EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN/PS/91-12 (OP)
10 April 1991

EXPERIENCE WITH A FAST WIRE SCANNER FOR BEAM PROFILE MEASUREMENTS AT THE CERN PS

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Paper presented at the 1991 Workshop on Advanced Beam Instrumentation (ABI)
22-24 April
KEK, Tsukuba, Japan

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Abstract. The fast wire scanner built at the CERN PS for beam profile monitoring has been improved, tested and used extensively since its first operation in 1985. The system is briefly described, the recent improvements are outlined and comparison of measurement results with other profile monitors are given and discussed.

Introduction

A fast wire scanner has been built at the CERN PS and became operational in 1985. It is used to measure the circulating beam profile and hence the emittance since the Twiss amplitude parameter, β_y, is normally well-known in both planes. It measures beams of various particles (leptons, protons, antiprotons and ions) from injection (1 GeV) to high energy (26 GeV/c) over a wide range of beam intensities (from less than 10^9 to approaching 10^{13} charges per pulse).

Principle of operation and technical characteristics

Two beam profile monitors are installed in the PS ring, one for each plane (Ref. 1). The major mechanical components of the fast scanners are:

- a printed circuit D.C. torque motor with its angular position and speed transducers;
- a transmission system including a crankshaft activating two push-pull rods;
- a stainless steel vacuum enclosure with two metallic bellows allowing the movement of these two rods through a flange into the vacuum;
- a low inertia U-shaped wire support on bearings.

The linear projected speed achieved by the wire as it crosses the beam is 20 m/s. Secondary particles produced in the interaction of the beam with the wire are detected in a scintillator positionned close to the tank. The scintillator is optically connected to a photomultiplier by a lightguide. The resulting analogue signal is sampled and digitized in a waveform analyzer for further treatment.

All the local controls are carried out in a first generation stand-alone PC with an 8-bit processor under the cp/m system. The PC is located in the PS control room together with a CAMAC crate containing all the interface and sampling hardware. It takes care of the real-time task of the digital feedback displacement control loop, the data acquisition and processing and the input and output to the system (request for measurements and visualization of results). Remote access is also possible from the main computer system via a RS232 connection between the local and general control system CAMAC crates. New controls are foreseen using a VME crate and a 32-bit processor.

Photomultipliers and signal processing

The first profiles were obtained with the two scintillators and their photomultipliers mounted directly on top of the tank, just above each wire. The photomultipliers had 14 dynodes which gave a very high gain; they were of a type used for particle calorimetry at relatively low counting rate.

The amplification turned out to be distinctly non-linear and also sensitive to the value of the high voltage chosen for the photomultipliers.

A careful study of these phenomena led to the conclusion that the photomultiplier gains were too high, the photocathodes were saturating and that direct radiation induced unwanted secondary electrons and persistent effects. Tests were carried out with 6-dynode photomultipliers to confirm the first hypothesis and then with a prototype lightguide to distance the photomultiplier from the secondary particle shower.

The final arrangement comprises scintillators of 0.5 l volume placed upstream and downstream of each wire (horizontal and vertical). Each serves either for positively charged particles (protons, ions or positrons) or negatively charged ones (antiprotons or electrons), these being accelerated in opposite directions during different magnetic cycles. The scintillators are placed directly in contact with the vacuum chamber in order to provide some acceptance down to a secondary particle production angle of the order of 15°. Plexiglass lightguides link them to the photomultipliers (through selectable optical filters mounted on a carousel mechanism) installed at ground level, 1.2 m below the PS vacuum chamber.

Optical filters are needed because of the wide range of energies and intensities which must be covered. One can remotely choose between calibrated transmission factors of 0.1% to 100%. This reduces the dynamic range with which the photomultipliers have to cope to less than a hundred.

The photomultipliers have 10 dynodes, a compromise which provides sufficient gain at low intensities and low energies (e.g. for antiprotons) at the expense of linearity at the highest beam intensities. The type chosen has a high photoelectron current capacity due to its tri-alkaline photocathode. Since it must work in proportional mode, the base has been designed specifically to permit high currents; the dynode voltages are obtained with relatively low resistance dividers. However, for the highest intensities (several 10^{12}) at high energy, the photomultipliers would have to be changed for less sensitive 6-dynode units.

