

# BUNCH BY BUNCH CURRENT AND LIFETIME MEASUREMENTS AT DAΦNE

A. Stella, G. Di Pirro, A. Drago, M. Serio, INFN-LNF, Italy

## Abstract

A dedicated system, based on digital sampling of beam signals with a commercial oscilloscope, has been developed to measure bunch by bunch current in the DAΦNE collider. It provides an automated tool to equalize bunch filling patterns in the main rings. Individual bunch current and lifetime are simultaneously computed from the sampled data, collected at a 4Hz rate and provided via ethernet to the accelerator control system to control individual bunch injection. System hardware and software data processing are reported, together with performance and results of the measurements obtained during DAΦNE operation.

## INTRODUCTION

In the electron-positron collider DAΦNE, the two symmetric rings can be filled with different patterns of maximum 120 bunches, spaced by 2.7ns and with a typical charge of  $1 \div 10$ nC. Storage of an equal charge in each bunch is crucial to optimize the luminosity.

By monitoring beam induced signals from wide band pickups the less charged buckets are selected for the next cycle of injection in order to obtain an even fill pattern.

This system provides to the accelerator control system an automated tool to perform this task; it is routinely used during the machine runs, being very useful and effective to maintain the average luminosity high and to increase the collider efficiency.

## HARDWARE

Sum signals from two beam position monitors (BPMs) installed in the electron and positron ring, are connected to a digital sampling oscilloscope Agilent Infinium 54832B (4GS/s real time sampling rate, 1GHz bandwidth) [1], through a 60m long coaxial cable (Andrew Heliax FSJ-50).

Electrodes used as pickups are of the *button* type with capacitance  $C_b=3.5$ pF showing a high pass frequency response. The transfer impedance is that of a time differentiator for frequencies  $f \ll 1/(2\pi R_0 C_b)=910$ MHz and of a resistor in the upper frequency range [2].

Each bunch induces a bipolar pulse signal in the button electrodes, whose peak to peak amplitude is proportional to its current. The system bandwidth, including the cable, is such that the peak-to-peak voltage is proportional to the bunch charge irrespective of the bunch length: in our case rms bunch length is less than 200 ps under all conditions.

The bunch pattern of the stored beam current will result, at the end of coaxial cables, in trains of pulses attenuated and stretched by the transfer function of the cable (Fig.1).

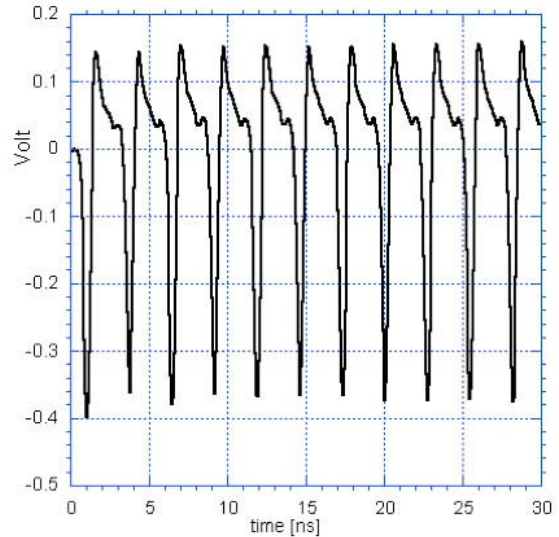


Figure 1: Detail of raw BPM signal waveform.

Due to the lack of DC response of the pickups, the resulting signals display also a significant drift of the base line which must be taken into account during data processing.

The digital oscilloscope samples the whole train of pulses both for electron and positron beams, with a 1GHz analog bandwidth (Fig. 2).

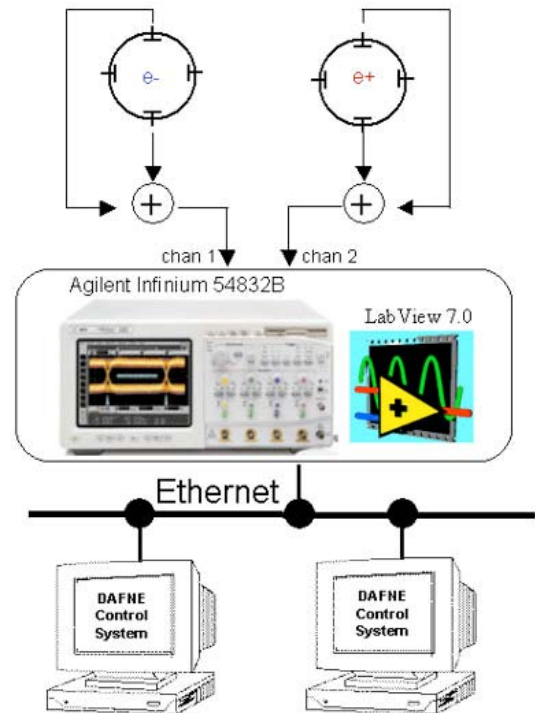


Figure 2: System block schematic.

