A HIGH RESOLUTION DIODE-BASED ORBIT MEASUREMENT SYSTEM – PROTOTYPE RESULTS FROM THE LHC

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Abstract

The prototype of a high resolution beam position monitor (BPM) electronics based on diode peak detectors has been tested with LHC beams. In this technique developed at CERN the short beam pulses from each BPM electrode are converted into slowly varying signals by compensated diode peak detectors. The slow signals can be digitized with a high resolution ADC. This technique allows resolutions well below 1 µm to be achieved with simple hardware. Ongoing developments and future prospects for the technique are also discussed.

HARDWARE

As shown in the block diagram in Fig. 1, the compensated diode peak detector consists of two detectors, one with a single, and the second with two fast Schottky diodes. All three diodes are integrated into one package, which allows good symmetry of the forward voltages and thermal coupling. The compensation circuit consists of two operational amplifiers, OA_1, OA_2. Assuming identical diodes, the voltage difference at the detector outputs is equal to one diode forward voltage V_d. This voltage is converted into current V_d/R_{oa2}, which in turn is converted back into V_d with $R_{oa1}=R_{oa2}$. In this way $2V_d$ is added to the output of OA_2, compensating $2V_d$ drop on the two diodes D_{2a}, D_{2b} and the output voltage V_o is equal to the input voltage V_i.

The principle and first lab measurements with the compensated diode peak detectors are described in [1]. This contribution focuses on the prototype of the Diode ORbit (DOR) front-end (FE), based on such detectors.

The prototype is housed in a 1U 19” unit accommodating four identical channels, one for each BPM electrode. Each channel consists of the following blocks:

- constant-impedance 80 MHz low-pass input filters followed by an insulation transformer;
- programmable gain amplifier built with an optional 10 dB attenuator and two fast op-amps having feedback resistors selected with GaAs switches for gains from 10 dB to 40 dB in 5 dB steps;
- compensated diode detectors with two low noise, precision JFET-input op-amps;
- 10 Hz low-pass filter with a precision op-amp.

The filter outputs are connected to front panel connectors foreseen for an external acquisition and internal 24-bit ADCs clocked from a local quartz oscillator. All ADC channels are sampled simultaneously at 11.7 kHz. The resulting data is transmitted to a simple microcontroller through an SPI interface, sending the data as UDP packets over an Ethernet link. The microcontroller has a simple web interface for controlling

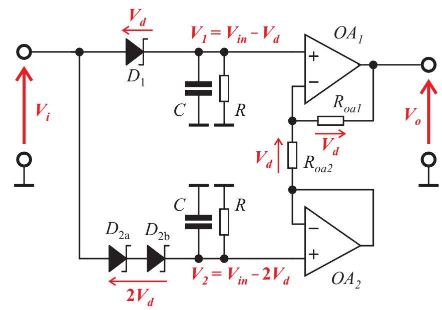

Figure 1: Compensated diode peak detector diagram.

the FE gains. The prototype does not have any temperature stabilisation, adjustable components nor calibration.

MEASUREMENTS

The described DOR FE was installed in the LHC and was connected over some 50 m of coaxial cables to a short-circuited 150 mm stripline BPM with an inter-electrode distance of 48 mm. The BPM signals were attenuated by 30 dB for testing with smaller signals and to operate the FE at its maximal gain of 40 dB to evaluate its noise performance. The FE output signals were acquired with the internal ADCs and in parallel with a 6.5-digit laboratory voltmeter with an Ethernet interface. The single voltmeter channel was multiplexed between the 4 FE outputs, resulting in one measurement every second for each channel, with some 0.1 s delay between the reading of the consecutive channels.

Figure 2 presents typical raw DOR signals acquired with the voltmeter during an LHC fill (# 1771, 20/05/11). The record starts with one nominal bunch in the machine. The signal step increase around 3:51 corresponds to the injection of a second bunch. These signals are used to calculate the beam positions presented in Fig. 3, alongside with the corresponding positions obtained with a button pick-up located within 0.5 m distance and used for the standard LHC BPM system [2]. The largest observed difference in readings from both systems is some 200 µm (i.e. about 0.5 % of the aperture), which is small, given the fact that none of the systems was subjected to any correction or calibration procedure.

