

Around the Laboratories

RUTHERFORD

A few topics from the Rutherford High Energy Laboratory where research is centred on the use of the 7 GeV proton synchrotron, Nimrod.

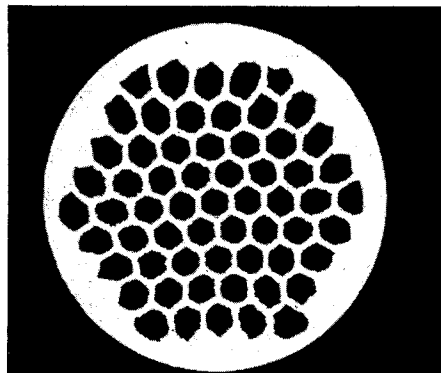
Major effort on superconductivity

As reported several times before (e.g. CERN COURIER vol. 8, page 186, vol. 9, page 261), important contributions to the theory and practice of superconducting magnets have come from the Rutherford Laboratory. To recap — the group of P.F. Smith has shown how to produce superconductor which is 'intrinsically stable', eliminating the problem of flux jumps producing heat and destroying the superconducting property. The solution is to have a conductor consisting of very fine filaments of superconductor (less than 0.005 cm diameter) embedded in a normal metal (usually copper) and twisted (typically with a pitch of a few centimetres) to reduce circulation currents between the filaments. Such a conductor is much more compact than the previous types which were not intrinsically stable, required a large proportion of normal metal, and were limited to current densities in the region of 10^3 to 10^4 A/cm², besides being much more difficult to wind into coils and to cool to superconducting temperatures. The intrinsically stable conductor is capable of overall current densities approaching 5×10^4 A/cm² and gives compact coils with much simpler cooling systems.

Development work towards applying fine filamentary conductors to d.c. magnets, such as would be used in polarized targets and beam transport magnets, is

well advanced. Emphasis in the research has now turned to a.c. magnets, such as would be used in a synchrotron ring. Again, the fine filament technique is applicable to achieve stability but account has to be taken of a.c. losses producing heat on each cycle. For fast rise-times (of the order of a second) it has proved expedient to have a resistive barrier between the superconductor and the copper, which is too ready to pass current, thus avoiding the need for a very small pitch when the filaments are twisted. The conductor then becomes a three-part composite — fine filaments of superconductor (with smaller diameters than for d.c. applications — about 0.001 cm) coated with cupro-nickel and embedded in pure copper (with a total diameter of about 0.05 cm). For slower rise-times (say about 5 s) a two-part composite with a higher resistivity copper should be sufficient. The production of such conductors (as of the others used in the Laboratory's programme) has been done in association with the research department of Imperial Metals Industries Ltd. There have been successful tests of small a.c. coils pulsing at a rate of once per two seconds.

The rest of this information covers the programme lined up for the next few years for a thorough investigation of the application of superconducting magnets in a synchrotron ring. Research at the Laboratory has previously been concentrated in a comparatively small group but a major effort is now being turned on in the Applied Physics Division led by L.C.W. Hobbs, to confront all the problems of integrating superconducting magnets into an operating machine. Machine aspects are being covered by N.M. King and D.A. Grey, magnet studies are continuing in the group of P.F. Smith under J.D. Lawson, and engineering support is under J. Marsh, H. Ashburn and B. Colyer. To give a practical aim under which to organize the research, work is directed towards producing a design for a superconducting conversion of Nimrod. Tentative parameters for such a conversion are to achieve an energy of 25 GeV with a beam intensity up to 10^{13} protons per pulse with a ring diameter set by the existing Nimrod hall as about 50 m. It will



A cross-section of composite superconductor which is intrinsically stable. It consists of 61 strands of niobium-titanium embedded in cupro-nickel. The overall diameter is 0.05 cm.

obviously be several years before anything like a detailed machine design can be drawn up. Nevertheless, it is generally accepted that any extension of the synchrotron beyond energies of a few hundreds of GeV will call for the use of superconducting magnets, and that, before such a machine could be confidently undertaken, there should be a sizable pilot project. Conversion of an existing machine is likely to be the most economical way of carrying out a pilot project. Also, if the ultimate goal is a very high energy European machine, then such a conversion, undertaken at one or other existing 'national' Laboratory, might qualify for consideration as a European project.

