DAFNE BUNCH-BY-BUNCH FEEDBACK UPGRADE AS SUPERB DESIGN TEST

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Abstract

DAFNE, the PHI-factory located in Frascati, has always shown a dynamic behavior strongly dependent on the bunch-by-bunch feedback, since its first runs in 1997. Over the years, to keep up with the evolving machine requirements, transverse and longitudinal systems have received multiple upgrades and updates. During fall 2010, all the six DAFNE feedback systems have been upgraded to support the next run for KLOE as well as to test bunch-by-bunch feedback architectures intended for the future Italian SuperB factory. Both e+/e- longitudinal feedback systems have been completely replaced with new hardware for increased reliability, better diagnostics and improved maintainability. In the effort to reduce residual transverse dipole beam motion, determined also by the front-end quantization noise floor, vertical feedback systems now feature a 12-bit ADC, in place of the older 8-bit design. In the paper we describe the hardware and software changes of this upgrade. Feedback performance analysis and beam dynamics data collected by the systems are presented.

INTRODUCTION

DAFNE, the PHI-factory located in Frascati [1],[2],[3], produces e+/e- collisions at 1.02 GeV in center of mass. In DAFNE 100-110 bunches are stored in two 97m main rings to achieve peak luminosity up to $4*10^{32}$ $cm^{-2}s^{-1}$. This result has been obtained in the last runs for Siddartha detector. Beam currents stored to accomplish the luminosity goal are in the range between 1 and 2 A. Since its first runs in 1997, DAFNE has always shown dynamic behavior strongly dependent on the bunch-by-bunch feedback. Over the years, to keep up with the evolving machine requirements, transverse and longitudinal systems have received multiple upgrades and updates. During fall 2010, all the six DAFNE feedback systems have been upgraded to support the incoming run for KLOE as well as to test new bunch-by-bunch feedback architectures [4] intended for the future Italian SuperB factory [5], [6], [7].

LONGITUDINAL FEEDBACK

In DAFNE, since the first runs and up to last October, the bunch-by-bunch feedback developed in mid nineties by a SLAC-ALS-LNF collaboration has been used [8] to control the synchrotron coupled bunch motion [9]. This system, based on 60 digital signal processor (DSP) running a real time firmware code in parallel, has demonstrated good reliability; nevertheless a complete upgrade has been realized in order to have the most modern hardware and software release and to test the design of the feedback system for the SuperB factory, a project for an e^+/e^- collider that should produce collisions with a peak luminosity of 10^{36} cm^{-2} s^{-1}.

Having in mind these two goals, during 2010 both e+/e- longitudinal feedback systems have been completely replaced with new hardware for increased reliability, better diagnostics and improved maintainability. With the improved technology of the last 15 years, a single FPGA (Field Programmable Gate Array) is now able to manage a large number of real time signal acquisition channels acquiring dipole oscillations of the bunches stored in each main rings. Each bunch signal is sampled by an 8 bit ADC and then processed by a per-bunch finite impulse response (FIR) filter. Filter coefficients can be modified on the fly while maintaining control of the beam. The FIR output is applied to the beam via the back-end, power amplifier, and the kicker. As new longitudinal bunch-by-bunch feedback, the iGp (integrated Gigasample processor) system, previously used at DAFNE as vertical processing unit, has been installed. The iGp has been developed by a SLAC-KEK-LNF collaboration in the years 2004-2005 [10] and later engineered by Dimtel, Inc., a SLAC spin-off company. iGp hardware can be configured to support harmonic numbers from 45 to 8192, making it a good fit to both DAFNE and SuperB with harmonic numbers of 120 and ~2000 respectively. Moreover, the system is compatible with the diagnostic tools used in the last 15 years [11], producing many examples of very powerful performance analysis [12].