In Fig. 4 the initial beam offsets of Fig. 3 are removed to reveal finer details of the orbit evolution. The orbit change around 3:55 corresponds to machine adjustments before the energy ramp. The fast orbit drifts at the beginning of the acceleration period around 4:02 are caused by the snap back with the later slow drifts occurring during the ramp. Around 4:28 the orbit feedback (OFB) is turned off, making the orbits measured by the DOR system more stable. This indicates that the

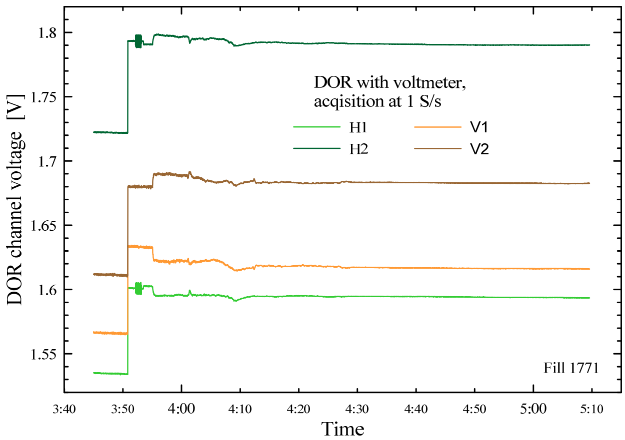

Figure 2: Raw signals from the DOR system.

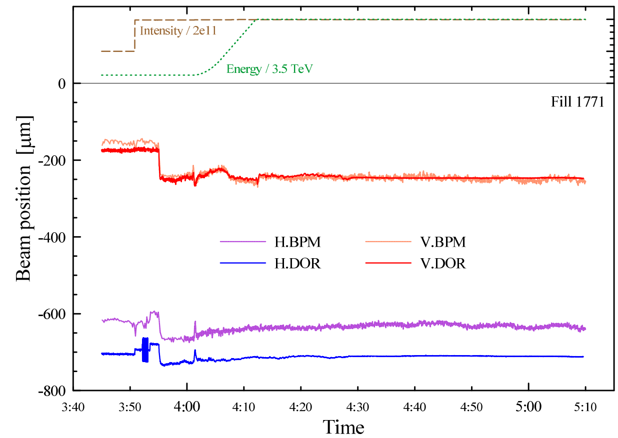

Figure 3: Beam orbits from the BPM and DOR systems.

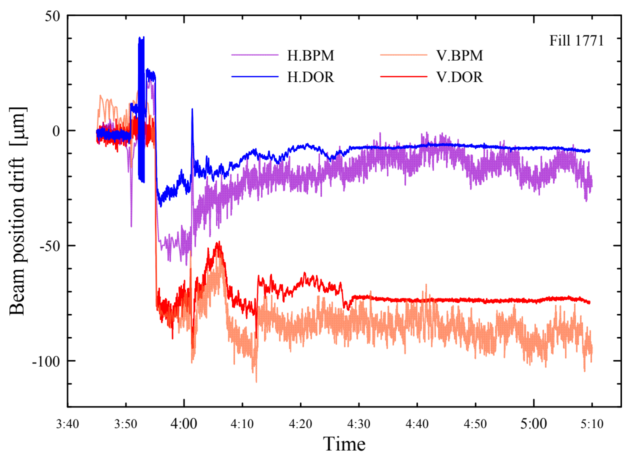

Figure 4: Beam orbits of Fig. 3 without initial offsets.

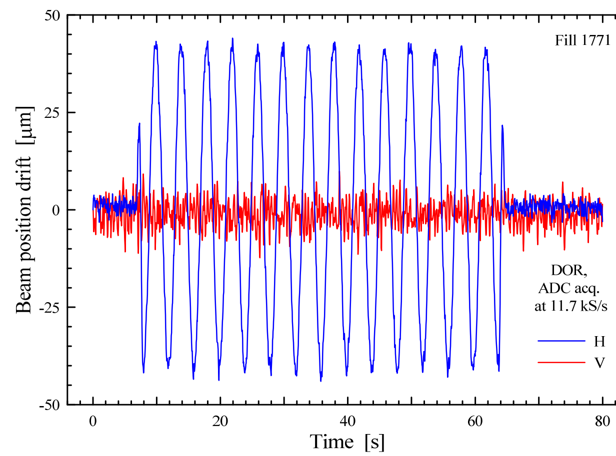

Figure 5: A zoom on the radial modulation part at 3:52.

residual orbit stability with the active OFB is given by the measurement noise of the standard LHC BPM system.

