CALIBRATION OF OLYMPUS/DORIS BEAM POSITION MONITORS

U. Schneekloth, N. Görrissen, G. Kube, J. Neugebauer, R. Neumann, F. Schmidt-Föhre
DESY, Hamburg, Germany

Abstract

The goal of the OLYMPUS experiment is a precise measurement of the ratio of the positron-proton and electron-proton elastic scattering cross sections in order to quantify the effect of two-photon exchange. The experiment was performed using intense beams of electrons and positrons stored in the DORIS ring at Deutsches Elektronen Synchrotron in Hamburg, impinging on an un-polarized, internal, hydrogen gas target. An essential ingredient of the experiment is a precise determination of the luminosity, which requires a precise knowledge of the beam position of both beam species. During DORIS operation cylindrical button beam position monitors, read out by two independent electronics systems, were mounted up- and downstream of the target chamber. After the end of operation, the readout systems were cross-calibrated. The BPMs were then calibrated using a test-stand, consisting of a wire scanner assembly. The beam was simulated by applying an RF signal to the wire. This paper describes the calibration principles and test setup, together with the results compared to the expected BPM response.

INTRODUCTION

The OLYMPUS experiment at DESY [1] aims to determine this two-photon contribution by measuring the ratio of the positron-proton to electron-proton cross sections. The experiment was performed at the DORIS storage ring, with 2 GeV electron and positron beams impinging on an un-polarized, internal, hydrogen gas target. For the aimed-for precision of the experiment, the beam position was required to be known on the 0.1 mm level, since it directly affects the acceptance of the detector systems.

During DORIS operation the beam position at the OLYMPUS target chamber was measured by two beam position monitors (BPMs), mounted up- and downstream of the target chamber. The BPMs consisted of four cylindrical pickup buttons of 10.8 mm diameter in a cylindrical 60.3 mm diameter beam pipe. The BPMs were readout by two independent electronics: the standard DORIS electronics (so-called Neumann electronics) [2] and the commercially available Libera Brilliance+ readout system [3]. Both readout systems use the same measurement principle: the beam position is calculated as $X = k_x((V_a + V_d) - (V_b + V_c))/\Sigma - X_{offset}$ and similarly for Y, where V_i is the voltage at pickup electrode i, k_x a calibration constant and Σ the sum of the four voltages. However, the signal processing is quite different. The Neumann electronics does serial signal processing (Delay-line Multiplex Single Pass Technology). The four analog signals are passed through a delay line and are then sent to the same ADC. A gain/attenuation correction in done is steps of 1 dB. In constrast, the Libera electronics uses parallel signal processing, including RF channel switching, amplitude compensation, phase equalization and automatic gain control. Calibration constants k_x and k_y for the standard DORIS vacuum chamber profile were determined by measurements many years ago. For the present cylindrical BPMs the constants were calculated using a boundary element method as described in [4].

Data from both readout systems were stored in the DORIS accelerator archive. All of the Neumann data were stored in the OLYMPUS slow control data base, whereas the Libera data were only available for the last part of the data taking period.

The goal of the present studies was: calibrate the up- and downstream BPMs, i.e. determine the zero-positions and the response to the wire position, check whether there was a dependence on the beam current (wire input signal) and beam species (pulse polarity), and to transform the beam position (wire position) into the OLYMPUS coordinate system. In addition, the two different readout electronics were cross-calibrated, in order to get consistent beam position information for the complete running period.

