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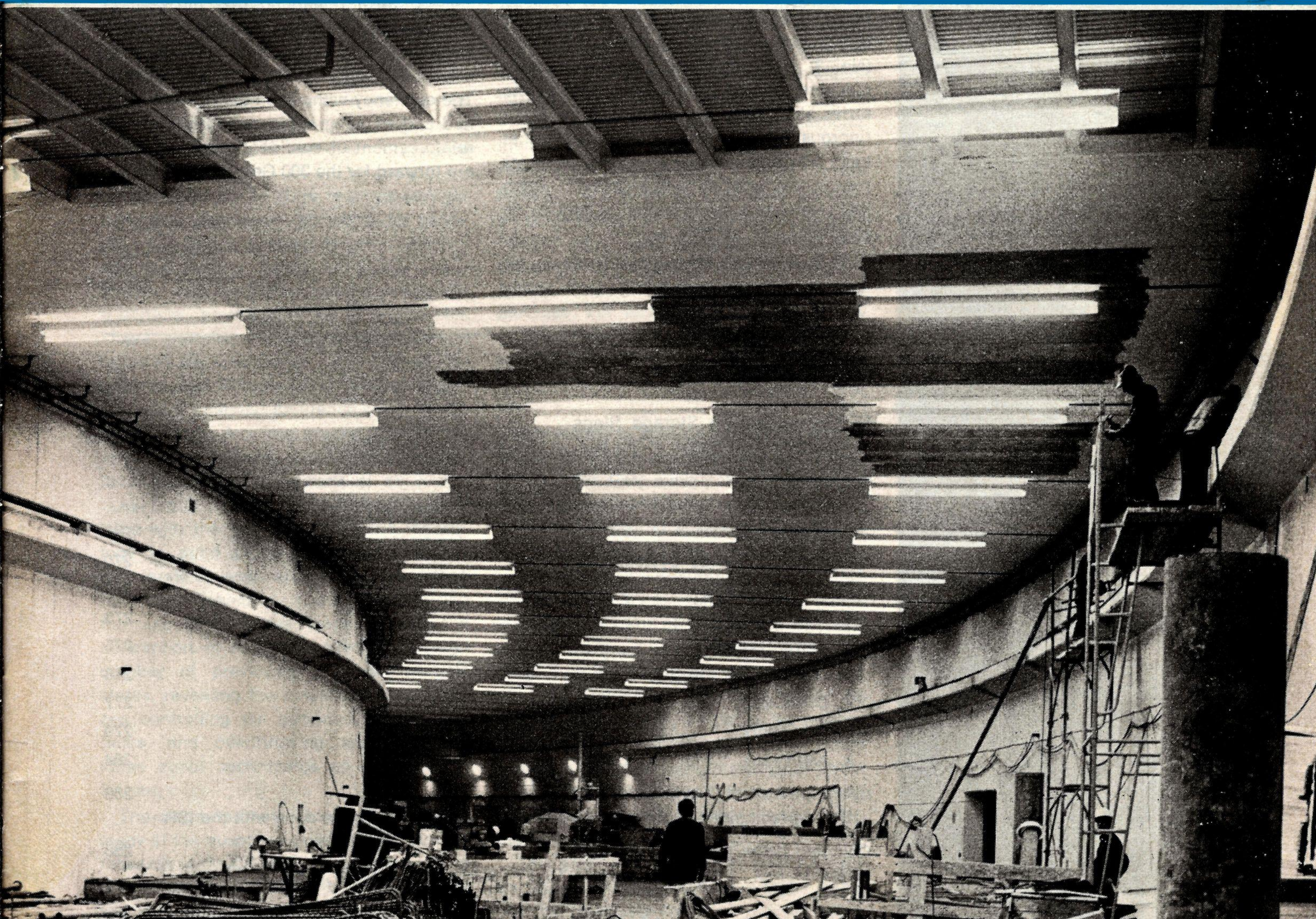

Comment

This issue is devoted exclusively to the Intersecting Storage Rings project (ISR) which was last covered in detail in CERN COURIER of July 1966. At that time the project was just getting off the ground. The first excavations had been made on the site and the groups concerned with the different aspects of the ISR were deep in model tests to finalize the design details of the various components.

Now the project is in full flight. The construction programme, which runs from the beginning of 1966 to the middle of 1971, has passed its half-way stage. The tunnel, which will house the two magnet rings, has advanced half-way round its 950 m circumference and the first octant (No. 3) is being made ready to receive machine components. These started to arrive at CERN a few months ago and the rigorous series of tests, to ensure that each unit meets its specification, is under way in the West experimental hall, which has been prepared to serve initially as an assembly and test building.

An overall idea of what the ISR involves can be obtained from the general article which opens the issue and a more detailed appreciation can be obtained from the articles describing the work of the various groups occupied with the project.

By now almost all the major contracts have been placed and it is very satisfying that the cost estimate for the project remains in line with that put forward in 1965 (332 million Swiss francs at 1965 prices) and that the construction programme is going to schedule. For such a large project, with so many novel and unique features, this is no small achievement.

It is worth remarking that the ISR, in many ways, imposes far more severe demands on accelerator technology than does the proposed 300 GeV accelerator. The efficiency with which the ISR was planned and is being implemented is a strong reinforcement of confidence in the figures put forward for the 300 GeV machine.

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Cover photograph : Inside the ISR ring tunnel ; Octant 3 is being made ready to receive the components of the magnet rings. Installation is scheduled to begin by the end of the year. (CERN/PI 113.11.68)

CERN, the European Organization for Nuclear Research, was established in 1954 to '... provide for collaboration among European States in nuclear research of a pure scientifice 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. CERN is one of the world's leading Laboratories in this field.

The experimental programme is based on the use of two proton accelerators — a 600 MeV synchro-cyclotron (SC) and a 28 GeV synchrotron (PS). At the latter machine, large intersecting storage rings (ISR), for experiments with colliding proton beams, are under construction. Scientists from many European Universities, as well as from CERN itself, take part in the experiments and it is estimated that some 700 physicists outside CERN are provided with their research material in this way.

The Laboratory is situated at Meyrin near Geneva in Switzerland. The site covers approximately 80 hectares equally divided on either side of the frontier between France and Switzerland. The staff totals about 2600 people and, in addition, there are over 400 Fellows and Visiting Scientists.

Thirteen European countries participate in the work of CERN, contributing to the cost of the basic programme, 197,5 million Swiss francs in 1968, in proportion to their net national income. Supplementary programmes cover the construction of the ISR and studies for a proposed 300 GeV proton synchrotron.

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Editor : Brian Southworth
Assistant Editor : Philippe d'Agraives
Advertisements : Micheline Falciola
Photographs : Gérard Bertin

Public Information Office
CERN, 1211 Geneva 23, Switzerland
Tel. (022) 41 98 11 Telex 2 36 98

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CERN Intersecting Storage Rings

A general article on the purpose of the ISR and on the major technical features of the project. Although most of this information has been covered in CERN COURIER before, particularly in July 1966, it is repeated here to refresh memories and for the benefit of the many new readers.

K. Johnsen

The research at CERN is part of what might be considered as the third generation of the scientific attack on the nature of matter. It follows on from the understanding of the nature of the atom and from the understanding (still only partial) of the nucleus at the heart of the atom. Now most effort is being concentrated on the understanding of the individual particles which go, for example, to make the nucleus.

The research has moved progressively to the examination of matter on a smaller and smaller scale — from the atom with dimensions of 10^{-8} cm (a hundredth of a millionth of a centimetre), to the nucleus of 10^{-12} cm (ten thousand times smaller) to the particle of about 10^{-13} (ten times smaller still). To look at phenomena of these progressively smaller dimensions has, paradoxically, called for larger and larger resources ; in particular larger and larger accelerators.

To break into an atom requires very little energy (atoms are 'smashed' for example every time a match is struck). To break into the nucleus needs an energy many millions of times greater, and to break into a particle, thousands of times greater still. These energies are usually expressed in terms of the electronvolt (eV) — the energy given to the electron which is accelerated through a potential difference of 1 volt. To smash atoms requires several tens of eV, nuclei many millions of eV (MeV) and particles thousands of millions of eV (GeV).

As higher energies have become available with the development of the technology to build higher and higher energy accelerators, new worlds of phenomena have been revealed. The research using the accelerators has revolutionized the conception of matter, uncovering a large number of previously unknown particle states, revealing the existence of new forces controlling the behaviour of the particles, and overthrowing some intuitive ideas about such things as symmetry in Nature.

The stage has now been reached where many of the questions posed by the current research call for still higher energies to attempt to answer them. It is for this reason that the construction of more powerful machines is beginning or is planned. The present major proton synchrotrons — 28 GeV at CERN, 33 GeV at Brookhaven (USA) and the recently completed 75 GeV at Serpukhov (USSR) — will be surpassed by the 200-400 GeV machine at Batavia (USA) and the proposed 300 GeV machine in Europe.

Colliding beams

It has been realized for many years that it would be possible to obtain a glimpse into a much higher energy region if particle beams could be persuaded to collide head-on.

To explain why this is so, we need to consider what happens in a conventional accelerator experiment. When particles have the required energy they are directed onto a target and collide with the stationary particles of the target. Most of the energy given to the accelerated particles then goes into keeping the particles which result from the collision moving in the direction of the incident particles (to conserve momentum). Only a quite modest fraction is 'useful energy' for the real purpose of the experiment — the transformation of particles, the creation of new particles. For example, at the full energy of the CERN 28 GeV synchrotron about 7 GeV is useful energy. (An approximate formula for determining the useful energy is :

Useful energy $= \sqrt{\text{Twice accelerator energy}}$ where the energies are expressed in GeV. Thus a 300 GeV machine gives about 24 GeV of useful energy.)

But if particles of the same energy were made to collide head-on, all their energy would be useful since none would be needed to conserve momentum, to keep things moving in a particular direction. The fascination of the CERN intersecting storage rings then lies in the prospect of colliding 28 GeV protons head-on and having 56 GeV of useful energy available. To achieve this with a conventional accelerator would require a machine with an energy of about 1700 GeV which is possibly beyond existing technology and certainly beyond existing financial resources.

This great leap forward in useful energy by using colliding beams has to be qualified by repeating that they will provide a glimpse into a much higher energy region rather than a broad look. The conventional accelerator is a prolific source of many types of particle and it can be used to investigate interactions involving protons, antiprotons, kaons, pions, neutrinos... With colliding beams the interaction is limited to that of the beam particles — for the CERN ISR this means the proton-proton interaction.

The Intersecting Storage Rings

In December 1965, the CERN Council approved the construction of intersecting storage rings ; France had already made available a piece of land across the border from Switzerland to build the ISR. What follows is a general description of the technical features of the machine. (More detailed descriptions of the component parts begin on page 267.)

The ISR consist of two concentric rings of magnets, 300 m in diameter, in which protons travel in opposite directions. The rings are built in a circular underground tunnel some 200 m away from the 28 GeV proton synchrotron. The two rings are not exactly circular but are interlaced so that they intersect at eight points, called interaction regions, where the beams can be brought into collision. A schematic representation of the configuration and of the beam paths can be seen in the Figure and the main parameters of the rings are given in the Table.

Protons are accelerated to the required energy (which can be between 8 and 28 GeV) in the PS. They are then ejected by a fast-ejection system into a transfer channel in which a magnet system guides them towards the ISR. This channel forks into two and, depending on whether a bending magnet at the fork is switched on or not, the protons go left or right to enter one or the other of the rings. The left and right channels then have to climb up-hill because the beam level in the ISR is about 12 m higher than in the PS. The protons are injected into a ring by a fast-injection system, so that they initially travel close to the inside wall of the ring vacuum chamber.

If simply one pulse was taken from the PS, containing say 10^{12} protons, and fed into one ring and another similar pulse was fed into the other ring orbiting in the opposite direction, the number of collisions per second which would take place

Main Parameters of the ISR

Number of rings	2
Circumference of rings	942.66 m
Number of intersections	8
Length of long straight section	16.8 m
Intersection angle at crossing points	14.7885°
Maximum energy of each beam	28 GeV
Magnet (one ring)	
Maximum field at equilibrium orbit	12 kG
Maximum current to magnet coils	3750 A
Maximum power dissipation	7.04 MW
Number of magnet periods	48
Number of superperiods	4
Total weight of steel	5000 ton
Total weight of copper	560 ton
R.F. system (one ring)	
Number of r.f. cavities	6
Harmonic number	30
Centre frequency of r.f.	9.53 MHz
Maximum peak r.f. voltage per turn	20 kV
Vacuum System	
Vacuum chamber material	low carbon stainless steel
Vacuum chamber inside dimensions	160 x 52 mm^2
Design pressure outside intersection regions	10^{-9} torr
Design pressure inside intersection regions	10^{-10} to 10^{-11} torr

when the beams met in the interaction regions would be unacceptably small. Experimenters using the beams produced by the PS are used to a hundred thousand collisions per second taking place, say, in a hydrogen target. The ISR has been designed to achieve a similar figure when the beams collide.

To do this, it is necessary to increase the intensity of the two orbiting beams so that they each contain 4 x 10^{14} protons, which is equivalent to a circulating current in each ring of about 20 A. It is achieved by stacking many successive pulses from the PS next to one another.

For this purpose a radio frequency system is needed. After the first pulse has been injected, this r.f. system accelerates the protons just enough to move the particles from their injection orbit to an orbit nearer the outside of the vacuum chamber. When this acceleration has been done the injection orbit is free to receive the next pulse, which, in its turn, is accelerated and moved to an orbit only a fraction of a millimetre from where the first pulse was left. This stacking process can be repeated again and again, in fact about 400 times in each ring, creating a stacked beam about 70 mm wide with the intensities mentioned above. (Variants of the stacking procedure are covered later.) With 400 pulses stacked there will be a momentum spread of 2% across the beam.

The time taken to stack each ring to such an intensity, with the present performance figures of the PS, would be less than an hour and when the improvements programme at the synchrotron is complete, this may fall to as low as five minutes. The protons can circulate in the rings and colliding beam experiments can be carried out for as long as a day before calling on the PS again for a refill.

Special requirements

Most of the major problems in constructing the ISR arise because of the need to build up intense proton beams and to keep them orbiting in their rings for many hours. The conditions which must be established are very different from the conventional accelerator where the beam is in and out of the machine in the order of a second.

The r.f. system is not required to produce unusually high accelerating voltages but has to be capable of carefully controlled voltage variations from 20 kV at injection to tens of volts at the end of the stacking process. The magnet system has to provide a very precise field configuration to guide and focus the beams and has to incorporate a full range of correction possibilities to cope with any deviations from the ideal in the beam paths. The main magnets have also to provide 'good field' across the full vacuum vessel aperture (over 150 mm horizontally) up to a field strength of 12 kG on the equilibrium orbit. The lay out of the two magnet rings where they pass between interaction regions 3 and 4 can be seen in Figure 2.

The demands placed on the vacuum system are particularly severe. If beams are to be retained in the rings for many millions of turns without serious loss in intensity, not only must the magnet guide fields keep them well under control, but also the number of residual gas molecules that the beams meet must be very small to avoid scattering protons out of the beams. In the conventional accelerator, pressures around 10^{-6} torr are adequate ; in the ISR this has to be pushed down to 10^{-9} torr (a pressure feasible only in small laboratory-bench set-ups just a few years ago). Taking the two rings together it involves holding a vacuum vessel of a total length of almost 2 km, with thousands of joints, at ultra-high vacuum. This is by far the biggest ultra-high vacuum system in the world.

Even with this low pressure the scattering caused by the residual gas molecules in the vacuum chamber will make the beams 'blow up' significantly in size over twenty hours and to cater for this, in addition to deviations which could be introduced by imperfections in the magnetic field, the vacuum vessel aperture is set at 160 mm horizontally and 52 mm vertically.

Another indication that the stability of the intense beams is fragile is that 'clearing electrodes' have to be installed to sweep away the electrons liberated when the beams ionize the residual gas. These electrons would tend to neutralize the positive charge in the beams and thus upset the delicate balance between the defocusing electric force acting within the beams and the focusing magnetic force that the fast moving charges set up. Without these clearing electrodes only half the planned beam intensity could be stored. Other possible sources of instability have been studied theoretically and some were investigated experimentally using the electron storage ring model CESAR (CERN COURIER vol. 7, page 247) which contributed a great deal to the ISR project, and also using the PS. They are not expected to be troublesome.

Interaction regions

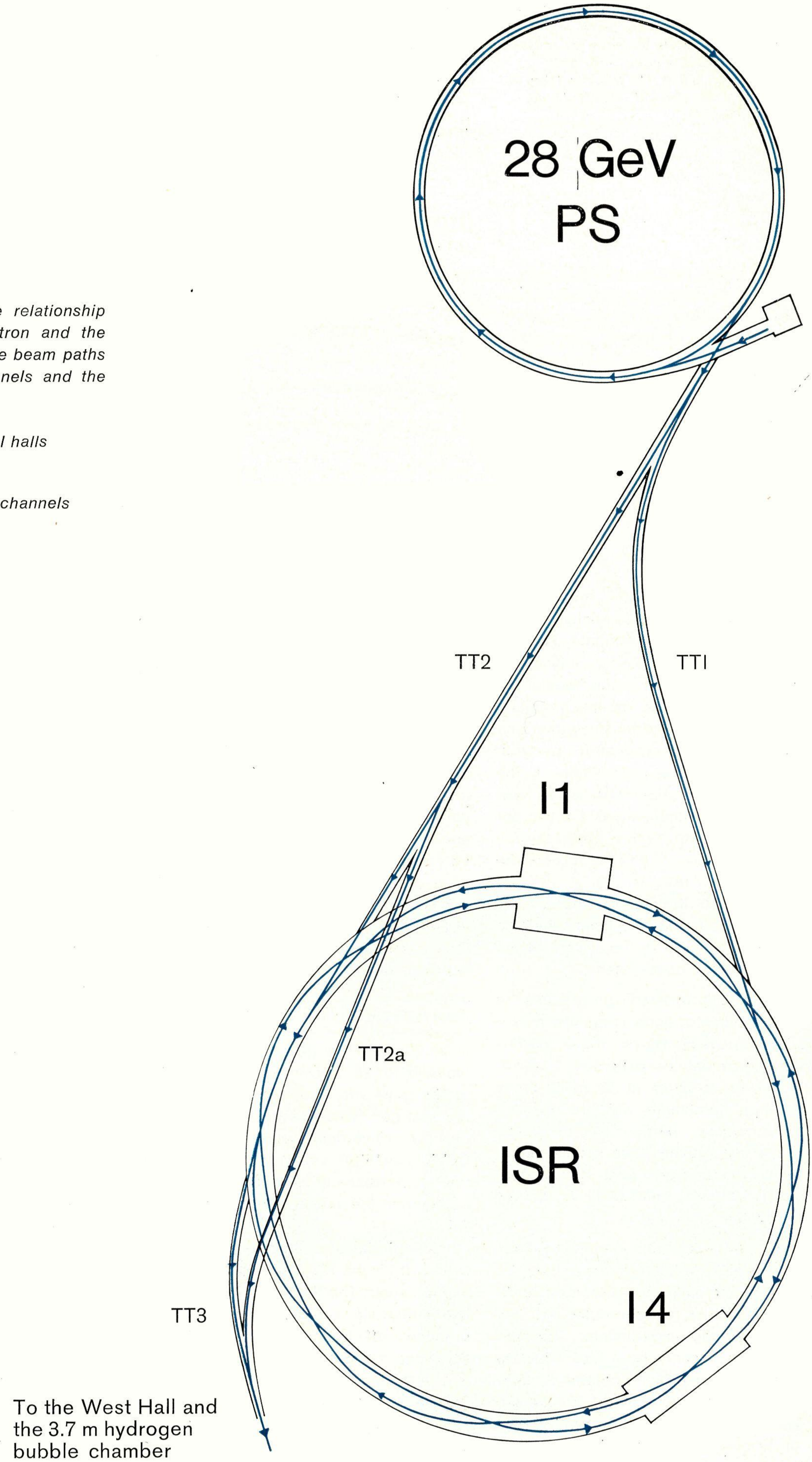
As mentioned above, the beams can be brought into collision at eight places around the rings. Initially two of these places, numbered 1 and 4, will be equipped with experimental halls.

When the currents of 20 A circulating in each ring have been built up, each beam looks like a ribbon 70 mm wide and 10 mm high. The ring structure is such that they cross at an angle of 15° and thus form a volume of about 200 cm^3 in which collisions take place.

A schematic diagram of the relationship between the proton synchrotron and the intersecting storage rings. The beam paths in the PS, the transfer channels and the ISR are shown in blue.

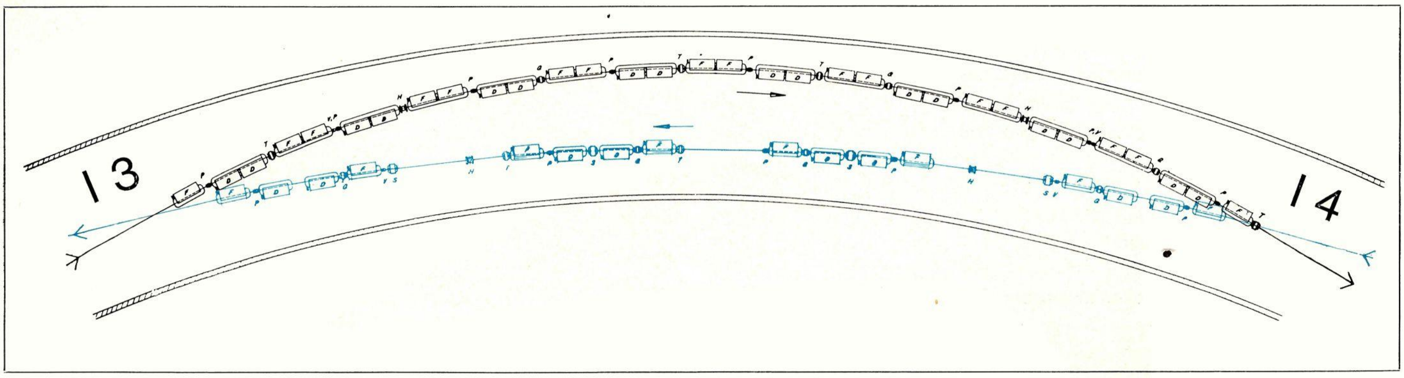
I1 and I4 are the experimental halls which are to be built initially

TT1 to TT3 are beam transfer channels



Lay-out of the two magnet rings between interaction regions I3 and I4. Notice that the outer arc, where most bending has to take place, is packed with magnet, while the inner arc is less congested. It is therefore in the inner arcs that beams are brought in. The two arcs taken in sequence form a 'superperiod', repeated four times around the ring.

The various components are :
F Focusing magnet
D Defocusing magnet
P Pick-up station
V Sector valve
T Terwilliger quadrupole
Q Skew quadrupole
S Sextupole
H Horizontal field magnet



The interaction rate within this volume is proportional to the cross-section of the process one wants to investigate. For this proportionality factor the term 'luminosity' is used among colliding beam specialists. The luminosity depends on the geometry of the beams in the interaction region and is proportional to the product of the circulating currents in the two beams. In the ISR, with the beam characteristics as described above, the luminosity is 4 x 10^{30} per second and per cm^2. With a proton-proton total cross-section of 4 x 10^{-26} cm^2 the total interaction rate is 1.6 x 10^5 per second. Through its dependence on the stacked beam currents, the luminosity also becomes proportional to the square of the momentum spread of the beams.

When the improvement programme of the proton synchrotron is complete, considerable improvements on these performance figures can be expected. Luminosities may be as much as 70 to 80 times higher than obtainable with the present PS performance, particularly in cases where the experiments have special requirements for low momentum spread that otherwise limit the luminosity to values well below that given above.

During 1967, some new interesting ideas emerged which indicate that it may be possible to increase the performance figures still further, in particular for low momentum-spread experiments. The method consists essentially in not injecting a whole PS pulse (which contains 20 bunches of protons) into the ISR in one go, but in injecting two halves of a pulse (two lots of 10 bunches) separately and with a short and properly chosen interval so that the two halves are superimposed in the injection orbit of the ISR. This is equivalent to a two-turn injection and to a corresponding increase by a factor of two in the local beam intensity. It is then possible to stack this superimposed shorter pulse in such a way that the final stack density goes up by the same factor two.

The method can in principle be extended to the equivalent of four-turn injection, but then it will be preferable to do part of the acrobatics between the new PS injector and the synchrotron. The methods proposed require solutions to very difficult technical problems, but there is nevertheless considerably hope that it will be possible, in the future, to take advantage of some of their potentialities and thus gain a further improvement in the luminosity figures.

West Hall and Bubble Chamber

In conjunction with the ISR proper, further facilities for 28 GeV physics are being built on the same site, particularly a large experimental hall (West Hall) and beyond it the new 3.7 m hydrogen bubble chamber (see CERN COURIER vol. 7, page 143). Their relative positions in relation to the ISR can be seen on the site lay-out drawing on page 282.

The hall almost doubles the area fed by beams from the PS which is available for experiments. The beams can reach the hall either via a transfer channel, which branches off from one of the channels supplying the ISR travelling under the ISR and surfacing in a 'switchyard' in front of the hall, or can come from one of the storage rings. The first possibility ensures that experiments can continue in the hall regardless of whether the ISR is in operation or not. The second possibility gives great flexibility in the sort of beam supplied to an experiment — after using the storage capability of the storage ring the experiment could receive an extremely intense beam in one burst or could receive a less intense beam spilled out continuously over a long period of time.

Programme

The construction programme began at the beginning of 1966. The major excavation work is complete and the tunnel to house the rings is built half way around its circumference.

The large West Hall has been finished as planned and is receiving ISR components, which began to arrive on the site a few months ago, for assembly and testing. By now, magnet components are arriving regularly and several complete units have been put together. About half the radio-frequency cavities are here as well as power supplies for the amplifiers. The deliveries of the sputter ion pumps for the vacuum pumps have also started.

One octant of the ISR tunnel will be handed over for the installation of the magnets etc. by the end of the year. There is every expectation that the project will be completed on schedule in the middle of 1971.

Meanwhile the experimentalists are beginning to work out detailed proposals for experiments. The experiments, like the project itself, confront novel problems and will in general need longer to prepare than those at a conventional accelerator. As the day approaches when 56 GeV of useful energy will be available, the interest in using this unique facility is growing throughout Europe.