Figure 5 shows orbits from the DOR system related to a radial modulation of $\Delta p/p = 2{\times}10^{-4}$ at 0.25 Hz, routinely used for chromaticity measurements. They were acquired with the DOR ADCs.

Comparisons between measurements covering 100-second beam orbit drifts measured with the DOR system and ADCs at two energies and OFB 'on' and 'off' are shown in Fig. 6. It can be seen that beam drifts are much larger at 450 GeV than those at 3.5 TeV. They are caused by power converter ripple propagated onto the beam and the ripple scales with energy.

To distinguish the DOR system noise from the beam noise, Fig. 7 shows the first second of each period of the orbit acquisitions shown in Fig. 6. The hypothesis is that the amplitude of the DOR system noise is only defined by the width of the orbit curves in Fig. 7. This is defended using Fig. 8, showing the raw DOR signals corresponding to the third "4:41" period of Fig. 7 as well as their algebraic sum. This sum changes much less than its components, indicating that the 4 individual DOR channels observe correlated signal drifts rather than incoherent noise, that is the observed slow orbit drifts are due to real beam motion. The residual ripple on the sum signal could be related to slow bunch shape modulation, resulting in the corresponding modulation of the bunch pulse amplitudes. Still, a certain contribution to this noise is from the DOR system itself. The presented measurements indicate that the DOR system noise is at least much smaller than the beam noise with 10 Hz analogue bandwidth and 40 dB FE gain.

The last plot in Fig. 9 presents the first 10 ms of the orbits shown in Fig. 7. The seen noise has a time structure beyond the 10 Hz bandwidth of the last filter in the DOR processing chain. Thus, it is likely related to the noise of the ADCs themselves. The shown orbits are derived from the ADC samples acquired at a 11.7 kHz rate. Therefore, if one averages them by e.g. a factor 470, down to 25 Hz, the rate presently used in the LHC OFB system, one would expect that the observed drifts of some 100 nm_{pp} (nm peak-peak) reduce to 5 nm_{pp}. This ADC noise is certainly not a limit for the LHC machine, since the orbit motion observed is orders of magnitude larger.

CONCLUSIONS AND OUTLOOK

Compensated diode detectors are an efficient and simple means of converting fast pulses into slowly varying signals, which can be digitized with very high resolution, typical for DC signals, without beam synchronous timing. Since each BPM electrode signal is

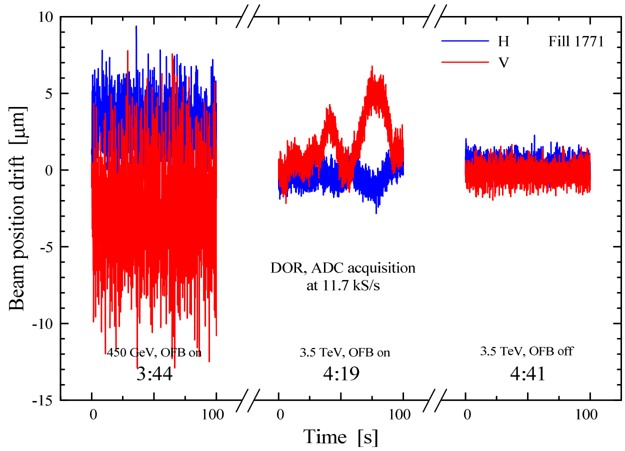

Figure 6: Zoom on 100-second DOR orbits.

