THE PETRA III MULTIBUNCH FEEDBACK SYSTEM

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Abstract

In order to fulfill the demands of a high brilliance synchrotron light source like PETRA III different feedback systems are required. The high brilliance is accomplished by high beam current of 100 mA and very small transverse emittances. The current in PETRA is limited by coupled bunch instabilities to rather low values and powerful longitudinal and transverse feedback systems are necessary to achieve the design current. A careful design of the feedback is required in order to avoid any kind of beam quality degradation such as beam blow up due to noise. Additional requirements on signal processing are: very high dynamic range, adaptive signal adjustment, very high sensitivity to beam oscillations, high resolution and very high bandwidth. This contribution will describe the most important components and their properties. Results of the feedback operation will be presented and discussed. The design current of 100mA has been achieved without the indication of emittance growth and the feedback has been operated reliably during the last user period.

PRINCIPLE SYSTEM LAYOUT

The principle functionality of multibunch feedback systems hasn't changed since the first digital processing system came into operation at PETRA in the late 80th [1]. In order to damp coupled bunch instabilities, transverse and longitudinal oscillations of each bunch have to be detected, shifted by 90 degree in Phase and feed back to the according bunches. To meet the requirements of modern synchrotron light sources serious improvements in respect of signal processing quality and stability are essential. PETRA is sectioned into octants, and the beam instrumentation electronics is located in eight buildings around the 2.4 km circumference. The instrumentation buildings are referred to as the cardinal points and they are about 300m far apart from each other. The accelerating RF transmitters and the central machine timing system is located in the south, the transverse feedback system is arranged in south-east and the longitudinal feedback system is installed in the east building. A basic requirement for the flawless function of MBFB components that are working together is a set of noiseless machine synchronous reference frequencies. Long term phase stability can only be provided by a PLL source oscillator that must be tracked to the locally detected beam phase. Phase changes caused by RF phasing or by temperature drifts of any components must be compensated to less than 10ps. The required resolution for transverse beam oscillations is in the sub micron range. This sensitivity can only be achieved by compensating for beam position offsets at the MBFB beam position monitors. Saturation detection and attenuation control of the cascaded amplifier stages inside the beam oscillation detector is a necessary feature to assure robust operation of the system over a wide range of bunch currents.

DESCRIPTION OF THE MAIN FEEDBACK COMPONENTS

The Beam Oscillation Detector

The minimum bunch spacing in PETRA III is 8ns, therefore the double sideband spectral components covering multibunch oscillations are periodically repeated with 125MHz. The spectral information of betatron beam oscillations is appearing as AM sidebands around the machines revolution lines. The principle functionality of the beam oscillation detector is the direct-to-baseband conversion of these AM sidebands. The LO frequency used for down conversion was chosen to be 500MHz. (f_{RF}) It is provided by an external module, that is described in the next chapter. As the detectors block diagram in Fig. 1 points, before down conversion, the input signal passes two amplifier and attenuator stages.

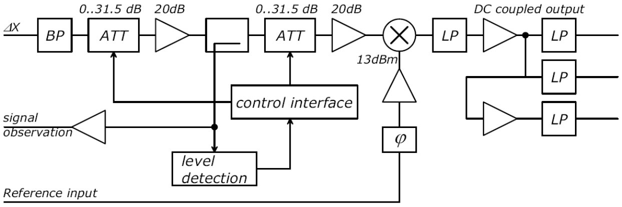

Figure 1: Diagram of a transverse detector channel.

The first amplifier has very low noise characteristics. Its output level is controlled to be about 20% below 1dB compression. The second amplifier matches the output of the first stage to the down converters RF input level. The attenuator in front of it is normally not varied, but it can be adjusted to less attenuation in order to detect beam oscillations at very low machine currents. The down converter consists of a double balanced high level mixer. In order to allow a compensation for the unwanted revolution harmonics that are produced by a non centred beam at the BPM, the mixers IF output must be capable to operate down to DC. As a consequence of this, the final amplifiers must achieve a linear transfer characteristic from about 100MHz down to DC. The beam oscillation detector device contains three sections for the transverse and the longitudinal plane. The phase detection part has only one amplifier attenuator stage in the RF input path, since the input signal is much higher than for the transverse detectors. The required sensitivity to phase oscillations is gained after down conversion to the base band. The beam oscillation detector was decided to be an in house development, because the specifications of a commercially available device did not suit our needs.

