TIME DEPENDENT STRUCTURE AND SPILL MEASUREMENTS OF PROTON BEAMS AT THE CERN SPS

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Abstract

For fixed target operation the proton beam is extracted at 14 GeV over 5 successive turns of each 2.1μs from the CPS and injected into the SPS. The current from a secondary emission monitor is sampled every 0.1μs by a charge coupled device. The stored signal is afterwards scanned at a lower frequency and provides an accurate profile evolution during injection. For slow proton beam extraction at 450 GeV a new type of detector has been developed. It uses the properties of the transition radiation created by the beam when traversing a thin aluminium foil. Accurate transverse profiles are obtained by such a detector. The disturbances to the beam are an order of magnitude less than with a classical secondary emission monitor.

Transition radiation monitor

For high energy proton beams, usually, secondary emission monitors are used for diagnostics. Such detectors are simple, but the emitting foils have a finite and non negligible thickness e.g, of the order of 100 μm aluminium or titanium. Usually these monitors are a disturbance to the beam leading e.g to emittance blow-up and, therefore, they cannot be left in the beam during normal operation.

These considerations have motivated our study on transition radiation [1] produced by high energy proton beams and its possible use as a permanent, quasi non-destructive beam diagnostic tool [2].

Transition radiation (TR) is emitted whenever a charged particle passes suddenly from one medium into another. This radiation is very attractive since the target can have a thickness one or two order of magnitude lower than the one used in a secondary emission detector. An additional advantage is the insensitivity of the optical arrangement against noise induced by the accelerator and its environment [3,4].

Experimental set-up

The radiator itself consists of a mylar sheet aluminised on one side. The aluminium layer has a thickness of about 0.5 μm whereas the mylar support is 3.5 μm thick. The sheet is stretched like a drum head on a ceramic support. It is mounted inside a "BTV" vacuum tank of the SPS extraction line under 45° with respect to the proton beam direction. Therefore the emitted TR can leave the vacuum tank through a quartz window and be collected by a light detector (Fig.1).

At the SPS during fixed target operation a slow extraction of about 2×10^{13}p, during 2s, is actived each cycle.

Amongst all the measurements on the extracted beam two types of diagnostics are of primary importance. The "spill" (the extracted beam intensity as a function of time) and the transverse beam profile. Almost all the present detectors used for this purpose are of the secondary emission type.

The "BSI" (beam secondary emission intensity) consists of a foil which covers the whole useful aperture of the beam line. The secondary emission current at the output of this detector represents the extracted proton beam spill (or intensity).

The "BBS" (beam secondary emission scanner) consists of thin horizontal and vertical beryllium wires which scan the beam with a resolution of 0.1mm. The wire output is integrated and an accurate beam profile measurement can be obtained from such a detector.

Spill measurements

For this measurement a "BSI" is installed in front of the above mentionned TR tank. The light detector is a photomultiplier mounted at the top of a light collecting cone. The spill behavior is observed at the output of the photomultiplier for TR and compared to the corresponding output of the secondary emission detector BSI on Fig.1. Fig.2 shows the results.
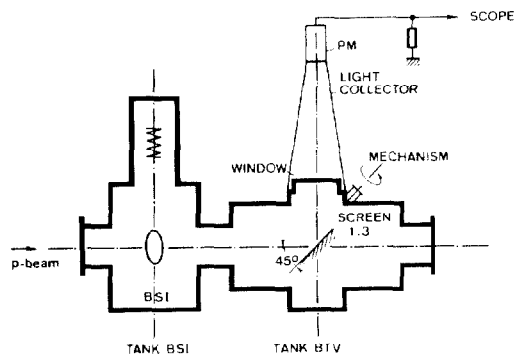

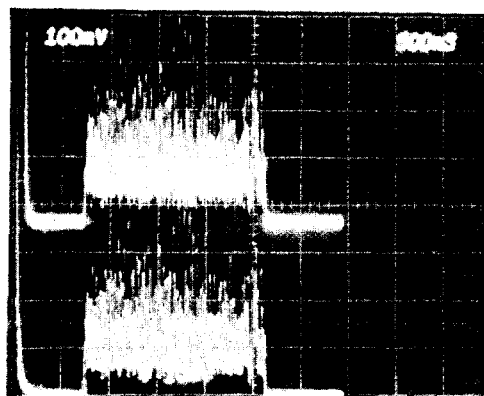Fig. 1. Spill measurement experimental set-up.

Fig.2. Spill measurements. The upper trace is the BSI current. The lower trace is the transition radiation photomultiplier output. Slow extraction of 1.4×10^{12}p.

