The Desy III Beam-Orbit Measurement System

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Abstract. The new beam-orbit measurement system for the 7.5 GeV/c proton synchrotron DESY-III is based on commercial read-out and data-acquisition electronics. The beam position is detected with 31 inductive pickup stations along the 300 m circumference. Technical details of the BOM-system and first orbit measurements are presented.

INTRODUCTION

Since 1992, the ring accelerator complex HERA is in operation on the DESY site, running with 920 GeV/c protons and 27.5 GeV/c (polarized) leptons for HEP experiments. One of the major luminosity limitations is due to the limited proton bunch charge. The maximum bunch charge is determined by that accelerated in DESY-III: at 310 MeV/c a H^- multiturn injection is realized between the LINAC-III and the proton synchrotron DESY-III. A thin foil (C, 30 μgcm^{-2}) strips off the electrons at injection, leaving protons circulating in the synchrotron. In this way we typically accumulate a coasting beam of $\approx 2.33 \times 10^{12}$ protons during 12 turns into the synchrotron. Emphasis is put on minimizing the beam-losses during the energy ramp in DESY-III and all further treatments of the proton beam in the post-accelerators.

The majority of the loss during acceleration in DESY-III occurs at low energy, mainly due to the large transverse emittance driven by space-charge effects (see Figure 1). Adjustment of the closed orbit at injection is critical to keep the losses at a minimum. At present this is a somewhat empirical process, hence the motivation to establish a *beam-orbit measurement system* for DESY-III.

This BOM-system has to be based on the 31 existing *inductive beam-position pickup stations* located along the $\approx$ 300 m circumfence of the synchrotron. In the past they were used to observe the beam-position of a selectable pickup vs. time, i.e. to watch the beam-position through the 1.65 sec of the energy-ramp. The new system should keep this BPM functionality and add simultaneous read-out of all

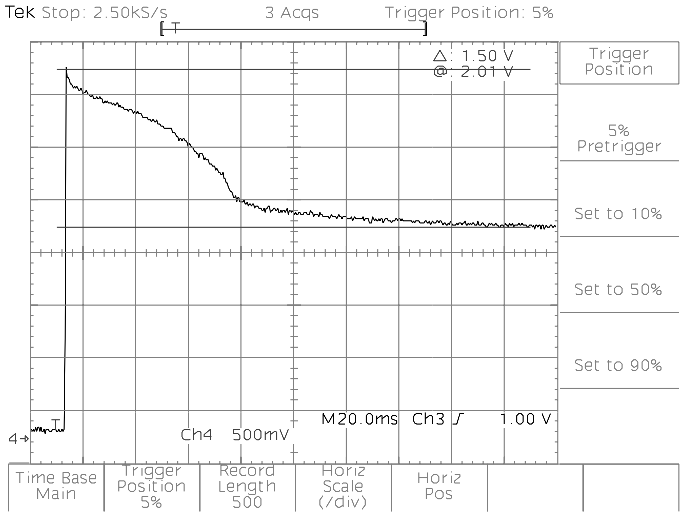

FIGURE 1. Proton current plot showing the beam-loss at the beginning of the energy-ramp in DESY-III (vert. scale: 6.67×10^{11} protons/volt).

31 pickup stations at a selectable time anywere in the ramp for the beam-orbit monitoring.

DESY-III BEAM PARAMETERS AND BOM-SYSTEM REQUIREMENTS

Some important parameters of DESY-III are (see also Table 1):

- 316.8 m circumference.
- H^- multiturn injection through a stripping foil (coasting beam at flat bottom energy).
- 4.48 sec cycle time, 1.65 sec ramp time.
- 11 bunches ($h = 11$) are formed within the first 50 ms of the injection porch.

TABLE 1. Energy variing parameters in DESY-III

	flat bottom	flat top
E	310 MeV/c	7.5 GeV/c
f_{rev}	297.05 kHz	938.99 kHz
p/bunch	2.0×10^{11}	1.3×10^{11}
f_s	4.5 kHz[a]	125 Hz

