CERN COURIER

NO. 4 VOL. 14 APRIL 1974

CERN, the European Organization for Nuclear Research, was established in 1954 to '... provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto'. It acts as a European centre and co-ordinator of research, theoretical and experimental, in the field of sub-nuclear physics. This branch of science is concerned with the fundamental questions of the basic laws governing the structure of matter. The Organization has its seat at Meyrin near Geneva in Switzerland. There are two adjoining Laboratories known as CERN Laboratory I and CERN Laboratory II.

CERN Laboratory I has existed since 1954. Its experimental programme is based on the use of two proton accelerators — a 600 MeV synchro-cyclotron (SC) and a 28 GeV synchrotron (PS). Large intersecting storage rings (ISR), are fed with protons from the PS for experiments with colliding beams. Scientists from many European Universities as well as from CERN itself take part in the experiments and it is estimated that some 1500 physicists draw research material from CERN.

The CERN Laboratory I site covers about 80 hectares almost equally divided on either side of the frontier between France and Switzerland. The staff totals about 3100 people and, in addition, there are about 1000 Fellows and Scientific Associates. Twelve European countries contribute, in proportion to their net national income, to the CERN Laboratory I budget, which totals 391.1 million Swiss francs in 1974.

CERN Laboratory II came into being in 1971. It is supported by eleven countries. A 'super proton synchrotron' (SPS), capable of a peak energy of 400 GeV, is being constructed. CERN Laboratory II also spans the Franco-Swiss frontier with 412 hectares in France and 68 hectares in Switzerland. Its budget for 1974 is 227.1 million Swiss francs and the staff totals about 350 plus 10 Scientific Associates.

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Cover photograph: This bird in flight has emerged from studies which trace charged particle motion under the influence of external and self-produced electromagnetic forces; the relevant equations also apply to astronomical phenomena and in control theory. The work, carried out in collaboration with LAAS Toulouse, is exhibited at CERN, together with hundreds of others, during a 'Meeting on Technology arising from High Energy Physics' from 24 to 26 April. It is described in Technology Note 'D20 Large amplitude solutions of non-linear dynamic systems' and will appear in the Proceedings of the ISIP Congress 1974. (Further information is available from I. Gumowski.)

meeting on TECHNOLOGY arising from HIGH ENERGY PHYSICS

From 24-26 April, CERN is the scene of a 'Meeting on Technology arising from High Energy Physics'. Over 300 participants, including industrialists, directors of applied research, senior staff from technical Universities, science journalists, etc. are invited for three days of review talks on advanced technology. They will also have the opportunity of touring an exhibition, with over 250 exhibits, of equipment and techniques which have emerged from the European high energy physics programme.

The main purpose of CERN is to provide Europe's scientists with first class facilities for high energy physics research. In so doing, it is a strong stimulus and support to the quality of physics in Europe and to the quality of science education in the European Universities where most of the physicists using CERN are based. The output is measured in new knowledge and in trained people. On these criteria, CERN can stand comparison with any Laboratory in the world and this main purpose is being fulfilled on a considerable scale.

A second purpose, which was even predominant at the time of CERN's formation twenty years ago, is the welding together of the efforts of many European countries to work for common aims. This purpose remains valid today and also seems well fulfilled. The Organization has been blessed with people of vision and ability (both from the governments of the Member States and from the high energy physics community), who have kept the European spirit very much alive.

If there is cause to feel reasonably satisfied about the way in which these main responsibilities are being discharged, there may be areas where CERN has something to contribute and where it has not been particularly active up to now. The field of technology is a possible example. A great deal of advanced technology is involved in carrying out high energy physics and, although knowledge of CERN's work is freely available, not much has so far been done to project this knowledge around Europe to people who could find it useful.

This concern has been a trigger for the April Meeting. In a kind of 'technological accounting' exercise, CERN will spread out some of the achievements in the field of technology from the European high energy physics programme for the participants at the Meeting to see. The emphasis will be on straightforward presentation, without trying to anticipate possible applications. Whether aspects of the technology will be of use to many people is not known and one of the objects of the Meeting is to discover the degree of interest. At least a more positive effort is being made to ensure that people are aware of the techniques and abilities that have been developed.

The development has not, of course, been confined to the boundaries of the CERN site. The technological needs have arisen in implementing high energy physics in Europe; responding to them has involved CERN staff, their colleagues in the national Laboratories and Universities, and many branches of European industry.

Another unknown on the technological front is the extent to which the collaboration with Laboratories helps industry to develop techniques, create new products, improve existing products and so on. It is sometimes put forward as an additional reason for supporting high energy physics that industry gains from having to push back the frontiers of technological expertise in meeting the extreme demands of frontier research. However, no-one has yet produced figures to support this belief. A study has started at CERN which, although very incomplete, seems to show that industry often does reap subsequent economic benefit, in ways it would have been difficult to predict beforehand, from having worked on CERN projects. Certainly it has been shown that some of the technology we generate or extend has immediate applications elsewhere.

The April Meeting may therefore do an important job in spreading knowledge of the technology arising from high energy physics. It will be interesting to see whether some of the relations with industry and governments merit developing along paths opened up by the Meeting.

The programme of the Meeting gives the mornings to review talks and afternoons to touring the exhibits.

The review talks cover - Magnetic and electrostatic deflecting devices (W.C. Middelkoop), Particle detectors (G. Charpak), Superconductivity (D. Thomas - Rutherford Laboratory), Ultra high vacuum (E. Fischer), Cryogenics (M. Firth), Realization of high energy projects in CERN (C. J. Zilverschoon), Control computers (M. Crowley-Milling), Synchrotron radiation (C. Kunz - DESY Laboratory), Tight tolerances for large physical structures (J. Gervaise), Handling of data from experiments (H. Davies). In addition there is an evening talk on 'What we have learned from high energy accelerators' by L. Van Hove.

The exhibits are divided into eight categories. In the following pages we tackle each exhibit category and give brief information on just a few of the items on display. This can give no more than a taste of their wide variety, of their range in scale and of the number of technological disciplines which are involved. Associated with each exhibit, a 'Technology Note' has been prepared and Note numbers (e.g. B14) are quoted when mentioning an exhibit. Copies of the Technology Notes are available from the Public Information Office.

Beams and Radiation

This category has been drawn up to cover a very wide range of technology. It includes the techniques of beam production in ion sources (where the aims are to achieve high intensity, good quality beams), instrumentation for beam monitoring (measuring beam intensity, position, size and density distribution), target techniques (with the problems of radioactivity, temperature control, etc.), particle detectors (ranging through plastic scintillators, spark chambers, Cherenkov counters, etc.) and the special requirements of radiation monitoring in the environment of high energy accelerators.

Beam monitoring devices have been developed in a variety of configurations to respond to different needs. They have ranged from the insertion into the beam of fluorescent screens watched by a closed circuit television camera, to a beam profile detector in the Intersecting Storage Rings which 'sees' the beam via ionization caused in a jet of sodium gas fired across the vacuum chamber, to a variety of current transformers to measure beam intensity, to the use of secondary emission chambers where the number of particles striking thin foils can be measured by observing the electrons they cause to be knocked out.

Another device collecting electrons is the ionization beam scanner (B23 The gas ionization beam scanner) which uses a completely non-destructive technique to gather information on beam size and the density distribution of the protons in the beam.

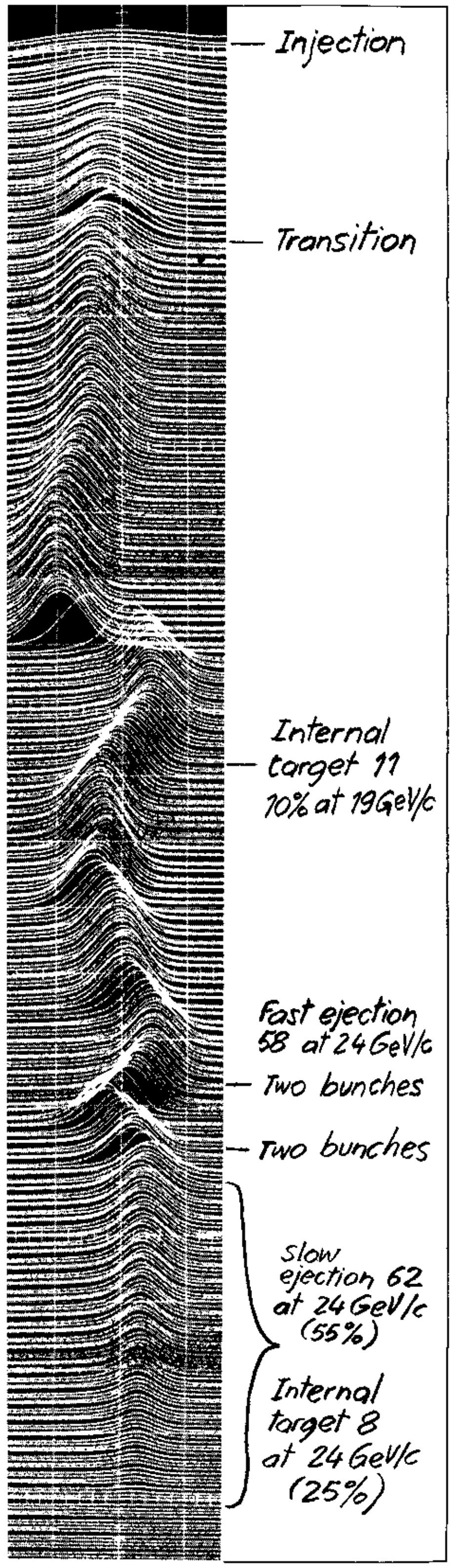
The IBS makes use of the electrons produced by ionization when the beam passes through residual gas in the accelerator vacuum chamber. The number of electrons liberated per unit volume is proportional to the number of protons passing through that volume and the aim is therefore to pull out the electrons in such a way that their position of origin is known. Crossed electric and magnetic fields are used to do this.

The electric fields are pulsed in such a way that an equipotential line is swept across the vacuum vessel scanning a cross-section where the beam has passed. A magnetic field of about 200 Gauss is applied along the beam direction and the result is that the liberated electrons spiral around the equipotential to arrive at an electron multiplier. The multiplier thus receives an electron signal varying according to the position of the equipotential and the number of electrons in the region of the equipotential.

The IBS operates satisfactorily in pressures from 10^{-8} to 10^{-1} torr and above 10^{-6} torr the electron multiplier may not be necessary to achieve adequate signals, depending on the frequency at which the equipotential is scanned across the beam region. The frequency can be varied from d.c. to 1 MHz when there is a pressure of 10^{-5} torr but the upper limit decreases to 1 kHz at 10^{-8} torr. With beams of low intensity (up to 10 mA) the measurements of beam size and density can be accurate to better than 0.1 mm. (Further information from T. Dorenbos or C.D. Johnson.)

Among particle detection techniques, the most dramatic change in recent years has followed the development of multiwire proportional chambers (MPCs) at CERN in 1968. Basically they consist of a flat sandwich of three planes of wires with a special gas in the gaps between the planes. The central plane is constructed of very thin wires (10 to 20 μm) held at a high positive d.c. voltage (3 to 4 kV). When a charged particle crosses a chamber it produces ionization in the gas and a liberated electron initiates an electron avalanche on the nearest central wire due to the high electric field around the wire. Thus the traversing particle can be located by virtue of the signal collected from the central wire.

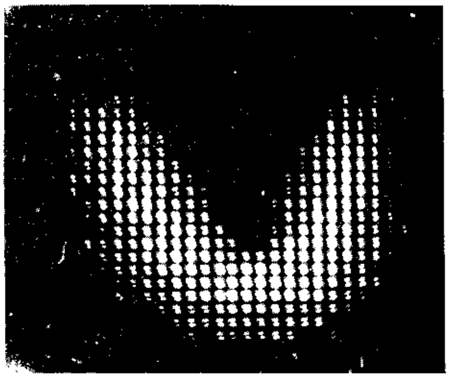
Signals given by the ionization beam scanner in the course of a single acceleration cycle of the proton synchrotron which took 1.2 seconds. The signal peaks indicate the position of the beam in the vacuum chamber and this moves about as the different operations of using the beam onto internal targets and of ejecting beam from the machine are carried out.



Demonstrating the abilities of multiwire proportional chambers as X-ray and gamma detectors.

1. *An X-ray photograph of a leaf taken using a MPC to detect the transmitted X-rays. A spacing of 1 mm between the wires achieved good definition.*
2. *MPC detects gammas, emitted from radio-isotopes in a thyroid gland, after they have passed through a grid collimator.*
3. *A prototype multiwire proportional chamber which was developed for use in the Split Field Magnet detection system at the Intersecting Storage Rings.*

1.



2.

3. *CERN 90.2.71*

Such a chamber is capable of very fast data taking rates and has other properties which put it in the front line of present particle detectors. Generally at least two MPCs are positioned one after the other. One central wire plane then locates a particle say in the vertical direction while the second central plane, with its wires at right angles to the first, locates the particle in the horizontal direction. However, a traversing particle produces not only a negative signal on a central wire but also a positive signal on the outer plane of wires due to the positive ions which it also liberates. This is a slower process and the two chamber array is preferred for high energy physics experiments. It is, nevertheless, a way of gaining positional information on low energy neutral particles (B34 Multiwire proportional chambers as position-sensitive X and γ ray detectors).

In trying to measure such neutral particles, the secondary particles they create in a chamber do not usually emerge to be spotted also by a second detector. Using an MPC with the central and outer wires at right angles the positive and negative pulses can be used to locate the incoming neutral particle. The technique can be used for taking X-ray 'photographs' or for detecting gammas emitted, for example, from isotopes fed into a human being. The spatial resolution is limited by the spacing of the wires (usually about 1 mm) but this is compensated by its much greater sensitivity than conventional photography since it records every X ray which produces ionization in the chamber gas.

Work on MPCs for neutral particle detection is going on in several hospitals. CERN has concentrated on trying to improve the spatial resolution which can be achieved in the chambers, on extending their energy range, and on their possibilities for the detection of other neutral particles such as neutrons.

Applications of MPCs in this way can be seen in high energy physics research, in medicine and biology, in X ray astronomy, in crystallography and in solid state physics. (Further information from G. Charpak.)

