kGs magnets of 7.5×7.5 cm aperture and six 5 kGs magnets of 5×7.5 cm aperture. These magnets are now ready for delivery to the Laboratory.

10.3 Hydrogen Targets

The standard target for general use at NINA will consists of a 10 cm long cylinder of 5 cm dia. or a 5 cm dia. vertical target directly linked to a hydrogen dewar. The target is filled by applying an excess pressure of helium gas to the dewar. A prototype dewar has been delivered by the British Oxygen Company and a prototype target is under construction for testing. In addition, two large volume hydrogen targets are being designed for specific requirements.

10.4 Quantameters and Integrators

A quantameter is an ionisation chamber which measures the total number of photons passing through the target by measuring the charge produced by the photon beam. Four quantameters are in process of manufacture. The total charge will be recorded by a current integrator. An order has been placed with the Atomic Energy Authority, Harwell, for four integrators together with preset scaler units. These units have been delivered to the Laboratory.

10.5 Cerenkov and Shower Counters

In addition to these items of physics apparatus which have a general application, considerable effort is being spent on some pieces of equipment intended for use in specific experiments. For instance, two different types of Cerenkov detectors, a gas threshold counter and a lead/lucite shower counter are now being manufactured. These counters are to be used in the wide angle electron pair production experiment of the Daresbury resident group. The purpose of the gas threshold counter is to distinguish high energy electrons from an intense flux of pions of the same momentum in the range 0.5 to 2.5 GeV/c. The pions arise from the decay of ρ mesons photoproduced in the carbon in the target.

The principle design parameter of the counter is the refractive index of the gas. This is chosen so that muons of momentum lower than a set limit, 2.8 GeV/c, cannot give rise to Cerenkov radiation.

Although momentum selected pions cannot count directly in the counter they can knock on electrons from the counter gas which are energetic enough (>10 MeV) to give rise to Cerenkov light. The gas with the lowest electron density for a given refractive index is hydrogen but the high pressure required means that the window of the counter pressure vessel is thick enough to give rise to many more knock-on electrons than produced in the hydrogen itself. It is found that a propane-filled counter at $\sim$0.8 atmospheres gives the lowest number of knock-on electrons. For a counter 2 metres long the total number of knock-on electrons per incident pion at 2.5 GeV/c is $\sim 3 \times 10^{-3}$.

The shower counter is to discriminate further between electrons and pions. It has been found by Heusch and Prescott (Cal. Tech. report CTSL.41) that a lead/lucite sandwich gives a better discrimination against pions and knock-on electrons than either a lead scintillator sandwich or a lead glass counter.

The combined rejection of the gas threshold and shower counter for pions should not be sensitive to the momentum of the incoming particles. The pulse height produced by pions in the shower counter is approximately constant within the range 0.5 to 2.5 GeV/c so that, at low incoming momenta, the decrease in pulse height and resolution for electrons will result in more pions giving pulses above the bias level than at high momenta. However, at lower momenta, the pions will produce fewer knock-on electrons with energies above the threshold of the gas counter. Thus the continued rejection for pions in the two counters should be $\sim 3 \times 10^{-5}$ of the incident pion flux in each channel.

10.6 Counting Systems

Considerable work has been carried out in the last six months directed towards instrumenting the resident group experiment on Wide Angle Pair Production (W.A.P.P.). Design work on various scintillation counter configurations has been completed and production of W.A.P.P. detectors has started. Studies of possible logic configurations have reached completion and monitoring systems are being investigated. Ferranti XP20 and XP21 fast light sources, which will be extensively used for this purpose, have undergone testing of their stability and life characteristics and are likely to prove satisfactory. A cable installation from the Counting Room to the appropriate area of the Electron Hall has been designed and materials are on order to provide about 100 fast data links as well as high voltage and other lines. The design of a standard photomultiplier housing of cylindrical symmetry has been completed and production has started to make 200 units which will also be available to visiting teams. The unit will house either the Philips 56AVP, the RCA 7265 or, with an adaptor available from RCA, the 8575.

11. EXPERIMENTAL PHYSICS PROGRAMMES

11.1 Liverpool University Experiment

The initial experiment proposed by the Liverpool Group is for the measurement of the photo-production of zero charged pions from hydrogen. The group intends to concentrate on measurements of cross-sections at small forward angles of the pion, detecting the associated low energy protons at centre of mass angles between 25° and 150° using a magnetic spectrometer. This will consist of quadrupole lenses and a bending magnet having a total weight of about 50 tons. These components will be mounted on a 30-ft long beam pivoted at the target and supported on balls running on a hardened steel plate at the other end.

Protons will be detected by an array of scintillation counters placed in the focal plane of the spectrometer. In order to eliminate particles such as positive mesons or protons from other reactions, coincidences will be taken between counts in the proton detector and those in a gamma-ray detector placed in the direction of the zero charged pion. This detector will be a Cerenkov counter mounted on a second pivoted arm. A small computer will be used to monitor and display the information from the 30 to 40 photo-multipliers used in the apparatus.

