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MEASUREMENTS WITH THE MAGNETIC QUADRUPOLE PICK-UP IN THE CERN PS

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Abstract

A prototype quadrupole pick-up, based on a new design concept, was recently installed in the CERN PS. It uses magnetic coupling rather than electric for reasons of radiation endurance and common mode rejection. The pick-up is mainly intended to detect and correct coherent oscillations of beam size due to injection mismatch. However, it can also be useful for other purposes, such as the study of space charge effects by measuring the damping time of the quadrupole mode of oscillation or the detuning of its frequency, and as a coupling meter, since the study of beam size oscillations due to coupling yields information that is complementary to the centre-of-mass oscillations. This paper presents a description of the data acquisition and treatment together with some recent measurement results. A general discussion of the potential uses of quadrupole pick-ups is also given.

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1 INTRODUCTION

For the future production of high brightness beams in the PS Complex, it would be extremely useful to have a non-invasive tool to verify the conservation of transverse emittance. A quadrupole pick-up measures the quadrupole moment

$$m_{\mathrm{Q}} = \sigma_{\mathrm{x}}^2 - \sigma_{\mathrm{y}}^2 \tag{1}$$

which is very sensitive to variations in the beam size, that can occur as a consequence of miss-matched injection, and therefore a quadrupole pick-up is a good candidate. Some time ago, a prototype quadrupole pick-up was installed in the PS. The design of the prototype was conceived to circumvent one of the major problems that have previously discouraged the use of quadrupole pick-ups, namely that of separating the tiny quadrupole signal from the huge common mode signal. This is achieved by coupling to the radial component of the magnetic field[1, 2].

The prototype pick-up was built partly from re-used material, in order to test this design idea, and is thus not entirely perfect. Measurements on different beams have been performed, and by comparing these to measurements made on a model in the lab, a lot of experience has been gained towards the design of the final version[3].

2 DATA ACQUISITION

The output signals of the four antenna loops in the pick-up are connected to a hybrid circuit, that provides the composite signals corresponding to quadrupole moment and position in the horizontal and vertical plane. The sum signal is zero by construction and is not used. The three composite signals are then amplified and sent to a building at the centre of the PS. Here, they, as well as a reference beam current signal from a wall-current monitor, are connected to a digital oscilloscope. The oscilloscope is triggered at injection and can acquire data over 200 to 800 machine revolutions depending on the time resolution required.

Using a GPIB-to-Ethernet converter, the oscilloscope can be remotely controlled and read out via the network from a PC in the main control room. A LabView application program has been written to control the oscilloscope, down-load and directly analyse the data. The data treatment is described below. Both raw and treated data can be saved to disk for further analysis.

3 DATA TREATMENT AND ANALYSIS

Previously, the signals from quadrupole pick-ups in circular machines[4, 5] were usually studied only in the frequency domain, since beam width oscillations give rise to sidebands at $\pm 2qf_{\mathrm{rev}}$ from the revolution harmonics. In the PS, this method is not applicable since each bunch injected in the machine comes from a different Booster ring, and thus can have different characteristics. In order to resolve separate bunches, the signal first has to be treated in the time domain. Several possibilities exist. The simplest method is peak detection. This is fast, but not very precise. Since only a single sample is used, the influence of noise is large, Also, a high sampling rate is required in order not to miss the peak value. Another error-source is the estimation of the base-line. A slightly more elaborate scheme is gated integration. By integrating over the pulse, noise can be significantly suppressed. On the other hand this method is even more sensitive to base-line errors.

In order to obtain maximum accuracy from the pick-up signals, a special fitting scheme has been developed. A curve is first fitted to the signal from the wall-current monitor to establish the functional shape of the pulse induced by the bunch. Since the signal is relatively strong, this can be done with good precision. Then, use is made of the fact that this pulse shape is the same on the pick-up outputs (provided the bandwidth is the same). The function resulting from the first fit is thus translated in time by a fixed amount to account for differences in cable lengths and instrument position, and used as basis function when analysing the position and quadrupole signals. For this second (linear) fit, only two basis functions are used: the fitted pulse shape and a constant base line. By using such a restricted basis, the influence of noise is reduced. This is particularly important for the quadrupole signal, where the signal levels are low.

