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CURRENT STATUS OF THE HESR BEAM INSTRUMENTATION

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Abstract

The High Energy Storage Ring (HESR), within the FAIR project, will according to current planning, provide antiproton beams for PANDA and heavy ion beams for i.a. the SPARC experiment. Manufacturing for most of the envisaged beam instrumentation devices in vacuum is completed and testing is well underway. The overall status update of the beam instrumentation devices is presented, with a focus on the test-bench results of the BPMs. In addition, the planned future timeline of the HESR beam instrumentation is briefly reported.

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 design with a length of 574 m. The foreseen beam instrumentation within the modularized start version is:

63	Diagonally Cut 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

BPM SYSTEM

The pick-up design is based upon the diagonally cut shoebox design of the COSY BPMs [2]. The design was shown in detail in [3]. While 62 BPMs will have the inner diameter of 89 mm, one is designated to be located closely after 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. This one has still to be designed and the production is not planned for the near future.

In the bend sections of the synchrotron, between the dipole magnets, different configurations of quadrupole, sextupole and steering magnets are foreseen, with at least one quadrupole magnet but a different secondary magnet being in place. In order to save as much longitudinal space as possible, the BPM is build in the single vacuum chamber serving through all these devices. But for each configuration a different length of the vacuum chamber, 1585 mm, 1249 mm, or 1180 mm, is needed. In addition, in the straight sections, these restrictions do not apply, therefore a 450 mm long vacuum chamber is used there. But the BPM pick-ups itself are identical in each configuration. All these different length vacuum chamber have to fit on the test stand.

Signal Chain

Within the FAIR project, the standard 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. It features an extension for orbit control, which has been adapted to the FAIR magnet control units (ACU). As an extension to the original plan, the orbit control extension units have been ordered for the HESR as well. As an addition to the FAIR standard, taking the low expected signal for the HESR into account, an additional low-noise head amplifier of 20 dB, will be used directly on the vacuum feedthroughs in front of the A110 pre-amplifiers. It is foreseen to use the same head-on amplifiers in other parts of FAIR with expected low signal, e.g. the high energy beam transport (HEBT) beamlines.

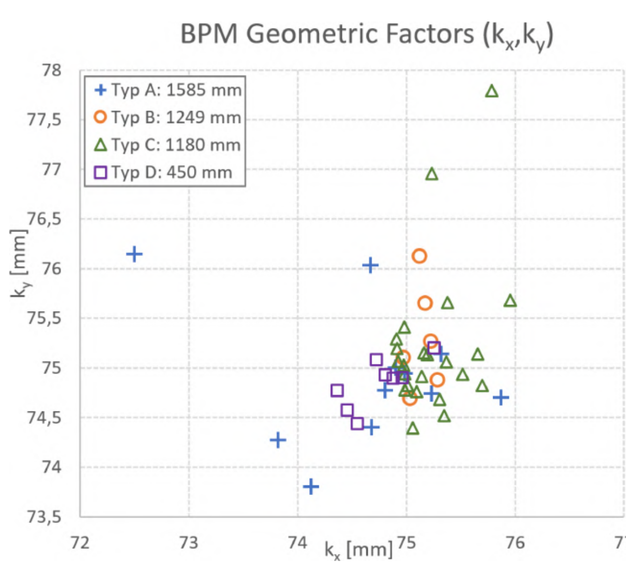

Figure 1: Overview of the measured geometric factors of the HESR BPMs. Notable spread and outliers result from the real statistical characteristic of the individual BPM, systematic errors on the test bench as well as measurement uncertainties. The standard deviations of the geometrical factors are $k_x = 0.55$ mm and $k_y = 0.66$ mm.

