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ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN PROTON SYNCHROTRON
Machine Group

OPERATION AND DEVELOPMENT
Quarterly report No. 2
April - June 1960

GÈNEVE
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Machine Group

OPERATION AND DEVELOPMENT
Quarterly report No. 2
April - June 1960

GENEVE
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TABLE OF CONTENTS

INTRODUCTORY NOTE ........................................................................ 5

I. CPS PARAMETERS ......................................................................... 7

II. MACHINE STATUS ....................................................................... 13
   1. Linear accelerator ................................................................. 13
   2. RF system ............................................................................ 15
   3. Magnet power supply ........................................................... 17
   4. Magnet ................................................................................. 17
   5. Vacuum system ..................................................................... 18
   6. Targets ................................................................................ 19
   7. Controls ................................................................................. 20
   8. Radiation measurements and security precautions ........... 21
   9. Running-in and machine measurements ........................... 23

III. MACHINE OPERATION ................................................................. 26

IV. EXPERIMENTS ........................................................................... 29
INTRODUCTORY NOTE

This is the second quarterly report issued by the Machine Group of the CERN Proton Synchrotron. A reasonable amount of time has been spent on finishing most of the installation work, on understanding more of the behaviour of the machine and on starting to improve the reliability of some parts. Studies on experimental facilities such as targeting problems were also continued and will be intensified in the future.

This policy of reserving systematically time for machine studies and improvements has given a good result, as shown in the present report.

Amongst the interesting features of this second quarter 1960:

(a) The buncher between the 500 kV column and the first tank of the Linac is now modified and works reliably. The normal operating intensity during the last weeks of the quarter was $1.5 \times 10^{11}$ protons/pulse. The peak intensity was $2.2 \times 10^{11}$ protons/pulse.

(b) A secondary proton beam scattered from the target with an energy nearly equal to the energy of the circulating protons is available in the Experimental Hall with an intensity of about $5 \times 10^3$ protons/cm$^2$ at 100 m. The range of energy available is 8 GeV/c to 28 GeV/c. This beam is useful for emulsion, bubble chamber and counter work.

At the end of the quarter, a 72 hour continuous run was carried out for the experimenters. Amongst others, cross-sections for $K^+$, $\pi^+$ mesons as well as for protons and antiprotons were measured at different energies in a liquid hydrogen target of 3.2 m long.

PS Machine Group
## Structure and Basic Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection 50 MeV</td>
<td>( B_0 = 148 ) G</td>
</tr>
<tr>
<td>Transition 4.8 GeV</td>
<td>( B_0 = 2840 ) G</td>
</tr>
<tr>
<td>Top energy 24.3 GeV</td>
<td>( B_0 = 12 ) kG</td>
</tr>
<tr>
<td></td>
<td>( B_0 = 14 ) kG</td>
</tr>
<tr>
<td>( r_o )</td>
<td>= 70.079 m</td>
</tr>
<tr>
<td>( r_m )</td>
<td>= 100.00 m</td>
</tr>
<tr>
<td>No. of magnet periods</td>
<td>( M = 50 )</td>
</tr>
<tr>
<td>No. of ( \frac{1}{2} F \frac{1}{2} D ) magnet units</td>
<td>( N = 100 )</td>
</tr>
<tr>
<td>No. of periods per superperiod</td>
<td>= 5</td>
</tr>
<tr>
<td>No. of superperiods</td>
<td>= 10</td>
</tr>
<tr>
<td>Field index</td>
<td>( n = 288.4 )</td>
</tr>
<tr>
<td>Mode</td>
<td>( \mu_r = \mu_v = \pi/4 )</td>
</tr>
<tr>
<td>No. of Betatron oscillations per revolution</td>
<td>( Q_r = Q_v = 6.25 )</td>
</tr>
<tr>
<td>Magnet gap on equilibrium orbit</td>
<td>= 0.10 m</td>
</tr>
<tr>
<td>Height of E.O. above floor</td>
<td>= 1.26 m</td>
</tr>
<tr>
<td>Nominal bending length of magnet units</td>
<td>= 4.40 m</td>
</tr>
<tr>
<td>Nominal length of 80 short field free sectors (f.f.s.)</td>
<td>= 1.60 m</td>
</tr>
<tr>
<td>Nominal length of 20 long field free sectors</td>
<td>= 3.00 m</td>
</tr>
<tr>
<td>No. of quadrupole lenses 80 cm long</td>
<td>10 pairs</td>
</tr>
<tr>
<td>No. of sextupole lenses 30 cm long</td>
<td>10 pairs</td>
</tr>
<tr>
<td>No. of combined octupole and dipole lenses 40 cm long</td>
<td>10 pairs</td>
</tr>
<tr>
<td>Lenses occupy 4 short f.f.s. per superperiod, 2 for quadrupoles, and 2 shared for dipoles, sextupoles and octupoles.</td>
<td></td>
</tr>
<tr>
<td>No. of radially sensitive pick-up electrodes</td>
<td>19</td>
</tr>
<tr>
<td>No. of vertically sensitive pick-up electrodes</td>
<td>19</td>
</tr>
<tr>
<td>No. of beam current pick-up electrodes</td>
<td>4</td>
</tr>
<tr>
<td>Combined vertical and horizontal electrodes occupy 2 short f.f.s. per superperiod (the inflector replaces them in one case).</td>
<td></td>
</tr>
<tr>
<td>Vertically or radially variable slits can be installed in any f.f.s.</td>
<td></td>
</tr>
</tbody>
</table>
Magnet and Magnet Power Supply

