1. Introduction

The 25 GeV proton synchrotron has now been put into operation. Towards the end of November 1959 protons were accelerated up to 24 GeV kinetic energy and a few weeks later, after adjustments had been made to the shape of the magnetic field at field values above 12,000 gauss by means of pole face windings, the maximum energy was increased to 28 GeV. The intensity of the accelerated beam of protons was measured as $10^{10}$ protons per pulse and there was no noticeable loss of particles during the whole acceleration period up to the maximum energy.

Measurements so far carried out on the PS are necessarily preliminary and incomplete. It will take at least six months of measurement work before sufficient is known about the behaviour of the machine to exploit it as a working nuclear physics tool.

The intensity of the proton beam is surprisingly high at this early stage of operation. Protons are injected into the synchrotron at an energy of 50 MeV from a proton linear accelerator, the design of which closely follows that developed at the Lawrence Radiation Laboratory, Berkeley. One important difference, however, is that the PS linear accelerator contains magnetic quadrupole alternating gradient focusing in the drift tubes, in place of the grid focusing originally used in the American machine.

The PS linear accelerator has produced intensities up to 5 mA peak, although for the tests so far carried out with the synchrotron a collimated 1 mA proton beam has been employed. A buncher and debuncher have been built for this linear accelerator, but neither have been used so far. With 1 mA being injected into the synchrotron and single turn injection, a capture efficiency of 20-25% has been measured, corresponding to a circulating beam of $10^{10}$ protons per pulse. The pulse repetition rate at 25 GeV is 20 a minute.

The energy of the protons in the synchrotron has, so far, been calculated from the magnetic field at the time the beam disappears and the radius of the machine. The earliest operational runs were carried out without any of the correcting devices being employed, except for the self-powered pole face windings needed to correct eddy currents in the metal vacuum chamber at injection when the guiding magnetic field is only 140 gauss. The proton beam then disappeared at a magnetic field of about 12 kgauss due to the number of free oscillations of the particles per revolution becoming an integer. As the magnet yoke saturates, the focusing forces diminish slightly, and instead of the machine working in the stable region between the unstable resonance bands, the operating point is slowly forced into a resonance and the particles are lost to the walls of the vacuum chamber. In later runs the pole face windings were energized by programmed generators designed to keep the focusing forces constant up to magnetic fields of over 14,000 gauss and it was observed that all of the proton beam then reached an energy of just over 28 GeV, limited only by the peak magnetic field available in the PS.

An attempt has been made to measure the number of free oscillations per revolution in both the axial and radial directions ($Q_x$ and $Q_y$) during the acceleration cycle. At injection, with the pulsed inflector voltages not energized and a 2 µs pulse of protons injected from the linear accelerator, the beam spirals inwards in radius due to the rising magnetic field for over one hundred microseconds, and the fractional $Q$-values can be observed in the two directions by pick-up electrodes sensitive to one or the other of the two directions of oscillation. For these measurements the beam is injected in such a way as to set up either axial or radial oscillations of the particles. During the acceleration cycle the $Q$-values were measured by pulsing the quadrupole correcting lenses at different times in the cycle and by variable amounts, and noting when the beam was lost. The nominal $Q$-values are both about 6.25, and if at a certain moment the quadrupole lenses are pulsed by an amount that shifts, say, the $Q_x$ value to 6.0, the beam will be lost due to instability at a radial first resonance. Similarly,
pulsing the lenses in the opposite direction by the same amount loses the beam due to instability at a radial second order resonance at $Q_2 = 6.5$. Apart from the shift of the $Q$-values when the magnet saturates, it appears that they remain close to $Q_2 = 6.3$, $Q_2 = 6.2$ during most of the acceleration cycle. Using this same method, the unstable boundaries of the stable operating region, namely $Q_2 = 6.0$, 6.5 and $Q_2 = 6.0$, 6.5, have been measured. So far, no higher order resonances due to non-linear instabilities have been observed, although whether this is a tribute to the linearity of the machine or due to the crudeness of the measurements remains to be seen.

Measurements have been made of the closed orbit displacement at 20 points around the circumference of the machine, from which the closed orbit amplitude and shape have been computed. The closed orbit is that orbit around which all particles perform free oscillations. In a perfect machine without field free sectors it would be a perfect circle in a plane. In an imperfect machine its shape and amplitude are due to the imperfections. At injection the peak to peak amplitude of the closed orbit in the radial direction is about 4 cm, and in the axial direction it is a few mm. Later on in the cycle the peak to peak amplitude diminishes in the radial direction to about 1 cm and remains negligible in the axial direction. Since the vacuum chamber dimensions are 14 cm in the radial direction and 7 cm in the axial direction, there is therefore no danger of beam loss due to magnet misalignments.

The transition energy, which seemed so formidable a barrier during the design stage, proved to be easily surmountable in practice. The precision of phase switching needed at transition for no noticeable loss of particles was found to be about $\pm 3$ ms, or $\pm 36$ gauss.

Both the computer and the beam control system for determining the frequency of the accelerating voltage have proved very satisfactory after minor adjustments. During the operational runs so far carried out the beam control system has been switched in about 1 ms after injection and there seems to be no noticeable loss of particles during this switch-over. During the early acceleration studies the radial control servo acted on the amplitude of the accelerating voltage, which in principle is as equally effective a means of controlling the radial position of the beam as varying the phase or frequency of the accelerating voltage. This arrangement was not successful, perhaps due to a certain amount of jitter in the phase-lock loop, and the system was modified so that the radial control servo acted on the phase of the accelerating voltage. This second method was completely successful and no particles were lost during acceleration (see page 31). Preliminary measurements indicated that the beam was not moving more than 1 cm from the centre of the vacuum chamber during the acceleration cycle. The beam control system depends for its operation on the presence of a bunched proton beam, and due to noise in the servo loops, there is a certain minimum value for the circulating beam current below which the system no longer maintains control. It appears from early measurements that the system will work with about $10^8$ protons per pulse.