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Profile measurements

In the case of profile measurements, the transition radiation tank is installed just behind a "BBS" monitor. The overall assembly is shown in Fig.3. The emitted TR light is focussed, by an optical arrangement, onto a very sensitive SIT-type image tube. The output of the camera is processed by the electronic system already used at the SPS for synchrotron radiation profile measurements [5,6]. The SIT target is scanned every 40ms and the image current is digitized. The digitized image can be acquired by the SPS computer control system in order to compute the beam profile width.
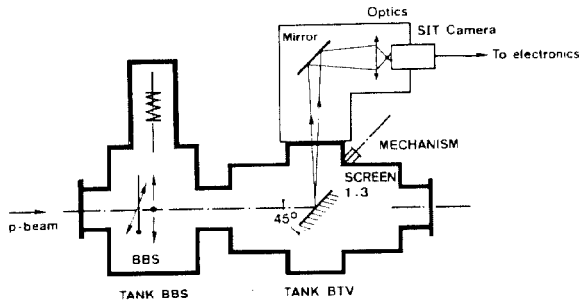

Fig.3. Profile measurement experimental set-up.

Knowing the optical magnification factor it is easy to calculate by computer, the horizontal and vertical dimensions of the proton beam. In the present case the resolution is approximatively 0.4 mm in the object plane.

The profiles have also been measured by using the BBS secondary emission wire scanner (BBS). As the wires are displaced by 0.1mm every SPS cycle (14s), direct comparison requires a very stable extracted beam.

In table 1, we give one of the measured half-widths obtained with the TR screen and the BBS.

Table 1
Measured half-widths

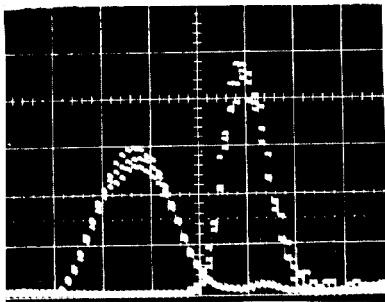|	Vertical (mm)	Horizontal (mm)
TR monitor	3.8	6.1
BBS	3.1	5.4

Fig.4. Horizontal (left) and vertical (right) profiles

Since the TR measurements are essentially instantaneous whereas for the BBS the overall scan lasts several minutes one can conclude that there is good agreement between the two detectors.

The extracted beam is of the order of 2.5×10^{12}p over 2s while the camera scan period is 40 ms. Therefore in the case of a bunched beam, or fast extractions the TR monitor will be able to measure beams of less than 5×10^{10} protons/bunch.

Fig.4 shows that the measurements are without noise in spite of the high loss rate which occurs in the extraction region of the SPS.

The SIT detector has been calibrated in the laboratory and we have verified that the measured photon yield agrees to within 20% with the theoretical results calculated for protons [7].

Conclusion

According to the above results transition radiation is a useful diagnostic tool for a high energy and relatively high intensity proton beam.

Since it causes less disturbance to the beam than the corresponding secondary emission monitors, this type of detector is of interest for spill and profile measurements in beam transfer lines.

Longitudinal profile measurement

Aim

Beam injection from the CERN-CPS into the CERN-SPS at 14 GeV/c is performed by the transfer of 2 proton batches, each extracted over 5 successive turns of 2.1µs duration.

Ideally each extracted turns should have a duration of 2.1µs, the same amplitude, a uniform time structure and should move along the same trajectory in order to form a homogeneous 10.5µs long batch of constant intensity.

With the present detector it is possible to measure the longitudinal beam profile I (t) of the batches simultaneously with their position. Hence it allows the monitoring of the quality of the beam injected into the SPS.

Principle of the detector

In the injection line (TT10) most of the beam position monitors make also use of the secondary emission effect. They consist of circular foils split in the middle horizontally to become a BSP-V or vertically for a BSP-H.

The difference of the integrated currents of each half foil determines the position of the beam relative to the geometrical center and is directly used for steering the beam line. Due to the low bandwidth of the integrating system only global intensity information is obtained for the full injection period of 10.5µs.

In order to obtain information of the time structure of the beam a system that samples and diagnoses the current of the foils at fixed intervals has been developed.

The constraint of a large bandwidth and the long cables to the control area has been resolved by the intermediate storage of the samples of each individual foil in a high accuracy "320 cell analog shift register" which is situated very close to the detector.