The object of the experiment is to check the theory of the photo-production process and hence to obtain information about the intermediate particles which are supposed to play a part.

11.2 Manchester University Experiment

The Manchester Group is interested in the photo-production of neutral kaons with particular reference to the Drell process. Apart from interest in the production mechanism itself, it is hoped that useful beams of high energy K^0s will be produced, suitable for many experiments.

A photon beam will be generated using an internal target and will be brought out through the shielding wall into a liquid hydrogen target. Half of the K^0s produced will decay as K_1^0s, leaving a beam of K_2^0s. These will be detected after a flight path of 30 m. Photon contamination will be removed by 20 radiation lengths of lead, which will reduce the K_2^0 intensity by a factor of two. The neutron background is expected to be predominantly low energy.

The K_2^0s will be detected using decay modes producing two charged particles. Detection is based on a scintillation hodoscope backed by plastic Cerenkov counters. In addition wire chambers will be used before the scintillators to observe the point of intersection of the two tracks. Information on the energy of the particles in the beam will be obtained by time of flight measurements using the r.f. structure of the NINA beam as a basis. All data will be processed by a small computer.

11.3 Glasgow University Experiment

This group proposes to measure the polarisation of protons in elastic e-p scattering.

The analysis of elastic e-p scattering is usually made in terms of two form factors, based on the Rosenbluth formula. The derivation of the formula assumes the process is dominated by a one photon exchange term, and that the amplitude of two photon exchange and higher terms is negligible. A test of the correctness of the assumption may be made in two possible ways: firstly, the possible inequality of $e^- - p$ and $e^+ - p$ elastic scattering, and secondly, the polarisation of the recoil proton, may both be measured. The experiment is of the latter type for an incident electron energy of 4 GeV and a momentum transfer $q^2 = 50\ F^{-2}$.

The experiment will be carried out using the extracted electron beam from NINA impinging on a polythene target. To define an elastic scatter of the required momentum transfer, electrons of energy 3 GeV at an angle of 23° to the incident electrons are detected in coincidence with protons of energy 1 GeV at an angle of 43°, both angles being in the laboratory frame of reference. For both particles momentum analysis will be made by magnetic spectrometers. The protons are then focused onto a hydrogen target and the left-right asymmetry of those elastically scattered is measured by a system of scintillation counters and spark chambers. From this the polarisation of the protons will be computed.

11.4 Daresbury Laboratory Experiment

The theory of quantum electrodynamics (Q.E.D.) at a distance of ~1 fermi has recently been put into question by an experiment on wide angle electron-positron pair production performed by a Harvard group at the C.E.A. In view of the great implications of the results of this experiment the resident group at Daresbury propose to study wide angle pair production (W.A.P.P.) extensively as an independent check of the validity of the theory.

The expectation value for the angle with respect to the photon momentum at which an electron or positron is produced in pair production is given by $\langle\theta\rangle = \frac{mc^2}{E_\gamma}$, where E_γ is the photon energy. Thus angles of a few degrees are "wide" for $E_\gamma \sim 5$ GeV. W.A.P.P. probes Q.E.D. to shorter distances as the four momentum of the virtual electron increases or alternatively as θ increases. As the cross section for symmetric pair production varies as $\sim \frac{1}{E_\gamma^{3}\theta^{6}}$ it soon becomes vanishingly small as θ increases setting an upper limit to the pair production angle θ of $\sim 10°$ for a feasible experiment, which corresponds to a four momentum for the virtual electron of 420 MeV/c at $E_\gamma = 5$ GeV.

The Daresbury group will study symmetric W.A.P.P. This arrangement eliminates contributions from competing Compton processes and minimises corrections due to nuclear recoil and form factors of the target nucleus even though the angular acceptance of the system is finite. The electron and positron will each be momentum analysed by two half quadrupoles, specially designed for small angle detection, followed by a bending magnet. These magnets will be located on spectrometer arms whose angle to the photon beam may be accurately adjusted. The geometry of the system sets a lower limit on the angle given by $\theta = 5°$.

The electrons will be detected by a threshold gas Cerenkov counter followed by a shower counter. The Cerenkov and shower detectors have been designed to give the maximum discrimination against knock-on electrons produced by pions arising from copious ρ photoproduction in the target.

11.5 Layout of Experimental Hall

The proposed layout of the Experimental Hall for the first four experiments described above is shown in Fig. 11.

The first experiments to run at NINA will use photon beams produced by allowing the circulating electron beam to strike targets inside the machine. Brief details of the method of doing this were included in DNPL 2. The photon beams emerge from straight sections and, after collimation and passage through clearing magnets, strike the experimental targets in the Experimental Hall. The intensity of the photon beam will be measured by use of a Wilson-type quantameter mounted in a beam stop behind each experiment.

