TRANSVERSE MEASUREMENTS WITH KICKER EXCITATION AT COSY-JÜLICH

J. Dietrich, J. Bojowald, I. Mohos and R. Wagner
Forschungszentrum Jülich GmbH (KFA), Jülich, Germany

Abstract

COSY-Jülich is a COoler SYnchrotron and storage ring designed to deliver high precision proton beams with a momentum range from 270 to 3300 MeV/c for medium energy physics. Beam particles can be excited by a fast diagnostic kicker magnet synchronously with the COSY bunch to collective transverse oscillations with betatron frequency. Raw data from the beam position monitors (BPMs) can be displayed, processed and analysed on PCs as well as online on Unix workstations of the accelerator control system. Experimental procedure and data analysis are described, measurements of lattice parameters and studies of the phase space boundary near the electrostatic septum in the case of resonant extraction are presented.

1 MEASUREMENTS AND ANALYSIS

The purpose of the fast diagnostic kicker magnet is to excite the beam particles to collective transverse (horizontal only) oscillations with betatron frequency which can be used e.g. to determine the tune or for phase space investigations. The beam bunch is short-time deflected (0.75 – 2μs width, rise- and falltime $< 1\mu$s) and the resulting bunch oscillations are measured using the beam position monitors (BPMs). The kicker excitation is synchronized with the COSY rf signal and can be adjusted in time by a programmable delay, so that a single deflection of the total bunch can be performed (bunch synchronous excitation) [1]. The short time kicker deflection is suitable for measuring the tune also during acceleration, in contrast to the time consuming resonant excitation by the stripline unit used under steady state conditions (e.g. in flat top). The amplified and filtered sum (Σ) and difference (Δ) signals from the BPM electrodes are digitized by flash ADCs (20 MHz clock rate), stored in FIFO memories [2] (4K or 64K width) and transferred to files which contain 4096 or 65536 data lines plus an end marker and 4 header lines. The header stores global features of BPM and measurement (x or y plane, BPM number, position on orbit, and monitor sensitivity S_{BPM} – different in cylindrical and rectangular sections of the beam tube), date and time of measurement, and the settings of the Σ and Δ branch of the BPM electronics (amplifications A_Σ and A_Δ [dB], filter bandwidth [kHz], and sampling repetition time [ns]). Depending on the FIFO width, data of about 200 or 3200 successive turns can be stored.

Figure 1 displays typical raw data for Σ and Δ. The oscillation in Δ is clearly seen. Diagnostic online tools include (a) shell scripts and C subroutines for plotting raw monitor data with selectable ranges in X11 windows or to PostScript files (as in Fig. 1) with Gnuplot [3], (b) search algorithms for Σ peaks in FIFO files with symmetric (normal), asymmetric, and double peaked bunch forms, and (c) C subroutines and scripts for calculating and plotting the true horizontal beam centroid positions x (e.g. in mm) for each turn from Δ_{peak}, Σ_{peak}, BPM sensitivity etc. according to

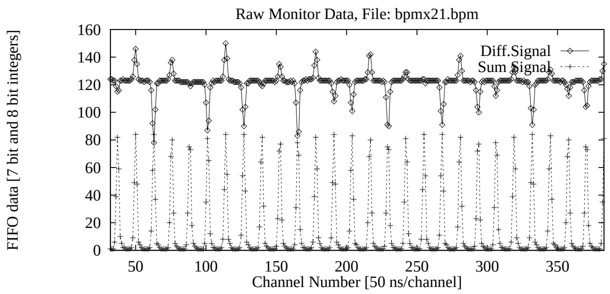

Figure 1: Raw Σ and Δ signals from BPM 21 sampled with 20 MHz clock-rate (50 ns/channel); normal (symmetric) bunch form.

$$x = \frac{\Delta_{peak} - \Delta_{zero}}{2(\Sigma_{peak} - \Sigma_{zero})10^{(A_\Delta - A_\Sigma)/20} \cdot S_{BPM}} \ .$$

