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BEAM STUDIES MADE WITH THE SPS IONIZATION PROFILE MONITOR

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Abstract

During the last two years of SPS operation, investigations were pursued on the ability of the SPS ionization profile monitor prototype to fulfill different tasks. It is now established that the instrument can be used for injection matching tuning, by turn to turn recording of the beam size after the injection. Other applications concern beam size measurements on beams ranging from an individual bunch to a nominal SPS batch foreseen for injection into the LHC (288 bunches). By continuously tracking throughout the SPS acceleration cycle from 26 GeV to 450 GeV the evolution of parameters associated to the beam size, it is possible to explain certain beam behaviour. Comparisons are also made at different beam currents and monitor gains with measurements made with the wire scanners. Data are presented and discussed, and the possible implementation of new features is suggested in order to further improve the consistency of the measurements.

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During the last two years of SPS operation, investigations were pursued on the ability of the SPS ionization profile monitor prototype to fulfill different tasks. It is now established that the instrument can be used for injection matching tuning, by turn to turn recording of the beam size after the injection. Other applications concern beam size measurements on beams ranging from an individual bunch to a nominal SPS batch foreseen for injection into the LHC (288 bunches). By continuously tracking throughout the SPS acceleration cycle from 26 GeV to 450 GeV the evolution of parameters associated to the beam size, it is possible to explain certain beam behaviour. Comparisons are also made at different beam currents and monitor gains with measurements made with the wire scanners. Data are presented and discussed, and the possible implementation of new features is suggested in order to further improve the consistency of the measurements.

1 INTRODUCTION

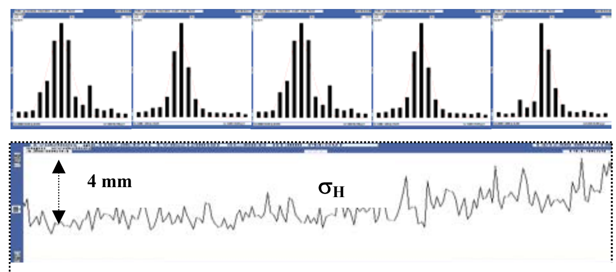
Data obtained with a gas ionisation beam profile (IPM) monitor under test in the SPS were already reported on several occasions, [1][2]. This type of monitor is one of the instruments considered to measure transverse beam distributions in the SPS and in the LHC.
The device can be used in "high resolution mode", using an optical detection bench with a CCD camera, and integrating the signal on several hundreds of beam passages (typically 20 milliseconds). For rms beam dimensions at the monitor much lower than 1 mm, a reproducibility better than 1% is possible, with a resolution lower than 0.1 mm. Moreover, data are in agreement within a few per cents with corresponding ones taken with wire scanners.

Tests were also performed in "high speed mode", sampling the beam at the SPS revolution frequency. This is achieved by replacing the CCD camera by a Photo Multiplier Tube (PMT) associated to a high speed acquisition electronics. It was shown in [2] that using 16 anode strips and a resolution of 3mm per strip, was a bit marginal to detect turn to turn injection oscillations.

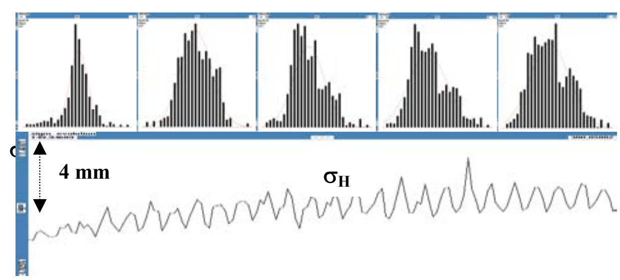
In the past two years new features occurred. Beams could be injected and accelerated to 450 GeV in the SPS with a structure fulfilling the nominal conditions required for injection into the LHC. The instrument was used to probe them in "high resolution mode". Comparisons were made with the same data recorded with wire scanners. Concerning the "high speed mode", the spatial resolution was improved down to 1.2 mm per strip, by doubling the number of anode strips (32 instead of 16) and re-tuning the optics.

