THE 800 MEV MEASUREMENT LINE OF THE CERN PS BOOSTER

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Introduction

The CERN 800 MeV PS Booster (PSB[1,2]) has been in its running-in stage since May 1972. It consists of 4 superposed synchrotrons which are filled in multiturn injection by double pulsing the present CPS injector, a 50 MeV linac. After RF-trapping 20 bunches of protons (5 per ring) are accelerated in about 0.6 s to 800 MeV. The 4 beams are then sequentially fast ejected and vertically recombined[3] for transfer to the 28 GeV PS.

A dump line, branching off the transfer line, was foreseen to dispose of the beam during any operation of the PSB without transfer to the CPS. It seemed attractive to make use of the necessary bending for spectrometry and to check in this line the quality of recombination. Thus, the dump line was promoted to a measurement line (Figs. 1,2) with the threefold purpose of

- emittance measurement
- spectrometry
- transport of the beams to a dump.

Emittance measurement

The emittance may be described by an ellipse of area $\pi\varepsilon$ in the phase space y, y':

$$\frac{1}{L}\left[y^2 - 2Syy' + (L^2 + S^2)y'^2\right] = \varepsilon$$

L, S and ε can be determined by measuring the beam radius.

$$\hat{y} = \sqrt{\varepsilon\,\frac{(L^2 + S^2)}{L}}$$

at three places along the beam.

The emittance not having a hard-edged contour we define for our purposes $\hat{y} = 2\sigma$, where σ is the second moment of the density distribution over y, i.e. 95,5% of all particles are included for a Gaussian distribution.

To minimize the relative errors $\Delta\varepsilon/\varepsilon$ and $\Delta L/L$, the positions for the beam profile measurement along a drift space have to be at a waist (S = 0) and at distance $\sqrt{3}$ L at either side of it.

The optics of the measurement line are described in Refs. 4,8. A layout with only 4 quadrupoles could be found, fulfilling the requirements for both spectrometry and emittance measurement by simply changing the excitations. For emittance measurement in the horizontal plane the dispersion can be made nearly zero at the waist point and as small as 1 m at the outside measurement points. With the expected $\varepsilon_H = 33 \times 10^6$ rad m a total momentum spread $\Delta p/p = 2 \times 10^{-3}$ this increases the beam size there by only 1 to 2%.

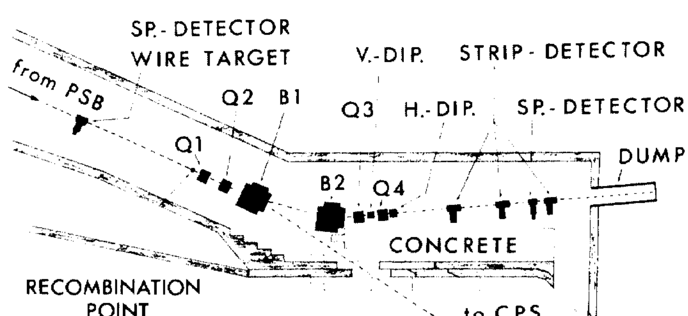

Fig. 1 : Layout of measurement line.

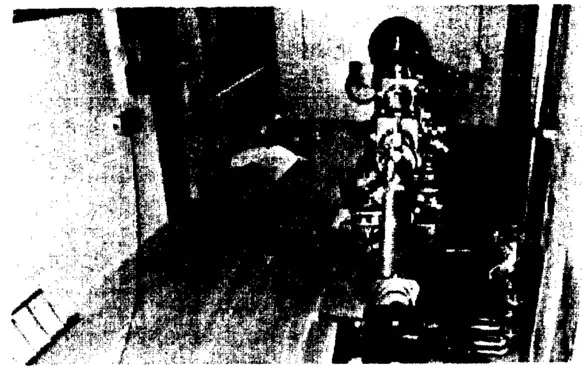

Fig. 2 : Detector area and dump

To measure ε with 5% precision at least 15 samples are required on each beam profile. This is obtained by the use of secondary emission type grid detectors with 20 strips. There are 6 of them, 3 for the horizontal and 3 for the vertical plane. Their spatial resolution can be adapted to the beam dimension by varying the angle between the detector and the beam. A 20-channel data acquisition system, gated in sequence to each of the 4 beams and connected to one detector after the other, delivers the data to IBM 1800 control computer[5,6]. The measurement in both planes therefore extends over 24 PSB cycles.