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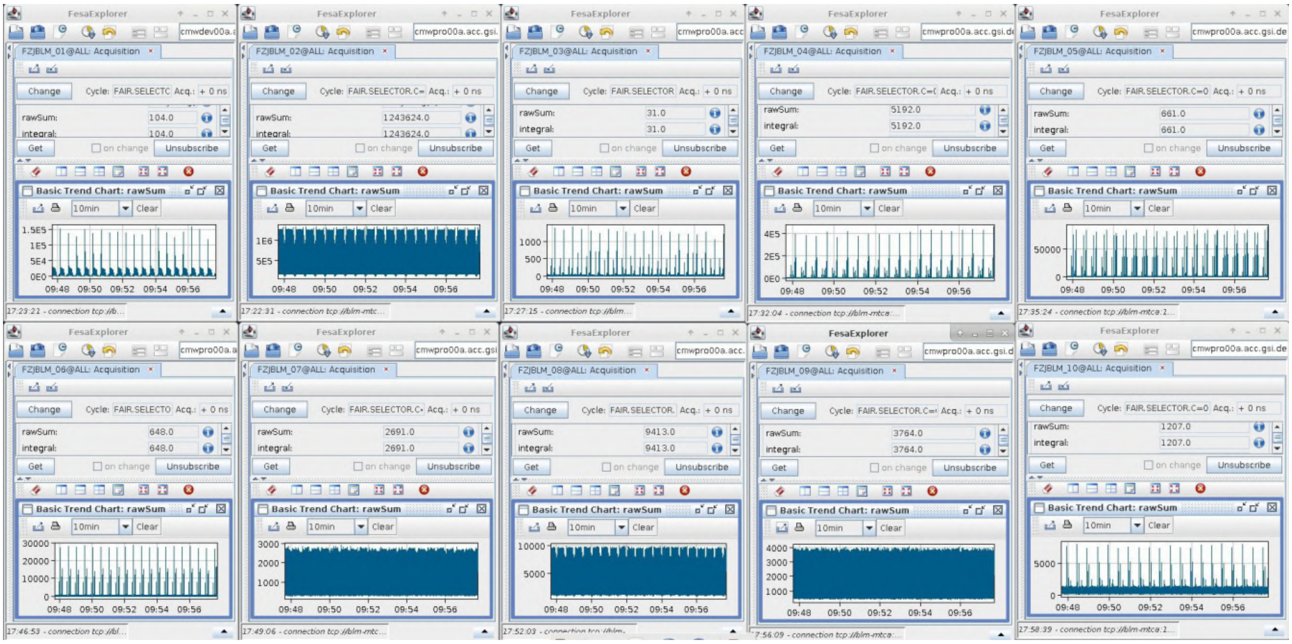

Figure 2: Overview of the BLM loss rate of the installed HESR BLMs at the COSY synchrotron for testing. The GUI is not the final GUI for HESR, but only for testing with the FESA explorer.

BPM Testing

Of the 62 envisaged 89 mm BPMs, 47 have been tested, the so far test results are shown in Fig. 1. An additional 14 recently received from production to be tested in the near future. That leaves one BPM to be delivered. Every BPM is tested using a wire test bench to check general electrical functionality and determine the linear coefficients and electrical offsets per plane. The test bench is fitted with µ-meter precision linear drives and optical micrometers for moving the wire and determining the precise position. In every BPM two highly precise measured 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 micro-meters to determine a suitable homing position. 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 micro-meter readings for the evaluation of the entire measurement run yielded an 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 micro-meters rotation and shifts. It has been concluded that the optical micro-meters 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 micro-meter motion, the examinations showed, the actual wire position should not be taken from raw set-values of the linear drives but the optical micro-meter readings should be favored.

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

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

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and y_{beam} analogous respectively. The terms k_{xV} and k_{yH} are small and could naivly 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.

BEAM LOSS MONITOR

For machine commissioning, routine operation and further beam optimization detailed beam loss data is very valuable. Unlike other accelerators, the HESR BLM data will not be used for an automated machine protection, as the stored total beam energy will not be high enough to damage the machine. Along the ring 118 BLMs will be used, of which 20 have been so far delivered by GSI, mainly for testing purposes.

The BLM consists of a BC-400 plastic scintillator and a Hamamatsu photomultiplier (PMT). This solution is favored over e.g. an ion chamber type loss monitor because of the low expected loss rates. The design was presented in detail at [7]. It was developed by GSI and will be used in other parts of FAIR as well, e.g. the HEBT.