Total weight of iron yoke (1000 blocks) 3000 t
Overall weight of one unit made of 10 blocks 34 t
Physical length of yoke 4.26 m
Overall length of unit 4.9 m
Thickness of iron laminations 1.5 mm
Total weight of coils 130 t
Section of aluminium conductor 38 x 55 mm
No. of turns per unit 20
Total inductance of magnet, apart from saturation effects 0.9 H
Total resistance of coils 0.3 Ω
Field rise time to 12 kG 1.0 s
1.2 s
Complete cycle time to 12 kG 3 s
5 s
Complete cycle time to 14 kG 3 s
5 s
Minimum cycle time, 0.543 Wb/m² (10.5 GeV) 1.0 s
Peak magnet current to 12 kG 5000 A
6400 A
Peak magnet current to 14 kG
Normal magnet voltage, 90% tapping
(100%, 75%, 50%, 25% tappings available for other
rates of rise)
Magnet power supply peak output at 12 kG 27 MW
32 MW
Magnet power supply peak output at 14 kG
Maximum average power supplied to magnet 1.5 MW
Stored energy in magnet at 12 kG 1.0 x 10⁷ J
1.6 x 10⁷ J
at 14 kG
Fall in \( n_0 \) with saturation at 12 kG
\[ \frac{\delta n}{n} = -2.2\% \]
\[ \frac{\delta n}{n} = -6.6\% \]
at 14 kG
Slope of \( n \) plateau at 12 kG
at 14 kG
\[ \frac{\delta n}{n} = 0.42\% \, cm^{-1} \]
\[ \frac{\delta n}{n} = 1.1\% \, cm^{-1} \]

(Correction by poleface windings)
Uniformity of magnet: block to block scatter in \( B_0 \)

at injection (148 G) 1.1 x 10⁻³ rms
at transition (2840 G) 0.25 x 10⁻³ rms
at top field (14 kG) 0.5 x 10⁻³ rms

Gradient errors of similar size, strongly correlated with \( \delta B_0 \).
Acceleration System

Energy gain per turn at 12 kG/s ............................... 54 keV
Normal peak RF volts per turn (64° phase angle) ............... 125 kV
No. of ferrite tuned accelerating cavities (each consisting of two λ/4 resonators) in long f.f.s. ................. 16
Length of cavity ................................................. 2.3 m
Normal rms gap voltage ........................................ 5.6 kV
Maximum available rms gap voltage .......................... ~ 6 kV
Cavity shunt impedance ......................................... ~ 7.8 kΩ
Normal power input to cavity .................................. ~ 4 kW
Weight of ferrite (FXC 4 H) per cavity (2 cylinders) ....... 560 kg
Harmonic number .................................................. 20
Frequency range ................................................... 2.9 - 9.55 MHz
Tuning range of automatic cavity tuning system ............. 2.4 - 10 MHz

Injector

Linac input energy, from Cockcroft-Walton HT set .......... 0.5 MeV
Linac output energy ............................................. 50 MeV
Output energy spread, without debuncher ........................
with debuncher (calculated) ......................................
Injection pulse length ........................................... 6 µs
Emittance of output beam (80% of 4 mA), radial vertical .... 5 µrad 12 µrad
Input pulse current to Linac .................................... 25-40 mA
Output pulse current, without buncher ........................ 4-6 mA
with buncher ..................................................... 10-15 mA

Linac Tank I
Energy .................................................................... 0.5-10 MeV
No. of gaps ......................................................... 42
Length ................................................................. 6 m
Diameter ............................................................. 1.08 m
RF power ............................................................ ~ 0.6 MW
Maximum quadrupole focusing gradient (pulsed) ............... 4 kG cm⁻¹

Linac Tank II
Energy .................................................................... 10-30 MeV
No. of gaps ......................................................... 41
Length ................................................................. 12 m
Diameter ............................................................. 0.92 m
RF power ............................................................ ~ 1.3 MW
Max. quadrupole focusing gradient (d.c.) ....................... 1 kG cm⁻¹
Linac Tank III Energy

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of gaps</td>
<td>30-50 MeV</td>
</tr>
<tr>
<td>Length</td>
<td>27</td>
</tr>
<tr>
<td>Diameter</td>
<td>12 m</td>
</tr>
<tr>
<td>RF power</td>
<td>0.81 m</td>
</tr>
<tr>
<td>Max. quadrupole focusing gradient (d.c.)</td>
<td>~ 1.5 MW</td>
</tr>
<tr>
<td></td>
<td>0.55 kG cm⁻¹</td>
</tr>
</tbody>
</table>

Accelerating radio-frequency

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of phase oscillations in Linac</td>
<td>202.6 MHz</td>
</tr>
<tr>
<td>No. of radial oscillations in Linac</td>
<td>~ 4.5</td>
</tr>
<tr>
<td>Quadrupole focusing structure period: + + - -</td>
<td>~ 3.4 over four drift tubes</td>
</tr>
</tbody>
</table>

Buncher gap voltage

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buncher distance from Tank I</td>
<td>15 kV peak</td>
</tr>
<tr>
<td>Debuncher gap voltage</td>
<td>0.7 m</td>
</tr>
<tr>
<td>Debuncher distance from Tank III</td>
<td>530 kV peak</td>
</tr>
<tr>
<td>Vacuum pumps, Hg diffusion type, No.</td>
<td>15 m</td>
</tr>
<tr>
<td>Diameter</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>0.5 m</td>
</tr>
</tbody>
</table>