The paper analyses the results of measurements made under these new conditions.

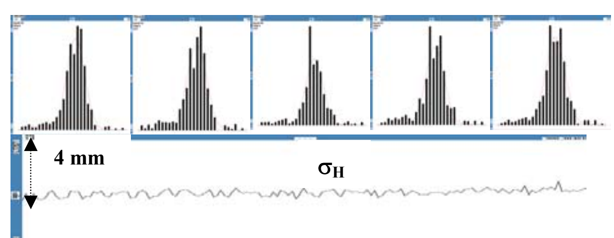
2 TURN BY TURN MODE – INJECTION MATCHING STUDIES



a) 16 strips /profile – 3 mm / strip – injection not matched



b) 32 strips /profile – 1.2 mm / strip – injection not matched



c) 32 strips /profile – 1.2 mm / strip –matched injection

Figure 1: Beam profiles measured on one passage at injection into the SPS and associated evolution of the horizontal beam rms dimension on the first 200 turns when – a) and b): the injection conditions are not matched – and c): matching is tuned.

The results of investigations made with the IPM in fast acquisition mode using 32 anodes strips with a resolution of 1.2 mm per strip are displayed in Figure 1 case b) and c) when the injection conditions are respectively not matched and matched. Compared to the same data acquired under noisy conditions with a resolution of 3 mm per strip and un-matched injection, case a), the oscillations of the rms value resulting from the mismatch are clearly detected, case b). A closer look would show up a periodicity of the oscillations of about six turns, related to the horizontal tune value. When matching conditions are better adjusted, case c), these oscillations are damped. The resolution on these oscillations of the rms value is in the order of 0.1 mm.

This test qualifies the IPM as a tool for injection tuning in a fully non-interacting way for the beam.

3 HIGH RESOLUTION MODE

In this mode, a CCD camera is used to acquire the beam profile, from a phosphorescent screen excited by the amplified electron signal. The resolution per pixel is 100 μm and each profile is integrated over 20 ms.

3.1 Single bunch profiles

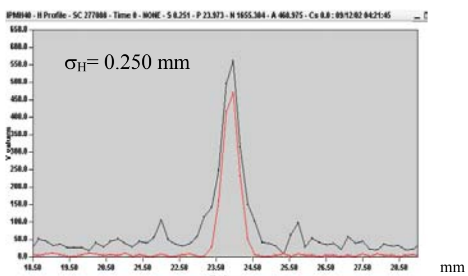


Figure 2: Profile of a bunch of 5.10^{10} protons.

In Figure 2 a profile is presented, measured on a single bunch after acceleration to 450 GeV. The rms dimension resulting from the fit is 0.250 mm. This example illustrates again the sensitivity and resolution capability of the IPM. The vacuum was in the range of 10^{-8} hPa

3.2 SPS beams for injection into the LHC

The IPM was used during the 2002 run for the study of beams prepared in the SPS for the LHC. Nominal conditions in current foresee a beam made of four trains, (batches), each of 72 bunches, accelerated from 26 to 450 GeV. The bunch population is 1.1 10^{11} protons.

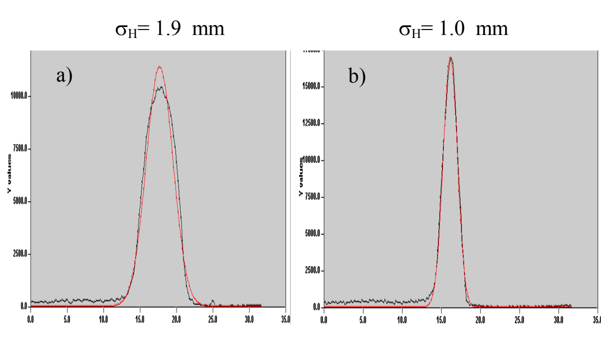


Figure 3: Profile of beam prepared for the LHC: 288 bunches of 1.1 10^{11} protons: a) before (26 GeV) - b) at the end of acceleration (450 GeV).