The radiation protection problems around accelerators are in many ways different from the thoroughly investigated problems of the nuclear power industry. There is induced radioactivity in accelerator components which can include complex families of isotopes formed by spallation due to the high energy of the incident particles. There is the radiation which comes directly from the machines when they are in operation, which is unique in type and energy. To ensure safety in these conditions has required careful study of the radiation phenomena and the development of special instrumentation.

A very compact monitor has been produced for measuring the total radiation dose received at specific points around the accelerators. It is a calorimeter using an epoxy resin absorber (B27 Calorimeter for radiation dosimeter). A calorimeter measures the energy deposited in a sample of known mass, geometry and composition and is the only way of obtaining an absolute measure of the absorbed radiation dose. Such devices are well known around reactors where they deal with dose rates of 10^8 rad per hour which produce a significant temperature rise and calorimeters had been developed to measure down to 10^6 rad/h. Around accelerators, dose rates much lower than this are encountered and special techniques are needed to detect very small temperature rises.

The absorber in the calorimeter used for radiation dosimetry at CERN is a small epoxy resin cylinder 30 mm long and 5 mm in diameter enclosed in a jacket of electrically conducting plastic. The absorbed energy is detected as a temperature change using thermistors. One thermistor is located at the centre of the epoxy resin cylinder and is one arm of a Wheatstone bridge. The output voltage at the bridge is calibrated in units of absorbed dose which is recorded as a function of time so as to have information on the dose rate as well as the integrated dose.

The calorimeter can cope with integrated doses of from 2×10^2 to 2×10^5 rad with dose rates of from 5×10^3 rad per hour. It is used as a standard to calibrate other dosimeters around the accelerator and there may be interest in such a compact and sensitive device in other fields where the comparatively low radiation doses are encountered such as in hospital radiotherapy units and in sterilization plants. (Further information from M.H. Van de Voorde or K.P. Lambert.)

Cryogenics and Superconductivity

Low temperature techniques have been used around high energy physics Laboratories for many years. They have been required, for example, in order to sustain large volumes of liquid hydrogen in bubble chambers and small volumes in targets. More recently the techniques have been extended in order to make use of superconductivity to achieve higher magnetic fields. This has involved the study of superconducting magnets, for both d.c. and pulsed operation, and of the associated refrigeration techniques needed to establish the near zero temperatures at which superconductivity manifests itself.

Very large d.c. superconducting magnets have been built for the 3.7 m European bubble chamber and (using a novel forced-cooling technique in hollow conductor) for the Omega spectrometer. Other d.c. bending and quadrupole focusing magnets are used in beam transport lines. Pulsed superconducting magnets are being developed at the Laboratories of Karlsruhe, Rutherford and Saclay where a variety of prototypes have been built.

CERN has concerned itself also with a few rather more unusual aspects of the technology of superconductivity. A superconducting field shield (described in vol. 11, page 155) has been used to protect low energy beams from being disturbed by the fringe field of the 2 m bubble chamber. A cylinder of superconductor resists the penetration of magnetic field inside its bore where the particles pass. This property achieves a permanently fieldless region but the inverse application can be used to achieve a permanently field-full region. Such devices are being tested at CERN (C 25 Permanent superconducting magnets).

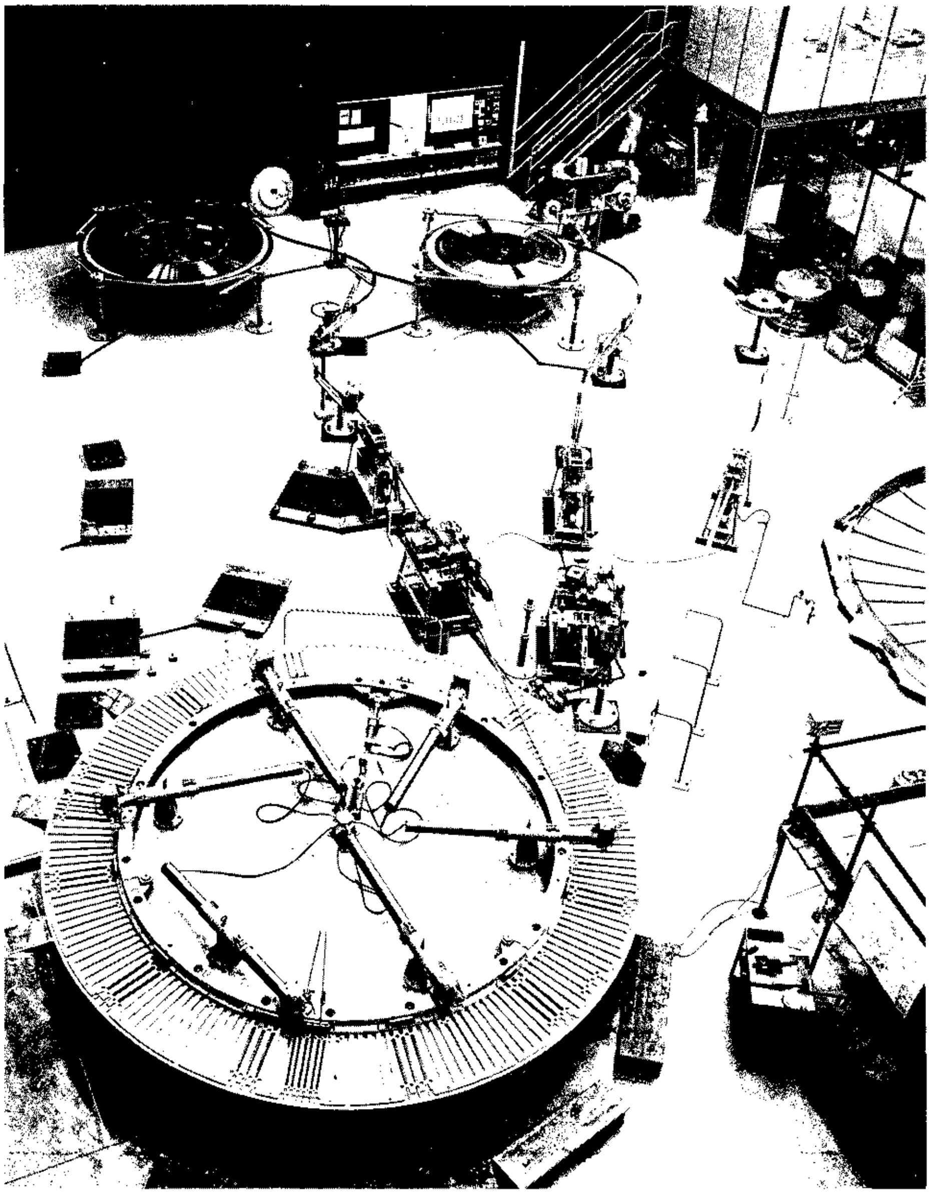
In this application a cylinder of superconductor is introduced into a magnetic field but its temperature is kept high so that the superconducting state has not been reached and field can readily penetrate the cylinder and its bore. The tube is then cooled down and the surrounding magnetic field is slowly switched off when the cylinder has become superconducting. The field change is resisted by the superconductor which sets up its own currents to retain the field previously existing. In normal conductor this effect would be rapidly damped out; in superconductor, with zero resistance to the induced currents, we are left with a cylinder holding a magnetic field.

Applying different external fields can produce permanent superconducting magnets with different field configurations. Care has to be taken in construction to ensure continuous superconductor current paths and to ensure efficient cooling. Configurations have been built at CERN for dipole and solenoid permanent magnets and stable fields up to 2.5 T using niobium-titanium superconductor and 4.5 T with niobium-tin. (Further information from E.U. Haebel.)

Superconductivity can also be used to eliminate the losses normally encountered in radio-frequency cavities (C16 superconducting r.f. cavities for particle separation and acceleration). Such cavities are used in pairs to separate different types of particle travelling down a beam-line. For example, it may be required to separate negative kaons at a momentum of say 5 GeV/c from negative pions and antiprotons. A magnet will select the kaons by bending them the right amount but will, since its bending is proportional to momentum, allow through some higher velocity lower mass pions and some lower velocity higher mass antiprotons. Applying r.f. fields causes a deflection to all particles in a first cavity and then, because of the time difference due to their different velocities, different deflections to the different particles in a second cavity positioned some tens of metres away. Only the desired particle will there be deflected so as to continue down the beam-line.

Using conventional copper cavities requires megawatt pulses of r.f. power and can only be applied for microseconds because of the high r.f. losses. Superconducting cavities allow d.c. operation with power losses of only 30 W per cavity and can thus be used to provide longer beam pulses. They are made of niobium or lead in rather complicated structures with extremely high quality factors (10^8 to 10^{10}). Niobium cavities are being built for CERN at Karlsruhe and have involved the development of much new technology in the machining and welding of this metal, since very high quality surfaces are essential. A programme of surface treatment, electropolishing, anodising and heat treatment under ultra high vacuum is carried out. Unlike d.c. superconductivity the resistance with r.f. does not fall to zero below the transition temperature but decreases exponentially to reach zero at O K. To achieve sufficiently low resistance, an operating temperature of 1.8 K is used involving the use of helium II for cooling and requiring powerful refrigerators to supply 100 W of refrigeration power at 1.8 K.

A superconducting r.f. separator to supply separated particles to the Omega spectrometer is being constructed ready for the coming into action of the SPS. It has a working frequency of 2855 MHz (S-band) with two irisloaded niobium deflectors each 3 m long. A deflector is assembled from five separate 20 cell sections machined out of high purity niobium (99.98 %) and electron beam welded around the outer circumference. They are designed to provide deflecting fields of



The multi-wheeled scene during the winding of the superconducting coils of the magnet for the 3.7 m European bubble chamber, BEBC (C23 Winding workshop for a huge magnet). In addition to the superconducting strip, mechanical reinforcement, spacers to allow helium to circulate and insulation were all wound in together. Exceptionally high engineering precision was required. (Further information from F. Wittgenstein.)

CERN 12.2.70

2 MV/m. (Further information from H. Lengeler.)

With large-scale superconducting systems becoming more common, the efficient transfer of liquid helium which establishes the necessary low temperature of the superconductor, has become more important. Efficient transfer will also be a crucial aspect of any superconducting synchrotron, where distributed refrigerators will probably be needed each feeding helium to the cryostats of several magnets, and will be a crucial aspect of superconducting power transmission lines for electricity networks.

Several types of transfer line have been developed (C 10 Liquid helium transfer lines with vapour cooled radiation shields). A classical vacuum insulated line with only reflective insulation to reduce cooling can result in a considerable amount of heat being transmitted to the helium and hence require extra refrigeration power. The lines at CERN use the fact that helium vapour will inevitably be produced when passing the liquid across the pressure difference to the cryostat (typically involving about 5 % of the liquid). If this vapour is returned via a tube which surrounds the tube where the liquid flows (separated by a vacuum space), it can absorb nearly all the heat coming from outside without climbing so high in temperature that it transmits it further to the liquid.

Rigid lines (using nickel-iron alloy to keep the differential thermal contractions between the various elements low) and semi-flexible lines (using ductile pure aluminium tubes and convoluted vacuum jackets) have been built. Special methods are needed for their mechanical construction. (Further information from D. Leroy or M. Firth.)

The preceding paragraph is a good indication that the selection of materials for cryogenic applications is very important. Quite apart from the specific property for which they are needed, they must retain that property reliably at near zero temperatures and must not be adversely affected by being cycled, possibly many times, from room temperature to cryogenic temperatures. A specific example is the seal used at the bottom of the 3.7 m European bubble chamber, BEBC (C 21 Elasto-plastic seal for the chamber bottom of BEBC).

The problem was to achieve a tight seal between the chamber body and the bottom plate. The seal has a diameter of 2 m. It must withstand an operating pressure of 6 kg/cm^2 at a temperature of 25 K (liquid hydrogen) and not deteriorate over several heating cycles up to room temperature. Its sealing abilities must cope with local imperfections in the surfaces of up to 0.2 mm.

The elastic body of the seal is made of cold-drawn stainless steel (23 % cromium, 15 % nickel) of C shaped cross-section. The dimensions and shape were selected following work at Saclay for the Mirabelle bubble chamber now in operation at the Serpukhov Laboratory near Moscow. The plastic part of the seal, which is in contact with the surfaces to be sealed, is made of indium fitted in a groove. The elastic deformation of the body of the seal retains pressure on the plastic part which takes up any surface imperfections and allows the mating surfaces to move slightly relative to one another.

Two such seals are in use in BEBC. They have fulfilled their specification and have also proved robust enough to withstand the dismantling of the components several times. (Further information from S. Peraire.)

Data processing

The central computer installations, one of the largest computer centres in the world. It is built around a CDC 7600 and handles a large proportion of the data processing required in the analysis of the results of the CERN particle physics experiments.

The category covers most of the ramifications of the use of computers at CERN. This is a vast subject in itself and was reviewed, for example, in a special 60 page issue of CERN COURIER in March 1973. There is a computer centre, among the biggest in the world, built around a CDC 7600 with two other CDCs as 'front end' computers. Here the bulk of the experimental data analysis is done. It is in action 24 hours a day, seven days a week, processing over 10 000 jobs per week for over 500 users.

In addition there are a 100 other computers scattered around CERN. Some are powerful machines, such as the CII 10070 linked on-line to the Omega spectrometer and the Split Field Magnet detection system. Others are small computers, such as PDP 11s devoted to on-line use for a single experiment or to specific bubble chamber film scanning equipment. The computers are used for data acquisition, component monitoring, mathematical computation, bubble chamber film analysis, interactive computing in problem solving or component design, control of the accelerators or in administration. In reporting a few items displayed at the Meeting we will steer away from the main themes that we have covered many times before.

