TURN BY TURN MEASUREMENTS AT DAΦNE BASED ON THE LIBERA BEAM POSITION PROCESSOR

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Abstract

The BPM detection electronics Libera, developed by Instrumentation Technologies implements digital receivers technology to measure the beam position from the amplitude of pick-up signals. Besides the average closed orbit mode, the Libera module can be operated also in the *Turn by Turn* mode. Operational experience with Libera at the e+ e- collider DAΦNE has been initially focused on this functionality. Data obtained from DAΦNE are processed with well established extraction algorithms to accurately measure the betatron tunes from a small number of turns, providing instantaneous information on tune variations occurring even during fast damped decays after a kick. Hardware and software implementation together with experimental data are reported.

INTRODUCTION

The e+/e- collider DAΦNE consists of two symmetrical storage rings at 1.02 GeV centre of mass energy, sharing a common vacuum chamber in each of the two interaction regions.

The 120 RF buckets of each ring are spaced by 2.7 ns. The design single bunch current is 44 mA (achieved > 200 mA) and, during operations for collisions up to 109 consecutive bunches of ~ 15 mA are typically stored. The total stored current is of the order of ~1 A. Other bunch patterns are sometimes used for machine studies.

Pickup signals from a beam position monitor (BPM) installed in the positron ring have been connected through 50 m long coaxial cables to a Libera Electron board [1]: RF signals are processed in the analog stage for filtering and gain adjustment, then sampled, down-converted using an under-sampling technique, and digitally filtered.

The beam position monitor used for this evaluation has four button electrodes placed symmetrically around a circular vacuum chamber of 44 mm radius.

Beam position is deduced onboard by comparing amplitudes between the sampled signals. The module provides several parallel data paths with different measurement bandwidths.

TURN BY TURN MEASUREMENTS

The frequency spectrum around the RF harmonic of the revolution frequency f_0, which is the line present in DAΦNE with every possible bunch pattern, is selected for sampling by Libera in the BPM signals.

The device supports *Turn by Turn* (TBT) measurements of beam position with a bandwidth of $f_0/2$. Once triggered, Libera stores up to 200k samples in a memory buffer and, on demand, provides it to the user.

An embedded single board computer (SBC) is equipped with a Linux operating system. It provides the platform for the software routines used for configuration, operation and diagnostics, and can be accessed across the Ethernet network through the TCP protocol.

Dedicated software, which has been developed on a remote host running the Matlab package, accesses the SBC at the application level using the SSH protocol, to control the data acquisition, collection and processing.

To test the TBT acquisition, data have been collected in different operating conditions and post-processed with the analysis tools developed with Matlab.

The resolution of the measurements performed with the DAΦNE BPMs changes with beam stored current as shown in Fig. 1. The product resolution times beam current is ~0.8 mm·mA, constant for total currents below ~35mA; beyond this threshold the onboard RF input attenuators must be used to expand the dynamic range.

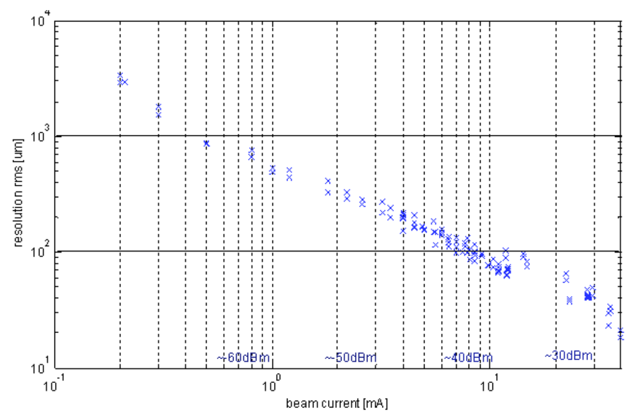


Figure 1: TBT resolution vs. beam current.

The device can operate also for a single beam passage. Figure 2 shows results obtained by injecting a single bunch of 1.5 nC into the positron ring while the RF cavity is switched off, so to simulate a condition occurring after a major shutdown or hardware modifications, when the beam is not yet stored. Measurements of the first turns of the bunch, characterized by large betatron oscillations, are recorded until the whole charge is lost.

Tune Measurements

The betatron tune Q can be measured by sampling for N turns the transverse position of the beam coherently oscillating and performing the FFT of the stored data to detect the frequency of the oscillation.

The stored beam is shock excited with a kicker magnet. A trigger signal, generated a few μs before the shot, is provided by the accelerator control system to Libera to start the acquisition of beam position.