Basic research on the production of superconductors will continue with a view to improving the current density and to minimizing the cost of the conductor. There is also interest in the possibility of producing filamentary conductors using niobium tin alloy. (Niobium tin can retain its superconducting property at much higher fields and temperatures than niobium titanium but is brittle and cannot be drawn into wire.)

A series of coils of increasing sophistication will be built to carry further the investigation of d.c. and pulsed performance and to tackle mechanical problems. Most coils have up to now been potted in wax so as to recover the superconductor easily — new coils will have different cables and insulations.

A d.c. quadrupole (about 40 cm long with a 12 cm aperture to give about 40 kG peak) will be constructed by industry to develop their ability to produce operational magnets. Pulsed magnet dipoles will be built, beginning with a coil about 30 cm long with a 4 cm aperture to give a field of 50 to 60 kG and moving to a first full-aperture prototype synchrotron magnet with a 12 cm aperture and a field above 50 kG. The aim is to have this prototype operational inside a vertical cryostat by the end of 1970.

Questions remain to be answered as to whether superconducting magnets can give the accurate magnetic fields that are required in a synchrotron. Studies will cover optimum coil configuration; accuracy to

which coils can be wound and potted; retention of accuracy when they are cooled to superconducting temperatures; accuracy of field configuration; effects of internal friction and mechanical heating on the superconducting property, etc. Much of this work will involve materials research to satisfy considerations of stress, mechanical and thermal cycling, heat transfer, and irradiation. The magnets have also to be insulated from room temperature, while being integrated into some type of cryogenic system.

On the cryogenic side, preference is at the moment for the use of supercritical helium. Test systems will be built and used with the magnets which are being produced to get some experience under operational conditions. A cryostat is scheduled to be ready by June.

The power supply for the magnets depends upon decisions on current, voltage and rise-time parameters. Some superconducting switching arrangement will be needed to introduce a flat top. There will also be tests of a new idea for superconductive energy storage which might prove the best solution for a superconducting synchrotron.

For the synchrotron itself, possible magnet lattices are being worked out including two ejection systems. Thought is being given to the problem of positioning the magnets (inside their cryostats) accurately around the ring, to optimum r.f. systems, to the possible need of iron shielding to avoid the effects of stray fields, etc.

There are obviously many problems to be solved and several fundamental questions need answers before the stage is reached where construction of a superconducting synchrotron could begin. Nevertheless the technological advances of the past few years, many of them emerging from the Rutherford Laboratory, are very encouraging. Pursuing this research could result in a command over superconductivity which will lead to it assuming an important place in everyday life, quite apart from its impact on the synchrotron.

Computer controlled ejected beam

A third ejected proton beam, X3, has been commissioned on Nimrod to feed the new

Experimental Hall 3 (4300 m²). A control computer was used in setting up the beam and now serves to monitor and control the ejection system and beam-line throughout machine operation. X3 currently serves two slow-spill beams — a pion beam (π 8) and a kaon beam (K15) and will later be extended to a further target downstream to yield additional slow-spill beams.

The ejection system is of the 'energy-loss' type and consists of a Piccioni target and two plunged magnets — an ejection magnet and a quadrupole to give achromatic correction. (These units are 90° around the ring from the equivalent units which serve both the previously existing ejected beams.)

The X3 beam emerges from Nimrod diverging in both horizontal and vertical planes and a quadrupole multiplet is positioned immediately outside the machine to produce a parallel beam which then traverses about 50 m of drift space. A further quadrupole multiplet focuses the beam onto the target.

The beam was commissioned, and is now monitored and controlled, using a PDP-8 computer in the Nimrod Main Control Room. A STAR data-link system is used with special interfaces. The ejected beam intensity is measured by a secondary emission chamber (SEC) involving aluminized milar disks. Absolute measurements are obtained by comparison with aluminium foils exposed to a known flux. In setting up the beam, the computer can compare the ejected beam with the circulating beam and can select magnet currents in steps for all the components of the ejection and beam transport system until an optimum has been achieved. During operation the computer can warn when settings drift outside prescribed limits, and parameters can be changed via the computer. There is automatic print out and graph-plotting of selected magnet currents, collimator settings, etc. and important data is automatically collected.