Component parts

1. Magnet System

L. Resegotti

The magnet system of the ISR guides the high energy protons along the orbits which they have to follow inside the vacuum chamber of the machine so that they may continue to circulate for many hours and have a sufficient probability of colliding with each other at the crossing points. Since the protons are moving at almost the speed of light, they accomplish many milliards of revolutions around the machine, during this time.

The smallest irregularity in the magnetic field distribution may badly perturb the trajectories of the protons, which meet it milliards of times, and the field in the main magnets has therefore to be tailored to the required pattern to very high accuracy and must be extremely stable. In addition, a number of auxiliary magnets and correcting elements have to be added in order to be able to apply corrections for any deviations, or unwanted behaviour of the proton beam, which are observed.

When the ISR magnet system was designed, interest was growing in the possibility of using superconducting magnets and a system based on superconductors was considered. However, no such magnet had been built for beam handling purposes and superconducting coils were encountering serious instability problems. It was also unknown whether the precise field distributions required by the ISR could be obtained using superconducting magnets. (This is still true today.)

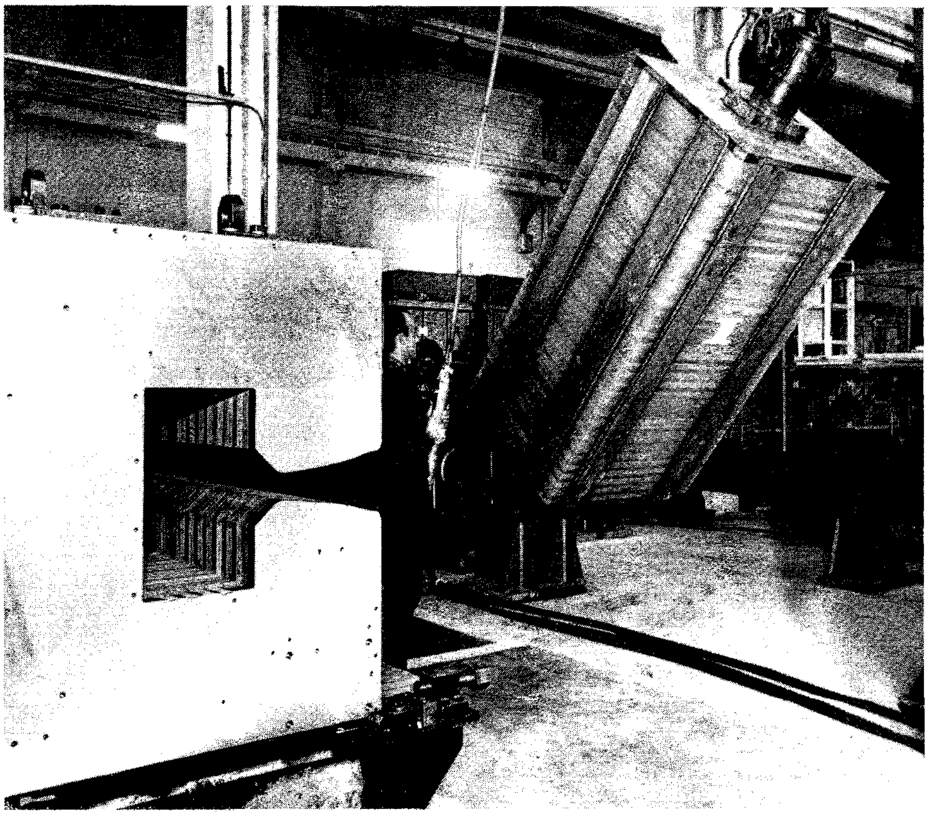
Conventional steel-cored magnets were therefore adopted. It was also decided that the main magnets would have C-shaped cores with excitation coils around the two poles like the magnets in the PS, but with all gaps widening on the side opposite to the yoke to give maximum access to the vacuum chamber for detection and suppression of leaks. The only basic difference with respect to the magnets of the PS is the non-linear distribution of magnetic field radially across the gap, which required the development of computer programs for the design of the profiles.

There are two types of magnet core, called F and D depending on whether they focus or defocus the protons in the radial direction. The cores are made out of stacks of precision punched laminations, held together by welded tension straps. All cores are 2.44 m long, but some of the magnet units are made by assembling two cores together on one girder and with one set of coils : these are called 'long units' and are located in the outer arcs of the machine, where the trajectories of the protons have maximum curvature. In each ring there will be 72 short units (40 F, 32 D) and 60 long units (28 F, 32 D). Each unit is supported by three screw-jacks, which make it possible to adjust its position to the required accuracy of a tenth of a millimeter.

In order to correct for orbit distortions, so that the proton beams can be centred in the vacuum chamber in the best possible way, small vertical and radial magnetic fields can be added in some of the magnet units, suitably distributed around the circumference. The vertical fields will be set up by powering auxiliary windings, which have the form of thin flat spirals of wire, placed between the main coils, the radial fields will be set-up by slightly lifting or lowering the units by means of their screw jacks. For this purpose, some of the jacks are driven by motors, which can be remotely controlled from the main control room of the ISR.

The strength of the restoring forces, which retain the protons near their ideal trajectory has to be adjusted in order to reduce the amplitude of the oscillations of the protons. It is especially important to avoid the number of oscillations per revolution being such that the effect of perturbing forces is amplified by their periodic repetition or, in other words, to avoid resonances between the forces and the oscillations of the protons. A fine adjustment of the focusing forces will be obtained by sending currents into twelve sets of wires stretched on each magnet, which can all be supplied with different currents. The wires are moulded together inside an insulating shell which fits onto the magnet pole and the assembly is called a pole-face winding. The currents are different in the pole-face windings on focusing and defocusing magnet units, so that 24 adjustments are possible in each ring. The pole-face windings also make it possible to compensate for changes of field distribution due to the variable permeability of the steel.

The effect of the restoring forces on a proton depends on the proton energy.



1.

1. A core being lowered after welding. The cores are stacked in a vertical frame and the tension straps welded in the same frame while the stack is under pressure. After welding, the frame is moved and the core is then lowered into the horizontal position for final machining of the end plates. A finished block can be seen on the left. (Photo ASGEN)

2. *A long magnet unit being lowered on to the transport lorry by means of a special harness. A complete long unit weighs about 53 tons and is assembled with a high degree of accuracy ; its transport into the ISR tunnel must therefore be done with great care. The lorry, which was specially built for this purpose, is equipped with hydraulic traction and a hydraulically controlled platform to keep the magnet horizontal, irrespective of the movements of the lorry.*

3. *The measuring stand for long units. Two precision-ground diabase benches, carrying the measuring coils, are carefully aligned to the angle of the two cores in the long unit. Both F- and D-units, which are bent in opposite directions, can be measured on this stand, using the alternative sides of the bench.*

CERN/PI 106.7.68 4.

Since protons with different energies will circulate at different radial positions inside the vacuum chamber, it is possible to adjust the restoring forces to fit their different energies by means of special magnets, called 'sextupole lenses'. There will be 32 of these sextupole lenses in the ISR.

Another effect to be avoided is the coupling of radial and vertical oscillations, which would cause protons oscillating in the horizontal plane around their ideal trajectory to go over progressively to perform the same oscillations in the vertical plane. Special magnetic lenses, called 'skew quadrupoles' will do this trick. There will be 56 of them.

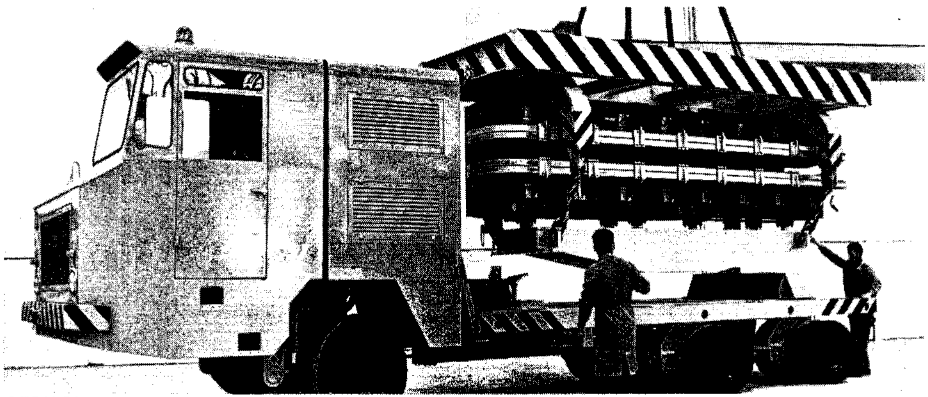
Finally, two different sets of magnets have been added to serve the special requirements of experimentation with colliding beams. 40 'radial field magnets' can steer the two circulating beams at each crossing point independently, so that at any particular time they collide or not, according to the requirement of the experiment set up around that point. 48 'Terwilliger quadrupoles' make it possible to guide protons of different energies along the same trajectories through four of the crossing points, thus reducing the cross-section of the beams at those points.

Technological developments were needed in order to cope with some of the specific problems of the ISR magnet and to ensure economy and speed in construction (to meet the construction programme the magnets have to be produced at about twice the rate required for the PS). Success in preliminary tests carried out in collaboration with industrial firms on the economical production of decarburized steel sheet to tight geometrical and magnetic specifications, on precision stacking and welding of laminations, and on the use of radiation resistant resins for coil insulation was reported in CERN COURIER vol. 6, page 130 : the results have now been confirmed in large-scale production. Another successful development has been the fabrication of high-current water-cooled cables for the interconnection of the magnet units. The complicated geometry of the machine and the need to keep the crossing regions clear for experimentation makes the path of the interconnections so tortuous that water-cooled bus-bars would have been very difficult to install and about twice as expensive.

Interesting problems also appeared in the design of the auxiliary magnets. Since all these elements are short, their end effects are far from negligible and the pole profiles had to be substantially modified to take them into account. Satisfactory results were obtained by applying alternatively bi-dimensional and tri-dimensional field computations to an existing model. An extra difficulty was found with the sextupole lenses, which were given an elliptical aperture to fit closely around the vacuum chamber. The overall dimensions and the power consumption were thus minimized, but the typical six-fold symmetry was lost. Eventually, after computations and mesurements, magnetic screens have been designed to shape their end-fields conveniently.

The parameters and design features of the main magnets were fixed by mid-1966. By that time, the construction of two models had proved that the design goals could be achieved and that industry was widely interested in the project. In August 1966, a specification of the steel sheet was sent to rolling mills for qualification tests and ten steelmakers submitted satisfactory samples. Tenders for the manufacture of the magnet cores were then invited.

During 1967, while the design of all other components was being finalized and the corresponding invitations to tender were being issued, the negotiation of major contracts began. In July 1967, the order for the supply of 400 steel cores was awarded to ASGEN (Italy) with the agreement that the



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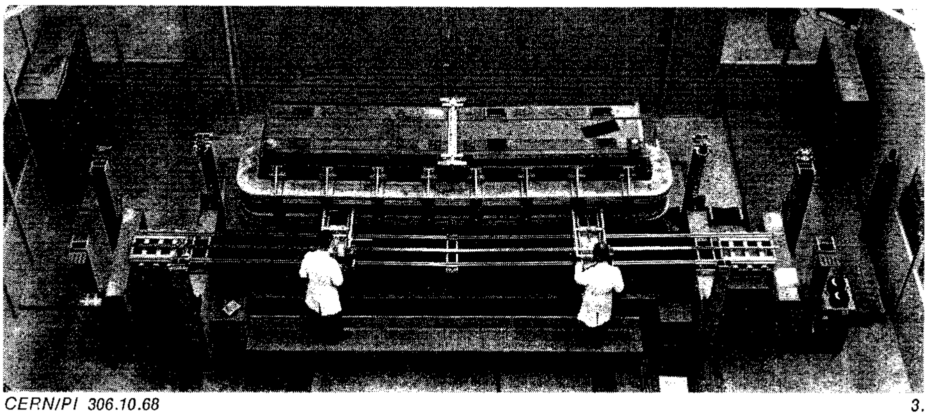
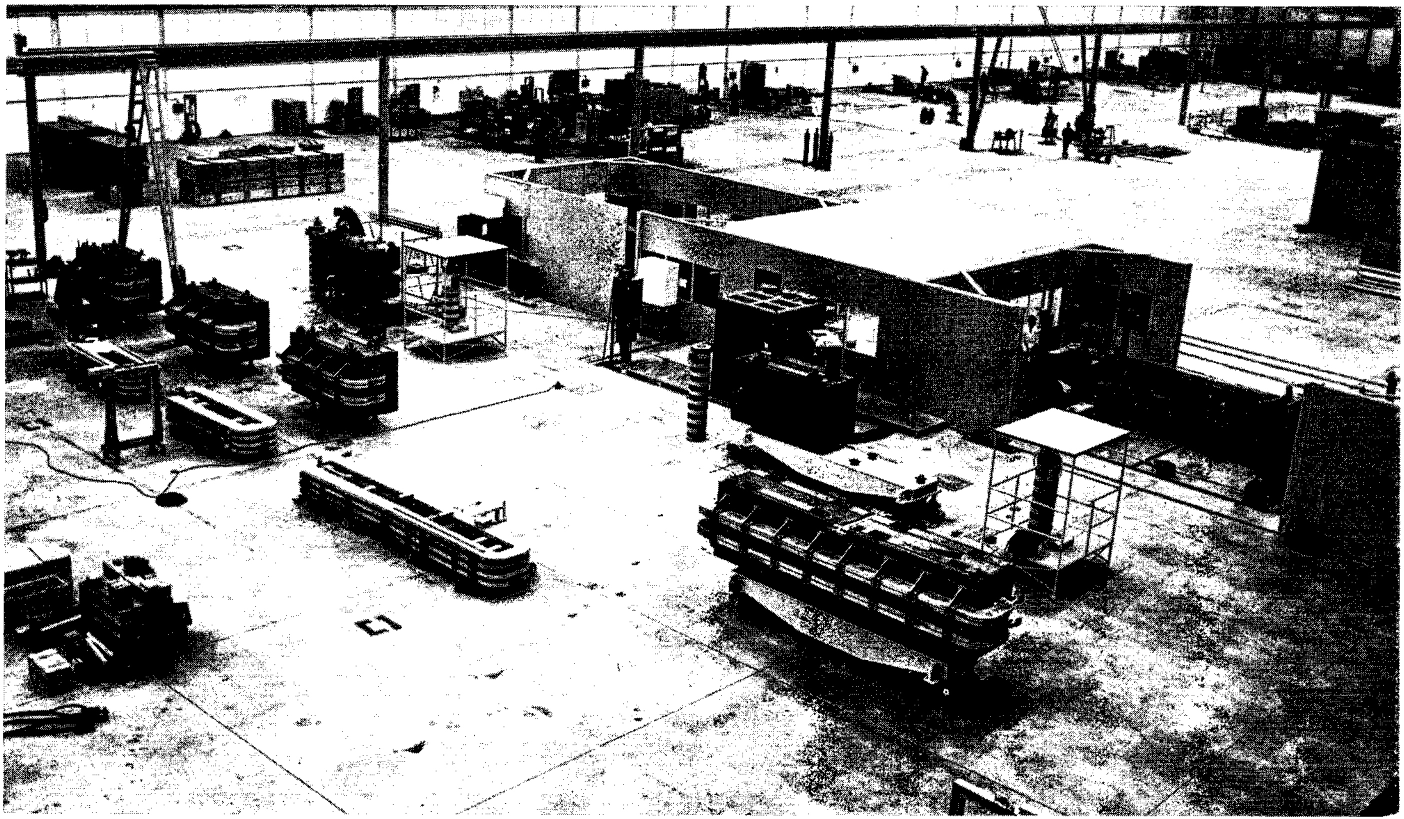


CERN/PI 306.10.68 3.

4. A cross-section of the water-cooled cable which will be used for connecting the magnet units. The cooling water is circulated in the central copper tube which has a 16 mm bore and a 1 mm wall thickness ; the cross-section of the standard conductor is 900 mm². The white core insulation and black sheath insulation are made from special radiation-resistant polyethylene. The minimum bending radius of this cable is 600 mm. It is probable that this type of cable, developed for the ISR, will find applications in many other fields.

5. The assembly and measuring area for the magnet units. At the back, are the magnetic measurement bays for short units (left) and long units (right), with the data reduction room in the centre. In front of the bays is the assembly line where units are built up from cores and girders and aligned between four alignment posts. In the foreground, the coils are being mounted on the units ; three completely assembled short units and one long unit are ready for the magnetic measurements.



CERN/PI 280.10.68

5.

10 800 tons of steel sheet would be produced by Italsider (Italy). In October, the contract for the supply of 1 100 excitation coils for the main magnet, containing 1 150 tons of copper bar was signed with Alsthom (France) and before the end of the year, the 800 pole-face windings and the 124 girders for the long units were ordered from two firms in the Federal Republic of Germany, respectively B.B.C. and Donges.

In the first months of 1968, it was agreed that 870 jacks would be manufactured by C.P.T. (UK) ; 15 km of 900 mm² water-cooled cables by Kabelmetal (Federal Republic of Germany) ; 4 km of cable ducts by Anton Klein (Federal Republic of Germany). The radial field magnets will be supplied by Siemens (Federal Republic of Germany); the sextupoles and the skew quadrupoles by Smit Slikkerveer (Netherlands) ; the Terwilliger quadrupoles by M.F.O. (Switzerland). Other firms who have received substantial orders for the supply of auxiliary magnet components are : Aluminium AG, Switzerland (15 800 aluminium magnet castings for coil supports) ; Jean Gallay, Switzerland (800 heat shields for pole-face windings) ; Progress-Werk, Federal Republic of Germany (279 protections for magnet coils).

In July 1968, the magnet group staff moved onto the ISR site to assemble and test components as they arrived. All components are delivered directly to the West Hall, where they are stored in a pre-established order : more than 50 000 components (not counting nuts and bolts) will be received. The assembly line includes two stands for the alignment of the cores and six stands for mounting the coils, the pole-face windings, the protections and other accessories.

Two measuring stations have been prepared for short and long units respectively: each is equipped with a precision bench made of black diabase, which supports and locates the measuring carriages, and with a set of telescopes to align the unit with respect to the bench. Both stations are powered by the same regulated rectifier system and controlled and monitored from a central desk. Output signals are processed by a small on-line computer and the results are immediately available in the form of printed tables of fields, gradients, errors, equivalent lengths, etc. This equipment is in operation and systematic measurements have started. Separate measuring stands are being set up for auxiliary magnets and lenses.

By the end of October, all 10 800 tons of steel sheet had been produced and a technician of the magnet group had measured at the Italsider plant the characteristics of 50 000 toroidal samples cut from the sheets, to ensure that the sheets entering the steel store were within magnetic specification. At ASGEN, 20 cores had been produced and 10 delivered to CERN. Alsthom had 100 coils on the production line and 32 were delivered to CERN ; Brown, Boveri had delivered 8 pole-face windings and Donges 12 girders. Delivery of other components for the main units had started accordingly, so that two complete units had been assembled and measured. Production prototypes of the water-cooled cables had brilliantly withstood the most severe tests at Kabelmetal. Installation in the ring building is expected to start in December.

2. Radio-frequency System

W. Schnell

With the present proton beam intensities available from the synchrotron, several hundred pulses have to be accumulated, or 'stacked', in order to reach the design intensity of 20 A circulating current in each storage ring. The stacking is done in 'longitudinal phase-space' which means that the particles of successively injected pulses are made to differ by a small amount of energy. This is achieved by means of the r.f. system. The bunches of particles arriving from the PS are captured at the injection orbit near the inner wall of the vacuum chamber and accelerated to the stacking orbit where they are deposited by turning off the r.f. voltage. The r.f. system then prepares to receive the next pulse and the same cycle is repeated every time a new set of particles is injected.

Two kinds of stacking schemes are possible and there will be provision for both. In the first scheme, called non-repetitive, the energy given to the protons in each pulse by the r.f. system (and hence the position in the vacuum chamber where the protons are deposited) is changed by a small amount in successive cycles so that the protons of different cycles are put side by side in the vacuum chamber of the ISR. In the second scheme, called repetitive, the newly injected particles are always deposited at the same place near the outer wall of the vacuum chamber. Particles that have been deposited earlier are automatically displaced inwards by the action of the same frequency modulated r.f. voltage that accelerates the new particles, thus making room for the newly injected pulse.

Each storage ring is equipped with six accelerating cavities. The cavities and high-power amplifiers have to cover a very large voltage range during the stacking process. Each cavity will generate a maximum of 3.5 kV and a controlled minimum of about 10 V peak r.f. voltage. Another difficulty is the strong interaction between the beam and the cavity. The latter problem is overcome by strong negative feed-back, which makes the cavity voltage virtually independent of beam loading, and by a design which carefully avoids higher-order resonances in the cavity.

The basic design of the high-power r.f. system is now complete, all components have been ordered, and production prototypes have been received and tested. At the time of writing, all power supplies for the final amplifiers, being built by Sionic S.A. (Switzerland), and half the total number of cavities, built by Jean Gallay (Switzerland), have been delivered. The series production of the power amplifiers is in progress at Zehnder Maschinenbau (Switzerland).

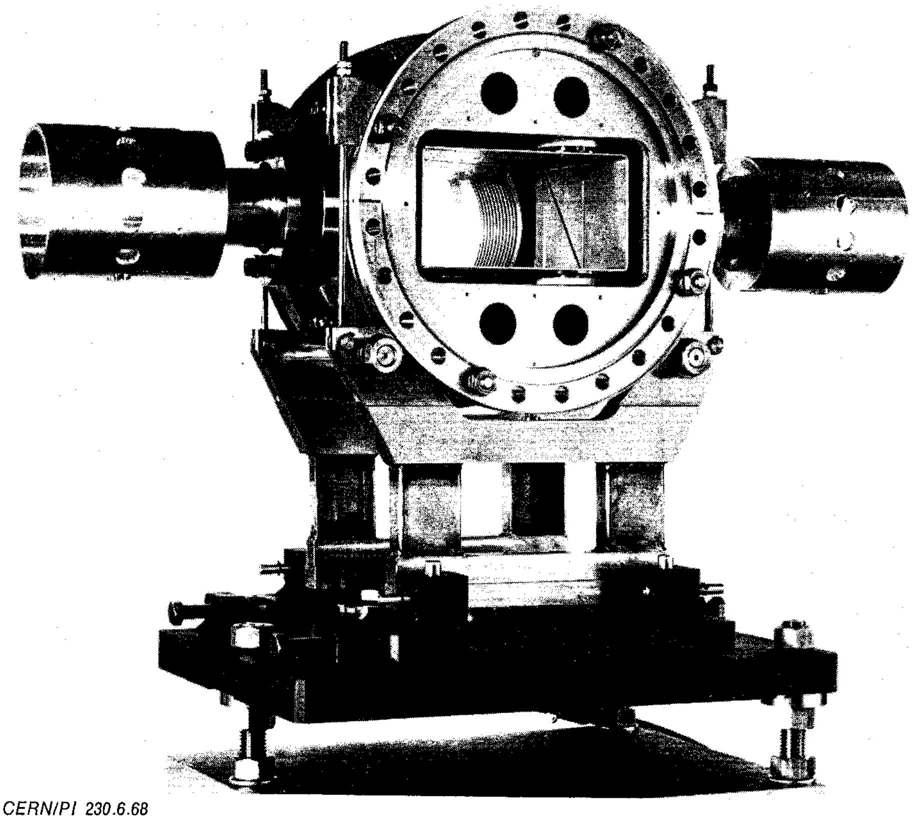
The low-power part of the r.f. system includes systems for programming the voltage and frequency (matching the r.f. 'buckets' to the shape of the PS bunches by manipulations with phase and amplitude), for phase-locking the r.f. to the beam, and for timing. The latter system includes a device that determines the exact moment to turn off the r.f. from a dynamic measurement of frequency. In the non-repetitive stacking scheme the turn-off frequency is changed a small amount (typically one part in 10^6) in successive cycles.

Phase-lock beam control has to be used at injection. When the newly injected and accelerated particles approach the beam which is already stacked, the use of phase-lock is complicated by the presence of the stacked beam whose density becomes modulated by the r.f. A method has been devised to overcome this problem. It involves leaving one or more r.f. 'buckets' empty to act as a marker which enables the phase-lock system to distinguish between the injected beam and the beam which has already been stacked. It will also be possible, however, to generate the correct frequency by a programming system alone, which meets the stringent requirements concerning freedom from noise.

At present, all the sub-systems mentioned above exist in prototype form and some exist in final execution. All devices have been tested individually and a global test of the r.f. system was successfully carried out at the end of 1967. This included a model cavity and all the parts of the low-power system which were available at that time.

During the last two years a further addition to the r.f. system has been invented. Its purpose is to solve the following problem :

A beam observation pick-up station on its support. It has been partially demounted to show the electrode structure. The head amplifiers which treat the signals coming from the pick-up electrodes will be placed in the two lateral casings.



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Since the circumference of the ISR is $1^1/_2$ times that of the PS, one beam pulse transferred from the PS fills only $^2/_3$ of the ISR circumference. Therefore, if nothing special is done, 10 out of the 30 r.f. 'buckets' generated by the ISR r.f. system would remain empty, resulting in a corresponding loss in the maximum intensity which could be attained in the stacked beam. It was originally intended to fill in the missing part of the beam by means of a second injection from the PS prior to starting each stacking cycle. This idea has now been abandoned and instead, a device that suppresses the unwanted empty buckets by switching off 10 out of every 30 r.f. waves will be incorporated in the r.f. system. This is possible since it needs to be done only towards the end of each stacking cycle, when the r.f. voltage is relatively low. The feasibility of this method has been successfully demonstrated and a prototype system is under development.

The r.f. group is also responsible for the beam observation system of the ISR. The main part of this is a system which makes it possible to measure the vertical and horizontal beam position at over 50 places in each ring by means of capacitive induction electrodes (generally called 'pick-up stations'). The signals from these stations can either be displayed directly or fed (after suitable treatment) to the ISR central control computer. The design of the pick-up station itself is complete, orders have been placed and the first batch of series delivery from N.V. Neratom (Netherlands) is expected to arrive before the end of 1968. Part of the design of the signal processing system is complete and the rest is in an advanced state.

3. Vacuum System

E. Fischer

The rings

The most important performance figure of storage rings for the experimentalist is the luminosity which determines the number of particle interactions which will occur per second. Not only should the luminosity be as high as possible, it should also decrease as slowly as possible after both rings have been filled with protons and the experiments have started. Calculations show that the main cause of the decrease in luminosity is the gradual blow-up (increase in the cross-section of the stored beam) due to multiple scattering of the protons on the residual gas. At an average residual gas pressure of 10^{-9} torr, which is the design value of the ISR, the luminosity will fall in 20 hours to one half of its initial value. This is satisfactory taking into account that it needs less than one hour to fill both rings with protons.