A very important parameter of an accelerator is the mean intensity. The table below shows that at an energy of 6 GeV the mean intensity of the

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Max. energy GeV</th>
<th>Mean intensity (particles per sec.)</th>
<th>Completion date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brookhaven proton synchrotron (COSMOTRON)</td>
<td>3</td>
<td>$2.10^{10}$</td>
<td>1952</td>
</tr>
<tr>
<td>Saclay proton synchrotron (SATURNE)</td>
<td>3</td>
<td>$2.10^{10}$</td>
<td>1958</td>
</tr>
<tr>
<td>Princeton-Pennsylvania proton synchrotron</td>
<td>3</td>
<td>$2.10^{10}$</td>
<td>1960</td>
</tr>
<tr>
<td>Berkeley proton synchrotron (BEVATRON)</td>
<td>6</td>
<td>$2.10^{10}$</td>
<td>1954</td>
</tr>
<tr>
<td>Rutherford Laboratory proton synchrotron (NIMROD)</td>
<td>7</td>
<td>$10^{12}$</td>
<td>1961/62</td>
</tr>
<tr>
<td>Russian A.G. proton synchrotron</td>
<td>7</td>
<td>$2.10^{12}$</td>
<td>1960</td>
</tr>
<tr>
<td>Russian proton synchrotron (synchro-phasotron)</td>
<td>10</td>
<td>$10^{10}$</td>
<td>1957</td>
</tr>
<tr>
<td>Australian proton synchrotron</td>
<td>10</td>
<td>$10^{10}$</td>
<td>1962/63</td>
</tr>
<tr>
<td>Argonne zero gradient proton synchrotron</td>
<td>12.5</td>
<td>$2.10^{12}$</td>
<td>1962</td>
</tr>
<tr>
<td>CERN proton synchrotron</td>
<td>28</td>
<td>$10^{12}$</td>
<td>1959</td>
</tr>
<tr>
<td>Brookhaven A.G. proton synchrotron</td>
<td>6-10</td>
<td>$10^{12}$</td>
<td>1960</td>
</tr>
<tr>
<td>Russian A.G. proton synchrotron</td>
<td>30</td>
<td>$3.10^{10}$</td>
<td>1961/62</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>$10^{10}$</td>
<td>(*) indicates target figures.</td>
</tr>
</tbody>
</table>
PS is now nearly as high as that of the Bevatron, and at 10 GeV considerably higher than that of the Russian machine. It is hoped to increase the intensity of the PS by an order of magnitude by bringing into operation the buncher and debuncher of the linear accelerator and allowing more protons to be injected into the synchrotron. At 25 GeV the yield of secondary particles from internal targets is considerably higher than at 6-10 GeV, and early measurements of secondary particle yields from the PS indicate that the machine may be a strong competitor to the lower energy high intensity machines now being built from this point of view.

Progress on the design and construction of the 1 m propane bubble chamber has been satisfactory and the present completion date is foreseen as mid 1960. The design of the 2 m hydrogen bubble chamber is nearly completed and contracts for the parts will be placed in 1960.

The analysing magnets and focusing magnets for transporting beams of particles emitted by the PS machine have been designed and ordered. A beam separator is being designed and full-scale model tests are yielding satisfactory results. Ejection systems are being designed and built together with target assemblies.

Generators, transformers and switchgear for supplying the bubble chamber magnets and beam transport magnets have been ordered for the South experimental area. Water-cooling plant for this equipment is on order.

The new East experimental area has been designed in detail in collaboration with the SB Division and the architects.

An electron model of a beam-stacking accelerator which can also be used as an intersecting beam machine has been studied this year. Designs for some of the component parts are well advanced. A building to house this machine has been planned.

Plans have been made to re-divide the PS Division in 1960 into four new groups in place of the present arrangement. The new groups are: the PS Machine Group, responsible for the operation, maintenance and development of the PS; the PS Engineering Group, responsible for the mechanical and electrical engineering of projects associated with the PS machine; two Bubble Chamber Groups, responsible for the design, construction and use of the 30 cm hydrogen chamber, the 1 m propane chamber and the 2 m hydrogen chamber together with beam transport equipment; and the Accelerator Research Group, responsible for investigating new ways of accelerating particles, new particle separators and other research activities.

2. Machine Installation

At the beginning of 1959 the situation with respect to the installation of the machine was as follows.

In the first tank of the linac, which had already produced a beam of 300 \( \mu \text{A} \) at 10 MeV, the drift tubes with grids were exchanged for drift tubes with magnetic quadrupole lenses. The drift tubes of the second tank were aligned, but the installation of the equipment in the third tank had still to be started. The installation of all inflector equipment was about to start. The magnet power supply and magnet cooling system were completely installed, ready to be tested with the proper load. Electric power, cooling water and compressed air were available wherever necessary. Control cables (multicore and coaxial) were being laid throughout the PS area. Apart from this, the ring tunnel and the control centres (except the power house control room) were virtually empty.

At this period a large amount of equipment was gathered in the experimental halls where it was undergoing a thorough testing programme before the installation would take place: in the South hall the 101 magnet units, 60 lenses and 200 coil busbars; in the North hall the 80 vacuum pumping stations, the 400 parts of the vacuum chamber, the 18 RF cavities and the 25 pick-up electrode stations. Large quantities of smaller equipment, such as power and cooling water outlets, junction boxes for control cables etc., were ready to be installed.

On 3 February the first magnet unit was placed in its position, and after a short running-in time a more or less regular installation rate of about five units per week could be maintained. Each unit was provided with its vacuum chamber and was aligned immediately by the Survey Group. The position of a magnet unit in the ring depends on the result of the magnetic measurements and, consequently, there were several isolated units at the beginning, but, as soon as two adjacent units were together in the ring, the magnet busbars could be connected and the appropriate equipment of the straight section installed (e.g. RF cavity, pick-up station, magnetic lens). By March the installation of all other equipment was following at the same rate as the magnet units.
By the middle of July the magnet ring was closed, and after a thorough investigation of each unit for installation faults, lost tools etc., the magnet was first powered on 27 July.