Pumping speed, baffled to -80°C

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working pressure</td>
<td>&lt; 10⁻⁵ mm Hg</td>
</tr>
<tr>
<td>Inflector system: 1st magnet</td>
<td>2.4 kG</td>
</tr>
<tr>
<td>Field</td>
<td>1.2 m</td>
</tr>
<tr>
<td>Length</td>
<td>- 300 mrad</td>
</tr>
<tr>
<td>Angle of bend</td>
<td>2.1 kG</td>
</tr>
<tr>
<td>2nd magnet</td>
<td>1.2 m</td>
</tr>
<tr>
<td>Field</td>
<td>+ 260 mrad</td>
</tr>
<tr>
<td>Length</td>
<td>1.2 m</td>
</tr>
<tr>
<td>Angle of bend</td>
<td>25 kV cm⁻¹</td>
</tr>
<tr>
<td>d.c. inflector</td>
<td>2.0 m</td>
</tr>
<tr>
<td>Field</td>
<td>+ 50 mrad</td>
</tr>
<tr>
<td>Length</td>
<td>2.1 kG</td>
</tr>
<tr>
<td>Angle of bend</td>
<td>25 kV cm⁻¹</td>
</tr>
<tr>
<td>1st and 2nd pulsed inflect.</td>
<td>0.85 m</td>
</tr>
<tr>
<td>Av. field</td>
<td>7.3 mrad</td>
</tr>
<tr>
<td>Length</td>
<td>3.65 kV cm⁻¹</td>
</tr>
<tr>
<td>Total angle of bend</td>
<td>0.85 m</td>
</tr>
<tr>
<td>3rd pulsed inflector</td>
<td>7.3 mrad</td>
</tr>
<tr>
<td>Field</td>
<td>4 kV cm⁻¹</td>
</tr>
<tr>
<td>Length</td>
<td>3.2 mrad</td>
</tr>
<tr>
<td>Angle of bend</td>
<td>0.75 m</td>
</tr>
</tbody>
</table>
Vacuum System

Vacuum Chamber  elliptical section
      wall thickness, stainless steel  7 x 14.5 cm  2 mm
Vacuum pumping stations. Number  50
      Oil diffusion pump, diam.  13 cm
      Pumping speed, baffled at 12°C  280 λ/s
      Working pressure  < 10⁻⁶ mm Hg

Orbit Parameters, Tolerances

Momentum compaction factor  0.027
Closed orbit shift for 1% momentum change  2.7 cm
      'wiggle factor'  1.35
      \( \frac{\beta_{\text{max}}}{\beta_{\text{min}}} \) (in matrices for one magnet period)  0.31
      0.17
Closed orbit peak displacement (rms over ensemble of errors)
      Due to 1% rms block-block \( R_b \) fluctuation \( \Delta Q \) calculated
      Due to 0.3 mm rms alignment error of ends of unit \( \Delta Q \) measured at injection without correction
      0.3 cm  0.43 cm
Max. vertical diameter of injected beam of 5 μrad acceptance, properly matched
      3 cm
Increase in beam diameter due to gas scattering in 10⁻⁵ mm air equivalent
      \( \Delta Q \approx 10 \frac{\delta R}{R} \)
      2.4 cm  0.5 cm
Changes of Q with momentum, near transition
      \( \Delta Q \approx 10 \frac{\delta R}{R} \)
      \( \Delta Q \approx 10 \frac{\delta R}{R} \)
      \( \Delta Q \approx 10 \frac{\delta R}{R} \)
Transition timing tolerances
      \( \delta \tau = \pm 1 \text{ ms} \)
Phase oscillations: peak amplitudes
      at injection  \( \delta \Phi = \pm 90°, \frac{\delta \Phi}{R_b} = \pm 0.36\% \)
      \( \delta \tau = \pm 1.1 \text{ cm} \)
      at transition, with full adiabatic damping  \( \pm 10° \)
      \( \pm 0.24\% \)
      \( \pm 0.75 \text{ cm} \)
      at transition, max. permissible to avoid loss later  \( \pm 40° \)
      \( \pm 1\% \)
      \( \pm 3 \text{ cm} \)
      at top energy, with full damping and perfect transition timing  \( \pm 10° \)
      \( \pm 0.02\% \)
      \( \pm 0.08 \text{ cm} \)
      at top energy, limits of stability  \( \pm 90° \)
      \( \pm 0.22\% \)
      \( \pm 0.68 \text{ cm} \)
      at top energy, measured  \( \pm 15° \)
      \( \pm 0.03\% \)
      \( \pm 0.12 \text{ cm} \)
Frequency of phase oscillations:
- at injection
- at adiabatic limit near transition
- at top energy

Adiabatic frequency tolerances, for 1 cm shift of closed orbit
- at injection
- at adiabatic limit near transition
- at top energy

Tolerances on $B$ or magnet power supply voltage ripple to avoid noticeable excitation of phase oscillations
- Ripple frequencies below 500 Hz
- 500 Hz
- up to 8 kHz

Circulating beam: 1 mA injected for 1 revolution

Accelerated beam:
- normal best performance
- 3.5 mA injected
- overall efficiency

with Linac buncher operating
- 12 mA injected
- overall efficiency

- 7.8 kHz
- ~ 0.1 kHz
- 0.26 kHz
- 0.3%
- ~ $10^{-8}$
- $10^{-4}$
- < 0.1%
- 0.5%
- falling to
- 0.05%
- = 4 $10^{10}$ protons
- 6 $10^{10}$ accelerated
- 43%
- 2 $10^{11}$ accelerated
- 42%
II. MACHINE STATUS

1. Linear accelerator

The period of this report covers the running-in of the Linac after
the March/April shut-down, a month or so's subsequent operation with cur-
rents of the order of 5 mA, the installation of the modified buncher at
the end of May resulting in currents of the order of 12 mA, then a period
of running at this new level followed by a "long run" and a two weeks'
shut-down at the end of June.

