MEASUREMENT AND MONITORING OF THE EJECTED PROTON BEAM "58" OF THE CERN PROTON SYNCHROTRON

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Summary

Instantaneous proton flux densities of the order of 10^{11} to 10^{20} p cm^{-2} s^{-1} have to be measured and monitored in this ejected proton beam, the mean fluxes being about 10^{10} to 10^{12} p s^{-1}, the burst durations ranging from about 10^{-8} to 10^{-1} s and the beam cross sections from 10^{-1} to several cm^2. These fluxes are much higher than those encountered previously in secondary beams but not yet high enough for macroscopic methods to be comfortably usable. Another difficulty results from the increased radiation damage. For the observation of the particle distribution in space and time, fluorescent screens and television, special nuclear emulsions and plastic counters are used; while current transformers and a secondary emission chamber serve for intensity measurements during normal operation. The choice of these detectors and monitors, their characteristics, their calibration, and experience with operation since Autumn 1965, are discussed.

Introduction

The instrumentation for measurement and monitoring of ejected proton beams presents different problems from those encountered in monitoring secondary beams, not to speak of particles, in physics experiments. In the latter case, the aim is often to detect a single minimum ionising particle. One of the main trends of the relevant detector development over the last years has therefore been towards higher sensitivity. Other important trends are towards better time resolution and particle identification[1].

In contrast, the problem on hand is to observe and monitor intense bursts of identical particles whose characteristics are given in Table 1. Thus one of the main boundary conditions is to avoid saturation of the detectors, and their too rapid deterioration from radiation damage, though the latter conditions are less severe than, for instance, at SLAC[3].

Scope of Instrumentation

The measuring and monitoring problems associated with the ejected proton beam from CPS straight section 58 (slow and fast ejection into the same transport channel[4]) included[5]: a) detailed geometry, b) beam intensity, c) distribution of useful protons in time and space, d) detection of proton losses.

Knowledge of the geometry is needed essentially to steer the beam to, and to focus it onto, the external target(s) (Fig. 1). During the setting-up period the detectors should in all cases indicate the beam position and size with a spatial resolution of a millimetre or less.

The beam intensity measurement is required during setting-up of the beam for optimizing ejection efficiency and, during running, for intensity monitoring, both from pulse-to-pulse and during an entire experimental run. For optimization, the detection efficiency should be independent of the beam position inside the detector.

The proton distribution in time has to be known

TABLE 1 : Characteristics of ejected beam

Internal beam intensity: 5 10^{11} to 10^{12} protons per pulse (shared between several users) repeated every 1 to 5 s.
Proton momentum: adjustable from 10 to 25 GeV/c.
Ejected beam cross-section: 0.1 cm^2 at focus, several cm^2 elsewhere in the beam (up to several tens cm^2 at final beam stopper).

Type of ejection[2]	Intensity (p/burst for 10^{12} p circulating)	Burst duration	Time structure	Flux density (p cm^{-2} s^{-1}) instantaneous	Flux density (p cm^{-2} s^{-1}) time average
Slow ejection	11^{11} to 5 10^{11}	100 - 200 ms	ideally square pulse without structure	10^{11} to 10^{14}	10^{10} to 10^{13}
Rapid ejection	5 10^{10} to 5 10^{11}	~ 1 ms	no structure	10^{13} to 10^{16}	10^{10} to 10^{13}
Fast ejection	5 10^{10} to 10^{12}	10 ns to 2 μs	1 to 20 bunches	10^{16} to 10^{20}	10^{10} to 10^{12}

in order to synchronize the various pulsed components of the ejection system and also the detection for the physics experiments, and to optimize the time distribution for the experiment in course. Knowledge of the spatial distribution of the protons across the beam is a basic requirement for beam design and has to be obtained at least once. During normal operation this knowledge is usually not required as it is not expected to change.

Detailed knowledge of proton losses is the basis for minimizing radiation damage of the accelerator and its installations and to reduce background radiation levels in the experimental area. As this system is only in an early stage of its development it will not be reported here.

Choice of detectors

The final choice resulted from an initial survey of possible detectors[6] and several experimental studies. It was notably found that the instantaneous flux densities were not yet quite high enough to comfortably use temperature changes caused by the beam[7] nor, in the case of slow ejection, a current transformer[8,9,10]. The experimental studies included use of a matrix of scintillation fibres[11,13] and operation on the raw video signal of the vidicon[12,13] as well as a 10 Si diodes[14] beam profile detector with display on an oscilloscope with a staggered time base[15].

Description of detectors in use

The detectors are detailed in Table 2. Comments are as follows.