The Carrier Frequency Generator PLL

The basic fundament for different devices such like modulators, synchronous detectors, digital signal processing and sampling devices that are jointly operating at a certain location, is the central generation of all needed reference frequencies. Synchronous references must have a fixed and defined phase relation to each other. The quality of beam oscillation detection depends on the provided reference frequencies used by the detectors down conversion. But also the ADC and DAC clock frequencies should be of pure quality and always phase locked to the devices working together. The central unit that generates these references is a voltage controlled crystal oscillator that is part of a phase locked loop. The crystal has been ordered to match the PETRA RF frequency that is 499.6655 MHz. Its phase noise is about -140 dBc at 1kHz. The adjustable frequency range of about 20 kHz is small and its span should only allow for the maximum RF frequency changes that may occur during machine studies. The machines timing system delivers a 125 MHz reference, but this cannot directly be used because of improper phase drifts related to the locally detected bunch signals. In addition, due to the long transmission distance from the central distribution system, the noise behaviour is not adequate for the MBFB operation. A phase shifter at the 125MHz reference input is used to adjust the whole system to the detected bunch phase. The PLL closed loop cut-off frequency has been chosen to be about 100 Hz. It must be high enough to ensure the proper tracking to phase changes during machine operation procedures like RF phasing or chromaticity measurements.

The Beam Position Monitors

A high sensitivity as well as best impedance matching to avoid signal reflections can be achieved with strip line monitors. The maxima of magnitude response exists at

$$f_c = (2n-1)\frac{c}{4l} \tag{1}$$

Since the detectors input frequency range is 500±62.5 MHz, the BPM consists of l = 15cm long strip lines that are embedded into an elliptical chamber profile. Each direction of the MBFB system has its own strip line monitor that is installed at high β positions in the ring.

The Transverse Beam Offset Compensation Bridge

To preserve the monitor strip lines from being irradiated by the synchrotron light they are not aligned in the transverse plane. Also they are not orthogonal because of the elliptical BPM profile. In order to monitor for transverse oscillations the sum of opposite lying strip lines must be subtracted. But if the beam is not exactly centred to the BPM this difference will not be zero. A constant beam offset produces spectral components at multiple of the bunch revolution frequency that may arise to very high magnitudes in respect of the oscillation signal. These offsets are limiting the dynamic range and they are leading to saturation within the detector device. A 180 degree hybrid produces the difference signal which is sampled by the ADC. The beam position offsets are being compensated by controlling two pin diode attenuators forming a balanced bridge.

The Digital Signal Processing Unit

This device consists of a single printed circuit board that covers all digital signal processing including AD and DA conversion. Three of these boards are required for the longitudinal and transverse directions. Each board is equipped with three 16 bit / 130MS/s ADCs and two 16 bit 160MS/s I-Q DACs. Additional lower bandwidth ADCs and DACs are used for external offset and phase controlling and for auxiliary input / output purpose. To be insensitive against mains failures, the current configuration settings are always stored in EEPROM. A standard USB interface is used to be connected to the server PC. Digital signal processing is executed by an ALTERA Stratix II FPGA. Fine adjustments of the ADC and the DAC clock timing can be accomplished during signal observation. The internal “multi bunch offset compensation” is an optional feature that can be enabled in the case of inhomogeneous machine fillings. Individual bunch signal offsets due to beam loading for instance, may be eliminated here. A similar feature is the “multi bunch band pass” that is optional as well. By enabling this, a configurable band pass is inserted for each bunch. This leads to an enhanced isolation of different tune signals that may occur due to coupling effects. Since each bunch can be described as a harmonic oscillator, the MBFB system works by increasing the damping term, implied by the additional D_{FB} in the general equation of motion:

$$\ddot{x}(t) + 2(D + D_{FB})\dot{x}(t) + \omega^2 x(t) = 0 \tag{2}$$

Thus the sampled beam oscillation of each bunch must be shifted by $\pi/2$ before feeding back to itself. Actually the phase must be adjustable because the signal processing path does not have the same phase advance as the bunch that travels around the machine and the kickers are not at the same location as the BPM. In order to adjust the processed signal delay to be the same as the bunch travelling time from the monitor to the kicker devices, a configurable FIFO storage has been inserted. The phase shifter consists of a five tap FIR filter. Additional FIFO storage is arranged in between the filter taps to store the position data of all bunches per revolution. Different phase settings can be performed by loading an adequate set of filter coefficients, which are kept ready to allow for one degree step adjustments. Because beam excitation with dedicated stimulus signals is of particular importance, the capability of a “multi bunch beam excitation generator” has been appended to the system. The stimulus can be added to the systems output while the MBFB is on or off. This is how the damping performance of the MBFB can be tested. The generators signal properties are: selectable single bunch or multi bunch, burst or continuous sine wave, noise, and selectable coupled mode. The frequency range is 0 to 62.5 MHz with a 1 Hz resolution. A further and very helpful feature is the implementation of a "signal scoping buffer" Hereby, the current input data stream is continuously stored in a ring buffer. External triggers provided by the machine protection system for instance, can stop the acquisition. The buffers readout provides useful information for troubleshooting by correlating it with other recorded events.

