BUNCH CURRENT AND PHASE DETECTION FOR THE APS PAR*

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Abstract

The Advanced Photon Source (APS) injector consists of a linac, a particle accumulator ring (PAR), and a booster synchrotron (booster). The PAR accumulates multiple linac bunches and compresses them into a single bunch for booster injection. Beam energy in the PAR is 325 MeV. Due to its low energy and relatively strong beam-loading effect, beam charge and phase (or timing) monitoring is critical to the stable operations of rf control loops. We implemented a monitor system with an FPGA processor, which provides both current monitor and stripline fast waveforms. The system provides a bunch charge reading with a data rate of up to 1 MHz and a beam phase resolution of 230 ps, which are sufficient for the rf phase control loops. The system is currently used for beam tuning and diagnostics during normal operation.

We present a description of the system and the measurement results.

INTRODUCTION

The APS injector consists of a linac, a particle accumulator ring (PAR), and a booster synchrotron (booster). The PAR accumulates multiple linac bunches and compresses them into a single bunch for booster injection. It has a fundamental rf system for initial beam accumulation and a 12th harmonic rf system for bunch length compression. Due to its low energy and relatively strong beam-loading effect, accurate beam charge monitoring is critical to the stable operations of rf control loops and beam capture by the harmonic rf system. The original beam current monitor interface was implemented as a gated integrator [1]. Its reading is not reliable because of the changes in the bunch length and beam phase during the PAR cycle. We replaced the original system with an FPGA-based system, that provides reliable beam current or charge readings. One of its MEDM [2] display also serves as a diagnostics tool for PAR beam tuning.

SYSTEM DESCRIPTION

Figure 1 shows a block diagram of our FPGA-based data acquisition system [3]. A 9.77-MHz and a 117.3-MHz clock signals from the rf system provide synchronization to the beam. An event input [4] from the APS timing system enables the data acquisition to trigger on a selected injector event. The available events are linac pretrigger and linac injection trigger. The ADC sample clock is based on the 117.3-MHz clock input. This clock is 12 times the PAR revolution frequency. To achieve interleaved sampling we multiply the 117.3-MHz input clock rate by a factor of 37/35 as a sampling clock. For every 35 turns or 3.58 μs in real time the system takes 444 sample points and maps into one frame of data, which represents one PAR turn. The FPGA processor has two 12-bit/125-MHz A/D channels. One channel is designated for PAR current monitoring. The other channel is shared between a pickup stripline, and the field probes of the fundamental and harmonic cavities. The rms value of the waveform is computed and recorded every 28.6 μs. The rf phase and amplitude are processed with digital demodulation for cavity signals. Raw ADC waveforms are also recorded with 3.5-μs frames in two modes: a normal mode that saves one frame per ms with a total of 500 frames, and a burst mode that saves continuously for 500 frames. The ADC records are mainly for off-line processing and diagnostics.

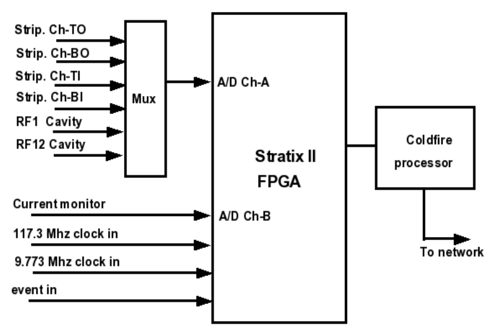

Figure 1: Block diagram of the PAR current monitor and rf cavity data acquisition system.

Several EPICS process variables [2] are installed for general beam monitoring and control purposes. They represent the average beam charge at various time widows (regions) of the PAR cycle, including the injection of each linac pulse, and beginning and end of harmonic capture. The system is a part of an integrated PAR bunch cleaning system.

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APPLICATION TO CURRENT MONITOR

Figure 2 shows the current monitor readback waveforms. Beam charge increases with each injection pulse. After about 270 ms, which is the time of the harmonic capture, the current readback remains constant. Figure 3 shows a calibration curve of the current monitor readings against the beam charge of the linac-to-PAR (LTP) beam transport line. The values of the last two regions are linear with an error of 1%.

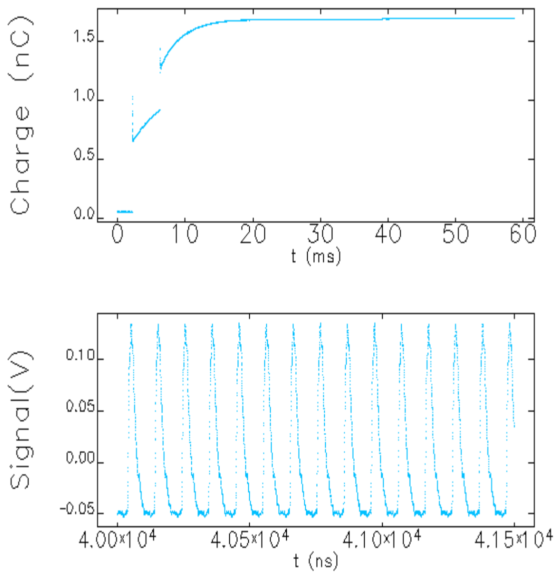

Figure 2: The rms (top) and raw ADC waveforms (bottom) of the PAR current monitor signals.

