DSP based Accelerator Applications at the COoler SYnchrotron COSY

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Abstract

Modern floating-point Digital Signal Processors (DSPs) improve stimulus generation and measurement of beam parameters. In this contribution three different applications are presented. As stimulus a DSP-based function-generator calculates sequences of 3rd order polynomials with 1 µs resolution to generate complex frequency, amplitude, and noise band sweeps, necessary for instance for ultraslow extraction. The spills are analysed by looking at detector signals of the actual experiment. Over 1 million bins are sampled with a minimum bin length of 2 µs. BTF and related parameters are measured as transient response with a modular 2 channel vector-FFT-analyser based on VXI AD-converters and DSP-boards.

1 DSP-BASED FUNCTION-GENERATOR

The system for ultraslow-extraction (USE) at COSY [1] and also the rf-system needs dynamic function generators for non-linear ramps. A DSP-based function-generator [2] has been build to produce sequences of digital control words. A signal-processor Motorola DSP 96002 calculates sequences of real polynomials of third order $y(n) = (a_3(n)\cdot t^3 + a_2(n)\cdot t^2 + a_1(n)\cdot t + a_0(n))$ using a small assembler program optimised that every calculation needs exactly 32 clock-cycles. A system clock of 32 MHz results in a data-rate on a 1 µs-time-scale which is precisely predictable. Each polynomial in the sequence (1…n) is only valid for a specified time Δt. During this time the polynomial is sampled. Then the next polynomial is taken until the end of the list. The 24 to 32 bit digital output of this function generator shown in figure 1 is compatible to COSY's dynamic devices. The program of the DSP is stored in an EPROM, so that it is operational after power-on and reset. A communication port (ONCE) allows on-line-debugging of the DSP. Installed inside a VME-crate it is activated via interrupt and fetches the actual ramping function from the dedicated communication CPU connected to the COSY-Network. Another interrupt connected to the timing trigger starts the ramp. A third interrupt channel can be configured for special purposes, e.g. to stop the function generator or to allow a smooth shutdown of an interrupted machine cycle. The internal RAM of the DSP limits the length of the sequence of polynomials to about 85 lines. A RAM-expansion (32k x 32bit) included in the third generation of these cards (8 layers) increases this limit.

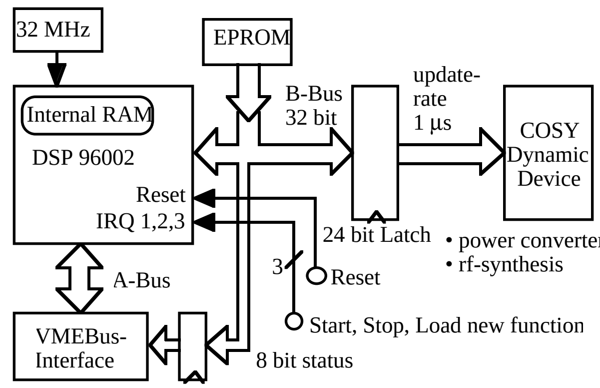

Figure 1: Circuit of the DSP-function generator [2].

One application is to establish the acceleration of deuterons instead of protons at COSY. As the minimum frequency of the cavity is not low enough for this species at (h=1), we inject the deuteron beam at (h=2) and accelerate with (h=2) until almost maximum frequency is reached. Then the frequency jumps from (h=2) to (h=1) within 1 µs without affecting the magnetic ramps (figure 2). During deceleration the process is reversed. Such a procedure has been tested during normal COSY operation with protons [3]. About 50% beamloss was found, but the principle works and shows that the digital rf-system of COSY allows such gymnastics.

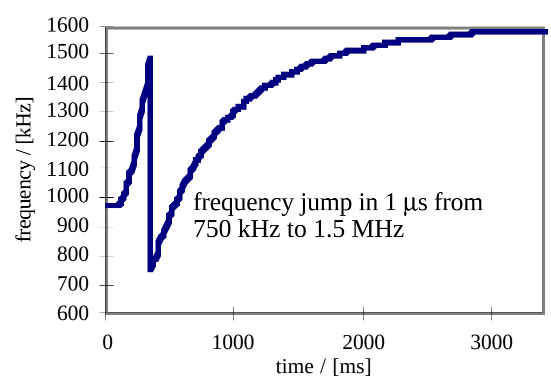

Figure 2: Frequency jump from (h=2) to (h=1).

2 SPILL MEASUREMENT

2.1 Motivation

The improvement of the resonant extraction at COSY [4] has lead to spill times of more than 160 s. This is accomplished by stochastic feeding [5] with the patented USE-system which is equipped with the same DSP function generators. To study the spill structure the detector signals delivered by the experiment are analysed.