In calculating the 20 hours half-life it is assumed that the beams are allowed to grow from an initial height of 10 mm up to a maximum height of 14 mm at the interaction points. However, physicists planning experiments with the ISR want beams which do not increase in height and, correspondingly, in angular spread. The larger the angular spread, the more difficult it is to interpret an observed event.

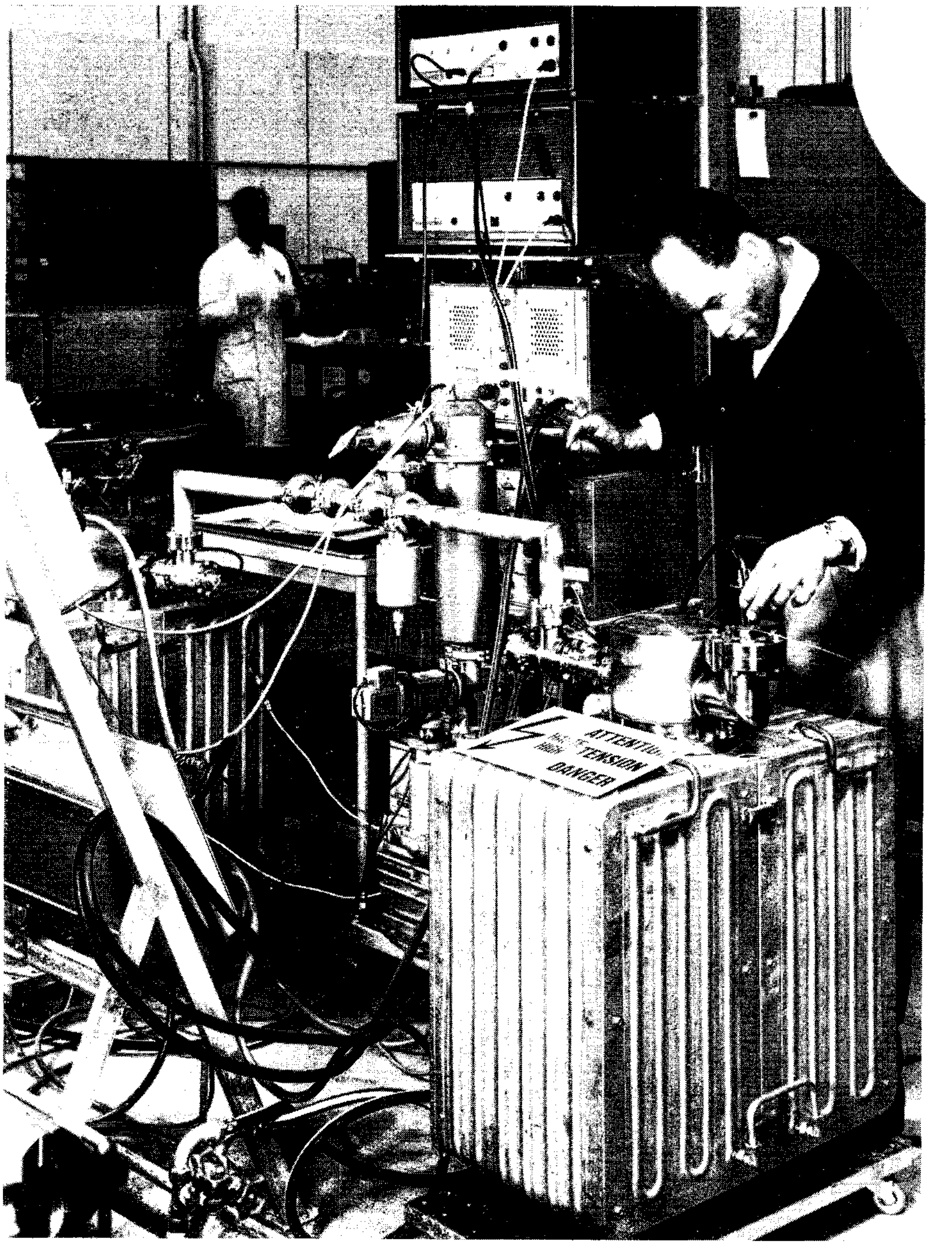
It is quite feasible to confine the beams by means of 'scraping targets' which eliminate all protons whose oscillations exceed the desired beam size. However, this would cause the luminosity to decrease much faster. Consequently, although it will be a considerable feat to achieve the design value of 10^{-9} torr for the average pressure in the rings, a further decrease towards 10^{-10} torr will almost certainly be called for, since this will improve the overall performance of the ISR.

The main problem in the construction of the ISR vacuum system is not the required low pressure — the technology to achieve a 10^{-9} to 10^{-10} torr vacuum is, by now, very well known. The problem is the sheer size and complexity of the system. The total length of the stainless steel chambers of the two rings is almost 2 km, subdivided into sections varying in length between 30 cm and 7 m. More than six thousand demountable flange seals are required for joining the chambers together and for connecting pumps, gauges and other equipment.

The pumping system will consist of 80 turbomolecular pumping stations with about 60 l/s pumping speed for pre-evacuation down to 10^{-6} torr, of 300 sputter-ion pumps with 350 l/s speed as main pumps and 100 titanium sublimation pumps as auxiliary pumps at critical places where higher pumping speed is required. More than 500 ionization gauges will be installed for total pressure measurement as well as 25 residual gas analysers. Some 1 200 clearing electrodes with high voltage feed-throughs must be installed within the coil overhangs of all magnets for the extraction of electrons from the beam region. Forty gate-valves will make it possible to divide the rings in sectors of 30 to 80 m length so that repairs or modifications can be done by letting only one sector up to atmospheric pressure and not the whole system. Furthermore, 130 roughing valves are required. The chamber will incorporate many hundreds of flexible stainless steel bellows, which will allow the vacuum chamber to follow the lateral motion of magnets and lenses by a few millimetres during their alignment without introducing mechanical stresses.

Finally, all chambers, pumps, gauges, valves, etc. will be equipped with heating elements, thermo-couples and thermal insulation. This equipment is needed for the bake-out of the chamber, sector by sector, so as to reduce the gas desorption from all internal surfaces.

An important aspect in selecting the equipment for the vacuum system is reliability and a great effort has been made over several years to find the most reliable pumps, the most reliable design for demountable seals, the most reliable electrical feed-throughs and so on. The contracts for the supply of all the major components have now been placed and the first units have arrived at the ISR site. The arduous task of testing every component as thoroughly as possible before it is installed is now beginning. It is necessary to detect faults such as leaks, insufficient cleanliness, malfunctioning of pumps, incorrect reading of gauges, and so on. The pressure which is finally achieved in the ISR will not



Acceptance tests on the first batch of sputter-ion pumps which have arrived at CERN. Each pump must demonstrate an ultimate pressure below 5 × 10^{-11} torr before it is accepted. The pumps are fully encapsulated by bake-out ovens with water-cooling of the outer walls.

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depend on the ideal conception of the vacuum system but on all types of faults which it has not been possible to avoid or to repair.

The interaction regions

Unusual vacuum problems must be solved for the interaction regions where the proton-proton collisions have to be distinguished from the background of collisions with the nuclei of the residual gas. This background will be at an acceptable level if the partial pressure of hydrogen in the interaction region is not higher than 10^{-10} torr and the partial pressure of nitrogen, carbon monoxide and gases of similar molecular weight not higher than 10^{-11} torr. By now, two different types of pump for obtaining such low pressures are built and have been tested at CERN. One pump uses surfaces cooled by liquid helium to about 2.7°K, the other uses titanium getter films at 78°K (the temperature of liquid nitrogen).

Unfortunately, for most ISR experiments the physicists do not want to have the intersection point cluttered by voluminous pumps. There is therefore a second requirement that the pumps to produce the very low pressure be placed as far away as possible from the interaction region. They will be installed alongside the four nearest bending magnets. Under these conditions, the gas desorption from the chamber wall becomes the limiting factor dictating the lowest pressure that can be achieved. The technology has been studied and developed for reducing the desorption rate of hydrogen from stainless steel down to 10^{-13} torr litre/s cm^2 and that of all other gases to below the detection limit. It involves high temperature (800-1000°C) vacuum annealing for several hours during the manufacturing process. The residual gas in the interaction regions will be 99 % hydrogen.

A third requirement concerns the thickness of the vacuum chamber wall. Protons or secondary particles from a proton-proton collision change their direction of flight while passing through the chamber walls due to multiple scattering. This change of direction should be smaller than the angular spread of the circulating protons in order not to introduce additional imprecision in the detection of the particles. Stainless steel walls with a thickness of a few tenths of a millimeter seem to be both acceptable and technically feasible.

Beam transfer channels

The vacuum system for the beam transfer channels between the PS, ISR and West Hall is relatively simple, since it is sufficient to have a pressure below 10^{-5} torr. Nevertheless, with 1.5 km total length it is twice as long as the vacuum chamber of the synchrotron itself. The guiding principles in designing the vacuum system of the beam transfer lines have been to build a system which will need practically no attention once it is completed, and to suppress all organic matter which might be damaged by radiation.

From the end of 1967, the contracts for the supply of all the main components for the vacuum system have been agreed.

The main contracts have been placed as follows :

ISR vacuum chamber
steel — Avesta Jernverks A.B. (Sweden)
machining — Noratom-Norcontrol A/S (Norway)
bellows — Société Calorstat (France)
assembly — Jean Gallay S.A. (Switzerland)
tests — Société générale du Vide (France)
370 sputter-ion pumps — Varian (Italy)
90 turbomolecular pumping stations — Pfeiffer GmbH (Federal Republic of Germany)
550 Bayard-Alpert ionization gauges — C.S.F. (France)
42 sector valves — Leybold-Heraeus (Federal Republic of Germany)
150 Roughing valves — S.R.T.I. (France)

The first batch of twenty sputter-ion pumps arrived in October 1968 on the ISR site, where the pumps are to be thoroughly tested in the West Hall before acceptance. This month, November, the first batch of turbomolecular pumping stations and also the first complete chamber sections are scheduled to arrive. In March 1969, the first chambers will be installed in the gaps of those magnets which will be, by then, already in their places in the ISR tunnel.

4. Beam transfer

B. de Raad

The requirements involved in transferring proton beams from the PS to the ISR and to the West Hall are unprecedented in scale and complexity. They will be described in four sections covering the activities of the Beam Transfer Group :

a) Beam transport

The Figure on page 265 shows the layout of the beam transfer system, consisting of four different channels. There is an almost straight channel (TT 2) from the PS to the ISR Ring 1. This channel has two branch points - for beams to Ring 2 (TT 1) and to the West Hall (TT 2a). A fourth, independent, channel (TT 3) transports the ejected proton beam from the ISR to the West Hall. The total length of these four channels is approximately 1.6 km and they contain about 125 bending magnets and 170 quadrupoles.

The level of the ISR site is up to 25 m higher than that of the PS site. To limit the cost of excavation and of access roads the beam level of the ISR was chosen as high as possible, subject to the requirement that the ISR tunnel floor should rest directly on the molasse practically everywhere. This resulted in a beam level 445.46 m above sea level for the ISR compared with 433.66 m for the PS. All the channels have to guide the beams both horizontally and vertically, so that their conception and alignment is a three-dimensional problem.

The beam path takes the following course. Just after emerging from the PS, a small vertical deflection takes it over the linac beam ; it then continues horizontally at a level of 434.24 m. Over the last 110 m to the ISR there is an upward slope of about 10 %, so that the transferred beams approach the ISR from below on the inside of the rings. The channel to the West Hall passes at a level of 434.24 m under the ISR and then rises, with a slope of 12 % to the beam level of 448.06 m in the West Hall.

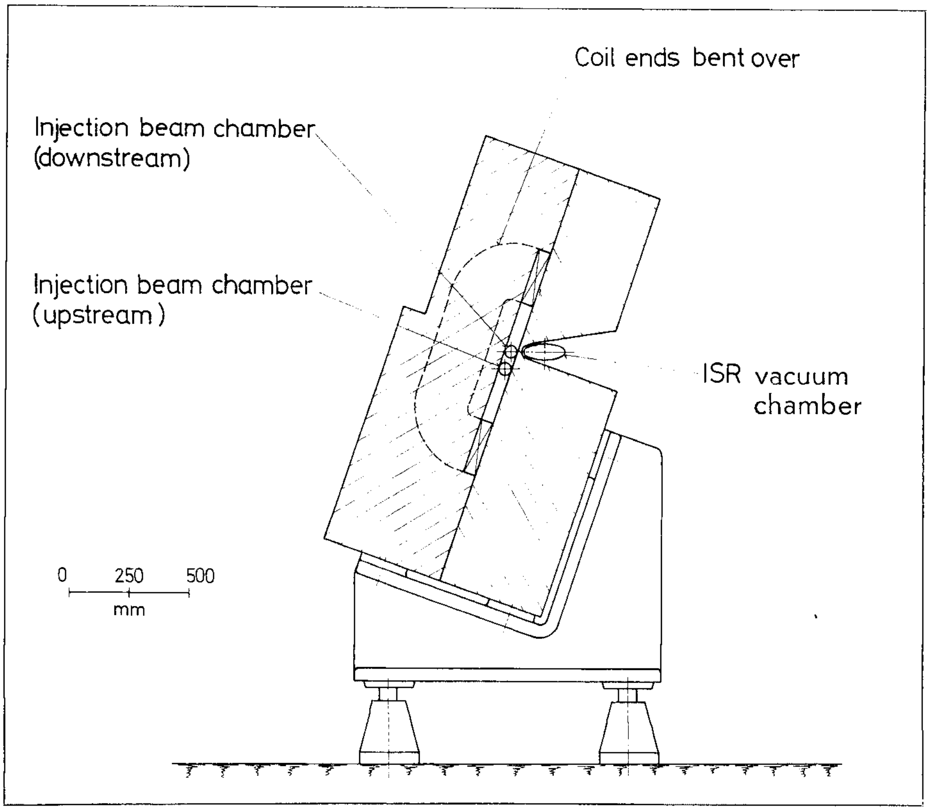
Extensive computations have been made to arrive at a system which will ensure that the beam quality does not deteriorate during transfer. Vertically, the channels are dispersion free and the horizontal dispersion has been adjusted so that 'off-momentum' particles are injected into the ISR approximately onto their respective equilibrium orbits. At the beginning and end of the transfer channels, there are separately excited quadrupoles to 'match' the proton beam respectively to the transfer channels and to the ISR.

The aperture of the vacuum vessel in the transfer channels is 130 mm horizontally and 80 mm vertically. The maximum field in the bending magnets is 12 kG and the maximum gradient in the quadrupoles about 1.5 kG/cm. All the bending magnets and quadrupoles are laminated to allow rapid changes and more reproducible setting of the magnetic fields. The quadrupoles will be constructed by B.B.C. (Federal Republic of Germany) who have already delivered a satisfactory prototype, the bending magnets by Alsthom (France).

As far as possible, groups of bending magnets and quadrupoles are excited in series. But, due to the complicated geometry and the large number of separately-excited quadrupoles there will be almost 100 power supplies ranging from 6 kW to 800 kW output power. Their half-hour stability and the amplitude of their current ripple has to be one part in 10^4, with even more stringent conditions (two parts in 10^5 of the instantaneous current, down to 1/5 of maximum current) for the power supplies which produce large vertical deflections. Each power supply will have, as a voltage reference source, a specially developed digital to analogue converter, which has a precision of ± 5 parts in 10^6 of the maximum output voltage of 10 V, with mains fluctuations of ± 15% and an output impedance that is independent of its setting. These converters can readily be set remotely by an operator but it is hoped that, soon after the initial running-in period, they will be set by the ISR control computer. The power supplies, including the digital to analogue converters, are under construction at Brentford Electric (UK).

b) Injection into the ISR

The injection system can be compared to a fast ejection system of an accelerator but with its components in reverse order. The beam approaches the ISR at a large angle and is made approximately parallel to the central orbit by a septum magnet. It enters the ring at a specially widened part of the vacuum chamber and somewhat less than one quarter of a betatron



1.

A cross-section of the downstream steel septum magnet used to inject beams into the ISR. Notice that the beam is being deflected vertically so that the vacuum chamber of the transfer channel rises as it passes through the magnet, and that the magnet has a groove where the vacuum chamber of the storage ring itself passes.

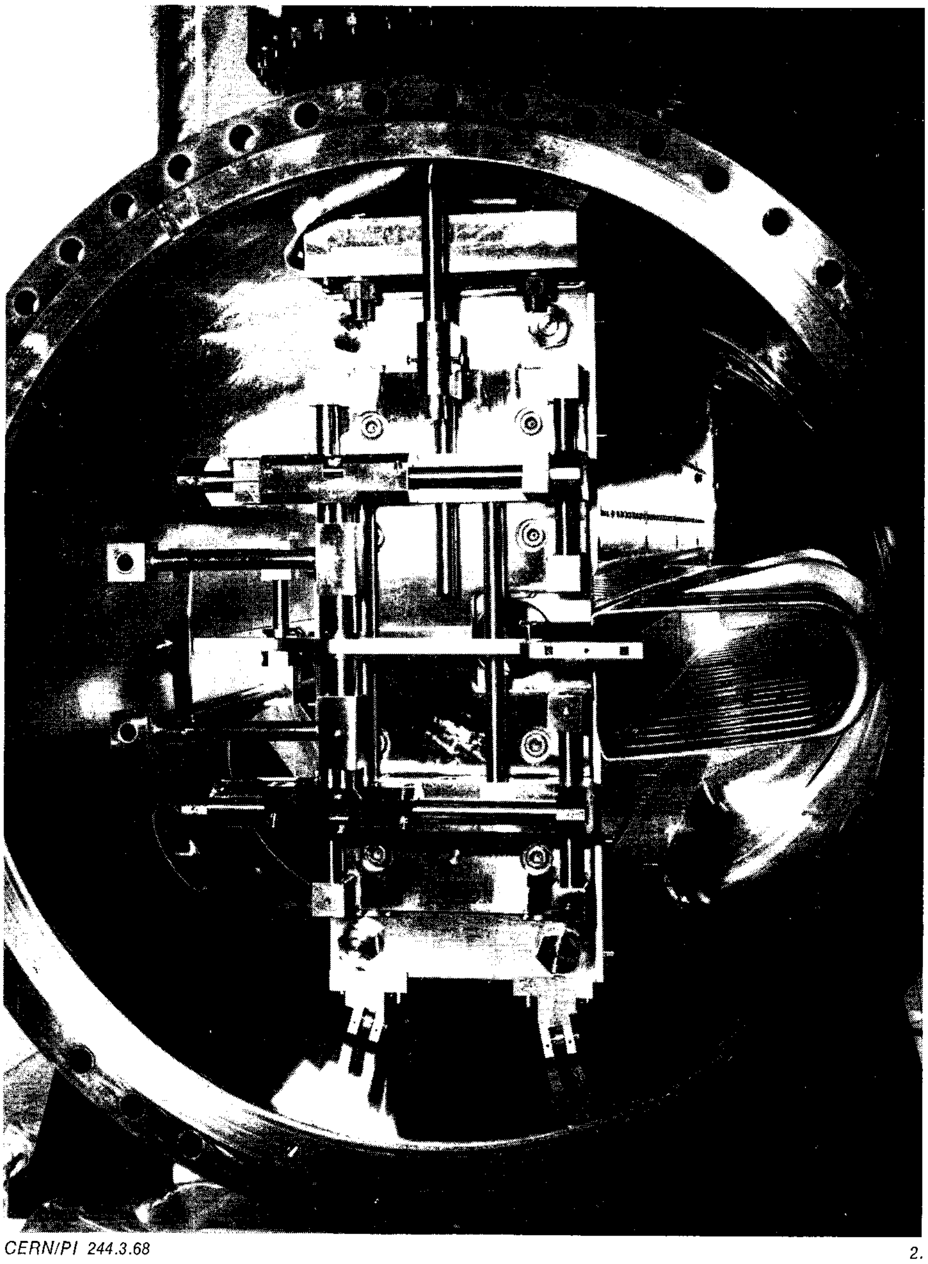
An end view of the fast injection kicker magnet. The aperture through which the beam passes is just visible (the dark slot at the centre of the magnet on the right). The screen which covers the aperture, to shield the stacked beam from the kicker magnet field, slides up from below. The equipment attached to the end of the magnet is temporarily installed for magnetic measurements.

wavelength downstream, passes through a fast kicker magnet which deflects it onto the injection orbit. The field of the fast kicker must be turned off before the protons pass through it again after their first revolution.

In existing ejection systems, the septum magnet is located inside the machine vacuum chamber and deflects the beam horizontally. The copper septum that forms the one-turn winding of the septum magnet has a thickness of a few mm and carries a pulsed current of the order of 20 kA. In the ISR, since the beam comes up from below anyhow, it was decided to use a magnetic steel septum which deflects the beam vertically. This has the advantage, that the coils of the steel septum magnet can have a normal size and be excited with direct current. Therefore a steel septum magnet can be more precise and more reliable than the pulsed-current septum magnets which have often given trouble in ejection systems. The disadvantage is that the steel septum has a thickness of 14 mm to which must be added 2 mm for magnetic shielding in the groove of the steel septum magnet and the beam has therefore to be given a bigger deflection by the kicker magnet. The ISR injection system has two steel septum magnets in series, which are inclined at angles of 14° and 19° to the vertical, to allow the injected beam to pass in front of the core of the F-unit at the upstream end of the injection straight section. A cross-section of the downstream steel septum magnet is shown in the Figure. To leave space for the ISR vacuum chamber the complete coil of each steel septum magnet is bent over towards one side. The vacuum chambers have been designed such that the steel septum magnet is entirely in air, thus greatly simplifying the design of the ultra-high vacuum system in that region.

The fast kicker consists of two modules, each 1.5 m long, which deflect a proton beam of momentum 25 GeV/c over 2.5 mrad when excited with a rectangular voltage pulse of 2.4 μs duration and 17.8 kV amplitude. Each burst of protons from the PS has a duration of 2 μs whereas the revolution time in the ISR is 3 μs. The pulse in the fast kicker can thus have a relatively long rise and fall time. But to restrict injection errors, it is essential that the transients and droop during the flat top of the pulse be as small as possible and that, in less than 1 μs after the end of the flat top, the magnetic field be reduced to, at most, a few thousandths of the flat top field. A large effort has therefore gone into making the electrical characteristics of the fast kicker and associated circuits as near ideal as possible. In the prototype kicker, a droop during flat top of 1 % and transients of about ± 1%, have been achieved.

The choice of materials and methods of construction for the fast kicker are severely restricted by the requirement that it must operate in ultra-high vacuum and be baked out at 300°C. Only metals, ceramic and ferrite can be used ; all the metal parts are made of titanium, which has the best voltage-holding characteristics and a shorter conditioning time than, for instance, stainless steel. All components of the kicker are chemically cleaned and assembled in a clean, dust-free room. Figure 2 shows a full-scale kicker module, made by Mullard (UK), who are construc-



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2.

ting all the kicker modules for the ISR.

Each kicker module is housed in its own ultra-high vacuum tank, which has a length of 1.96 m and a diameter of 0.625 m. Two prototype tanks, made by Leybold-Heraeus (Federal Republic of Germany) who are now constructing the final tanks for the injection system, were pumped down to 6×10^{-11} torr when empty and to 10^{-10} torr with the prototype kicker inside.

To shield the stacked beam from the stray field of the kicker, an aluminium screen is moved in front of its gap, while it is being pulsed. The screen is actuated, via bellows, by a hydraulic servo-actuator located outside the tank. Extensive life tests of bellows have been made to prove the reliability of such a system and, as a typical example, welded bellows with a length of 154 mm, were still ultra-high vacuum tight after 2×10^7 cycles.

c) Ejection from the ISR

The ISR can supply experimenters in the West Hall with protons at a repetition rate and duty cycle that can be varied over a wide range, independent of the PS. For example, all the accelerated protons from the PS could be injected every 2 seconds into the ISR and then each of the 20 bunches could be ejected one at time at 0.1 s intervals, from the ISR. Alternatively, every fifth burst from the PS could be injected into the ISR and then spilled out slowly over, say, 10 s. Many other modes of operation can be envisaged.

Extensive computations, which were made to determine the relative merits of various slow ejection systems, indicate that ejection using the $8^{2}/_{3}$ resonance is the most attractive for the ISR. It is intended to construct a feedback system which measures the instantaneous external beam current and controls the rate of shrinking of the phase-stable area. It is hoped that, in this way, reproducible spill-out can be achieved during time intervals that are more than an order of magnitude longer than the present PS flat top. The ejection channel will consist of a thin and thick septum magnet, both d.c. operated. Prototypes are under construction.

Fast ejection will use the same ejection channel as slow ejection and will be designed to cope with a large range of pulse lengths and repetition rates.

d) Beam dumping

At 28 GeV and at the design current of 20 A, the stored energy in each beam is about 1.7×10^6 J, which is enough to heat about 3 kg of steel to a temperature of 1000°C. If, for instance, the power supply of the ISR magnet rings dropped out due to mains failure, the stacked beams would spiral outward (as the strength of the magnetic field fell) with a pitch of a few microns per revolution. Most of the protons would then be absorbed in a small region of the ISR vacuum chamber, where the closed orbit is nearest to its outside wall, so that a severe risk of damage to the vacuum chamber would exist.

It is therefore necessary to have a system that is reliable and simple to operate, which can dump the beams whenever safety circuits indicate faulty operation or radiation detectors detect excessive beam less. The same beam-dumping system will, of course, also be used for scheduled beam-dumping in order to concentrate the beam loss, as much as possible, in a small region of the ISR to reduce the induced radioactivity elsewhere.

The beam dumping system which is under development makes use of the fact that the vertical beam size is small in the straight-sections between two focusing magnets and is independent of the beam current. A fast kicker will be placed at the upstream ends of the two 17 m long straight-sections at crossing point 3 (one for each ring) to deflect the beam vertically into a dump block at the downstream ends.

The material for the dump block must have a large specific heat, a small coefficient of thermal expansion, a small modulus of elasticity and a high yield strength. The best combination of these properties is offered by titanium alloys. Monte Carlo computations of the nuclear shower in a block of titanium indicate that, with a 20 A beam current, the maximum local temperature rise is about 350°C and the maximum stress about 25 % of the yield stress at 20°C. The beam dump kicker will be pulsed from a delay line, or possibly simply from a capacitor, and, since these devices will be permanently charged, the kicker can still be pulsed once in the event of a mains failure.

