DESIGN OF A LOCAL IP ORBIT FEEDBACK AT HERA-E

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Abstract

At the electron-proton collider HERA (**H**adron **E**lectron **R**ing **A**ccelerator) it is often observed that the emittance growth rate of colliding proton bunches is larger compared to non-colliding proton bunches. In addition the proton background rates are increasing when the two beams are brought into collision. There are indications that a contribution results from closed orbit oscillations of the electron beam at the two IPs (**I**nteraction **P**oints). In the arcs of the electron ring oscillation amplitudes of 100 μm with frequencies of 2 – 15 Hz and harmonics of 50 Hz are observed. In order to stabilize the position of the electron beam at the IPs a local orbit feedback system with a bandwidth of more than 20 Hz has been developed. The beam positions at the IPs are measured with four BPMs (**B**eam **P**osition **M**onitors) using dedicated electronics. The four local orbit bumps are produced by ironless dipole magnets. The data are transmitted using SEDAC field bus lines to a central PC which is used for the computation of the correction.

INTRODUCTION

The electron-proton collider HERA at DESY is a double-ring in operation since the year 1992 and is used to explore the quark structure of the proton [1]. Protons with a momentum of 920 GeV/c are brought into collision with electrons or positrons of 27.5 GeV/c at two interaction points in the north (H1) and south (ZEUS). The spin-structure of the nucleons is explored at the fixed target experiment HERMES.

In the year 2000/2001 the interaction regions have been upgraded to increase the specific luminosity of HERA. The low-beta quadrupole triplet magnets of the electron ring and the double doublet of the proton ring have been moved nearer to the IP. Superconducting quadrupole magnets have been installed inside the detectors of H1 and ZEUS to achieve a beam size of $\sigma_x^\star = 118\,\mu$m and $\sigma_y^\star = 32\,\mu$m at the IPs. Due to the stronger focusing of the electron triplets and the quadrupoles in the arcs HERA-e got more sensitive to ground motion after the luminosity upgrade. The geometry of the new HERA interaction region is shown in Fig. 1.

MOTIVATION

The experience after the HERA luminosity upgrade shows that a good orbit correction of the electron ring is crucial. Synchrotron-betatron resonances can be enhanced by an oscillating orbit distortion [2]. For this reason a slow global orbit feedback system was developed [3]. It uses all 287 BPMs and a set of corrector magnets near the two interaction points for global corrections. The maximum correction frequency of the system is ≈ 1 Hz due to the bandwidth of the corrector magnets and the data transmission rate.

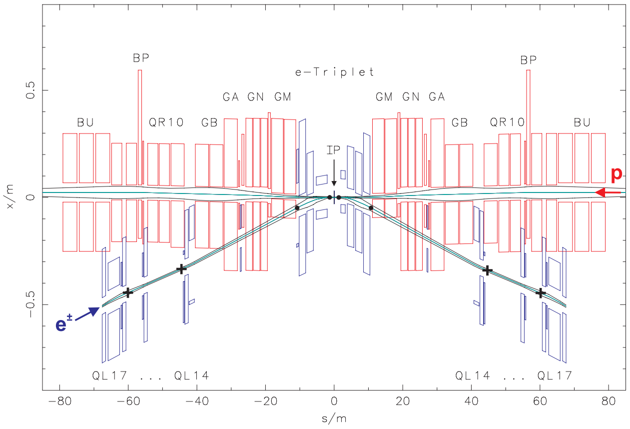

Figure 1: Top view of the HERA interaction region with the positions of the four BPMs (●) and the four corrector magnets (+) used for the local orbit feedback system.

Perturbations of the proton beam can enhance the production of the beam halo and can increase the emittance growth rate. This will deteriorate the particle background at the experiments. Modulation of the proton tune due to ripple of magnet power supplies [4][5] and orbit oscillations of the proton beam due to quadrupole movements driven by ground motion are major reasons. Another source of perturbations for the proton beam are changes of the beam-beam-force at the IPs due to beam-size or beam-orbit oscillations of the electron beam [6][7].

The closed orbit of HERA-e shows fast movements with amplitudes of $\Delta x \approx 80\,\mu$m and $\Delta y \approx 50\,\mu$m at the BPMs in the arcs. This corresponds to $\Delta x = 0.15\,\sigma_x$ and $\Delta y = 0.15\,\sigma_y$, whereas σ is the beam size. The typical spectrum of orbit oscillations measured by a BPM in the arc is shown in Fig. 2. The spectrum is dominated in both planes by frequency components between 2-15 Hz. It is likely that the source of these oscillations arise from movements of quadrupole magnets driven by ground motion. Possible candidates are the electron triplet magnets in the interaction region of H1 and ZEUS. In addition there are frequency lines at 50 Hz, 100 Hz, 300 Hz and 600 Hz with a fixed amplitude and which may results from magnet power supply ripple.

