NEW TUNE MEASUREMENT SYSTEM FOR THE ESRF BOOSTER

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Abstract

The injection of electrons in the ESRF storage ring is performed at full energy, i.e. 6GeV. A linear accelerator provides the booster with a beam at an energy of 200MeV. During the accelerating cycle of the booster, from 200MeV to 6GeV, the tune of the electron beam varies according to the no-proportionality of the magnetic field in the quadrupole magnets as compared to the dipole field. This is mainly due to the harmonic content of the current in the magnets which differs with the load of these systems resonating at 10Hz and their saturation level. In order to measure the fractional part of the tunes all along the accelerating cycle, (50ms) it is necessary to acquire the beam position at a rate of at least one sample per turn, each µs. A set of 48 tune values can be extracted from this record with an accuracy of better than 10^{-3}.

INTRODUCTION

The measurement of the tune of the booster has been made automatic in the last few years, but due to the fact that the beam is excited with short kicks, it is only possible to obtain one measurement per accelerating cycle. To build the curve of the tune, we have to re-construct it point by point by delaying the excitation from the injection time. With an injection rate of one second and an average of a few data per point, it takes a few minutes before the curve for the full cycle can be established and the different points do not belong to the same cycle. Therefore, it was decided to use a white noise excitation present all along the cycle, and an acquisition system that can compute the tunes for the whole accelerating cycle in one go. Although this system is not already in operation, the first tests have shown that it works as expected. In addition to the increase in the tune measurement rate, it will be possible to add new features like the automation of the chromaticity measurement.

SYSTEM LAYOUT

Excitation of the Beam Oscillation

We excite the beam oscillation using magnetic kickers; these kickers are made of 6 coils enclosed in a ferrite box, with a ceramic vacuum chamber surrounding them. The kickers have a 0 to 600 KHz bandwidth when terminated on a 50Ω load and an efficiency of 3 G.m/A. The kickers are driven by a 50W amplifier. The input signal is a white noise in a bandwidth from 0 to 500 KHz.

Analog Front End

The beam position is measured using 2 sets of 4 capacitive pick-ups. The sensitivity of the electrode is improved by using resonant RF transformers to match the pick up capacitance to the 50Ω line impedance. The electrode signals are combined in ΔΣ RF combiners to produce signals proportional to the horizontal and vertical beam offset and beam intensity.

The pick up signals are detected using a 2 stage synchronous detection electronic scheme: The first stage is a 352.2 to 10.7MHz down converter. The second stage is a synchronous vector detection circuit of the Δ signal; the reference signal is the output of a limiting amplifier fed by the Σ signal. This scheme aims at getting the best signal to noise ratio rather than good position accuracy, which is pointless in a tune measurement.

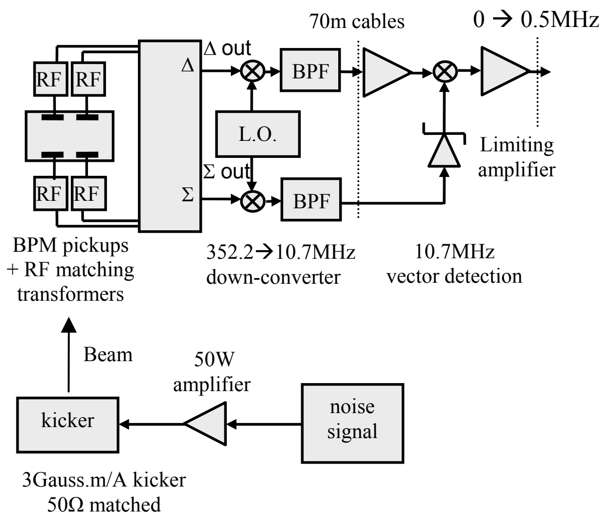

Figure 1: Analog front-end

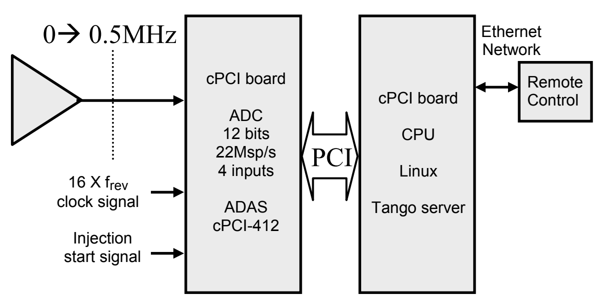

Figure 2: Digital acquisition & processing hardware

Computing

The positions are digitised by using one 12 bit acquisition board able to store a large amount of data at a rate up to 22Msample/s. Over-sampling by a factor 16 is used to enhance the signal over noise ratio. The data buffer is then transferred to a CPU that processes it to produce the results.
A tango server [3] running on a compact PCI CPU under Linux performs all the tasks required for the data processing. New data buffer is available every 2 seconds. A remote application will be developed to access and display the results requested by the operator. The tests have been made with a generic application available for any tango server that allows the commands to be launched and to display the results in several ways:

1) One tune spectrum at any time in the accelerating cycle.
2) A curve representative of the tunes along the accelerating cycle.
3) A three-dimensional picture displaying the spectra amplitude along with the measurements.
4) An array filled with all the data for one cycle.
From the generic application, it is possible as well to set the parameters, averaging number, measurement plane, index for spectrum and a Boolean to position in which part of the spectrum the tunes are, < 0.5 or > 0.5

DATA PROCESSING

Tunes

The method used is based on a Fourier transform of the transverse oscillations of the beam in the booster. The signal from the Beam Position Monitor block representative of the vertical and horizontal position is acquired at the rate of 16 samples per revolution. Whilst one sample per turn is enough to cover the frequency range of Frevolution/2 necessary to analyse the tunes with a full span, we took advantage of the possibility of over-sampling to increase the signal over noise ratio.
The system average the data over 16 samples and group the result in 1024 data long buffers. Then, each buffer is windowed by a Hanning window and processed with a fast Fourier transform. The resulting amplitude spectrum can be averaged with those from the previous cycles. A second-order interpolation is then performed in the area where the signal is maximum; the gain in accuracy depends, however, on the level of noise present on the signal. From each spectrum a peak detection is made, representative of the value of the tune. As the beam oscillation is maintained throughout the energy ramping by a shaker driven by white noise, it is possible to obtain as many points as we need along the accelerating cycle. We found a compromise between the number of points versus the frequency resolution and the choice was made to use contiguous buffers of 1024 data each. The full accelerating cycle is covered with about 48 points for 50ms. A compact numerical result is produced with a set of 48 data per plane and per cycle.

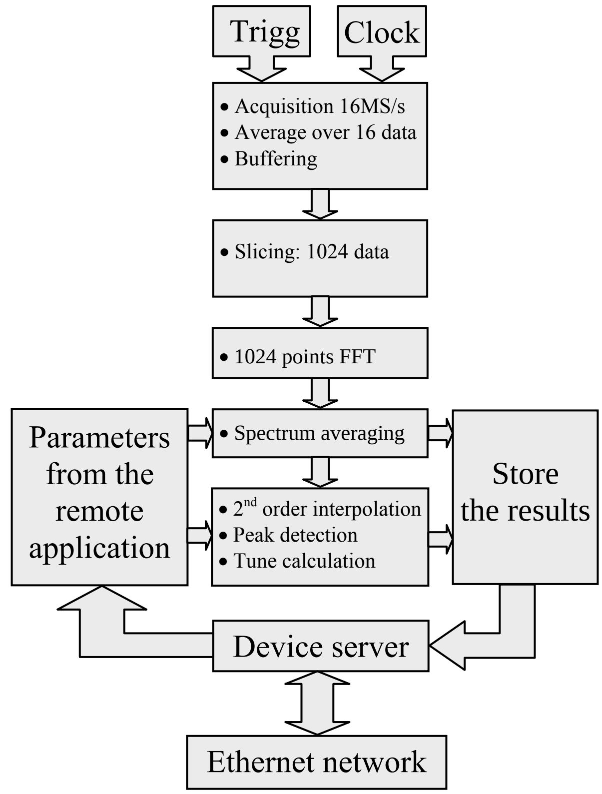

Figure 3: Signal acquisition & processing

Possible Enhancements

The fact of using a system dedicated can be useful in removing spurious frequency lines by including very specific functionalities:

1. Extending the analysis to a span of twice the range required, the frequencies that are not present at the same time on the signal and its image[4] can be disregarded.
2. Subtracting the background obtained without excitation, only the resonance frequency shows-up with a high signal over noise ratio[4].

Another point concerning the oscillation excitation is the rather wide energy range to cover; it can be difficult to find a compromise that gives the right shaker strength for the whole accelerating cycle. Too much strength will induce beam-losses at low energy and a too little will not allow the measurement to reach full energy. Therefore, strength proportional to the energy would be a solution to optimise excitation.

Chromaticity

Automatic measurement of the chromaticity will be envisaged by changing the booster RF frequency between two accelerating cycle and sequentially record the tunes with and without this change.

The averaged results will be processed to give an image of the behaviour of the chromaticity along the accelerating cycle.

MEASURMENT RESULTS

The measurements shown here (Fig.4 & Fig.5) have been plot under Matlab from data arrays (512 x 48) processed by the system.