With true horizontal bunch positions x_1 and x_2 at **two** BPMs with orbit positions s_1 and s_2 (preferably with a betatron phase difference $\Delta\phi_{12} = \phi_2 - \phi_1$ near $\pi/2$) the slopes x_1' and x_2' of the bunch centroid trajectory are accessible. In order to obtain x_1', x_2' from x_1, x_2 the (horizontal) TWISS parameters $\beta_1, \beta_2, \alpha_1, \alpha_2$, and μ_1, μ_2 (index x omitted for convenience) are needed and have to be calculated with MAD [4] as can be seen in the fully symmetric formulae for x_1' and x_2', respectively:

$$x_1' = \frac{1}{sin2\pi\Delta\mu_{12}}\left(\frac{x_2}{\sqrt{\beta_1\beta_2}} - \frac{x_1}{\beta_1}(cos2\pi\Delta\mu_{12} + \alpha_1 sin2\pi\Delta\mu_{12})\right)$$

and

$$x_2' = \frac{1}{sin2\pi\Delta\mu_{21}}\left(\frac{x_1}{\sqrt{\beta_2\beta_1}} - \frac{x_2}{\beta_2}(cos2\pi\Delta\mu_{21} + \alpha_2 sin2\pi\Delta\mu_{21})\right)$$

with $\Delta\mu_{12} = \mu_2 - \mu_1$ and $\Delta\mu_{21} = \mu_1 - \mu_2$.

Scripts `pp1` and `pp2` (with file names and other parameters) evaluate these formulae and perform phase space plots at the positions of the 1st and 2nd BPM considered, respectively; range of turn numbers is selectable.

In Figure 2 the kick-excited damped bunch centroid oscillations around the closed orbit value R_0 are shown. The

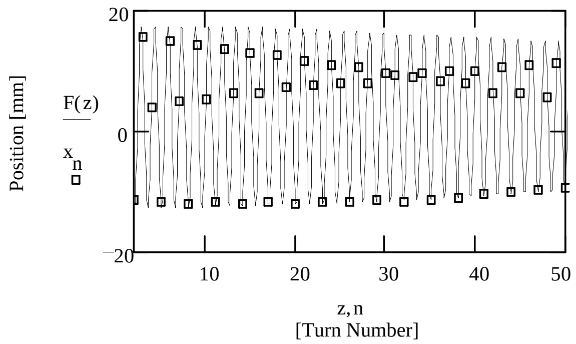

Figure 2: Damped oscillation of beam centroid after kick excitation and fitted curve (see text).

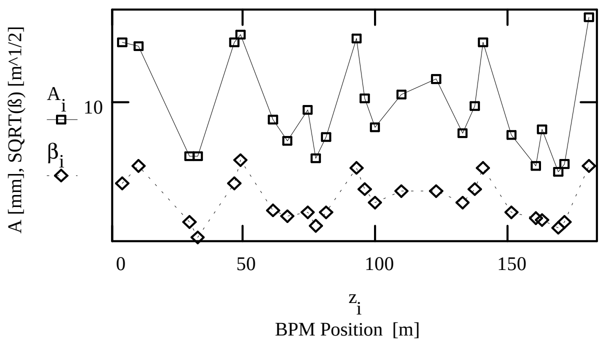

Figure 3: Amplitude A_i compared with B_i, the square root of $\beta(z_i)$ (calculated with MAD) at BPM positions z_i (cf. text).

open squares are measured values from turn to turn. The solid line is a fit for a damped oscillation assuming a gaussian tune distribution [5]. The measured "damping" of the oscillation is caused by vanishing of the collective motion of the particles in the bunch due to their finite betatron frequency spread. The curve fit for the damped oscillation is done using the expression [5]

$$x_n = A(\epsilon, \beta(s)) \cdot e^{-\frac{(n\pi \cdot \delta Q)^2}{2}} \cdot cos(2\pi(nQ + \phi)) + R_0$$

with x_n= beam centroid position at the n-th turn, A = $\sqrt{\epsilon \cdot \beta(s)}$ = amplitude term with ϵ = emittance of the kicked beam and $\beta(s)$ = beta function, Q = tune, δQ = tune spread, ϕ = betatron phase and R_0 = closed orbit value. By least squares fit of this function to the measured positions at each BPM accurate results for the key parameters in this expression are obtained.