During the running-in period in April, the emittance of the emergent
Linac beam was measured and found to be 6.1 μrad and 12.3 μrad in the y
and z planes respectively. The corresponding axial ratios were 3.0 mrad/m
and 3.3 mrad/cm. These measurements were made for 80% of the total current
(4 mA) and agreed fairly well with previous values. The momentum spread
was about ± 2.5% corresponding to ± 250 kV which is also normal. What
had changed, however, was the sensitivity of the 50 MeV beam to the 500 kV
focusing conditions resulting from the installation of strong-focusing tri-
plets in place of solenoids. This led to some initial difficulty in set-
ting up the optimum Linac beam. Tests showed finally that the quickest
method was:

a) as before, set the Tank RF levels by momentum analysis;

b) discontinue the use of steering magnets at 50 MeV and steer the
output beam and optimize the pulse shape and amplitude by adjust-
ing the input parameters, i.e. 500 kV steering magnets and
500 kV triplets, followed by Tank focusing. For this adjustment,
the current passing through a 15 × 15 mm aperture 15 metres from
the end of Tank III was observed.

c) adjust an aperture limiting system to define a pencil beam matched
to the synchrotron and trim the matching lenses to give maximum
current through this system.

This procedure results in a circulating synchrotron beam which cannot
be much improved by further trimming of the Linac, as distinct from some
of the earlier attempts made during these tests.
To give some idea of the time scale involved, a typical day's operation (Monday, Tuesday or Friday) during this period from April through June was:

08.30 Switch-on. Maintenance, repairs etc. during warm-up. 10 MeV produced at about 09.15.

10.00 Security barriers closed and 50 MeV produced. Tank levels set by momentum analysis. Period till midday available for experiments, faults investigation and operator training.

12.00 Momentum analysis checked and steering and focusing adjusted as in a) and b) above.

12.30 Clearance given for injection into synchrotron. Matching lenses trimmed as in c) above.

13.00 Matched pencil beam made available to PS Main Control Room for adjustment of spiralling beam followed by acceleration.

13.00 - 24.00 Beam as requested for synchrotron.

Considering new specific items in the Linac, the multipactoring in the buncher was overcome by installing a 2 kV bias plate which extends to the grid at the centre. The timing does not have to be adjusted during operation in order to maintain the current increase of about 2.5, and the Linac beam is not noticeably more sensitive to injected energy with the buncher in.

Part of the pre-injector vacuum system was modified in June, namely by the installation of two new -40°C refrigerators and a new alcohol/refrigerant heat exchanger, with automatic change-over in the event of failure. At the same time, a new corona shield was fitted to the 500 kV accelerating column, and on the central platform was mounted an improved monitoring oscilloscope with displays of RF match, beam current and extraction voltage, together with remote indication of RF timing. In the laboratories, a second spare source block was completed.
In the Linac RF system, the definitive modulator supplying the Siemens drive chain was installed and put into service. The provisional modulator will be rebuilt and used to feed the spare F.T.H. cavity utilized for testing cables etc..

The main change in the vacuum system was the replacement of the bellows type beam connections between the tanks. The new beam pipes can slide longitudinally and pivot about O-rings in flanges mounted on the ends of the tanks.

In the inflector region, two ± 40 kV pulsed supplies were installed and partly tested. These supplies will be used for investigating the behaviour of the beam during injection into the synchrotron.

2. RF System

a) Beam intensity measurement. Further improvements have been made to the beam intensity measuring equipment described in the last report.

Since the beam intensity has, on occasions, exceeded $2 \times 10^{11}$ protons and further increases are hoped for, it has been necessary to provide three measuring ranges of $10^{10}$, $10^{11}$ and $10^{12}$ protons per pulse full scale.

The d.c. voltage proportional to the accelerated beam intensity is measured with a digital voltmeter feeding a print-out unit. The magnet pulse number and intensity of the Linac output current will later be printed on the same tape. The following information about the measured beam intensity is now distributed round the machine:

i) Signals for digital read-out units or printers;

ii) An analogue d.c. voltage for meters and recorders which hold the reading until the intensity changes;

iii) A train of pulses, each of which corresponds to $2 \times 10^8$, $2 \times 10^9$ or $2 \times 10^{10}$ protons according to the chosen range of measurement. These pulses allow the intensity to be integrated over any desired time interval or number of pulses.
b) **Pick-up stations.** The head amplifiers of the pick-up stations had to be adapted to the higher accelerated beam intensity. To do this, three different means have been chosen:

i) The cathode-biased head amplifiers have been replaced by cathode followers.

ii) A relay controlled 1:5 capacitive voltage divider has been added between the pick-up electrode and head amplifier.

iii) The band width is already limited to about 30 MHz before the head amplifier. This decreases strongly the peak values of the pulses picked up specially near transition where bunches are very narrow.

c) **Vertical RF knock-out.** A vertical RF knock-out system has been installed to measure the betatron oscillation frequency by resonance excitation as described in the previous report. For the elliptical cross-section of the vacuum chamber, less power is needed for vertical excitation with an electric field than with a magnetic field, and a vertical field of 7kV/cm has been provided.

d) **Remote control of Computer Room.** Equipment for remote control and measurement of the frequency programme (frequency and rate of rise of frequency at injection) and for important fault indication has been installed in the Main Control Room.

e) **Timing system.** The master timer in the Main Control Room has been condensed and its duties extended. Similar systems are now used to provide timing signals locked either to the magnet field (B timing) or to the rotation of the magnet generator (M timing). The B pulse train occurs at intervals of 10 G (about 1 ms), the M train twice per revolution of the generator (about 10 ms).