2.2 Spill Diagnosis

We measure the spill by accumulation of the detector signals in fixed time intervals (bins). The method [6] was proven with a commercial „Frequency / Time Interval Analyser“ limited to 8000 bins which is sufficient for a spill of some seconds. The DSP-solution shown in figure 3 is an extension of the DSP board described before: It takes the numerical value of an 8-bit counter acting as a pre-scaler and stores the 16-bit data over the VME-BUS to the RAM of a CPU via DMA. The number of data points is only limited by the amount of RAM on the CPU board.

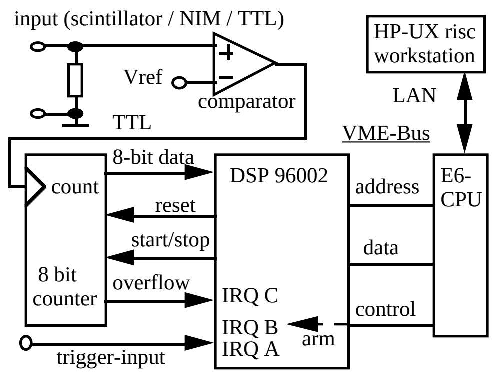

Figure 3: Circuit layout of DSP-based spill measurement.

The bin width is an integer multiple of 2 µs. With over 10^6 data points we have a record length of 1048 s with a resolution of 1 ms (sufficient to find 50, 150…, 450 Hz time structures) or for instance 10 s with a resolution of 10 µs or anything in between. The spill data is transferred to a workstation to compute on-line statistics (mean-value, max., min., RMS.-value, and Duty-factor). A FFT with e.g. 524288 points to discover time structures in the extracted beam takes about 30 s. Graphs (spill, statistic distribution, and FFT) are created with a program that handles more than 10^6 data points. An example of a spill taken with 1 ms bin width is shown in figure 4.

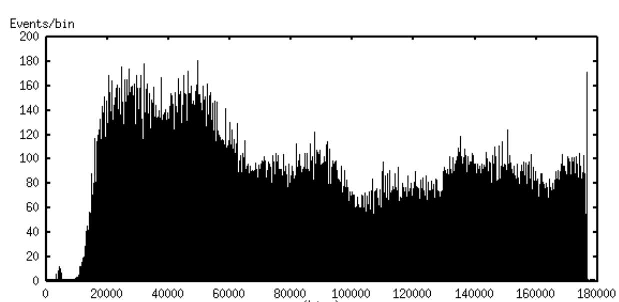

Figure 4: Recent example of a measured spill over 160 s.

2.3 High resolution digitizer

This equipment solves other acquisition problems by offering an 32 bit port, which can interface two 16-bit ADCs, for instance. In an rf-application, we connect the outputs of amplitude and phase delivered by the digital rf-system of COSY. The signal of a Σ-pickup is mixed with the revolution frequency. This phase is compared to the phase of the voltage at the acceleration gap of the cavity. The amplitude is proportional to the number of particles, but it is also sensitive to the actual acceleration voltage, the shape of the beam, and transfer functions of rf elements. Figure 5 shows a measurement during a slow ramp (5 times slower than normal) within a machine cycle of 40 s. This special cycle is required for internal experiments (e.g. EDDA) with thin target to take data during the ramp. The phase signal indicates that there are no disturbing longitudinal instabilities, so that the digital phase control loop does not need to be activated. The signal of the amplitude detector shows some loss of particles when entering and leaving the flat-top.

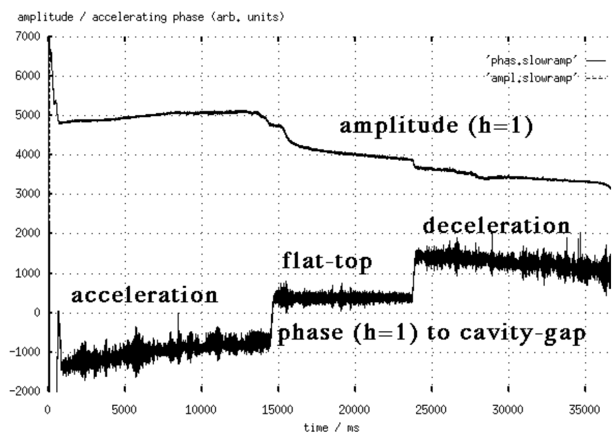

Figure 5: Longitudinal measurement of amplitude & phase of a digitised Σ-signal.

3 VXI VECTOR-FFT ANALYSER

Non-disturbing beam diagnosis of the circulating beam in COSY includes detecting the beam with pick-up structures connected to spectrum analysers. The measurement time of analogue spectrum analysers increases with higher resolution (reduced resolution bandwidth). A FFT-spectrum analyser allows a much shorter measurement time, because it needs only one time sequence of sampled values. We present a system now operational at COSY [7], that combines high-speed FFT with a broad frequency range.