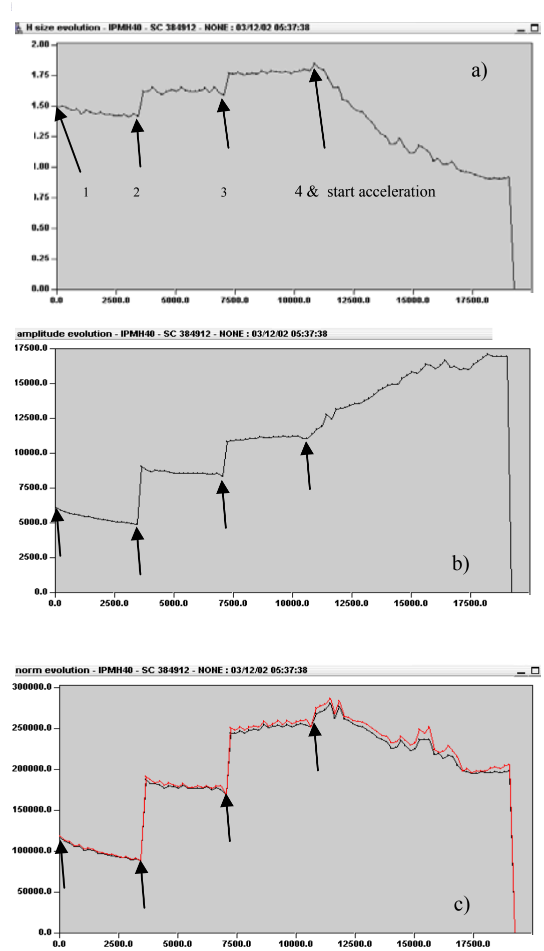


Figure 4: Evolution of: a) the horizontal beam rms, b) the amplitude and c) the integral of the IPM signal during injection then acceleration of 4 batches of 72 bunches of 1.1 10^{11} protons.

Profiles of such a beam arranged in four trains are displayed in Figure 3, after injection of the fourth train at 26 GeV before acceleration starts (at 10.8 s within the cycle), and at the end of acceleration to 450 GeV just before beam dumping. The IPM allows continuous monitoring of the beam profile from injection of the first train (taken as the time origin) throughout the acceleration cycle. The evolution of a few related parameters is shown in Figure 4. The beam acceleration takes place between 10.8 s, after the fourth train is injected, and 19 s.

The variation of the beam horizontal rms value is represented in Figure 4 a). The beam widens by about 8% at injection of each train due to either a blow-up or to the fact that trains are not exactly on the same orbit. During acceleration, a global shrinking of 40% is apparent, which should actually be 10 times larger considering only the Lorentz factor from 26 to 450 GeV. Hence some blow-up occurs during acceleration; the final value got at 450 GeV is 1 mm (Figure 3 b) and should be twice smaller to meet the LHC emittance requirements.

Figures 4 b) and c) track the corresponding evolution of the profile amplitude and integral, the later being in principle directly related to the total circulating current. Steps are observed on the beam profile amplitude at injection of the second and third trains but with steadily decreasing magnitude, indicating that current loss or beam widening effects become more important at each injection. No step is seen at injection of the fourth train.

On the profile integral in Figure 4 c) the step amplitude is more balanced at the second and third injections, indicating that widening effects are better candidates than current losses. This is in agreement with the behaviour of the rms value (Figure 4 a)). Nearly no increase is observed on the profile integral at injection of the fourth train: the current brought by this train is balanced by losses occurring when the acceleration starts.