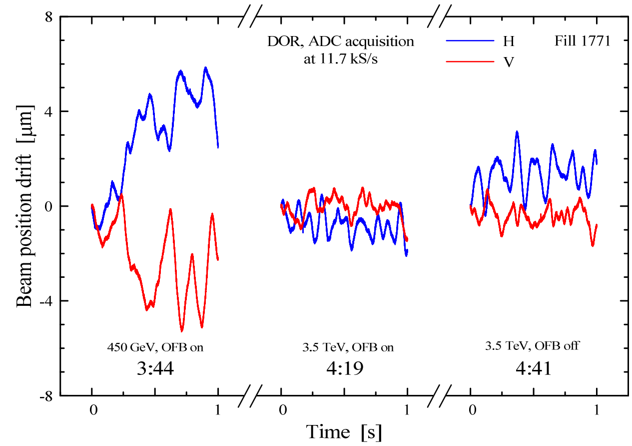

Figure 7: Zoom on the first second of the orbits in Fig. 6.

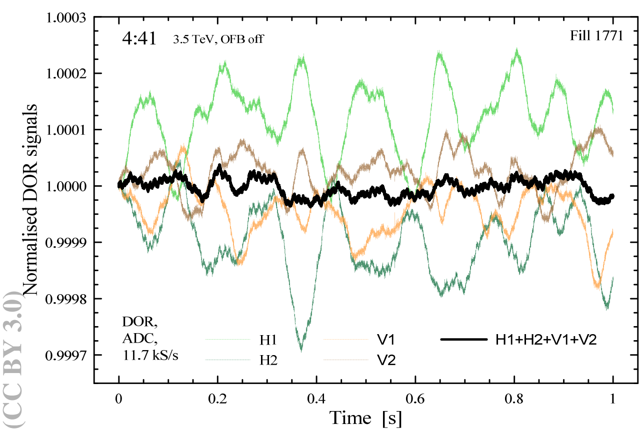

Figure 8: Zoom on the first second of raw signals at 4:41.

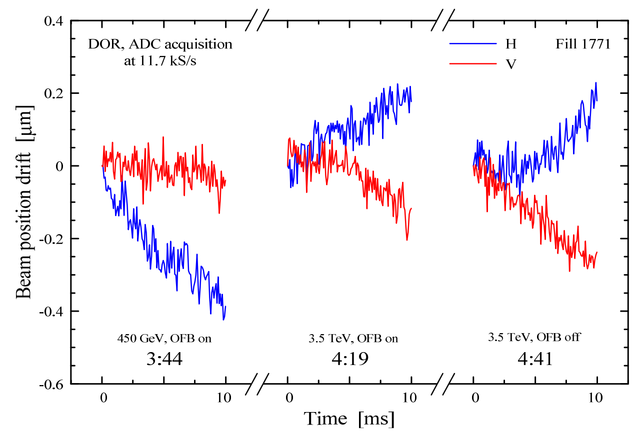

Figure 9: Zoom on the first 10 ms of the orbits in Fig. 7.

processed separately, a tight phase matching of the input cables is not required.

The compensation scheme works well for signals with amplitudes in the order of 1 Vpp. Smaller signals require amplification, but the related noise is gated by the diode detectors and, for short pulses and large detector time constants, contributes very little to the output signal. Similarly, natural gating capabilities make this technique insensitive for signal imperfections in between the processed pulses, e.g. those related to signal reflections.

The prototype of the diode orbit measurement system has been evaluated with beam and compared to a standard LHC BPM. The DOR resolution obtained is much better than the natural LHC orbit drifts observed and is estimated to be well below 1 µm with 40 dB FE gain and with a 10 Hz analogue bandwidth.

In order to achieve a high absolute accuracy it is planned to compensate any slow drifts of the electronics and input cables by multiplexing the BPM signals between the FE channels [1]. The performance of this approach remains to be evaluated.

The DOR technique was primarily developed for the future LHC BPMs which are foreseen to be embedded into collimator jaws [3]. The results obtained encourage its use for other applications, e.g. to improve orbit measurement in critical LHC locations.

The inherent gating capabilities of the technique can also be employed in LHC locations where both beams share one vacuum chamber. The separation of the signals related to each beam is currently limited by the directivity of the stripline BPMs used. Any residual signals from cross-talk from the other beam would be ignored by DOR electronics.

The described DOR prototype was equipped with two separate channels for processing beam oscillation signals, similar to those used for tune measurement [4]. Results from this sub-system will be described in a separate publication.

ACKNOWLEDGMENTS

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