A typical value for the ejected beam intensity is 5×10^{11} protons per pulse with a total beam cross-section at the target of 4×4 mm². This represents about 30 % ejection efficiency (Nimrod being a constant gradient machine).

Computer control of X3 has been so

reliable and efficient that work is proceeding to bring the other two ejected beams into the same system. The experience has been so fruitful that other candidates for computer control, such as a bubble chamber beam and operation of the 1.5 m hydrogen chamber, are likely to be tackled in the future.

Further developments on ejection planned for this year are the installation of a 'thin' septum ejection magnet and resonant ejection. In the existing energy-loss systems, target thicknesses of about 2 cm of beryllium are needed so that the protons lose enough energy on passing through the target to take their subsequent trajectories into the apertures of the quadrupole and the ejection magnet, jumping across septa of 8 cm and 6 cm respectively. The resulting spread in energies gives a loss of about 10 % on each septum. A new ejection magnet with a 1 cm septum is to be installed which will enable the target thickness to be reduced somewhat, with the target repositioned, and dispensing with the quadrupole. A resonant ejection system has also

been designed and some preliminary tests in Nimrod gave results remarkably close to the theoretical prediction.

Preliminary commissioning tests were carried out during the last week of January on the thin-septum system and results were extremely encouraging: a conservative estimate is that 9×10^{11} protons per pulse were delivered at the external target within a 1.0 cm diameter spot. This corresponds to about 45 % extraction efficiency, a factor 1.5 greater than the normal X3 system. To capture the ejected beam, two specially designed 'Header-tank quadrupoles', XHQ2 and XHQ3, are required, located inside the Nimrod vacuum header vessel. For the recent tests, only XHQ2 was installed and a further increase of efficiency (to 60 % or more) is anticipated when XHQ3 arrives later this year. It is hoped to try an improved version of the ejection magnet before the middle of 1970.

PLA closed down

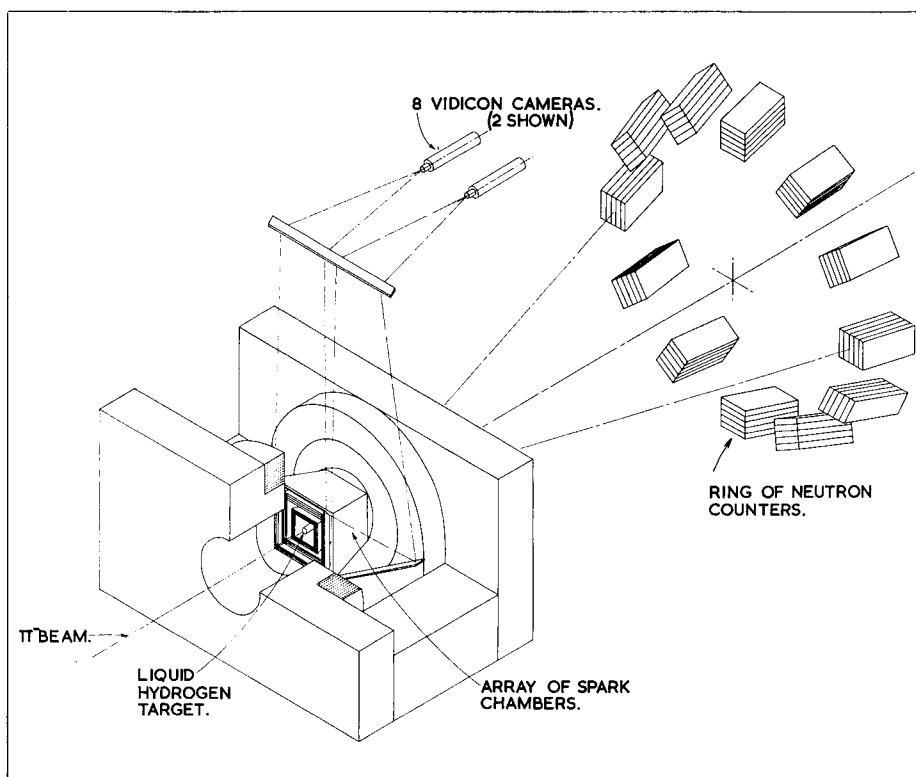
The 50 MeV Proton Linear Accelerator, PLA, was closed down on 3 October 1969.