5. Power Supplies

S. van der Meer

The power supplies for the two main magnet rings of the ISR have very different requirements from those of an accelerator. In the first place, the magnets are not pulsed and there is no need for rotating plant or static compensators to ease the burden on the mains. The magnets can be run up to the required field level and the current fed to the magnets may then be kept constant for many hours.

On the other hand, there is need for exceptional stability in the current. In order to retain beams circulating for many hours the magnet field has to be kept extremely steady, which imposes the requirement that the output currents from the power supplies must be stable to within $\pm 3 \times 10^{-5}$ of their nominal value over 10 min and to within $\pm 10^{-4}$ over 2 months. This applies over the full current range needed to store beams with energies from around 8 GeV to 28 GeV. Very low ripple in the output voltage of the power supplies, about 100 mV in 1800 V, is required and is achieved by means of passive and active ripple filters.

The power supplies are therefore essentially straightforward d.c. supplies using solid-state rectifiers, equipped with exceptional regulation systems. Tests on a small-scale model to prove the regulation system were successfully carried out at CERN.

Two big units (7 MW each) are now being manufactured by Smit-Brentford (Netherlands/UK). Their output current will be continuously adjustable between 940 A and 3750 A. The current can be set anywhere between these two values to take beams of different energy or can be varied slowly during the time that the beams are stored so that slow acceleration or deceleration of either or both beams can be carried out.

Auxiliary power supplies

In addition, as many as 192 auxiliary rectifier sets are needed to feed the correcting elements, such as pole-face windings, sextupole and quadrupole lenses, radial field magnets, etc. Most of these rectifiers also have to deliver extremely smooth output voltage.

These units can be obtained virtually 'off-the-shelf' and it has not been necessary to carry out development work at CERN. There will, of course, be the usual series of acceptance tests, as the sets are manufactured. An order for 68 medium-power rectifiers (between 14 and 75 kW) was recently placed with Oerlikon (Switzerland). The remaining 124 low-power rectifiers (between 2.5 and 15 kW) will be ordered before the end of 1968.

Considerable effort is being made to achieve power supply operation as automatic as possible. Obviously, when so many units are involved, individual setting needs to be avoided. Digital to analogue converters will be used and the supplies will eventually be set via the ISR control computer.

6. General Engineering

H. Horisberger

The General Engineering Group offers services, mainly in the field of mechanical engineering, to all the other groups involved in the ISR project. It consists of four sections.

1. The Drawing Office

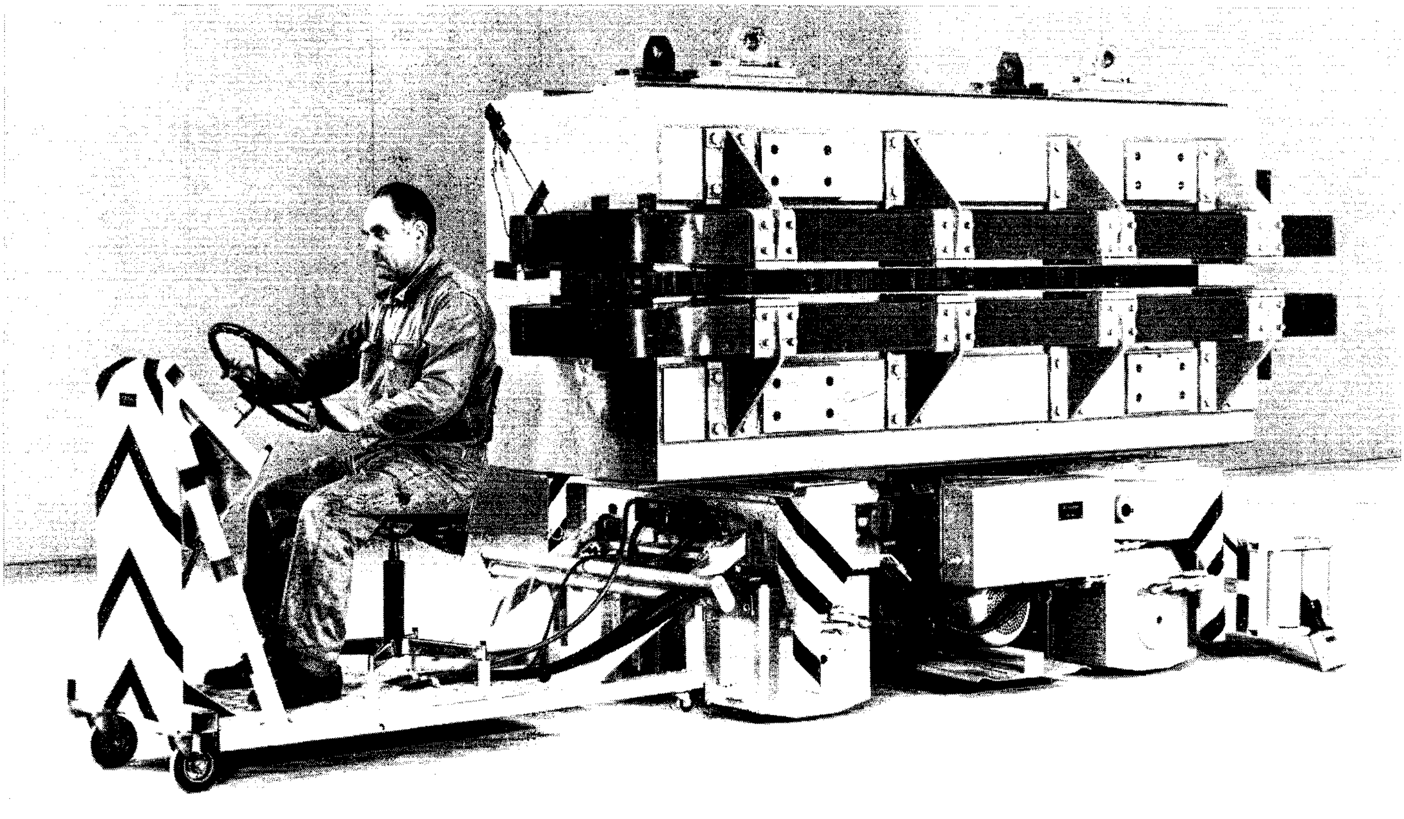
In close collaboration with the engineers of the various groups, the drawing office designs and establishes the manufacturing drawings of practically all machine components involving mechanical design. It helps to prepare specifications for these items and is often responsible for ordering and following up orders.

A typical example of a piece of equipment entirely designed by the drawing office is shown in the photograph. It is the special vehicle to transport some 130 bending magnets, weighing up to 20 tons, inside the beam transfer tunnels where no overhead cranes are available. Some of the design parameters were extremely severe : the magnets have to be driven down slopes of up to 12 % (equivalent to the steepest mountain passes), stopped with millimeter accuracy, the wheels turned through 90° and the magnet moved onto its final supports. Important safety considerations had to be taken into account. Each of the four wheels, for instance, is equipped with an emergency brake which would block the carriage in case of a power failure. The vehicle passed a number of factory tests with success at the manufacturers, Von Roll (Switzerland), and has recently been delivered to CERN where it is undergoing further tests before beginning regular operation next year.

2. Mechanical Workshop

It was clear from the beginning, that the construction of the ISR would require a large amount of development and prototype work and a divisional workshop was therefore set up in 1966. It is equipped with modern machine tools, a sheet metal and welding shop, and a tool room, and staffed with highly qualified personnel.

Together with the Vacuum Group it has carried out a lot of development work to find economic and reliable manufacturing methods for ultra-high vacuum components, and has built prototypes of chamber sec-



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The extraordinary transport vehicle designed to carry magnets down the transfer tunnels where there are no cranes. It has to protect the magnets from any shock which would disturb its precise assembly and has to descend steep hills since the tunnels rise up from below the level of the ISR. When it reaches the desired position it stops with a precision of 1 mm and then moves exactly at right angles to its initial direction. It stops again with precision and jacks are inserted to lift the magnet clear. It then moves out and the proper magnet supports are put in position.

tions, valves, etc. Large quantities of welding samples, including plasma welding for thin wall stainless steel membranes, have been produced.

For the Magnet Group, the workshop built cutting devices to take samples from steel sheets for permeability measurements, high precision calibrating and measuring coils for magnetic measurements, precision tools for pole profile measurements etc. Furthermore, it carried out a series of qualifying tests on magnet supporting jacks and, recently, a checking section has been set up to make dimensional checks on the large series of magnet components.

For the Radio Frequency Group, it contributed to the contruction of r.f. cavity models, pick-up stations, etc.

3. Cooling and Air Conditioning

This section is responsible for the design, ordering, installation and putting into operation of all the cooling and air conditioning installations required in the ISR and beam transfer systems. The work has been divided into the following components :

a) Air conditioning system of the ISR Ring Tunnel — a total volume of about 140 000 m³. To retain accurate alignment of the machine components, the temperature must be maintained at 20 ± 1°C which imposes severe requirements on the air distribution and regulation system. A proportional-integral temperature regulator was chosen to satisfy these tight temperature tolerances. The air is recirculated through nine air treatment plants, situated in specially elevated roof structures of the ring-tunnel, and distributed through round ducts of 80 cm diameter. Installation has already started in Octant 3.

b) Air conditioning system of the beam transfer tunnels — a total volume of about 15 000 m³. The temperature conditions are similar to those in the ring and the same regulation system has been adopted. There will be 14 air-conditioning units, situated in enlarged tunnel sections along the various transfer channels. The installation work is scheduled to start this month.

c) Re-cooling plant — serving the various closed cooling water circuits of the magnet systems and the air conditioning systems. Since natural cooling water is rather scarce on the CERN site, a system using water chillers with centrifugal compressors and cooling towers has been adopted. The total design capacity is 26.4 Gcal/h and the cooling water temperatures, at full load will be 13 to 33°C for the magnet systems and 5 to 12°C for the air conditioning systems. The plant will be one of the largest of its kind in Europe.

The tenders for the complete installation have been received and a contract will be placed shortly. Installation will start in May 1969.

d) Piping system — distributing cooling water to the various users. It includes also the hot water pipes of the air conditioning systems. The installation consists of 22 km of low carbon stainless steel pipes carrying demineralized water to the magnet cooling systems, and 8 km of normal steel pipes for the air conditioning system. Installation will start this month.

e) Distribution network for general purpose and drinking water, and for compressed air — serving the ISR and beam transfer tunnels. Specifications for these items are in preparation.

4. Coordination and Planning

The group is responsible for the coordination and planning of the installation of the machine. An important part of coordination is already done in the drawing office, to the extent that it must avoid interference between the many components it designs. For this purpose, it executes also the layout and assembly drawings.

Modern planning methods (PERT programming) are employed, using computer programs developpped at CERN for the CDC 6600 computer. A first installation programme has been established for Octant 3 and the adjacent service tunnels, where installation work has started. A Technical Committee, with two members from each group, was set up early this year. All constructional aspects involving several groups, and all problems concerning installation are discussed and approved in this committee.

7. Controls

G. Schaffer

The ISR project involves a very large complex of sophisticated equipment and requires a considerable effort to study and solve the control problems in detail. A Controls Group was therefore set up about two years ago. Work on self-contained parts of the control system is assigned to project engineers or physicists who link a specific ISR Group with the Controls Group. But general development and standardization of control techniques, such as data acquisition and transmission, and planning of the control cable network, is carried out centrally according to overall requirements.

The location of the storage rings control centre (SRC) can be seen on the Figure. It will be combined with the switchyard (SY) and West Hall (E_1) control centre, to facilitate communication between operators and to avoid duplicated controls for the beam transfer channels.

Safety aspects

The personnel radiation protection system (or access control system) has to take into account four basic modes of operation of the ISR complex, as indicated in the Table. It will subdivide the entire tunnel system into four main zones (see Figure) with either restricted or authorized access, depending on the mode of operation in use.

The radiation safety of the staff working inside one or several zones will be ensured by the following main elements (in addition to the general provision of shielding and radiation warnings) :

— remotely controlled access doors and safety keys ;

— beam dumps, stoppers and concrete separation walls in the transfer tunnels;

— 'off' status of power supplied to some of the beam transfer bending magnets;

— beam dumping mechanisms in the storage rings.

The first elements to be installed, during the next programmed shut-down of the PS, are dump D1 and stopper ST1, both in front of separation wall W1.

The design study of the ISR access control system has been completed. A model of a typical control and monitoring panel has been built in order to simulate the logic applied to door interlocks.

Beam transfer channels

The necessary deflection of the ejected PS or ISR beams through both horizontal and vertical angles results in complicated beam optics and about 70 beam monitors of various types are required to set up and monitor the beams in the beam transfer channels. New versions of beam profile and position monitors based on the principle of secondary emission are under development and construction.

The type shown in the Figure is designed for beam emittance measuring and matching purposes. It uses a row of horizontal and a row of vertical thin aluminium foils and the electronic circuits connected to the individual foils deliver quantitative signals on the beam intensity profile. They are designed to work with both fast and slow ejected beams. A prototype secondary emission monitor (SEM) has been successfully tested at the PS in a fast-ejected beam ; tests in slow-ejected beams will follow. Besides quantitative information, this monitor offers the advantage of introducing smaller multiple scattering than monitors involving an inorganic luminescent screen and TV camera (although the latter will also have to be used in some places to observe the beam size).

Another new type of profile monitor uses two SEM probes, which are driven by stepping motors, to find the edges of the beam or to plot the intensity distribution.

Since these monitors are beam-intercepting types, they are normally moved away from the beam path. Some of these devices must also be used in the storage rings proper for adjustments of the beam on its first revolution and, therefore, must be suitable for ultra-high vacuum.

Vacuum problems

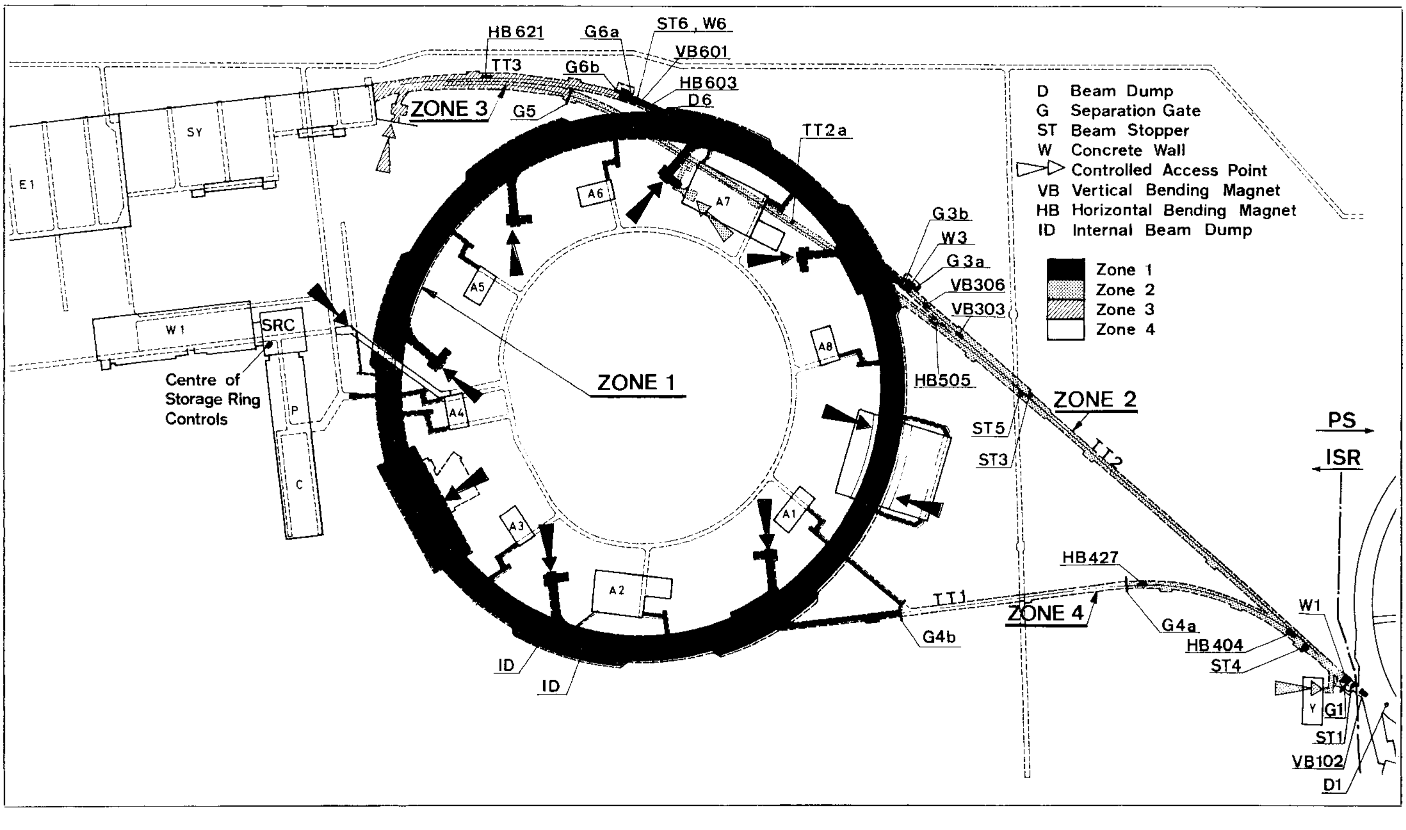
The Controls Group is providing the power supplies and control units for the sputter ion pumps (325), roughing stations, Bayard Alpert ionization gauges (300), sublimation pumps, clearing electrodes, sector valves and scanners for bake-out temperature measurements. Most of these units must be remotely controlled and require careful attention in design specifications and prototype tests (in particular, the control units for ionization gauges). 300 of these units were recently ordered from Balzers (Liechtenstein). Tenders have been received or are being prepared for the other items.

Signal transmission and monitoring

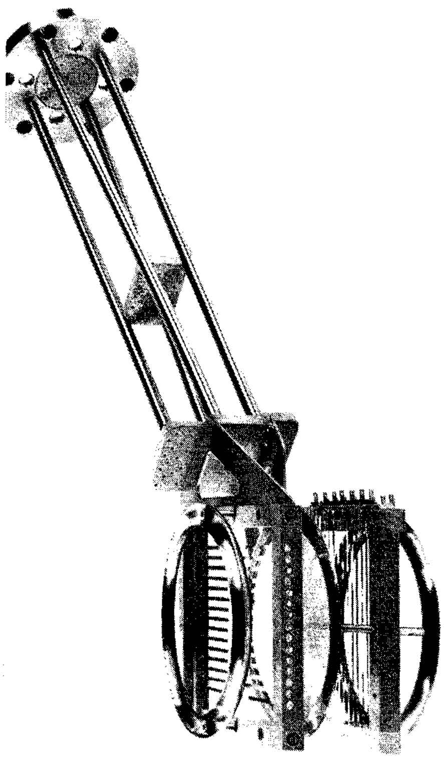
The requirements for signal transmission to or from the ISR control centre include :

- safety elements (access doors, keys, radiation monitors, beam dumps) ;
- information on PS ejected beams ;
- beam steering and matching in the beam transfer channels ;
- ultra-high vacuum system performance;
- ISR timing system ;
- measurement and display of orbits and Q-values during injection and stacking;
- closed orbit and beam profile correction via pole-face windings, auxiliary magnets, and position adjustments of magnets ;
- acceleration or deceleration of stored protons ;
- steering and monitoring of intersecting beams.

It is obvious that the operators of this complex need an electronic robot to help



A secondary emission monitor (SEM) developed for quantitative beam profile measurements in the ISR and the transfer channels. 15 horizontal and 15 vertical thin foils are connected to individual 100 pf capacitors, and signals, varying from 5 to 500 mA, are sequentially gated into a cable after passing through 'sample and hold' circuits.



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collect, select, display and evaluate the necessary information for their tasks. Therefore, a major part of the ISR controls will be based on a digital process computer system. The computer's main functions will be :

- — accurate setting of magnet power supplies ;
- — gathering, evaluation, display and recording of data on circulating beams and various ISR components.

The computer system must be capable of recording magnet currents and of adjusting about 300 magnet power supplies. About 100 of these are involved in the beam transfer system which requires quick and reliable changes in settings for different modes of operation (e.g. filling the ISR, or transfer of beams to the West Hall). The 200 power supplies used in the storage rings themselves need coordinated incremental adjustment during acceleration or deceleration of stacked protons.

Typical examples for data collection, evaluation and display via the computer are beam position monitoring by signals originating from the 108 pick-up stations in the storage rings, and monitoring of the ultra-high vacuum system by signals coming from the ionization gauges.

Obviously, in a control system of this type, the computer itself must be extremely reliable. The ISR computer system will have the central processor and critical peripherals duplicated to ensure the permanent availability of a minimum configuration for the vital functions. A specification for the computer was issued during 1968 and it is expected that the order will be placed by the end of this year.

A considerable amount of work is also going into component and circuit standardization, production of electronics, audio and video inter-communication systems, and development of techniques for data collection and multiplex signal transmission.

Finally, an installation service for the control cable system has recently been set up and detailed requirements are being worked out. Installation will start with Octant 3 and its related equipment building A3 and will build up to a peak in 1969 and 1970. The installation labour required for the ISR control system is of the order of 150 man-years. The length of cabling involved is estimated to be 1500 km.

Basic modes of ISR Operation	Restricted Zones	
	1	2, 3, 4
1. Setting up an ejected beam from the PS, with the beam not entering the transfer channels	No	No
2. Filling, re-filling or running the ISR with alternate supply of beams to the West Hall or the switchyard directly or from the ISR	Yes	Yes
3. No beams in the transfer channels but circulating beams inside the storage rings	Yes	No (2, 3) Yes (4)
4. No circulating ISR beams, but transmission of PS beams to the switchyard and the West Hall	No	Yes

8. Site Work

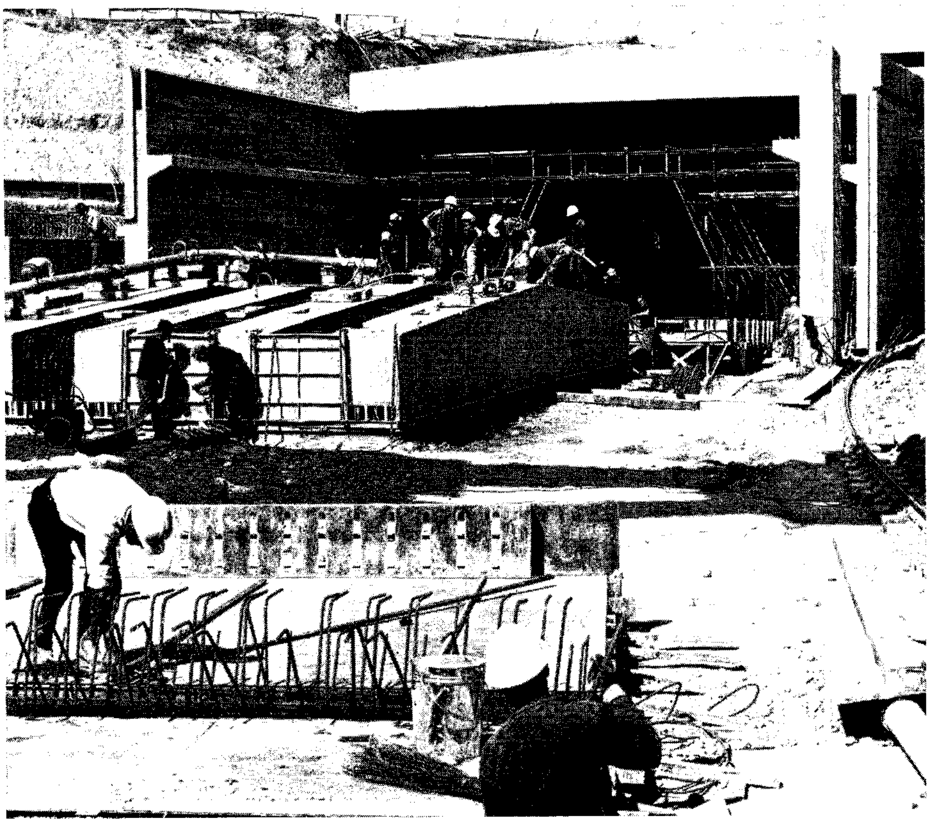
F. Bonaudi

During the summer, some of the ISR staff occupied their first buildings on the ISR site. These included the largest of them all — the huge (10 000 m^2) West experimental Hall (numbered Hall El on the site layout drawing). It is in this hall that all the components for the ISR will be assembled and tested before final installation. The hall had priority in the construction programme so that it would be ready to receive components, which have already started to arrive. As it is the largest experimental hall of its type in the world, it is useful to recall its main characteristics (see Table on page 281). Photographs of the exterior and interior of the hall can be seen on pages 182 and 183.

The construction effort on the rest of the project has now reached its peak, notably on the machine housing and on the beam transfer tunnels.

The circular tunnel in which the ISR rings will be housed has a diameter of about 300 m. It is much wider than is usual in the case of an accelerator, firstly because it must contain two magnet rings instead of one, and secondly because of the special geometry of the rings which involves eight 'bulges' in the orbits. In the centre of each of these 'bulges' the orbits of the two rings are nearly 9 m distant from each other. Therefore the net inside dimensions of the ring tunnel are 15 m wide and 6.5 m high. The machine has an eightfold symmetry (which, in the days of unitary symmetry, seems most appropriate for a particle physics project) and in principle it could be made in eight identical sectors. However, there are many other requirements (injection and ejection regions, pits under some intersection points to give more space for experiments, experimental halls etc.) such that there is little uniformity around the ring and the construction is quite complicated, each octant having its own special features. Two of the intersection points are to be initially equipped with experimental halls. I4 will have a hall 70 m by 25 m ; I1 a hall 50 m by 55 m with flexible shielding arrangements which can be readily adapted to different experimental requirements.

