A MULTI-TURN MEASUREMENT SYSTEM FOR THE CERN PS

M.E. Angoletta, A.-S. Müller, CERN, Geneva, Switzerland

Abstract

Multi-turn beam position measurements on one or more pickups provide very important information needed to derive machine optics parameters. A variety of analyses is possible, such as determination of phase advance, detuning with amplitude, and most important, the exploration of phase space. In this paper we present a new multi-turn acquisition system for the CERN Proton Synchrotron based on a CompactPCI fast digitiser and a new general object-oriented visualisation and analysis tool for the acquired multi-turn data.

1 INTRODUCTION

The observation of beam centroid motion over many turns is a standard tool in accelerator physics. It allows, for example, to study build-up and damping of instabilities, decoherence and re-coherence of a bunch. If the beam motion is observed at more than one beam position monitor, it is possible to reconstruct the motion in phase space. This is very attractive for many subjects (like topology of resonances) that profit from a good knowledge of transverse phase space. Studies in the framework of the new continuous transfer [1] showed the need for a new, flexible system to study multi-turn behaviour of a beam bunch after an excitation.

To cover a wide range in synchrotron tune and to acquire over as long a time as possible (for example to study periodic disappearance and reappearance of the beam's centre-of charge signal), one needs a high sampling rate and sufficient memory for each acquired signal. The new system is based on an Acqiris DC625 fast digitiser, that can sample synchronously several channels at frequencies up to 500 MHz, with a per channel memory of 2 Msamples. Data of two pick-ups can be acquired simultaneously. For each monitor, horizontal and vertical Δ and Σ signals are available (see [2] for a detailed description).

Two separate software packages have been developed: the Control and Processing (CaP) program on a PC running Windows 2000, connected to the fast digitiser, and an analysis toolkit (KiTA – Kilo Turn Analysis) on a Linux system.

CaP carries out two tasks. First, it controls the fast digitiser through its graphical user interface. This enables the user to set up the digitiser, arm it for an acquisition and retrieve data. Second, it processes digitised data to obtain the true beam position at each turn. The KiTA toolkit provides visualisation of the CaP output data and interactive analysis functions. A variety of analyses are possible (e.g. time series).

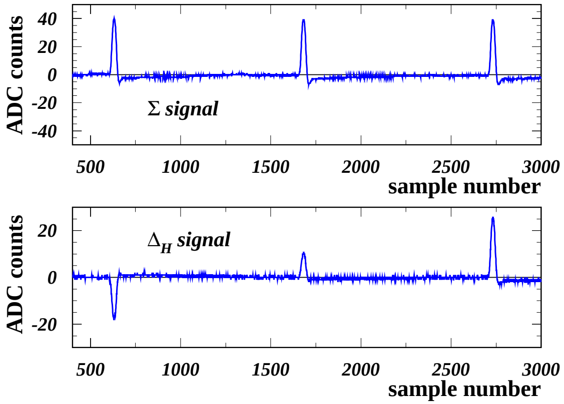


Figure 1: Sum signal and horizontal difference signal in ADC counts as a function of the sample number over a range of about two turns. The magnitude variation with revolution is clearly visible on the Δ_H signal.

The interface between CaP and KiTA is implemented via a plain ASCII file. In this file, beam intensity (sum signal) and horizontal and vertical displacement for each connected pick-up are stored for each acquired turn. A header part includes measurement conditions, such as the names of the connected pick-ups, the beam user and the timing of the trigger.

2 CONTROL AND PROCESSING (CAP) PROGRAM

The CaP program is written in VisualC++ and uses the Acqiris DC265 driver for Windows. In the following, an overview of the two tasks carried out by CaP is given. A detailed description of its capabilities and how to use it can be found in [3].

2.1 Fast Digitiser Control

The fast digitiser is used in continuous sampling mode, where each of the six input channels is sampled until the whole memory associated with that channel is filled. The sampling frequency used is 500 MHz. This allows to acquire and store data for 4 ms, corresponding to about 2000 beam revolutions. Data are acquired by the fast digitiser as outputs of the 8-bit ADC, thus taking integer values between -128 and +127.