In its lifetime (it came into operation for physics on 20 April 1960) it yielded 44 000 hours of useful beam for experiments out of 53 000 hours scheduled — an overall operating efficiency of 83 % (it was over 90 % in the last years of its life). The experimental programme concentrated on several topics in nuclear physics and involved about fifty research scientists, predominantly in teams from UK Universities, at any one time. Nearly forty Ph.D.s have been awarded for theses based on work at the PLA and several more theses are in preparation. About 140 papers appeared in the technical press from PLA research.

The machine had three linac tanks (taking protons to energies of 10, 30 and finally 50 MeV) of the Alvarez type with grid focusing in the first tank (which severely limited peak intensity) and quadrupole focusing in the others. The 50 MeV beam intensity reached $5 \mu\text{A}$ reliably with an energy spread of better than 50 keV and a pulse rate of 50 pulses per second. Two special facilities had a considerable impact on the fruitfulness of the experi-

One of the experiments drawing its particles from the new ejected proton beam, X3, is a search for charge symmetry violation in the electro-magnetic interaction which hopes to settle definitively the controversy of the past few years. In 1966 a bubble chamber experiment at Brookhaven indicated a breakdown of charge symmetry in the decay of the eta meson into three pions on the basis of 1441 events observed. A CERN counter experiment with 10 600 events refuted this conclusion. A further experiment at Brookhaven with 40 000 events gave an asymmetry but not strongly enough to be convincing. The Rutherford experiment intends to amass 400 000 events and solve the question once and for all.

A schematic layout of their experiment is shown in the diagram. A negative pion beam is directed onto a hydrogen target surrounded by a spark chamber array in a magnetic field. Eta mesons will be identified by observing the neutron produced at the same time using a ring of counters. The eta spectrum has been clearly observed in preliminary runs. (An IBM 1130 is on-line to the experiment and final analysis is done on the Laboratory IBM 360/75.) A vidicon system looks at the spark chambers where charged particles from the decay of the eta will be recorded. It is the observation of these charged particles which will be used to check charge symmetry.



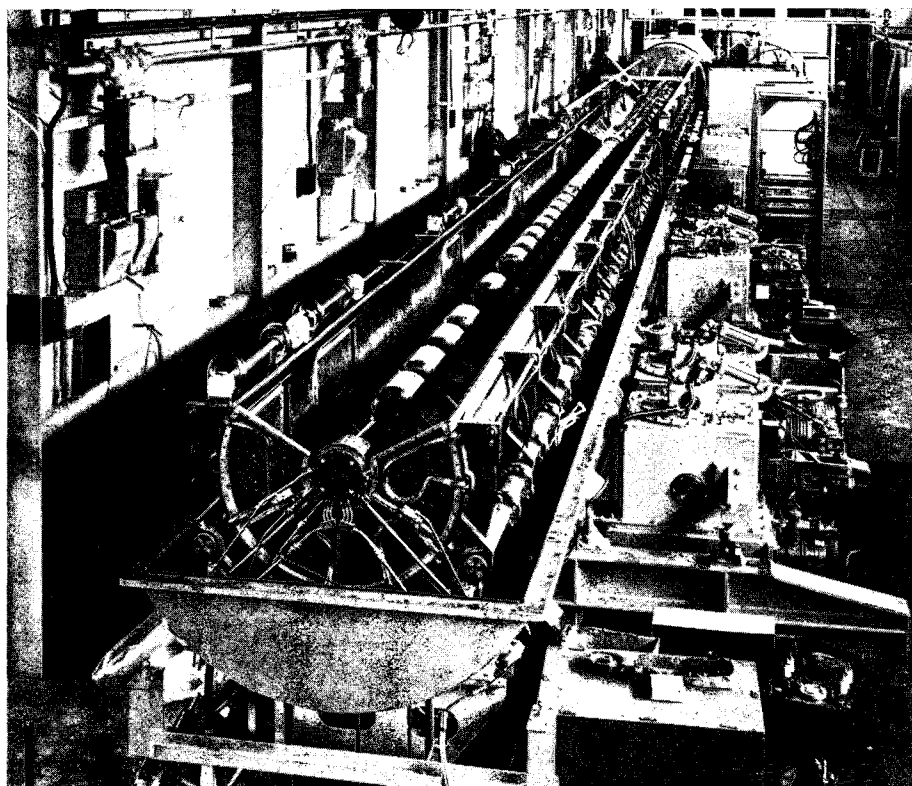
A view from the output end of the 50 MeV proton linear accelerator, PLA, at the Rutherford Laboratory which has now been closed down. This photograph was taken in 1959 during construction and shows tanks 2 and 3 with the vacuum lids removed while installation of drift tubes in tank 3 was proceeding.