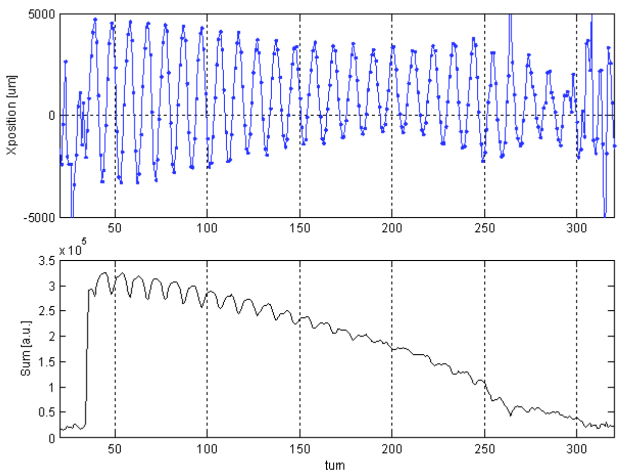


Figure 2: First turns data without RF: radial beam position (top) and sum of pickup signals (bottom) vs. turns.

Figure 3 (top) shows a typical damped betatron oscillation of the radial beam position to the pulse of the injection kicker.

The decay time is considerably shorter than the incoherent radiation damping time (110 kturns) because of the head-tail damping and of the decoherence induced by the nonlinear terms of the optics.

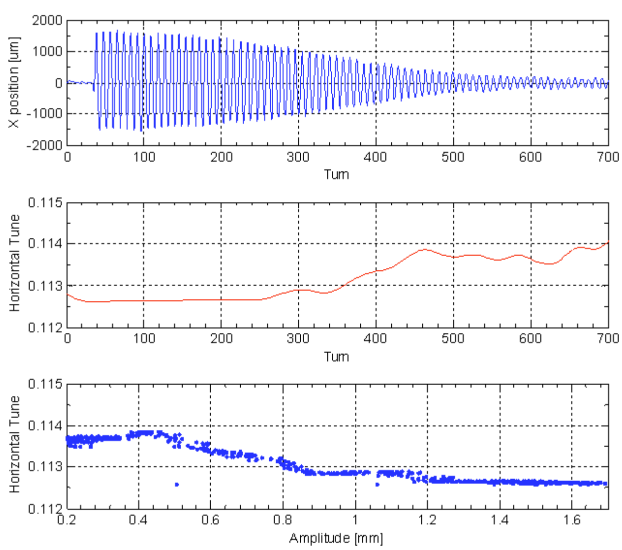


Figure 3: Radial beam position oscillation and horizontal tune measurements after a kicker pulse (beam current I_b~10mA).

This fast decay limits the number of turns *N* during which the beam oscillation can be measured. The resolution of tune measurement based on a simple FFT is proportional to 1/N and has been enhanced:

- by improving the accuracy of the Fourier analysis using Hanning window filters,
- by interpolating the shape of the spectrum around the main peak with the continuous spectrum of a pure sinusoidal signal.

The error associated to this method is in principle proportional to $1/N^4$ in the absence of noise.

Tunes are computed with the following interpolation formula [2]:

$$Q = \frac{k}{N} + \frac{1}{2\pi}\arcsin\left[A\left(\phi_k, \phi_{k+1}, \cos\frac{2\pi}{N}\right)\sin\frac{2\pi}{N}\right] \qquad (1)$$

where the function *A* is given by:

$$A(a,b,c) = \frac{-(a+bc)(a-b)+b\sqrt{\Delta}}{a^2+b^2+2abc} \qquad 2)$$

and

$$\Delta = c^2(a+b)^2 - 2ab(2c^2-c-1) \qquad (3)$$

ϕ_k and ϕ_{k+1} are the two values of the FFT amplitude spectrum with larger amplitudes.

The horizontal betatron tune values in Fig. 3 have been extracted by the above algorithm, from consecutive blocks of *N*=128 turns and are shown vs. turn number and vs. oscillation amplitude (deduced from the magnitude of the Hilbert transform of the beam position data). Evaluation of the tunes over a sliding window of *N* turns, rather than on the whole set of data, allows measuring an amplitude dependent tune shift.

