IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

BEAM INTENSITY, POSITION AND PROFILE MEASUREMENTS FOR PPBAR COLLIDERS

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Abstract

In a ppbar collider like the CERN SPS where only three dense pbar bunches of about 2×10^{10} particules per bunch can be injected once a day, the beam characteristics of these rare shots must be known systematically with a high precision to better understand and improve the collider performance. This paper describes the measurements of three important beam parameters : intensity, position and transverse profiles.

Intensity

From intensity measurements, one can deduce the transmission efficiency between the injector complex and the collider and the losses during the several stages up to the coasting beam : injection, capture, acceleration, low-beta squeezing. For the coasting beam, the intensity knowledge determines directly the beam life-time and the luminosity in conjunction with the beam emittances (transverse profiles).

In contrast to synchrotrons used for fixed target physics where almost all the RF buckets contain particles (CW mode), a collider runs with a limited number of bunches. The SPS collider in '84 ran mainly with 3 proton against 3 antiproton bunches, an extension to 6x6 being foreseen in the future. While in CW mode one is mainly interested in the global intensity, it is important for a collider to know the individual bunch behaviour (single bunch mode).

At injection mainly two mechanisms can cause a loss; either the alignement of the injected beam is bad and losses occur in the first few turns or the bunches are not properly injected into the RF-buckets. This can be detected a few milliseconds later by an electronics with a suitable band pass filter. Therefore the intensity of each individual bunch is measured every turn for 1000 turns after injection ($\approx$23 ms). During the ramp and the flat top the losses are detected by measuring each individual bunch at intervals of about 20 ms until the beams are coasting [1].

The bunch signal is derived from a directional coupler, which has four orthogonal strips in a cylindrical vacuum chamber. These beam monitors are normally used for position measurements. The directivity is necessary for the measurement of the weak antiproton bunches (10^9 particles) in the presence of proton bunches (10^{11} particles). To obtain a position signal, independent of the intensity, the RF signals of the four striplines are added together by hybrid junctions.

The signal produced by the directional couplers is bunch length dependent. This is minimised by the signal processing electronics. The signal is first passed through a narrow band (20±2) MHz filter, the resulting oscillation is amplified by a programmable amplifier and passed through a second filter. The envelope of the oscillation is then detected by a synchronous demodulator.

The peak value of the demodulator output is sampled by a peak-hold inside a 400 ns window. The window origin is programable in 100 ns steps relative to the SPS-revolution trigger signal. This allows the equipment to select the bunch to be measured. The output of the peak/hold unit is converted by a fast successive approximation Analog-Digital-Converter, with 12 bits resolution and 6 microseconds conversion time. This intensity value is stored in a buffer memory which can hold up to 1000 values. The memory allows the equiment to measure the bunch intensity every revolution (23 microsec) for 1000 consecutive turns.

The pulse height measured with the analog digital converter is proportional to the intensity. The proportionality factor is determined by comparison with a D.C. beam current transformer (BCT), which has an accuracy of about 0.3%, but measures the total circulating current. If only one proton bunch is injected, the total current is concentrated in this bunch. At the injection energy protons can nevertheless spill out of the bucket. This reduces the bunch intensity without a change of the total current. On the energy ramp the number of particles in the bunch and the total number of particles is the same, because the protons outside the bucket are lost. When both values are measured at the same time during the energy ramp the calibration factor can be calculated. The accuracy of the calibration of the number of protons in a bunch is about 1%.

Once the equipment is calibrated with protons the equipment is switched over to measure the antiproton intensity. This can simply be done by switching the cables to the other end of the directional coupler by means of coaxial relays and by changing the timing window in the electronics. As the directional coupler is made to very high mechanical precision it can be assumed to have the same sensitivity to antiprotons as to protons. Using the calibration factor already determined for the protons the number of antiprotons is known. This leads to an accuracy in the number of antiprotons of about 2%.

Fig. 1 is an example of a good transmission of the antiprotons. The intensity along the first 1000 turns is displayed for three antiproton bunches in A,B and C. The losses are negligible. D,E and F show the intensities from injection until the bunches are coasting. The total losses are smaller than 6%. The three bunches are injected into the SPS with a time difference of 2.4 seconds. The horizontal scale is given in turns for A,B,C and in milliseconds for D,E and F. The vertical scale is given in units of 10^{10}.