The fast digitiser is armed by the CaP program and expects to receive an external trigger to start an acquisition. Furthermore, the CaP program sets a timeout, so that the fast digitiser gets un-armed if the trigger signal is not received within the specified time window. All selected channels are sampled synchronously after the reception of one trigger pulse. For a quick assessment of the acquired data, these can be displayed graphically. Figure 1 shows typical signals acquired with the CaP program.

2.2 Data Processing

Information about the true beam position at each turn is obtained in two steps. First, data referring to the passage of the beam near the pick-up are extracted from all digitised data. In fact, Fig. 1 shows that there are only about 50 meaningful samples out of the 1000 samples acquired at each turn. Second, the extracted data are integrated and baseline-compensated. For the first step, a peak-search algorithm was implemented to extract turn-by-turn bunch data, due to the revolution frequency oscillations. The user can graphically select the observation window for all turns and the position of the bunch within. It is then possible to scan on a turn-by-turn basis all Σ, Δ_H and Δ_V data for each pick-up. The software also accounts for the different arrival times of the beam at each pick-up.

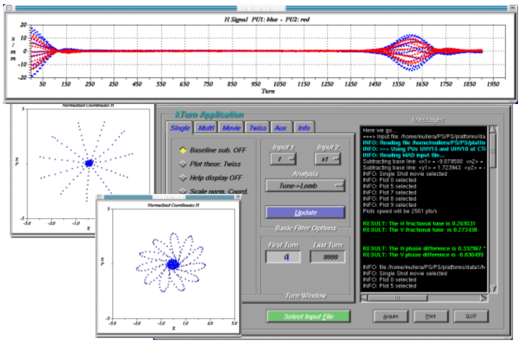
The final signal is the time integral over the observation window with baseline subtraction. The user can select whether the tail of the bunch is included in the integration. If this is not the case, the integration is stopped as soon as the bunch tail drops below the baseline value. Integrated Δ_H and Δ_V data are divided by the integrated Σ, referred to as Σ_i (“beam intensity”). They are then multiplied by a conversion factor that depends on the pick-up amplifier gain. In this way, one obtains horizontal and vertical displacement, indicated as $\Delta_{H\,i}$ and $\Delta_{V\,i}$ respectively.

3 ANALYSIS TOOLKIT

The X-Application KiTA running under the Linux operating system provides the tools necessary to perform a first analysis of the acquired data. It is written in C++ and makes use of the Forms library [4] to build a Graphical User Interface (GUI). The ASCII output of the CaP program to be read in can be selected by the user with a file selector. The program also reads in the output of a MAD [5] OPTICS command and stores the optics functions for the connected pick-ups. The MAD reference used is also user-defined. Several types of analysis can be selected and data can be displayed in various representations. Figure 2 shows a screen shot of the analysis toolkit with main form, representations of the measured beam position at two pick-ups as a function of turn, and the reconstructed horizontal phase space for different turn ranges in normalised coordinates (X, X') [1].

3.1 Graphics Implementation

The application program enters the GUI’s X-event loop at start-up after a general initialisation with default input files (e.g. MAD description of the PS machine). The various functionalities are implemented in different dedicated classes. Data representation is done either with the HPLOT/HIGZ [6, 7] packages or with the Forms library’s plotting facilities, depending on the use. For output using XForms plot utilities, a system independent plot speed selection has been implemented. This makes it possible to watch for example the crossing of a resonance in a selected representation, with a specified number of points (measurements/turns) per second (a turn counter tracks the progress). To achieve this, the plotting has to be done in X idle call-backs, closely monitoring the X-server’s state.



```
Here we go...
===> Input file: /home/mullera/PS/PS/platforms/da
INFO: Reading file /home/mullera/PS/PS/platfo
INFO: ==> Using PUs UHV15 and UHV10 at CT
INFO: Reading MAD input file...
Subtracting base line: <x1> = -9.079500  <x2> = 
Subtracting base line: <y1> = 1.723943  <y2> = 
INFO: Single Shot movie selected
INFO: Plot 0 selected
INFO: Plot 5 selected
INFO: Plot 7 selected
INFO: Plot 8 selected
INFO: Plot 9 selected
Plots speed will be 2501 pts/s

RESULT: The H fractional tune is 0.269531
RESULT: The V fractional tune  is 0.273438


RESULT: The H phase difference is 0.332967 *
RESULT: The V phase difference is -0.830499

INFO: file /home/mullera/PS/PS/platforms/data1/
INFO: Single Shot movie selected
INFO: Plot 0 selected
INFO: Plot 5 selected
```