Since the ISR is a new type of experimental equipment, it is necessary to build it in as flexible a way as possible so that changes, or even major modifications, can



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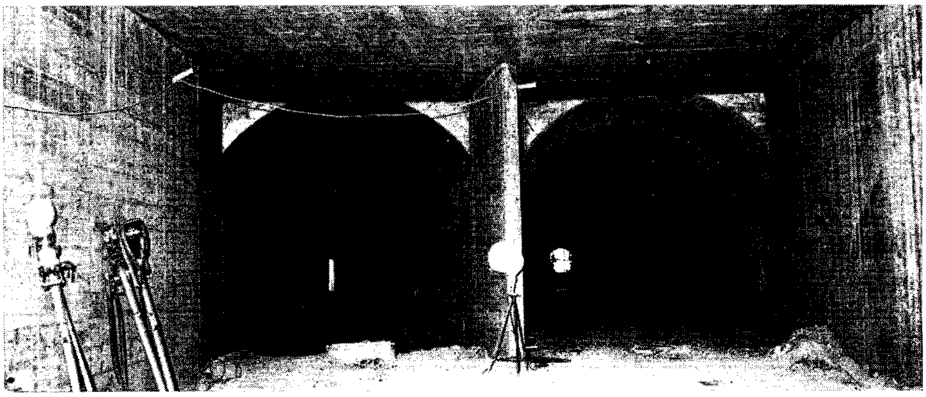


CERN/PI 291.7.68 3.

be easily made if they are found necessary. For example, additional experimental halls could be called for, involving dismantling part of the ring building itself. To make this possible, and to take advantage of modern prefabrication methods, most of the ring tunnel (nearly 75 %) has its main structure (walls and roof) assembled out of prefabricated pieces of reinforced concrete, each weighing 50 to 60 tons.

Excavation of the ring (carried out by a subcontractor, the firm Albanese of Italy) began in November 1966, and was completed within a year ; more than one million cubic metres of 'molasse', rock and aluvial soil were removed. Most of this was transported off the site but two temporary mountains have been left to be used for covering over the ring tunnel, when it is completed, with a depth of about 4 m of earth shielding. The main contractor (the firm Sogene of Italy) then set to work on the ring tunnel structure in the autumn of 1967 ; this consisted first of all in constructing the foundations and all the special elements required before the prefabrication could start.

The first prefabricated pieces were manufactured and assembled in March 1968. The prefabrication 'shop' moves around the ring as the work progresses at a normal rate of 15 metres per week. It consists of the forms for casting the concrete pieces, a steam-curing plant and a huge gantry crane which spans the tunnel structure. The fresh concrete is pumped to the forms via a system of pipes reaching all around the ring. Within six months the prefabrication shop has gone round one half of the ring and it is expected that by the autumn of 1969 the ring tunnel will be complete. One completed octant (Octant 3) is now being made ready for handing over to the rest of the project before the end of the year ; it includes the special magnet foundations, in the form of reinforced concrete beams of 3 different lengths (6, 10 and 15 m, the last two types being prestressed), the survey monuments, one pair of 30-ton cranes, lighting, etc.

In this octant the installation of all the numerous ISR components (magnets, vacuum equipment, cables, piping, controls etc.) will start and it will serve effectively as a full-scale model to test the assembly procedures. The remaining octants will be

1. Prefabrication of the blocks of reinforced concrete, each weighing 50 to 60 tons, which are used to build up the ISR ring tunnel. A partly completed section of the tunnel can be seen in the background. The prefabrication 'shop' moves round the ring as the construction progresses.

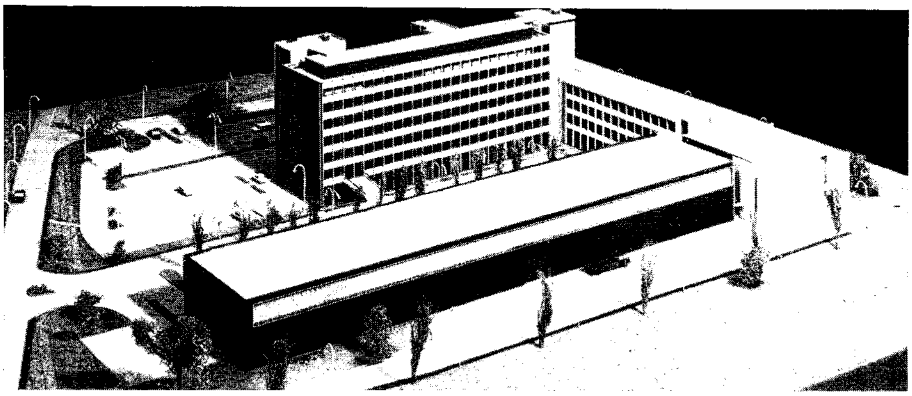
2. Looking down into the ISR canyon at Octant N° 1 of the ring tunnel. Work is in progress on the next octant (to the right on the photograph) and the large gantry crane which spans the tunnel can be seen.

3. Beam transfer tunnels. These, for the most part, are actually tunnelled through the ground rather than being excavated and then covered over. At this particular point, a magnet will switch beams coming from the PS either down the right tunnel (to enter Ring 1 or to go to the West Hall) or down the left tunnel (to enter Ring 2).

4. A model of the block of buildings which will house the power supplies for the main magnets and the cooling water plant (the long low building in the foreground), the ISR control room (on the right), a workshop (at right angles), and the office and laboratory building (behind).

5. An exterior view of the huge West experimental hall with the Jura mountains in the background. This photograph was taken when the finishing touches were being put to the building in August. The two low buildings to the left are the temporary offices for the staff carrying out testing and assembly work in the hall.

6. An interior view of the West Hall. In the foreground is the area reserved for magnet assembly and testing. The hall will soon be filled with ISR components being made ready for the rings. At the far end of the hall can be seen one of the huge cranes which span the full width of the building.



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Characteristics of Hall EI

Length		159.35 m
Width		63.70 m
Internal height		20.40 m
Floor area		10 150 m^2
Enclosed volume	about	20 000 m^3

* Cranes : one of 60 ton, one of 40 ton (Hook height 9.5 m)

Type of construction :
reinforced concrete understructure ; steel pillars and girders ; metal cladding
Foundations :
longitudinal walls are supported by 182 piles of 0.8 m diameter, having an average length of 12 m ; floor slab rests on a 3 m backfill of compacted gravel
Service tunnels :
8 transversal and one longitudinal tunnels of cross-sections ranging from 2.5 x 2.65 m^2 to 2.5 x 3 m^2, for a total length of about 660 m
Electric power available :
2050 kVA (1st stage)
* Other services :
compressed air, water (cooling and fire hydrants)
* Heating system :
radiating panels and air blowers (each 50 % of the total capacity)

(Technical Services and Buildings Division was responsible for these installations.)*

handed over progressively during 1969 and the installation of the machine is planned to proceed in step.

About 80 % of the beam transfer tunnels have been made, most of them by tunnelling through the rock ; the junction to the PS was completed during the recent long shut down and is now blocked by temporary shielding, awaiting the day when the beam ejection and transfer equipment are installed.

Work is also in progress on the construction of the auxiliary (equipment) buildings around the main ring building and on several kilometers of service tunnels interconnecting them. Work on the block of buildings comprising the Power and Cooling Rooms, the ISR Control Room, workshop, and offices is also under way or is about to start.

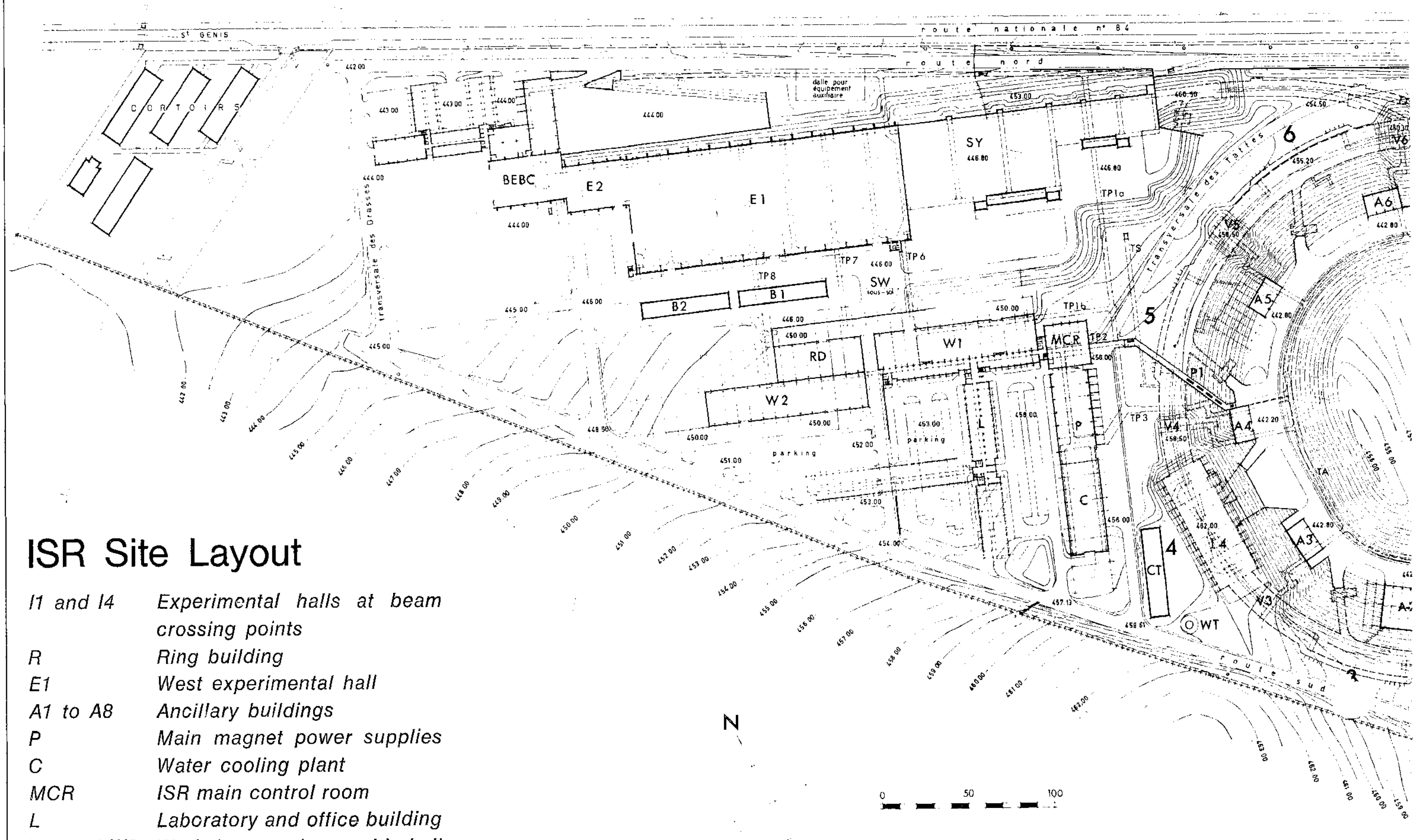
Contractors and suppliers

a) Civil Engineering

1. Main contractor :	Sogene (Italy)
2. Subcontractors :	
Excavation work	Albanese (Italy)
Steel construction	Schweisswerk Bülach (Switzerland)
Cement supplier	Vicat (France)
Reinforcing steel maker	Von Roll (Switzerland)
Reinforcing steel supplier	Noverraz L'Huilier (Switzerland)
Cladding (walls and roof)	Robertson Galbestos (Switzerland)
Windows	Keller (Switzerland)
Skylights	Metallzug (Switzerland)
Motorized doors	Bolton Gate Co. (UK)
3. Others :	
Painting	Birkle & Thomer (Federal Republic of Germany)

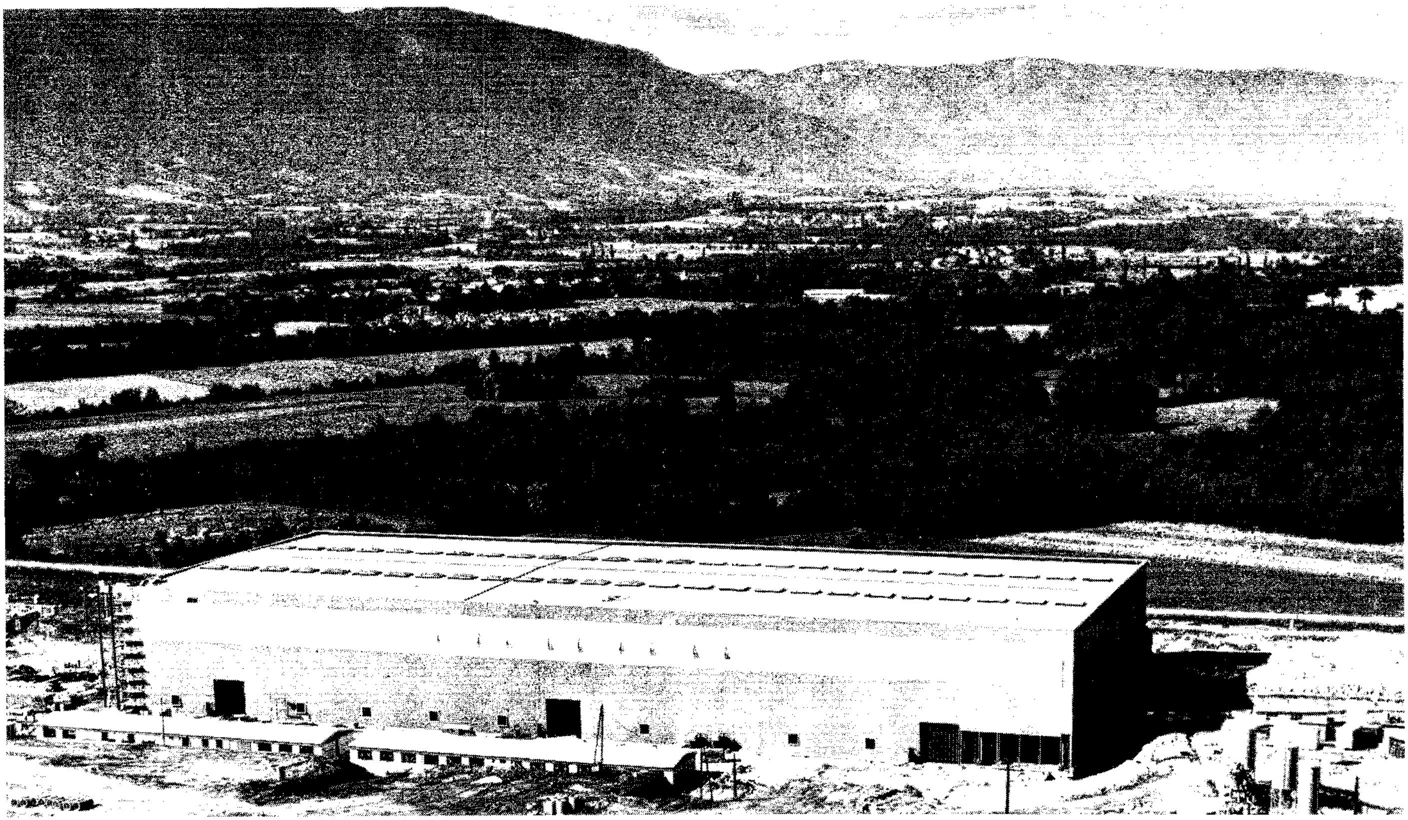
b) Technical Installations

Cranes	De Bartolomeis (Italy)
Heating	Aster (Italy)
Piping	Nordon, Fruhinsholz, Diebold (France)
High voltage cubicles and switchgear Low voltage cubicles	Panel-Gardy (Switzerland)
Power transformers	Lepper (Federal Republic of Germany)
Lighting appliances	Atlas (UK)
Electric installations	Rhône-Electra (Switzerland)



ISR Site Layout

I1 and I4	Experimental halls at beam crossing points
R	Ring building
E1	West experimental hall
A1 to A8	Ancillary buildings
P	Main magnet power supplies
C	Water cooling plant
MCR	ISR main control room
L	Laboratory and office building
W1 and W2	Workshops and assembly hall
SY	Switchyard
SW	Electricity sub-station
TT1 to TT3	Beam transfer tunnels
TP1 to TP8	Service tunnels
TA	Tunnel connecting ancillary buildings
TS	Calibration tunnel for alignment
P1	Bridge
V1 to V8	Air conditioning rooms
WT	Water tower
PST	Pumping station and water reservoir
CT	Cooling towers
B1 and B2	Temporary office accommodation
Y	Power supplies for beam transfer channels
E2	Annexe to the West Hall
BEBC	European bubble chamber buildings
RD	Power supply building



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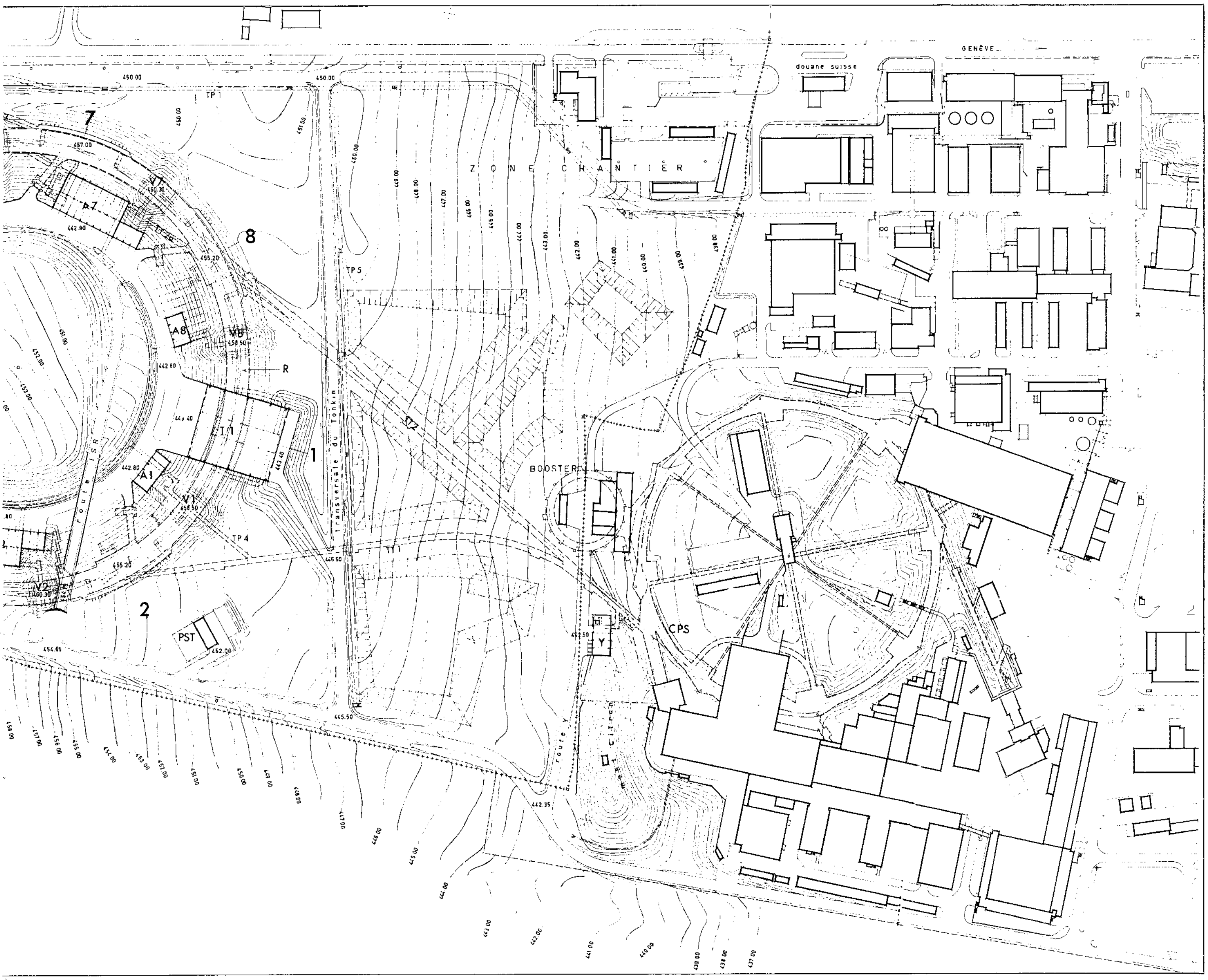
5.



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6.

9. Alignment

J. Gervaise

The 28 GeV proton synchrotron, the transfer tunnels and the intersecting storage rings make up one of the two largest complexes in the world designed for subnuclear physics research. To the surveyors of the ISR Metrology Group it consists of more than four kilometres of tunnels in which some 1500 components have to be installed with a relative accuracy of a tenth of a millimetre. To achieve this, use is made of 'microgeodetic' or 'macrometrological' methods, most of which have originated at CERN itself since 1954 and have been continuously developed to incorporate the advances made in a technology which is still evolving.

Civil engineering work

The limited width of the site (a ring 300 m in diameter has to be installed in an area of land barely 400 m wide) and the amount of earth-moving involved have made the alignment work difficult. The depth of the excavations — up to 25 m in some places — has disturbed the natural stability of the ground. Movements due to the changes in mechanical balance on the site have been further accentuated by disturbance of the hydro-geological balance. Pillars sunk into the upper layers of the soil on the site, which serve as reference points, moved sideways by as much as two centimetres and vertically by about a centimetre.

Geodetic methods, involving repeated triangulation with a 600 m base to keep the triangulation to scale (Figure 1) have maintained an accuracy of 1.5 mm in the reference points for the axis of the ring and for the transfer tunnels (Figure 2).

Design of measuring instruments

While triangulation has provided an accuracy of 1.5 mm for the civil engineering work, even higher precision (of the order of a tenth of a millimetre) is necessary in the installation of the ISR equipment such as magnets. This requires individual measurements made to within a few tens of microns (a few ten thousandths of a millimetre). Fortunately, improvements in the methods of measuring distances have been made over the past ten years in response to the increasing scale of construction work and of 'scientific equipment' which still impose the same, or more severe, requirements for accuracy.

The whole of ISR alignment is based on distance measurements. The basic standard is a 4 m Invar metal rule on a calibration bench which will be installed in a new air conditioned tunnel. Using this bench it is possible to measure a length of 50 m accurate to within 5 microns. The next step is to transfer the length thus calibrated between the points to be measured, and, to this end, the group's mechanical and electronic workshop has designed some new instruments :

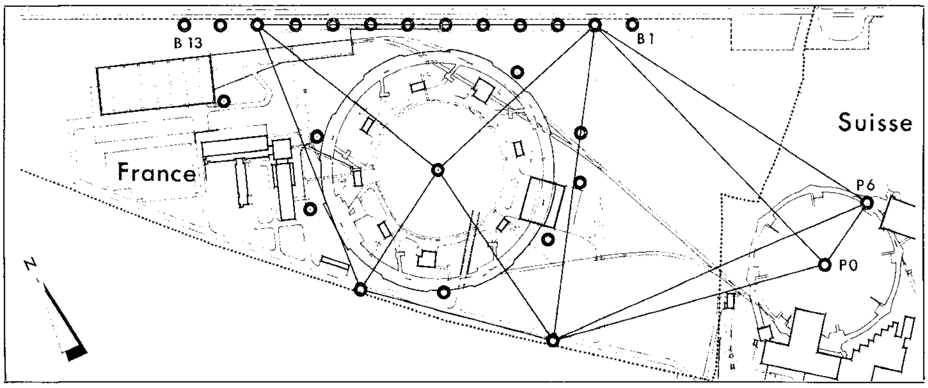
- The 'Distinvar' (which was described in CERN COURIER vol. 7, page 251). This instrument is now fully automatic and is connected directly to a computer. It uses Invar wires and measures to an accuracy of 15 microns over 50 m.
- The mekometer, designed in cooperation with the National Physical Laboratory at Teddington. This electronic distance measuring instrument, which uses the modulation by a high-frequency field of the plane of polarization of light, allows distances from 50 to 600 m to be measured to within 0.2 to 0.4 mm.
- An alignment instrument using a laser beam for simultaneous measurements in the horizontal and vertical planes. Its accuracy in air up to 40 m is from seven to eight hundredths of a mm.

Metrology

In the tunnel of the ISR itself, a double ring of pillars make up a closed set of braced quadrilaterals (Figure 3) and the six lengths in each quadrilateral will be measured with the 'Distinvar'. Within each quadrilateral, magnets will be installed at positions given by distance measurements taken from the relevant four pillars.

The transfer tunnels (Figure 4) are the most delicate part of the ISR geometry. They involve the alignment of a beam channel consisting of long straight sections followed by curves in which the inclination changes ; the alignment is therefore to be made in three-dimensions simultaneously. The guiding framework will be provided by pillars set up at regular intervals along the beams.

The elimination of angular measurements, which are always troublesome and time-consuming, and the great flexibility afforded by the distance measurements will go a long way towards reducing the time needed to align the ISR components. This saving of time will also apply when experiments are being set up around the intersection regions. There is the possibility of settlement of the ground in these regions when experimental equipment is installed, and time may be required to realign some of the ring components during the installation of the experiment.



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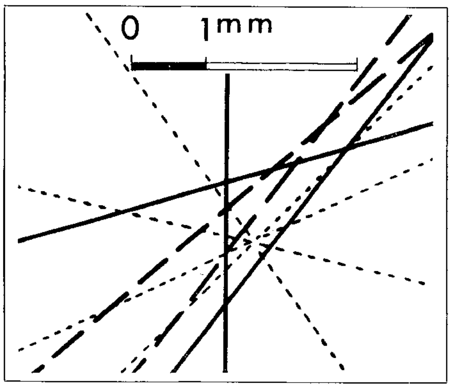


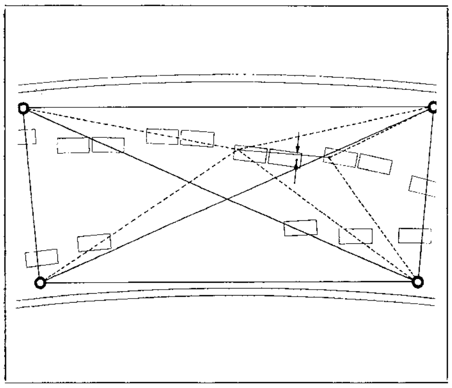
2.