SETUP OF BPM TEST STAND

The calibration of the OLYMPUS/DORIS BPMs was done on a vertical BPM test-stand, based on an original design by Paul-Scherrer-Institute (PSI), Villigen, Switzerland. The original test stand construction was comprised of a vertically oriented segment of the beam tube containing a single button-type BPM chamber, fixed by a flange on a holder-table at the lower end of the setup. A thin wire-antenna, stretched by an oil-damped steel-weight at its lower end, is fixed in a N-type RF-connector, that is placed at the outer end of a horizontal wire-holder plate attached to a x/y- micrometer-portal-guide (mover) on top of the C-shaped steel holder-frame of the test-stand. The wire-antenna is driven by an appropriate pulsed or cw RF-generator-signal via the N-connector. A solid RF-ground connection between the RF-connector and the fixed beam-tube enables an optimum conduction of the RF-signal, avoiding an instable transition of the characteristic impedance between signal source cable and antenna. The present setup incorporated a second button BPM chamber, located below the first one on the upper end of the structure. During the pre-tests, the signal originally driving the antenna by a tuned, typically 2 ns long button-type pulse-signal of 40 V, turned out to be too low for the Libera electronics. After changing the source generator setup to a sinusoidal 500 MHz-cw-signal and optimization

ISBN 978-3-95450-141-0

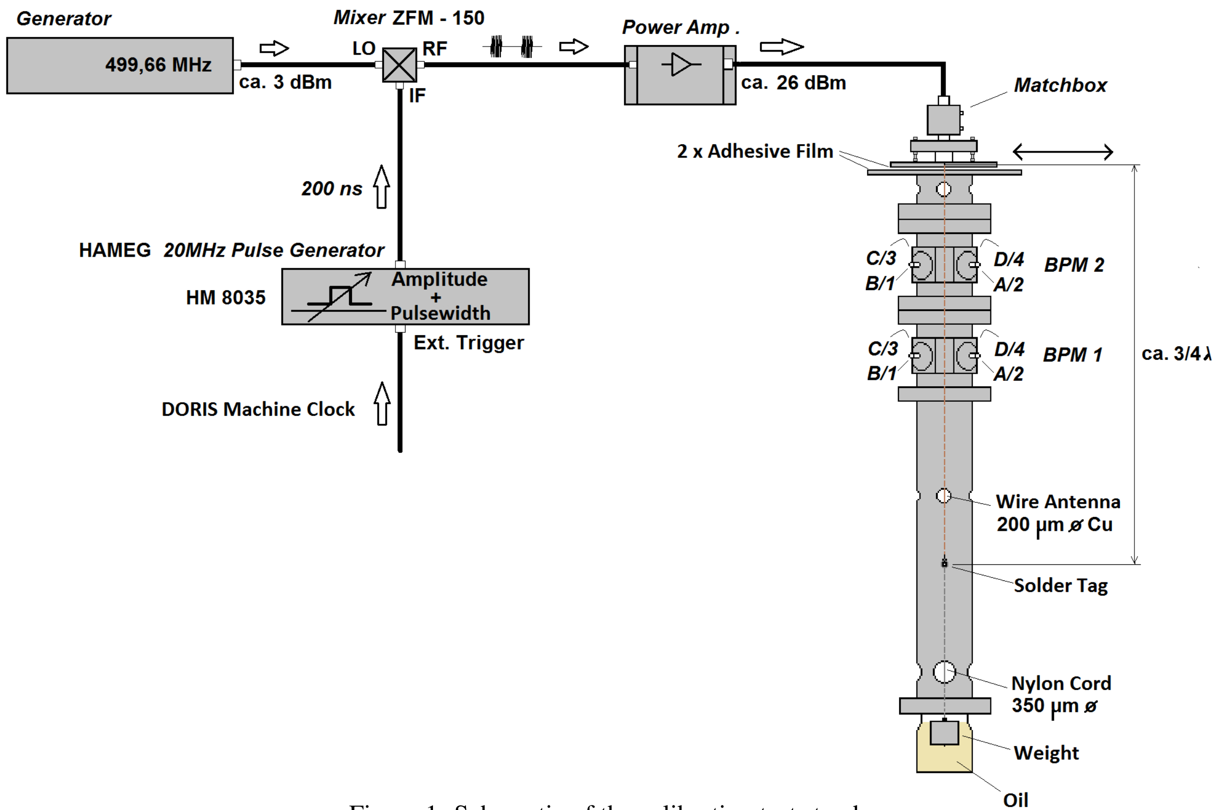

Figure 1: Schematic of the calibration test stand.

of the incoupling signal- and ground-conduction, sufficient RF-signal-level was coupled from the wire-antenna to the BPM-electrodes to drive the electronics.