The resulting waveform, as displayed from the digital oscilloscope, is acquired point by point and software processed to extract the bunch current through peak amplitude measurements of each pulse.

## DATA ACQUISITION

Interfacing of the digital oscilloscope with the DAΦNE control system has been realized with a client-server architecture through the TCP/IP protocol.

### Server Software

A LabView application, running on the Windows XPpro platform integrated in the Agilent digital scope, works as server.

The server runs in multitasking with the software process provided with the instrument, which controls and manages the oscilloscope. Interaction with it occurs through VISA, the high-level application programming interface widely used to communicate with instrumentation buses [1].

It has been developed to perform the following tasks:

- Setting up of the desired working parameters for the acquisition in connection with the current beam signal characteristics: i.e. sampling rate, acquisition mode, vertical and horizontal scale, channel selection, trigger, etc.
- Collecting the two arrays of data sampled by the scope, representing the electron and positron beam signal waveforms, at fixed intervals of time, through calling of GPIB standard library.
- Sending to the accelerator control system through a TCP/IP connection, upon client request, the two arrays of data together with a time stamp generated by the instrument CPU, identifying when the acquisition has been performed.

### Client Software

The client software, fully integrated in the accelerator control system environment, is developed in LabView for Unix Solaris O.S.; it asks to the server for data containing the sampled waveform at a rate of 4Hz and processes it to extract the current of each bunch.

The waveforms collected are fragmented in smaller blocks containing only data sampled in an interval corresponding to the minimum bunch spacing. Individual bunch induced signals are isolated and the absolute values of the two peak amplitudes of each bipolar pulse are measured and summed to deduce the bunch current. By considering both peaks of each pulse signal one can get rid of the drift of the base line.

Peak voltages are normalized to the total beam current through an online calibration with the DC Current Transformers installed on each ring.

Tools to display individual bunch currents of electron and positron beams are also provided (Fig. 3).

Upon operator request a bunch charge equalization procedure is initiated: the buckets in which the current is below a user set threshold (default: average beam current

– 3% see Fig. 3) will be selected for the next injection shot [3].

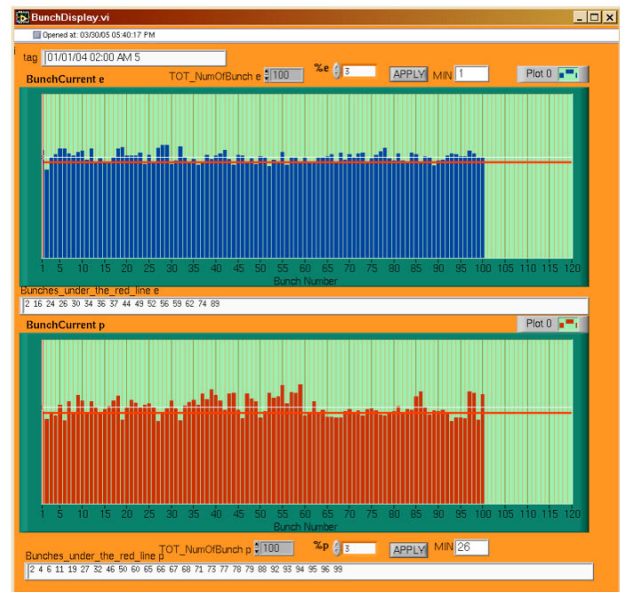


Figure 3: Bunch Current Monitor display for  $e^-$  beam (top) and  $e^+$  beam (bottom).

## CURRENT MEASUREMENTS

To improve measurements resolution, data are sampled in *equivalent time mode* [1] and averaged, taking advantage of the processing capabilities of the oscilloscope.