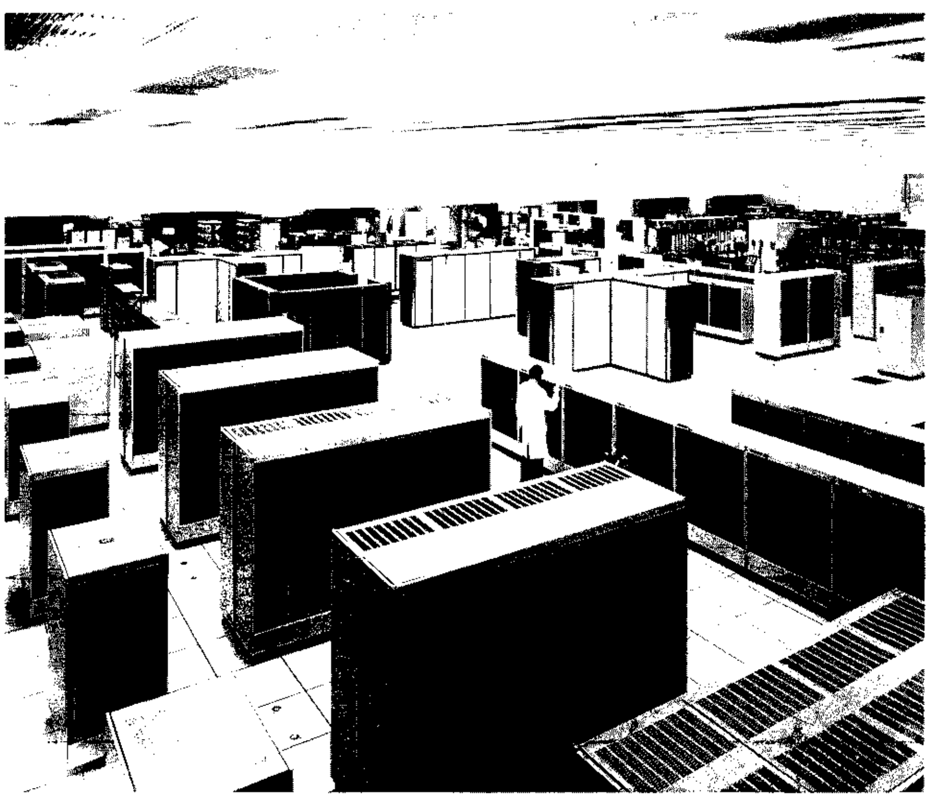
An indication of the sheer volume of computation done by the CERN computers, quite apart from its complexity, is in the number of punched cards fed to the machines (35 million in 1973), the number of magnetic tapes storing data (60 000 in 1973 and growing at the disturbing rate of 12 000 per year) and in the quantity of paper used to print output (30 million pages in 1973). The last figure may be reduced in the future because the use of microfilm is being promoted (D30 Computer output onto microfilm). This involves presenting output as a picture on a cathode ray tube and photographing the picture so that the information is made available on a piece of film.

A Ferranti EP 140 microfilm plotter was installed in 1971 and can give output nine times faster than the conventional pen and ink plotter. It is a much more efficient device whenever large numbers of drawings or very complicated drawings are required. The output is either on 35 mm film (developed in an independent processor) or on aperture cards (developed in the EP140 itself); the cards are much more expensive. Plots are viewed by using microfilm readers and can be copied on film, projected on a screen or enlarged onto paper.

Very recently a NCR Quantor 105 microfiche recorder has come into use. At present, it operates off line, taking output reels of magnetic tape from the CDC 7600 and converting them to microfiche at a speed of up to 10 000 lines per minute (equivalent to about ten line printers), but it is planned to connect it directly to the 7600 to reduce the tape handling involved. A single roll of film corresponds to 200 microfiche each 147×105 mm². The film is developed and cut in the Q-105 after exposure and output is available within a minute of the computer handling the data.

Various reduction ratios are possible, the maximum giving 270 individual frames (18 rows, 15 columns) on a single fiche. The top row is written in large characters so that it can be read by the naked eye and the bottom right frame is an index for the fiche.

A fiche carrying more than 50 frames is more economic than using paper output. It is more easily stored (an envelope of ten fiche contains as much information as a 22 cm high heap of paper) and easily copied and



CERN 161.11.73

Smiling presentation of the touch screen developed for use in the control system of the SPS. Etched almost invisibly on the screen are capacitors which are changed in value by a large factor when touched. They are etched so as to form four rows of four 'buttons' and the computer writes the title of each button on a cathode ray tube behind the screen. This can serve to control any number of parameters since the computer can call up the relevant controls and rewrite the button titles. In this way the touch screen can replace, at a single operation console, a multitude of controls to be found in a conventional control room.

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distributed. (Further information from D. Stungo.)

The extensive use of computers in accelerator control is, surprisingly, a comparatively new feature. However, though they arrived quite late they have made their presence felt very quickly and control of the new SPS will be entirely based on a linked series of small computers. The SPS system will push many of the techniques of computer control a stage further. It incorporates some novel devices for the operator's control console.

One of these is a panel to enable the operator to call all the control functions he wishes to exercise to a single console (D26 Touch buttons). The aim is to condense the hundreds of controls which clutter the conventional control room so that the operator is only confronted with the information he needs for a particular control function.

The panel is a glass sheet on which capacitors are thinly etched in copper. The proximity of a flat conductor such as a finger increases a capacitance by a large factor and thus the selection of a particular capacitor by pressing the panel at a particular point can be detected as an electrical signal. The capacitors are arranged as buttons in four rows of four and a television tube behind the touch panel can write titles on each button as instructed by the computer. An earthed pattern on the unused parts of the panel prevents interference between adjacent capacitors.

The panel is manufactured by normal printed circuit techniques but exceptional care is needed since the conductors comprising the capacitors and leads are only 80 μm wide. Ion-sputtering, depositing the copper slowly, gave sufficiently strong adherence to the glass. Thin gold plating is applied as a protection against corrosion and a thin transparent cover, integral with the glass sheet prevents actual control between a finger and the capacitors.

The capacitance is about 200 pF, rising by about 10% when a finger tip is brought close. For each capacitor, a phase-locked oscillator circuit, available as integrated circuit chip, running at 120 kHz locks to a reference oscillator (one of the chips) and a change in capacitance gives a detectable change in phase. The firm Ferroperm is now producing some of these touch button panels. (Further information from F. Beck.)

The extremely fast data collection rates which are now possible from multiwire proportional chambers and drift chambers bring in their wake an acute problem of analysing enormous quantities of data. A few seconds of operation of the MPC detection system in the Split Field Magnet at the Intersecting Storage Rings could drown even the large CERN computer centre for an hour. It is not much use being able to collect information a hundred times faster than a few years ago if data processing techniques cannot keep pace. Fortunately new processors have recently emerged which will take the edge off this problem. (D48 Special hardware processors for wire chamber data.)

A high proportion of the analysis task previously assigned to a large general purpose computer is of a rather simple and repetitive character. With a magnetic field and an array of multiwire proportional chambers, for example, it has to perform pattern recognition — identifying unambiguously where particles traversed a detector and tracing tracks through the system. Conventional computer architecture nevertheless makes this a laborious job. The hardware processors are given this limited, well defined task and need not follow a sequential route in the calculations. They make maximum use of the parallelism inherent in the problem using a programmable logic array which results in parallel execution of all the program 'instructions'.

For both point and track finding it has been found that special hardware processors (using normal MSI TTL logic) is 40 times faster than using a Fortran programme in the CDC 7600. Using content addressable memories it is believed that in the near future the performance can be improved still further. (Further information from C. Verkerk.)

Electronics

Advanced electronics are part and parcel of all modern scientific research and at CERN they are behind almost everything from the operation of the accelerators, to the collection of the experimental data and to its subsequent analysis. The volume of electronics involved is very high but standardization has been achieved to a considerable extent — through the NIM system and more recently through the CAMAC system (see vol. 8, page 314) which has simplified life for the users and for the electronics industry.

A particular CERN requirement is for very high speeds. Nanosecond timescales are called for when carrying out measurements on high energy particles. For example the new detectors, such as multiwire proportional chambers and drift chambers, have a voracious appetite for collecting data on particle events and the speed of the associated electronics is an important aspect of their abilities. In general, high energy physics is still pushing for faster instrumentation. It has been one of the first fields where integrated circuits have been used on a large scale and has called for devices to achieve ultra fast switching at nanosecond or even sub-nanosecond speeds.

An example of instrumentation developed for special requirements is a device called the Digitron to be used in the 'g-2' experiment (E24 Multichannel time recorder — Digitron). The experiment requires the precise timing of electrons emerging from the decay of muons orbiting a small storage ring. From this timing, via a series of steps which is beautiful physics all the way (see vol. 6 page 152), it is possible to deduce the g-2 value of the muon to an accuracy of few parts per ten million and thus to test rigorously the theory of quantum electrodynamics and to probe the nature of the mysterious muon.

Many time measurements are required and conventional systems of scalers would be complex and expensive. The Digitron circumvents this by using only four scalers and a buffer memory. It can make 200 time measurements with a precision of $\pm$ 5 ns. The timing precision comes from a crystal-controlled 100 MHz clock which runs continuously. Its pulses are counted by the scalers controlled by a recirculating shift-register which has a single bit and three zeros. Thus only one scaler counts at a time. The arrival of a signal due to an electron being detected stops the scaler, thus recording a time interval, and the shift register moves on to start the next scaler. The shift takes place between two clock pulses which avoids losing a count; this is covered by having the input signals also pass via a time-quantizer which assigns them to the nearest 10 ns time-bin.

When a scaler is stopped, its timing information is passed to a buffer memory the transfer taking 500 ns. Thus several scalers can be queuing to pass their information to the memory. However, the chance that all four scalers are so occupied is likely to be very small in most applications. (Further information from I. Pizer.)

The refined use of electronics in data analysis equipment is illustrated by a special digital to analogue converter built for the ERASME system for measuring tracks on film from the 3.7 m European bubble chamber, BEBC. ERASME looks for tracks on the film with a cathode ray tube flying spot and the spot is made to scan the film by powering two deflection coils. High performance digital to analog (DAC) converters control the currents to the two coils (E12 High speed 16 bit digital to analogue converter and digital deglitcher).

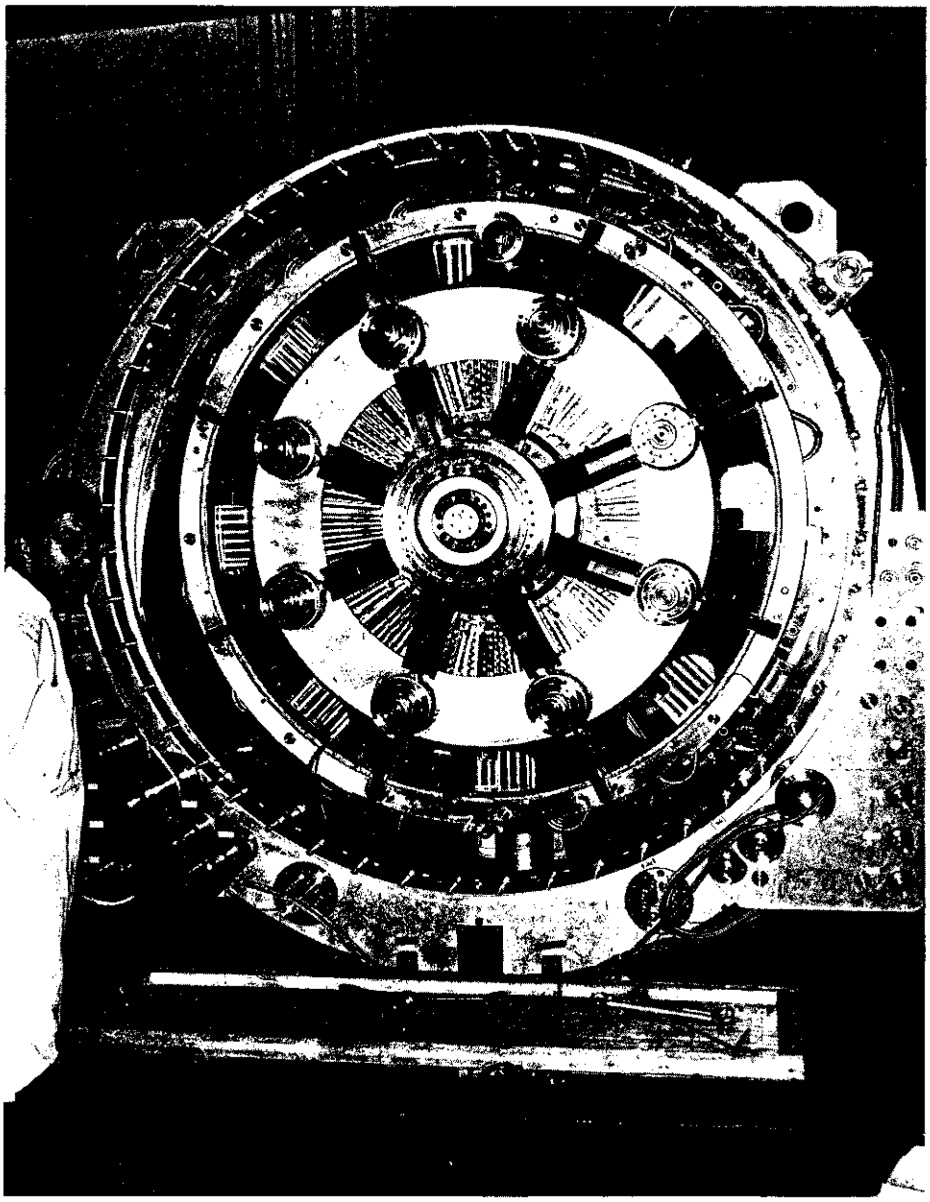
Since 12 bit DACs could easily be purchased, it was decided to build the required 16 bit devices by adding units designed and built at CERN to cope with the 4 most significant bits. The full converter then includes a high speed 12 bit DAC, an ultra high stability voltage reference, four fast switches, a high stability resistor network (using metal film technology) and an amplifier with high slew rate and very fast settling.

With 16 bits an accuracy of 1 in 65 000 is possible, corresponding to 150 μV in 10 V output, but special precautions have to be taken to achieve such accuracy. A 12 bit DAC with low cross-talk between digital and analogue signals was necessary and, throughout the converter, special care had to be taken with component positioning, ground distribution, minimizing white noise and electromagnetic radiation and with thermal stability.

It has also been important to suppress 'glitches' — a sort of bounce of the output when many bits in the DAC are changed at the same time. A digital 'deglitcher' has been built which removes the problem by introducing delays between a synchronous counter and the DAC to compensate for the delays of each bit and the lack of symmetry of positive and negative edges. (Further information from J.C. Wolles.)

Another 16 bit DAC is involved in a different application at the Intersecting Storage Rings (E10 Precision reference source). The need is for a very precise, ultra stable voltage reference for the power supplies to the ISR magnets since the stability of the currents in the magnets is crucial for the good performance of the ISR.