The above fitting scheme is performed on each bunch in the machine over a certain number of turns. The resulting data can then be studied either in time or frequency domain.

4 MEASUREMENT RESULTS

4.1 Pick-Up Development Tests

Already before the pick-up was installed, it was observed that it suffered from a common mode rejection problem. Although at low frequencies the common mode rejection is excellent, a parasitic signal was observed, almost independent of beam position and size and increasing approximately linearly with frequency. Because of its frequency response this signal will approximately have the shape of the time derivative of the bunch shape. This common mode signal is most visible in the quadrupole signal, since it is the smallest. The main part of the parasitic signal is, however, suppressed in the fitting scheme, since the first derivative of a symmetric function (bunch shape) is an odd function and therefore orthogonal to the function itself.

A series of test-bench measurements have been performed in order to understand and eliminate this problem. It was found that the signal originates from capacitive inter-winding coupling in a transformer. This finding has led to a re-design of that part of the pick-up for the final version.

The oscillation amplitude measured with the quadrupole pick-up have been compared to data from a SEM-grid used for turn-by-turn profile acquisition, with good agreement (Fig. 1).

4.2 Beam Studies

Since the aim of the prototype pick-up was to investigate and improve the new design idea, no major studies of beam physics have been performed so far. However, while testing the pick-up on different beams, a number of interesting phenomena have been observed and recorded, some of which are presented here.

When measuring at injection of an elliptic beam (horizontal emittance larger the vertical) into the PS, with a working point close to the diagonal and strong skew quadrupole gradients, a large oscillation of the beam size was observed at a frequency given by the separation of the tunes. This was interpreted as the coherent transfer of emittance between the two planes. In fact, when injecting a beam into a strongly-coupled machine, standard betatron matching it not sufficient since the normal modes of the motion do not lie in the horizontal or vertical planes.

In the case of coherent dipole oscillations, the beam can be considered as a macro-particle and thus does not see any direct space-charge. However, in the case of coherent size oscillations, each individual particle sees the full space-charge of the beam. This has two effects: the coherent tune for the quadrupole mode is reduced, and the tune spread