4 IPM AND WIRE SCANNERS

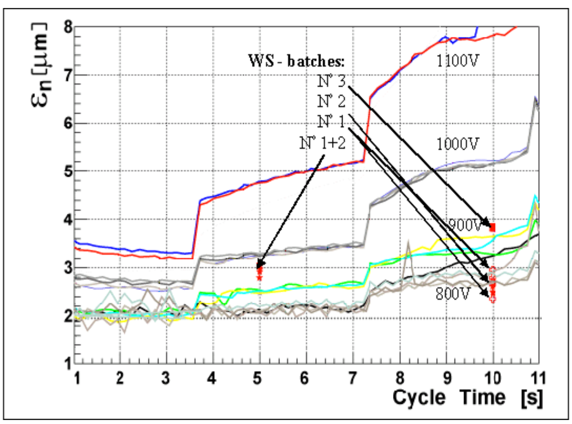


Figure 5: Evolution of the normalised horizontal beam emittance along the SPS cycle for different IPM gains

Data acquired with the IPM were compared with data taken in parallel with the wire scanners at given times of the SPS cycle. The results are illustrated in Figure 5 where the normalised horizontal emittance is processed from the recorded rms value. Different curves are for different IPM gain settings, adjusted by varying the voltage between the INPUT and OUTPUT ends of the micro channel plate between 800V and 1200V. Wire scanner data are given by the points at t = 5s and t = 10s.

Good agreement between the two devices is observed within a given range of the IPM gain, (between 800 V and 900 V). For higher gains (1000 V and 1100 V) non-linearity and saturation effects show-up on the IPM, increasing the discrepancies between the data collected with the two devices. These effects are illustrated in Figure 6 where a discrepancy of 18 % on the rms value is observed between profiles of the same beam measured with the IPM at two different gains. To avoid this it would be necessary to control the gain during the cycle in order to stabilize the signal amplitude. This facility is foreseen.

However, there are sources of discrepancies when normalizing the data between the two devices. They are not at the same location and an error contribution of several per cents comes from the imperfect machine optics model. Another contribution is due to the different acquisition strategy. A wire scanner samples a beam portion at each passage and appreciates differences when its gating is adjusted on different beam trains having different distribution: the square dots are the results of scanning only the third train whereas the other points deal with the first two trains. For the IPM, each point is the result of integrating the whole beam over several hundreds of turns. Therefore, the two instruments appreciate in a different way a non-homogeneous beam structure and eventual instabilities.

Gain: 1050V-σ_H=1.42 mm Gain: 1150V-σ_H=1.67 mm

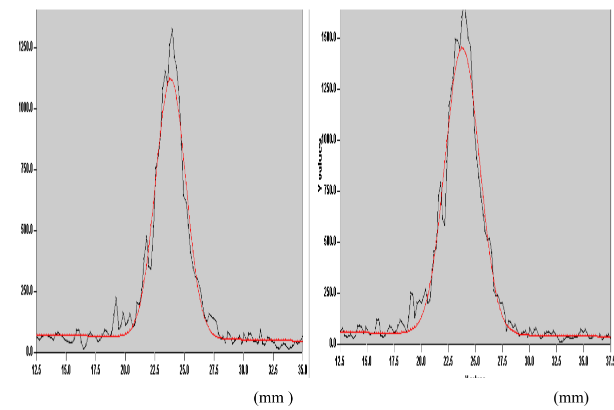


Figure 6: Profiles measured with the IPM at two different gains of the same coasting beam of 2 10^{12} p.

5 SUMMARY

Using turn by turn acquisition, the IPM can be used for injection matching. In high resolution mode and continuous beam profile monitoring during an SPS cycle, the instrument is useful to observe phenomena and cure them to achieve the performance required for LHC. The same gain was used throughout one cycle. To cover the required dynamic and avoid saturation effects, the amplitude should be kept within a given range. Automatic gain control during the cycle is needed. A new IPM was installed last year in the SPS, with a design compatible for integration in the LHC where four devices are foreseen. Its behaviour with beams having the structure required for the LHC needs further investigations.

ACKNOWLEDGMENTS

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REFERENCES

[1] C. Fischer, J. Koopman, BIW2000, Cambridge, MA.
[2] G. Ferioli et Al., DIPAC 2001, Grenoble, May 2001.