The reference source is suitable for any application where a power supply must give ultra high performance. It is designed as a self-contained unit which can be readily incorporated



The rotary capacitor which will be used to provide the 600 MeV synchro-cyclotron with radio-frequency power to accelerate a more intense beam of protons. It gives a time varying capacitance so as to cover a frequency range from 30 MHz to 17 MHz and has to handle up to 50 MVA of r.f. power. The electronic and mechanical problems involved were not easy to solve.

in any system, being either set locally or set remotely by computer. At the ISR, the control computer sends its requirements as digital signals which emerge from the unit as an analogue reference voltage.

It is a completely solid state, electronic device with no mechanically moving parts. From 10 V to zero its output can be varied in steps of 150 μV thus giving steps of 15 parts per million in selecting the reference voltage. As with the DAC mentioned above, special care is needed in the design and construction to achieve such accuracy and some additional measures were taken to reduce output variations with temperature to as little as 7·5 parts per million.

A new technique, which recently emerged from the aerospace industry, is used to ensure precise switching. Electronic components do not give such a distinct difference in the 'on' and 'off' situations as mechanical relays but positioning several of them in parallel in shunt positions, rather than in series in the resistor network, results in switching errors of less than 1 part per million. A second new technique is to compensate for changes due to temperature by changing the 10 V primary reference voltage in the opposite direction. Thus if higher temperatures are tending to drift the output reference voltage upwards, the primary reference voltage is lowered to keep the output steady. This works to accuracies of better than 4 parts per million over a 30 °C range. (Further information from J. Pett.)

To put alongside the lilliputian world of transistors, integrated circuits and so on, CERN has also been involved in large-scale electronic systems, in particular in order to provide high power radio-frequency systems for the acceleration of charged particles.

The latest equipment of this type is the rotary capacitor which is to be incorporated in the radio-frequency system of the 600 MeV synchro-cyclotron presently undergoing a series of improvements. (E28 The new SC radio-frequency system: essential technological features of its rotary capacitor.)

It is required to provide a time varying capacitance, with a rotor carrying 3 rows of 16 teeth moving between 4 rows of stator blades, and has to handle up to 50 MVA. The rotor-stator gap is 1.1 to 4 mm with a tolerance of 0.1 mm. The rotor speed is 2200 rpm.

CERN and AEG confronted the problems of building such a device to operate in high vacuum, free of hydrocarbon vapour, and in high r.f. fields. Water cooling is necessary for the system, including the rotor, which for r.f. reasons could only be supported by a cantilevered shaft so as to leave one side free. The high mechanical tolerances make it necessary to use pre-stressed ball-bearings which have to be lubricated, cooled and protected from r.f. currents.

The lubrication and cooling is done by pumping oil with an automatic centrifugal system brought into action by movement of the rotor. The oil has to be prevented from entering the high vacuum region and a special steel and carbon-ceramic seal has been developed. The problem of r.f. current flowing through the bearings is removed by establishing a capacitance bridge with the bearings in one of the balance arms. The bridge is set so as to be in balance at the centre of the frequency range covered by the rotary capacitor. (Further information from H. Berger, A. Fiebig, R. Hohbach or S. Talas.)

Magnets and Electricity

Under 'Magnets and Electricity' come the design and construction of magnets for accelerators, beam-lines and detectors, the precision measurement of magnetic fields and properties, the design of special power supplies, and the high voltage and high current techniques for pulsed and d.c. applications.

Magnets have obviously been a CERN speciality since the early days of building the synchro-cyclotron and proton synchrotron. The CERN work at that time had an important impact on European industry. It led to the use of low carbon steel rather than the more expensive low silicon steel. Low carbon steel then proved ideal for small electric motors and thus a few francs have been chipped off such things as washing machines, etc... Also the use of araldite in large electrical installations was promoted by CERN and this is now a standard technique, for example for the gluing of transformer laminations.

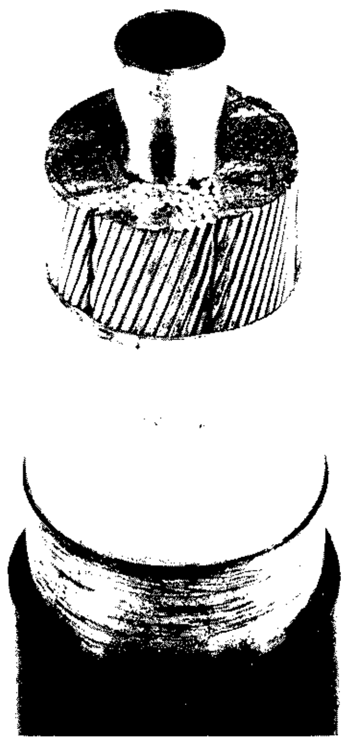
Nowadays it is in the use of superconductivity that high energy physics research is pushing magnet technology. Nevertheless even with conventional magnets, new skills are being used in the building of the thousand magnets for the ring of the SPS. The problems are nicely illustrated in the huge Assembly Hall of Laboratory II where magnets are being built and measured. Many now lie stacked waiting to be wheeled into the machine tunnel. It is a mass production situation where high precision has still to be retained (covered in Technology Notes M25, M26 and M27).

During construction of the ISR, a new type of cable (M10 Water-cooled cable and terminations) was developed in collaboration with Kabel-Metal for passing current to the magnets of the storage rings. Previously current had been transmitted to magnets via preformed rigid structures of hollow copper or aluminium bar. During the ISR construction it was realized that, with the sizes involved, it is feasible to wrap conductor around a thin-walled copper pipe. This has been achieved resulting in a flexible cable which can be transported by drum and cut to measure when installation is in progress.

The cross-section of the cable is 900 mm^2 and it has a minimum bending radius of 600 mm. It withstands a voltage to ground of 2 kV and the current it can carry depends on the available water pressure between inlet and outlet. The central water channel is 16 mm in diameter. At the ISR, where 14 km of this cable are installed, the current rating is 1900 A. The insulation and outer sheath are made of special radiation resistant polyethylene.

One problem was to design terminations for the cable where they join the magnets because the possibilities of water leakage in high voltage conditions could obviously lead to breakdown. A method was evolved whereby the lug is crimped to the cable with a hydraulically operated tool and then insulated with radiation resistant epoxy resin. This type of cable has subsequently been used in the construction of the PS Booster and will link the SPS power supplies via the access shafts to busbars in the ring tunnel. (Further information from S. Pichler.)

The water-cooled cable which was developed to power the magnets of the Intersecting Storage Rings. It is a high current conductor but is flexible and can be transported on a drum and cut to size where it is to be used.



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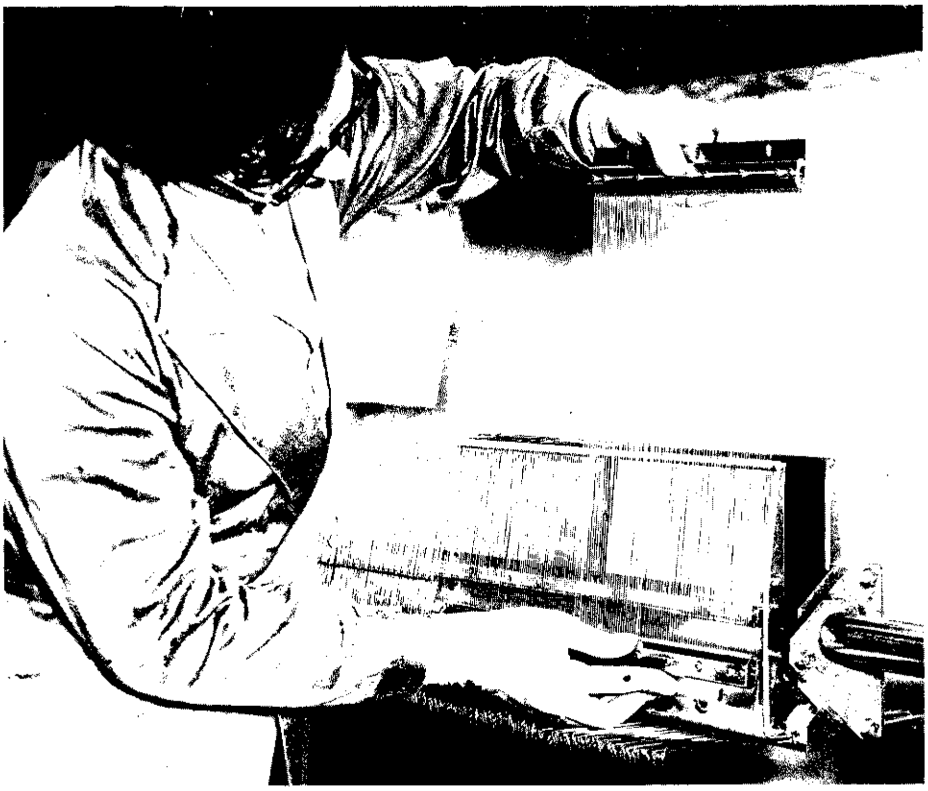
The measurement of magnetic field has become a highly automated process. An example is the system developed to remeasure the 600 MeV synchro-cyclotron (M35 A high precision device for the measurement of the magnetic field in the synchro-cyclotron). The magnet, which is 5 m in diameter, has received a number of modifications during the improvement programme at the machine, including the installation of new coils and the boring of an axial hole to give access for a new type of ion source. A remapping is needed because the beam intensity which it will be possible to accelerate depends crucially on establishing the correct relationship between the r.f. accelerating voltages and the field.

The field is about 2 T and the required measurement precision is $\pm 2 \times 10^{-4}$. The measuring gear consists of an aluminium bar 3.5 m long carrying 100 Hall plates, temperature stabilized to 25 ± 0.1 °C, mounted with a 3 cm spacing. Before mounting, each plate is calibrated in a test magnet by comparison with a proton resonance probe. The bar is fixed to a turntable positioned at the centre of the magnet aperture and can be swung azimuthally with a precision of 0.01 degree by a step motor controlled by a computer. The Hall plates are also linked to the computer via a

Construction of the electrostatic septum for the beam ejection system of the SPS. Its special feature is a precisely aligned plane of thin wires. The wires are individually held taut across the aperture where the protons pass by means of springs. On the left, the wires are already in place. On the right a new frame of wires is being positioned and the springs which will hold them can be seen protruding below on each side.



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120 channel analog scanner. The plate voltages are read channel by channel by a digital voltmeter and passed to the computer in digital form. The voltages are converted to field values while the bar moves to the next position. The time needed for a complete map of the field with 36 000 readings is only about 40 minutes. (Further information from E. Braunersreuther.)

High voltage techniques are well illustrated by the switch developed for the full aperture kicker magnet of the proton synchrotron (M20 High voltage switch for kicker magnet applications). Such magnets, like the electrostatic septum discussed below, are used in the ejection of protons from an accelerator. They take advantage of the fact that the protons orbit the machine in bunches. The aim is to allow a bunch to pass and to bring the magnet to its required power in the interval before the next bunch arrives. This bunch will then feel the kicker magnet field and be ejected from the machine.

At the PS the interbunch interval is only 85 ns and therefore the design of the kicker and its pulse switching system has to allow very fast operation. The switch discharges a 15 ohm cable pulse forming network, charged to 80 kV, into a transmission line leading to the kicker magnet and terminating resistor. The switched current is 2.7 kA.

An English Electric Valve Co. thyratron (CX 1171A) is the essential element of the switch. It is operated with a floating cathode so that the supplies to the heater, reservoir and grid have to be fully isolated. To achieve fast rise time the thyratron is mounted in a close fitting coaxial housing (25 mm radial clearance). Oil and solid dielectric provides the insulation between the anode and the earthed housing; the oil also serves for cooling. Some of the supplies are drawn from an insulated Faraday cage which enables the reservoir heater voltage to be rapidly adjusted and this determines the switch rise time.

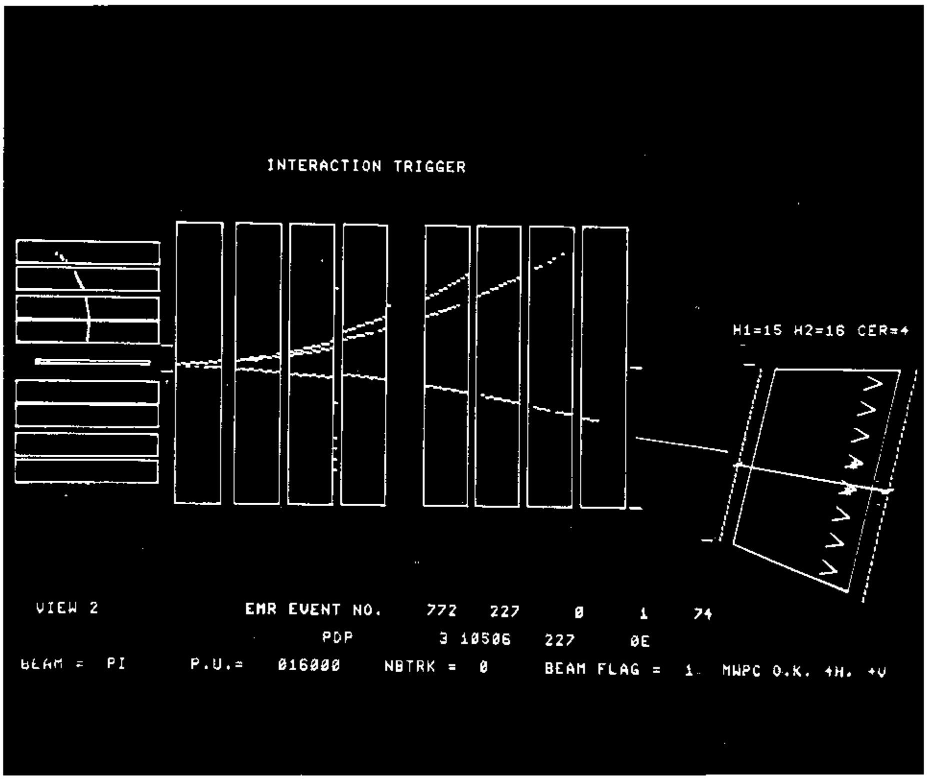
The switch has been rigorously tested during 5000 hours of operation and 100 million pulses. Ten of them are now in operation at the PS powering ten kicker modules. They give a rise time of 30 ns with a time jitter of less than 6 ns and can provide a pulse every 30 ms. During development tests, a variant of this design provided pulses once every 50 μs at 40 kV with about the same rise time conditions. (Further information from D. Fiander, D. Grier, K.D. Metzmacher or P. Pearce.)