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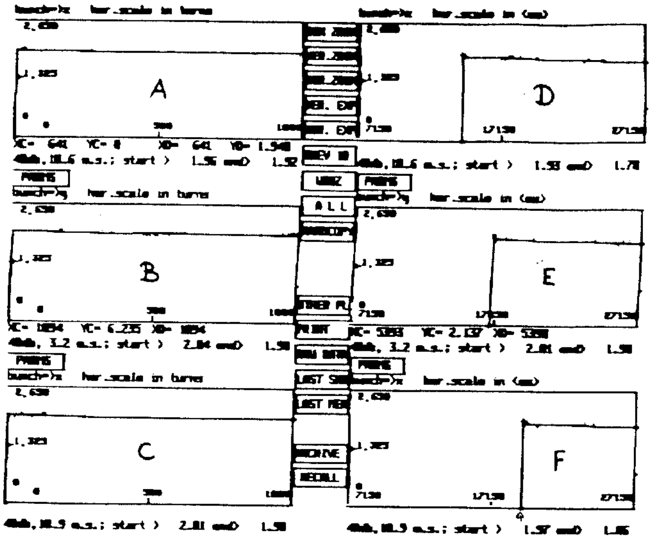

Fig.1 Injection and cycle intensity of the antiprotons

For lifetime measurements of coasting bunches, the same directional couplers are used with slight modifications in the electronics. Because the beam pulse length in coast is less subject to variation than at injection, the receiver selects the frequency spectrum 50±2 MHz giving a higher response

Six different proton bunches can be measured simultaneously by 6 gated integrators connected to the same receiver, the same applies for the 6 pbar bunches. The scalers are measuring for 20 ms and provide a resolution of 10^{-5} full scale. The relative stability of the electronics is 10^{-4}/hour. The absolute accuracy of the intensity measurement is ±2% over a month. When measuring a pilot bunch of 10^{9} pbar, the sensitivity is 3×10^{5} particles/bunch during the coast.

Position

To minimize the emittances, the particles must be injected with the maximum of accuracy onto the closed orbit. This can be done by the classical orthogonal steering of the injection line on the injection point for both planes. The measurements, being not possible at the injection point, are made by two directional couplers located at two positions downstream the injection. Knowing these positions and the Twiss parameters one can deduce the position and angle of the injected beam at the injection point. For each individual p or pbar bunch, the difference and sum signals of 2 opposite strip lines are triggered to measure the first turn trajectory followed by the closed orbit measurement at the same points. The measurements are made simultaneously for both planes, allowing the steering to be made during the setting up.

Once the setting up is made, the injection trajectory and the closed orbit of each individual bunch is systematically measured during the injection of the three dense pbar bunches for the coast.

