FIRST RESULTS FROM BETATRON MATCHING MONITORS INSTALLED IN THE CERN PSB AND SPS

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Abstract

In order to satisfy the tight emittance requirements of LHC, betatron matching monitors, based on multiturn beam profile measurements, have been proposed and installed in the CERN SPS and PSB. The SPS monitor is based on a OTR beam profile acquisition system and was installed two years ago and has since been tested. It helped to uncover a mismatch between PS and SPS. Experience and more results will be presented. The PSB monitor is based on a wire SEM and has been installed at the beginning of 1998. The first results presented here are very promising.

1 INTRODUCTION

A new method for verifying betatron matching at injection into a circular machine was proposed two years ago [1]. Its principle is the observation of transverse beam size over many turns, after injection into a circular machine and before filamentation takes place. All measurements are made using a single detector.

The advantage of this method lies in the fact that it requires the knowledge of only one machine optics parameter, i.e. the betatron phase advance per turn, q_x or q_y (fractional part of $Q_{x,y}$) which can be adjusted and measured with great accuracy. Perfect matching is achieved when the r.m.s. beam sizes measured on successive turns are identical (after correction for multiple scattering) which does not even require the monitor to be calibrated, nor for machine physicists to agree on a definition of emittance !

If there is a mismatch, one will see a beam size modulation at twice the betatron frequency. This is a very sensitive means, since 10% modulation of the r.m.s. beam size ,which is not too difficult to observe, would result, after filamentation, in an emittance blow-up of only 1% because this effect adds in quadrature to the r.m.s. betatron amplitude distribution. When there is no beam size modulation, the matching is perfect.

Wire SEM grids were recently installed in the PSB and used to observe for about 30 turns the proton beams injected at 50 MeV. Thin screens observed with a CCD camera, working in a fast acquisition mode, allow the visualisation of the beams injected into the SPS at 26 GeV, for up to 100 turns.

2 USE OF SEM GRIDS IN THE PSB

One of the four PSB rings has been equipped with two new SEM grids, one of which is observing the injected beam, while the other one sees the circulating beam. The SEM grids consist of 2 planes (horizontal and vertical) of gold-plated tungsten wires of 50 µm diameter, spaced at 1mm interval. For cost reasons only every second wire is connected to an electronics chain, of which there are a total of 24, thus covering 48 mm. The other wires are grounded. The electronics chains are multiplexed between the horizontal and the vertical wire planes. The injection SEM grid observing a single beam passage has a classical amplification and digitisation electronics and will not be described any further.

The SEM grid covering the circulating beam is equipped with a fast (100 ns rise time) amplifier and a 40 MHz 8-bit Flash ADC channel who's digital output is stored in an associated 2 Kbytes memory.

All 24 ADCs are triggered in parallel shortly before injecting the beam and continue to convert the signals seen on the wires synchronously at a 40 MHz rate until the memory buffers are full.

A readout program waits for the "conversion ready" signal, reads all ADC channels and saves the 24 (wires) x 2048 (depth of memory) data array into an ASCII file that may be read by a plot program.

The data file is processed off-line for further evaluation (e.g. using Mathematica).

Figure 1 shows a contour plot of the raw data as they are acquired by the ADCs. The beam's position oscillations are clearly seen.

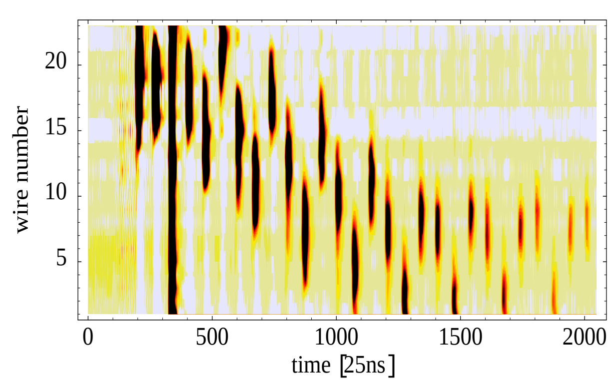

Fig. 1: Contour plot of raw data.

The strong signal on the third turn is due to beam loss on the SEM grid frame, producing secondary particles which in turn create secondary emission in the SEM grid. To obtain numerical values for the amplitude and frequency of these oscillations, the surface under the peaks corresponding to a single turn (see Fig. 2) is calculated for each wire, resulting in a profile for that particular beam passage.

