

INJECTION MATCHING STUDIES USING TURN BY TURN BEAM PROFILE MEASUREMENTS IN THE CERN PS

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Abstract

The very small emittance beam needed for the LHC requires that the emittance blow-up in its injector machines must be kept to a minimum. Mismatch upon the beam transfer from one machine to the next is a potential source of such blow-up.

The CERN PS ring is equipped with 3 Secondary Emission Grids (SEM-Grids) which are used for emittance measurement at injection. One of these has been converted to a multi-turn mode, in which several tens of consecutive beam passages can be observed. This allows the study of mismatch between the PS-Booster and the PS.

This paper describes the instrument and experimental results obtained during the last year.

1 MOTIVATION

Since the construction of the PS Booster (PSB) the transfer line between the PSB and the PS has been operated with a rather large dispersion mismatch. This was acceptable for beams with relatively large transverse emittance and small momentum spread. For LHC-type beams however, due to their low emittance requirements, it is essential to improve the dispersion matching.

The method described was used to measure this mismatch and to investigate new quadrupole settings in the transfer line in order to reduce it[1].

2 EXPERIMENTAL SETUP

Three SEM-Grids are installed in the PS ring in order to measure beam emittance at injection into the machine. After traversal of the detectors, the beam is normally stopped by an internal dump in order to prevent multiple passages, heating the SEM-Grid wires and destroying the detectors. Slow charge integrating electronics is used for the measurements.

However for the measurements reported here, one of the SEM-Grids has been equipped with a fast amplifier (100 ns rise-time) and 40 MHz Flash-ADC associated with 2 kbytes of memory for each SEM-Grid wire. The injection kicker is pulsed twice at 60 μ s time interval. The second kick destroys the beam after 28 turns (revolution period in the PS at 1.4 GeV is 2.2 μ s) in the machine, thus avoiding unnecessary heating of the SEM-Grid wires.

The ADCs are triggered a few μ s before injection and the wire signals are converted and stored in memory at the ADC's internal clock frequency of 40 MHz.

An acquisition program reads out the ADC channels and saves the results onto a disk file for offline evaluation.

The beams used for the measurement had a bunch length of \sim 80ns, an intensity of 10^{11} protons and a small momentum spread in order to ease the evaluation of the betatron mismatch. The method has been first proposed in [2] and preliminary results presented in [3].

3 DATA EVALUATION

A *Mathematica* [4] program reads the disk file and evaluates the data.

3.1 The Raw Data

The raw data correspond to a copy of the ADC memory contents consisting of 2048 samples (one sample every 25 ns) for each of the 20 wires.

Figure 1 shows the signal seen on a single SEM-Grid wire in the centre of the SEM-Grid (wire 11).

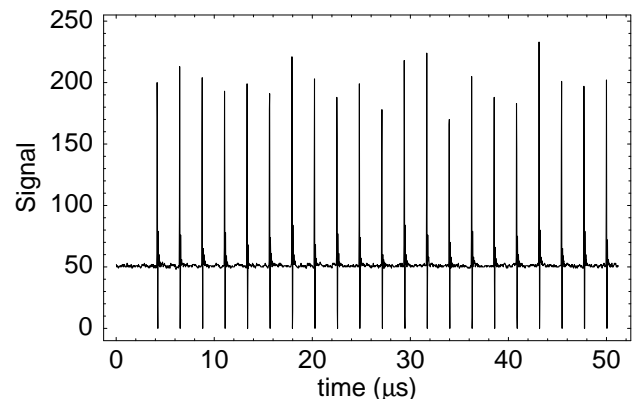


Figure 1: Raw data on a single wire

The raw data from 20 wires around a single beam passage is shown in fig. 2. Here 12 samples of the wire signals from all wires is plotted.