There is an additional analogue amplifier in the ring to transform the equivalent current source of the photomultiplier into a voltage one that is able to drive the 50 Ω cable taking the signal to the control room.

The signal-to-noise ratio is improved by the use of a low-pass Bessel filter of 6th order. The passband is thereby reduced to a minimum without signal deformation since the group delay is independent of frequency. A choice is available between two cut-off frequencies: 15 kHz and 75 kHz for wide and narrow beams (Ref.2). Fig.1 gives a typical example of the result obtained with a proton beam.

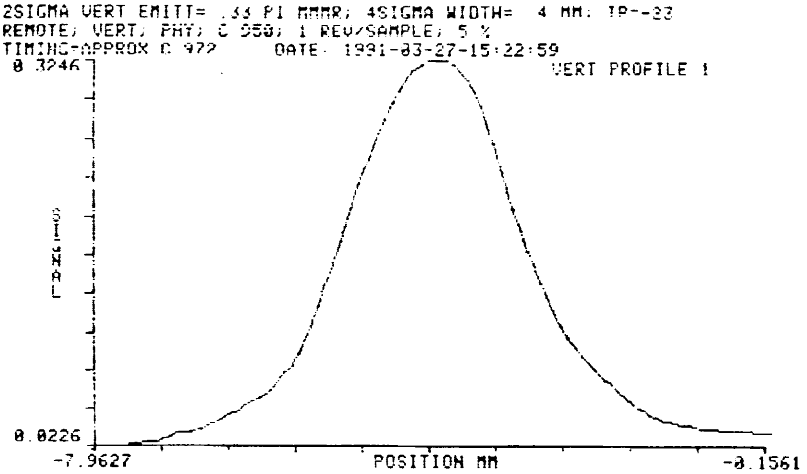

Fig.1: Profile and emittance of a 23 10^{10} proton beam at 24 GeV/c

Beam scattering

When crossing the wire, particles undergo multiple Coulomb scattering which blows up the beam. Using the Rossi formula for the mean square scattering angle (Ref. 3), averaging over successive wire traversals and the betatron phases, and correcting for the cylindrical shape of the wire, the 2 r.m.s. emittance increase (expressed in π mm mrad) is given by:

$$\Delta\varepsilon_y = \frac{\pi}{2}\,\frac{\beta_y d^2}{v\,\tau\,X_0}\left[\frac{15}{\beta p}\right]^2$$

where β_y is the local Twiss amplitude parameter in the measurement plane, d is the wire diameter, v the projected transverse wire velocity, τ the revolution period of the particles around the machine, X_0 the radiation length in the wire material, β the particle velocity in units of c and p the particle momentum (in MeV/c).

The velocity of the wire (20 m/s) was chosen in order to reduce the effect of the multiple scattering as much as possible.

For the most interesting PS hadron energies, we obtain the following results (expressed in units of π mm mrad):

Energy	Blow-up in measurement plane	Blow-up in other plane	Normalized blow-up in meas. plane	Normalized blow-up in other plane
1 GeV (standard injection)	0.32	0.59	0.58	1.06
3.5 GeV/c (antiproton injection)	0.062	0.113	0.23	0.42
26 Gev/c (highest energy)	0.001	0.002	0.029	0.053

Table 1

The smallest normalized emittance we want to measure in the PS is 10 π mm mrad. We see that the Coulomb scattering of the beam during traversal of the wire is negligible at high energies and relatively small at low energies (hardly more than 10 %).

Heating of the wire at high intensities

For a long time, the wire scanner was mainly used to measure the proton and antiproton beams of relatively low intensity accelerated in the PS to be used in the SPS collider experiments. There was, therefore, no practical experience of the maximum intensity that the wire could withstand without damage. More recently, the first studies on the future PS beam for the LHC machine has revived interest in the measurement of the emittance of high intensity beams.

The temperature increase of the wire during one traversal of the beam has been calculated (Ref. 4) as:

$$\Delta T = \frac{k}{C_v} \frac{dE}{dx} \frac{\beta N}{v \tau} \sqrt{\frac{3}{\pi \beta_y \varepsilon_y}}$$

where k is the fraction of ionisation loss converted into heat, C_v the heat capacity of the wire material, dE/dx the rate of ionization loss of the particles in the wire, N the number of particles and ε_y is the emittance in the other plane.