CALIBRATION MEASUREMENTS

Several calibration measurements were performed, where the wire was usually kept in the center of the BPMs in one coordinate and scanned in steps of 1 mm up to $\pm$ 10 mm in the other coordinate. The maximum deviation of the BPM readings w.r.t the wire positions were ± 0.9 mm at the extreme wire positions of ± 10 mm, where the maximum deviation from a straight line fit was ± 0.4 mm. Individual positions were reproducible to about 3 μm. Note, that geometry and alignment corrections were not applied to the BPM readings.

Scans in x for y positions of +2, 0 and -2 mm were done and compared to the calculations using a boundary element method [4]. The shape of the deviation of measured BPM readout positions from the true positions as a function of the true values are very well described by the calculations, as shown in Fig. 2. A small rotation of 20 mrad was applied to the data. At 1 mm the measurements and calculations agree within 5μm. The largest disagreement, at 5 mm, is about 0.1 mm. This could be due to a misalignment of the BPMs w.r.t. the test stand, fabrication tolerances or due to asymmetries in the cabling or readout electronics.

In order to check a possible dependence on the beam current, the level of the input pulse was varied over a factor of 6. No systematic dependence on the signal level was observed. The readout positions were stable with a standard deviation of 1.3 μm. The dependence on the input signal polarity was checked by injecting a bipolar pulse into the BPM cables with and without an inverting transformer. The measured BPM readings were equal within about 5 μm, which is well below the requirements of the OLYMPUS experiment. This was an important check, since the experiment relies on a precise measurement of the luminosity ratio for positron and electron beams.

In addition, several scans in steps of 0.2 mm over a range of 1 mm were performed for various x and y values, which corresponded to the beam positions during DORIS operation. The deviations w.r.t. to the wire positions were within a few μm.

CROSS-CALIBRATION OF ELECTRONICS

During beam operation, the BPMs in the interaction region were read out by two independent readout systems, providing significantly different beam position, as shown in Fig. 3. This was caused by the very different treatment of the BPM signals in the readout systems. In particular, the standard DORIS readout (Neumann) used the first negative part of the pulse, which is obviously different for electron beam and the inverted positron beam signals. Whereas the Libera electronics performed a narrow bandwidth analysis of the RF pulse, which is by design independent of the pulse polarity. This was confirmed by the measurements

ISBN 978-3-95450-141-0

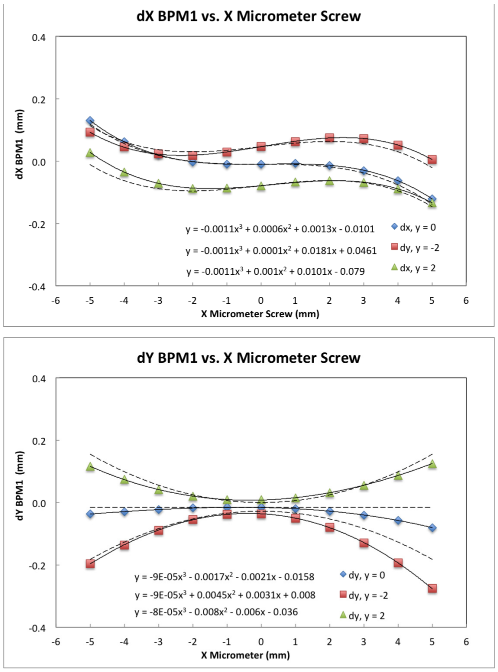

Figure 2: Deviation of the measured (calculated) BPM readout from the true position as a function of the wire position. Top figure: deviation in x for x movements for three y values. Bottom figure: deviations in y. Also shown is a 3rd order polynomial fit to the data.

