THE LONGITUDINAL COUPLED BUNCH FEEDBACK FOR HERA-p

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Abstract

A longitudinal broadband damper system to control coupled bunch instabilities has recently been constructed and installed in the 920 GeV proton accelereator HERA-p at the Deutsches Elektronen-Synchrotron DESY. This represents one of the attempts to increase the specific luminosity at HERA by reducing the bunch length.

Without additional damping the bunch length is about 1.5 ns (FWHM) at the beginning of a typical luminosity run. The bunch length is defined by the initial emittance after injection and by the acceleration process where multiply occuring coupled bunch instabilities provoke bunch length blow up at discrete energies during the ramp.

The feedback system measures the phases of all bunches and calculates corrections in real time (bunch spacing: 96 ns) which are then applied to the beam via a longitudinal feedback kicker. The controller has to be able to deal with a slowly changing synchrotron frequency (20–80 Hz). Transverse and longitudinal emittances of a proton beam are very sensitive to any (noise-) exitation because of the missing synchrotron radiation damping. Therefore the feedback system for a hadron beam accelerator is much more challenging than that for electron accelerators where longitudinal coupled bunch feedback systems are widely used.

HERA-P

The layout of HERA-p and all preaccelerators together with their typical fill patterns is shown in fig. 1.

During the 30 minutes acceleration from 40 GeV/c to 920 GeV/c the bunches suffer from coupled bunch instabilities (a typical oscillation pattern is shown in fig. 4), which typically cause the bunch length to blow up twice on the ramp when the bunch length becomes less than 1.5 ns. We end up with bunch lengths of more than 1.5 ns ($\varepsilon_s \approx 0.3$ eVs, $l \approx 19$ cm) at the beginning of a luminosity run (see fig. 1). Calculations from the applied voltages of the two RF systems (52 MHz and 208 MHz) and the nominal injected emittance lead us to expect a bunch length of less than 1 ns at the end of the ramp assuming complete emittance preservation. A bunch length reduction from 1.5 ns down to 1.0 ns would lead to 5 % more luminosity for the present focussing ($\beta_y = 18$ cm) at the interaction points. At the moment a typical luminosity run lasts 12 hours.

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THE FEEDBACK SYSTEM

The actual feedback design consists of a fast, high precision bunch centroid phase detector, a 1 kW feedback cavity with 104 MHz centre frequency and 8 MHz bandwidth (FWHM), a I/Q-vector modulator, the low level digital FPGA-board with 14 Bit ADCs and DACs and a cavity transient diagnostics (see fig. 2).
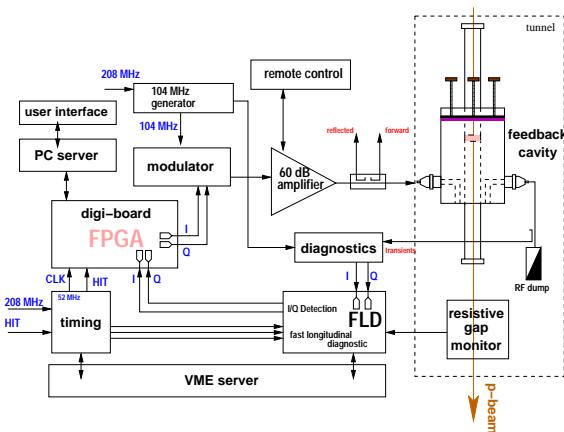

Figure 2: Overview of all components of the longitudinal feedback.

The high precision bunch phase detector has been in operation since 2003. It was designed as a fast logitudinal diagnostics system [1], and its analog RF hardware is now also used for the feedback system. It consists of a 4 GHz bandwidth resistive gap monitor, a 52 MHz bandpass filter with about 30 MHz bandwidth and a 52 MHz I/Q-demodulator.