For the readout of the BLMs a µTCA system will be used utilizing scaler/counter SIS8800 and RTM discriminator SIS8980 from Struck Innovative Systeme GmbH. Both cards are connected to each other via the µTCA backplane and provide 16 channels per card. The BLM PMTs will be powered individually utilizing a multichannel HV system in order to be able to compensate for the properties of the individual BLM detector and the individual location.

FESA Control Test System

In order to have a Front-end Software Architecture (FESA) control system operational for development and testing, a stripped down test system was installed by Cosylab d.d. at COSY. As a functioning system the control and readout of the BLM system was implemented and can be used in addition to the COSY BLM system with additional BLMs, with its GUI shown in Fig. 2. Besides this test setup, the system is also designed as a reference for further FESA development and testing.

IONIZATION BEAM PROFILE MONITOR

Ionization Beam Profile Monitors (IPM) have been built and tested in cooperation with the GSI since 2007 [8], becoming a very valuable instrument in beam diagnostics at COSY and GSI [9]. Based on the experiences, a similar device is under development for the HESR. Depicted in Fig. 3, it is being designed in a size that would not only fit the HESR but also in the HEBT. Because of the delicate nature of the microchannel plates and the importance of the system, 2 systems will be installed, providing one backup system in case of failure. Unlike other systems the side electrodes of the E-field-box are connected individually, thus giving a greater control over the E-field and eliminating the need of resistors within the vacuum. Parts of that wiring is shown in Fig. 3. Within the HESR and HEBT an amount of 17 devices is foreseen, although some of them shall provide only one plane-measurments.

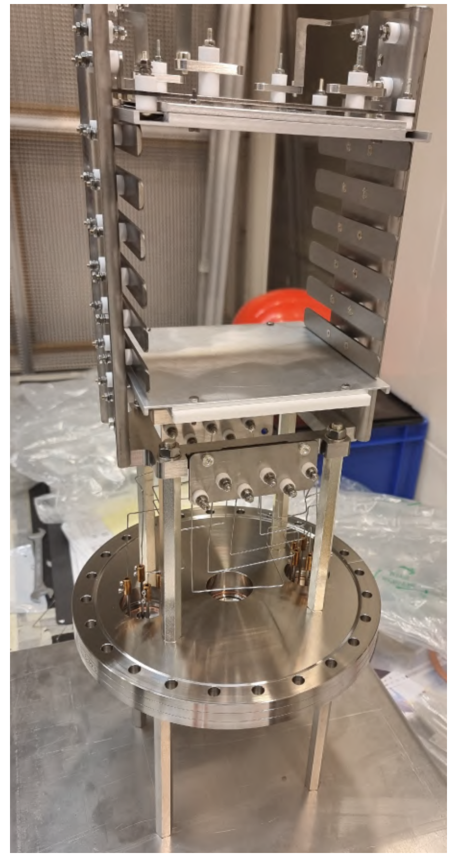

Figure 3: The ready mounted vacuum part of the IPM. On top a module with a MCP stack and a phosphor screen will be mounted. The E-field-box with its 6 field flattening electrodes is visible. On the bottom, covered with a protective shield during mounting, a fine mesh will be installed, which flattens the electric field but lets through UV light for calibration purposes. The UV light will be generated by a lamp mounted outside the vacuum, right behind the vacuum window in the lower CF flange.

The first of series device is being build at the Research Center Jülich with the setup being almost complete, some in-vacuum wiring has still to be done. The manufacturing of the vacuum chamber, after facing some delays, has just been completed, with vacuum-testing still to be done.

VIEWER

There will be 6 viewers installed in the HESR. One in the injection beamline. Within the HESR ring, one will be installed at the beginning and end of each telescope and an additional one directly after the injection septum magnet. The ring viewers consist of a scintillation screen mounted at 45°. They will be moved by a pneumatic drive and, as a speciality at the HESR, if the viewer is not used a RF cage will be moved into its place. This is done in order to minimize the overall impedance of the ring. If the RF cage is in its operational position, a second pneumatic drive will move RF fingers in their position to ensure an optimal electrical conduction. Before moving the RF cage out, these springs will be pulled back. A RF cage before being mounted onto the system is shown in Fig. 4.