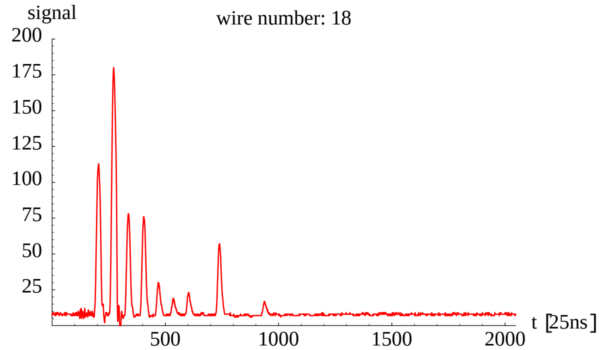

Fig. 2: Signal on a single wire. Each peak corresponds to one turn in the accelerator.

The profile (Fig. 3) is fitted with a Gaussian from which position and size of the beam can be derived.

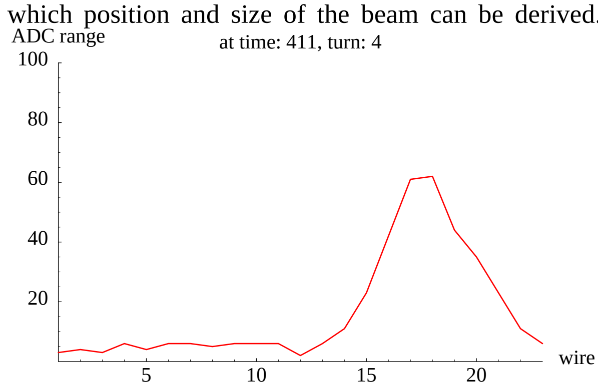

Fig. 3: The beam profile for one passage through the SEM grid.

From the frequency of the position oscillations (Fig. 4) the non-integral part of the PSB tune is calculated to 0.332 which compares to 0.326 as measured with a beam position monitor.

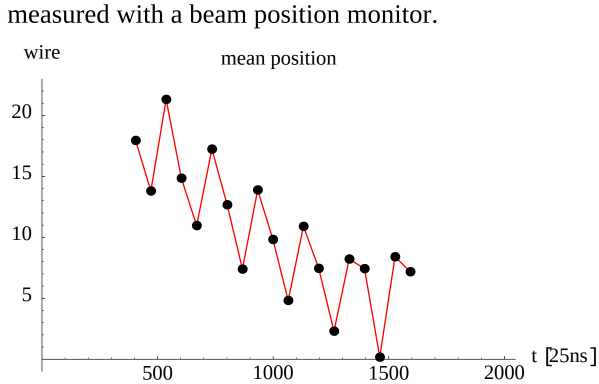

Fig. 4: Position oscillations. Each point corresponds to one beam passage through the SEM grid.

3 OTR SCREENS IN THE SPS

A 12 μm thin titanium screen was installed in 1996 in a Luminescent Screen tank in the SPS for preliminary tests. The beam could be left circulating with the foil in place for over 300 turns without damaging the titanium foil. Under normal conditions, the beam is dumped after 1.6 ms, i.e.70 turns. The foil is placed at 45° with respect to the beam trajectory and is used as an OTR generator in the reflective mode. For the 1997 run, a dedicated monitor, see Fig. 5, was installed for best OTR light collection at the low injection energy of 14 to 26 GeV. The screen is observed with an intensified CCD camera and the optical set-up is adjusted to have a pitch of 500 μm per pixel. A different pitch can be obtained by simply changing the positions of the optics.

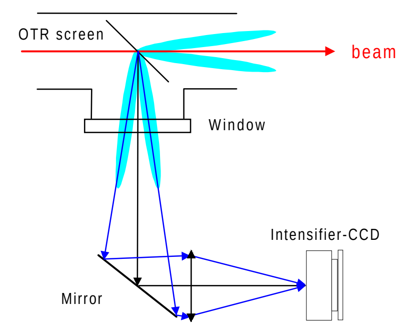

Fig.5: Matching monitor set-up in the SPS

The images of the individual SPS turns are selected by a fast gated intensifier and acquired on the CCD used as a fast buffer memory. The principle of the system has been described in [2]. Up to nine beam images taken at selected turns can be stored on the CCD chip. They are then digitised with a 12 bit/1 MHz ADC between two successive injections in the SPS. Due to the larger emittances of the present beams delivered by the PS, only one out of two images is acquired to have well separated beam images. A typical result is given in Fig. 6.