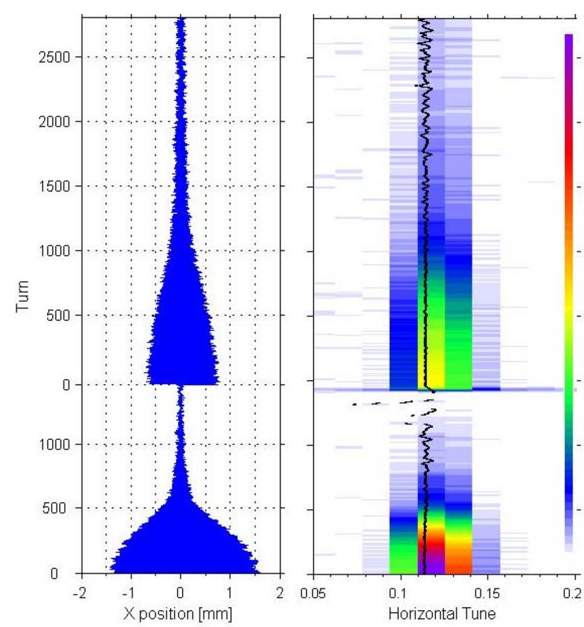


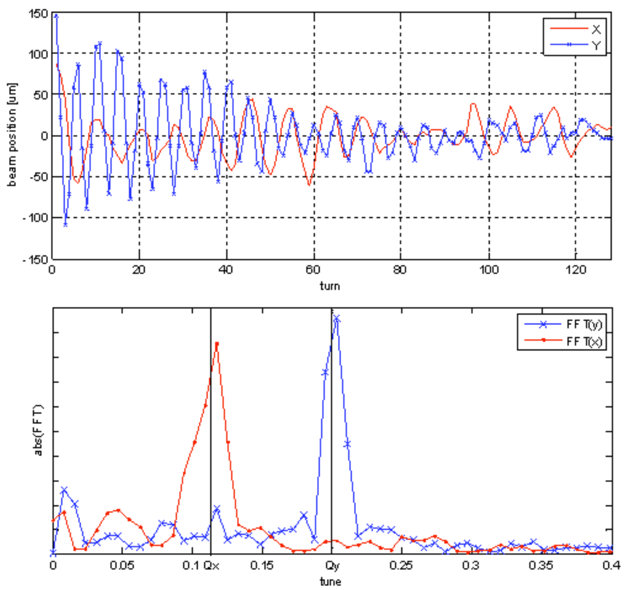
Figure 4: Horizontal beam position vs. turns and spectrogram with interpolated tune value (N=64) for two kicks of different amplitudes.

In Fig. 4 (left), radial response of the beam to two kicker pulses, whose second amplitude is halved with respect to the first, have been collected.

In the right figure we show the spectrogram of the FFT amplitude of each block of consecutive *N*=64 turns together with the tunes computed using the interpolation technique on the same block of data. The tune obtained with the interpolated data is plotted (black trace) on the plain FFT spectrogram to show the finer accuracy.

The residual betatron oscillations excited by the injection kick, have been acquired to evaluate the tune values during normal collider operation.

Figure 5 (top) reports the horizontal and vertical beam position together with the plot of the magnitude of the FFT and the interpolated tune values Q_x, Q_y over N=128 turns following an injection pulse in the positron ring..



Figre 5: Tune measurements during beam injection.

An amplitude oscillation in the vertical plane has been also observed, probably due to an initial vertical angle of the injected beam and/or to an uncompensated vertical kick component.

Effect of noise on tune evaluation

The effect of the finite resolution of the turn by turn measurements reduces the precision by which the tune is determined with the interpolating procedure.

A bench test has been performed to evaluate how the errors affect the tune reconstruction, in order to characterize the measurements obtained with the DAΦNE beam. To simulate the beam signals coming from the BPM pickups during a betatron oscillation, Libera has been connected to CW signals at f = 120f_0, generated by an oscillator. One of the four inputs has been amplitude modulated with a frequency Δf variable in the 0 ÷ $f_0/2$ range. Power levels of the carrier and of the modulation signal have been adjusted to reproduce the spectrum of the DAΦNE beam signal with current in the 0.1-1000 mA and oscillations of ~1000 μm.

Turn by turn data acquired by Libera, locked with a clock signal to the nominal frequency of 120f_0, have been post processed with the described algorithm to compute the frequency of the modulating signal, so to simulate a tune measurement.

In Fig. 6 we report results obtained for different signal to noise ratios, equivalent to different ratio between beam current and amplitude of the beam oscillation, so to estimate the resolution of the tune measurements computed over blocks of N data.

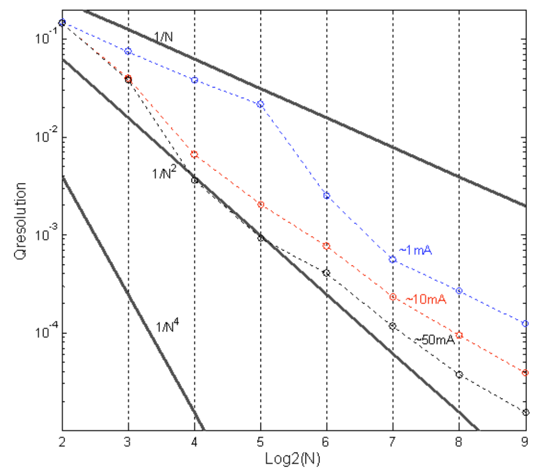


Figure 6: Expected tune measurements resolution based on N turns at beam currents corresponding to Signal/Noise ratios of ~ 2, ~ 15, ~ 100.

Due to the noise, the precision of the tune is reduced but scales always better than 1/N, which should be associated with an extrapolation based on a plain FFT.

SUMMARY

The Libera TBT acquisition mode has been tested in DAΦNE at different working conditions. An interpolating technique has been applied to extract betatron tunes from experimental data. Beam results have been complemented by bench tests.

The development of software dedicated to control, management and data analysis, turns Libera into a useful tool for beam diagnostics during both collider operation and machine studies.

ACKNOWLEDGMENTS

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REFERENCES

[1] Instrumentation Technologies, “Libera Electron User Manual", 2006.

[2] R. Bartolini et al., “Tune Evaluation in Simulations and Experiments”, Particle Accelerators, 1996, Vol. 52, p. 147.