Screens and television

To increase the rather limited range of sensitivity and the relatively short life of a given screen, a 12-position pivotable screen support was designed for the oval screens of about 40 mm x 60 mm (Fig. 2). The reproducibility of a given screen position is

TABLE 2 : Characteristics of detectors

Type	Purpose	Range of intensity	Time resolution	Accuracy	Remarks
Light producing screens	beam geometry (location and size of beam cross-section at specific points like targets)		~ 0.1s	location of beam centre to ± 0.2 mm	
- Radelin FG-P		$\geq 5\ 10^{9}$ p cm^{-2}*			supplied by US Radium Corp.
- Zinc sulfide		$\geq 10^{10}$ p cm^{-2}*			3 layers; lifetime 10^{17} p cm^{-2}
- Temperature resistant plastic scintillator NE 160		$\geq 8\ 10^{10}$ p cm^{-2}*			plates 1 mm thick supplied by Nuclear Enterprises, Edinburgh; lifetime larger than for ZnS
- Cd WO_4		$\geq 10^{12}$ p cm^{-2}*			supplied by Valvo, Hamburg
TV system		*$\geq$ 20 lux on screen and 1:1.4 aperture		linearity better than 2% over entire area	commercial type EMI Mk6 625 lines; control of focus, tilt and angle by remote control
2 µs current transformer a)	beam intensity	$\geq 10^{9}$ p/pulse	5 ns	± 2 10^{8} p	stability from cycle to cycle: equivalent to ± 2 10^{8} p
b)	number of bunches ejected			± 1% of reading	drift: equivalent to ± 5 10^{7} p per °C
Secondary emission chamber	beam intensity	$\geq 10^{10}$ p/pulse	2 ms	linearity better than ± 1% from 0.3 to 5 x 10^{11} p/pulse	short term stability: 1% efficiency, $\eta \simeq 10\%$
Plastic counters a) b)	a) proton distribution in time b) rough indication of burst intensity	single particle to 10^{7} p cm^{-2}	20 ns	given by PM RCA 6810 A or Dario 56 AVP Dario 56 UVP	Lucite commercial type or Nuclear Enterprises 102; sensitive element 40 mm dia x 20 mm; located at ejection magnet or target
Nuclear emulsions	proton distribution in space	1 to 10^{13}p cm^{-2} depending on type	~ 1 s^{+}	1 µm	$^{+}$exposure by remotely controlled dispenser

± 0.2 mm both for rotating a screen into the beam by remote control and for exchanging it manually for an other one. Usually 3 types of screens of different sensitivity[16] are provided on one wheel together with an insulated plate used to measure the beam intensity with the charge emission method[17]. These screens are only used during setting-up and occasional checks, thereby minimizing beam disturbance and radiation damage. The wheel is mounted in a tank evacuated to 10^{-5} torr. Inside this tank a 6V 15W light bulb (or its spare) illuminates the 5 mm grid on the screens. The low supply voltage avoids destruction of the bulb socket by avalanche gas discharges occurring at certain pressures when pumping down. Nine stations are installed along the beam, at the foci and small aperture points. The first screen support (in front of the ejection magnet aperture) is of a special 2-position design.

Vidicon cameras equipped with tubes or nuvistors (to reduce radiation damage) are used[18], connected by special cables to the control units located at a distance of about 50 m in a low radiation area. Radiation browning of the standard glass lenses (with "C" mounting) requires their reconditioning every 6 - 12 months in most positions and about every month at the ejection magnet position. Tests are under way with more radiation resistant lenses.

Current transformers

The induction type beam detector[19,20] may be considered as a wide-band current transformer with the beam current forming the primary winding and the secondary working into the very low impedance formed by the star point of a high gain feedback amplifier (Fig. 3). As any measures to enlarge the bandwidth usually improve the frequency characteristics at one end of the range while worsening it at the other, several transformers were built to cover the whole range of burst durations[21]. Thus, for long bursts (lasting a fraction of a second) the low frequency characteristics can be improved by using a tertiary feedback winding for eliminating the influence of the winding resistance[8,9,10], as first suggested by H.G. Hereward. In contrast, for short bursts emphasis is on the high frequency characteristics which meant a reduction of coil stray capacity and winding resistance by working with a low number of turns (permissible because of the higher instantaneous currents).

2 μs transformer. (used for fast ejection[2], see Table 1). The principle adopted[22] for the current measurement is shown in Fig. 3. For calibration a well known charge is sent through an auxiliary winding N_3.

A separate transformer without amplifier is used for displaying the burst shape on an oscilloscope. A ten-turn winding on an ultraperm core gave the remarkably low rise time of 2 ns.