Fairly soon after the initial operation of NINA an ejected beam of electrons (see Section 8.2) will be brought into operation. This beam will emerge from straight section 8 and serve the Glasgow experiment and also be used for calibration purposes in the Daresbury experiment. The beam transport system to take the ejected beam to the Daresbury and Glasgow targets is currently under design. The intensity of the electron beam will be measured using a Faraday cup.

Three of the four initial experiments require momentum selection over a wide range of production angles. This requirement entails the use of spectrometer platforms and six are currently in the course of design for use in the Experimental Hall. For the spectrometers to move freely and accurately over the floor, a special hardened steel floor will have to be provided and the material for this is now on order.

The d.c. power required for magnets is provided from 20 rectifier sets situated in a separate Plant Room. Connection between supplies and magnets is facilitated by a link-board which allows connection of any power supply to any magnet. Electrical and mechanical services will be carried from the outlet points on the North wall of the Experimental Hall via an overhead distribution system.

Most of the apparatus required for the initial beam is now being designed in detail or out to manufacture. The installation programme for the Experimental Hall will begin shortly with the rebuilding of the main shield wall and establishment of survey points for accurate positioning of apparatus.

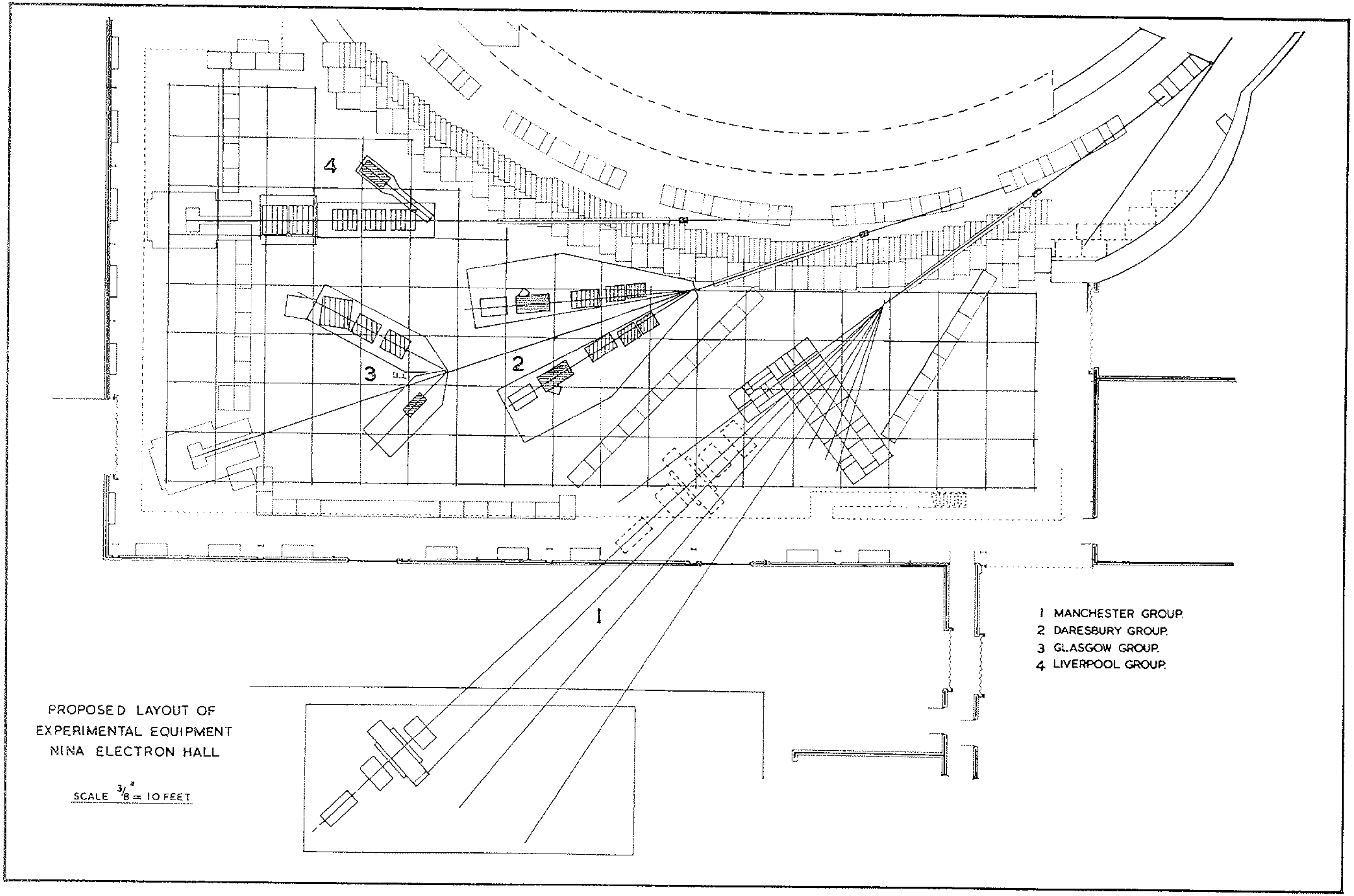


Fig. 11. Proposed Layout of Experimental Hall