Coupled bunch oscillations have been recorded for over two years now. Considerable archived data have been analysed to reveal, which coupled bunch instability modes occur and at what strength. We frequently observed modes 5 and 11 at lower energies, but also very often the mode 164 (HERA has 220 bunch positions) which lead to bunch length blow up at ≈ 300 GeV and at > 670 GeV (see fig. 5 (top) and fig. 4). A single impedance driving the modes 5, 11 and 164 has not been identified. Rather mode 164 seems to be driven by a broadband impedance. It is therefore not sufficient to have a near-by-mode or a single mode feedback. A broadband coupled bunch feedback is necessary. Growth times of the instabilities are typically more than 2 seconds, hence, a relatively moderate kick voltage is sufficient to damp the oscillations. The synchrotron frequency of HERA-p is typically 35 Hz but can vary from 20 Hz to 80 Hz during acceleration.
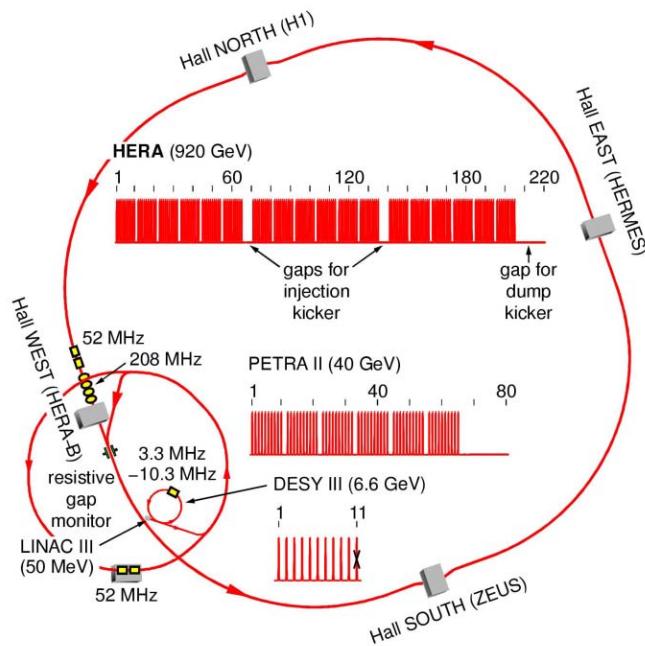
Figure 1: The Hadron Elektron Ring Accelerator HERA-p with all preaccelerators and their fill patterns.

THE CONTROLLER ALGORITHM

The I and Q components of the bunch signals are sampled by 14 bit ADC's with a rate of 10.4 MHz. The phase calculation for all bunches and offset correction are done by FPGA software. It includes a multipexer and 220 indepandant digital filters to produce the correction kicks. The controller algorithm has to be able to deal with a slowly changing synchrotron frequency (20–80 Hz). Here we considered a filter design which treats every bunch as an indepandant oscillator which has to be damped. Wheter the long term noise behaviour can be improved by using more sophisticated mode filter algorithms is currently under investigation. The details of the algorithm are presented in [4]. The layout is shown in fig. 3.

THE CAVITY SIGNAL MODULATOR

We have chosen a feedback kicker cavity design with a center frequency of 104 MHz (which is 10 times the bunch frequency, correspondig to a bunch spacing of 96 ns). The correction kick signal produced by the controller algorithm therefor has to be modulated to a 104 MHz carrier frequency. To use full capacity of the kicker system we developped a modulation method which is a combination of digital signal processing and an analog vector modulator. The digital part of the modulator is calculated by the FPGA. The board produces two streams of output which then go to the vector modulator. Its input is calculated in such a way that each bunch sees the desired voltage on top of the 104 MHz sine wave when it passes the kicker. This ensures no waste of power of the feedback amplifier and also makes the kick voltage insensible to individual phase deviations of

the bunches. The modulated signal is finally amplified by a 1 kW broadband linear amplifier, which is placed near the HERA tunnel, where the feedback kicker is installed.

THE FEEDBACK KICKER CAVITY

A 1 kW cavity system (which can produce the moderate longitudinal kicks of about 1.6 kV where 200 V are necessary to suppress all visible multibunch instabilities) was found to be adequat. No special water cooling is necessary.

The modulation principle used works with a cavity of any bandwith if the available power is unlimited. In our case a bandwidth of 8 MHz ($Q = 13$) was realized by externally loading of the cavity with a 50 Ohm wave dump. All details of the cavity system are described in [3].

The cavity has two symmetrical RF couplers for RF input and a RF load output. For diagnostics and timing adjustment, the cavity transient signals, picked up at the load coupler of the cavity are fed back to a vector demodulator and are sampled and archived by the fast longitudinal diagnostic system. In this way the kicker can also be used as a narrow bandwidth longitudinal beam monitor.