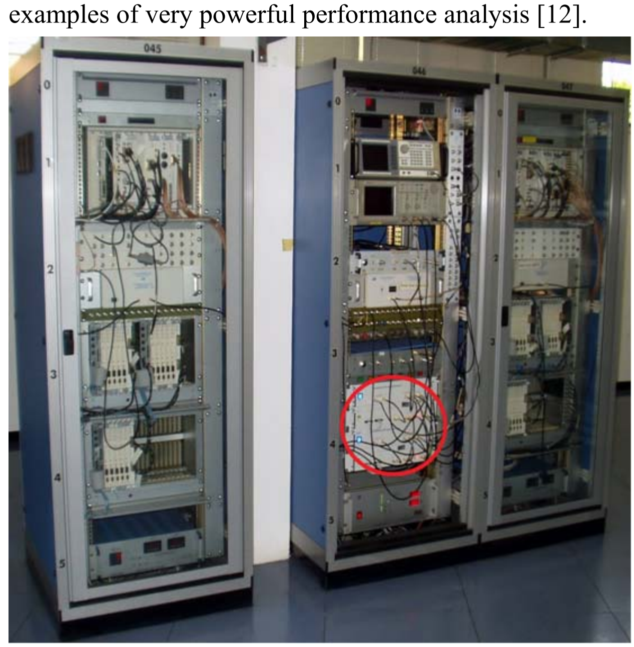

Figure 1: Three racks with the previous version of the longitudinal feedback electronics and the new one circled in red.

As a consequence of using a new processing unit,the analog front end as well as the analog back end have been renewed to have updated interfaces to the new system, more modern components and simpler approach, but maintaining the same overall design philosophy. A picture of both systems is presented in Fig. 1, showing three racks used for the previous version of the systems and, circled in red for comparison, four small units containing the new digital and analog feedback hardware for both rings. Advantages are evident also in terms of occupied space and power consumption.

TRANSVERSE FEEDBACK

In DAFNE, over the years, to keep up with the evolving machine requirements, the transverse feedback systems have received many upgrades and updates since the first system to damp the vertical motion designed in 2001 [13], [14], and the feedback itself has been a powerful beam diagnostics tool [15].

In the effort to reduce residual transverse dipole beam motion, determined also by the front-end quantization noise floor, the systems for the vertical feedback now feature a 12bit ADC, in place of the older 8bit design. As shown in Fig.2, the new iGp-12 unit has the same chassis layout as the previous iGp version. The printed circuit board at the chassis front includes a Xilinx Virtex-5 FPGA and 12bit ADC/DAC, to implement the bunch-by-bunch processing. A USB cable connects the feedback PCB to an embedded Mini-ITX motherboard and solid-state drive combination running customized version of Linux operating system.

Figure 2: The iGp-12 feedback unit including 12bit ADC and DAC, Xilinx Virtex-5 FPGA, a Mini-ITX motherboard with a solid-state drive.

Due to the ultra-low emittance and size of the SuperB bunches, feedback systems with at least 12bit analog conversion will be necessary. In DAFNE, during the past runs, a small influence on the beam size due to the vertical feedback gain, has been observed during collisions. This effect can be explained basically by one or more of following reasons:

a) ADC quantization noise;

b) insufficient rejection of the out of band noise;

c) analog front-end and/or back-end noise.

The new system improves significantly on the first point and, by transitioning from 16 to 32 filter taps, enables narrower control bandwidth. Larger dynamic range also simplifies operation in presence of orbit offsets and front-end imperfections.

Experiments are in progress at DAFNE with the goal to study vertical beam size variations (in collision) by comparing feedback filters of different bandwidths. Configuring two filters of 6 and 12 taps at identical overall gain at the betatron frequency, one expects to quantify the effect of controller bandwidth on the steady-state residual beam motion. While this is still work in progress, the larger dynamic range of iGp12 allows more flexibility than in the previous feedback versions.

RESULTS AND COMMISSIONING

The new longitudinal and vertical feedback systems have been put under test during DAFNE runs from November 2010 to May 2011. The feedback behavior did not present remarkable problems or failures. The very peculiar beam diagnostics made by software tools based on the feedback internal capabilities, have been used to measure growth and damping rates in different machine setup as in the previous system versions. The performance of the new iGp12 system shows significant improvements with respect to the original iGp hardware maintaining, in the same time, backward compatibility.

In the longitudinal analog front end, using the new version, it has been possible to write a MATLAB/EPICS routine to control automatically the input signal range and applying, when necessary, real time adaptation of the input level by sending commands to modify the front end attenuator value.