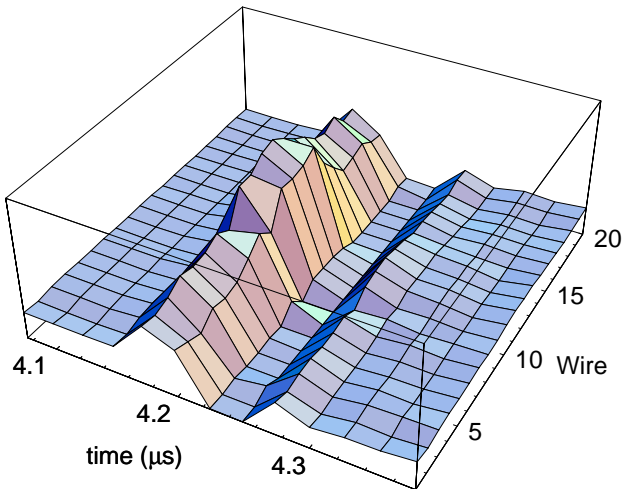


Figure 2: Raw data around 1 beam passage

The signal has 2 components:

- Signal induced on the wire by the charges of the beam (the outer wire see a signal) approximately proportional to the derivative of the longitudinal bunch shape, leading to a negative signal component.
- Signal created by secondary emission

Integration of the signal makes the first component vanish and keeps only the secondary emission part.

As can be seen from fig. 2 the ADC sampling rate is not high enough for the signal time-scale and a longer bunch-length would have been preferable.

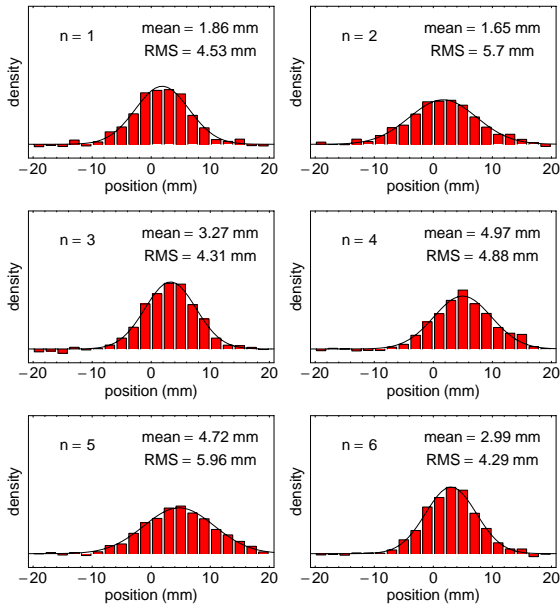


Figure 3: Turn-by-Turn Profile

The profiles obtained by integrating the signals from each wire can be seen in fig. 3 for the first 6 turns.

3.2 Trajectories and Dispersion Mismatch

The turn-by-turn profiles are fitted with a Gaussian and the mean position and beam width of are extracted from the fit parameters.

The mean position for a beam with a relative momentum offset of 4 ‰ is plotted in fig. 4. The solid curve is a fit from which the following parameters are extracted:

- The trajectory's mean position ($\langle x \rangle = 3.5$ mm). It is dominated by momentum offset via dispersion with a small contribution from the closed orbit.
- The amplitude (1.74 mm) with a main contribution from the dispersion mismatch and a small part due to mis-steering.
- The non-integral part of the tune (0.176). The method can be used to determine the tune to a precision of 0.001.
- The phase at the first passage (2.54 rad, phase=0 if the oscillation is at its maximum at the first passage)

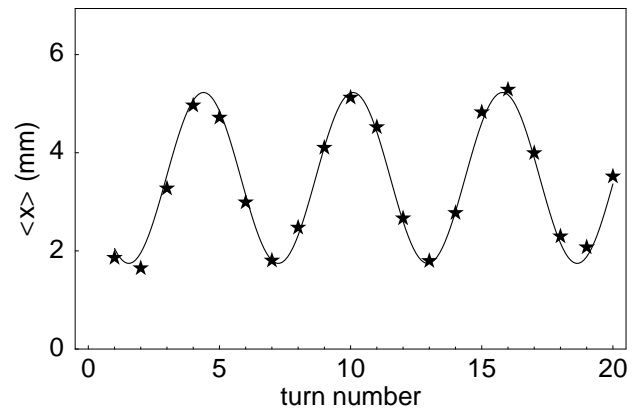


Figure 4: Square of the mean positions extracted from the profiles

From two acquisitions measured with different momentum offsets, the dispersion of the receiving synchrotron and the dispersion mismatch can be determined.