The parameters ε, L, S are computed for each of the 4 beams as well as for the minimum ellipse containing them all. For display all parameters are transferred to the "recombination point" (Fig. 1) by establishing the transfer matrices from the quadrupole currents.

If the 4 centres of the horizontal or vertical emittances do not coincide this means an increase of the total emittance. The coordinates in phase space of the centres are calculated with that of ring 3 (straight transfer) defined as the origin. Manual action on the recombination system can now be taken to make them coincide.

Spectrometry

A spectrometer resolving the momentum distribution to $\delta p/p = 10^{-4}$ would have required too much effort and cost. A so-called "restricted" spectrometer was therefore adopted which, without high precision elements, would be capable of comparing the average momenta of the 4 beams to $\delta\bar{p}/\bar{p} = 10^{-4}$ [7,8]. Such an inequality leads to a 10% dilution in longitudinal phase space after RF trapping in the CPS.

The spectrometry is based on the measurement of the position of the beam centre with split-plate secondary emission detector (Fig. 3a). The signals from the 2 plates being I_1 and I_2 we have for any distribution

$$\frac{I_1 - I_2}{I_1 + I_2} = f\left(\frac{\delta x}{2\sigma}\right)$$

where f is a function of the density distribution, the displacement δx of the centre and the beam radius 2σ. For a Gaussian distribution f is nearly linear for small values of $\delta x/2\sigma$ (Fig. 3b).

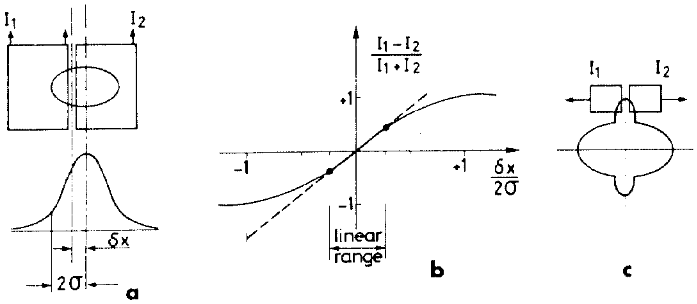

Fig. 3 : Spectrometry: a) principle of measurement with a split-plate detector; b) response of a split-plate for a Gaussian distribution; c) beam cross section in the image plane.

A variation of the beam position on the detector in the image plane may be due to a change in $\overline{p}$ as well as to a change in beam position at the object plane. As for radiation reasons, we cannot afford a defining slit the beam position there is determined in either of two ways:

Mode A. Another split-plate detector is placed in the object plane. Its signal is used to correct the signal from the image detector. The resolution in this mode depends on beam size. With $\varepsilon_H = 33.10^{-6}$ rad m and a dispersion of 7.5 m it is $\delta\overline{p}/\overline{p} = 1.10^{-4}$.

Mode B. A vertical wire is placed in the object plane. The protons scattered on it are separated vertically from the main beam at the image plane (Fig. 3c). The position of this sample depends on $\overline{p}$ only and with a dispersion of 9 m the resolution is $\delta\overline{p}/\overline{p} = 2.10^{-5}$. In this mode the steering dipole, H-DIP of Fig. 1, is controlled by the computer in closed loop to maintain the beam in the linear range of the detector.

Detectors

All detectors are of the secondary emission type.

The 6 grid detectors consist of 20 nickel strips, 6μ thick, welded to printed circuit connections on ceramic plates. Each strip is kept under tension by an Ω-shaped spring. The 2 detectors (hor. + vert.) for the waist point have strips 1 mm wide and spaces of 0.2 mm between them. Oriented at 90^0 to the beam axis their resolution is 1.2 mm. The 4 other grid detectors have a resolution of 2.4 mm. The set of strips is mounted between 2 aluminium collector foils of 4.5 μ. To allow fast change the whole detectors set-up is fixed to the plunging and rotation mechanism by means of a plug-in socket (Fig. 4).