Figure 2: Screen shot of the KiTA toolkit with main form, representations of measured horizontal beam centre-of-charge position at two pick-ups as a function of turn and reconstructed normalised phase space for different turn ranges (0–250 and 1450–1850, respectively).

3.2 Physics and Analysis Functions

This section gives a very brief overview over the different analyses possible with the KiTA toolkit. The current functionality of the application will be extended in the near future, for example to allow 3D plotting. The available features include base line subtraction, time series tools (e.g. FFT or Lomb Normalised Periodograms – “LNP” [8, 9]), reconstruction of physical or normalised phase space and representations in action/angle coordinates, as well as chromaticity determination with least squares fits. All analyses can be performed on the full dataset or on selected sub-sets. The base line is estimated from the average of the measured centre-of-charge positions in the full range and its subtraction can be enabled or disabled. The time series analyses can be performed on all input signals ($\Delta_{H\,i}$, $\Delta_{V\,i}$ and Σ_i of both connected pick-ups) which can be very useful for the investigation of intensity variations that would show up on the Σ signal. The amplitude and phase information obtained from regular FFT is reported in the application’s message browser and the corresponding power spectrum is displayed. The automatically determined phase difference between the two connected pick-ups can be selected to be used for the reconstruction of transverse phase space. By default, the phase difference obtained from the MAD reference is used. The phase differences determined with this utility under different machine conditions can be used to test the modelling of the PS [10].

Since it is not as widely known as FFT, we will give here a short summary of the principles underlying Lomb’s method for harmonic analysis. Lomb’s method performs a harmonic analysis of an arbitrary data sample without any constraints on the number of data points and the sampling times, in contrast to the well established FFT. It weights

---

[1] related to the physical coordinates (x, x') by $X = x/\sqrt{\beta_x}$ and $X' = \sqrt{\beta_x}x' + \alpha_x x/\sqrt{\beta_x}$ with α_x and β_x the Twiss parameters.

the data on a "per point" basis instead of on a "per time interval" basis like FFT methods. For N data points h_i measured at times t_i the so-called Lomb normalised periodogram $P_N(\omega)$ is defined by

$$\begin{aligned} P_N(\omega) \;=\; & \frac{1}{2\sigma^2}\,\frac{\left[\sum_j\, d_j\, \cos\left(\omega(t_j-\tau)\right)\right]^2}{\sum_j\, \cos^2\left(\omega(t_j-\tau)\right)} \\ +\; & \frac{1}{2\sigma^2}\,\frac{\left[\sum_j\, d_j\, \sin\left(\omega(t_j-\tau)\right)\right]^2}{\sum_j\, \sin^2\left(\omega(t_j-\tau)\right)} \end{aligned} \qquad (1)$$

with

$$d_j = h_j - \frac{1}{N}\sum_{i=1}^{N} h_i, \qquad \sigma^2 = \frac{1}{N-1}\sum_{i=1}^{N} d_i^2,$$

$$\text{and} \qquad \tan\left(2\omega\tau\right) = \frac{\sum_j \sin\left(2\omega t_j\right)}{\sum_j \cos\left(2\omega t_j\right)}.$$

This implies that for any test frequency ω the content of that frequency in the given dataset is evaluated. The constant τ is constructed to make the value $P_N(\omega)$ independent of the phase of the original harmonic. In contrast to the regular FFT, the LNP method yields only the tune power spectrum and no phase information. This has the advantage of a faster convergence, since the full number of data points can be used for the frequency analysis. Furthermore there is no restriction for the input number to be a power of two. As a result, LNP can distinguish close frequencies even if the number of points is not sufficient for FFT to resolve the difference. The output of such a LNP analysis is shown in the form of a histogram, and peak values are reported with their estimated significance level in the application's message browser.