A scaler counts the B (or M) pulse train and coincidence units enable 12 independently variable timing signals to be selected; these signals are available for general use in the Main Control Room.
3. Magnet power supply

The security of the cooling system for the main converter set bearings has been improved. Firstly, an independent water supply from the town mains has been connected to the oil recouler in case the CERN pumping station fails. Secondly, the control circuits of the a.c. and standby d.c. oil pumps have been modified so that both pumps now run continuously and the converter is stopped if either pump fails.

Wear of the alternator slip ring brushes has been too great; this was partly caused by uneven wear of the slip rings which had to be reground.

A magnetic amplifier in the equipment controlling the phase of the grid pulses during inversion showed a large drift in its characteristic with rising temperature. This resulted in a longer de-energizing time of the PS magnet and a consequent rise of about 300 kW (about 10%) in the mean power consumption. This was cured during the June shut-down.

A number of measurements and tests were carried out to find a temporary method of extending the "Flat-Top" period and to investigate a final solution to the problem. Magnet cycle repetition rates and power consumption were measured with different "Flat-Top" lengths up to 500 ms.

The primary water pipework of the magnet cooling plant, originally in aluminium, has been replaced by galvanized steel conduits, as it was badly corroded.

Further tubes in the magnet cooling heat exchangers have had to be blocked off. The replacement stainless steel tube bundles have not yet been delivered; they should be installed during the next shut-down.

4. Magnet

The magnet has continued to give satisfactory service during the period under review.

Most of the double earth connections of the magnet units have been removed during the June shut-down. No direct effects of this measure have been noticed so far.
Originally the current through the pole-face windings was automatically switched off at the end of the rising part of the magnet cycle. The switching operation is now delayed, so that the field correction remains over the entire flat top (50 ms); this has greatly facilitated flat top target operation for counter experiments.

5. Vacuum system

The straight section vacuum chamber including a Mylar window which was mentioned in the last report, was installed and has been in operational use for the last two months.

The target and slow ejection tank has been tested along with its vacuum system but it will not be installed until the ejection gear is available. A prototype actuator for the slow ejection magnet has been measured and tested in the laboratory; some modifications in the mechanical structure proved to be necessary and are being carried out.

Design work on the special magnet section vacuum chamber for both fast and slow ejection systems has been largely completed. In order to avoid very difficult eddy current corrections, the proposed chamber is to be a composite one of stainless steel and reinforced plastic and it is intended to have Mylar windows along the length of the magnet unit(*).

A prototype short length of such a chamber has been ordered after investigating the possible manufacturers. A variety of smaller problems associated with this project is being investigated.

The studies on the special vacuum chamber are being done in conjunction with the Propane Chamber and Engineering Groups.

6. Targets

Six target mechanisms of the type described in the last report are now in operation in the synchrotron and eight further mechanisms are in the various stages of manufacture.

The linkage between the electro-magnet and the shaft carrying the target head has been redesigned and the new linkage has withstood a laboratory test of $2.5 \times 10^6$ target cycles without failure. No mechanical failure of the improved target mechanisms has occurred during machine operation.

With the higher beam intensity, the increase in temperature of the target head led to the destruction of heads made from aluminium foils of less than 25 $\mu$ thickness. Work is in progress with the aim of lengthening the life of thin targets for high beam intensity work.

Electronic apparatus for 12 timing and 12 drive channels has been completed and is now in use in the Main Control Room. A prototype automatic programme selector has been produced and is under test.

The special target cable network between the target area and the Main Control Room has been completed and is being tested.

Target operation has been standardized as far as possible and Control Room Operators have been trained accordingly but, as this work is under continuous review, frequent changes continue to be necessary.

The present development is occurring mainly in two directions: i) targets which represent a point source and ii) beam sharing between different targets.

As it is difficult to calculate accurately the dynamics of the interaction between the beam and narrow targets of various shapes, this problem is being studied experimentally.

Work is under way to improve the accuracy and fine control of the radial setting of the targets.

Simultaneous beam sharing between two thin targets has been possible for some time; sharing at different times in the cycle is now being studied. Simultaneous sharing of short bursts can be done with two thick
targets using radio-frequency knock-out. There is, however, much work to do on these projects before they are well understood.

A new requirement is to share the beam between a low intensity short burst and a high intensity long burst. An investigation is under way for the production of the short burst using the standard target with the following modifications. A second shaft carrying a wire target head rotates through about 150° and the effective radius of this shaft is made to become smaller when the head rotates into the beam. Thus the head cuts through the beam with the maximum speed. The rotational speeds so far obtained in the laboratory lead one to expect bursts of about 400 μs duration and the intensity expected will be of the order of one percent of the circulating beam. Work is continuing on this investigation.

7. Controls

In the Ring, the installation of the new cabling network for targets was almost finished at the end of this quarter. It consists of eleven junction boxes mounted on the girders of the magnet units, spread along the target and inflection areas, four with plug-in points for eight target heads and seven for four target heads, and connected to a patch-panel in the Ring itself. From this, twelve target heads can be connected to the target racks in the Main Control Room simultaneously.

