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RESULTS OF HESR BPM TESTING

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Abstract

For the High Energy Storage Ring (HESR) diagonally cut BPMs were designed, with 63 manufactured and tested with a purpose-built BPM test stand. This test stand had to host BPMs of various lengths, the overall length of the vacuum chamber varies from 450 mm to 158 mm. For all BPMs the geometric factors or the electrical center in relation to the geometric center were measured utilizing the test stand. The results of these measurements are presented together with the challenges resulting from the design choices made for the layout of the test stand.

INTRODUCTION

The HESR, part of the Facility of Antiproton and Ion Research in Europe (FAIR) in Darmstadt, Germany, is dedicated to the field of antiproton and heavy ion physics. The envisaged energy range is 0.8 GeV to 14 GeV for antiprotons and 0.17 GeV/a to 5 GeV/a for heavy ions [1]. The ring will be a racetrack shape with a length of 574 m. The beam instrumentation consists of 64 Beam Position Monitors (BPM), 118 Beam Loss Monitors (BLM), 2 Beam Current Transformers (BCT), 2 Ionization Beam Profile Monitors (IPM), 1 In-Gap Particle Measurement, 1 Schottky Pick-up, 1 Phase Pick-up, 1 Dynamical Tune-meter, 5 Viewer, 2 Scraper, as well as 73 Ion Clearing Chambers and a fast orbit feedback based on the LIBERA beam processors.

BPM SYSTEM

The pick-up design is based upon the diagonally cut shoebox design of the COSY BPMs [2]. The design is shown in Fig. 1, with more details presented in [3]. While 63 BPMs will have the inner diameter of 89 mm, one is designated to be located downstream of the injection septum, where the beam pipe has a diameter of 150 mm. Therefore, this BPM has to have a larger diameter to not limit the aperture at this place.

In the arcs of the synchrotron, between the dipole magnets, different configurations of quadrupole, sextupole and steering magnets are foreseen, with at least one quadrupole magnet per slot, but a different secondary magnet being in place. Due to the space limitations of the very dense magnet placement, beam pipes of different lengths are directly welded to the BPM vacuum enclosure. This approach results in BPM assemblies of different lengths, 1585 mm, 1249 mm, or 1180 mm. In the straight sections, these restrictions do not apply, therefore a 450 mm long vacuum chamber is used there. The pick-ups themself are identical in each configuration.

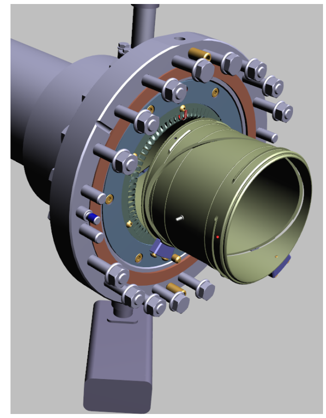

Figure 1: Design of the 89 mm BPM Pick-up.

BPM Signal Chain

Within the FAIR project, the standard BPM signal chain consists of the A110 pre-amplifier [4], which features an amplification range of +60 dB to -60 dB. For the readout and calculation of the beam position the LIBERA Hadron [5] was chosen.

As an addition to the FAIR standard, taking the low expected signal for the HESR into account, an additional 20 dB low-noise head amplifier will be installed directly on the vacuum feedthroughs boosting the input signal of the A110 pre-amplifiers.

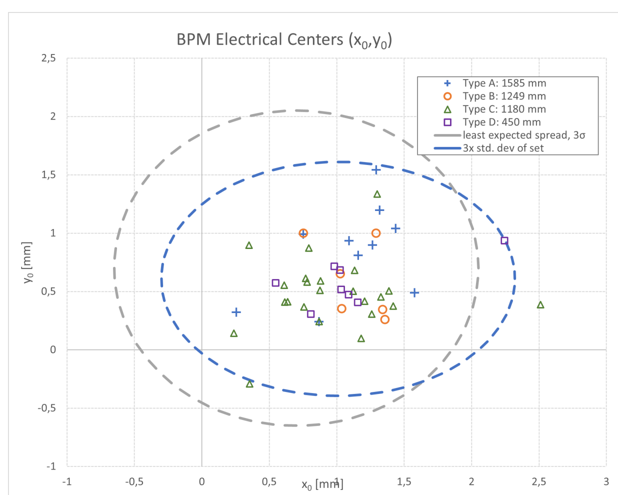

Figure 2: Overview of the measured offsets between the mechanical and the electrical center of the HESR BPMs. The standard deviations of the offsets are x_0 = 0.44 mm and y_0 = 0.33 mm.