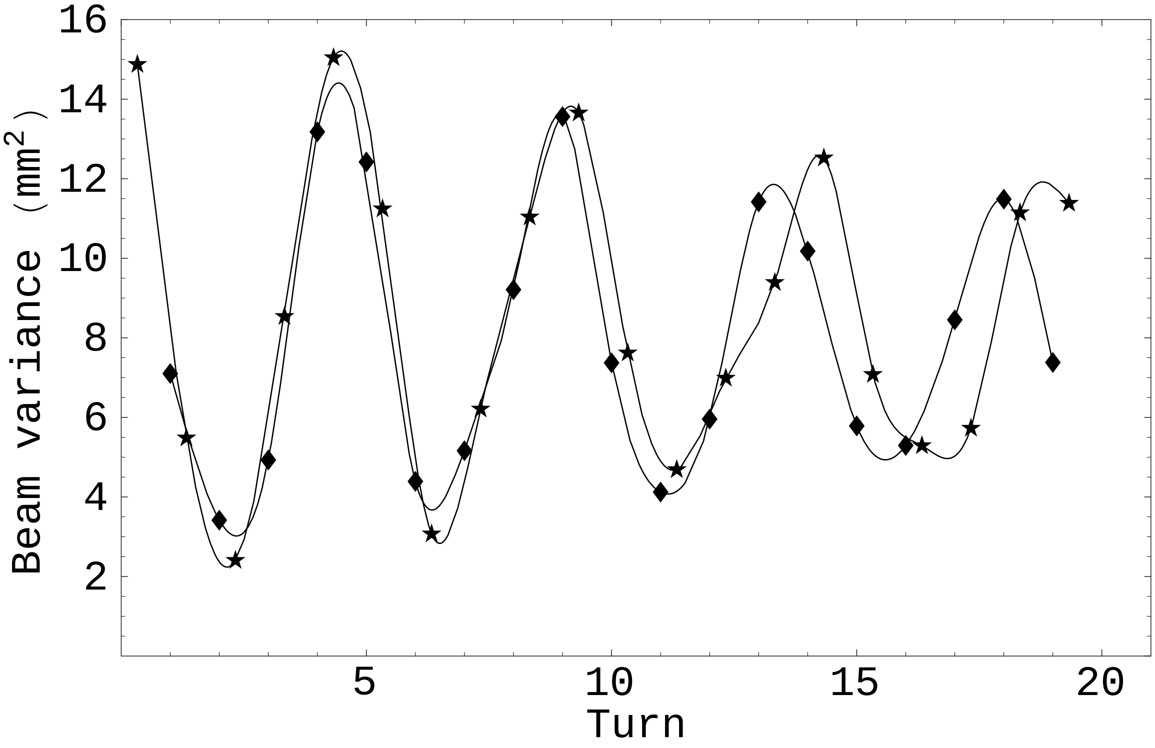

Figure 1: Horizontal beam width oscillations measured with the quadrupole pick-up (stars) and a SEM-grid (diamonds). The lines are spline interpolations.

increases. This has been observed with the pick-up. Figs. 3 and4 show how the frequency and damping time (inversely proportional to the tune spread) change with intensity.

A nice example of the usefulness of a quadrupole pick-up as a diagnostic tool was found when extending the number of turns acquired by decreasing the sampling rate. It was seen that the beam seemed to be violently disrupted approximately 180 turns after injection. This was found to coincide with the onset of the so-called longitudinal blow-up, that consists of shaking the buckets using phase-modulated RF on a high harmonic to improve the longitudinal distribution.

5 DISCUSSION AND FUTURE PERSPECTIVES

The aim of the prototype pick-up was to refine the new design towards the final version. This has been achieved, and a new improved pick-up based on the experience gained from the prototype has now been installed.

The signal from a single quadrupole pick-up can be difficult to interpret, since it is affected by both horizontal and vertical beam size. This is particularly true in the PS since the tunes are often such that the quadrupolar frequencies are almost equal. Due to the strong damping, the signals are thus hard to separate. It is therefore foreseen to install two pick-ups at locations with very different ratio between horizontal and vertical beta functions. Analysing the data from the two pick-ups together will permit a separation of the effect from the two transverse planes.

Although the main reason for developing the pick-up was to detect injection mismatch, it is clear that the use of such a system can be extended beyond that. The results in Fig. 2 suggest that the pick-ups could be used to study the effects of coupling, perhaps even to quantify the coupling and determine its phase, something that is not obvious