[a] maximum f_s @ 100 ms after injection

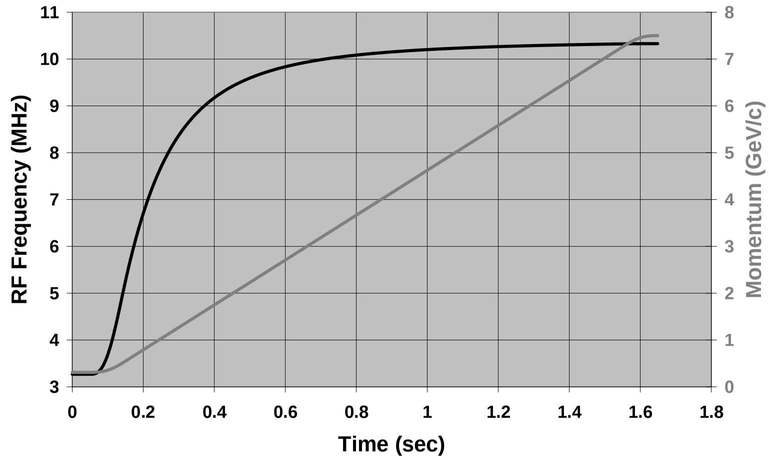

FIGURE 2. RF frequency and momentum vs. time during the DESY-III energy-ramp.

For the design of the BOM-system it is important to notice the large change of f_{rev} during the 1.65 sec energy-ramp (Figure 2). This also has a strong influence on the bunch length:
Just after the injection (20 ms) 11 bunches are formed by raising the voltage on the rf-transmitter ($f_{\text{RF-bottom}} = 3.27$ MHz); here the bunch-to-bunch spacing is 306 ns and the bunch length is nearly 100 ns. During the ramp the voltage of the rf-transmitter is raised, while the frequency is increased about a factor of 3 to finally $f_{\text{RF-top}} = 10.33$ MHz at the flat-top ejection energy. This corresponds to a bunch-to-bunch spacing of 96.8 ns, while the bunch length reduces to 6...8 ns(FWHM).

One consequence of this frequency variation is that a time-domain approach is rather difficult to realize for the BPM read-out electronics. A self- or external triggered peak detection method has not only to cope with a high dynamic range and varying bunch-to-bunch spacing, but also with large longitudinal oscillations due to instabilities at higher beam intensities. The amplitude of this motion can be as large as the bunch length(!) and results in non-equidistant bunch-to-bunch spacings.

The main specifications for the BOM-system can be summarized:

- *Beam-orbit monitoring (BOM)*, by read-out and acquisition of all 31 beam-position pickups simultaneously, at a selectable time anywere in the 1.65 sec energy-ramp.
- *Beam-position monitoring (BPM)* of a selectable beam-position pickup vs. ramp-time.
- The BOM/BPM measurement has to supply reliable data, starting from $t \geq 20$ ms after injection; here the BPM-pickups delivers detectable signals because of the rf-bunching.
- The dynamic range must be sufficient to detect beam signals with intensity variations of 0.1...1.5 times the nominal beam current (assuming all 11 bunches

are ramped); but shall also operate with a reduced number of bunches in the ring.

- The read-out electronics do not have to acquire the beam-position of a single bunch or operate on a turn-by-turn basis; the beam-position measurement may integrate over some 100 turns.
- The resolution requirements are moderate, a relative resolution of 0.2...0.4 mm in the 84 mm circular vacuum chamber is sufficient.
- The BOM/BPM measurement should also operate – although with limited performance – in the presence of strong longitudinal oscillations of individual bunches (synchrotron frequency oscillations, not in phase).

DETAILS OF THE BEAM-ORBIT MEASUREMENT SYSTEM

Collecting all the boundary conditions and requirements, a frequency-domain approach for the DESY-III beam-orbit measurement system was favored. Due to manpower limitations we focused on commercial subsystems and modules for the electronics hardware wherever possible.