Transverse and Longitudinal Power Amplifiers

In order to be prepared for intended higher operation band widths, the transverse feedback amplifiers have been specified to operate up to 250 MHz. The eight solid state amplifiers have performed excellently right from the beginning. Additional passive diplexer networks have been inserted at the amplifiers outputs for protection reasons. The cavity driving solid state amplifiers used at the longitudinal MBFB must be protected against backward propagating beam components that are out-coupled by the cavities. Circulators and passive filters are mandatory. Two different types of amplifiers have been purchased. After some redesigns and repair, the amplifiers now seem to do their job [4].

The Transverse MBFB Kickers

The beam excitation devices are made of two strip line kickers for the horizontal and the vertical directions. A kicker consists of two 1m long strip lines that are connected to a feed through at each end. Therefore the strip lines can be driven separately by power amplifiers. Due to the influence of synchrotron radiation water cooling is necessary to prevent the conductors from heating up too much. The kickers have an elliptical profile of 40 x 80 mm, strip line impedance is 50 Ohms and the deflection angle is 1µrad.

The Longitudinal MBFB Kickers

Eight single cell feedback cavities are installed to damp the coupled bunch longitudinal phase oscillations. The cavity has been adopted from the SLS and DAFNE feedback cavity designs [2]. Its centre frequency has been tuned to 1375 MHz. The cavity has eight ports and its bandwidth may be varied by terminating or shorting some ports according to the requirements. At start-up the bandwidth has been chosen to match for less than -1dB at the edges of the needed 125 MHz DSB range. But operating experience showed an unacceptable heating at the four shorted feedthroughs of the cavities when PETRA was operated with 40 bunches and with single bunch currents above 2mA. The solution was found in terminating all feed throughs, thus doubling the band with of the feedback cavities and accepting a loss of kick performance by a factor of 1/ sqrt(2) [3]. Computation of wakefields and impedances for the cavity can be found in [4].

THE MBFB SYSTEM PERFORMANCE

Figure 2 shows the single bunch input spectra of the three MBFB systems being in operation. PETRA was filled with 240 equally spaced bunches giving a total beam current of 100 mA. The left scale indicates the ADCs full range reference as 0 dB. The frequency range is for Q = 0 to 0.5 (up to 65 kHz). The notches at the tune frequencies appear due to the negative feedback of the systems noise that is transferred over the beam. Therefore the damping due to the MBFB system can be evaluated by regarding the broad band widths of these notches. Since they are associated with the second order beam transfer functions that have a decay time of

$$\tau = \frac{1}{2\pi\Delta f_{3dB}} \qquad (3)$$

the transverse beam oscillation decay times have been adjusted to be less than 100µs.

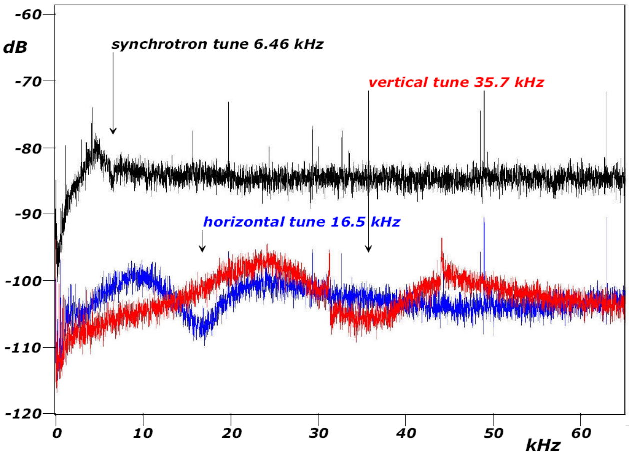

Figure 2: ADC single bunch spectra while MBFB system is in operation.

REFERENCES

[1] D. Heins, J. Klute, R.D. Kohaupt, K.H. Matthiesen, S. Patzold, J. Rummler, M. Schweiger, "Wide Band Multibunch Feedback Systems For Petra", DESY . DESY-89-157

[2] M. Dehler, "Kicker design for the ELETTRA/SLS longitudinal multi-bunch feedback", EPAC 2002, Paris, France.

[3] O. Coiro, F. Marcellini, D. Pellegrini, GSI, "Bandwidth measurements of the DAFNE longitudinal kickers", DAΦNE technical note CD-12

[4] A. K. Bandyopadhyay, A. Joestingmeier, A. S. Omar, Otto-Von-Guericke University, Magdeburg, K. Balewski, R. Wanzenberg, DESY, Hamburg, "Computation of wakefields and impedances for the PETRA III longitudinal feedback cavity", APAC 2007,

[5] M. Ebert, "PETRA-III Longitudinal Feedback RF", 13th ESLS-RF Meeting, DESY 2009, http://esls-rf-2009.desy.de