In the meantime all the linac tanks had been completed and a beam of protons accelerated (tank I by the middle of May, tank II by the end of May and tank III towards the end of August). By continuous alignments and adjustments the linac output was rapidly raised to about 5 mA.

Bending magnets, quadrupole lenses, inflector electrode boxes and their power supplies had by this time all been installed in the inflector area.

The RF cavities, the magnetic lenses, the beam pick-up stations and the ring vacuum system were completed, and at the beginning of September the PS was ready for injection studies.

The baryte concrete shielding walls were also ready at that time, but the main control room contained only the bare minimum of equipment necessary to run the machine. The other control centres were much further advanced, but there too installation was still continuing.

During the period September to December the installation of the control centres was completed sufficiently for operating the PS.

3. Injection Studies

Following on the tests on the different components of the machine described in other sections of this Report, the work of commissioning the machine itself, the running-in programme, has been started.

The 50 MeV beam was first available for study and use at the end of August 1959, and its parameters such as diameter, angular spread, momentum spread and their variation with time and linac adjustments measured to enable a properly matched pencil beam to be prepared in the inflector area ready for injection studies. Typical values found were:

<table>
<thead>
<tr>
<th>Linac output beam diameter and angular spread (containing 50% of the current):</th>
<th>6 mm × 0.7 mrad. horizontally</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentum spread:</td>
<td>3.5 mm × 1.3 mrad. vertically</td>
</tr>
<tr>
<td>Current into a 5 µ × rad. emittance pencil beam:</td>
<td>2 mA out of 5 mA total</td>
</tr>
</tbody>
</table>

The process of injection of such a beam was studied using fluorescent screens which could be moved across the synchrotron vacuum chamber and viewed by television from the control room. The settings of the various inflector voltages and of the injection timing were worked out, so that the beam could be injected onto the axis of the vacuum chamber in a rather well-defined way. With this procedure the beam went completely round the machine on the first attempt, on 16 September. It appeared to lie within 1 cm of the centre line all round on the first revolution.

Subsequently the pulsing circuits for the inflectors were brought into use, so that the beam could be made to circulate for some 15-20 revolutions, while spiralling in to hit the inner wall of the vacuum chamber. Preliminary position measurements made on it with the pick-up electrode system showed that there were noticeable radial oscillations present during the spiralling time, which could be much reduced by readjusting the inflector voltages until the beam was injected near to the closed orbit rather than to the axis of the chamber.

Substantial beam-time was used for operational tests of measuring gear, including the flags and TV screens for observing the beam cross-section, and the pick-up electrode system of some twenty stations round the ring equipped with electrodes sensitive to radial and vertical movements of the beam.

4. Accelerator Research Group

a) Plasma betatrons

Two plasma betatrons were built during this last year. Several major improvements were made. For example, the accelerating electric field was increased to approximately 100 V cm⁻¹, and the minimum pressure for ionization reduced to 10⁻⁴ mm Hg. As a result, the beam of runaway electrons attained the top energy of the machine (2 MeV) without the previous erratic behaviour. The intensity of the beam, however, was not increased substantially, and it is believed that the electrons are lost quite early in the accelerating period. Theoretical and experimental work is being done in an endeavour to understand this effect.
Oscillogram showing the first acceleration to full energy in the CERN proton synchrotron. The middle trace (magnet voltage) shows the end of the 1 second acceleration time. The top trace shows, by its width, the constancy of the circulating beam from the start up to almost maximum field. (The apparent small increase in beam at transition is a spurious indication.) The lower trace is the output of a scintillation counter placed near the vacuum chamber showing a large burst at the instant the accelerator beam vanishes, and also a very small pip at transition, where a few protons were being lost from the beam.
Linear accelerator control room. In the left foreground, the control desk for the 500 kV high tension for the pre-injector.

General view of the inflector. The beam emerging from the linear accelerator in the background on the right enters the synchrotron vacuum tank in the d.c. electric deflector in the foreground.
The beam entering the synchrotron tunnel after emerging from the linear accelerator. Near the shielding wall can be seen a triplet of quadrupole lenses.

Injector. Towards the right, second magnetic deflector. On the left, vacuum tank of d.c. electric deflector.
Main control room; row of racks for beam observation. On the left: equipment for the display of the signals from the pick-up electrodes. On the right: control devices and television receivers for the flags.

Central building control room; equipment for beam control and for distribution of the exciting frequency to the accelerating units.
b) *Beam-stacking accelerator*

Experimental and theoretical design studies were continued. Field measurements on the first magnet model were completed. Azimuthally profiled pole pieces were computed and machining nearly finished. Extensive orbit calculations were made with the Mercury computer and are continuing. They cover magnet structures without superperiods and with superperiods of various types.

A full-scale model of an RF accelerating cavity was constructed and the problem of matching this cavity to the power amplifier was studied in detail. It proved possible to achieve a transfer impedance of $90 \Omega$. The programme-generating circuits were built, and stability was tested and found satisfactory. A full-scale model of a possible drift tube or dee alternative to the re-entrant cavity is under construction.

Testing and development of ultra-high vacuum pumping systems and components continue.

General design studies were made of the mechanical layout of a complete accelerator and of the procedure for bake-out of the vacuum chamber. Preliminary experiments were made on pulsed fields of the type that may be used in a “programmed bump” inflector.

Specifications for tenders were sent out for the high voltage injector which, it is hoped, will be ordered early in 1960.