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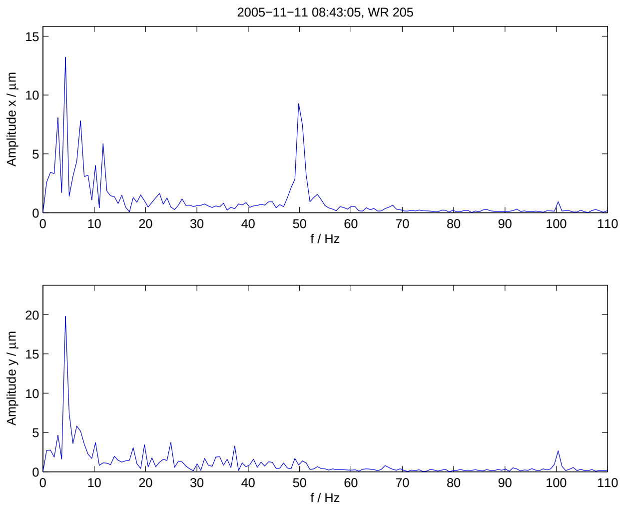

Figure 2: Orbit spectrum in the horizontal (top) and vertical plane (bottom) measured by BPM WR 205.

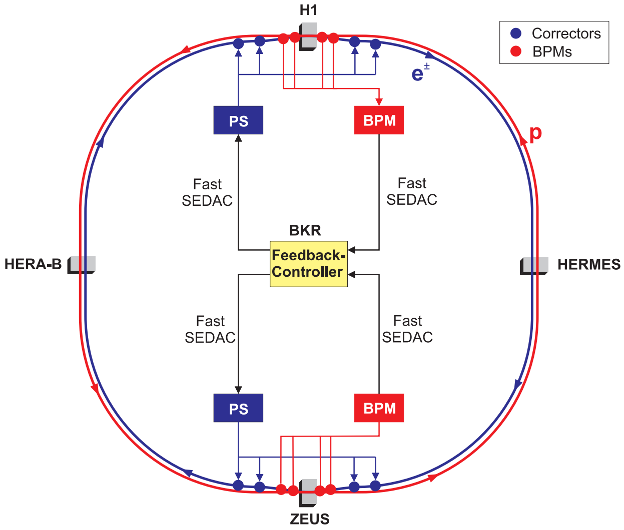

Figure 3: Layout of the local IP orbit feedback of HERA.

IMPLEMENTATION

To reduce the amplitude of the orbit oscillations of the electron beam at the interaction points at ZEUS and H1 a fast local orbit feedback has been designed.

The last two BPMs upstream and the first two BPMs downstream of each IP are used for the system. They were equipped with special electronics, which allow to transmit the data with a high transmission rate to the central control computer. All BPMs can measure in both planes.

Stabilizing the electron position at the IPs is sufficient for background reduction, because beam angle oscillations at the IP have a negligible influence on the proton beam dynamics. To reduce the required kick strength of the steerer magnets and to have more flexibility in case of optic changes four magnets are used for each bump. The complete feedback system consists of four independently controlled local bumps for two IPs and two planes.

A central PC is used as the controller for the four feedback loops. The layout of the new local IP orbit feedback system is shown in Fig. 3. At the moment the system is in the final production and installation phase.

The feedback is designed to reduce the horizontal and vertical orbit oscillations of the electron beam at the IPs by at least a factor of 10 for frequencies $1 \leq f \leq 50$ Hz.

Beam Position Monitors

The BPM system of HERA-e uses monitors with four round electrodes in a symmetrical configuration. The signals induced by the beam on the electrodes are individually delayed and then combined on a single coax cable connected to the BPM electronics. Then they pass a low pass filter and a switchable attenuator. The signals of all four buttons is send to an amplifier, a peak-hold circuit and is then digitized by a fast 8 bit ADC. The system is self-triggered and all of the bunches (typically 150 to 180) in the filling can be used for the measurement of the beam position. To improve the accuracy several measurements can be added before the result is stored in an internal register. The BPM modules are connected to a field bus and the data can be read out by a computer. Beam positions are calculated from the four electrode signals using the Δ/Σ-algorithm.