Returning to the SPS, an unusual device is the electrostatic septum which will be used to eject protons with energies of several hundred GeV from the accelerator (M32 The electrostatic septum of the SPS). The septum slices off part of the circulating beam and the sliced off protons are subjected to an electrostatic field of 100 kV/cm. Protons of such high energy are very 'stiff' to bend out of the machine and the electrostatic septum has to be 12 m long (it is built in four 3 m modules). In order that as few protons as possible collide with the septum it has to be very thin and straight. It must also withstand being heated to 300 °C by the beam and the whole device has to be bakeable so that a vacuum of 10^{-9} torr can be achieved.

To meet these requirements each septum module has a line of 2000 tungsten or molybdenum wires, 0.15 mm thick spaced 1.5 mm apart, each wire being held taut by two springs. Having a plane of wires under tension avoids the possibility of distortion which could happen if a foil was used as the septum. At the same time it minimizes the volume of matter which is put in the way of the protons. In the event of a wire breaking, the springs will pull it out of the path of beam. The deflecting field is established by having a titanium alloy cathode, held at —200 kV during normal operation, positioned 10 to 30 mm away from the wire plane.

The whole system has to be correctly aligned to ±0.05 mm and careful stress-relieving has to be carried out on all the component parts. Alignment rods project outside the vacuum tank. They carry targets for optical alignment and an alignment control system using a stretched wire as a stable reference. Final alignment will be done using the beam itself as the reference, the aim being to minimize the loss of protons in ejecting them from the machine. This can be done by watching, with infra-red detectors, the temperature rise of the wires hit by the protons. (Further information from Y. Baconnier.)

Photography and Optics



The signals from the plumbicon cameras recording sparks produced by the passage of charged particles in the banks of optical chambers in the Omega spectrometer. This view of the event is reconstructed by the on-line computer. The cameras are able to take data at such a high rate that to record 100 000 events per day is not unusual.

The interest in these fields has been mainly connected with the optical systems needed to record the visual signs of the passage of a charged particle (bubbles in a bubble chamber, sparks in a spark chamber, tracks in nuclear emulsions).

In recent years the urge to collect large volumes of information quickly has required much faster data-taking rates and thus much faster operation speeds from the optical systems. An example from the bubble chamber world is a camera (P 13 Pulsed high speed camera) developed for the 2 m chamber at CERN. In the more leisurely years gone by, the chamber was pulsed so as to record tracks of particles once every acceleration cycle of the proton synchrotron. This meant that the camera system had a few seconds to recover, move onto the next frame of the film and so on. Now it is required to take several pictures per cycle — the accelerator can send particles to the chamber in bursts separated by the order of a tenth of a second.

The camera has to be capable of taking four photographs in 0.3 s (the photographs being 170 mm long on 50 mm wide film). It has to move a new length of film into position in less than 60 ms without pulling it with a force greater than 2 kg (so as not to break it) and to hold the film very flat (so as to be well in focus when the picture is taken) before releasing it and pulling a new length across. Environmental problems were to ensure operation of the mechanical and electronic components in a stray magnetic field of 700 gauss and to ensure safety in a hydrogen area.

A loop of film sufficient for four photographs is pulled into a right-hand vacuum pocket from the spool of unexposed film. This is done on a signal from a capacitative device which measures the length of film in the pocket. A motor driven capstan, in one revolution, pulls one frame of film from the pocket into position for exposure and it is held flat on the film back (made of 0.3 mm diameter quartz capilliary tubes fused together and ground optically flat) by suction. After exposure a burst of compressed air releases the film from the film back and it is wound into a left-hand vacuum pocket while a new frame moves into position.

This type of camera has been in use on the 2 m bubble chamber since 1969. (Further information from L. Naumann, M. Schmitt, M. Dykes or R. Stierling.)

A very different camera system (P 29 Automatic recording of spark chamber pictures by means of a computer controlled television camera system) has been developed, mainly by a Birmingham/Rutherford/Westfield College collaboration, to photograph particle interactions in the Omega spectrometer. The aim was to convert the visual information from spark chambers into electronic form without the need for the intermediate stage of photographs which then require scanning and measuring. The camera system operates only when triggered by counters which indicate that an interaction of interest has taken place. It uses TV plumbicon cameras to scan the volume of the spark chambers ($3.7 \times 1.5 \times 1$ m^3).

When a trigger occurs, the spot in each TV tube, which has been continually scanning in an 'erase mode' to remove background illumination, returns to the corner of the picture and starts an 'event mode' scan roster covering the image of each spark chamber gap in turn. The image is retained on the tube surface for some milliseconds after the sparks occur. At the start of each scan line a train of clock pulses is fed to scalers. The first scaler stops when the first

Developing refined survey instruments in the hygienic conditions of a laboratory is quite another thing from using them on a construction site. Here a gyrotheodolite is in use in the tunnel of the SPS while an umbrella protects its operator from seeping water. Use of the gyrotheodolite has been automated so that no highly delicate operations are necessary.

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spark is encountered, the second scaler when the second spark is encountered and so on. Thus spark positions are immediately in digital form and can be stored on magnetic tape for subsequent computer analysis.

Using a fiducial light system, to help correct for scanning spot speed and for distortions and non-linearities in the camera tube, sparks can be located to the required accuracy of 0.5 mm. Collecting all the necessary information takes only about 18 ms and Omega is then ready to record the next event. Using these cameras the data-taking rate is therefore very high — 100 000 events per day is not exceptional and 10 million events were clocked up during 1973. No system based on conventional cameras, no matter how fast, could get anywhere near these rates quite apart from the advantage of having data immediately in digital form. (Further information from O. Gildermeister.)

Also grouped under 'Photography and Optics' are the refinements in survey techniques which have been necessary to achieve the tenth of a millimetre order of alignment precision when dealing with accelerator systems spreading over kilometres. In particular, automatic instruments have been developed to give fast and accurate measurements of length and direction.

One of them, called the Distinvar (P 14 Precise length measuring automatic device), has been in operation for some years and was used in construction of the Intersecting Storage Rings and the PS Booster and is now used for the SPS. It uses a calibrated invar wire, 1.65 mm in diameter, to one end of which is attached a balance beam. A carriage carrying the balance can be moved to and fro along a precision micrometer screw until a centre of equilibrium is reached at which a 1.5 kg weight produces a 15 kg traction in the wire. This position can be read off and gives the difference between the true measured length and the calibration length of the wire.

The Distinvar can be used for length measurements from 0.4 to 50 m — the accuracy is not determined by the length to be measured but by the sensitivity of the balance. Accuracies of better than one part in a million can be achieved. Each measurement need take only a few minutes, the reading itself involving only a few seconds. The Distinvar can be used for absolute measurements, as in site surveys when the lengths are calibrated against a standard length, and for differential measurements, such as are needed in the construction of bridges, tunnels, buildings, etc. (when calibration is not needed).

A second instrument (P 17 Automatic gyrotheodolite) has been used for direction finding in the SPS tunnel. Using a gyroscope to find the meridian plane (i.e. the geographical North) can be a delicate operation when accuracies of a few seconds of arc are required. An automatic device was therefore developed using a gyrotheodolite and measuring (with phototransistors) the transit time of oscillations to right and left. The difference between the right and left oscillations is a function of the angle between the gyrotheodolite axis and North.

In the SPS tunnel any survey direction can be found with a standard deviation of only 25 centisimal seconds by using the automatic gyrotheodolite three times to find North. All the surveyor needs to do is to direct the gyrotheodolite roughly in the direction North and the correct readings can be printed out. (Further information from D. Bois or J. Olsfors.)

Standard techniques may need considerable adaptation when brought into the environment of an accelerator. Television cameras can be used close to the machine to watch fluorescent screens in monitoring the position of an accelerated beam and in a variety of other ways to provide an eye into the machine region where radiation levels prevent access during operation. A camera has been developed for such use (P 11 Miniature radiation resistant television camera). It can withstand high radiation doses, operates in fields of 100 gauss, is highly reliable and easy to maintain.

Nuvistorised circuits are used since they can accept radiation doses of over 10^6 rem compared with the 10^5 rem of transistors. The camera is in two distinct parts — the head (with a nuvistor preamplifier, a vidicon tube and deflection unit) and the control equipment (power supply, pulse generator, scanning circuits and video amplifier).

The deflection unit is the most sensitive to magnetic field and it is protected by shielding and by having the camera casing in mu-metal. The unit is mounted on slides so that the camera can be easily focused even on very close objects, either manually or remotely via a motor.

The camera head is only 82 × 92 × 237 mm or, if the transistorised preamplifier is incorporated, 82 × 184 × 234 mm. Its weight is 2.6 kg or 4.6 kg respectively. It is now being manufactured by CEMEL. (Further information from P. Monnet or J. Robert.)

Vacuum

The needs for high vacuum have been around at CERN for a long time. The region in which protons are accelerated has to be evacuated so that collisions with residual air molecules, especially at lower energies, does not cause loss of beam or serious deterioration of beam quality. However, it was with the coming of the Intersecting Storage Rings that the requirement to establish ultra high vacuum in large scale systems pushed the known technology into new fields.

In the conventional accelerator a proton beam spends a few seconds in the machine and pressures in the region 10^{-6} to 10^{-7} torr are adequate. In the storage rings the protons may be retained for a day and the vacuum in which they orbit has to be several orders of magnitude better. When the ISR were designed, the aim was to achieve pressures of 10^{-9} torr around the rings with 10^{-11} torr in the intersection regions where the experimentors want to be sure that they are seeing true proton-proton collisions and not collisions with residual gas molecules.

This was already a challenging requirement. It meant building a system 2 kilometres in extent to hold ultra high vacuum such as was previously achieved only in small-scale apparatus in the laboratory. This challenge has been met and far exceeded because it was found, when the machine came into operation, that vacuum conditions can be the major obstacle to reaching high stored beam currents because of a phenomenon known colloquially as 'pressure bumps'. The present aim, which is largely realised, is to establish vacuum of 10^{-11} torr around the full circumference of both rings, with 10^{-12} torr or better in the intersection regions, and to be able to sustain such a vacuum for a year if necessary (V17 How we get next to nothing in the ISR).

The vacuum chamber in each ring is a 'doughnut' about 1 km in circumference and 160 mm diameter in cross-section (160 × 56 mm elliptical cross-section in the magnet apertures). It is built of nitrogen enriched austenitic stainless steel. The steel is baked at 800 °C for a few hours in a vacuum oven at 10^{-4} torr before the vacuum tubes are made. This reduces the quantity of gas trapped in the steel (mainly hydrogen) which subsequently diffuses out and is the major source of gas input in the ISR chambers.

When the chambers are installed, there is further baking in situ by means of heating tapes wrapped around the tubes. They are baked for 24 hours at 300 °C (controlled to within 10 °C by thermocouples) while rotating vane turbo-molecular pumps, distributed along the chamber at intervals of about 25 m, pump down to a pressure below 10^{-5} torr. The temperature is then allowed to fall to 200 °C while the pressure continues to be pulled down to about 10^{-6} torr. Titanium sputter-ion pumps are brought into action while the turbo-molecular pumps are valved off. The pressure dips further to around 10^{-7} torr when sublimation pumps and vacuum gauges are degassed ready for action. The 'bakeout' is stopped and the chamber temperature falls back to room temperature while pumping continues. After five hours the pressure is usually in the 10^{-10} torr range. The sublimation pumps then start to 'getter' (actively pump) and this additional pumping speed brings the pressure in the chambers to the low 10^{-11} range and even below.

The 'pressure bump' phenomenon mentioned above has called for very careful detective work on vacuum conditions in the chambers. It manifests itself as a localised region of about 10 m length where the pressure rises when the orbiting beam current exceeds a certain value. Ions produced by the protons in collision with residual gas molecules strike the vacuum chamber wall, release more gas causing more ions to be produced so that an avalanche effect can develop and destroy the beam.

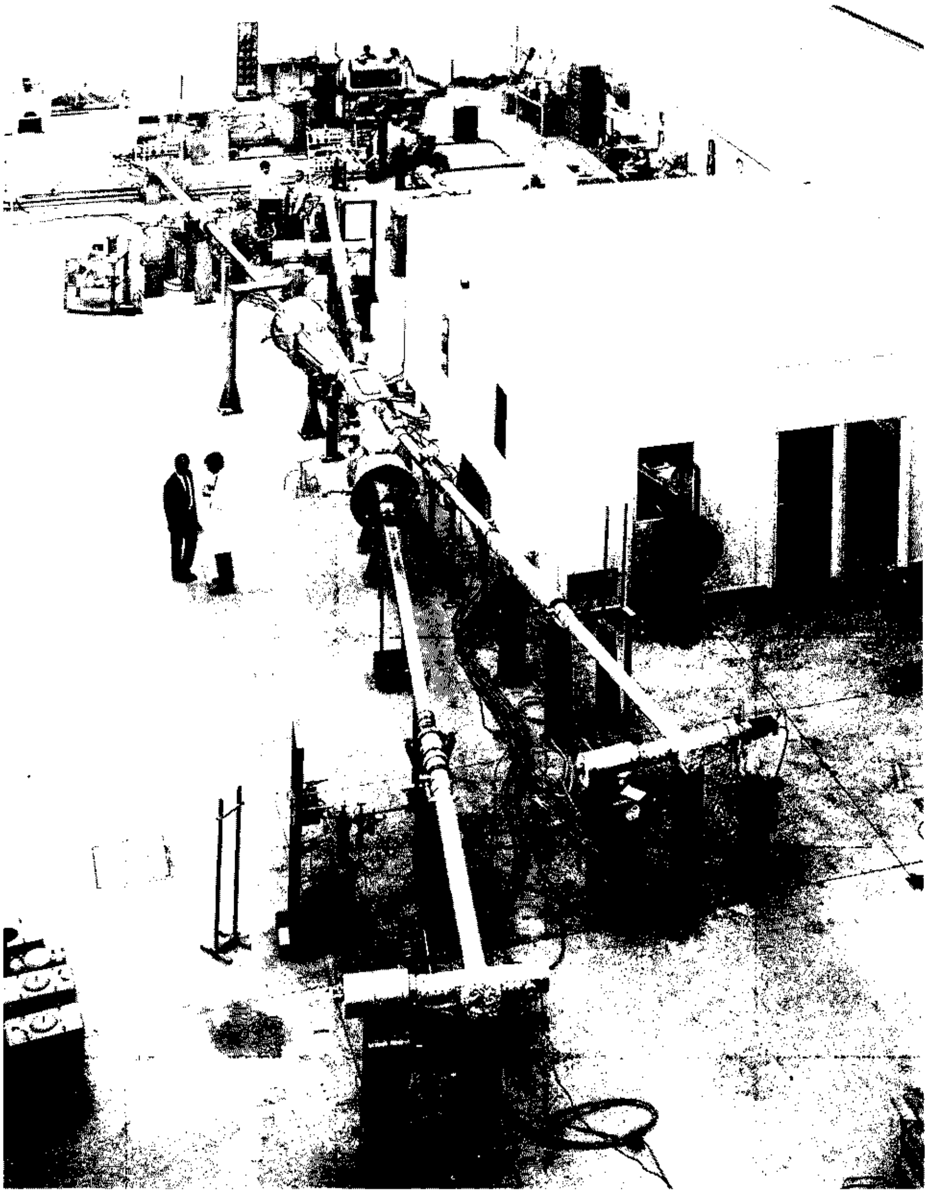
Studying this phenomenon revealed that the stainless steel surface is covered with a layer of strongly absorbed gases in addition to hydrogen (water molecules, carbon monoxide, carbon dioxide, methane, hydrocarbons) which are only released by ion bombardment. Running a high pressure (10^{-2} torr) inert gas discharge in the vacuum chamber can help remove these contaminants — subsequent gas release under ion bombardment is then reduced by two or three orders of magnitude.