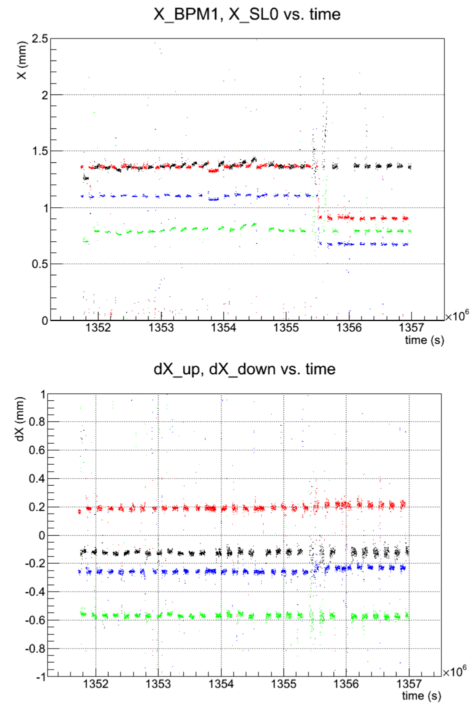

Figure 3: Top: Upstream horizontal Libera and Neumann BPM positions as function of time for e^+ and e^- beams (fall running period Oct. 2012 to Jan. 2013.) Bottom: Difference of Neumann and Libera horizontal positions vs. time. Data are from the DORIS accelerator archive.

as described above. The Neumann values were available in the OLYMPUS slow control system for the full running period, but unfortunately, the Libera values were only stored for part of the fall run. Corrections were therefore determined for the Neumann readout.

The difference of Neumann and Libera positions as a function of time was quite stable, as plotted in Fig. 3. Other effects like the beam current dependence were relatively small. Steps of 30 μm in the Libera positions were observed for beam current drops of 4 - 5 mA, i.e. 5% of the beam current, when the beam position was fixed by the feed back system using the Neumann BPM information. During stable fills, the position was stable within 15 μm. The Neumann Libera differences were quite substantial, from 0.1 to 1.4 mm depending on the BPM channel, and were simply added as offsets to the Neumann values. These offsets were stable within 15 μm over the full running period, except for one BPM channel which showed a somewhat larger deviation during the initial run.

CONCLUSIONS

BPM position deviations from the true position are quite substantial at large positions, 0.9 mm at 10 mm wire positions. They are very small for small position, a few μm for 0.5 mm offsets. The BPM response is in very good agreement with the calculations. No significant dependence on the input signal level and the signal polarity was observed. The readout systems were cross-calibrated, resulting in offsets for the Neumann electronics.

The survey of the wire, BPMs and target chamber locations [5] was used to transform the BPMs positions into the OLYMPUS coordinate system [6]. The uncertainties of the calibrated BPM data are within the requirements of the OLYMPUS experiment.

ACKNOWLEDGEMENTS

We gratefully acknowledge the contributions of R. Bacher, J. Bernauer, U. Laustroer, M. Noak, J. Wilgen and K. Wittenburg to this work.

REFERENCES

[1] R. Milner et al., "The OLYMPUS Experiment", NIM **A741**, 1 (2014).

[2] R. Neumann, private communication; F. Schmidt-Föhre et al., "BPM System Upgrades in the PETRA III Pre-Accelerator Chain during the 2008 Shutdown", DIPAC09, Basel, Switzerland.

[3] Libera+ Brilliance Electron beam position processor, Instrumentation Technologies,d.d., Solkan, Slovenia.

[4] G. Kube, "Sensitivity Estimation for the PETRA-III Beam Position Monitors based on a Boundary Element Method", DESY Technical Note 07-01 (2007); G. Kube, M. Werner "Signal Level Calculation for the PETRA III Beam Position Monitor System", DIPAC 2007, Venice, Italy

[5] M. Noak et al., private communication.

[6] J.C. Bernauer, private communication.