APPLICATION TO CAVITY AND STRIPLINE SIGNALS

We captured waveforms from the fundamental and harmonic cavities with digital demodulation. Figure 4 shows a plot of amplitude and phase of the harmonic rf cavity of a injection-extraction cycle. The large jump in the harmonic rf phase is around 250º. The estimated time resolution of the phase measurement is 3.5 us with a phase resolution of 0.36 degree for the harmonic rf and 0.03 degree for the fundamental.

Another interesting application is to monitor longitudinal centroid motion during the harmonic capture process. In this case we sample the beam-induced signal on a stripline blade. Figure 5 shows a contour plot of the stripline signal during that period. Clearly there is a small time shift of PAR bunch that is due to increased beam loading with bunch length damping in the first half cycle and a dramatic time shift of ~5.2 ns during the harmonic capture. After that, beam centroid remains steady. This observation agrees both with the harmonic cavity phase measurement result and streak camera measurement of longitudinal bunch centroid movement with synchrotron light from the PAR beam.

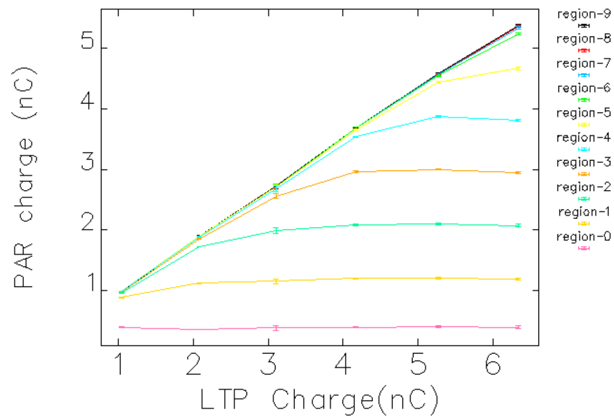

Figure 3: PAR current monitor readbacks versus LTP beam charge. Region refers to time windows in a PAR cycle.

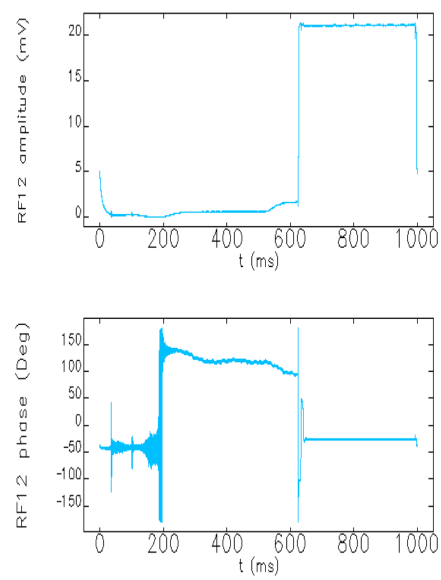

Figure 4: Amplitude (top) and phase (bottom) of PAR harmonic cavity during a full PAR cycle with two linac pulses injected. Trace start time corresponds to a few ms before the RF12 capture.

FURTHER DEVELOPMENT PLAN

We are developing a system that produces a data stream of beam charge, cavity amplitude and phase, as well as longitudinal beam phase based on this work. The new system will be incorporated into the feedback loops of new PAR control systems. The advantage of implementing an rf control loop in an FPGA-based processor is obvious. First, monitoring accuracy can be improved substantially with direct sampling and digital processing. Second, many analog circuits, such as envelope detectors and phase detectors of the original rf control loops, can be simplified or eliminated. And third, we will be able to implement multi-phase control loops that synchronously apply different algorithms for different parts of the machine cycle, a feature that is critical to system performance but difficult to realize with analog circuits.

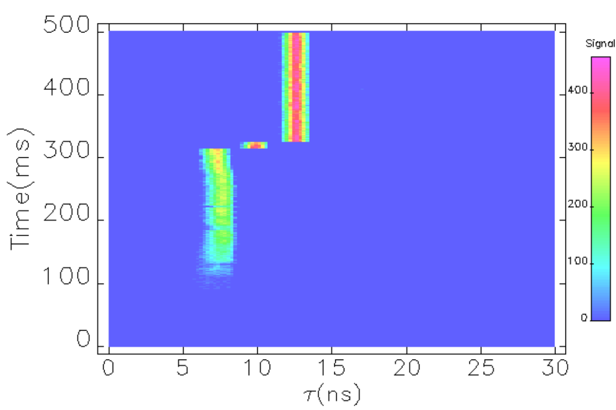

Figure 5: A contour plot of PAR beam longitudinal centroid change during a cycle. The horizontal axis is the beam longitudinal time. The vertical axis is slow time of the PAR injection-extraction cycle.

CONCLUSIONS

The FPGA-based acquisition system works well for the APS PAR beam current monitor. It also serves as an important diagnostics tool for beam tuning. The FPGA-based control and monitoring system has many advantages over an analog-based system. It can be further expanded and applied to such areas as beam phase and rf phase monitoring, and rf control loops.

ACKNOWLEDGMENTS

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