1. *The Triangulation scheme used to establish the reference points for the axis of the ring and for the transfer tunnels.*
2. *Triangulation in action*
   - ———————— *intersection*
   - . . . . *bearing*
   - — — — — — — *intersection from neighbouring axis points*

3.a. *The double ring of pillars to make up a closed set of braced quadrilaterals to align the ISR components to an accuracy of a tenth of a millimetre.*

b. *Alignment of magnets within a quadrilateral.*

4. *The arrangement of pillars for aligning components in the beam transfer tunnels.*



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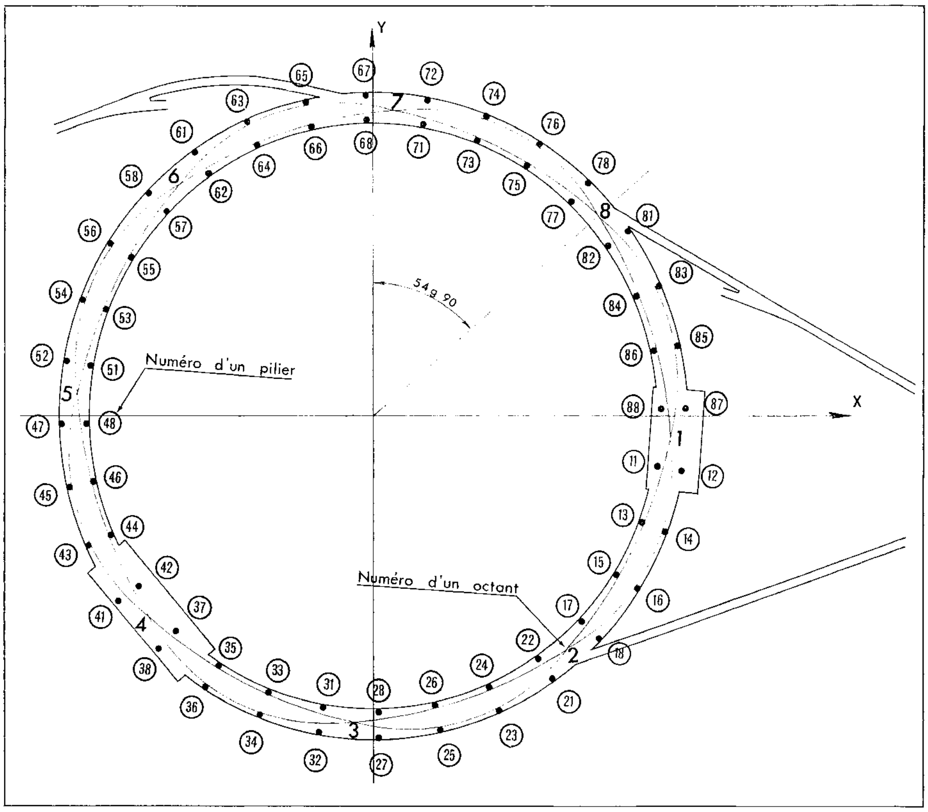

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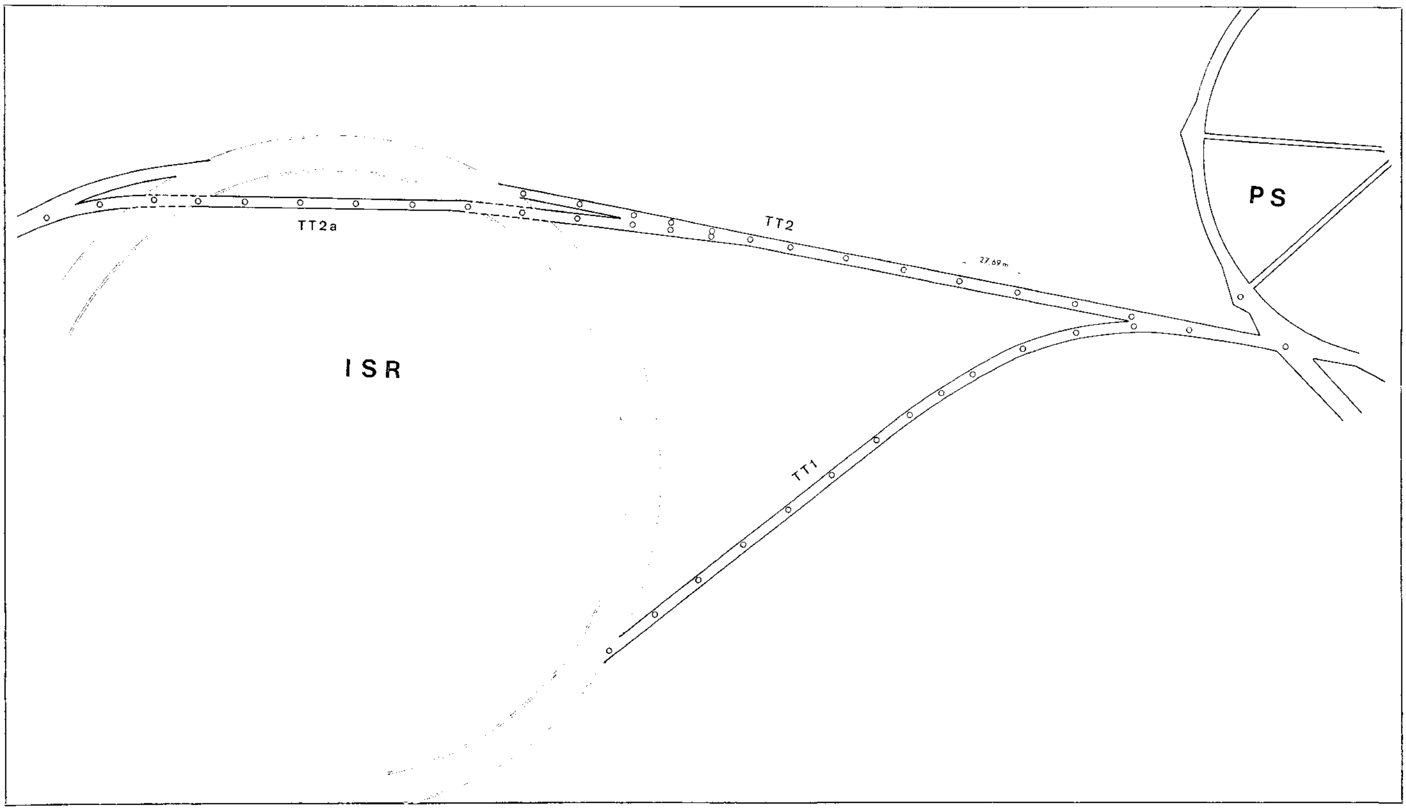


4.

ISR Experiments

A preliminary look at the types of experiment which could be mounted at the ISR when they come into operation in 1971.

The time is fast approaching when the thoughts about possible experiments at the ISR have to take definite shape so that experiments will be ready for the date when colliding beams become available. Two years may seem ample time to prepare an experiment but experimentation at the ISR is likely to take much longer in preparation than at a conventional accelerator. The experimental set-up will involve an integral part of the ISR and will not be something fed from afar with particles. Problems such as ensuring that the magnets used in the experiment do not disturb the delicate stability of the circulating beams, ensuring that the vacuum vessel in the interaction region is appropriate for the experiment, and so on, may well involve the installation of unique components which cannot be constructed overnight.

Since the beginning of this year a working party of experimental physicists and machine builders have met regularly to tackle some of these problems in detail. In June, participation in these discussions was extended to all interested European groups when an ISR Users Meeting was held at CERN. More than a hundred potential users took part and the interest that was generated has led to several European collaborations becoming busy developing proposals for experiments. A second Users Meeting is scheduled for 2, 3 December.

Experimental equipment

It is probable that in at least one of the two interaction regions, where experiments are initially planned to take place, a large general purpose magnet system will be installed. It would serve to analyse the high energy particles produced in the proton-proton collisions and its design would need to cover a rather narrow cone around the two downstream vacuum pipes. In this cone most of the high energy particles will emerge.

Several designs for such a magnet system are now under examination. Their main feature is that they must bend out the collision particles without, overall, disturbing the circulating beam. The system of magnetic fields must compensate for any effect on the beams.

Other devices will be needed to take measurements on the beam so that the experimenters know what sort of initial conditions have produced the particles they observe. Thus, for example, to make cross-section measurements information on the beam currents, the beam shapes and the volume within which the beams are interacting when they pass through one another is essential.

Methods of finding the beam shapes in the interaction regions such as by sweeping a thin wire at constant velocity across the beam have been proposed. A set of counter telescopes could be used to detect the forward emitted particles from collisions with the wire.

Some possible experiments

The range of energy beyond that available at present machines is often called the 'asymptotic region' since the energy extends to infinity. It is expected that particle phenomena will become much simpler at much higher energies and thus more easily understood. By reflecting backwards to present energies it is possible that much of the still confused behaviour that is now observed will become clearer.

The ISR is going to give a limited look into a very high energy region. Several 'expectations' can be put forward but most of the fascination in using the ISR lies in the fact that no-one knows what phenomena will be revealed — Nature has always proved richer than man's imagination.

Experiments at the energies available on existing accelerators have given evidence of two dominent mechanisms in particle interactions — particularly in the two-body or quasi two-body interactions (those involving two incident particles and two outgoing particles). These mechanisms are known as diffractive processes and exchange processes. With the diffractive process the outgoing particles have the same internal quantum numbers as the incident particles ; with the exchange process the outgoing particles have different internal quantum numbers — and hence the name 'exchange' since something carrying quantum numbers must have passed between the incident particles in the interaction.

A striking difference in the behaviour of the two processes is seen in the limited energy range investigated so far, namely that they vary with energy in a very different way. If no quantum numbers are exchanged, the cross-section for the interaction varies little as the energy is increased but if quantum numbers are exchanged the cross-section falls off very rapidly as the energy is increased. (Also, there appears to be hierarchy in the quantum numbers — the rate of fall off depends upon what is exchanged.) To take a specific example — the cross-section of the two body process involving the N* resonance of mass 1238, which has a different isospin quantum number

$$p + p \rightarrow n + N^{*++}\ (1238)$$

will be down by a factor of a thousand at full ISR energy, if it continues to fall at the rate observed so far.

Since the ability to trace phenomena over a very big energy range is one of the prominent experimental features of the ISR, it will be possible to extend the study of these differences in considerable detail.

One of the first experiments to be done will be the measurement of the proton-proton elastic scattering.

$$p + p \rightarrow p + p$$

It is expected that, even at the very high energies available, the elastic scattering cross-section will be a significant fraction of the total cross-section — that protons will continue to bounce off one another very often rather than transforming into other particles. One of the first things the experiment will reveal is whether this expectation is true.

The way in which they 'bounce off' says something about the size and the structure of the particles. Does the proton effectively grow in size in higher energy interactions ? What is the proton structure — does it have an irreducible, hard core with a diffuse sphere of influence around it ? What is the mechanism of the scattering process ? Measurements of the angular distribution of the scattered particles and the way this distribution varies with energy, together with some theoretical ideas, will give answers to this type of question.

At energies so far investigated in the GeV range, the elastic scattering is largely 'diffraction scattering' where the distribution of the scattered protons is strongly influenced by the many possible 'inelastic' processes (where other particles are formed) which can occur. The angular distribution is strongly peaked in the forward direction, in other words, the scattered protons move predominently in the direction of the incident particles. This diffraction peak has been shown to shrink (its width decreasing) with increasing energy. It is the detailed shape of this diffraction peak and its variation with energy which will be of interest at the new energies made available at the ISR.

To point to a few of the experimental complications. A special vacuum chamber with thin walls will be needed where the scattered protons emerge to avoid losing precision in the measurement of their true scattering angle due to the scattering introduced in the walls. Care will be needed to ensure that the measured protons come from a true beam-beam interaction and not from a collision with a proton in the residual gas in the vacuum vessel. (The fact that the two scattered protons would lie almost along the same line travelling in opposite direction will help to distinguish them correctly.) Also the momentum measurements on the scattered protons must ensure that no other particles have been produced in the collision (the event would then not be an elastic scattering event). Wire spark chamber and counter arrays could be used to detect and measure the trajectories of the protons.

A further development, which could take place if it proves possible to accelerate deuterons in the PS and store them in the ISR, would be to investigate the proton-neutron interaction. It should be possible to extract the proton-neutron scattering occurring in the deuteron, assuming that the proton-proton scattering is known.

Total cross-section measurements, by observing the loss of particles from the interaction region, is another important experiment taking in both elastic and inelastic scattering. The way in which the total cross-section of the proton-proton and the proton-neutron interaction varies with energy is of fundamental importance to check ideas about the asymptotic nature of strong interactions. The expectation is that at sufficiently high energies the cross-section will no longer vary with energy and will become equal for both interactions.

One of the first experiments will be a survey type experiment which adds up the energy of two outgoing protons to see what they have lost in the interaction. It may emerge that particular amounts of energy are frequently 'lost' indicating that particles, equivalent in mass to these lost energies, are being produced.

The production of other particles when two high energy protons collide is an obvious source of interest. It is another way to look at the structure of the proton.

When two protons collide they may shake each other so violently that other particles are shaken off from them. If the proton is considered as a cloud in which there is some sort of structure, the production of new particles can be considered as the tearing away of part of the cloud. The most prolifically produced particle is the pion, which is a light particle easily knocked off from the proton — energies of around 140 MeV are sufficient. They can be considered as the constituents of the outer rim of the cloud. At higher energies, kaons and hyperons, or, at higher energies still, pairs of nucleons can be produced as if coming from deeper in the proton structure.

As energies at conventional accelerators have been pushed higher, the predominant observation in particle production has been that, as the proton is shaken more and more violently more and more pions are produced. (The predominant observation might have been that, instead of more and more pions, fewer heavier particles were produced). The colliding protons fly off with their clouds excited to high energy (these excited states are called isobars) and return to their normal state by emitting pions. In such a collision very little of the available energy goes into the production of new particles. The 'normal state' protons which result still keep say 60 % of the initial colliding proton energies. Occasionally, however, the protons share the full energy of the collision forming for an instant something like a hot droplet from which heavy particles can boil off.

To examine these phenomena at ISR energies will be very intriguing. Again the experimental demands will be quite stringent and detection arrays will have to cope with the production of many particles per collision.

Two searches for heavy mass particles of vital interest in sub-nuclear physics become much more interesting with the energies available at the ISR.

The first of these is the quark, the particle postulated to explain the observed patterns in the list of strongly interacting particles. The experimental searches so far indicate that if the quark exists it has a mass probably in excess of 2.5 GeV. But the high energy of the ISR may be ample for production of the quark.

The second elusive particle is the intermediate vector boson, the postulated mediator of the weak interaction (just as the pion is the mediator of the strong interaction and the proton of the electromagnetic interaction.) Experiments at conventional accelerators have failed to reveal the W and suggest that if the particle exists its mass is in excess of 2 GeV. Here again the high energies available at the ISR could be ample to produce the intermediate boson.

These are some general thoughts about the experimental programme at the ISR. The detailed work on preparing proposals for specific experiments is now under way.

Colliding beam projects elsewhere

Reports on the status of colliding beam projects in operation, under construction, or planned, at other Laboratories.

Novosibirsk

The most adventurous of all the colliding beam projects is that under construction at Novosibirsk, USSR, under the leadership of Professor G. Budker. The aim is to achieve 25 GeV proton-antiproton collisions.

The Laboratory has already built and operated an electron-electron machine (VEP I, 160 MeV) and an electron-positron machine (VEP 2, 700 MeV) which have contributed to some important experimental results in sub-nuclear physics. VEP 2 is temporarily shut down for improvements.

An element of the proton-antiproton machine was a smaller, separate ring built inside the main ring to be used for antiproton storage where electron cooling would damp the oscillations in the antiproton beam (see CERN COURIER vol. 7, page 88). This smaller ring was also designed to operate with electron-positron beams with energies of 3.5 GeV. It has become known as VEP 3.

It is now probable that this ring will be given exclusively to electron experiments. Closer examination of the electron cooling problems indicated that radiation levels would be uncomfortably high and that the cooling time would be too long. To build up the shielding would have meant abandoning the use of the ring for electron-positron colliding beams. All the magnets for this ring are complete and are ready to be installed. A 500 MeV injector synchrotron is being installed. The ring will probably be used first for tests on electron cooling using 200 MeV protons and 100 keV electrons.

A further small ring may now be added outside the main ring. It will have four 7.5 m straights with four 3 m radius magnet sections (a square with the corners rounded). One straight will be used for injection and ejection and the other three for electron cooling. This will reduce the cooling time to 100 s.

The operating sequence is —

1. Accelerate 10^{13} protons to 1.8 GeV in an injector synchrotron.
2. Transfer to main ring ; repeat ten times trapping 10^{14} protons (the calculated space-charge limit is about 3×10^{13} but it is hoped that this can be exceeded) ; accelerate to 25 GeV (over 20 s).
3. Eject into target to produce antiprotons (it is estimated that the conversion and capture efficiency will yield 10^8 antiprotons at 1 GeV).
4. Feed antiprotons into the small ring and electron cool them for 100 s ; re-inject into main ring.
5. Inject 10^{14} protons, as above, into main ring ; accelerate both beams travelling in opposite directions to 25 GeV.

This would give colliding beams of 10^{14} protons against 10^8 antiprotons, and a luminosity of $10^{28}/\text{cm}^2$ s. If the antiproton capture efficiency is down a factor of ten and if the calculated space charge limit proves correct, the luminosity would be down to about $3 \times 10^{26}/\text{cm}^2$ s. The total filling time is 200 s and the beams will have a lifetime of about 20 min.

Some thought is still being given to the construction of an ironless synchrotron of 10 m radius and 120 kG field to give 25 GeV protons. If intense beam of protons could be accelerated in this way and transferred to the main ring, it would avoid any trouble with the space-charge limit. But its main purpose would be to serve as a more efficient source of antiprotons.

Construction of the main ring is scheduled to be completed in 1970 and it is estimated that, if all goes well, experiments could start mid-1971 (the same time as with the ISR). It is known as VAP 4 (A for antiproton) and could eventually be used for — 25 GeV proton-antiproton ; 6 GeV electron-positron, 6 GeV proton-electron or 6 GeV antiproton-positron collisions.

Stanford

For several years now, a project for a 3 GeV electron-positron storage ring has been on the table at the Stanford Linear Accelerator Centre, USA.

The proposal is to use electron and positron beams, generated in the 20 GeV electron linear accelerator which came into operation in 1966. The beams, with energies up to 3 GeV would be fed into a single ring, 65 m in diameter, and built up in intensity to 1 A circulating in each direction. The beams would be separated vertically by electrostatic fields set up by electrodes inside the vacuum chamber. The fields would be arranged so that the beams intersect at one or two positions in the ring.

With 1 A circulating in each beam the anticipated luminosity is $1.3 \times 10^{32}/\text{cm}^2$ s at 3 GeV. The luminosity increases for lower energy beams of higher intensity.

A 3 GeV electron circulating in such a ring loses energy by synchrotron radiation at the rate of 563 keV per turn. To compensate this loss for two 1 A beams requires 1.13 MW of power and six r.f. cavities are planned with a total power of 1.3 MW.

With the available positron intensities from the linear accelerator, the positron filling time to build up a circulating current of 1 A is about 1 s. A total filling time for the electrons and positrons of the order of 2 s would therefore be needed and the operation of the storage ring would interfere very little with the normal operation of the linear accelerator. Beam lifetimes in the storage ring would be over two hours with a pressure, in an aluminium vacuum vessel, of around 10^{-9} torr.

The storage ring would be built so that the beam energies could be increased to 4.5 GeV at a later date if it proved desirable. This would involve little modification to the magnets, more magnet power and more r.f. power.

The proposed cost of the project, including a large detector and contingency, is $ 19 million and the construction programme covers 3 ½ years. It is hoped that the project will be authorized in the next fiscal year (beginning 1 April 1969).

Frascati

The 1.5 GeV electron-positron storage ring ADONE at the Frascati Laboratory in Italy, was described in CERN COURIER vol. 8, page 12. Operation has not begun as smoothly as had been hoped and the experimental programme has been delayed. A thorough investigation of beam behaviour in the ring has been instigated, and tests are now under way using single beams of electrons or positrons.

With electron beams, currents of up to 200 mA can be obtained without any difficulty in one bunch in the presence of ions, using the focusing effects of the ions.

Phase instabilities (the relative motion in phase of the bunches) have been cured in a clever way by splitting the synchrotron oscillation frequencies of the individual bunches by a few percent.

With positron beams, currents of up to 25 mA (5 x 10^{10} positrons in the ring) have been stored using an injection rate, which is not yet optimized, of 10 mA/minute (1.5 pulses/s). Transverse instabilities appear for positron beams at a very low intensity threshold. The threshold does not depend on the total charge stored but on the charge per bunch. This, together with other observations, indicates that the instability is due to short duration forces acting within each bunch. It is being investigated further.

The vacuum system has not yet been baked and the base pressure is usually around 10^{-9} torr. When beams are injected, there is quite a high rise in the pressure. Experimental groups have carried out background measurements and it appears that the background should not be troublesome with pressures in the range of 10^{-9} torr.

DESY

The electron synchrotron Laboratory at DESY, Hamburg, in the Federal Republic of Germany has a project for 3 GeV electron-positron colliding beams.

The proposal is for two separate rings stacked one on top of the other (a similar arrangement to the four stacked rings of the CERN proton synchrotron booster). One ring would receive electrons and the other ring positrons, orbiting in opposite directions. The beams would be brought into collision in two interaction regions located at the centre of two 60 m long straight sections. These straight sections will also contain the r.f. cavities to restore the energy lost by synchrotron radiation (twelve cavities per beam providing a total power of up to 1.3 MW). The vacuum system will be bakeable to achieve an operating pressure of 10^{-9} torr.

The configuration of the storage rings in relation to the 7 GeV electron synchrotron and the injector is shown in the diagram. Beams could be taken to the rings after preliminary acceleration in the synchrotron or directly from the new injector which is now under construction and will be operational in about two years. For the production of positrons, a positron converter will be used like the one in use for ADONE.

With the installed r.f. power the stored currents could be taken to 1 A in each beam at 3 GeV, or 10 A in each beam at 1.5 GeV. The calculated luminosity is of the order of 10^{33}/cm^2 s at 3 GeV.

Using the synchrotron to accelerate the beams prior to transfer into the storage rings, electrons could be transferred at energies up to 2 GeV and a current of 25 mA, involving a filling time of 3 s for 1 A stored beam. Positrons at the same energy and a current of 1 mA would need almost 1.5 min filling time. Thus the filling of the storage rings would interrupt the normal operation of the synchrotron for a few minutes. The lifetime of the beams in the storage rings would be about 7 hours.

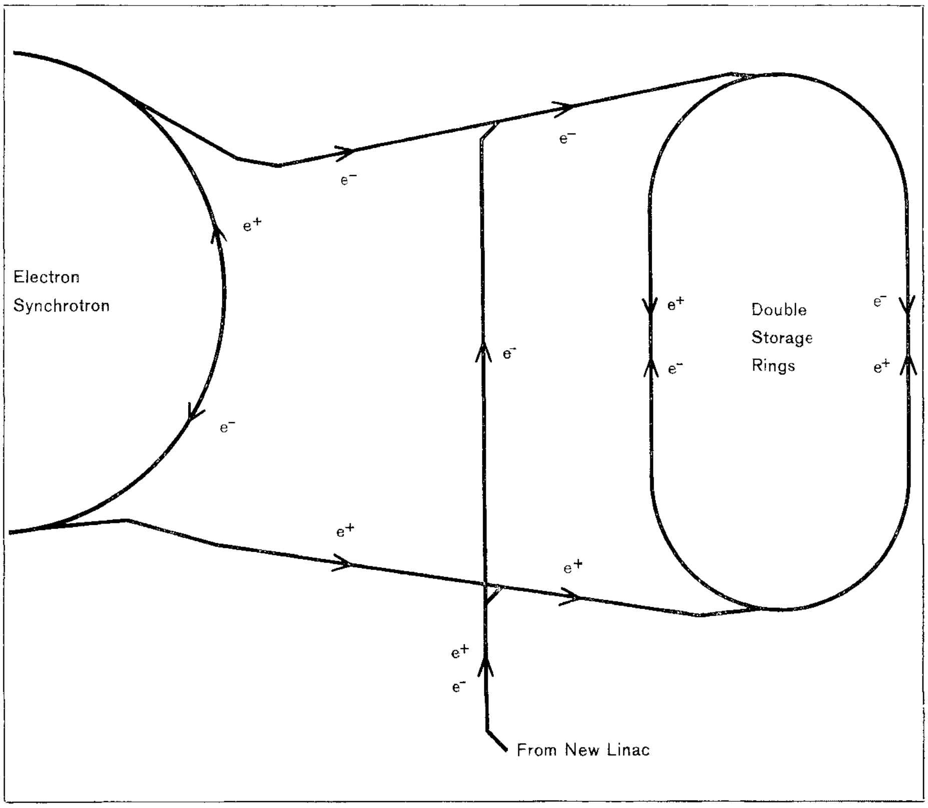
If the linac is used to inject directly into the storage rings, normal operation of the synchrotron would not be interrupted. However, the beams would be of low energy (perhaps eventually up to 500 MeV) and the filling time for positrons could be about forty minutes. The different beam paths involved can be worked out from the diagram.

It is expected that authorization for the construction of the storage rings will be forthcoming at the beginning of 1969. Colliding beam experiments could then begin in 1974. The total cost of the project is estimated at 70 million DM.

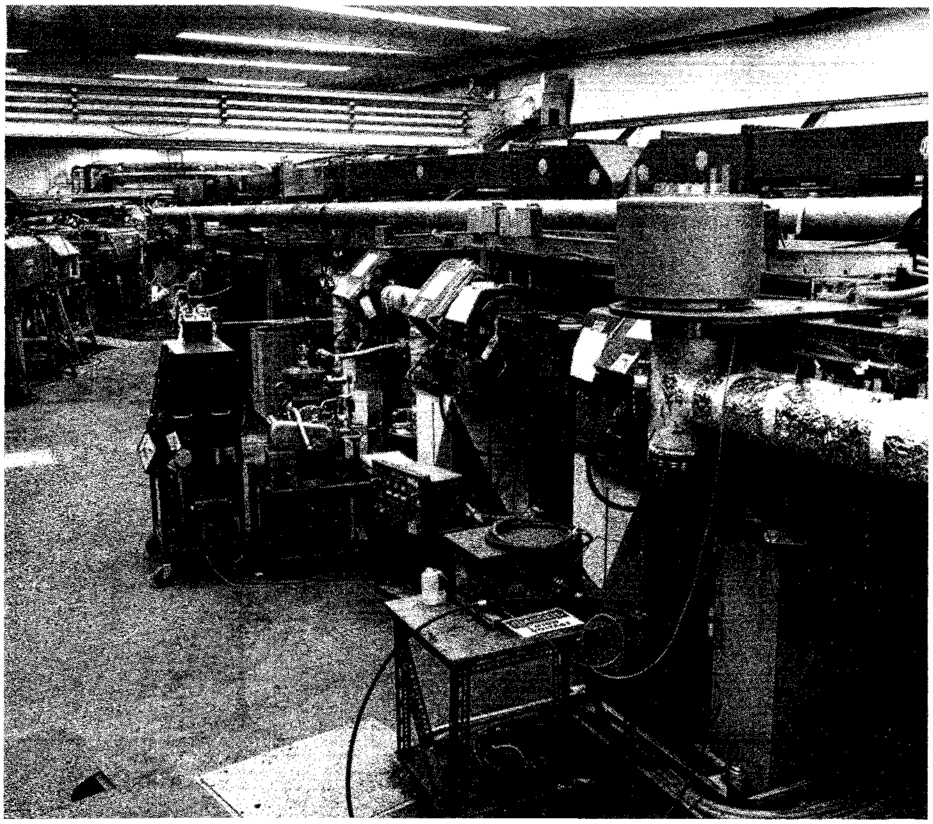
Cambridge

The construction of 'Project Bypass' to give electron-positron colliding beams at energies of up to 3.5 GeV is well advanced at the Cambridge Electron Accelerator Laboratory in the USA.