System Overview

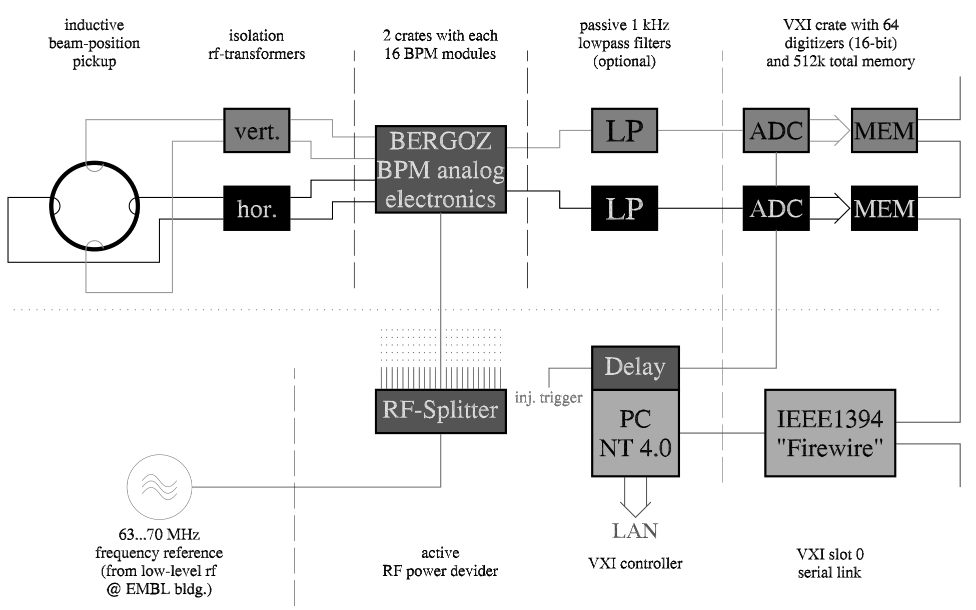

FIGURE 3. Overview of the DESY-III BOM/BPM-system (one read-out channel).

Figure 3 shows a simplified overview of one channel of the BPM hardware. The signals of the orthogonally arranged coils of the inductive beam-position pickup are fed via isolation rf-transformers into the analogue *BPM read-out electronics*. This modified *BERGOZ* BPM-electronics outputs horizontal and vertical *beam-position dependent signals* with the help of a rf-synchronous *reference signal*. Passing an optional 1 kHz lowpass filter, these DC-like analogue signals are digitized and acquired with commercial *16-bit VXI-digitizers*. The VXI-crate is controlled from a server-PC through an IEEE1394 "firewire"-link, on which the BPM server application program runs. The DESY-III injection trigger is used as reference time. A programable delay generator, located as a plug-in card on the AT-bus of the server-PC, defines the required trigger point on the ramp, triggering simultaneously all ADC's in the digitizer modules. The server-PC is connected to the DESY-LAN and controlled with a client program from the central control room.

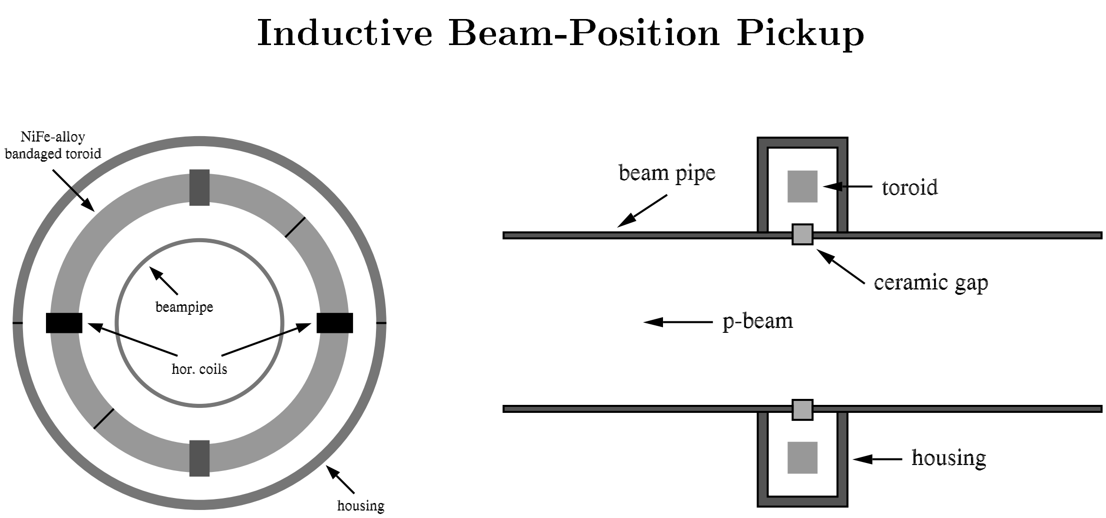

FIGURE 4. Schematic of the inductive beam-position pickup

The inductive beam-position pickup consists of a ferrite core of 120 mm inner diameter, holding 4 orthogonally arranged coils (Figure 4). The device acts on the magnetic field components of the proton beam, which passes the circular beam pipe of 84 mm diameter through a 10 mm long ceramic gap. The signal-levels of each coil depend on the beam intensity, as well as on the beam-to-electrode(coil) distance, i.e. the beam position (it's center of charge). The principle of operation of the inductive pickup can be compared with a transformer, the proton beam acting as primary coil and each of the 4 coils on the ferrite core as secondary one. For this reason it is impossible to detect a signal from the injected coasting beam, which would be equivalent to simply transforming DC. Useful signals are picked up about 20 ms after injection, when the rf-voltage is raised and the beam bunched.