mental programme. The first was a polarized proton source which could give proton beams with 60% polarization and an intensity of about 2×10^9 protons per second (compared with 30% and 10^7 when it first came into operation in 1961). This was one of the most powerful polarized beams available anywhere and it was used for about 40% of the programme. The second was a time of flight technique which used the bunch structure of the beam within each pulse (proton bursts of 0.5 ns every 5 ns) to give very precise time fixes in the measurement of neutron energy and in particle identification.

A double-focusing spectrometer magnet was one of the major items of experimental equipment, being used for about 40% of the experiments in the last years of the machine's life. The spectrometer measured particle energies with a resolution of 50 keV and was used to measure the spectra of protons (elastically and inelastically scattered) and deuterons, tritons and helium — 3 particles from nuclear reactions.

Some of the main topics of the research programme were the study of polarization phenomena in proton scattering and reactions, and the study of proton scattering by nuclei for analysis by the optical model. The PLA contributed much to the assembly of the consistent data on proton scattering, with several series of isotopes studied in great detail. It was this data which led to the recent refinement of the optical model.

Advances in the technology of other accelerators capable of intermediate energies appropriate for nuclear physics research, such as the tandem Van de Graaff and the cyclotron, put the proton linear accelerator at a disadvantage in terms of flexibility as a research tool. Some of the latest machines can give variable energy output, can accelerate many types of particle and can give beams with very small energy spread. The Rutherford PLA has therefore followed its twin from Minnesota into retirement. (The 68 MeV PLA closed down in January 1969 — see CERN COURIER vol. 9, page 15.)



A new nuclear structure facility for the UK is now under study.

BERKELEY

Latest ERA research

The latest series of experiments on the Electron Ring Accelerator at Berkeley were reported by G. Lambertson visiting CERN early in February. (For the story so far, see CERN COURIER vol. 8, page 28, vol. 9, pages 40 and 261.) In a second run with Compressor 3 (the third of the series of units where the formation of electron rings has been studied) fed by the Astron electron accelerator at Livermore, electron rings were again produced but it was not possible, because of phenomena which are not yet well understood, to produce them with the parameters necessary for acceleration out of the compressor along a steadily decreasing magnetic field.

The minor radius of the electron rings was observed to change considerably with the intensity of the injected electron beam. This was much more marked than in the previous experiments and the number of electrons which could be captured in a ring was a factor of ten down on what had been achieved before. A variety of probes all revealed the same effect and it is not clear whether it was due to a growth of momentum spread or of the amplitude of the betatron oscillations of the orbiting electrons. It is likely that both phenomena were present — single particle effects leading to high betatron amplitudes, collective effects leading to longitudinal instability (bunching of the particles around the ring) occurring very early in the injection cycle. This could be the 'negative mass instability' which can occur in a beam with a momentum spread below several percent and it is known that the beam from the Astron injector has a spread of less than 0.1%.

Attempts were made, nevertheless, to move the compressed rings out of the compressor down the solenoid field. The extraction cycle was successfully carried out and the rings moved as expected. They were not retained during acceleration which was no surprise since the compressed rings were known to have