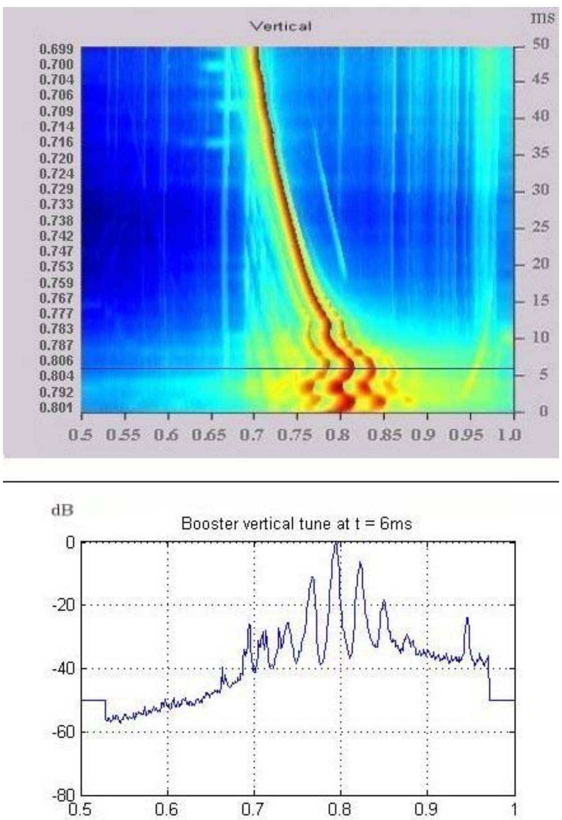

Figure 4: 3-D view of the spectra of the vertical motion during the acceleration cycle and below, one spectrum 6ms after injection

CONCLUSION

By taking full advantage of the use of an acquisition set-up already integrated in the control system and set-up for other purposes, it was possible in a short time to develop the server gathering the functionalities and to demonstrate that the results correspond with the requirements.

As compared with the previous system, the faster measurement rate brought by this system will be a great improvement for all the experiments involving booster tune measurements. A specific application will be developed soon to cover all functionalities in addition of those already available with the generic application.

Both excitation (shaker) and measurement (BPM) planes are switched between horizontal and vertical plane to obtain independent measurements.

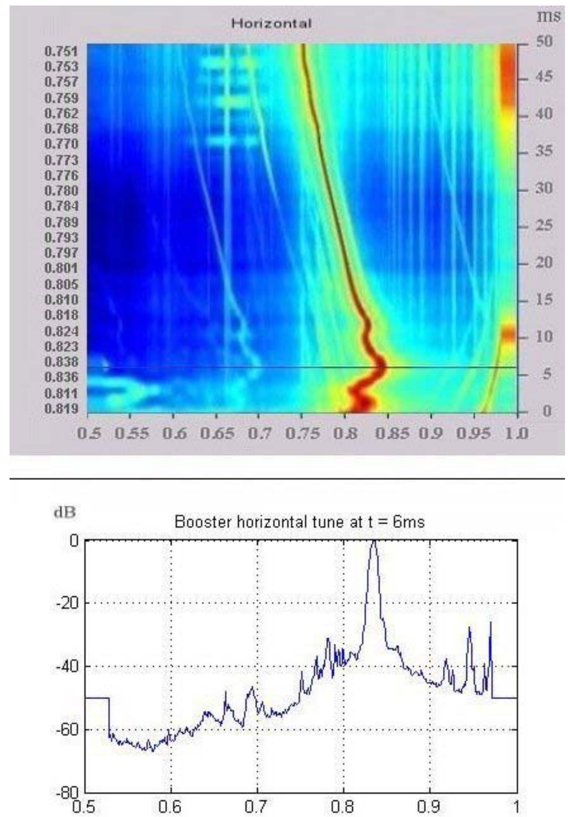

Figure 5: 3-D view of the spectra of the horizontal motion during the acceleration cycle and below, one spectrum 6ms after injection

ACKNOWLEDGEMENTS

We would like to thanks Y. Papaphilippou, N. Michel and our colleagues from the Computing Services.

REFERENCES

[1] J.P. Koutchouk, Advanced diagnostics of lattice parameters in hadron colliders. IT10 Dipac 2003, Mainz.

[2] S. Bassanese et al., Fast tune measurement system for the Elettra booster. PT25 Dipac 2003, Mainz.

[3] TANGO, an object oriented distributed control system. http://www.esrf.fr/Infrastructure/Computing/tango

[4] J.M. Koch, Use of DSP based systems at the ESRF (2.2 - Fast tune monitor). Dipac 1997, Frascati