Design studies for the accelerator building and its associated shielding have been made, and the architects are working on the plans.

c) *Ultrasonic expansion systems, etc.*

In order to determine whether a bubble chamber could be operated with an ultrasonic expansion system, a general review was made of conventional bubble chamber data, of the theories of bubble formation by ionizing particles and of sonic properties of different liquids. An experimental chamber was built, including piping and schlieren optics. Tests can begin when the electronic components are completed.

Various new principles for liquid hydrogen bubble chamber expansion were investigated.

A survey was made of data available on the resistivity and magneto-resistivity of metals at very low temperatures for application to cryogenic magnets. Measurements are being made by a manufacturer on the purest aluminium available on a production scale. A rough estimate was made of power saving that might result from the use of such magnets, for example in large liquid hydrogen bubble chambers.

5. Magnet

In January all 101 magnet units were ready for testing in the unit measuring machine. A modified high-speed programme had been put into operation due to some difficulties in the manufacture of the pole face windings. After six months of mechanical, electrical and magnetic testing and measuring on a shift basis, the four thousand tons of the components of the magnet system were all installed without accident on the ring beam. Three weeks were then spent in thoroughly inspecting the whole installation so that no error could cause a fault in the 450 heavy current connections and the 1.5 km of busbars on first making the system live.

The quadrupole, sextupole and octupole lenses were installed in phase with the magnet units. The generators, amplidynes and metadynes which act as their power supplies were all installed and meet the specifications of extreme electrical symmetry and very low ripple content required of them.

On 27 July, 1959, the main power supply was connected to the magnet system without incident. Magnetic and electrical measurements of the uniformity of the whole installation were completely satisfactory, as was proved when protons travelled completely around the system at the first attempt on 16 September.

6. Radio Frequency

The entire RF system was installed. Its parts as well as the whole system were thoroughly tested.

Life tests on the accelerating units were carried out over several months. As a result of these tests several modifications and improvements were made, and a preliminary remote control and monitoring system was constructed and installed. The accelerating units work satisfactorily.

The frequency programming system was installed and very thoroughly tested. Performance and reliability were very satisfactory. The flexibility of the system was extended by adding a programme corrector, which allowed the introduction of empiric corrections to the theoretical frequency programme owing, for example, to variations in the effective length of the magnet units.

The beam control system was installed and tested with a simulated beam. Its main electronic part,
the automatic phase control system, was used also during programmed acceleration, the phase reference then being the programme itself instead of the beam pick-up signal. In this way the overall performance of the RF system was improved considerably.

The pick-up electrode system was installed and tested. Some modifications of the amplifiers proved necessary in order to meet special requirements for early running-in tests with the machine. A very simple beam display system was put into operation, and a more elaborate system is under construction.

The main timing system was finished and is in operation. The transition timer was designed, constructed and successfully tested.

On 1 October, 1959, the RF system was ready for acceleration tests.

7. Linac and Injection System

a) Results obtained

The installation of the linear accelerator was pursued very actively so that injection tests were started in September.

The most important stages were the following:

22 May : Protons first accelerated by the first tank (with quadrupole focusing)
   Current obtained : 350 µA at 10 MeV.

29 May : Protons first accelerated by the second tank
   Current obtained : 200 µA at 30 MeV.

From the beginning of June the introduction of new devices focusing the beam injected into the linac improved upon the above preliminary results giving
   1.7 mA at 10 MeV
   and 1.3 mA at 30 MeV.

In July the adjustment of this focusing system was improved and the current at 30 MeV increased first to 2 and then to 3 mA.

A change in the quadrupole focusing of the first tank further increased this current at the end of July to 4 and then to 5 mA. During this time the commissioning of the servo-tuning system for the RF cavities improved the stability of the beam.

24 August : Protons first accelerated by the third tank
   Current obtained: 500 µA at 50 MeV.

On 31 August, the following currents were obtained:

<table>
<thead>
<tr>
<th>Current injected at</th>
<th>0.5 MeV</th>
<th>28 mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current accelerated to</td>
<td>10 MeV</td>
<td>5.5 mA</td>
</tr>
<tr>
<td></td>
<td>30 MeV</td>
<td>5.3 mA</td>
</tr>
<tr>
<td></td>
<td>50 MeV</td>
<td>4.8 mA</td>
</tr>
</tbody>
</table>

After the different components of the inflector, between the linac and the synchrotron, had been tested, the 50 MeV beam made the first orbit of the synchrotron ring on 16 September.

When the discharge circuits of the pulsed electrostatic deflectors had been put into operation the beam made 15 to 20 turns on 2 October.

The installation of the accelerating cavities of the linac (with quadrupole focusing) was held back on several occasions during the year by difficulties in aligning the drift tubes; in particular manufacturing tolerances specified were not held. Numerous vacuum leaks also made progress difficult at times.

The various defects have been repaired, but there are still modifications to be made, either to improve the characteristics of the machine or to improve its stability.

b) Work in progress

i) Pre-injector

A test installation for the ion source is now being set up in the laboratory. This has a double aim:

— to make possible the adjustment of a spare source, which can replace a defective source in the pre-injector in less than one hour.

— to investigate and develop a source with better characteristics and producing a larger current.

Possible modifications to the focusing system at the input of the linac are being considered to obtain better matching with more reliable apparatus.

A buncher, which should increase the fraction of injected current which is accelerated, is being installed.

ii) Accelerating cavities and RF circuits

Work is being done to improve the stability of the high power RF amplifiers.

A systematic study is being made of the multipacting which sometimes occurs in tank I. The percentage of pulses lost is at present less than 1%, but certain instabilities are also due to this effect.
iii) Inflector

Various components which will give either greater flexibility of operation or more precise control of the injected beam are being modified or installed. The debuncher, which will reduce the energy spread of the beam injected into the synchrotron, is in operation.

iv) Control position

Installation of control equipment is well under way; modifications continue to be made in the light of experience gained while operating the machine. The transfer of those controls necessary in the main control room is being made.

c) Operation Group

The Linac Operation Group set up during the year has progressively taken charge of the different parts of the linac; operating crews are being trained.