Fig. 2 shows typical single bunch pbar trajectories measured at 4 different locations in the injection transfer line (7022, 7020, 6103, 6100) and at 2 locations downstream of the injection point (6130, 6110) compared with the closed orbit measured at the same 2 points in the same cycle. The difference between injection trajectories and closed orbit is less than ±2mm.

```
 25 NOV 84          GP6  PAPOS  POSITIONS(mm)         10:26:13
                                BunchZ   BunchY    BunchX
Closed Orbit         HORIZONTAL PLANE   [illegible]
6110                       |    -3.1     -3.3      -2.5
6130                       |    -2.3     -2.4      -2.2
Single Passage             |
6110                       |    -2.7     -3.1      -3.1
6130                       |     -.9      -.8       -.7
6100                       |     -.5      -.9       -.9
6103                       |      .4       .7        .9
7020                       |    0        0         0
7022                       |     -.5      -.2      0
Closed Orbit          VERTICAL PLANE
6110                       |      .4       .5        .4
6130                       |     -.4      -.3       -.3
Single Passage             |
6110                       |      .6       .7        .6
6130                       |      .7       .7        .5
6100                       |     4.7      4.7       4.4
6103                       |      .3       .4        .2
7020                       |      .9       .8       1.0
7022                       |      .5       .4        .6
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An important improvement is being made on the closed orbit acquisition, by installing on each position monitor of the ring an electronics able to detect the single bunch position [2]. In march '85, 4 out of 6 sextants were equipped. It has already shown that the closed orbit at injection corrected with the SPS set in continuous wave mode is slightly different of the closed orbit measured when the SPS is set in single bunch mode, due to different RF programs. This new electronics will then allow a better closed orbit correction at injection and also a good analysis of some closed orbit drifts occuring during the coast.

Profile

Two types of monitors are currently used : the rapid wire scanner and the synchrotron light. A fine wire is passed through the beams at a speed of up to 6 m s^{-1}. The transverse profiles at the wire location are measured by intercepting high energy secondary particles produced by the interaction of the beam with the wire using scintillators placed close to the beam pipe in the downstream proton and antiproton directions respectively. Use is made of the strong directivity of secondary particle production to separately record the profiles of the two beams [3].

For single bunch measuremnt the wires are 50 micron diameter beryllium stretched on a fork 170 mm long. The upper limit of the required traversal speed is governed by the precision of measurement of the profile of a single bunch. To obtain a wire displacement of 0.1 mm during the revolution time of the bunch requires a speed of 4.3 m s^{-1}. Consequently, the wire scanners have been built to work in the range 1-6 m s^{-1}.

The scintillators are coupled to a photomultiplier by plexiglass light guides. In order to keep the system linear over a wide intensity range the tube is always run at maximum voltage and if necessary the incoming light is attenuated with neutral density filters placed between the tube and the light guide. The attenuators are mounted on a rotating disc driven by a stepping motor and can be changed remotely.

The electronics consists basically of a peak-and-hold circuit followed by an ADC and memory. The peak voltages detected inside time windows correspond to the signal produced by each bunch hitting the wire at each revolution. A maximum of 6 bunches per beam with a maximum of 512 acquisitions per bunch can be recorded.

Each detector has one horizontal and one vertical wire giving the transverse profiles in both planes. Four detectors are in operation : two in the vicinity of the two low-beta insertions but precisely where the beam is large (i.e. near the β_{max} region) are only used during low-beta studies causing too much background in the physics experiments, two others far from the low-beta regions were used to measure the emittances mainly at injection and during the coast.

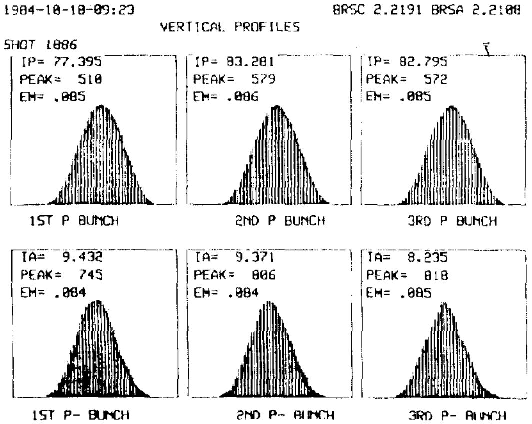
But even if the emittance growth per scan due to Coulomb scattering is small (1.4×10^{-5} mm. mrad/scan) during beam storage compared with the natural emittance growth due to multiple scattering with the residual gas (1.3×10^{-4} mm. mrad/hour), the background of the experiments drastically increases when the wire passes through the beam.

To avoid it the wire scan method is only used a few times during a coast (about once every two hours). The synchrotron light monitor is not interceptive and is continuously used during a coast.

To detect single pbar bunches of 10^9 to 10^{10} particles around 300 Gev, it was necessary to enhance the synchrotron light by an undulator and to develop a sensitive and gated detector [4]. To operate at this energy in the visible range, the 5 period undulator has a magnetic period of 88mm and its magnetic field on the axis can be adjusted according to the beam energy and intensity up to a maximum of .32 T. The image detectors consist of a micro-channel intensifier followed by very sensitive vidicon of silicon intensified target type (ISIT). The associated electronics allows the bunch selection by gating the micro-channel intensifier to take the light emitted by only one bunch at each revolution. Each diode charge of the vidicon target is scanned at a rate of 40 ms, digitised and stored in memory; from the memory horizontal and vertical profiles can be displayed in the same pattern as for the wire scanner profiles.

Fig.3 shows the vertical profiles of 3 proton and antiproton bunches measured by the two methods at about the same instant of a given coast. Fig.3a corresponds to the synchrotron light measurement where the intensity of each individual bunch (IP) is given in units of 10^9. Fig.3b corresponds to the wire scanner measurement with IP in 10^8 units. In both cases the emittance (EM) is given in mm mrad/π units. The agreement in these measurements between the two methods is better than 4% for the proton emittances but reaches 25% for the antiproton emittances.

Fig.3a



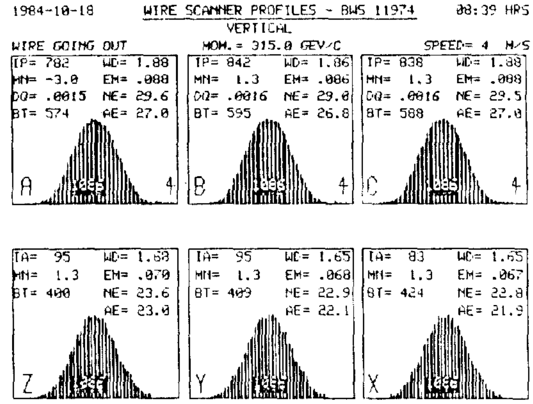


Fig.3b

The emittance evolution during a coast is easily measured by these two methods, in particular the luminosity life time obtained from the emittances and intensity agrees to the luminosity given by the telescope method within 5%.

But a precise absolute emittance measurement better than 10% remains delicate and some data treatment has to be done. The raw beam profile data are affected by measurement noise and systematic errors due to the detector behaviour. The latter is removed by simple substraction according to the results of experiments. For instance for the synchrotron light this can be done with the detector under simulation conditions (the beam is mimicked with a LED). Of course care is taken to avoid the largest source of error, i.e. the distribution tails, which are ignored. The remaining noise is reduced by gaussian fit, which consists in fitting a parabola to the logarithms of the data. Tests of goodness of fit are carried out along with an estimation of the probable error affecting the computation of the variance, which is the important parameter.

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