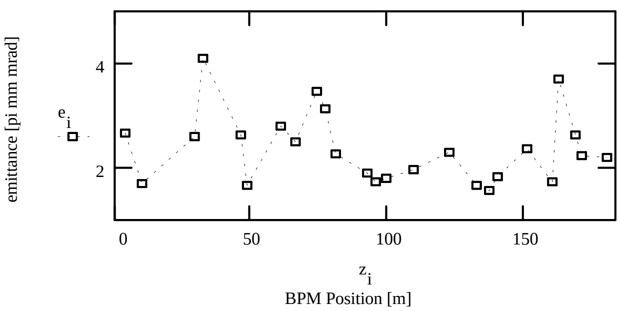

Figure 4: Emittance ϵ_i of kicked beam calculated with A_i and β_i (from MAD) at BPM positions z_i.

In Figure 3 the amplitudes at each BPM position are compared with $\sqrt{\beta(s)}$ obtained from MAD [4] calculations . Figure 4 shows the emittance of the kicked beam at the BPM positions calculated from the amplitudes and the MAD β values. Variations of the emittance values are mainly due to uncertainties in calculated β values.

2 PHASE SPACE STUDIES

For the resonant extraction process at COSY the horizontal tune is moved towards a third order resonance and the particles are shifted towards the electrostatic septum by a local closed orbit bump. By additionally exciting one or more sextupoles a triangular shaped phase space boundary (separatrix) characteristic for the resonance is created. The correct orientation of this separatrix at the location of the electrostatic septum is essential for getting a good extraction efficiency. For this purpose measurements of phase space conditions at the position of the electrostatic septum have been performed. The beam centroid displacement (the betatron motion) after kicker excitation with different kick strengths was measured turn by turn using two BPMs located near the electrostatic septum and with a phase advance much different from n$\cdot\pi$.

Figure 5 shows transverse phase space plots (first hundred turns) at operation near the third order resonance for four different kick strengths (deflection angles). Different representations of the results at the same deflection angle are arranged in the columns of Figure 5. In the rows the results for the different kick strengths are represented in the same manner. Figure 5a shows from turn to turn the horizontal position of the beam centroid at monitor BPM24 (just in front of the electrostatic septum) versus the position at BPM21 located 18.7 m before the electrostatic septum . In Figure 5b the phase ellipse calculated with MAD and the beam centroid motion in the phase space at BPM24 are compared. The horizontal axis corresponds to a normalized beam position $x_{norm} = (x_n - R_o)/A(\epsilon, \beta)$ with x_n = beam centroid position at the n-th turn, $A(\epsilon, \beta)$ = amplitude term with ϵ = emittance of the kicked beam and β = beta function and R_o = closed orbit value; the vertical axis corresponds to the normalized angle calculated from the normalized beam centroid positions at the two BPMs and the transfer matrix. From the normalized angle and beam centroid positions the conjugate variable of the displacement x_{norm}, namely $p_{xnorm} = \alpha x_{norm} + \beta x'_{norm}$ is calculated, where p_{xnorm} is a function of the α- and β-function values at the BPMs. In Figure 5c the same data (first hundred turns) are plotted for the conjugate variable p_{xnorm} along the vertical axis versus the normalized beam centroid position along the horizontal axis.

With increasing angular deflection the horizontal tune changes to higher values. From Figure 5 the width of the