8. Electrical Engineering

a) Power engineering

i) A. C. power distribution system

A 380/220 V power distribution board was installed in the subsidiary generator room of the PS power house for supplying the motor-generator sets in this room. A 380/220 V panel and a distribution network were installed in the main control room, and an additional panel was ordered for the experimental control room. The various components in the ring building, including pole face windings and magnetic lenses, were connected to their supply systems. The substation and the whole power distribution network have worked very reliably during the year.

ii) Magnet power supply

Various load tests, especially with the mercury-arc power converters, had been made before the main magnet was available as a load. Although the test conditions were more severe than under normal operation, the performance of the converter tubes was excellent, but some minor modifications and improvements in the auxiliaries and the control circuits became necessary. The running-in tests with the magnet as a load started on 27 July and were completed within two months. The equipment performed exceptionally well. Quick progress was partly due to the preliminary tests and the improvements carried out before the magnet was available for pulsing.

The measurements showed that magnet voltage stability and ripple, pulse reproducibility and repetition rate, and motor input power variations during pulsing remained well within the specified tolerances. However, it turned out that during the change-over from rectification to inversion the interphase reactors of the intermediate transformer became saturated. This had no influence on the magnet, but limited the peak current of the rectifiers. To avoid this effect, additional reactors were connected in series to the existing ones.

The magnet power supply is in normal service, and any pulse programme up to peak currents of 6 400 A, giving a magnet field of 14 kgauss, is possible. As was anticipated, only 90% of the rated voltage is required to reach this peak magnet current within 1 second.

b) Machine controls

i) Cabling

The work of laying and connecting of control cables between the various parts of the proton synchrotron and between the control centres is nearing completion. 221 km of multicore cables and 156 km of coaxial cables of different types have been laid on trays which have a total length of 11 km. The average number of cores in multicore cables is 15, giving an overall length of wire of 3 343 km, including 28 km of internal wiring.

A total number of 66 000 double terminals have been installed in 146 junction boxes; 53 500 of these terminals are at present connected and used. Furthermore, a total number of 4 000 double sockets and 8 000 plugs for coaxial cables have been mounted. About 1 000 jumpers are also available.

All this installation work was done by a contractor, following CERN-PS drawings, under close supervision of staff of the Control Section.

ii) Control room equipment

In addition to the 50 racks for electronic and control equipment mentioned in the last Annual Report, 150 new racks were ordered and are already delivered to CERN. About 120 of them were equipped by different groups of the Division and are now installed in the various control centres.

Although the major parts of the proton synchrotron are controlled from the local control centres, it is now possible to supervise some of them, such as the magnet power supply, the vacuum system and part of the linac and the RF system from the main control room. The whole flag system and
the pole face winding and lens generators are remotely controlled from there, and the beam observation system and the master timer have been cabled up and put into operation.

The 48 V d.c. distribution system for control purposes is completed and has worked very satisfactorily. Equipment for personnel safety and control is being installed and will soon be completed.

**iii) Intercommunication and television**

The intercommunication and public address systems were extended and put into operation in the ring building and in the experimental halls. Monitor loudspeakers were installed in the control centres.

Two television links between the ring building and the main control room were put into operation and are actually used for beam observation. A further order for four cameras and four receivers has recently been placed with the same firm which delivered the first sets.

**iv) Radiation monitoring and personnel security**

In addition to the equipment already installed and put into operation in the linac wing, a further order for 20 ionization chambers and 11 measuring channels has been placed. Five tissue equivalent chambers have already been temporarily installed in the ring building and the control centres. The rest will be installed shortly.

The installation of door locks and interlocks, including the necessary cabling, is nearly completed.

A fence has also been erected around the proton synchrotron, to prevent persons from penetrating into dangerous areas.

c) **Power supplies, cooling and controls for experimental equipment**

**i) Power supplies**

Extensive studies have shown that motor-generator sets would be best suited for powering beam transport and track chamber magnets. For the South experimental area, these machines with their a.c. supply, control and regulating equipment will be installed in a new building adjacent to the South experimental hall. This building will also house the compressors for controlling propane bubble chambers.

Specifications of HT switchgear, transformers and motor-generator sets, including their regulation, were sent to a large number of firms during the early part of this year. The following equipment was ordered in July:

- The 18 kV switchgear (air-blast circuit breakers).
- Two 4 MVA transformers 18/6 kV and three 2 MVA transformers 18/0.4/0.23 kV.
- 19 motor-generator sets with a total d.c. power of 5 300 kW for supplying beam transport magnets. Included in this order is a 380/220 V distribution board for supplying the driving motors of the generators, the compressors and the generator house auxiliaries.
- Two motor-generator sets with a total d.c. power of 6 000 kW for supplying track chamber magnets.

Specifications for a line selector and the busbar system supplying the d.c. power to the experimental halls were sent to firms in September. Design studies were also made of the d.c. distribution system, including terminal boxes and flexible cable connections to the magnets in the experimental area, and the remote control of the generators from this area and from the experimental control room.

**ii) Cooling equipment**

A total heat of the order of 2 000 kcal/s will be dissipated by the experimental equipment in the South experimental area. This heat will be removed directly by water which is being pumped through the hollow conductors of the magnet coils. In order to minimize corrosion, demineralized water must be used. For recooling this water, three different systems were taken into consideration:

- Water-to-water heat exchanger using fresh water in its primary circuit.
- Water-to-air heat exchanger consisting of finned coils over the surface of which outside air is blown by ventilators.
- Water-to-water heat exchanger with a cooling tower in its primary circuit.