The losses by radiation and conduction along the wire are neglected because the time to cross the beam is short (almost always less than a millisecond).

An attempt to burn the wire in a high intensity proton beam failed at high energy (26 GeV/c) after numerous scans in a 1.8 10^{13} proton beam. Initial calculations of temperature rise assumed k=1 and, in this case, yielded ΔT=1260°C. However, at the CERN SPS it has been estimated (Ref. 5) that the actual heat deposited corresponds to only one third of the ionization loss (i.e. k=1/3). According to this hypothesis, the temperature in the wire would not exceed 420°C, which explains why the destruction test was unsuccessful.

Comparison with other monitors

For comparison, transverse beam profile measurements have been carried out by means of measurement targets in the PS and Secondary Emission Monitor grids (SEM-grids) at injection in the PS and in the extraction line.

Measurement targets comprise a pair of mobile blades. The method involves moving the blades transversely stepwise into the beam shot after shot and recording the beam loss. The derivative of the remaining beam intensity with respect to the blade position yields the particle distribution profile. Measurement targets are thus destructive.

SEM-grids are made up of narrow strips of thin foil placed in the beam. Secondary electrons are emitted upon the impact of beam particles. This emission induces a voltage on each strip that depends on the number of incident particles.

Beam profile measurement are used to determine the r.m.s. beam width (σ_x) or beam height (σ_z), from which the horizontal or vertical beam emittance (at $2\sigma_{x,z}$ projected) can be evaluated. In the horizontal plane, the beam profile includes a contribution from the momentum distribution if the dispersion is non-zero at the monitor location. However, the momentum spread in the PS was not considered because its effect, assuming quadratic addition of the betatron and momentum dispersion terms (Ref. 6), is of the order of only 2% for a 20 mm wide beam.

Table 2 shows some emittance measurements (at $2\sigma_y$) performed between 1988 and 1991. It can be seen that the emittance values derived from beam profiles obtained with the various monitors agree rather well.

	Wire scanner	Measurement targets	SEM-grids
vertical emittance (3.5 GeV/c $5\ 10^{10}$ p)	0.74 π mm mrad	0.70 π mm mrad	0.68 π mm mrad [1]
horizontal emittance (1 GeV $6\ 10^{11}$ p)	19.7 π mm mrad	–	18.5 π mm mrad [2]
horizontal emittance (1 GeV $4.3\ 10^{11}$ p)	24.8 π mm mrad	–	23.3 π mm mrad [2]
vertical emittance (1 GeV $4.3\ 10^{11}$ p)	9.0 π mm mrad	–	9.1 π mm mrad [2]

[1] SEM-grids installed in the PS-SPS transfer line.

[2] SEM-grids installed in the PS downstream of the injection septum.

Table 2

Conclusion

The performance of the CERN PS fast wire scanner has been improved since its first operation. Its accuracy, versatility and user-friendliness have been enhanced. Comparisons with other profile monitors agree well and confirm the importance of this monitor for non-destructive measurements.

Acknowledgements

We wish to thank all the people who worked on this project and on the comparison with other monitors, especially E. Asseo, J.P. Bovigny, R. Cappi, F. Hoekemeijer, G.Martini, T. Risselada and J.P. Riunaud.

References

1 - A scanning wire beam profile monitor, Ch. Steinbach and M. van Rooij, 1985 IEEE Particle Accelerator Conference, Vancouver, B.C., Canada.
2 - E. Asseo, private communication.
3 - High-Energy Particles, B. Rossi, Prentice-Hall Inc., 1956.
4 - Mesure très peu destructive des distributions transversales dans le PS de 800 MeV à 26 GeV/c, P. Lefèvre, PS/DL/Note 78-8, 1978.
5 - Wire scanner news from the CERN-SPS, A. Burns et al., 1989 IEEE Particle Accelerator Conference, Chicago, Il, USA.
6 - Calcul de la désadaptation dans la ligne d'injection à 800 MeV du PS, M. Martini, CERN/PS 84-12 (OP), 1984.