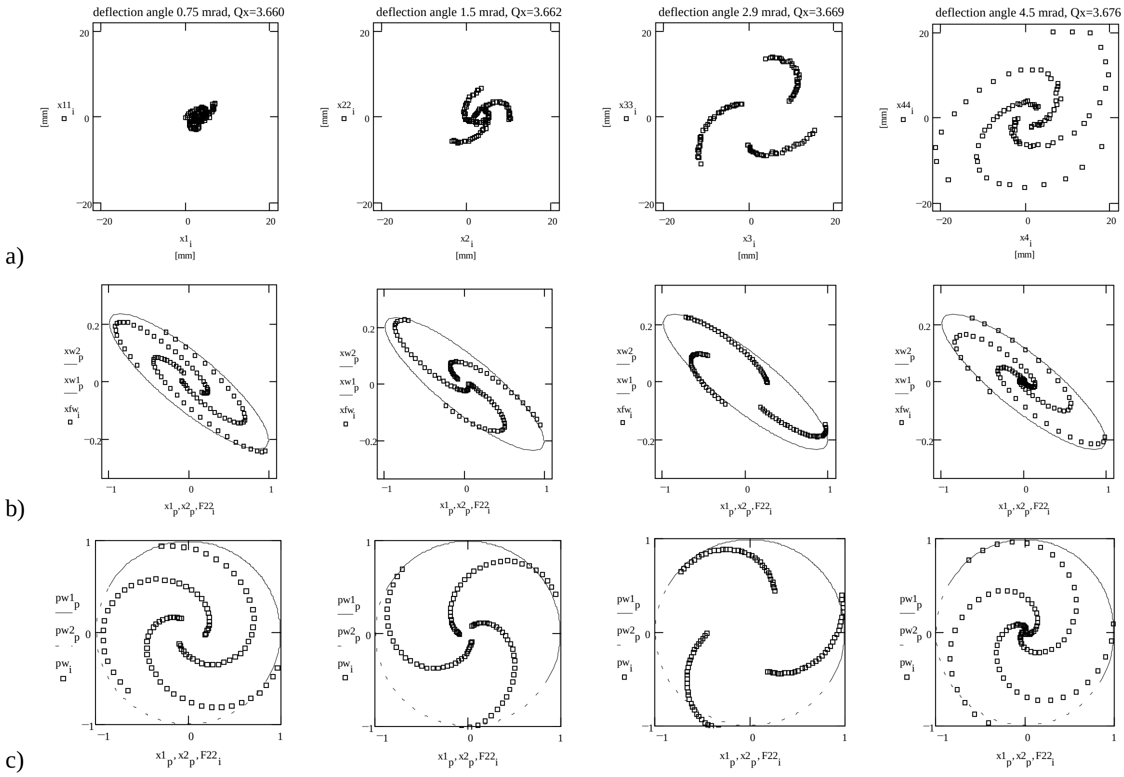

Figure 5: Transverse phase space plots for 4 different kick strengths (deflection angles). In the columns different phase space representations are shown for the same deflection angle (further explanation in the text). Proton momentum is 800 MeV/c.

resonance curve can be estimated to about ΔQ = 0.01. This explains why the results of the large deflection angle of 4.5 mrad are very similar to those with the small deflection angle of 0.75 mrad. Note that in the case of the large deflection angle the tune changes by $\Delta Q \approx 0.02$ and therefore shifts the particles out of the resonance region.

A minimum value of the tune spread was observed when the tune is close to the third order resonance (plot with Q_x = 3.669). This is in contrast to the fact that the betatron motion decoherence time is inversely proportional to the kicked amplitude [6]. In the case of a seventh order resonance an increasing tune spread by increasing kick amplitude was found.

The measured oscillation amplitudes decrease from turn to turn due to Landau damping. If the damping is numerically eliminated for all four cases the thus corrected amplitudes fill a circle with increasing radius as expected. In addition the studies of motion of the beam centroid after collectively perturbing the beam by a fast kicker and using the data of all BPMs yield important information about the lattice [7]. This procedure is also useful in the study of nonlinear beam dynamics. Due to the non-negligible beam size the interpretation of the experimental results is difficult, especially if the beam center is displaced near the separatrix. Some of the particles are stable here, some are unstable. The degree to which the beam centroid motion accurately represents the motion of a single particle depends on the emittance of the beam; the smaller the emittance of the beam, the more accurate is its representation of single particle motion. Further limitations are the decoherence of the betatron motion and the crossing of uncontrollable nonlinear resonances. Work is going on including experiments with cooled beams.

3 REFERENCES

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