Extensive studies have shown that the last mentioned solution would be the most favourable one. The equipment required for the South and future East area with a total heat dissipation of about 4 000 kcal/s can be installed in the existing cooling room in the PS power house; the cooling towers will be erected adjacent to this building.
Partial view of target showing the part which is inserted into the vacuum chamber. The lower head which is in the "in" position consists of a 0.01 mm Al foil, mounted on a 1 mm Al frame. Its radial position corresponds to the equilibrium orbit when the target is mounted into the machine. The upper head, which is in the "out" position, is a self-supported 0.2 mm Al sheet. Note the white microswitch, which indicates the target position.

Target mounted in the downstream end of magnet unit No. 5. On the right hand side the drive for the radial positioning. In the foreground a lead collimator for the 180° secondary beam from this target.
End view of one of the 1 m quadrupole magnets.

Propane bubble chamber. Double coaxial valves for expansion and recompression.

General picture of programming system for lenses (quadrupole, sextupole and octupole) and pole face windings.

Main control room, "machine" control room. From left to right: equipment for monitoring and control of supply of the poleface windings, lenses and magnets and for monitoring and control of the accelerating system and the linac. In the background: master timer.

Stainless steel body of the propane bubble chamber (mirror finished interior).
A positron from a decaying $\mu^-$-meson scatters on an electron. 30 cm liquid hydrogen bubble chamber.

Production of a $\pi^+$-meson by a $\pi^+$-meson of 320 MeV by the reaction $\pi^+ + p \rightarrow n + \pi^+ + \pi^+$. 30 cm liquid hydrogen bubble chamber.
Model of East experimental area.

General view of the experimental arrangement of the 30 cm liquid hydrogen bubble chamber at the synchro-cyclotron, taken shortly before the run November 1959.
Specifications for the recooling plant required for the South experimental area were sent to firms in April. An order was placed in July.

The cooling water distribution system in the South experimental hall was ordered in December and will be installed early in 1960.

iii) Experimental control room equipment and cables

A layout for the racks was established in cooperation with the SC Division, and an order for these racks was placed. The first bay will be mounted shortly. Cooling units have also been ordered and received. The piping for the refrigerant is already installed.

Plans of the cable network for experimental purposes in the South area have been completed and 5.5 km of low-loss coaxial cables have already been laid in the South and North experimental halls. Considerable quantities of other coaxial and multicore cables were ordered, received and installed.

9. Mechanical Engineering

a) Vacuum system and targets

Work on examination and testing of all the vacuum chamber components continued until the middle of the year. A small number of repairs and minor modifications were made successfully. Early in the year the installation of the magnet vacuum chambers in the magnet units was started when a number of difficulties concerned with the alignment of the chambers became apparent; these were resolved fairly rapidly, and the desired tolerances were obtained.

A programme of testing the pumping stations was started which revealed a number of weak components, mostly in the control circuits. Detailed investigation by CERN and the contractors eliminated the principal faults. After this smaller problems needed to be investigated, for example the oil seals on the rotary pumps. These matters did not affect the performance of the stations, nor hinder the installation which proceeded without difficulty.

Special vacuum control units for safeguarding the RF cavities were designed, manufactured, installed and tested. These units also control the sector valves which allow the ring system to be divided into ten parts for test and repair purposes.

The whole ring vacuum system was put under vacuum at the beginning of September, and a mean pressure of less than 10^{-5} torr (air equivalent) was estimated. Subsequently the whole or parts of the system have been frequently brought up to atmosphere pressure for the addition or change of devices connected with the initial beam studies, and no difficulties have been experienced in producing the required working pressure. Work is continuing on removing minor difficulties and introducing modifications when necessary.

The remote control measuring system in the PS central building has been installed and tested.

Recently some preliminary work on targets and their associated installations has started. A prototype fairly fast light target mechanism has been designed and made for use with the early beam and nuclear physics experiments. Tests, which appear promising, are continuing while a further five models are now under manufacture. The electronic work associated with the timing and triggering of these targets is in hand. A target tank for a long straight section was designed in the Design Office and an order was placed. The auxiliary pumping equipment for the tank was ordered and some items are being manufactured.

b) Design Office

The PS Design Office continues to give service to the whole Division.

At present the main efforts are concentrated on the design and construction of the 2 m liquid hydrogen bubble chamber and the 1 m propane bubble chamber. However, work is still continuing on components of the PS machine and its facilities such as the RF knock-out system, beam ejection, transport and separation facilities.

Work has started on the design of a 100 MeV two-way FFAG electron accelerator for beam-stacking experiments.

10. Survey

The first accurate positioning of the magnet units was carried out. The deformations of the subsoil having remained small in the summer (< 0.1 mm/100 m), the consequent corrections between the geodetic monuments and the concrete beam were quite unimportant. The data of bubble levellings showed the magnets to be sinking as a whole (2.6 mm since the beginning of the year) with small local variations (± 0.15), so that the corrections in elevation remained small. The accuracy of this survey was around ± 0.1 mm, both vertically and horizontally.

Checkings made immediately after this survey showed that the units had not remained exactly in position, the discrepancies reaching in some cases nearly 1 mm.
To get to the origin of these movements different checks of possible movements were undertaken, either with invar wires or with recording inductive coils (shielded, of course, against stray fields). It was found that during pulses the units were deformed, causing displacements at the top ends reaching about 3 hundredths of a mm, and that these deformations were not perfectly elastic, which caused a systematic drift of a few tenths of a mm after several weeks. Happily, these drifts were of an asymptotic nature, and after a great number of pulses they tended to disappear altogether. They were of different origins: some originating between the blocks of units, some between the blocks and the supporting girders, and some between the concrete beam and girder through the jacks. The last type took place only after a unit had been moved and were probably due to some small instabilities inside the jacks. They were always smaller than 0.1 mm, short-lived (a few days) and easy to correct.

The second were certainly due to some internal stress due to deformation during transportation of the units, which were subsequently shaken down during pulsing. They usually disappeared after a month of pulsing.

Drifts of the first sort were the longest-lived and took some months to become negligible. They were also due to internal stresses which were released by pulsing.