For the reconstruction of the phase space portrait from measured centre-of-charge bunch positions of two arbitrary connected pick-ups, the optical functions for the respective MAD elements are read from the output file of a MAD OPTICS command. The MAD file is user-selected, so a direct comparison of measured phase advances between two pick-ups with the model is possible. The physical phase space portraits are obtained from the coordinates by transforming the second pick-up's x into an x' at the first pick-up's location, using measured or calculated phase advance and the acquired optics functions. Therefore phase space reconstructions are possible for arbitrary pick-up combinations, not only for a 90^o phase difference. The normalised phase space portraits are derived from the physical ones using the selected optics functions. The theoretical phase space ellipses can be overlaid for a 1 μm emittance at 2 σ. Action–angle coordinates can be trivially calculated from the representation in normalised coordinates and displayed in various combinations with other observables. All results obtained with the application can be saved in user-named postscript files (see Fig. 2).

Under special conditions, for example when a signal de- and re-coherence takes places as in Fig. 2, KiTA allows to extract the chromaticity $Q' = \xi/Q_x$ with a fit to the acquired data of a model describing centroid motion in the presence of momentum spread and non-linearities [11]. The initial tune is determined with LNP from the first 100 turns; the external input parameter momentum spread is measured independently. The resulting Q' is reported to the message browser together with its statistical uncertainty scaled for a χ^2 per degree of freedom of one.

4 SUMMARY AND OUTLOOK

For many problems in accelerator physics, multi-turn studies are a vital tool. In 2001, a new acquisition system was installed in the CERN PS, based on a fast digitiser, and software packages were developed to handle and steer the data taking and provide an interactive analysis tool. The first phase of the project has been successfully completed; the system was used for data taking and analysis [10]. In order to avoid sampling data outside the interesting signal region and thus to increase the number of acquired turns to 10^5, a burst mode operation is envisaged for 2002.

5 ACKNOWLEDGEMENTS

Many thanks to all who have contributed to the work presented above and in particular to J. Belleman, R. Cappi, V. Chohan, M. Giovannozzi, J.-L. Gonzalez and M. Martini for help, inspiration and interesting discussions.

6 REFERENCES

[1] R. Cappi and M. Giovannozzi. Novel Method for Multi-Turn Extractions : Trapping Charged Particles in Islands of Phase Space. CERN/PS 2001-015 (AE), CERN, 2001.

[2] M. E. Angoletta et al. First Experience with a New Multi-Turn Beam Position Acquisition and Analysis System of the PS. CERN PS/AE Note, 2002.

[3] M. E. Angoletta. CaP User's Manual - Control And Processing program for the Acqiris DC265 Digitizer. CERN PS Note, 2002. In preparation.

[4] T.C. Zhao, Mark Overmars. Forms Library – A Graphical User Interface Toolkit for X. See *http://world.std.com/∼xforms/*, 1995.

[5] H. Grote and F. C. Iselin. The MAD Program, User's Reference Manual. SL Note 90-13 (AP) (Rev. 4), CERN, March 1995.

[6] H. Watkins. Hplot: the graphics interface package for the hbook histogramming package. CERN 78-06, 1978.

[7] R. Bock et al. Higz – high level interface to graphics and zebra. CERN program library Q129, 1988.

[8] N.R. Lomb. In *Astrophysics and Space Science*, volume 39, pages 447–462. 1976.

[9] W.T. Vetterling W.H. Press, S.A. Teukolsky and B.P. Flannery., editors. *Numerical Recipes*. Cambridge University Press, 1992.

[10] M. E. Angoletta et al. Analysis of Multi-Turn Beam Position Measurements in the CERN PS. In *these proceedings*, 2002.

[11] R. E. Meller et al. Decoherence of kicked beams. SSC-N-360, 1987.