The project uses the existing 6 GeV electron synchrotron both to accelerate the two beams and as the storage ring when colliding beam experiments are under way. A special loop about 40 m long has been added through which particles can travel bypassing part of the synchrotron ring (see photographs). When the electrons and positrons have been accelerated to the



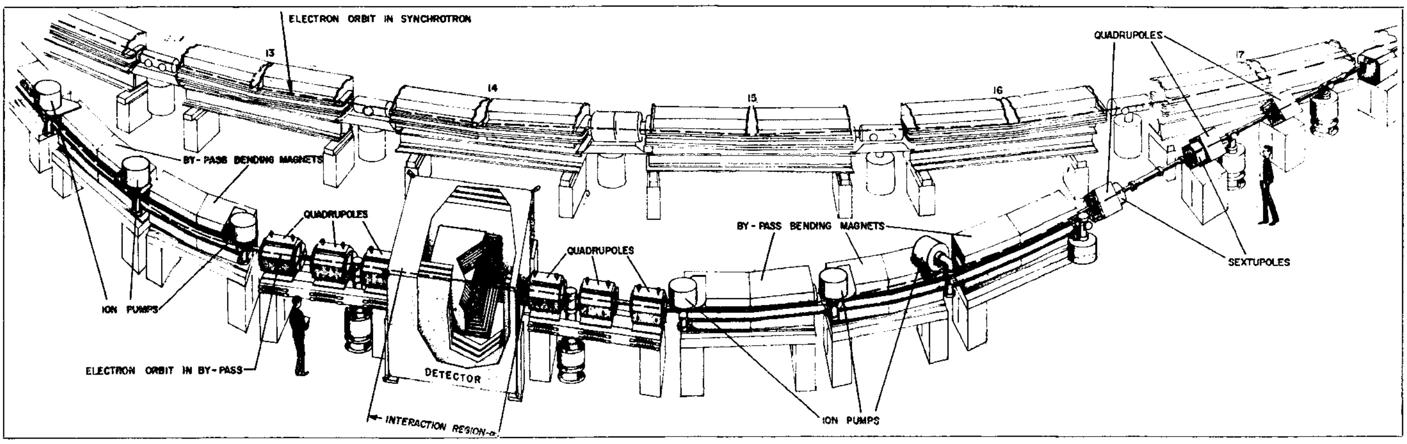
A schematic representation of the proposed double storage rings at DESY and their relationship to the existing synchrotron and to a new injector which is under construction. The beam paths which are indicated show how the rings can be filled using preliminary acceleration in the synchrotron or using the injector only.



The photograph shows the west half of the CEA bypass (on the right) which joins the synchrotron close to where the technician is standing. On the extreme left is a beamline for ejected electrons (not related to the bypass).

Below is a schematic representation of the bypass. Behind can be seen the normal particle trajectories in the synchrotron ; in front is the configuration of magnets in the bypass.

(Photographs CEA)



required energy following their normal circular paths in the synchrotron, the magnetic field in the ring is held steady so that the particles are stored, orbiting at a fixed energy. Special magnets are then switched (rise-times of about 100 ns) so that the beams travel on each orbit through the bypass where the collisions take place.

The operating sequence is as follows : Positrons are injected into the synchrotron at an energy of 120 MeV using multi-cycle single turn injection. For each injected pulse the synchrotron goes through part of its normal accelerating cycle (up to 2.75 GeV) coming back to the injection energy. This process damps the particle oscillation amplitudes and makes room for injection of the next pulse. The total filling time to built up the required positron beam intensity (peak current 0.1 A) is about 16 s. When sufficient positrons are circulating, the magnet cycle comes back to the field level appropriate for the injection of an electron beam at 245 MeV (about twice that used for positron injection) to be built up to the same intensity (0.1 A) in less than 1 s, travelling in the opposite direction. Vertical electrostatic fields keep the beams apart. The two beams are then accelerated together to the required collision energy which can be chosen within the range 0.5 to 3.5 GeV. (The upper limit is set by the installed r.f. power which is needed to compensate for the synchrotron radiation from the beams and the limit could eventually be increased.) At 3 GeV the beam lifetime will be at least 1 hour.

When the beams have reached the required energy they are switched into the bypass where they collide head-on. The configuration of magnets for the bypass squeezes the beams (by a factor of about 140 in area) so that in the interaction region the luminosity will be high — 2 x $10^{31}/\text{cm}^2$ s. The bypass has a clear region just over 2 m long for the installation of detectors.

Work on the project has gone to schedule so far without meeting major difficulties. A special damping-magnet system to damp particle oscillations during the beam storage time has been installed in the synchrotron and it has proved possible to store 3.5 GeV electron beams for 6.5 minutes when the average gas pressure was 4 x 10^{-7} torr. A major improvement of the vacuum system, including the installation of ceramic vacuum chambers, is almost complete and will greatly improve the beam lifetime by taking the pressure down to around 10^{-9} torr. Such pressures have already been achieved in completed regions of the vacuum system. Within the bypass where the interactions take place still better vacuum will be achieved.

Multi-cycle injection has been successfully tested. Installation of the bypass itself is complete and the first tests taking beams through the bypass have started. The positron injector is scheduled to be installed early in 1969, and by mid-year it is hoped that all the components of the project will be ready for operation. Colliding beam experiments would then begin at the end of 1969.

News has just arrived that, during the night of 10 November, electrons were successfully orbited through the bypass for 700 turns, which in fact indicated that an unlimited number of turns could be achieved.

The test was carried out while the magnet was being cycled in its normal manner (as mentioned above, colliding beam operation will be done with the magnet powered d.c). This meant that appropriate conditions lasted for 0.5 ms while the field was effectively constant at the top of the magnet cycle. 0.5 ms corresponds to about 700 turns. The beam was switched through the bypass and was retained travelling through the bypass for 700 turns, indicating that when d.c. is applied an unlimited number of turns (subject to the usual limitations from gas scattering etc.) will be possible.

Jubilation reigns at Cambridge.

Orsay

A colliding beam project which is in operation and yielding significant experimental results is ACO (Anneau de Collision d'Orsay) an electron-positron ring, of maximum energy 550 MeV per beam, at the Orsay Laboratory in France. The report from ACO concentrates therefore on the experimental programme.

Early in 1968, an extensive study of the three vector mesons — rho (ϱ_0), omega (ω_0), and phi (φ_0) — began at ACO. The main interest lies in studying the leptonic decay of the mesons for which a number of theoretical predictions exist. The first experiment was reported last year (see CERN COURIER vol. 7, page 203) on the measurement of the rho branching ratio into an electron-positron pair.

In the experiments, the energy of each beam was in the range 320 to 520 MeV and the following events were selected :

- on the ϱ_0 : 800 $\pi^+\pi^-$ pairs and 1600 $e^+ e^-$ large angle pairs ;
- on the ω_0 : 230 $\pi^+\pi^-\pi^0$ events, 1600 $\pi^+\pi^-$ pairs, and 2100 $e^+ e^-$;
- on the φ_0 : 150 K^0K^0 events, 50 $\pi^+\pi^-\pi^0$ events, 1200 e^+e^- pairs, and about 40 $\pi^+\pi^-$ pairs.

This data has already yielded several exciting results which were reported at the Vienna Conference (CERN COURIER vol. 8, page 245), including :

- partial widths for the decay of the vector mesons into $e^+ e^-$ pairs ;
- the mixing angle of the ω_0 and φ_0 ;
- the width of the ϱ_0 (112 ± 12 MeV) which came out substantially higher than the value reported last year by the Novosibirsk group.

The data on pion pairs which were obtained during the omega experiment is now being evaluated to look for vacuum polarization or other possible effects. An improvement in the reliability of zero degree double Bremsstrahlung monitoring makes it possible to use the Bhabha electron-positron pairs at large angle around 510 MeV to put a limit on quantum electrodynamics. Other studies are going on ; in particular, the search for a possible progressive polarization of the beam due to synchrotron light emission (by looking for pairs of particles scattered within the same bunch).

Physics will continue along these lines during next year with a study of the phi decay into a positive and negative kaon. A third generation of spark chamber and counter equipment having a larger solid angle for detection than the existing one will make other experiments with low counting rates possible, such as the electron-positron annihilation into two gammas, the eta-gamma decay of the phi, as well as more accurate experiments on the three pion decays of the omega and phi.

An extensive programme of beam studies has been under way at the same time. Luminosities up to $2.2\ 10^{28}/cm^2\ s$ have been obtained at 510 MeV. During the physics experiments, one bunch in each beam was filled, which suppressed phase oscillations completely, at least in the range of currents necessary to achieve the luminosities stated above. Beam lifetimes range from 10 to 20 hours between 320 and 520 MeV and are mainly limited by the interaction of particles with gases desorbed from the walls of the vacuum chamber by the synchrotron radiation.

A thorough study of single bunch transverse instability over the full energy range of the machine revealed a simple dependence of the threshold : $I \sim EL\ \Delta\nu$, where E is the beam energy, L the bunch length and $\Delta\nu$ the betatron frequency spread of the particles. The $\Delta\nu$ dependence was directly confirmed by cancelling the machine non-linearities using an additional octupolar field which drastically lowered the threshold of the instability. It is hoped that when the vacuum chamber is next opened, which should occur soon, it will shed some light on problems in connexion with the interaction of the bunch with the vacuum chamber, the electrodes and the r.f. cavity. Efforts to increase the luminosity are continuing in various ways, such as incoherent increase of the beam transverse cross-section, and investigation of the optimum working point.

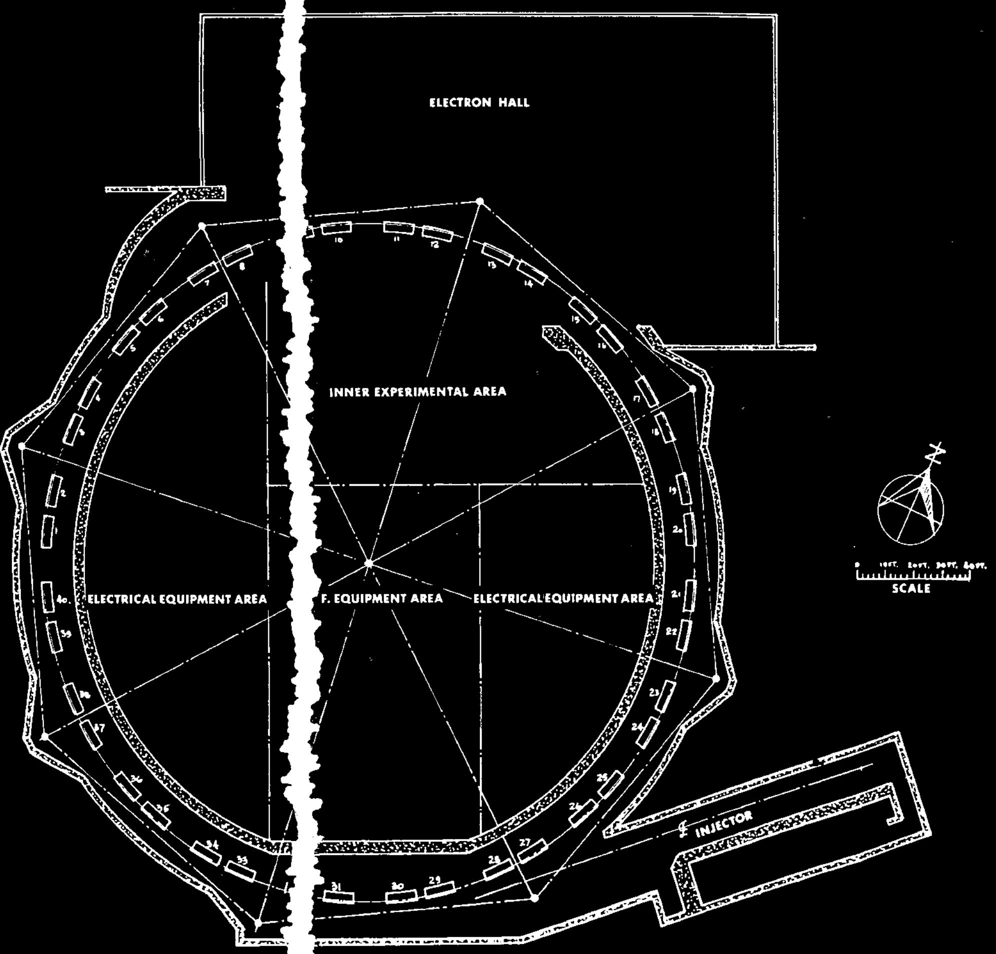
The progressive improvement of the ring performance as well as the success of the first physics experiments has lead to the consideration of a bigger ring for higher energy and luminosity. The possibility is being thoroughly investigated from the point of view of the physics to be done, keeping in mind those machine problems of existing storage rings which have not yet been solved.

Batavia

The USA 200 GeV accelerator Laboratory organized a Storage Ring Summer Study to investigate the design of storage rings which might eventually be built at the 200 GeV machine. Discussions had been held with experimentalists at Aspen concerning experiments using the storage rings and the outcome of these discussions had a major influence on the designs which were studied.

The bypass concept was abandoned because of the vacuum problem. In the main accelerator the pressure will be about 10^{-7} torr, which is good for an accelerator but poor for storage rings. Beam lifetimes would be short, severe radiation problems would be introduced in the main ring and, also, the accelerator would be inoperable for normal experiments during the time it was used for colliding beam experiments.

The design therefore concentrated on two concentric 100 GeV rings with six straight sections. Two of these would be used for injection into the rings, the remaining four being available for colliding beam experiments. Various magnet lattices were investigated, together with three different possibilities for the magnets — conventional magnets, cryogenic aluminium coil magnets (see CERN COURIER vol. 8, page 185), and superconducting magnets.


ELECTRON HALL
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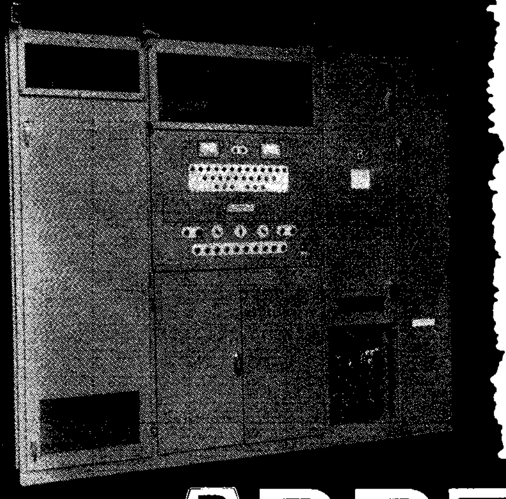

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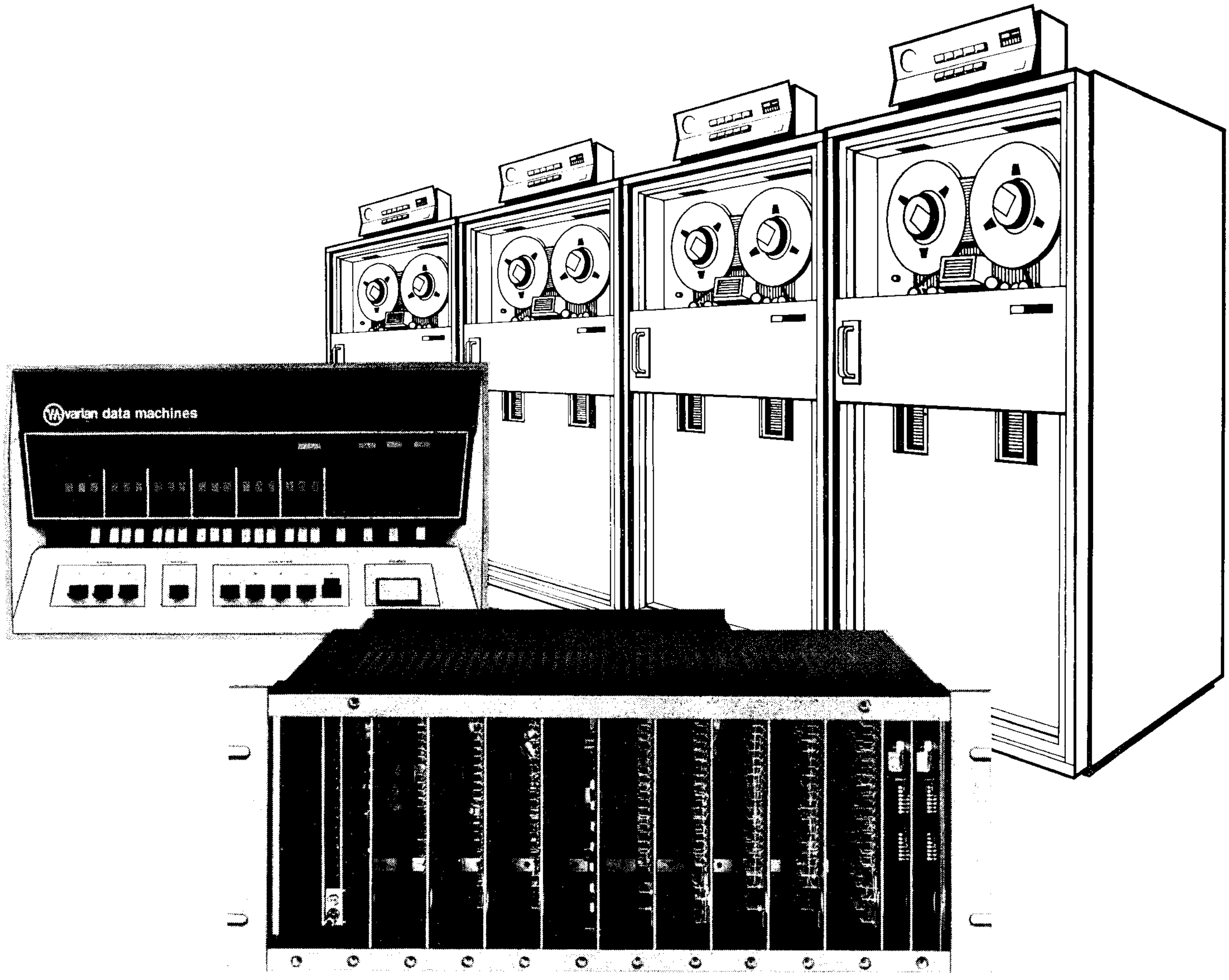

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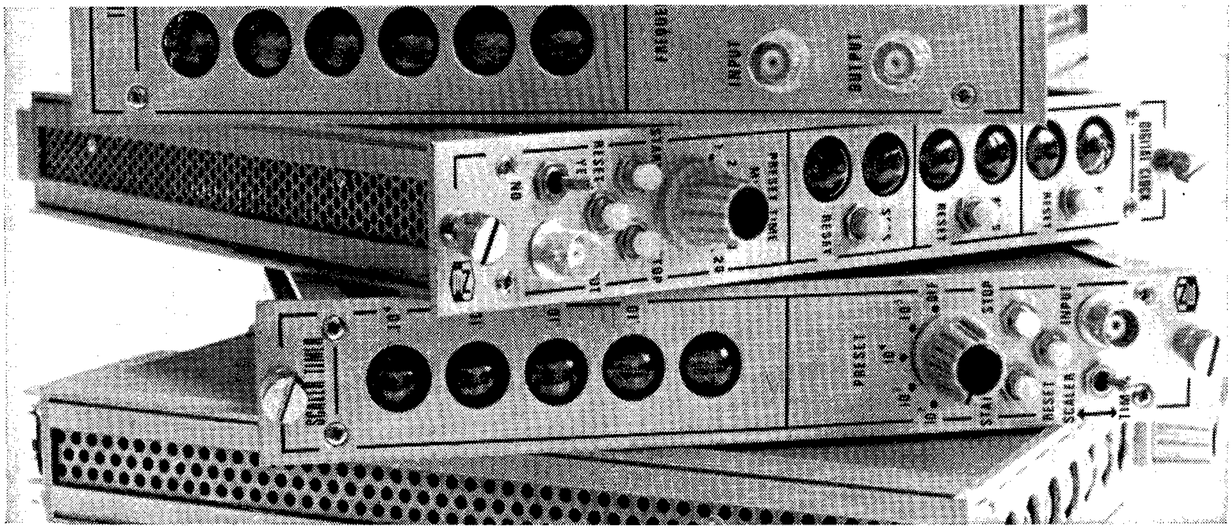

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Start-Stop-Reset Control	Manual or Auto	Manual or Auto	Manual or Auto	Manual or Auto	Manual or Auto	Manual Clock Reset. Manual or Auto Timer Control	Manual or Auto
Preset Control	Count or Time: 10^2 to 10^5 Off	Count or Time: 10^2 to 10^6 Off	Count or Time: 10^2 to 10^7 Off	Count or Time: in each decade 1, 2, 4, 8, Off	Time: 10^{-4} to 10^3 seconds with x1 to x10 multiplier	Time: 1, 2, 5, 10, or 20 minutes	May be set by f.s.d.
Time Base	0.1 second	0.1 second	0.1 second	0.01, 0.1, 1, 10, seconds	10 microseconds	—	Timer or Ratemeter 0.1, 1, 10, 100† seconds
Time Reference	50 or 60 Hz supply	50 or 60 Hz supply	50 or 60 Hz supply	Crystal controlled	Crystal controlled	50 or 60 Hz supply	50 or 60 Hz supply
"Nixie" type Display	Vertical: 5 Decade	Vertical: 6 Decade	Vertical: 7 Decade	Vertical: 6 Decade	—	Vertical: 6 Decade as hr. min. sec.	Horizontal: 4 Decade. Adjustable 10^2, 10^3 or 10^4 f.s.d.
Output	+5V pulse at 10^5 overflow	+5V pulse at 10^6 overflow	+5V pulse at 10^7 overflow	+5V pulse at 10^6 overflow	+5V at 100kHz +5V pulse at preset time	+5V pulse at preset time	+5V pulse at f.s.d.
Module Width	single	single	single	double	single	single	treble
Power Requirements	+24V at 0.2A +12V at 0.2A 117V ac at 10mA or +6V at 0.4A 117V ac at 10mA	+24V at 0.2A +12V at 0.25A 117V ac at 11mA or +6V at 0.45A 117V ac at 11mA	+24V at 0.2A +12V at 0.3A 117V ac at 12mA or +6V at 0.5A 117V ac at 12mA	+24V at 0.2A +12V at 0.3A 117V ac at 11mA or +6V at 0.5A 117V ac at 11mA	+24V at 0.12A +12V at 0.18A or +6V at 0.3A	+12V at 0.5A 117V at 11mA or +6V at 0.5A 117V ac at 11mA	+24V at 10mA +12V at 0.4A —24V at 10mA 117V ac at 9mA

Note:— Unit Nos. NE 4611, 12, 13, 22, 49, 52 may be used with the NE 4617 Print Control for serial print out. The NE 4625 parallel interface may be used where different parallel output levels are required.

† This is an optional feature.