Installation of the warning lights for security has also been finished, as well as that of plug-in boxes for radiation monitors (tissue-equivalent ion chambers complete with test sources).

In-line indicators showing the number of the magnet cycle, driven by a central uniselector unit, have been installed in the control centres and were put under test at the end of the quarter.

The design of the new panel for door interlocks has been completed and a prototype produced. Maximum flexibility and ease of restoring normal conditions after a fault have been the aims of the design. All the control cables from any given door arrive at a 24-way socket in a crate, which can accept twelve plug-in units. Each unit contains all the control equipment for a door and so can be easily replaced. In addition, various types of
plug-in units can be used (with and without electrical lock, suspension of the interlock, etc.) so that the status of a door can be changed simply by changing the plug-in unit.

In the Main Control Room additional facilities have been added to the beam observation equipment:

a) an internal beam monitor giving the energy up to which particles are accelerated, associated with a discriminator driving an alarm unit and a mechanical register.

b) an external beam monitor accepting scintillation counter signals and driving an alarm unit working on height discrimination and a register.

c) a scaler driving a register to integrate the number of accelerated protons.

In the Counting Room the air cooling system has been put into service. An extension of the system is almost installed in the Main Control Room.

8. Radiation measurements and security precautions

During the period under review, no machine time has been devoted specially to radiation survey, since it has been possible to make a number of measurements during normal operation.

The considerable increase in beam current has necessitated further checks of regions already surveyed, but no major unanticipated changes in security zones have been required. Some special surveys have been carried out, during time earmarked for nuclear physics experiments, in order to establish special conditions where presence of personnel was required in areas normally closed (particularly in connection with the use of liquid hydrogen targets in the South Hall).

The last major increase in circulating beam (by a factor of between 3 and 4) occurred just before the 72 hour "long run". These circumstances combined to produce a much higher level of induced radioactivity in the vacuum envelope than hitherto. It thus became necessary to restrict access to the immediate vicinity (within 50 - 100 cm) of the chamber over approximately one-third of its circumference, and to control more stringently work
going on within a few metres of the target. However, the level of activity was nowhere high enough to prohibit work on the vacuum envelope, with relatively simple precautions, and no deterioration in materials or components has yet been observed (except a tendency for fire-alarms of the ionisation chamber smoke detector type to operate spuriously near a working target). Since the long run was followed by a shut-down, the decay of remanant activity could be observed. Starting from a time seven hours after operation ceased, the level diminished to approximately one-half in the following 20 hours, was halved again in the next 40 - 60 hours, and had fallen to approximately one-tenth of the initial value after 15 days. As might be expected from these figures, a resumption of "short" 6 - 10 hour runs resulted in a much lower build-up of activity, to only about 10% - 20% of the peak values measured. A useful by-product of the higher level of induced activity was that it gave a clear indication of points round the machine where beam is lost to the chamber walls.

The higher beam intensity also made it possible to observe for the first time, with ionisation chamber instruments, peaks and troughs in the stray radiation penetrating the earth cover over the Ring building. These correspond well, so far as measurements have gone, with the regions of beam loss discovered by other means. Actual dose-rates are not high (about 2.5 - 5 mrem per hour) except in an area of a few metres radius above an operating target. Here the situation was somewhat aggravated because the targets mostly in use are below a region where, for structural reasons, the earth-cover is thinnest (approximately 2 instead of 3 metres) and some ventilation openings have been made. The area over the ordinary target region has been permanently closed, and the remainder of the Ring embankment will be restricted during operation.

With regard to the mechanics of security precautions, it has finally been possible to bring into use the last security barrier so that the accelerator itself is now entirely enclosed by interlocked doors and guards are no longer necessary. In the experimental areas, however, guards are still used in order to provide the high degree of flexibility required by frequent changes in beams and layout, and to allow special access arrangements.
9. Running-in and machine measurements

a) Injection behaviour. The coupling between vertical and horizontal betatron oscillations which makes observations and adjustments during injection very confusing for operators, was studied in some detail during this quarter. The 50 MeV beam was injected through a 1 mm² hole and observed by TV on fluorescent screens at distances of approximately 1, 2, 3, 4, 6 wavelengths round the machine during the first revolution. These distances could, in effect, be varied slightly by exciting equally the two sets of quadrupole lenses in the machine; because the wavelengths of the two independent modes of betatron oscillation are different, the imaging effect of the machine at points ~ n λ apart is astigmatic, two line images of the point source being formed at slightly different distances round the machine. The directions of these line images on the screens are normal to the planes of polarization of the two modes of oscillation, and these in practice appeared to be at approximately ± 45°, in agreement with earlier observations of the oscillations themselves by vertically and horizontally sensitive pick-up electrodes. The results in detail were more in agreement with the source of the coupling being distributed round the machine, rather than being localized in some single place, so attempts will be made to remove the coupling by adding quadrupole windings to the octupole lenses aligned at 45° to the normal positions. As part of the start up procedure after the March shut-down, measurements of the range of inflector electrode voltages and of injection timing which would just permit the beam to circulate 3 - 4 times before being lost, indicated a useful aperture of some 12 x 6 cm for the vacuum chamber at injection (14 x 7 cm mechanical aperture).

b) Shape of the closed orbit, and Q values, at various energies. The radial position of the closed orbit was measured at 20 points round the machine at several times in the acceleration cycle, at 2, 100, 500, 950 ms after injection. With the beam near the centre of the vacuum chamber, the shape of the closed orbit at the three higher field levels was found to be much the same, with a peak to peak excursion of less than 1 cm, and roughly agreeing with the shape calculated from the magnet position errors measured in the December 1959 and March 1960 resurveys of the magnet. At 2 ms, the distortion was larger and similar to that measured at injection into the spiralling beam.
The distortion of the closed orbit was also measured for a beam displaced bodily inwards or outwards by acting on the radio-frequency system, and the results showed that at medium field levels, the distortion was somewhat increased towards the outside, probably because of a decrease in $Q_R$, but that a mean displacement of $\pm 6$ cm was possible before beam loss occurred. At higher fields ($\sim 11000$ gauss) the distortion of the closed orbit for a displaced beam was larger, so that mean displacements of only $+4$, $-5$ cm were possible before loss started; the peak to peak distortion was about $3.5$ cm for the beam displaced outwards by the maximum amount.