Many other refinements have been brought into the ISR vacuum system after completely new investigations into ultra high vacuum properties. But equally important in achieving the exceptional vacuum conditions in the machine has been the extremely high reliability of a multitude of apparently commonplace components. To cite one example — over ten thousand demountable flanges all have to be leak-tight simultaneously. A thorough approach to every detail of the vacuum system has been vital. (Further information from E. Fischer or R. Calder.)

Research on the vacuum properties of materials is continuing (V27 Choice and conditioning of ultra high vacuum materials). One approach is to see whether the diffusion coefficient of hydrogen, particularly in stainless steel, can be reduced. This can be studied by following the evolution of hydrogen from a sample of the material using, for example, a gas chromatograph.

Two methods of lowering the coefficient are being examined. The first method is to introduce more dis-

Vacuum chamber for one of the intersection regions in the ISR under test before installation in the machine. The pressure in the chamber is required to be about 10^{-12} torr. Note the strange conical form on two of the arms; these are upstream of the crossing beams and have very thin walls so that particles produced in the proton collisions can emerge through the minimum amount of matter to be detected.



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locations in the crystal lattice by cold working of the material (the density of dislocations is closely related to cold strain). Since hydrogen diffuses interstitially through the lattice, the dislocations might act as barriers to delay the passage of the hydrogen molecules. The second method is to set up traps of a chemical nature for the hydrogen by implanting halogen ions in the material.

These methods may help but the techniques to reduce the quantity of hydrogen present in the material have proved the most efficient. For this purpose, a high temperature vacuum furnace capable of treating components up to 3.5 m long by 1 m diameter will soon be in operation at CERN. It will operate at 1000 °C and a pressure of 10^{-6} torr (later to be improved to 10^{-8} torr) for outgassing stainless steel and it is hoped that an order of magnitude improvement in the final outgassing rate will be achieved. (Further information from K.S. Niel or F. Thizy.)

The search for better materials is pointing towards titanium (V14 Components of a prototype titanium vacuum chamber). Titanium sleeves have been successfully introduced into the ring vacuum chambers and a prototype chamber is now being constructed for installation at an intersection region to replace the standard stainless steel bicone. Titanium has the added advantage that, compared with stainless steel, it is twice as transparent to the particles emerging from the collisions towards the detectors.

Forming complex structures with titanium is however not so easy. The separate parts are all cold formed by pressing, rolling and pressurising. Special machines have been constructed for carefully welding the parts together in an argon atmosphere to avoid a brittle joint which results from hydrogen absorption. (Further information from I. Wilson, J.C. Brunet, W. Jeker or E. André.)

To reach 10^{-12} torr or better in the intersection regions, cryopumping techniques have been studied (V13 Condensation cryopump). A surface cooled to very low temperature acts as a trap to immobilise any gas molecule which falls on it. Unfortunately hydrogen is the most recalcitrant of all the gases (with the exception of helium) and at 4.2 K (boiling temperature of helium at atmospheric pressure) its vapour pressure is still 10^{-6} torr. However, cooling to 2.3 K takes it to the 10^{-15} torr region and in theory a cryopump should achieve the pressures required.

In practice, it initially proved impossible to get beyond about 10^{-10} torr. This was due to thermal radiation from the vacuum chamber walls causing the condensed hydrogen to be desorbed again, the rate depending in a complex way on the quality of the cooled surface. A cold screen, of the Chevron baffle type cooled to 80 K, shielding the surface, greatly reduced this problem though at some cost in pumping speed. The screens have a molecular transmissivity of about 0.24 and a radiation transmissivity of about 7×10^{-4}. A silver surface coated with a few monolayers of condensed nitrogen proved the most efficient and these measures enabled a pressure of 10^{-13} torr, with the surface operated at 2.3 K, to be obtained.

Four pumps have been built and two have operated successfully in an intersection region of the ISR. A model has been standardized for general use and six condensation cryopumps are being prepared for installation in 1975. (Further information from C. Benvenuti or R. Calder.)

Workshop Techniques and General Engineering

The teleoperator in action. On the left at the 'master unit', the operator using the device watches the progress of the manoeuvres on television screens. On the right, the 'slave' unit brings a quick release flange into position while TV cameras survey the operation.

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CERN's major construction projects are obviously implemented via European industry. There are, however, many small-scale 'one-off' jobs that industry is not keen to take on, or that need unusual skills, or that cannot be cleanly specified before they are tackled. There is also the need for on-the-spot engineering support. To meet these needs CERN has built up a workshop force of very high standard where skills exist appropriate to the needs of the research programme. A few of these skills are picked out here.

A large amount of sheet metal work is done for producing vacuum chambers, cryogenic systems, high voltage electrodes etc... It can involve special features such as large areas of very thin metal (which must gain mechanical strength in some other way), the use of materials which are difficult to work, or the specification of very tight tolerances which are unusual for the size or the type of material being worked.

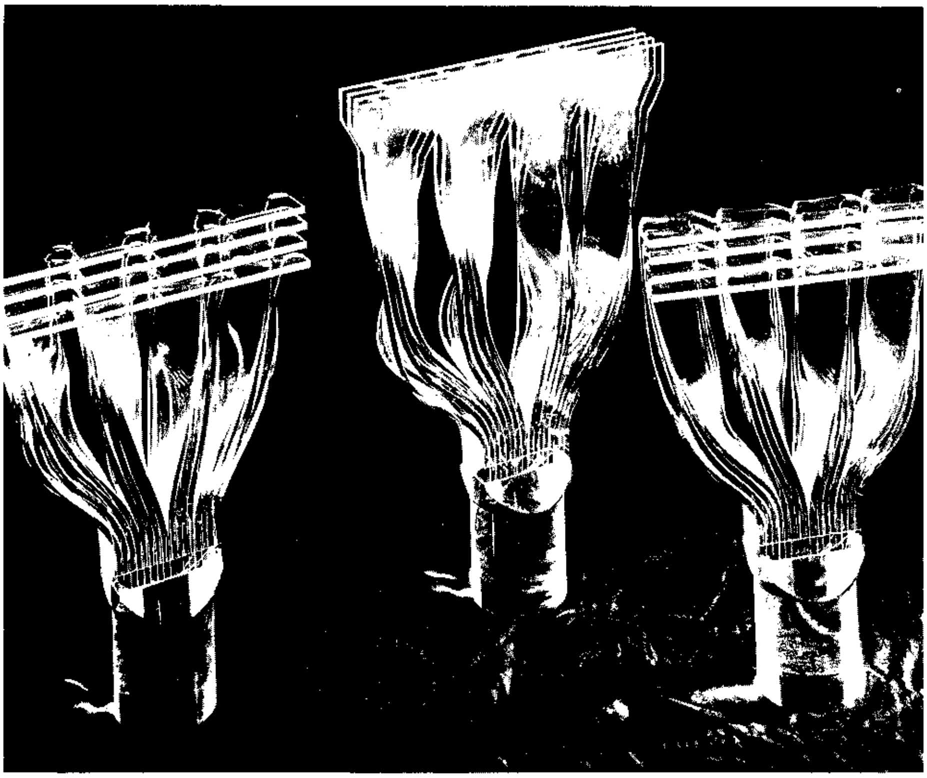
Rolling, angle forming, tube bending, swaging and drawing are all performed with advanced techniques. Examples of sheet metal work (described in W27 Sheet metal work for ultra high vacuum and cryogenic applications) are — an aluminium alloy magnetic deflector, 2 to 3 mm thick, built in six conical sections of different dimensions with a base diameter of 2.4 m, a total length of 5 m and a tolerance of only 0.2 mm; r.f. cavity made of 20 mm thick steel coated with 5 mm copper, 1 m long and 0.9 m diameter with a tolerance of 1 mm; a variety of elliptical cross-section vacuum chambers in stainless steel, aluminium alloy and titanium, and a complex titanium vacuum chamber (0.6 mm thick) for an intersection region at the ISR. (Further information from G. Dervey or J. Tallon.)

One way of tackling the problem of joining such delicate components together is to use electron beam welding (W32 Electron beam welding). An electron beam can cause melting in very small volumes so that deformation and shrinkage are limited. Its high power density make it suitable for the welding of refractory materials as well as high conductivity materials and its high penetration allow welds to be made on thick sections in one operation. Welding is performed under vacuum so that contamination, particularly of highly reactive metals such as titanium, is avoided.

The technique has been used on components of aluminium, copper, titanium, molybdenum, niobium, tantalum, rhenium and alloys of aluminium, nickel, cobalt, stainless steels etc... Heterogeneous welds such as stainless steel to copper have been made. Using an electron gun operating at 150 kV and 7 kW, a weld 25 mm thick is possible in one operation with copper, 30 mm with aluminium, 35 mm with stainless steel. (Further information from B. Thony or B. Trincat.)

Work on a minute scale has been needed to meet the demand for prototype printed circuits (W29 Photomechanical and chemical etching techniques). Chemical machining of metal involves dissolving unwanted areas of the metal while protecting the required pattern with a mask. The master drawing can be produced by hand or by machine using an automatic co-ordinatograph (possibly with an optical plotter head) on photosensitive film. The machine can be computer programmed. Scales as high as 1000 to 1 can be used for producing integrated circuits drawing on areas up to 1 × 1.5 m^2 with a minimum line width of 0.1 mm. Line spacing of at least 0.2 mm is necessary and allowance has to be made for the chemical

Familiar works of sculpture at high energy physics Laboratories — light guides to convey the light signals produced when charged particles traverse sheets of plastic scintillator to photomultipliers, which convert the information into electronic form. These particular specimens were made in the CERN West Workshop.



CERN 58.6.71

attacking the edges of the desired pattern under the mask.

Careful photography of the master drawing can give resolution of 300 to 600 lines per millimetre for a 1 m^2 surface and even 2000 lines/mm over a 150 mm diameter surface using high resolution lenses in the camera. Normally, flexible or rigid supports (such as plastic or glass) can be used to carry the high contrast photographic emulsion but, for high resolution, glass plates are preferred with an evaporated chromium layer about 1 μm thick photo-engraved for increased stability and resistance to corrosion.

The mask can be produced by impressing (when high precision is not needed), by serigraphy (giving at best 60 μm line width) or by using photosensitive resin (where the resolution is, in theory, unlimited — resin thickness and cleanliness give the resolution in practice). Sprinkling is used for the actual engraving, reducing the engraving time and the problem of edge attack. After engraving the resin is dissolved away.

Printed circuits of size up to 1.2 × 0.5 m^2 have been produced. Chemical machining has also been carried out on silver, aluminium, nickel, stainless steel, tungsten, etc... since no internal stresses are introduced by the process. (Further information from J. Birabeau, A. Gandi or P. Guerineau.)

Also in this category are investigations into remote handling techniques (W13 Teleoperator — long range high speed remote handling). A radioactive environment prevents normal human intervention at the accelerators when they are in operation. Even when the machines are shut down there are zones, such as where targets are located, where induced activity is high and which are inaccessible for a considerable time. There is also, from time to time, need to handle highly radioactive components. Remote handling techniques are one solution to these problems but the conventional manipulators used in reactor and radiochemical laboratories are not appropriate because of the distances involved. A variant of the switch operated electric arm type of manipulator was therefore tried in prototype form at the PS.

The arm was mounted on a crane bridge accompanied by cameras and lighting. It could travel around the ring and a method of automatically plugging-in its cables at connection boxes spaced around the accelerator tunnel wall has been developed.

The manipulator operated with a range of 40 m from a plug-in box and was controlled from a building at the centre of the accelerator ring. The prototype proved useful for many jobs such as remote dosimetry and beam-loss detection and for dismantling radioactive components. It was clear, however, that higher speed and versatility was needed.

A Selenia Mascot Electronic Servo Master-Slave has been acquired to continue these investigations. The manipulator has two arms and equals the hot cell type in its dexterity. Each arm can lift 20 kg and the operator can feel the forces being applied via a feedback to the master arms. Since master and slave stations are linked electronically the slave can, in principle, work anywhere around the accelerator. To match the increased abilities of the Mascot, the supporting units have been improved (faster carrying bridges, better cabling and link mechanisms, compact cameras, motorised pivots for the arms).

With these improvements the new teleoperator is a hundred times faster than the prototype and in many cases can approach the speed of direct manual working. (Further information from R. Horne.)

Around the Laboratories

ORSAY
On-line separator in action

A newcomer in the family of on-line isotope separators came into action at the Orsay synchro-cyclotron at the beginning of March. It is known as ISOCELE and will be used for nuclear spectroscopy on short-lived isotopes.

The synchro-cyclotron is used to produce beams of protons (0.2 μA at 157 MeV), deuterons (79 MeV), alphas (157 MeV) and helium 3 ions (236 MeV). It will soon be modified to reach 200 MeV for protons with more intense beams, 7 μA. Accelerated protons are brought to a target/ion source which will initially be of the kind pioneered by R. Bernas (see, for example, vol. 13, page 185). The source and acceleration stage is followed by an analysing magnet, which separates ions according to mass. Finally an electrostatic switch can send selected, focused ion beams to any of three experiments.