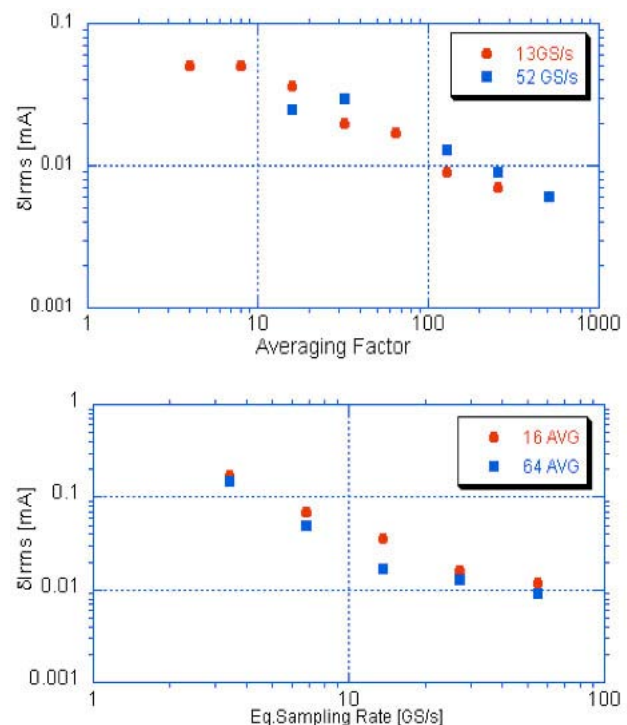


Figure 4: *rms* resolution of current measurements for different averaging factor (top) and sampling rates (bottom).

A limit to the measurement accuracy, i.e. the capability to measure exactly the absolute value of bunch currents, has been found to be due to the excessive length of the coaxial cables carrying the signal to be sampled.

The peculiar decay time of the cable impulse response is longer than the minimum bunch spacing and can overlaps with the following bunch signal. This leakage has been evaluated to be <3% of the bunch current.

RMS resolution  $\delta_I$  of the current measurements are dependent from the sampling rate and averaging factor used.

Figure 4 reports some results to show system performance.

### LIFETIME MEASUREMENTS

Individual bunch lifetime are computed from:

$$\tau_i = \frac{I_i}{\Delta I_i} \cdot \Delta t \quad (1)$$

where  $I_i$  is the bunch current and  $\Delta I_i$  is the current decay in an interval of time  $\Delta t$ .

An estimate of the relative error  $\delta_\tau/\tau_i$  affecting lifetime calculation, due to the resolution of the current measurements is written as:

$$\frac{\delta_\tau}{\tau_i} \approx \frac{\delta_I}{\Delta I_i} \cdot \left( 1 + \frac{\Delta I_i}{I_i} \right) \quad (2)$$

A software routine, implemented in the control system, continuously acquires bunch currents and stores it in a memory buffer.

Calculation of the bunch lifetimes is performed only when a user configurable ratio  $\Delta I_i/\delta_I$  is reached, where  $\delta_I$  is updated during acquisition.

In the measurements reported, lifetimes for each bunch are evaluated after a current decay  $\Delta I_i=50\delta_I$ . Substituting in Eq. (2) it leads to an expected rms relative error ~2%.

For typical values of DAΦNE lifetime during luminosity shifts, one needs interval of times of about one minute to obtain single bunch lifetime measurements with the requested resolution.

A graphic interface allows analysis and display of the lifetime values during machine operation (Fig. 5).

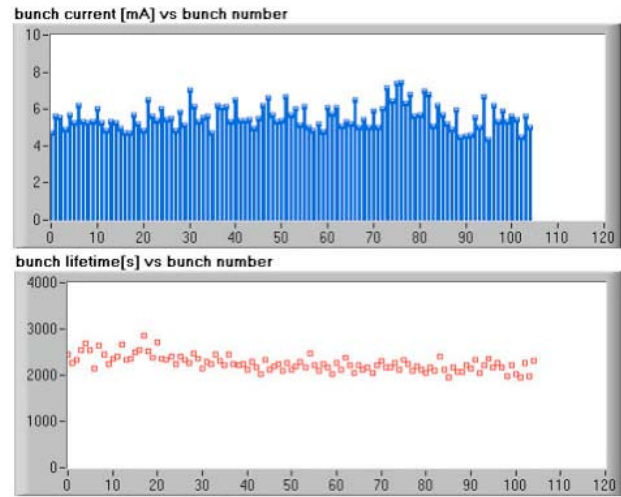


Figure 5: Bunch lifetime monitor display.

### ACKNOWLEDGMENTS

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### REFERENCES

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