Measurements with the RF knock-out system at medium and high field levels, showed that the radial $Q$ was about 6.25 in the centre of the vacuum chamber, and that it changed by $\sim 0.03$ for each centimetre displacement of the beam. This, for a $4-5$ cm mean displacement is enough to lower $Q_R$ to a value near to 6.0, and thus explains the increased distortion of the closed orbit.

No signs of a vertical resonance could be detected at any frequency of the (horizontal) RF knock-out, and when the horizontal resonance was excited, there was no trace of oscillation visible on the vertically sensitive pick-up electrodes, showing that the $\pm 45^\circ$ planes of polarization for the betatron oscillations are a low field effect.

c) Acceleration behaviour. Immediately after the March shut-down, it was found that $50-75\%$ of beam was being lost between 0.5 and 10 ms after injection, with the very early beam control take-over which had been so successful earlier. The loss was accompanied by very noticeable bunch width oscillations at 12 - 14 kHz, i.e. twice the phase oscillation frequency. The effect could be cured by limiting the gain of the radial beam control loop at these frequencies, and the fault was traced to the replacement of an amplifier in this loop during the shut-down, which had an unsuspected very low saturation level for these frequencies, by an "improved" model without this effective high frequency limitation.

Another set of observations showed that to trap with maximum efficiency ($\sim 40\%$) the beam radius control, effectively the stable phase angle during the short trapping period had to be set so that the beam after trapping was several centimetres inside the central orbit. This makes some difficulties, on occasion, at transition.
The original system of radial control (radial error signal altering accelerating voltage) was tested again to see if, with the improved signal waveforms now present in the amplifiers and discriminators, it would accelerate up to top energy. This was found to be the case, though there was lower trapping efficiency and loss of some 50% of beam, steadily during the first 50 ms. This is probably due to the reduction in normal accelerating voltage, and consequent smaller stable area unavoidable with a voltage control system. Transition adjustments were very sensitive with this system.

The lower current limit of acceleration by the present beam control system has been studied. The system runs rather stably down to ~ 0.1 mA injected current, i.e. ~ 1.5 \(10^9\) protons accelerated per pulse; below this level, there is not sufficient signal at the time of take-over to permit beam control to be switched in. Lower currents than this can be accelerated if there is loss of beam after take-over.

d) **Target measurements.** Apart from operational developments described elsewhere, some first attempts were made to measure the scattering in Aluminium of 25 GeV protons, by chopping a large very thin foil target across the beam during acceleration, which took some tens of milliseconds to absorb the beam, and then examining the induced radioactivity in the foil by autoradiography. First tests were not completely successful because the target could not be moved fast enough, but the irradiated spot on the target seemed very intense over a 1 cm diameter spot, but with some activity over the whole area of the foil.

Similar measurements, using both autoradiography and a pin-hole scanning counter, were used on a normal 25 \(\mu\) foil target, and again gave a similar picture of current distribution average over the whole period of target operation.

The available range of radial position of the standard targets was measured, displacing the accelerated beam and target together outwards or inwards by known amounts. A range of \(\pm 2\) to \(-4\) cm for the position of the free edge of the target in straight section \#1 from the central orbit is possible, with the present high field behaviour of the magnet and pole-face windings.
III. MACHINE OPERATION

In the new operating schedule, started on April 18th, the weekly available time was divided as follows:

a) Setting-up of the linear accelerator and tests on parts of the machine : 22.5 hours

b) Machine studies and operational training : 20.0 hours

c) Nuclear physics experiments : 13.0 hours

Nuclear physicists were also able to "parasite" on external beams available during 6.5 hours of time b).

At the end of the quarter, a 72 hour continuous run has taken place during which external beams for counter experiments were available during 96% of the scheduled time (67.5 hours). The peak accelerated beam intensity was $2.2 \times 10^{11}$ protons/pulse. The average, with the buncher working, higher than $1 \times 10^{11}$ protons/pulse.

The time devoted to studies with the 50 MeV beam spiralling in the synchrotron vacuum chamber has been progressively reduced so that for most of time b) there has also been an accelerated beam.