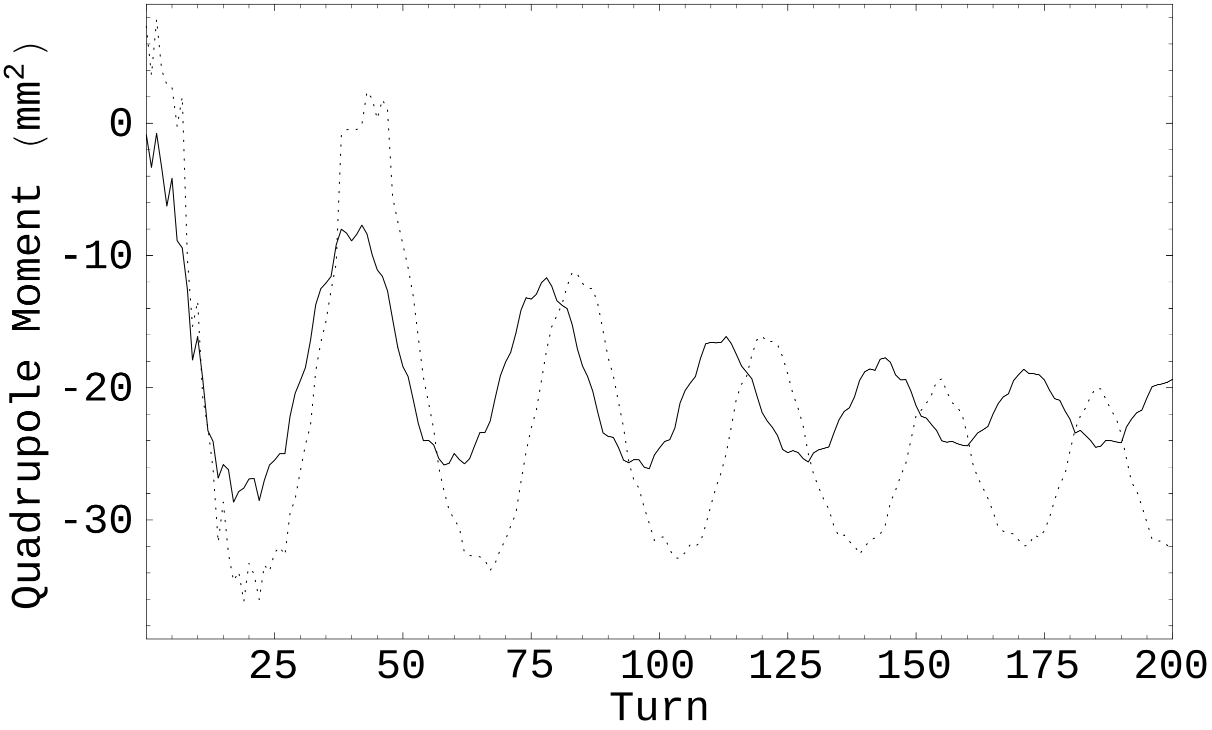

Figure 2: Quadrupole moment measured for an elliptic beam at injection into a strongly-coupled PS. The horizontal emittance of the injected beam depends on the number of turns used for multi-turn injection in the Booster, whereas the vertical emittance is approximately constant. The solid and dotted line correspond to 6 and 9 turns multi-turn injection, respectively. It can be seen that the oscillation amplitude increases with the initial ellipticity of the beam.

using normal position pick-ups. Also, as indicated by Figs. 3 and 4, the effects of space charge (e.g. tune spread) can be studied directly. The pick-up is also useful to diagnose transverse emittance blow-up at any given point in the machine cycle, as indicated by Fig. 5. Finally, using the technique of Miller et al, the emittance can be measured[6], provided the noise can be sufficiently suppressed.

References

[1] A. Jansson, "The Measurement of Higher Order Moments of Beam Transverse Distribution using a Magnetic Pick-up", CERN internal note, PS/OP/Note 98-27

[2] A. Chapman-Hatchett, A. Jansson and D.J. Williams, "A Magnetic Quadrupole Pick-up for the CERN PS", PAC'99, New York, April 1999

[3] A. Jansson and D.J. Williams, "A New Optimised Design of Quadrupole Pick-up using Magnetic Coupling", To be submitted to Nucl. Inst. and Meth. in Phys. Res. A

[4] M. Chohan et al, "Measurement of Coherent Quadrupole Oscillations at Injection into the Antiproton Accumulator", EPAC'90, Nice, 1990

[5] M. Chanel, "Study of Beam Envelope Oscillations Measuring the Beam Transfer Function with a Quadrupolar Pick-Up and Kicker", EPAC'96, Sitges, 1996

[6] R.H. Miller et al "Non-Intercepting Emittance Monitor", PAC'83, Washington, 1983