The data shown in fig. 4 are combined with an acquisition at the relative momentum offset of -1.4 ‰ leading to:

- Dispersion of the PS at the position of the SEM-Grid: 2.53 m
- Amplitude of the dispersion mismatch: 0.5 m
- Phase of the dispersion mismatch: 2.47 rad.

3.3 Width Oscillations and Betatron Mismatch

The variance of the beam distribution extracted from the fitted profiles is shown in fig. 5. This oscillation is determined by betatron mismatch, by dispersion mismatch, and from a very small contribution due to scattering on the SEM-Grid wires.

In addition to the dispersion parameters, which have been evaluated as described in section 3.2, the momentum spread is estimated from a longitudinal bunch-shape measurement and introduced into the calculations.

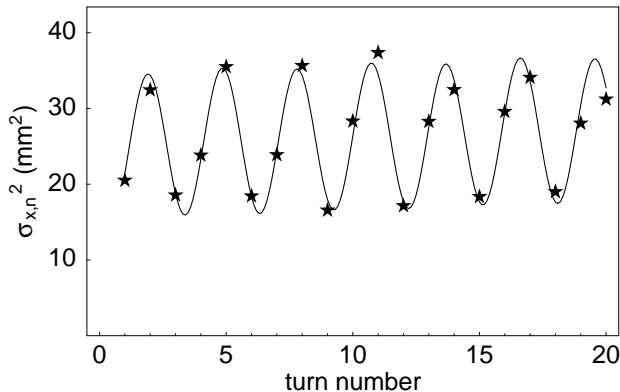


Figure 5: Beam width for each turn

The following parameters can be obtained by fitting the data points:

- The emittance of the injected beam ($1.82 \pi \mu\text{m}$). The advantage of this method, as compared to the standard 3-profile method, lies in the fact that only the beta function has to be taken into account and good statistics are obtained for the beam width due to multiple measurements on the same beam.
- Geometric betatron mismatch ($\sim 50\%$) which leads to an RMS blow-up of 8%.
- The contribution of the beam width due to scattering on the SEM-Grid wires is barely visible. The RMS scattering angle is estimated to 0.04 mrad per turn.

4 POSSIBLE IMPROVEMENTS

On the electronics side, several improvements can be considered:

- The ADC sampling rate should be increased by at least a factor 2 and its dynamic range improved. 10 bits resolution or better would simplify the adjustment of the beam intensity to the ADC range.
- The amplifier bandwidth should be extended in order to cope with the rather short bunches of a few tens of ns. Limits are the small momentum spread desired the minimum voltage of the PSB RF system and the fact that longitudinal scraping is used in order to adjust the beam intensity.

The injection of longer bunches would reduce the negative signal component. Limits are the small momentum spread desired, the minimum voltage of the PSB RF system and the fact that longitudinal scraping is used in order to adjust the beam intensity.

The CERN PS uses a pulse-to-pulse modulation scheme (ppm) that allows re-configuring the machine for 2 consecutive acceleration cycles in order to produce different types of beams for different users.

When performing the matching measurements, the accelerator must be dedicated to these studies and no other beams are allowed in order to protect the SEM-Grid. Improvements in the insertion mechanism such that the SEM-Grid can be inserted into the beam passage just before injection of the beam to be measured, and taken out before the next acceleration cycle, would allow using the scheme without blocking the accelerator for other users.

5 CONCLUSIONS

Machine experiments using multi-turn profile measurements have shown that valuable information on injection matching can be extracted.

It was possible to determine the mismatch in dispersion and in both transverse phase planes. In addition the tune, the emittance of the injected beam and the dispersion of the PS could be obtained.

REFERENCES

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