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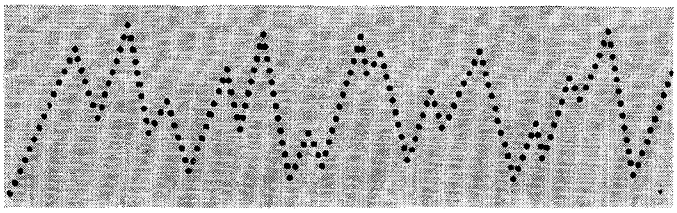


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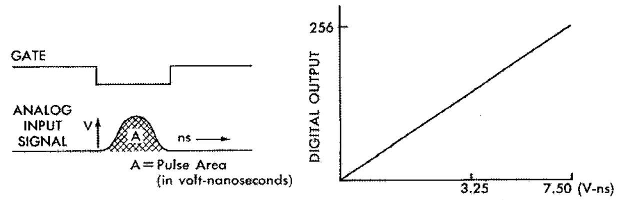
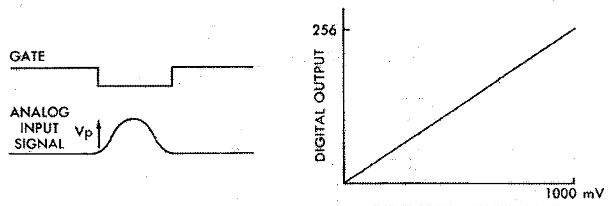
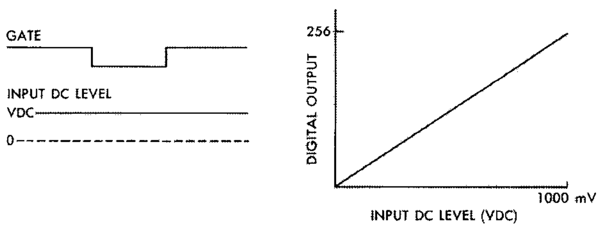


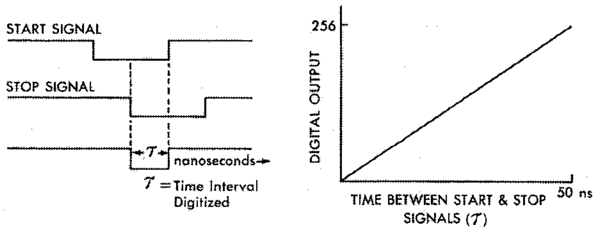
PULSE AREA



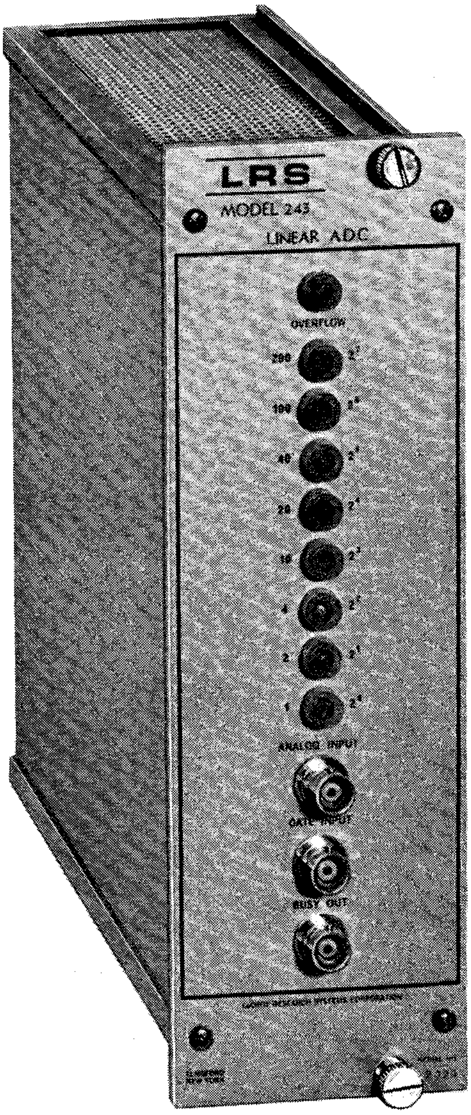
PEAK PULSE AMPLITUDE



SLOW PULSE OR DC AMPLITUDE



NANOSECOND TIME INTERVALS



You ought to know the versatile LRS Model 243 *Gated Linear Analog-To-Digital Converter.* It's optimized to digitize the amplitude or area of nanosecond analog signals. But it can also handle more slowly changing waveforms . . . DC levels . . . or measure digitally nanosecond time intervals. That's big capability. And in a small package. ■ Actually, the 243 is a complete analytical instrument in itself. The unit contains its own fast built-in linear gate to permit selection of the input pulse or interval to be digitized . . . as well as a built-in pulse stretcher, 40 MHz crystal clock, and binary output register. The 243 accepts unstretched pulses from 2 to 100 nanosecond duration directly . . . and delivers an 8-bit coding of the input amplitude or area. Maximum digitizing time: 6.4 μs. Resolution: 1 part in 256. ■ There are many plus features, too. Positive or negative inputs permit analysis of pulses from virtually any source. Front panel visual display continuously monitors the state of the internal buffer register. Buffered outputs are suitable for use with on-line computer, magnetic tape transport, typewriter, or other digital output device. For full details, *write for Bulletin 243.*

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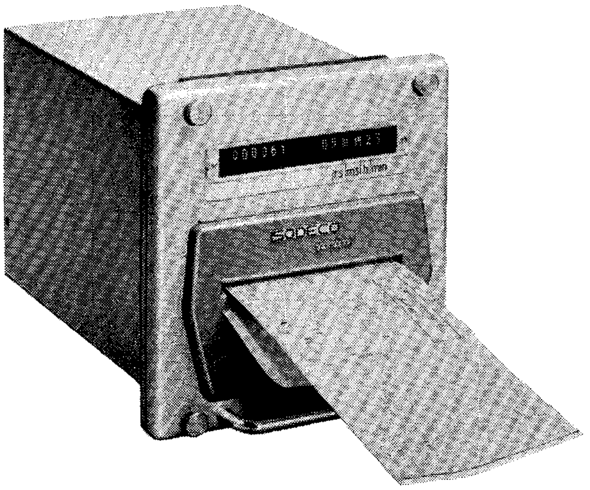

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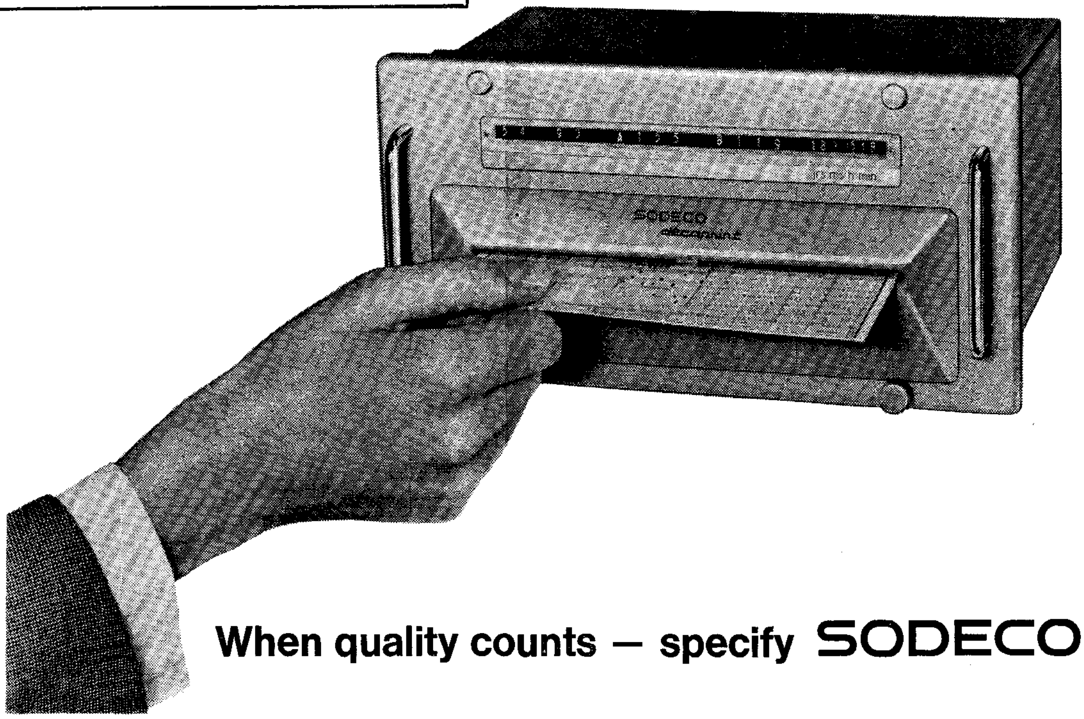

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The 8002A Pulse Generator gives you excellent control of your pulses, with rise and fall independently controllable by means of a vernier. Variable rise and fall times, 10 nsec to 2 sec, and rise/fall, fall/rise ratios up to 30:1. Repetition rate is 0.3 Hz to 10 MHz. 50 ohm source impedance, even during transitions; reflections are minimized. Price: $700 fob factory.

For the best pulses and greatest versatility for your money, the 8003A Programmable Pulse Generator is your best buy. Here you get simultaneous positive and negative outputs, 5 nsec rise time, pulse width of 30 nsec to 3 sec and a 10 MHz repetition rate. Great for fast switching applications, wide frequency testing capability of the 8003A also makes it ideal for testing analog devices such as wideband amplifiers, filters and other linear circuits. Price: $470 fob factory.

If you've been searching for a better way to test circuits, a way to get better, more accurate results, get complete details on these two pulsers by calling your local HP field engineer.

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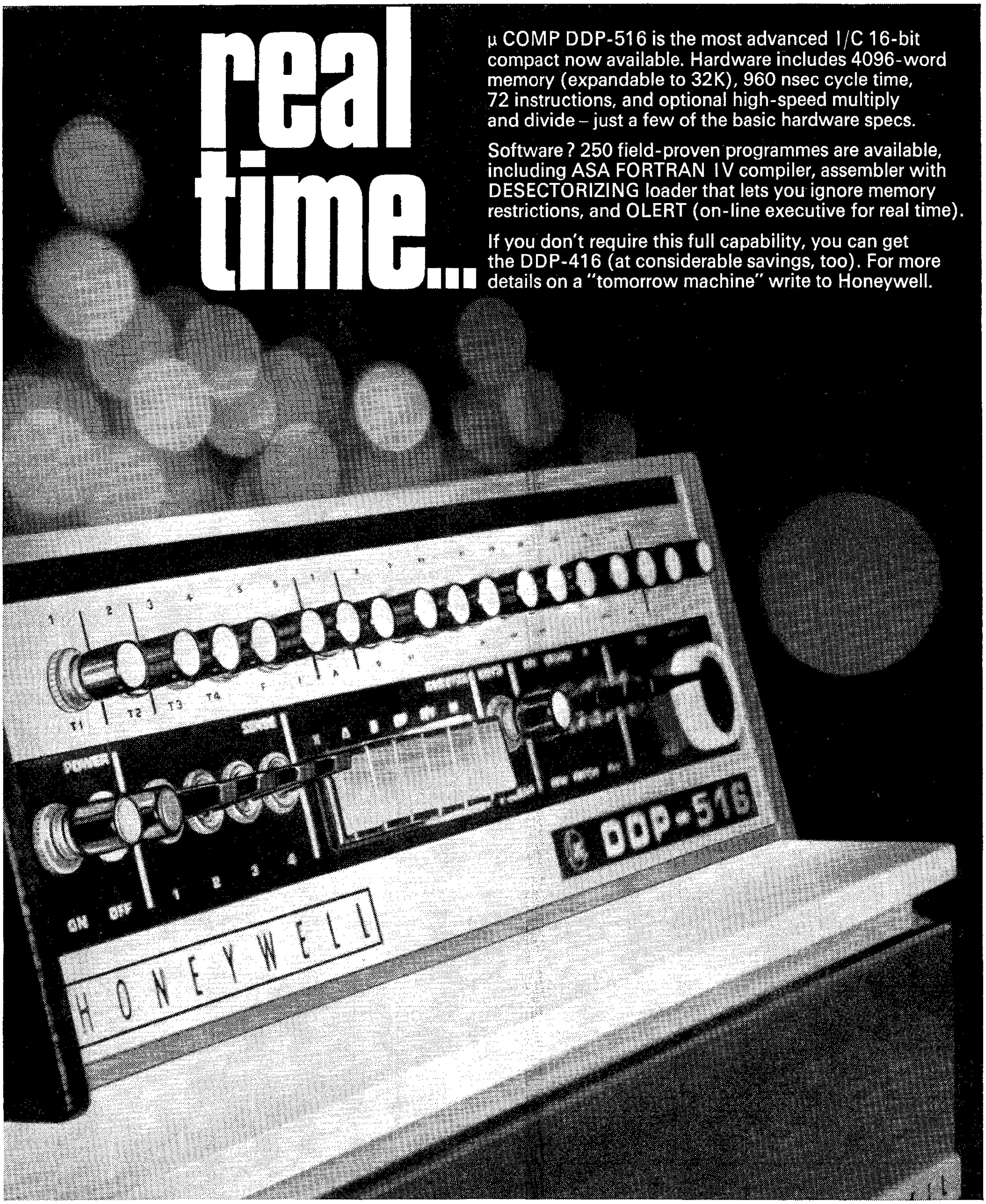
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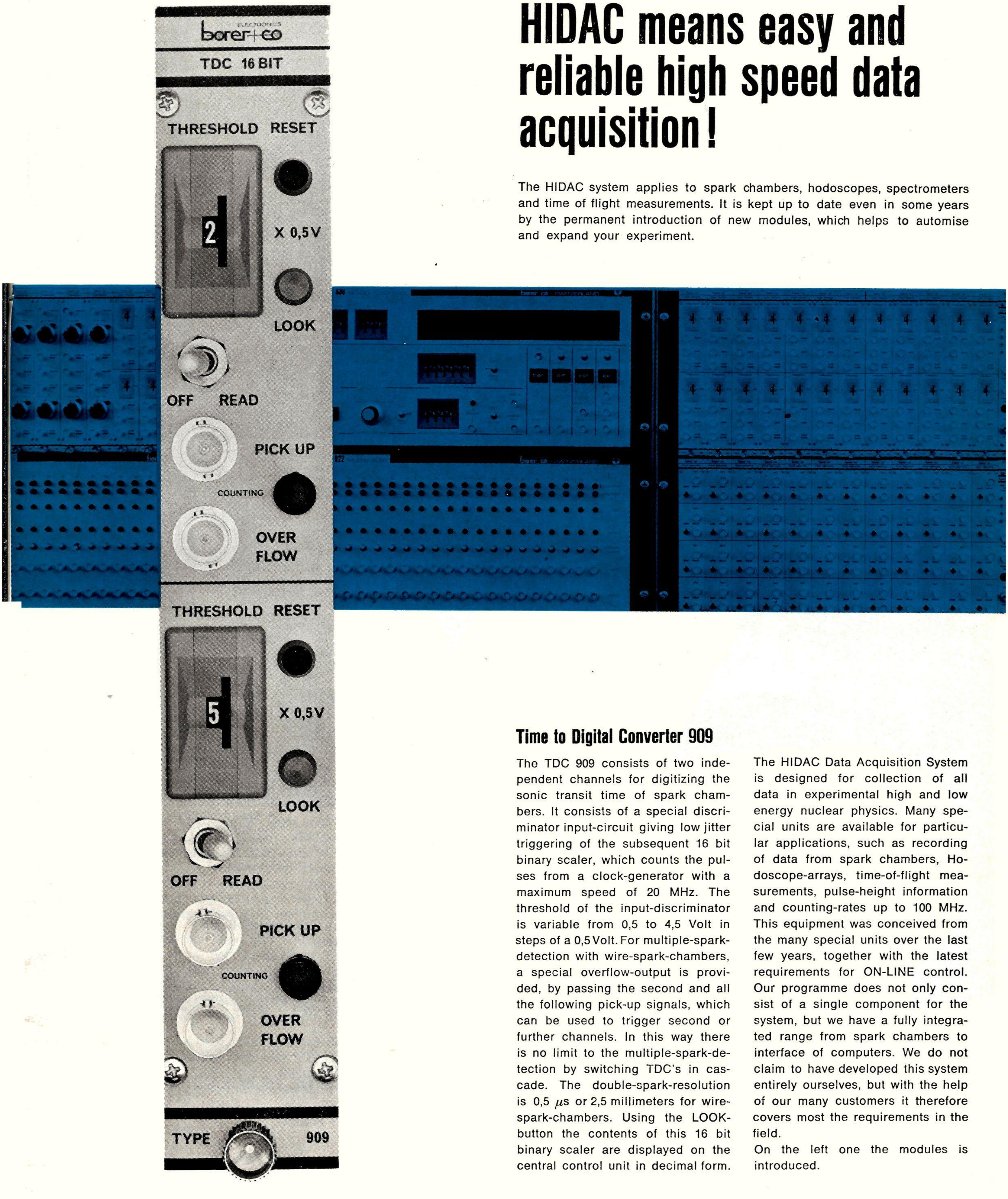
HIDAC means easy and reliable high speed data acquisition!

The HIDAC system applies to spark chambers, hodoscopes, spectrometers and time of flight measurements. It is kept up to date even in some years by the permanent introduction of new modules, which helps to automise and expand your experiment.



Time to Digital Converter 909

The TDC 909 consists of two independent channels for digitizing the sonic transit time of spark chambers. It consists of a special discriminator input-circuit giving low jitter triggering of the subsequent 16 bit binary scaler, which counts the pulses from a clock-generator with a maximum speed of 20 MHz. The threshold of the input-discriminator is variable from 0,5 to 4,5 Volt in steps of a 0,5 Volt. For multiple-spark-detection with wire-spark-chambers, a special overflow-output is provided, by passing the second and all the following pick-up signals, which can be used to trigger second or further channels. In this way there is no limit to the multiple-spark-detection by switching TDC's in cascade. The double-spark-resolution is 0,5 μs or 2,5 millimeters for wire-spark-chambers. Using the LOOK-button the contents of this 16 bit binary scaler are displayed on the central control unit in decimal form.

The HIDAC Data Acquisition System is designed for collection of all data in experimental high and low energy nuclear physics. Many special units are available for particular applications, such as recording of data from spark chambers, Hodoscope-arrays, time-of-flight measurements, pulse-height information and counting-rates up to 100 MHz. This equipment was conceived from the many special units over the last few years, together with the latest requirements for ON-LINE control. Our programme does not only consist of a single component for the system, but we have a fully integrated range from spark chambers to interface of computers. We do not claim to have developed this system entirely ourselves, but with the help of our many customers it therefore covers most the requirements in the field.
On the left one the modules is introduced.

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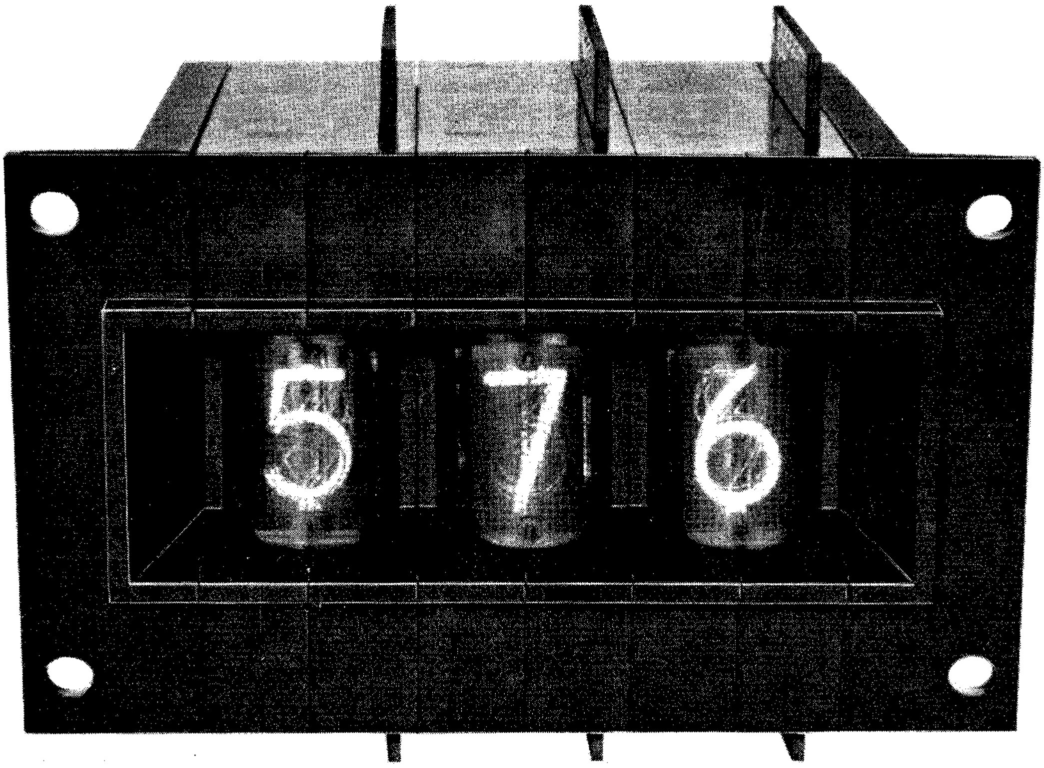
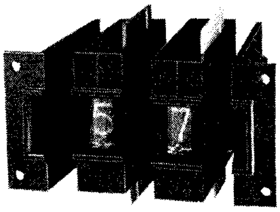


- Structure mono-décadique
- Grande simplicité d'assemblage et de fixation
- Affichage sur tube incorporé (point décimal sur option)

Modules de comptage et de décodage électroniques



Compteur

Cadence de comptage 250 kHz
Basse tension unique d'alim.
12 V ± 10 %
Sorties binaires bipolaires :
Standard 1-2-4-8
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Courant disponible 15 mA

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Décodage binaire décimal
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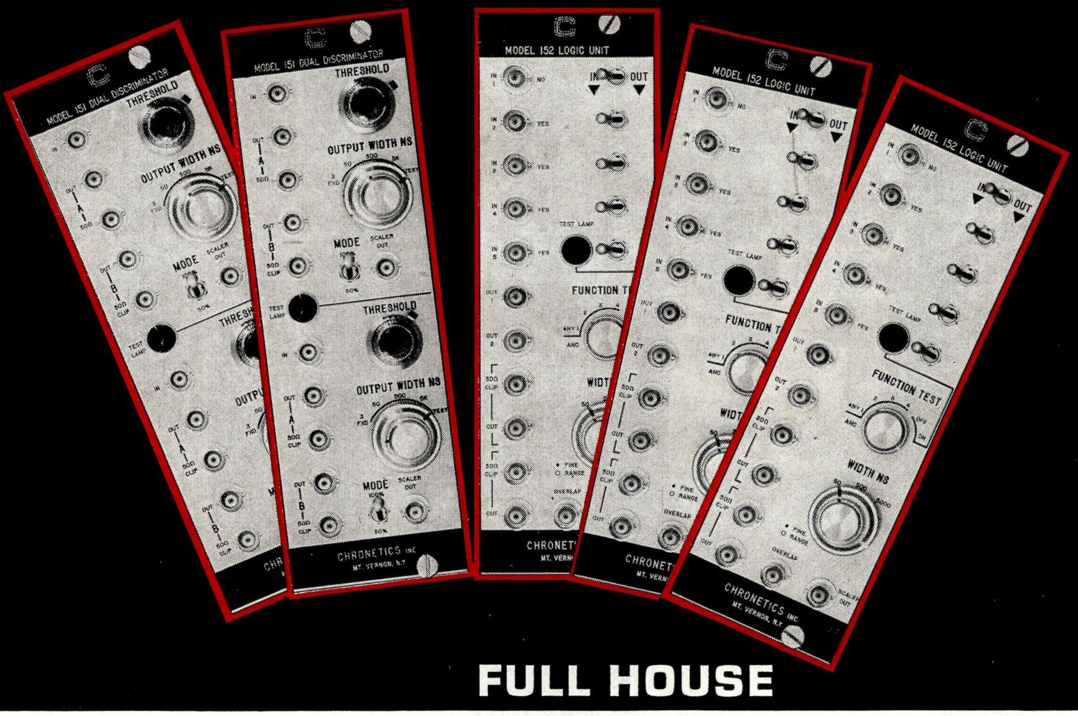

FULL HOUSE

We're raising the ante: Most modules of our splendid new NANOLOGIC 150, 200 MHz, AEC-compatible Counting System are now available **off the shelf.** We can ship from stock discriminators, logic units, amplifiers, linear adders, prescalers, fan-ins, fan-outs, linear gates, gates with stretcher/hold etc, etc, etc, etc. Just about any logic function in a NIM package you care to mention. Call our full house and everybody wins.

Observe, by the way, that NANOLOGIC 150 is a completely new System — not a repackage to meet TID-20893. A **new System. All new.** From the grounds up. All DC-coupled; normal or complementary outputs; output widths variable over a 1000:1 range. Much higher performance and greater operating flexibility. Care for a couple of examples?

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Model 152 is to logic units what the 151 is to discriminators. MAJORITY, AND, OR, ANTI logic functions; all of them in one module. Coincidence resolving time better than 2 ns FWHM at 200 MHz. Any input (4 YES, 1 NO) can be switched in or out independently. Output width continuously variable over a full 1000:1 dynamic range and normal and/or complementary outputs. An overlap output is also provided.

We're not standing pat though. More new 150 modules are on the way. If you need counting/logic with the highest available performance, stability and quality call or write for technical literature or a demonstration.

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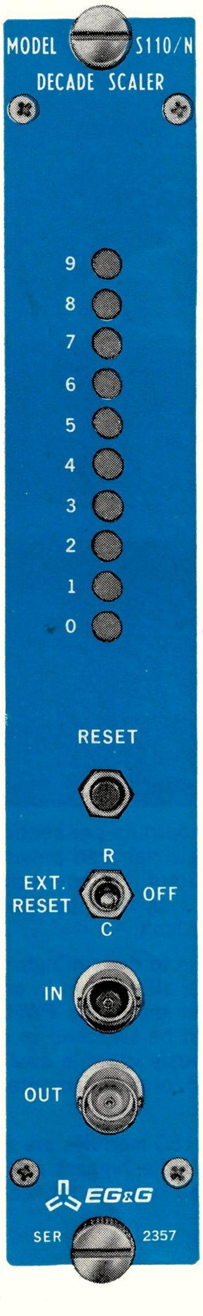

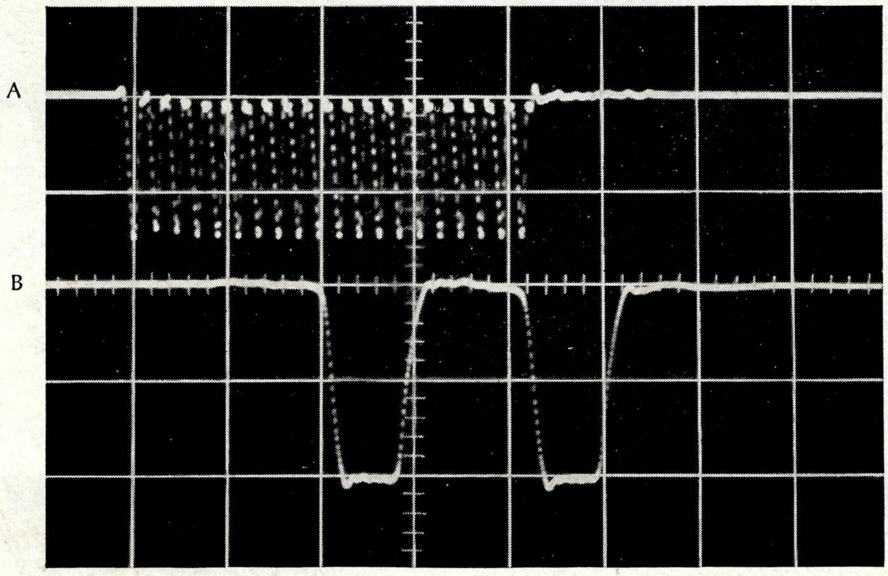

A: 20-pulse input burst, at 4.4 nsec spacing. B: Carry output.

Horizontal scale 20 nsec/div. Vertical scale 400 mV/div.

Our new S110/N DECADE SCALER Module is capable of correctly scaling in excess of 200 MHz CW, or resolving pulse pairs spaced less than 4 nsec apart.

The input accepts NIM-standard fast logic signals. However, even less than minimum-amplitude NIM signals can be scaled. The input is protected by a limiter which provides good termination and fast recovery, so the input may accept raw phototube signals. A stable, —400 mV discriminator follows the limiter to drive the scaler. The circuitry is, of course, direct-coupled.

The unique design of the direct-coupled scaling circuitry obviates the need for selected components, trimming adjustments, etc. This allows us to deliver to you a field-servicable instrument at low cost.

The S110/N is adaptable to system use, since it provides gated NIM-standard slow logic signal outputs. The coding is 1248 BCD, which may be changed to 122'4 if desired. Provision is made for diode isolation at the outputs, to permit "wired-OR" bussing.

The carry output is a NIM-standard fast logic signal of nominal 20 nsec width. The "universal" reset/inhibit input accepts either positive or negative signals, and an internal driver assures that reset action is always completed.

The S110/N is packaged in a single-width NIM-standard module, and 12 modules may be put in our new NIM bin. Even though compact, user convenience features such as visual readout and reset mode selection have not been omitted.

Write or call for detailed specifications, EG&G, Inc., Nuclear Instrumentation Division, 40 Congress Street, Salem Massachusetts 01970. Telephone: (617) 745-3200. Cables: EGGINC-SALEM.