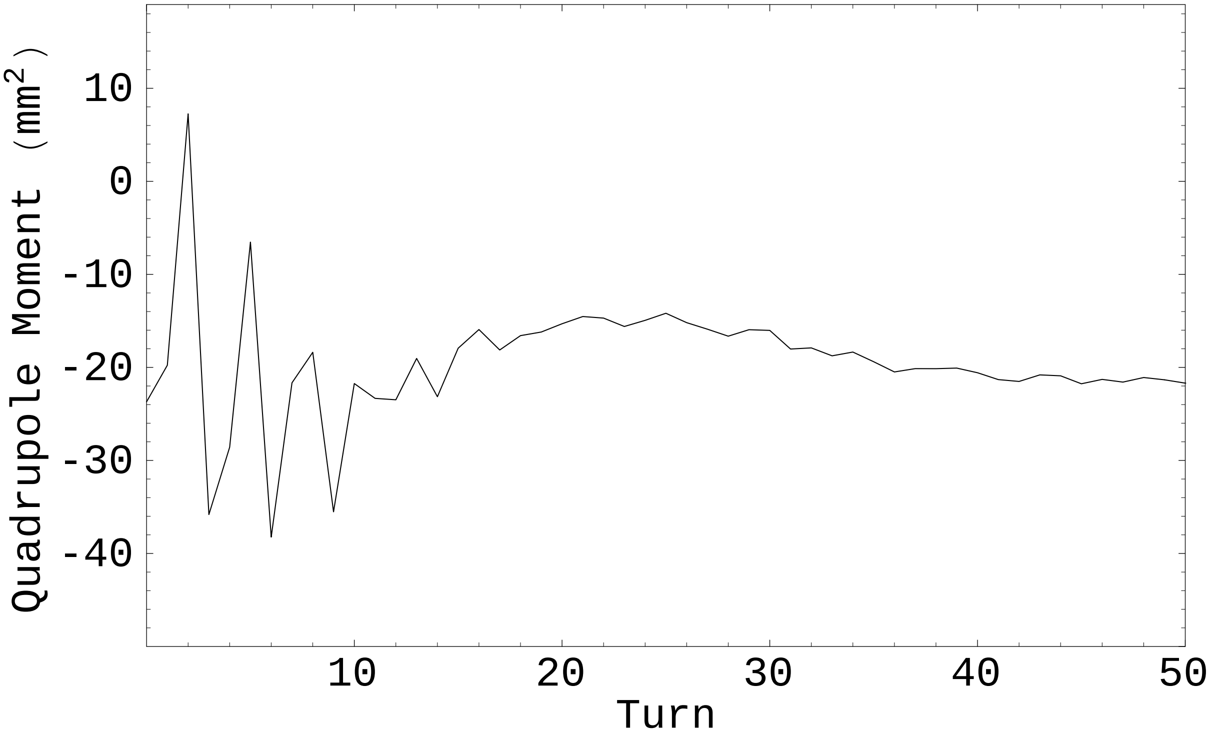

Figure 3: Quadrupole moment over the first 100 turns for a deliberately mismatched beam. Note the very short damping time due to incoherent space-charge tune shift.