The split-plate detectors are of similar design. The grids are replaced by 2 strips each 40 mm wide with a 0.2 mm gap between them, and to ascertain a high precision in the position of the gap, the detectors are

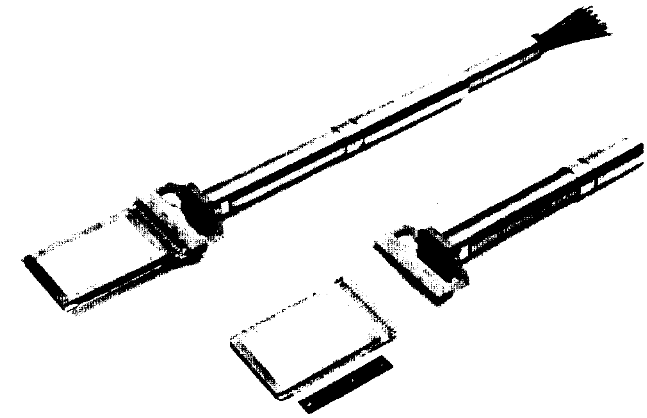

Fig. 4 : SEM-grid detectors: they are fixed on the plunging arm by mean of a plug-in socket

rigidly fixed to the plunging arm. The nickel-strips are produced by electrolytical deposition to guarantee high flatness. With a collector voltage of + 100 V the secondary emission coefficient was measured to 5% in tests at the 600 MeV CERN Synchrotron[9]. The response to beam intensity is linear. To avoid instability due to ionization of the residual gas the pressure must not exceed 5×10^{-5} Torr.

Electronics

Fairly high radiation levels may occur around the measurement line. This led us to install only the strict minimum of electronics in the tunnel. All analogue electronics and most of the controls are located above the accelerator in the permanently accessible Booster central electronics room (BCER).

Split-plate and grid detectors are essentially the same type of transducer. They generate similar signals, differing only in amplitude. The same basic analogue electronics is therefore used for both types of detectors (Fig. 5).

Each split-plate detector supplies 2 signals (20 pulses at 124 ns period). All the signals are transmitted to the BCER in differential mode.

Each grid detector supplies 20 analogue signals. As only one detector is used for measurement at a time, 20 analogue multiplexers (6 inputs/1 output) are provided close to the grid detectors. They are radiation resistant and fit directly into 3/8" coaxial connectors. The switching elements are high frequency reed relays.

The 20 analogue signals from the selected detector are transmitted in differential mode to BCER. The differential amplifiers there have 4 levels of sensitivity which are set manually according to beam intensity.

In spectrometry mode A split-plate detectors SP1 and SP2 are measured, whilst in mode B only SP3 is measured. SP2 and SP3 share the same conversion equipment. Each analogue signal is fed to 4 integrator converters, each gated to 1 of the 4 rings.

For emittance measurement each of the 20 analogue signals from the selected grid detector is measured in a single integrator converter picking out one ring after the other in 4 successive cycles by current gates. To guarantee a precise separation of the signals from