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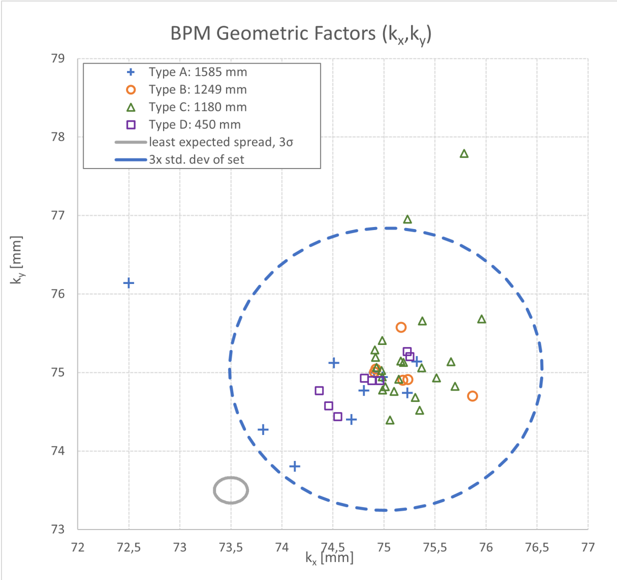

Figure 3: Overview of the measured geometric factors of the HESR BPMs. Notable spread and outliers result from the real statistical characteristic of the individual BPM, systematic errors on the test bench as well as measurement uncertainties. The standard deviations of the geometrical factors are k_x = 0.51 mm and k_y = 0.60 mm.

BPM Testing

62 of the 63 89 mm BPMs, and one additional production test BPM, have been tested. The test results are shown in Fig. 2 and Fig. 3. The last additional BPM was recently received from production and is scheduled for testing soon.

Every BPM is tested using a wire test bench to check general electrical functionality and determine the linear coefficients and electrical offsets per plane, as shown in Fig. 4. The test bench is fitted with μ-meter precision linear drives and optical micrometers for moving the wire and determining its precise position. In every BPM two high precision reference markers are added during manufacturing, which deliver a reference for the wire positioning. The signals are amplified by head amplifiers and the A110, before being digitized by a Spectrum 16-bit 250 MHz ADC card. The whole measurement process, including the positioning of the wire, control of the gain of the A110, the ADC signal readout, and writing the measured values to a file is done with LabView.

The initial concept of performing tests at the test bench did only include centering the wire using the XY-arrangement of optical micrometers to determine a suitable homing position. This decision was initially made, as the optical micrometers only cover the center 60 mm of the 89 mm diameter of the BPM and, in addition the high precision reference markers limit, through their shadows, the wire position measurement. Drifts and mishaps during start up of a measurement run may ruin an entire measurement cycle, as a permanent unspecified shift from the geometrical center may occur in such circumstances. Endeavours to include the optical micrometer readings for the evaluation of the entire measurement run yielded in increased robustness and the means to mitigate such shifts have been performed.

Concerns over some results lead to a photogrammetric investigation to determine the optical micrometers rotation and shifts. It has been concluded that the optical micrometers in the lower box are rotated by 1.4° for one and 0.5° for the second device and for the upper box 0.6° and 0.03°. The statistical uncertainty of these values is estimated around 0.1°. Comparing electrically and optically derived positional wire positions indicate a tilting behaviour for every position of the meander path of the linear drive assembly through the BPM while measuring. Although the linear drives allow for sub micrometer motion, the examinations showed that the actual wire position should not be taken from raw set-values of the linear drives but the optical micrometer readings should be favoured.

While the mechanical tolerances for the parts of the BPM directly involved in the measurement process, such as the pick-up electrodes, have been specified with tolerances lower than 2/100 mm, the mechanical deviations have an impact on both, the electrical zero position in regards to the mechanical zero position, and the geometrical factors used for the calculation of the position of the particle beam.

An additional source for spread of the additive coefficients may be explained by a large contribution of mechanical deviations in the electrical signal feedthroughs of the BPM because of their varying parasitic capacity. An analysis of 10 feedthroughs and their effects on signal strength against their individual capacitance indicates strong correlation as

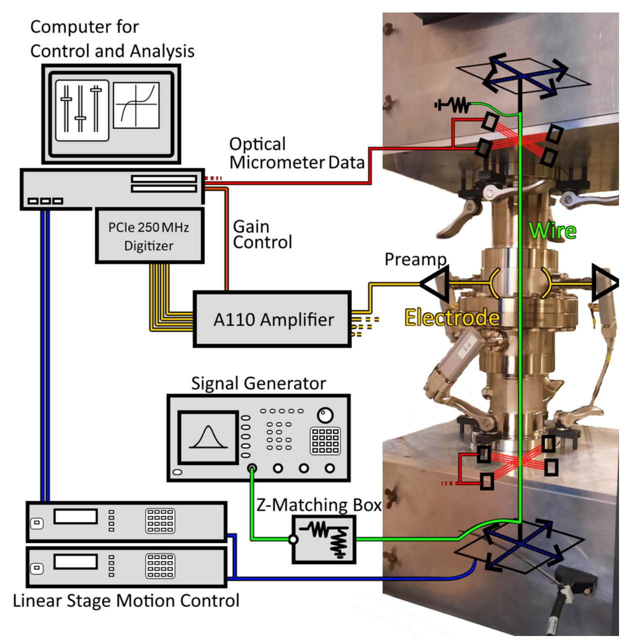

Figure 4: Schematic representation of the test stand with measurement setup outlined. To accommodate varying BPM lengths two boxes containing the linear drive assemblies and optical micrometers are independently attached to both BPM vacuum flanges.