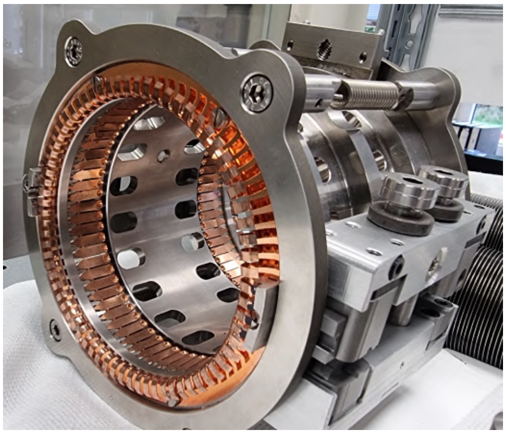

Figure 4: RF cage that is being moved into position if the vievers are not used. Once in its position the Copper-Beyllium springs will be moved outwards to insure a good electric conductivity. This is done in order to minimize the overall impedance of the storage ring.

SCRAPER

The scraper system is shown in Fig. 5. There will be 2 scraper systems installed in the HESR. Each system consists of 2 vertical and 2 horizontal jaws. Each jaw contains 10 copper rods which are placed in an alternating manner and are each 25 mm in diameter. This layout ensures a particle will be slowed down by at least 50 mm of material while the structure will have a minimal effect on the RF impedance while being in its out position. Each jaw can move in further than the middle of the beam pipe, in order to allow the scraping of a non-centered region. In order for the jaws not accidentally touching each other, they have been placed in succession. The manufacturing and testing of these devices is completed.

PHASE PICK-UP

The in-vacuum part of the Phase Pick-Up will be a non-split BPM. This is derived from the construction layout of the regular BPMs and will be manufactured directly after all regular BPMs have been manufactured. The readout of the Phase Pick-Up still has to be defined.

BEAM CURRENT

For beam current measurements, two commercially available Bergoz transformers will be used. One NPCT and one FCT have already been delivered and the site acceptance test was successfully performed.

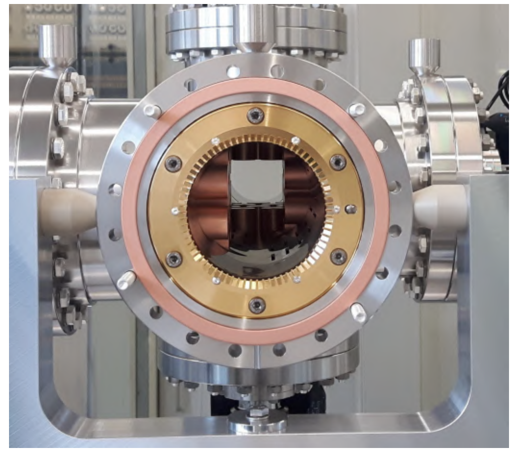

Figure 5: Look into the scraper in the beam plane. The 4 jaws from top, bottom, and the sides are partially moved in [10].

OUTLOOK

To the present day, 61 of 63 of the BPM pick-ups have been produced and delivered. The measurement of the BPMs on the test stand is also well underway, as well as the calculation of the individual geometrical factors and offsets, which has been done for 47 so far. The beam current transformers and the scrapers are completely manufactured and tested. The viewers are partly manufactured, while their vacuum chamber manufacturing is delayed, and therefore their overall completion. For the IPM, the first of series is almost completed, with vacuum tests and about half of the in-vacuum wiring still to be done.
Because of the recent desicions of the FAIR council, the stepwise approach for the completion of FAIR will be pursued [11]. The first step (Early Science: ES) includes the Super-FRS using beams from the existing SIS18 and will be possible from 2028, followed by First Science (FS), which provides beams from the SIS100 for NUSTAR and and atomic physics (APPA) experiments. This will be followed by the First Science Plus (FS+) step, in which beams will be extracted to the CBM cave. After these steps the rest of the Modularized Start Version of FAIR, which includes the antiproton part, the p-bar target, the Collector Ring (CR), and the HESR, will be realized. Therefore further developments of other HESR beam instrumentation, like the measurement of the amount of trapped particles in the injection gap, or the beam damping, have been postponed.

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