1.5 ms transformer. The main differences with respect to the 2 μs transformer are use of a secondary winding symmetric to earth (in order to reduce the effect of stray protons hitting the winding), capacitive coupling of this winding (to reduce low-frequency microphonic effects[10]) and addition of a current preamplifier (because of the lower currents).

Secondary emission chamber

As one could not count safely on a (self-calibrating, non-destructive) current transformer for long bursts[8,9,10], the secondary emission chamber[23] (SEC) shown in Fig. 4 was designed and built. This chamber, described elsewhere[24], can also be used for fast bursts, with the same calibration. The chamber efficiency is defined as

$$\eta = \frac{\text{charge of emitted electrons}}{\text{charge of incident beam}}$$

which means using a positive bias voltage to avoid collection of electrons from the chamber walls. The dependence of η on foil material, chamber bias and vacuum pressure has been studied mainly for *electron* beams[23]. One also expects a dependence on beam energy[1]. The main conclusion is that frequent recalibration is advisable until the stability of the calibration is well ascertained.

Plastic and dE/dx scintillation counters

The counters are of conventional design[25,26] but can be connected to a rapid integrator and AD converter. Care was taken to keep the overall time constant below 1 μs in order to display the beam fine structure.

Nuclear emulsions

The fluxes being not high enough for single shot exposure of glass plates[27] nuclear emulsions were used for beam profile measurements[28,29]. They were specially prepared by diluting Ilford K-2 gel with 90% non sensitive gelatin and coating a glass support with a layer 25 μm thick.

As previously[30] the measurements[4] were reduced with a microphotometer now complete with automatic advance and recorder.

Calibration of beam intensity monitors

Al foil activation measurements[31,32] measuring the γ and β activity of ^{24}Na and the β activity of ^{18}F and the 2 μs beam current transformer were used for the absolute calibration of the SEC (and the charge emitting plates[17]) and a check of their linearity[33]. The absolute values given by the current transformer and the foil activation agree within 7.5%, the cross-sections for the activation being known with an accuracy of ± 5% to ± 7%. The SEC (and the plates) were found to have a linear output independent of burst duration in the intensity range available (0.3 to 5 x 10^{11} protons/burst).

Experience with operation and conclusion

On the whole the detectors and monitors performed successfully[34]. The current transformer for long bursts turned out to be as difficult a task as anticipated and has not yet found a satisfactory solution. The screen changer proved very valuable and also allowed the charge emitting plates to be incorporated easily into the system. Further developments[35] include notably the display of the particle distribution across the beam by feeding the vidicon signal to an oscilloscope for the sweep duration of one line[13,36], a 2 x 20 foil SEC, and air ionisation chambers for beam loss measurements[37].

We thank our numerous colleagues in the MPS Division who contributed in one way or another to the work described.

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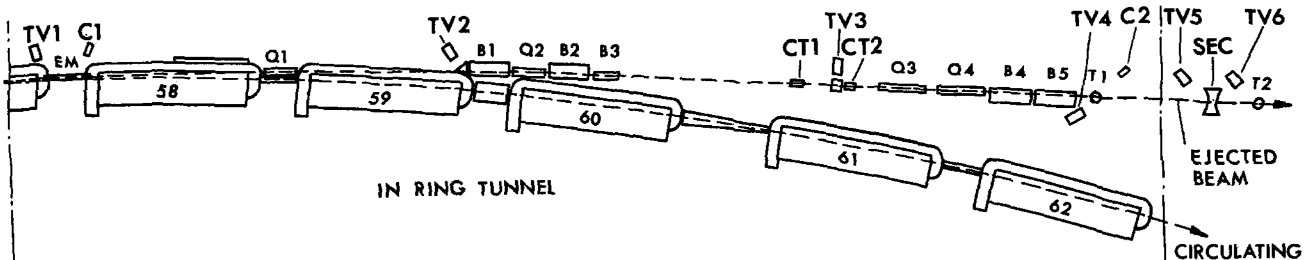

Fig. 1. Beam layout.

EM = Ejection magnet
Q_i = Quadrupole lenses
B_i = Bending magnets
T_i = Targets
TV_i = Screens and TV cameras
C_i = Plastic or dE/dx counters
CT_i = Current transformers
SEC = Secondary emission chamber

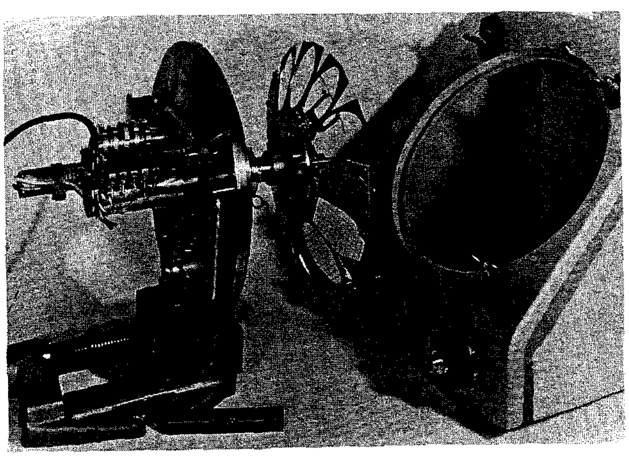

Fig. 2. Pivotable screen support and tank (taken apart for illustration).