The characteristics of the pickup were studied in detail on a computer-controlled bench-teststand, with the beam simulated by a moveable coaxial wire on which bunch-like signals were fed from a pulse-generator [1]. The normalized position characteristic of $\Delta/\Sigma \approx 1.2$ %/mm is rather insensitive, but very linear over the complete aperture. The measured frequency response ranges from 30kHz...250MHz (-3 dB).

The beam induced signal levels of each coil electrode were measured with an oscilloscope during standard operation of DESY-III. They range between some 10 mV at the flat-bottom and several volts at the flat-top energy (peak-peak amplitudes, 50 Ω termination).

Analogue BPM Read-Out Electronics

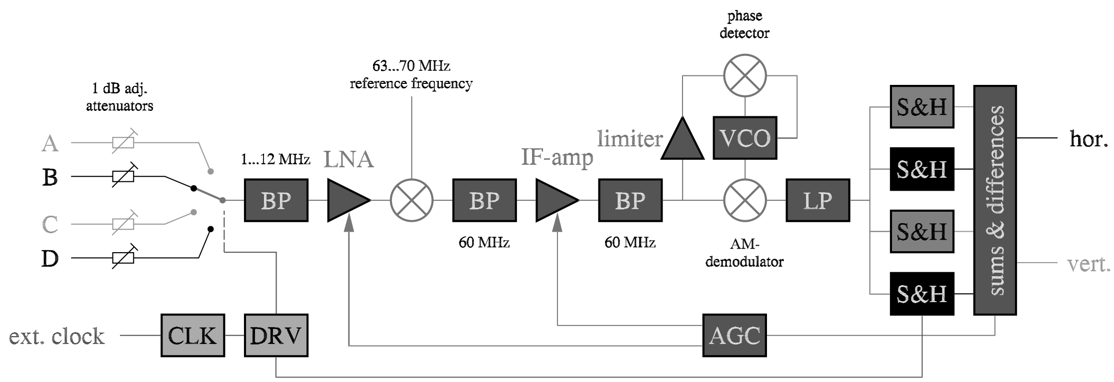

FIGURE 5. Schematic of the *BERGOZ* BPM-electronics.

An important part of the BOM-system is the analogue BPM read-out electronics, which is supplied for each beam-position pickup. Fed with the 4 signals from the pickup it deduces a beam intensity independent position signal for the horizontal and vertical plane. We decided to use the commercial *BERGOZ* BPM-electronics (details see [2], [3]), which was originally developed for the ALS at LBL. It processes the signals in the frequency-domain with a switched single channel superheterodyne receiver (Figure 5). To make it operate under DESY-III conditions *BERGOZ* had to make some modifications:

- Lower the input frequency range to $\approx$ 3...10 MHz.
- Change the IF stages to 60 MHz center frequency, 500 kHz 3 dB-bandwidth.
- External LO input for feeding the rf-synchronous $\approx$ 63...70 MHz reference signal from the DESY-III low-level rf-synthesizer.
- Increase of the clock frequency for the electronic switches (4 kHz).
- Speed up the AGC feedback loops to achieve a beam-position detection 20 ms after the injection.

The BPM receiver analyses the input level of a pickup coil-electrode for 62.5 μsec, before switching to the next electrode. The demodulated signals are frozen with a separate sample&hold circuit for each electrode, so that an analogue op-amp circuit deduces Σ-normalized horizontal and vertical position signals. The varying input frequencies of the bunch signals are upconverted to a constant 60 MHz IF. Using a rf-synchronous LO-frequency of $\approx$ 63...70 MHz converts the input frequency range to 3...10 MHz. In this way we can detect the beam position everywhere through the complete energy-ramp of DESY-III, being insensitive to the number of bunches (1...11) ramped up.