3.1 Instrument description

The layout of the instrument shown in figure 6 is based on the HP 3587S Realtime Signal Analyser hardware, which incorporates only one channel, no mixers and operates from DC…8 MHz, driven by the software HP 35687B [8]. Together with the manufacturer Schönhofer (Siegburg, Germany), we expanded the system to two channels and completed it with a filter section and mixers to extend the frequency range to 20 MHz-3.4 GHz covering the operation regime of stochastic cooling [9]. The frequency span is 8 MHz in the baseband. Between

7.4 and 25.8 MHz the sampling frequencies are modified. With additional bandpass-filters the FFT operates on mirrored spectra. Above 20 MHz the input signal is mixed with local oscillators. We use two independent local oscillators, to measure different sidebands at the same time.

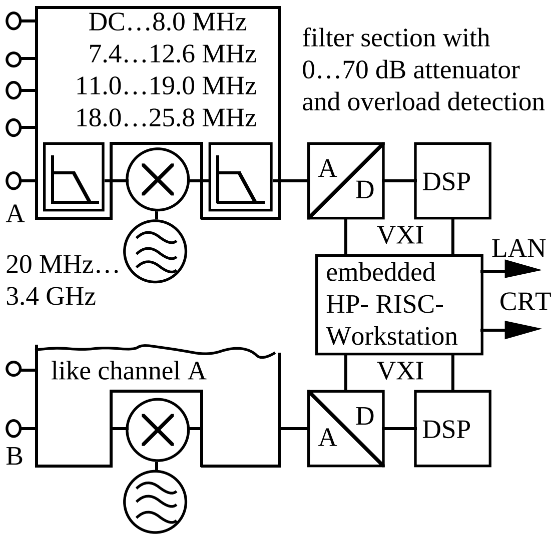

Figure 6: Simplified set-up of the VXI-spectrum analyser.

Filters, attenuators, input selectors, and overload-detection are in a separated housing optimised for micro-wave frequencies. The other modules are VXI-standard. The analogue/digital converter modules (ADC) operate at 20.48 MHz sampling clock and provide an effective dynamic range of -110 dBfs. The DSP-modules compute a 801 lines complex FFT in about 800 µs. We get up to 12801 frequency lines and a resolution in the 10^{-3}-Hz range. The data transfer is via local bus between ADC and DSP and via VXI backplane to the embedded controller.

3.2 Application: slow ramps for polarisation

For the acceleration of polarised beam we have to control the vertical tune of the synchrotron to make sure that the polarisation is not lost. To study the betatron sidebands during acceleration we apply broadband-noise to a strip-line unit and measure the difference signal of a Schottky-pickup. In figure 7 the spectrogram shows the measured spectrum versus time. During acquisition the picture scrolls upwards on the screen. Each line represents a full spectrum measurement of 2 MHz width 1.25 kHz resolution and 10 averages. The colour of each pixel represents the measured spectral intensity. The bold line in the middle is the fundamental (h=1) during acceleration up to about 1.57 MHz. The two lines to the left and right are the vertical betatron sidebands. This type of measurement is limited by the dynamic-range of the pre-amplifiers and the analyser itself. The method will be extended by removing the effect of the varying reference frequency. We will add a mixer which is driven by an integer multiple of the actual revolution frequency.

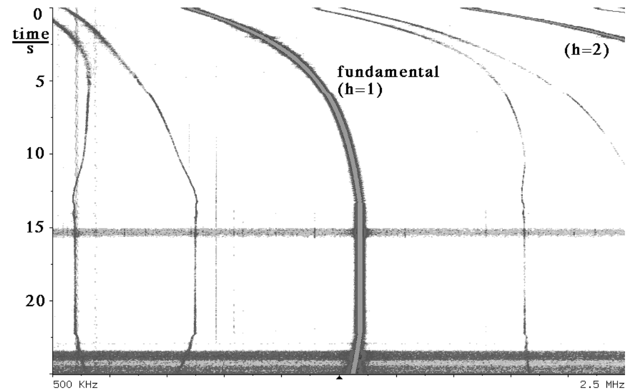

Figure 7: Spectrogram of vertical Δ-Schottky-signal showing fundamental and betatron sidebands during a slow ramp to final energy.

4 OUTLOOK

We will increase the number of DSP-based function-generator at COSY to allow more complicated rf-gymnastics. The set-up for spill-measurement allows counting and binning of single particles. The logic signal is immune against electric noise. In machine runs this has proven to be very helpful for optimisation of the extracted proton beam. The vector FFT-analyser will help with demanding tasks: analysis and optimisation of the extracted beam, improvement of acceleration and deceleration for experiments with polarised proton beams.

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