The Geneva mechanism on the left pivotes the wheel supporting (from top to bottom) an insulated plate for measurement of beam intensity by the charge collection method, an empty frame (for undisturbed passage of the beam), and one of each of NE 160, Radelin FG-P and ZnS screens (together with spares on the opposite side). The beam passes through the lower central hole in the tank; the sockets on either side are connected to the light bulbs illuminating the screens.

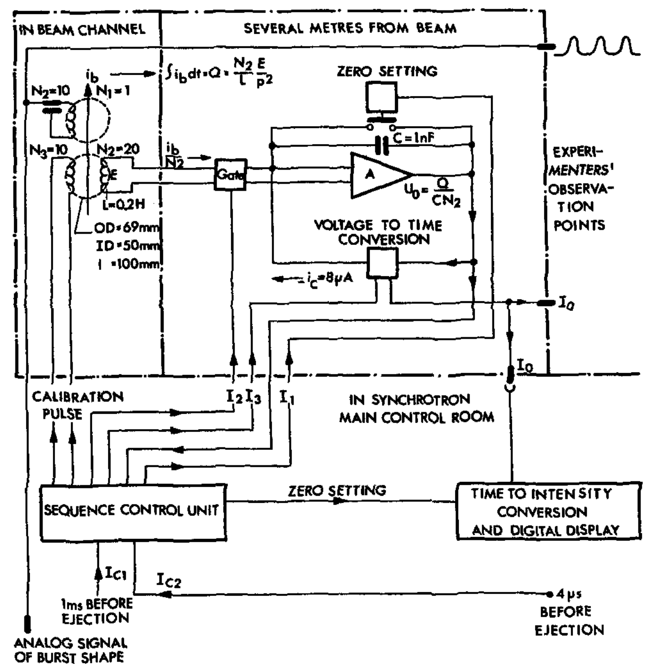

Fig. 3. 2 μs current transformer.

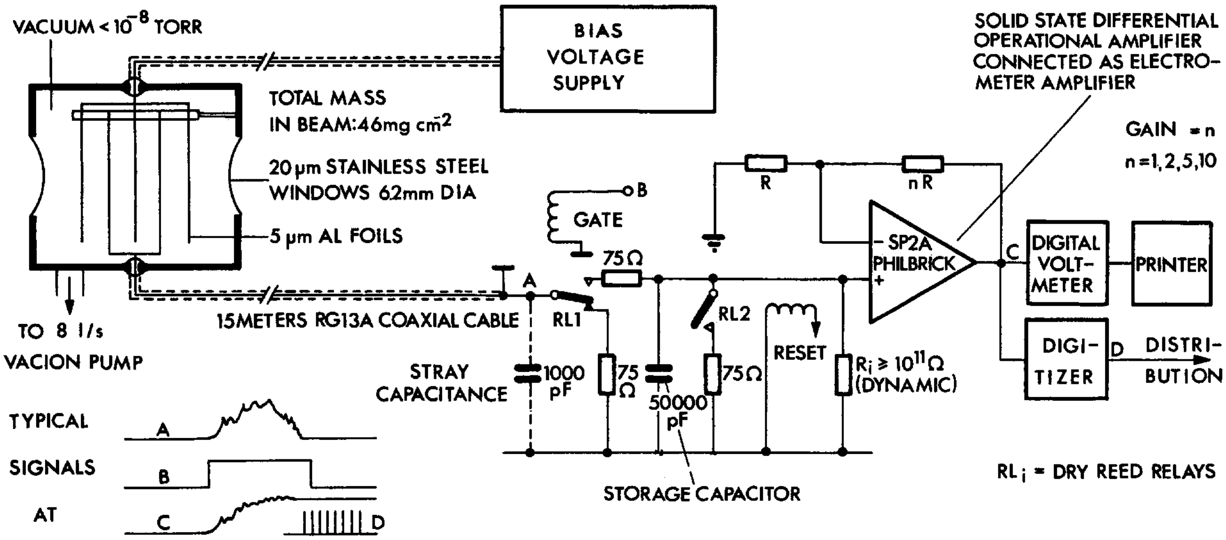

Fig. 4. Secondary emission chamber system.