Data-Acquisition

The horizontal and vertical output signals of the analogue BPM-electronics are DC-like signals (bandwidth $<$ 10 kHz), ranging -10...+10 volts, with $\approx$ 0 volt for a centered beam. The *data-acquisition* is realized with 64 (using 62) independent 16-bit analog/digital-converters (ADC) sharing 512kWords of total memory. This commercial data-acquisition system is housed on 2 VXI C-sized boards, each with 2 submodules containing 16 ADC's and 128kWords memory (*VXI-Technologies VM2616*). Without upgrading the memory each complete DESY-III ramp may be acquired in 500 μsec steps simultaniously from all 2×31 channels. The minimum sampling time of the ADCs of 10 μsec is not used, for most BOM/BPM applications the sampling time is set to 1 ms.

The VXI slot-0 controller is realized by an IEEE1394 "firewire"-link to the PCI-bus of the server-PC, which runs under the Windows NT 4.0 operation system. Also controlled by the server-PC is the delay generator (*Stanford DG135* PC plug-in card), which delivers the ADC trigger.

FIRST OPERATION EXPERIENCE WITH THE BOM-SYSTEM

For commissioning of the DESY-III BOM-system a *HP-VEE* server program was written, controlling the VXI-crate and the delay generator. It is easy editable and has an interface to the accelerator control system. We limited the server functionality to the two main tasks: beam-orbit monitoring and beam-position monitoring, which are realized as two different subroutines in the code.

After successful implementation of the server routine, a client program was established for operation in the control room (see Figure 6).

The two bar graphs on the left side in Figure 6 are show a measured difference orbit: in the lower plot of the vertical plane no significant difference is observed, while the upper plot of the horizontal plane shows the effect of a "frequency"-bump. The orbits were taken at the end of the ramp (flat-top), trigger point was 1.8 sec after injection.

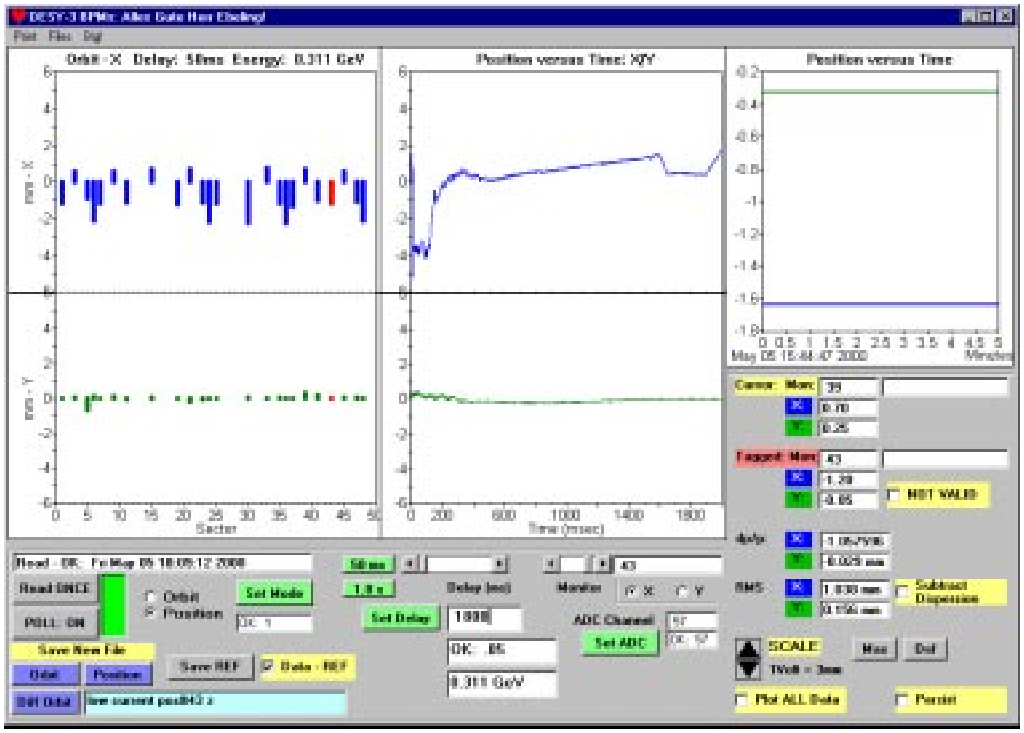

FIGURE 6. Desy-III BOM/BPM display in the control room (*Visual Basic* client program).

The actual beam-position vs. time is plotted in the center of the display. At the end of the upper, horizontal, BPM trace a trapezoidal bump of ≈ 100 ms duration appears because of the programmed frequency-bump. The beam-position at this location is by no means constant throughout the ramp, which is typical for all horizontal monitors. In the lower, vertical, BPM trace no large position displacements are observed through the ramp.

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