Four BPMs near the interaction points at ZEUS and H1 are equipped with special electronics, which allows to measure and transmit orbit data with a high rate. In principle the two BPMs located nearest to the IP at 2 m up- and downstream of the IP are sufficient for the computation of the beam position at the IP, because a drift space is between them. Nevertheless two more BPMs located at 11 m left and 15 m right are used to improve the accuracy of the measurement and to make the system more fault-tolerant.

To improve the position resolution 4096 measurements are averaged. This takes approx. 0.6 ms or 27 turns for a filling of 150 bunches. Because the BPMs at 2 m can measure the electron and proton positions simultaneously they need non-colliding bunches in the filling pattern for operation. Due to the limitation of only one measurement per turn the resolution of the 2 m BPMs is by a factor of 10 lower compared to the other two BPMs. On the other side these BPMs give the opportunity to correct the electron-protron orbit difference at the IPs.

Corrector Magnets

The dipole magnets used for the orbit correction at HERA are unsuitable for a fast feedback system due to their high resistance and inductance. For this reason an ironless dipole magnet, which consists of two racetrack coils, was designed.

The horizontal dipole magnet has 2×210 turns, an effective field length of 0.33 m, and produces a magnetic field of 23 Gauss for a current of 1 A. The coil resistance including the cable to the power supply is $8\,\Omega$ and the inductance $36\,$mH. The parameters of the vertical magnet are similar. The magnets are installed at 42 m and 61 m up- and downstream of the IP (see Fig. 3).

Bipolar computer controlled power supplies were designed which have a maximum current of $\pm 2.5\,$A and a bandwidth of more than 1 kHz. One magnet module can power four independent corrector magnets. In total two magnet modules are needed per interaction region. As a compromise between resolution and data transmission rate 8 bit DACs were chosen. The reference values of the DACs can be set individually.

Eddy Current Effects

The vacuum chamber of HERA-e has a rectangular shape with slanted corners and attached cooling channels at both sides. It has been manufactured from a copper alloy of $4\,$mm thickness. Eddy currents are induced in the chamber which increase strongly for higher frequencies. They generate additional magnetic fields which attenuate the field of the coil and shift its phase.

Due to the high conductivity of the material of 30 % of copper this effect is relatively big. Field attenuation, phase shift and the change of the field form have been measured on a magnetic test stand for different frequencies. At 20 Hz the attenuation is 30 % and the phase shift 30°, at 50 Hz it is 60 % and 50° for the horizontal magnet including the chamber.

The magnets will be installed at locations where the geometry of the vacuum chamber is identical. Otherwise the different temporal behaviors of the fields produced by the eddy currents prevent the bump closure during correction.

Data Communication and Control

All BPM modules in each IR are connected to one field bus. The in-house developed Fast-SEDAC (**SE**rial **D**ata **A**cquisition and **C**ontrol) field bus is used, which is a 1 Mbit/s serial bus. It has a single master and multiple slaves.

To reduce the time lag between data acquisition and orbit correction the data transmission rate needs to be as high as possible. Therefore four independent field bus lines for the BPMs are used. The two magnet modules which supply eight correctors in each interaction region have a separate field bus line.

A 3 GHz standard PC running Windows XP is used as the controller for the four feedback loops. It reads out periodically the BPM modules, calculates the beam position at the IPs, determines correction kicks of the corrector magnets and sends new current set points to the magnet modules. The control software used is based on a similar fast global orbit feedback system developed for DORIS [8].

To assure that all BPM modules start their data acquisition simultaneously and that all magnet modules set the correction at the same time a configurable trigger module is used. The readout cycle of the BPMs is synchronized to this trigger module.

The time needed to transmit a 32 bit data packet (“SEDAC telegram”) is $90\,\mu$s and in total 10 telegrams are necessary to read out all electrode signals of all four BPMs (four electron and two proton beam positions) in one interaction region. In addition telegrams are send to change the attenuator and the add-value and to read status information. This limits the sampling rate of the IP trajectory to 850 Hz. The computation of the correction is short compared to the time necessary to transmit a telegram. To set the corrector currents two SEDAC telegrams for each IP are necessary. This adds another $180\,\mu$s to the total time delay between measurement and correction.

The main contribution of the time delay in the feedback loop is the phase shift due to eddy currents in the chamber. This limits the correction of the frequency component at 50 Hz. Fortunately this component is stable in phase over a longer time and can therefore be corrected by an additional feed-forward loop.

SUMMARY

A fast local closed orbit feedback has been designed and is in its final production phase. The readout of the BPM modules, the computation of the IP-orbit positions and the control of the magnet modules is ready. Prototypes of correction coils have been built and tested both on a test stand and in the ring. The coils are currently in the production process and ready for the installation in July. First results are expected in summer this year.

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