Using the feedback systems, horizontal and vertical decoherence measurements have been performed during February 2011. These measurements have been done in the horizontal plane by exciting the beam with 2-10kV pulses to the injection kicker, which delivers a horizontal angle to the beam. Using the same trigger, turn-by-turn records are stored by the feedback software tools.

For the vertical case, no similar excitation is possible, so the feedback system itself has been used in anti-damping mode to excite the beam. Fig. 3 shows the natural decoherence of the beam with feedback-off after a 0.4 ms excitation period.

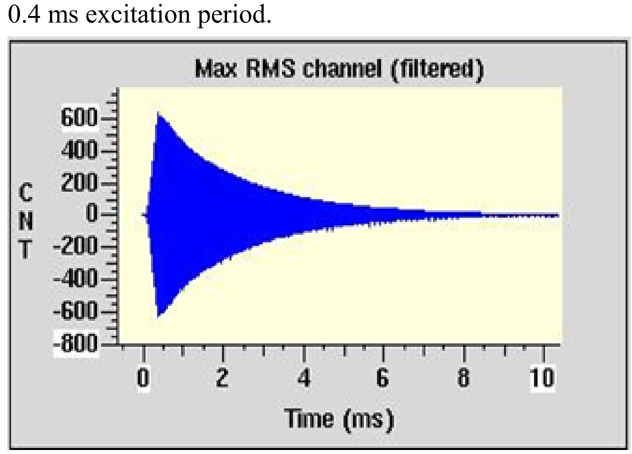

Figure 3: Vertical decoherence measurements, obtained by exciting the beam with the vertical feedback.

The measurement results are shown automatically in the plot produced by the feedback. It is worth remarking the very high vertical sensitivity and the large amount of memory that is available for each bunch by recording turn by turn (~10ms).

From decoherence data measurements, it is possible to estimate the 12bit vertical feedback resolution versus the 8bit horizontal system resolution: the first one gives 0.001 mm/mA/counts (average) using only <1/3 of the full ADC range, whilst the second one gives 0.01 mm/mA/counts using all the input range and often very close to saturation. Note that all the measurements were done with different vertical and horizontal beta as well as different analog input amplification or attenuation.

A MATLAB routine is used to convert acquired bunch-by-bunch data to a spreadsheet format file in a time stamped data base to track beam decoherence behavior. Dependence on excitation strength can also be characterized. In the vertical case, the excitation level is adjusted by varying the antidamping period length in the range 0.1 – 0.5 ms while monitoring the record quality in the real time data plot.

The updated operator interface can now easily poll single bunch data by selecting the bunch number; this feature makes possible to write a simple MATLAB/EPICS routine to perform bunch-by-bunch tune spread analysis. This very fast program takes ~1-2 minutes giving, as final result, a complete graphical presentation by four plots with horizontal and vertical e+/e- tune spread versus bunch number. During these 2010-2011 DAFNE runs, limited amount of beam current has been stored due to a poor injection caused by temporary technical reasons. As soon as the DAFNE performance will be high enough (>1A), detailed bunch-by-bunch tune measurements will be done to compare behavior differences between the two rings.

CONCLUSION

In this paper we have described hardware and software improvements in DAFNE bunch-by-bunch feedback systems after a recent upgrade. The longitudinal feedback has been upgraded to a new, much more compact, version with a complete backward compatibility with the existing diagnostic tools. In the vertical oscillation plane, an upgraded version of iGp feedback system (with 12 bit ADC/DAC and a more powerful FPGA) has been installed and tested with DAFNE beams in the last runs. New system commissioning has been very successful so far, but its completion depends on DAFNE beams reaching full operating currents. Our experience shows that the iGp12 larger dynamic range improves system flexibility. Studies of the effect of the reduced quantization noise on machine luminosity are still in progress. Comparing iGp/iGp12 to the previous generation of the feedback systems shows significant simplification in the hardware design (consistent with the evolving technological base) and, on the other hand, an extremely sophisticated and more powerful software design. Feedback performance evaluation as well as the analysis of beam dynamics data collected by using new software tools is currently in progress.

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