The first successful run in March bombarded a target of molten gold. Mercury isotopes, down to 186, were detected in high intensities. Another series of tests is now under way to check the performance of different types of target and to look at operation with a helium ion beam into the target rather than a proton beam. Regular operation for physics experiments is expected to start in May.

OXFORD
ISIS for high energy particle detection

A team at Oxford University has proposed a new variant of the multiwire proportional chamber/drift chamber techniques to identify particles up to very high energies. They have baptised their system ISIS (Identification of Secondaries by Ionisation Sampling) — a respectful reference to the name of the river which flows past the dreaming spires of their University.

We have referred many times before to the difficulties of experimentation at energies of several hundred GeV. To identify and measure particles at NAL and SPS energies using the techniques which have been applied at energies of tens of GeV can require detectors of great size, complexity and cost. Rising to this challenge, ideas have not been lacking as can be seen, for example, in the report of the Frascati Instrumentation Conference last year (vol. 13, page 175). At that Conference drift chambers were in the limelight. To collect their signals the drift chambers use the multiwire proportional chamber principle where individual wires receive an avalanche of electrons initiated by a charged particle passing in the vicinity. The word 'drift' refers to the movement of the electrons produced by ionization of the gas in the wake of the particle. They drift to the wires under the influence of an electric field gradient. The time that this takes can be measured and gives a highly accurate estimate of the distance of the particle from the wires. Signals from the wires can give position measurements accurate to fractions of a millimetre.

The Oxford work tries to add another piece of information — distinguishing between particles by means of the 'relativistic rise of ionization loss'. As a charged particle approaches the speed of light, the electric field which is associated with it spreads out in the plane at right angles to the direction of motion. If we consider the particle at rest as a tiny sphere it expands, flattening into a disc due to relativistic effects as its velocity increases. Its electric field then brushes against more atoms in the gas through which it passes, causes more ionization and the particle therefore suffers more ionization loss. For the different types of particle, at a given momentum, the ionization loss is different. For example, there is about 15 % more loss for pions than kaons and about 10 % more loss for kaons than protons over a wide range of energies (5 to 100 GeV). If we can measure the ionization loss by counting the number of electrons liberated in the gas we can distinguish between the particles.

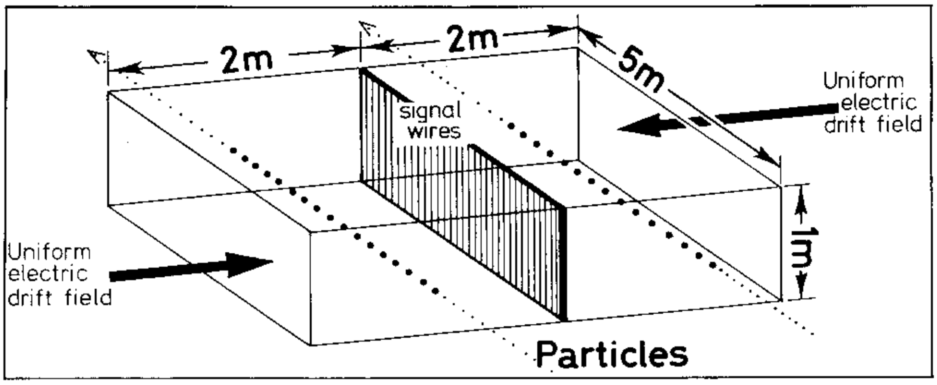
What has held back the application of this attractive property is that the variation in energy loss for a particular particle in passing through a small distance of gas is considerable. Most measurements will cluster around an average value but a significant number will be much higher; the graph of number of measurements against energy loss tails off slowly (known as the Landau tail since L. Landau was the first to investigate it in 1944). It is necessary to take a series of measurements on the same particle (well over a hundred) as it passes through a series of small distances of gas so as to avoid being confused by the higher energy losses which can occur as Landau fluctuations.

The use of the ionization loss phenomenon is being applied in a device being constructed by the Track Chambers Division at CERN which will be used to identify high energy particles emerging from the 3.7 m European bubble chamber, BEBC. Because of the need to take a large series of measurements on the same particle, the device is rather complex with many arrays of wires.

The ISIS proposal is to enclose a large volume of gas (parameters might be 5 m along the beam direction, 4 m across and 1 m deep) in which a uniform electric field is established. A line of wires is strung vertically along the centre of the box. They are sandwiched closely between two planes

Schematic diagram of ISIS showing the arrangement of drift field and signal wires which is rather different from other detectors. The signals, resulting from the drifted electrons liberated by high energy particles traversing the device, can, by their timing and their amplitude, convey information on position and on type of particle.

The 1 m test module for ISIS which has given encouraging results in use at the Rutherford Laboratory NIMROD synchrotron. In the module the drift direction is vertical rather than horizontal as foreseen in the large detector proposed for use at the SPS.



of high voltage wires which, together with electrodes along the sides of the box, give the field gradients across the box producing a drift region on each side of the central wires.

Particles can be expected to traverse the box roughly parallel to the central wire plane. The electrons liberated along a track will drift towards the central wires which act as in normal multiwire proportional chambers. Close to the wires an electron avalanche is initiated as the drifting electrons arrive and each wire records a signal, the timing of which depends on the time taken for the drift electrons to arrive. This in turn depends on the position of the charged particle track. Different particles arrive in general at slightly different times but even with several in the box at the same time, clever electronics should be able to separate them. Even with drift distances of as long as 2 m, position measurement accuracy of 2 mm or better is anticipated.

The second piece of information comes from measuring not just the time of arrival of each pulse on a central wire but also its amplitude. This is related to the number of electrons produced in the ionization of the gas and thus the ionization loss, making it possible to identify the particles as discussed above.

A technical problem is to select an appropriate gas to feed into the box. It is important that the electrons from the ionization all arrive at the wires and are not captured by the gas molecules. Also the electrons must travel cleanly under the influence of the electric field and not be bounced around by the gas molecules so that they finish on the wrong wires. A mixture of argon (which with its full atomic shells has no interest in capturing more electrons) and 20 % carbon dioxide (which 'cools' the electrons reducing their random velocity) has proved highly suitable.

A test detector based on these ISIS principles has been built. It has a 1 m wide drift space, a wire plane 30 cm by 30 cm with wires 30 μm thick located every 1.5 cm. This device was tested on the 7 GeV proton synchrotron, Nimrod, at the Rutherford Laboratory. It was shown to be possible to distinguish between pions and protons and to record track positions to better than 2 mm (information checked by a surrounding system of time-of-flight, Cherenkov and shower detectors).

One limitation of ISIS in these days of voracious data-taking is that maximum detection rates are of the order of 10^4 per second. This is because the positive ions also created in the avalanche near the central wires, amble slowly (compared with the electron velocities) towards the negative electrodes on the walls of the box and enough of them have to be out of the way before the next data is taken. There are, however, many experiments for which such a rate is ample. For example, an ISIS plus rapid cycling bubble chamber detection system is currently being studied for use at the CERN SPS.

Late news: On 17 April, the accelerator at the National Accelerator Laboratory Batavia became the first synchrotron to top 10^{13} protons per pulse. Despite comparatively low transmission efficiency of the 8 GeV booster (which was receiving 10^{14} protons from the 200 MeV linac with multiturn injection but transmitting only 16 % to the main ring) and 38 % loss in the main ring, a beam of 10^{13} protons was accelerated to 300 GeV with one pulse every 6 seconds. Even this record figure may therefore be exceeded and NAL could reach their seemingly extremely ambitious design intensity of 5×10^{13} ppp.

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- Built-in test mode.
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- Power dissipation within CAMAC limits.

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- Fast digitizing rate.
- Full LAM functions.
- Power dissipation within CAMAC limits.

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- 4 NIM overlap outputs/channel.
- Low 3 ns input-output delay.
- Double-pulse resolution < 8 ns.
- Single-width module.

Model 333
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- Bipolar operation.
- Direct-coupled.
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- Low time slewing.
- Rapid overload recovery.
- High stability.

Model 335
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- Direct-coupled.
- Delay < 2 ns.
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- Noise < 100 μV rms, referred to input.
- DC stability 0.2 mV per degree C.

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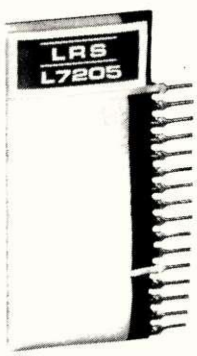

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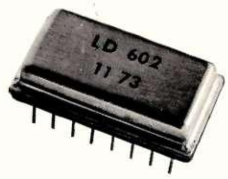

Model LD602: Drift Chamber Discriminator

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- Output variable from 5-25 ns.
- MECL or NIM level outputs.
- Time slewing 1.5 ns, 2x to 20x.
- Directly compatible with standard TDC's.

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The contact surface condition assures more uniform and homogenous protective platings thereby eliminating porosity and improving substantially the corrosion and abrasion resistance features. The contacts are gold over nickel plated. The contact is retained in the connector body, in such a way, that the stresses generated by the wiring process will not affect the required spring contact functions. This also maintains the spring contact alignment in the required tolerances.

The PCB contact terminals

The PCB connectors are available with 0.6 × 0.6 mm terminals for solderless mini-wrap or dip solder type terminations. Terminals for hand solder type termination are also available. The terminal dimensions, location and straightness are in the tolerances specified by the applied wiring processes.

The PCB connector polarization

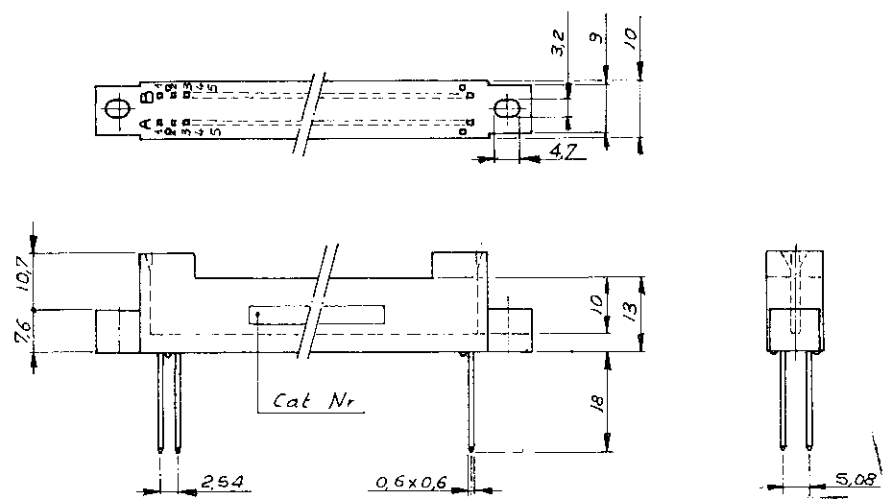
Polarization is achieved by removable plastic key located either on or between the contact positions. This allows to make full use of all contact positions.

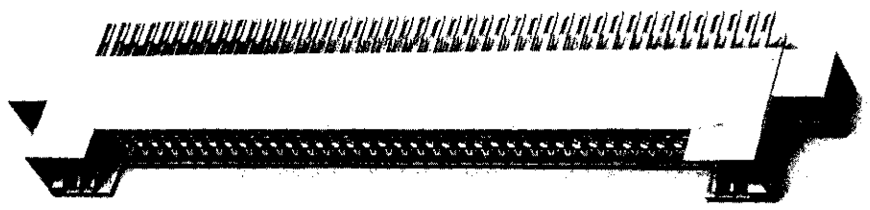
The PCB connector sizes

The BURNDY PCB connector type CAMAC is available with 43 contact positions. For specific applications, the connector size with 31 contact positions has been added.

The main BURNDY PCB connector performances

Current rating: 3A
Operating temperature: —55°C to +125°C
Operating voltage: 230 V AC, 330 V DC
Contact resistance: $< 0.007\ \Omega$
Insulation resistance: 5000 M Ω (Min)
Contact retention: > 3 kg
Contact force: > 50 gr





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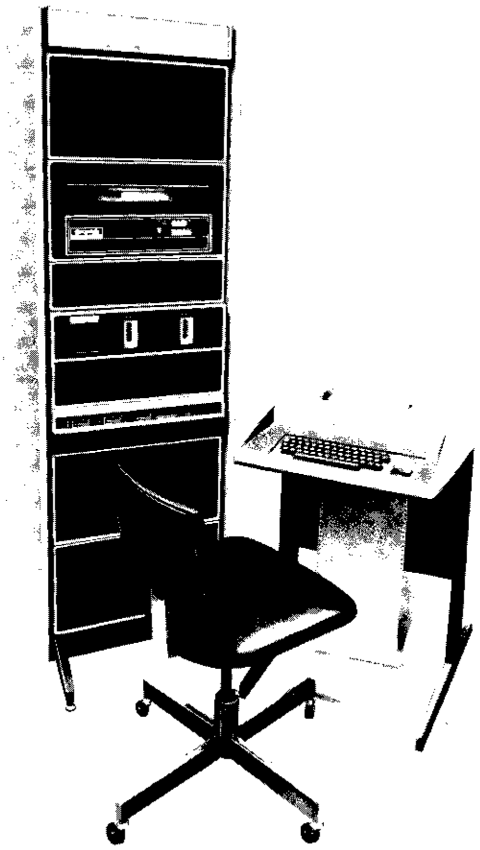
Digital Mini