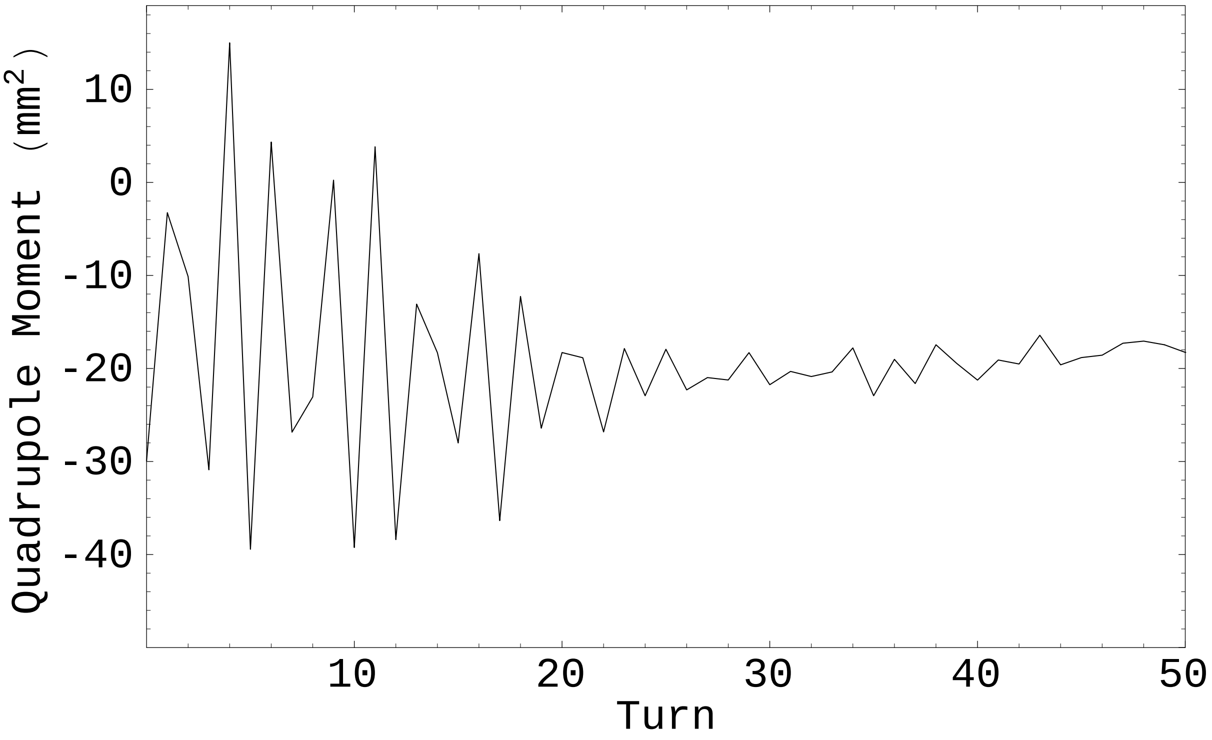

Figure 4: Quadrupole moment over the first 100 turns for the same beam as in Fig. 3, but with the intensity reduced by about a factor five. The intensity was reduced in a way that approximately preserves the transverse and longitudinal emittances. It is clear that the damping time has increased. It can also be seen that the frequency of the oscillation has increased, due to the lower space-charge.

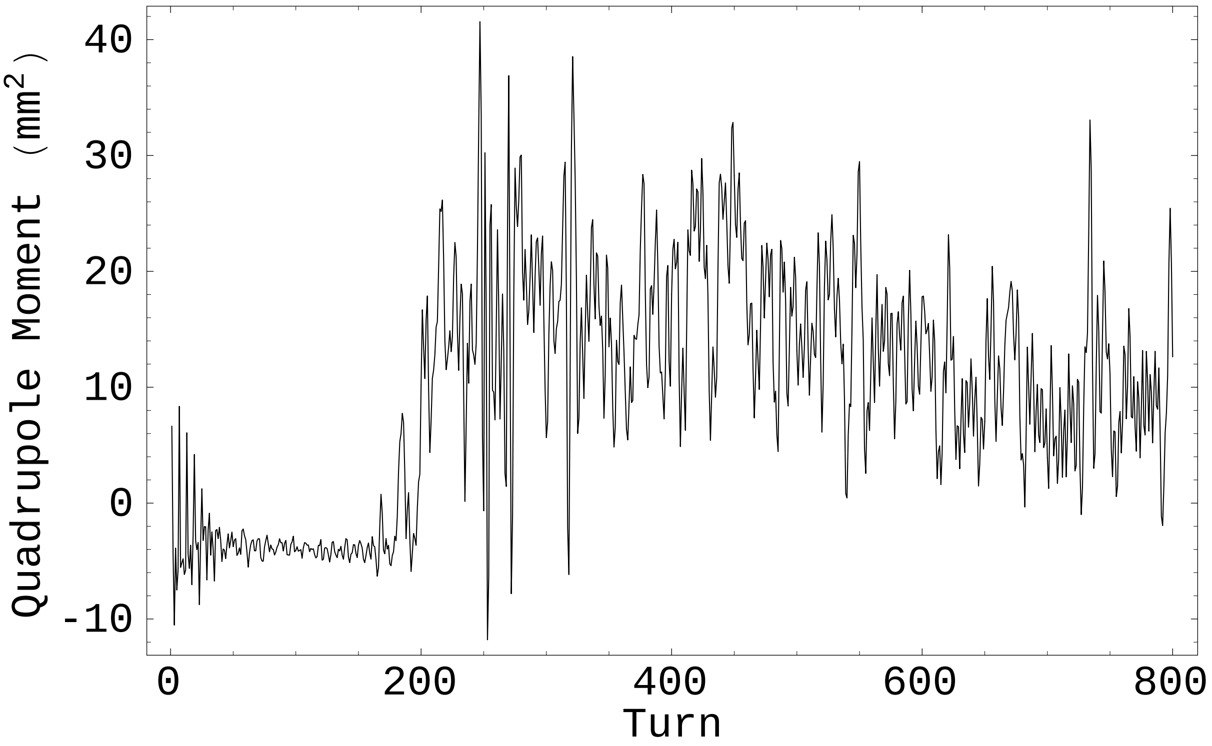

Figure 5: Quadrupole moment over the first 800 turns in the machine. The oscillations at injection are due to dispersion mismatch. After about 180 turns, the longitudinal blow-up starts shaking the beam longitudinally, and an effect can be seen in the transverse plane.