Units are still being kept under observation between pulses, and the drifts are steadily decreasing. After $10^6$ pulses it will probably be possible to perform a new survey at $\pm 0.1$ mm accuracy.

11. Propane Bubble Chamber

The Propane Bubble Chamber Group was formed from part of the group responsible for the synchrotron magnet, so that for the early part of the year, while the magnet work had top priority, very few staff were available for design studies. Despite this difficulty, progress was made and some components were already delivered this year.

In January an informal meeting with representatives of other European heavy liquid bubble chamber groups was held in CERN. As a result of discussions at this meeting, it was decided to modify the original design of the expansion and recompression valves and auxiliary reservoirs to exploit the advantages of the circular symmetry of the chamber to a maximum. All these components together with the body are being constructed and will be tested early in 1960.

An extensive investigation of European and American production facilities permitted the placing of a satisfactory contract with a European supplier for a chamber window of optical glass quality, precision finished and 115 cm in diameter and 25 cm thick.

The 82 ton electromagnet to produce a field of 20 kgauss is ordered and the manufacturer is preparing a prototype coil to prove that the extremely highly stressed working conditions can be met. The whole of the 400 HP compressor installation, including reservoirs, filters and regulating devices, is also ordered.

A complete study was made of the optical requirements of the bubble chamber, including theoretical studies of the possibility of correcting for distortions due to refraction and dispersion in the propane and thick glass windows. Owing to the very kind loan of a glass slab 22 cm thick and weighing some 300 kg, it was possible to study practically many problems arising from chromatic distortion and small variations in refractive index in the window. Design on the camera systems is in progress.

The mechanism of pneumatic expansion was studied experimentally and practical limitations to expansion speed assessed. Various types of fast-acting valves were tested and substantially improved.

Studies were made with a prototype of one of the five systems for control of the chamber temperature. The remaining systems are under construction, together with apparatus for hydraulic testing of the chamber body. All the control and monitoring systems are under design, and some timing circuits and a prototype energy storage system for the flash lamps are completed.

A study was made of experiments to exploit fully the special properties of the propane chamber. Many can be foreseen, and suitable beam transport channels for the first of them are being planned.

12. Beam Transport, Particle Separators and Ejection

a) Beam transport

At the beginning of the year, designs were finalized for bending magnets and quadrupole lenses, based on the beam transport channels shown in the last Annual Report. A contract was signed in May for the manufacture of 44 components as follows:
Component | Number | Max. excitation (kW) | Unit weight (tons)
--- | --- | --- | ---
One metre bending magnets | 5 | 100 | 15
Two metre bending magnets | 13 | 155 | 29
One metre quadrupole lenses | 18 | 90 | 5
Two metre quadrupole lenses | 8 | 130 | 9

The gap height of the bending magnets is adjustable in steps between 11 cm and 20 cm and the maximum magnetic field with a 14 cm gap is 1.6 Wb/m². The quadrupoles have an aperture of 20 cm and a maximum gradient of 10 Wb/m³. Delivery will start in January 1960 and continue until October 1960.

Because electrical breakdown can easily come from condensation of atmospheric water on water-cooled coils at the site, the contract demands that all coils pass insulation tests completely immersed in water, a procedure which was adopted with the coils for the magnet of the proton synchrotron. Economical processes have been found which give this quality of insulation.

Each component will be mounted on a reinforced block of heavy concrete which will serve both as a support and as part of the shielding system. The whole will be transportable with a crane or, for places without crane facilities, will be moved by readily attachable caterpillar trolleys at present under construction. Adequate means of fine adjustment are incorporated to reduce loss of time to a minimum during installation and alignment.

Preparations have been made for magnetic studies on the prototypes to fix the polar profiles of the production components.

During the year computations have continued on the trajectories of particles in the vicinity of the magnet of the synchrotron. More refined calculations have also been undertaken on the compensation of aberrations in the beam transport systems.

b) Electrostatic separators

A full-scale model of a section of one of the proposed electrostatic mass separators was studied. Essential information was obtained about high voltage and vacuum problems as well as about the effects of magnetic fields on the electrical properties of the system.

The design of the separator tanks has commenced and it is planned to obtain a separated antiproton beam with momentum up to about 2.5 GeV/c in the South experimental hall. About 30 metres of parallel electrodes with potentials of ± 500 kV are being designed.

A preliminary computation of the beam optics has been made and the correction of the aberrations is now being studied.

c) Ejection systems

Preliminary studies of methods of ejecting the circulating proton beam in the synchrotron in times comparable with the revolution period were made. Many possible methods of using such a facility in bubble chamber and other experiments are envisaged.

A model of a fast deflecting magnet of a delay line type of construction together with a matching fast discharge circuit has been constructed and is being tested.

Model work is also in progress with a design study for a slow ejection system. A septum type of magnet has been built and measurements confirm the theoretical prediction of a very low leakage field. A larger magnet is being constructed which can serve both as a component of the fast ejection system or, in conjunction with a scattering target in the synchrotron, to give a slowly ejected beam of low intensity.

13. Hydrogen Bubble Chambers

a) 30 cm bubble chamber

The 30 cm liquid hydrogen bubble chamber was tested with nitrogen in April and with hydrogen on 7 May. Tracks of Compton electrons and cosmic rays were observed during this first test. The performance of the apparatus was completely satisfactory. No other development test was neces-
sary before the first run in a $\pi^+$ meson beam produced by the outside proton beam of the CERN synchro-cyclotron. This test was made at the end of August and the performance of the chamber was almost perfect. $\pi^+$, $p$ elastic scattering events obtained during this test are now being measured.

When the 30 cm chamber was designed, emphasis was laid on reliability and ease and speed of positioning. Up to now these efforts seem to have been worthwhile. In particular, the seals and valves specially developed at CERN have given complete satisfaction.

The chamber can give one photograph every two seconds. At this rate the dynamic consumption is only 0.5 litre of liquid $H_2$ per hour, and the static consumption 4.5 litres.