The analog shift register is a charge coupled device (C.C.D, Lecroy MV200) which consists of a sampling stage converting the input voltage into a charge on the first capacitor of a row of 320 capacitors. A clocking mechanism shifts the charge from the nth capacitor to the $(n+1)^{th}$ capacitor. Thus after 320 clock pulses the charge initially applied to the first capacitor is presented to the last capacitor. An ouput stage converts this charge back again into voltage.

With a constant clock rate this analog shift register thus is acting as a sampled analog line. Stopping the clock, at the end of the injection into the SPS, converts the delay line in a kind of multi-cell analog memory where the time structure of the injection pulse is stored. The information can then be retrieved with a much lower clock rate.

Electronic set-up

Figure 5 represents the electronic principle. A horizontal (BSP-H) and a vertical (BSP-V) beam position monitor are used together with an intensity monitor (BSI). All are housed in the same detector head.
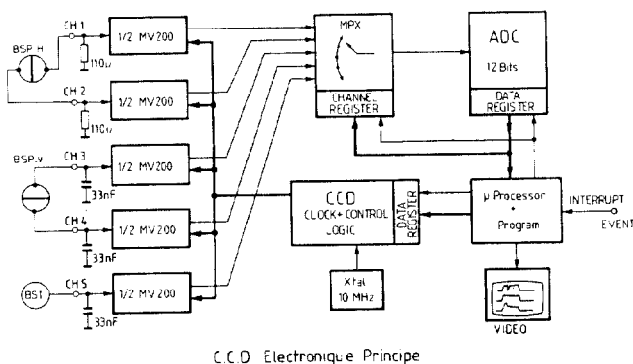
C.C.D Electronique Principe

Fig. 5 . Electronic set-up

The output current of each foil is sampled and stored by a C.C.D. Two foils produce over a resistor of 110Ω a voltage proportionnal to the beam intensity. The other 3 foils produce on a capacitor a voltage proportionnal to the integrated intensity. Each sample has a duration of 100ns. Therefore the injection signal (5x2.1μs) will be stored in 105, out of the 320 analog memory cells, at a well defined instant of the injection process.

The sampled analog signals of all foils are retrieved at a much lower frequency, converted by an 12 bits Analog to Digital Converter (ADC) and stored into digital memories.

The recording and digitizing process is controlled by a micro-processor (μ-P) which is interrupt driven for synchronisation purposes. The digital data is processed by background programs in different ways. Normally the μ-P provides a display but it can also calculate averaged Fourier-Transforms or comparisons between different injections.

Experimental results

One set of measurements is shown in figure 6 where:
- Channel 2 represents the longitudinal profile of the current from the right (R) foil of the BSP-H

- Channel 1 shows the longitudinal profile of the current at the ouput of the left (L) foil of BSP-H followed by the digital integration $\int (L+R)dt$
- Channel 4 shows the integration on the bottom (B) BSP-V foil whereas channel 3 represents the upper (U) BSP-V foil followed by the sum $\int Udt + \int Bdt$
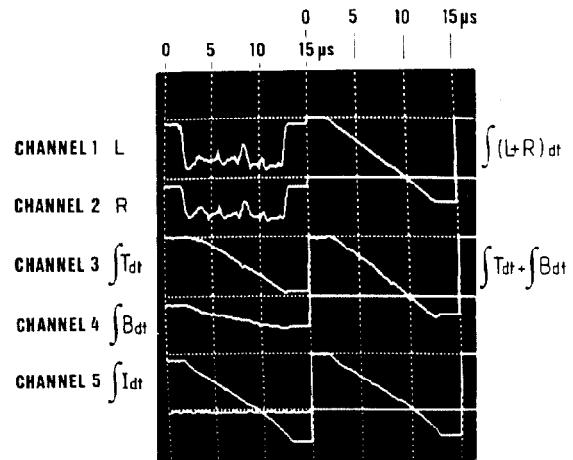- Channel 5 gives the integrated signal of the B.S.I (intensity monitor).

Fig. 6. Experiment results

It is worth noting that for each longitudinal profile the injected beam intensity is of the order of 10^{13}p during 10.5μs.

From the longitudinal profiles each of the five successive turns (2.1μs of duration) can be easily distinguished. Each turn consists of 21 samples. It can be seen that the digital integration $\int (L+R)$ gives coherent results with the analog integration $\int U + \int B$.

Conclusions

The use of C.C.D in conjunction with secondary emission monitors provides an accurate diagnostic tool for the injected beam. In particular the advantage of having a digitized representation of the beam current allows many accurate data treatments such as the computation of the duty factor.

Using several of such systems, but with more profile detectors, would allow emittance measurements on distinct time slices.

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