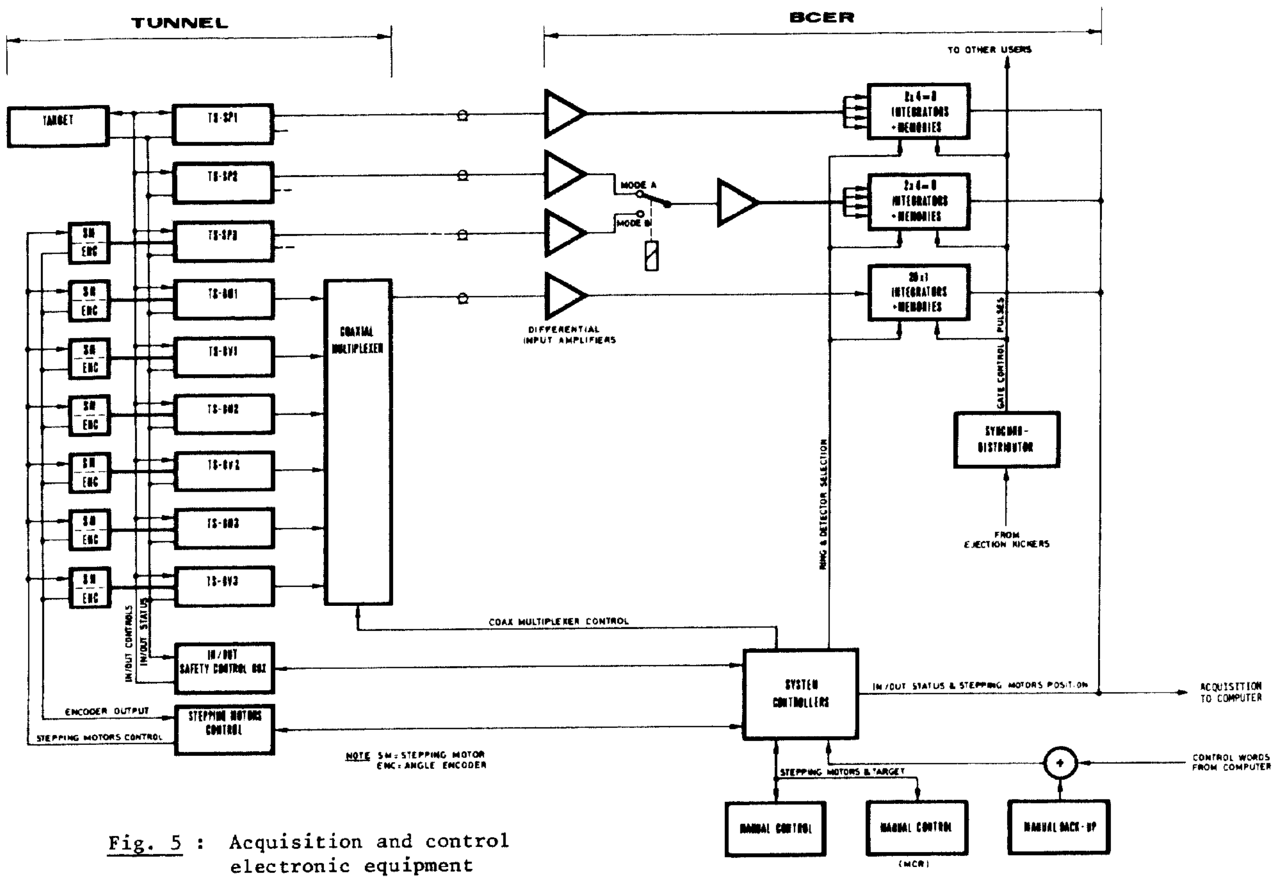

Fig. 5 : Acquisition and control electronic equipment

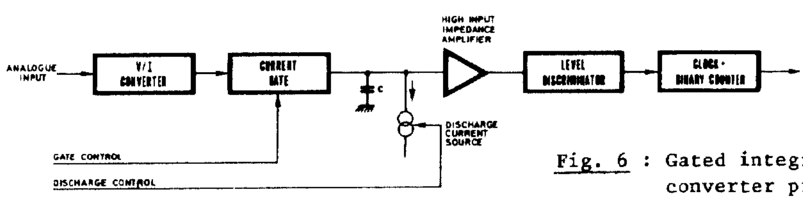

Fig. 6 : Gated integrator - converter principle.

the 4 rings the gate synchronization is derived from the trigger pulses for the fast ejection kickers[10].

The principle of the gated integrator converter is shown in Fig. 6. The input signal is converted to current source. The current gate either short-circuits or allows the current to charge condenser C during one revolution period (5 bunches). C is then discharged at constant current. Thus the level discriminator yields a pulse with a duration proportional to the charge accumulated on C. The pulse length is stored in a 11 bit binary counter and then acquired for the computer via the standard PS acquisition system.

Controls

All split-plate and grid detectors are plunged into the vacuum chamber by means of a pneumatic mechanism. Simultaneous insertion of some detectors being mechanically incompatible, the plunging is interlocked in an "in/out safety box" to avoid any possible damage.

The orientation with respect to the beam axis of the 6 grid detectors is adjusted by means of stepping motors, as well as the vertical position of split-plate detector SP3. Angular encoders give the information to the computer.

Except for the vertical positioning of SP3 and the orientation of the grid detectors, which are controlled from either the BCER or the main control room (MCR), all other movements as well as the analogue multiplexers are controlled via the computer. Manual back-up is provided locally for test purposes.

With the choice from MCR of a particular measurement (e.g. spectrometer mode A or ε-measurement, vertical plane) the computer automatically sets all lenses to the corresponding excitations, it plunges the required detectors and initiates the sequential setting of the multiplexers and gates[6].

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