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digital

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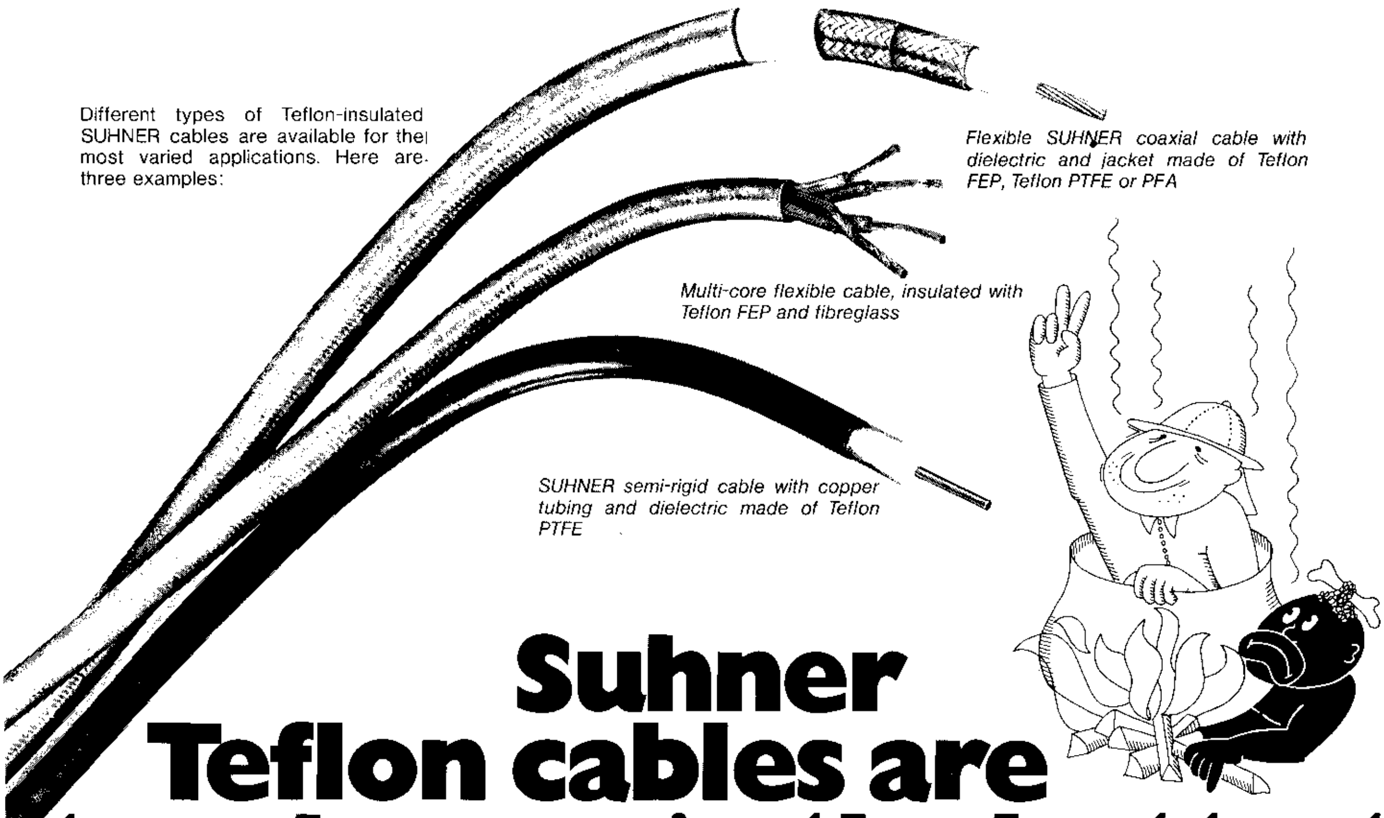

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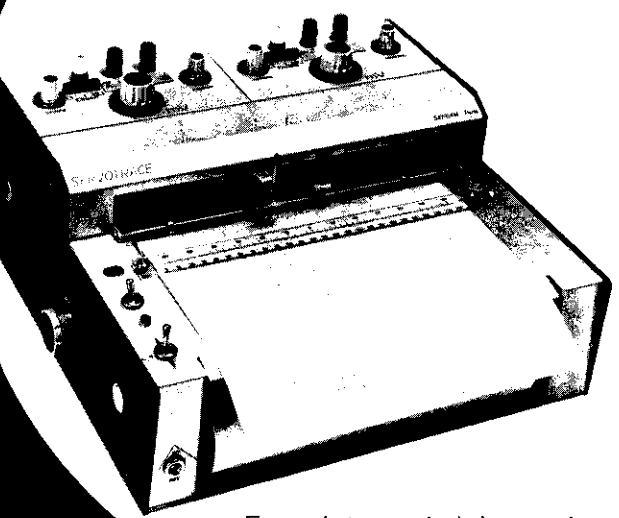

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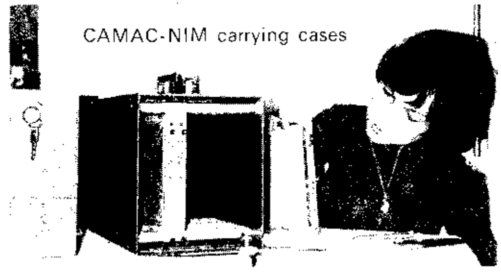

"HENESA was established in Geneva seven years ago to act as the technical liaison link between science based industry and CERN, other similar establishments, Universities, Medical Centres and Industry at large. Our Suppliers — mostly in the United Kingdom, Canada and the U.S.A. — employ over 1000 physicists, engineers and other technical staff specialized in the design and manufacture of Systems, Radiation Detection Devices and associated electronics, Compact Cyclotrons, NMR Digital Gaussmeters, Ion Beam Optical Systems, very small Reactors, Cobalt-60 Irradiators and Sterilization Systems, Cobalt-60 and other Sources including MAPLE independent Cobalt-60/electrical power generators, Cobalt Therapy Units, and biological instruments for the rapid detection of bacteria and for photometric analysis of cells.

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We would also like to highlight the availability, from stock, of our 8 and 12 Module CAMAC carrying cases (illustrated in the photograph). These are equally suitable for NIM units, they are lockable, strong and inexpensive as well as being ideal for the safe storage of instruments in the laboratory or when they have to be moved."

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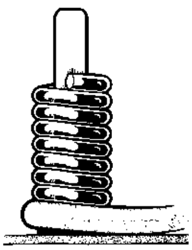

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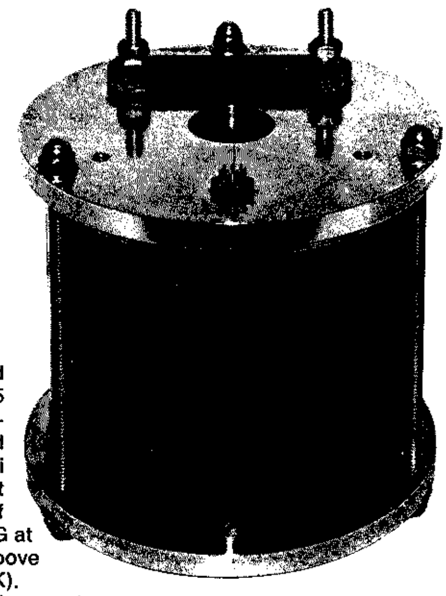

At IGC (where we build Nb_3Sn magnets to 165 kiloGauss) we are applying new techniques and building stable Nb-Ti magnets and magnet systems to fields of 88kG at 4.2K, and 110kG at temperatures slightly above the helium λ point (2.18K).

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TABLE OF PERFORMANCE SPECIFICATIONS	
Quench Field at 4.2K	88 kiloGauss
Quench Field at 2.2K	110 kiloGauss
Clear Bore Diameter	30 mm
Outer Diameter	130 mm
Length	125 mm
Operating Current at 110kG	69 Amperes
Field Homogeneity *	5×10^{-4} in a 5 mm DSV *
Time to 110kG	Under one minute
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Average Current Density in Winding Space at 110kG	25,000 A/cm²

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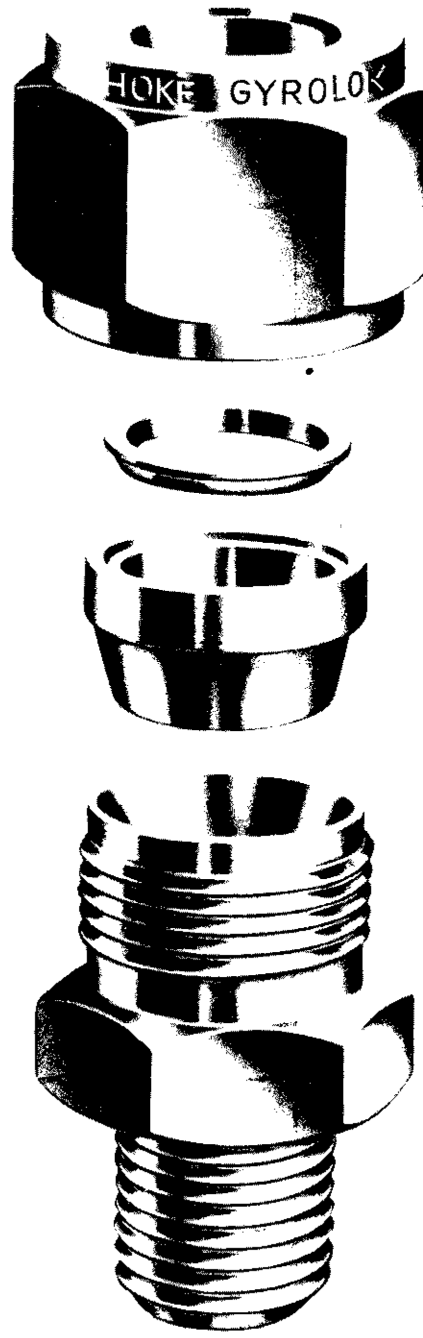

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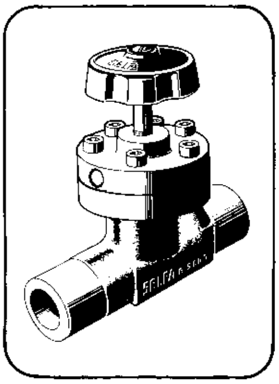

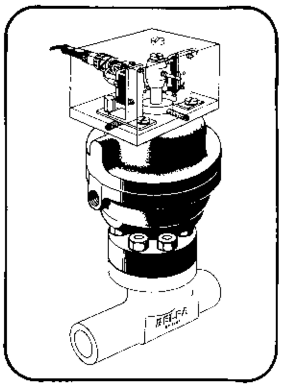

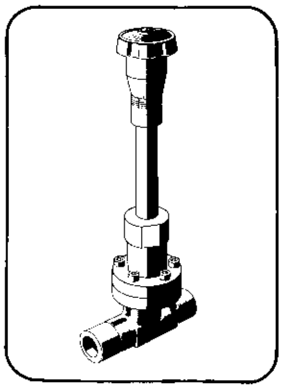

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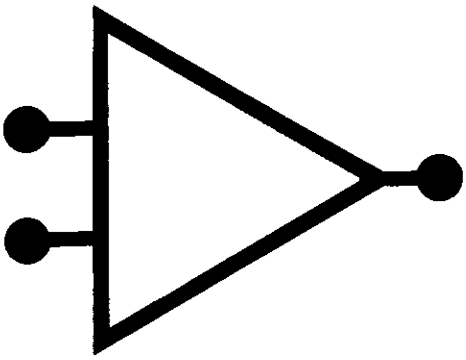

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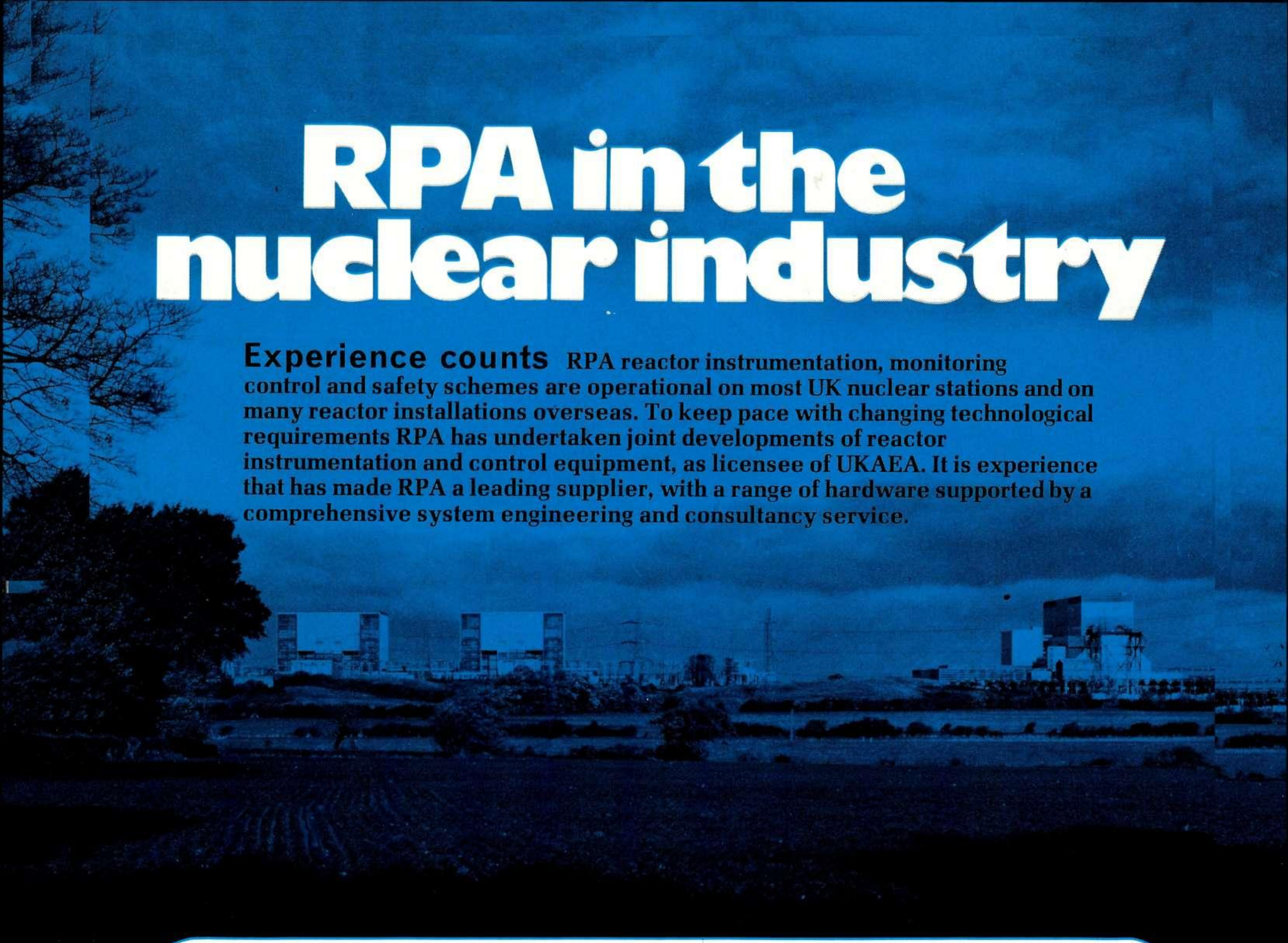

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