The 30 cm chamber was run at the synchrocyclotron for five days from 15 November, and 100 000 photographs were taken. Beams of positive $\pi$-mesons of 265 and 330 MeV were used and the photographs will be analysed to study the two reactions

$$\pi^+ + p \rightarrow \pi^+ + \pi^+ + n \quad \text{and} \quad \pi^+ + p \rightarrow \pi^+ + \pi^0 + p.$$  

b) Measurement of distortion

A systematic study of the distortion of tracks without a magnetic field is being made in cooperation with the CERN Iep Group on the photographs taken with the 10 cm and the 30 cm chambers. In the 10 cm chamber, distortion has only been observed in the immediate vicinity of the expansion neck, which means that, in the useful region of the chamber, distortion was less than the curve caused by Coulomb scattering of the particles in hydrogen. Only preliminary results have been obtained with the 30 cm chamber; they are the same except that no distortion has yet been observed near the expansion neck. It can therefore reasonably be hoped that the curvature produced by the distortion will not be much over 0.05 mm, which means that the pulse measurement should be at least as accurate as in a cloud chamber of the same size.

c) Ionization measurements

Systematic ionization measurement was undertaken on tracks obtained with the 10 cm and 30 cm chambers. The method used was that of measuring the mean gap length with a projecting microscope. Results were very encouraging. The sensitivity of the chamber proved constant over its whole volume. The variation of sensitivity from one photograph to another, while not negligible, was not very great. It can therefore be hoped that a slightly stricter control of the expansion will make it possible to carry out measurements without even using a reference track in the same photograph. The variations in the measurements (with reference track) are small enough to permit the use of ionization measurements to identify particles with an almost minimum ionization.

These experiments will be made especially to find out whether it is possible to measure a rise in ionization in liquid hydrogen. In theory, there is not much hope of success, but, on the other hand, a positive result would be so important for high energy physics that it is worthwhile trying even with very slender hopes.

d) Tests for the 2 m chamber

It became clear that to achieve a reasonable design and particularly to limit the expenditure connected with the dynamic consumption, it was necessary to have a much more intimate knowledge than was the case of the different phenomena occurring during gas or liquid expansion. A considerable part of the testing of the 10 and 30 cm chambers was therefore devoted to such systematic studies. Special attention was paid to the law of bubble growth, the light energy necessary to obtain good photographs, boiling in the expansion mechanism and its effect on dynamic consumption, the temperature and expansion rate necessary for obtaining good tracks, etc. In addition, a special experiment was carried out in order to study gas expansion. These tests will be pursued and considerably extended.

e) 2 metre chamber

Work on this project has gone forward as quickly as possible, considering it was necessary first of all to recruit and train a competent and homogeneous team.

Plans were drawn up for the various buildings (bubble chamber building, experimental services building, beam transport platform, junction with PS ring).

Further consideration was given to the design of the chamber and magnet to find a suitable compromise between the contradictory requirements of magnetic field and easy assembly and operation of the chamber.

The final design of the magnet and its transport and pivoting system is now practically complete,
tor building
The above three views show the complete assembled apparatus.

The chamber body and its radiation shield are inside a vacuum tank, which is itself enclosed in the magnet. The chamber is piston-expanded, has two vertical windows and a straight-through illumination system. The useful volume of the chamber is 200 cm long x 60 cm high x 50 cm deep.

The chamber and its vacuum tank hang from the platform-bridge, which is itself supported by the top of the magnet, except for disassembly. The magnet is supported via hydraulic jacks by four three-wheeled chariots. To turn the assembled apparatus, the chariots are retracted and the magnet rests on a large turntable with conical rollers. To disassemble, the platform-bridge is supported by its four wheels via hydraulic jacks, and the magnet is split open symmetrically along the rail direction, its halves being supported by the three-wheeled chariots and by four supplementary wheels; then the chamber body is removed from the vacuum tank.

The liquefier, the purifier, the pneumatic drive of the piston, the valve box, the junction box, and the control panels are all supported by the platform-bridge. The valve box is connected to the chamber proper by a small number of transfer lines; it is pneumatically operated.

The control panels of the magnet, of the transport system, of the cameras and of the flash-lights are all located on the lower platforms, which remain attached to the magnet shell.

The beams of particles enter and emerge via the large pipes which connect the vacuum tank to the diffusion pumps through openings in the magnet shell. A built-in correcting coil allows the entry of low energy beams into the chamber.
particular attention having been paid to ease of assembly. Various firms have already been approached. A 1/10 model using Monel instead of steel to simulate the conditions of the magnetic field has been constructed. The design of the vacuum tank is also well under way; a model was studied under vacuum and under pressure by means of strain gauges. The suspension of the chamber body and the system of assembly were studied in detail; although the chamber body has been designed in detail, it may still be somewhat modified according to the construction method chosen (casting or welding). Various firms were contacted in order to investigate this problem. An installation for measuring the magnetic properties of stainless steel at the temperature of liquid hydrogen is being constructed.

Several firms were contacted on the question of dry compressors for the recompression circuit and the refrigerating system.

f) Liquefier

The hydrogen liquefier has continued to function satisfactorily. Between 1 January and 1 October 1959, the output was 4 300 litres of liquid hydrogen, which was sufficient for all CERN’s requirements. The following improvements were made:

— A 200 m³/h compressor was installed in June 1959 and functions satisfactorily: this increased production to 50 litres/hour. 1 800 litres have been produced with this new compressor.

— The gasometer was made automatic and safety installations have been improved.

— A liquid nitrogen purifier was designed by the PS Design Office and is now being manufactured. It should enable the liquefier to operate almost continuously over long periods, which will be necessary to supply medium size bubble chambers used with the PS.

14. Publications


Publications by members of the Division other than CERN “yellow” Reports are mentioned in Appendix A (reprints).