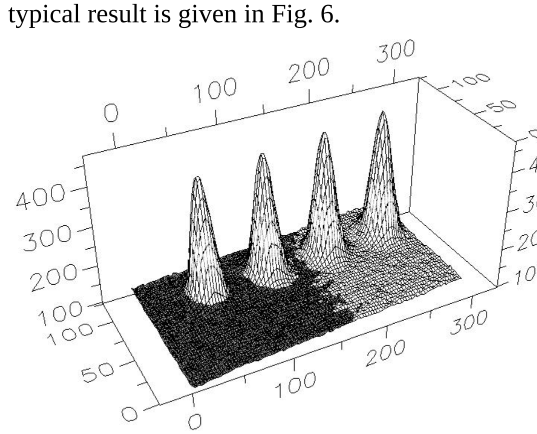

Fig. 6: Result of the digitisation of four beam images from successive SPS turns memorised on the CCD.

The horizontal and vertical projections are then calculated, from which the beam sizes are obtained with a gaussian fit using a χ^2 minimisation routine.

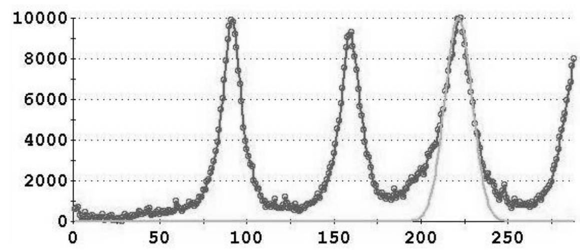

Fig. 7: Vertical projection of acquired beam images, together with the gaussian fit of the third profile. The units on the x-axis are in pixels [500 μm/px].

To complete the data set with the missing turns, a timing sequencer was developed which automatically scans the missing turns by displacing the first acquired image for the subsequent injections. A full scan measuring the beam sizes every second SPS turn takes two minutes. It has been verified that during this duration, the measurements are reproducible and consistent. The sigmas of the gaussian fits are plotted in Fig. 8 as a function of the SPS revolutions.

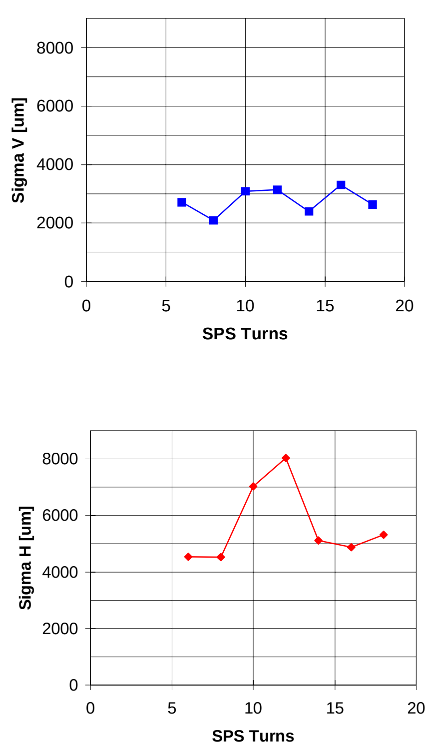

Fig.8: Horizontal and vertical beam size variation measured over 12 turns in the SPS: the matching is acceptable in the vertical direction and worse in the horizontal one.

In the measurement given in Fig. 8, the vertical beam size variation is ±20% whereas the horizontal one is ±35%. The influence of the foil on the beam blow-up can best be seen on the vertical beam size evolution. It does not seem to influence the measurement up to 60 turns. For the future runs, it is contemplated to replace the standard 12 μm titanium foil by a thinner one, 5 μm of titanium and 2 μm of aluminium will be tested, to decrease further the beam blow-up and to improve the reflectivity of the OTR foil to generate more light.

The main limitation in the image acquisition rate was found to be the repetition rate of the intensifier. The rate, and hence the image acquisition, could be increased to 10 kHz only by using a high strip current MCP intensifier. To have some safety margin, the acquisition rate was decreased to one every sixteen SPS turns, i.e. 2.75 kHz, still a hundred times faster than the 25 Hz rate of usual frame grabbers.

CONCLUSION

It is impressive to see that multitraversal of a thin detector can be used even with low energy machines like the PSB. The preliminary results obtained there are showing trajectory oscillations and further analysis will be needed to unveil matching errors.

In the SPS where OTR techniques have been pursued for more than two years, beam sizes have been measured and show amplitude modulation at twice the betatron frequency with a slight emittance blow-up due to multiple scattering. Amplitude variations of ±20% have been detected which proves that the method is already accurate enough for an optimization of the betatron phase space matching at injection.

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REFERENCES

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2. R.J. Colchester et al.: “Towards the limits of frame Transfer CCDs in Beam Observation”, BIW96, Argonne, May 1996, AIP Conf. Proc.390, 1996, pp. 215-222.