The training of operators has been actively pursued so that the normal operating staff has been able to cope entirely with machine operation including operation of internal targets.
STATISTICS of P.S. OPERATION

Second Quarter
(April 4 - July 1)

QUARTERLY TOTALS

- Time for part tests and setting up.
- Time for 50 MeV operation.
- Time for acceleration.
- Total time for operation, maintenance and installation.
- Long run
- One day holiday.
### DISTRIBUTION of MACHINE ACCELERATION TIME

#### WEEK BEGINNING

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
<th>Total Acceleration Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 April</td>
<td>SHUT DOWN</td>
<td>—</td>
</tr>
<tr>
<td>11 April</td>
<td></td>
<td>18</td>
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<tr>
<td>18 April</td>
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<tr>
<td>13 June</td>
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<td>67</td>
</tr>
<tr>
<td>20 June</td>
<td>SHUT DOWN</td>
<td>—</td>
</tr>
<tr>
<td>27 June</td>
<td>SHUT DOWN</td>
<td>—</td>
</tr>
</tbody>
</table>

#### QUARTERLY TOTALS

- Actual accelerated beam time: 72%
- Time before accelerated beam: 7.5%
- Interruptions requested by users: 1.3%
- "Off" time due to components failure: 5%

Total acceleration time: 313.0 hours
IV. EXPERIMENTS

During the period considered, more beam transport equipment has been used; one of each type of the new analysing magnets (respectively 1 m and 2 m long) and a total of ten focusing quadrupoles (eight of 5.6 m and two of 5 m focal length at 5 GeV/c) have been used. One additional generator has been available (80 V, 400 A non stabilized) and repeated use has been made of the cable link with the synchro-cyclotron building to transfer varying amounts of d.c. power.

Two independent charged beams (see below - Counter Teams No. 3 and 5) have been set up to run simultaneously and this fact, combined with the extended use of "parasiting", has considerably improved the efficiency of the accelerator. No bubble chamber runs have taken place during this period.

The following is a summary of the time allocated to the various groups; no attempt is made here to describe the experiments themselves.

A. Counter Teams

<table>
<thead>
<tr>
<th>Group</th>
<th>Beam</th>
<th>Scheduled Time</th>
<th>Programme and Techniques used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. G. Bernardini</td>
<td>Neutral, 0°, 2°, 3°, 15.5°</td>
<td>3 x 6 hours and several runs as parasites</td>
<td>Exploration of neutral beam (γ rays and neutrons), calibration of lead glass Cherenkov counter.</td>
</tr>
<tr>
<td>W. Middelkoop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. G. Cocconi</td>
<td>γ rays, scattered protons</td>
<td>Several runs as parasites</td>
<td>Operation of γ ray beam monitor, 25 GeV proton beam analysis and cross-section measurements using counters.</td>
</tr>
<tr>
<td>3. G. von Dardel</td>
<td>Charged, 6°, 5-11 GeV/c</td>
<td>3 x 6 hours; 67 hours continuous run and several runs as parasites</td>
<td>Exploration of charged beam by means of a gas Cherenkov counter. Cross-section measurements of p, p, k⁺ k⁻, π⁺ π⁻ on H₂ (100 litres liquid hydrogen target).</td>
</tr>
<tr>
<td>4. A. Lundby</td>
<td>Neutral 0°, 15.5°</td>
<td>3 x 6 hours; several runs as parasites</td>
<td>Investigation of beam composition using scintillation and Cherenkov counters. Measurements in Mount Citron of K⁺ particles.</td>
</tr>
</tbody>
</table>
5. G. Fidecaro  
A. Merrison  
Charged $15.5^\circ$, $6 \times 6$ hours; Exploration of charged beam, 
$11.5^\circ$  
67 hours continuous run and using a time-of-flight 
1-12 GeV/c  
several runs 
as parasites

6. B.D. Hyams  
H. Faissner  
W. Love  
Background surveys in view of the neutrino experiment.

B. Emulsions

7. W. Gibson  
In co-operation with the Universities of Bern, Brussels, 
Chicago, Clermont-Ferrand, Copenhagen, Dublin, Durham, 
Genoa, Lausanne, Liège, U.C. London, Melbourne, Milan, 
München, Nebraska, Oxford, Paris, Rome, Strasbourg, Turin:

Investigation of composition of secondary beams, scattered 
proton beam, background measurements for Machine Group.

In total 9 sessions of exposures took place, some of them 
involving a large number of stacks for CERN or other 
institutes. Details as follows:

a. Scattered proton beam  
b. Neutral beam ($0^\circ$ and $3^\circ$)  
c. Momentum analyzed beam (6 and 10 GeV/c, $\pi^-$)  
d. Background survey

2  
2  
4  
1

C. Radio-chemistry

8. G. Rudstam  
K. Goebel  
Four exposures of targets to the internal proton beam took 
place, each lasting 1/4 hour.

D. Radiation Survey

9. B. Wheatley  
Several runs as parasites  
General and special surveys around the PS in co-operation 
as parasites 
with the Machine Group.
Fig. 1  Standard target unit showing from left to right the 2 electromagnetic actuators for flipping the target heads, the square flange for mounting the unit into the vacuum chamber and the motors for the remote control of the radial target position.

Fig. 2  Target unit mounted in standard position in magnet unit No. 5. From right to left: vacuum tight socket and connector for actuator leads and target "in-out" signal, motors, gear boxes and potentiometers for control and indication of radial position, window (in flange) for observation of target motion.
Fig. 3 Partial view of target unit showing lower target head of 0.01 mm aluminium in the "in" position, upper head of 0.2 mm aluminium in the "out" position. Note white microwitch, which indicates either of these positions. The indicated position of the vacuum chamber and the beam corresponds to the standard mounting of the target.

Fig. 4 Photograph of oscilloscope screen showing the four standard traces for "Flat-Top" target operation for counter experiments.

- **Uppermost trace**: Magnet voltage.
- **Second trace**: Target "in" signal.
- **Third trace**: Intensity of bunched beam (beam is debunched by removing action of RF acceleration on reaching the "Flat-Top").
- **Fourth trace**: Signal from scintillation counter looking at target. The burst of about 20 ns duration starts when spiralling out beam reaches the target, ends when beam has interacted in target or has been scattered out of the vacuum chamber.