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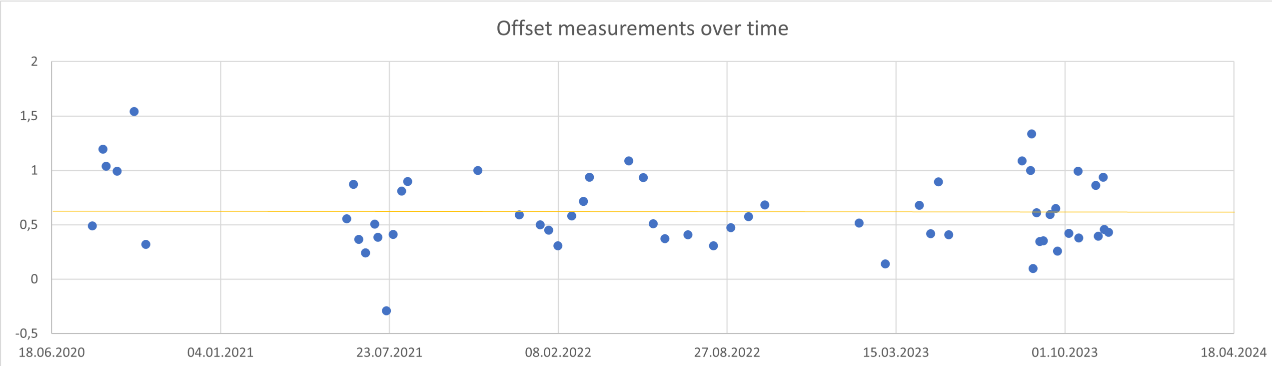

Figure 5: The results of single BPM measurements, here the y offset, over the time from 2020 to 2023 with the mean value of 0.6 marked for reference. While testing more and more BPMs, the handling of the measurement would be more trained and therefore less errors are to be expected. But no significant reduction of the spread can be noticed over time.

well as a spread in capacitance in the entire tested set that would accommodate a good part of the noted distribution of the electrical centers. In case of a failure and following replacement of a vacuum feedthrough, this would mean the BPM setup would have to be measured again. While, once installed, the failure of a feedthrough is rather unlikely, during the installation of the components, the mechanical stress could result in the damage of feedthroughs and therefore caution during installation should be applied. Further investigations of calculating the center position and the geometrical factor when replacing one feedthrough, instead of performing a complete re-measurement, have been postponed due to the project holdup, described in more detail in the outlook section.

The expected values for the BPMs have been presented in [6]. There simulations resulted in k=73.52 mm and the offset to 0.7 mm.

Theoretical models have shown a weak but noticeable coupling between the vertical and horizontal measurement plane of BPM electrodes. A more realistic approach to convert the electrical signals to beam position would be to append a linear term for each decoupled case:

$$x_{beam} = x_0 + k_{xH} \cdot DOS_H + k_{xV} \cdot DOS_V$$

and y_{beam} analogous respectively. The terms k_{xV} and k_{yH} are small and could naively be omitted and even will be for the simplicity with the Libera Hardron implementation. Yet one can include a correction calculation within the control system software to transform $xy_{beam-naiv}$ to $xy_{coupled}$ using a predetermined 2x2 matrix for each BPM.

Time dependence of measurements

In Fig. 5 the measured mean value of each BPM is displayed, as example here the center deviation of the y axis, according to the date of the measurement. The whole process, dominated by the speed of fabrication of the devices, took about 3 years. While performing more and more measurements, the handling of the test bench got more routinised, software bugs were fixed and new ideas how to handle the entire measurement setup were introduced. The question arose, if this advancements would affect, apart from the time spend on the measurements of each BPM, the resulting quality of measurements. As the spread of the measurements does not decrease significantly over time, the assumption is, the spread reflects the real electrical deviations based on the mechanical ones. Not included in this statistics are the measurements of about 3 BPMs in the beginning, which had to be completely re-done. The reason for this was mainly the lack of some data being recorded that later was found to be essential for data processing and to a minor degree handling issues, like e.g. wrong termination of the signal wire.

OUTLOOK

To the present day, all 63 89 mm BPMs have been delivered, with 62 of them tested and sent to FAIR storage.
Because of the recent decisions of the FAIR council, a stepwise approach to the completion of FAIR will be pursued [7]. HESR being a part of the Modularized Start Version of FAIR will be built after the phases Early Science, First Science and First Science Plus have been realized.

Therefore for the BPM system, the detailed design and production of the one 150 mm BPM and the production of the fixed-gain head amplifiers have been postponed. To mitigate the project risks some critical parts of the head amplifiers have been purchased and stored. However, the strategy may still result in a partial re-design of the device as some parts may no longer be available on the market at the time of intended production. Further developments of other HESR beam instrumentation, like the measurement of the amount of trapped particles in the injection gap or the production of the BLM detectors have been postponed. For the remaining beam instrumentation components, the status reported in [8] is still valid.

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