PERFORMANCE

The longitudinal feedback is in operation since March 2006. It has proven its capability to suppress all coupled bunch instabilities during the energy ramp of HERA-p and also during hours of beam storage. The bunch lengthening due to diffusion processes is expected to be dominated by intra beam scattering effects, and the contribution of feedback noise during normal operation is hardly notica-

ble. When stable, the feedback system does not kick nor excite the bunches. Fig. 5 shows the evolution of the bunch length during a typical energy ramp at HERA-p without the longitudinal feedback (top) and with the feedback switched on (bottom). The initial bunch length after injection is about 2.4 ns. Without the feedback a multibunch instability (mode 164) showed up at 300 GeV and at 700 GeV with correlated bunch length blow up. With the feedback switched on the instability could be suppessed until the feedback was switched off after some time (t=1050 s) where immediately the bunch length blew up.
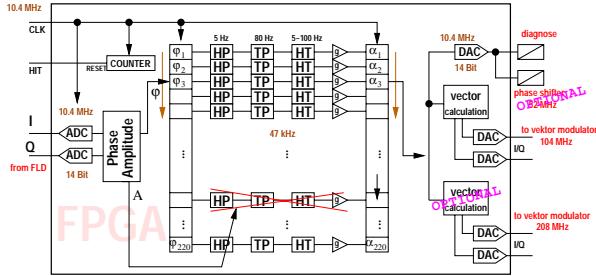

Figure 3: Layout of the controller algorithm realized in a FPGA. The signals are multiplexed to 220 channels (each for a bucket) which operate in parallel.

OUTLOOK

We are currently working on an automation to integrate the feedback operation completely into the control system and the sequence of HERA standard operation. So the feedback needs not to manually be switched on or off. For the near future a feature to actively excite a single bunch to measure beam transfer functions, bunch coupling and the loop gain is going to be implemented into the FPGA firmware. Also a new proton optics is to be applied to the machine to further reduce the transversal beam size at the interaction points ($\beta_y = 15$ cm). This together with the reduction of the bunch length should lead to an increase in luminosity of about 15 % in total. Further attempts to reduce the bunch length by increasing the acceleration voltages are now possible. We expect, that with this method, also the bunch lengthening over hours due to intra beam scattering will be slowed down.

REFERENCES

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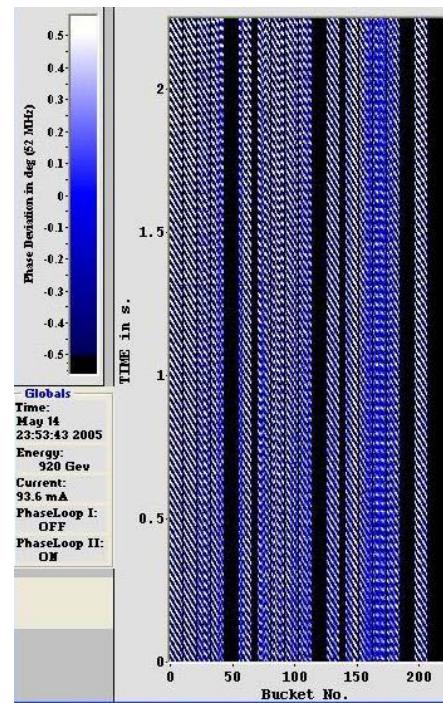
Figure 4: Signature of the mode 164: The pattern shows 512 samples of the bunch phases of all 220 bunch positions.
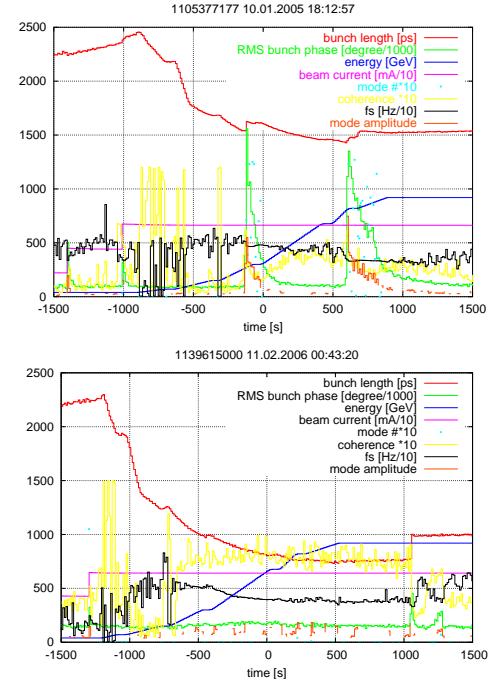

Figure 5: A typical energy ramp at HERA-p. The graph shows energy, current, mean bunch length, RMS bunch phases, measured f_s and other data derived from the FLD. The data was taken with 70 mA filled in 150 bunches. Top: Without longitudinal feedback. Bottom: With the longitudinal feedback switched on. (Here bunch lengh values for $E > 300$ GeV have to be multiplied by a factor 1.45 due to calibration mismatch.)