

# STATUS OVERVIEW 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 anti-proton beams for PANDA and heavy ion beams for a.o. SPARC. With the beam instrumentation devices envisaged in larger quantities, e.g. BPM and BLM, testing is well underway. Other beam instrumentation instruments like Viewer are in late production stage, Scraper is being tested and for the IPM the 1st of series production has started. An overview of the status of the work package beam instrumentation will be presented as well as test bench results of already produced instruments.

## INTRODUCTION

The HESR, part of the FAIR project 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 574 m long in a racetrack shape. The foreseen beam instrumentation within the modularized start version is:

- 64 Diagonally Cut Beam Position Monitors (BPM)
- 118 Beam Loss Monitors (BLM)
- 2 Beam Current Transformers (BCT)
- 2 Ionization Beam Profile Monitor (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 COSY BPMs [2], which is a diagonally cut pick-up design. The design was shown in detail in [3]. While 63 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, to not limit the aperture at this place, one BPM has to have a larger diameter. This one is still to be designed.

### BPM Testing

Of the 64 envisaged BPMs, 44 have been tested, with an additional 11 recently received from production to be tested in the near future. 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

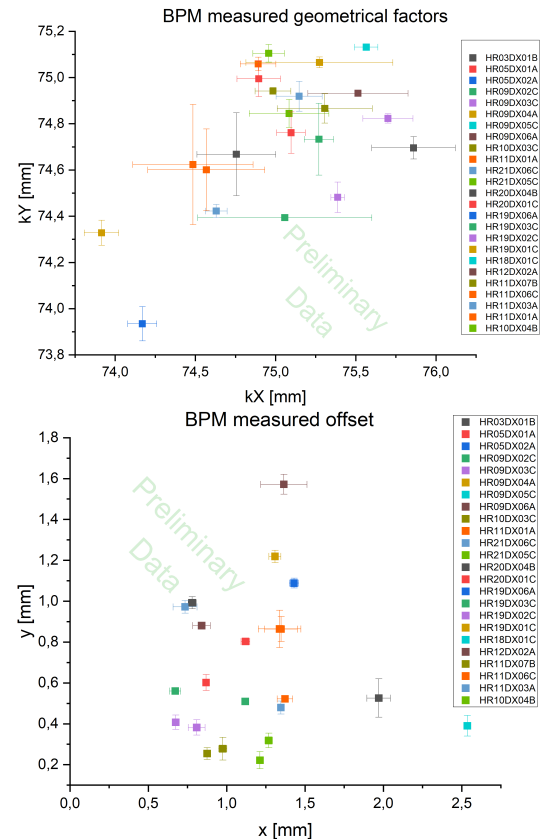


Figure 1: Measured properties of the first 25 BPMs. On the top picture the geometrical factors and the lower picture the electrical offsets compared to the mechanical middle position.

test bench is fitted with  $\mu$ -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 are functioning as reference for the wire positioning. The signals are amplified by head amplifiers and the AMPLIFIER 110, 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 AMPLIFIER 110, the ADC signal readout, and writing the measured values to a file is done with LabView.

Figure 1 shows the preliminary results of the first 25 tested BPMs for the measurements of the geometrical factors (upper figure) and the electrical center in regards to the mechanical center (lower figure). While the mechanical tolerances for the parts of the BPM directly involved in the measurement process, like the pick-up electrodes, have been specified

with tolerances lower than 0.02 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. The expected values for the BPMs have been presented in [4]. These simulations resulted in  $k=73.52$  and for the offset to 0.7 mm.

With further evaluation of the measured data the statistical errors should be reduced. During the measurement process in some cases the wire, simulating the beam within the test stand, does not move to the foreseen position. Therefore a wrong measurement is recorded leading to an increased statistical error. These cases are not identified reliably by the automated data analysis algorithm, therefore a manual check has to be performed. This is still ongoing.

### Signal Amplification

**Fixed Gain Head Amplifiers** Due to low amplitudes the HESR BPM signals require additional boosting prior to transmission over cables. In order to achieve a better signal to noise ratio head amplifiers with a high impedance low noise input were developed, with the high impedance also flattens the frequency response, especially at low frequencies. At the HESR the expected radiation levels are low enough so that an active solution could be implemented. The amplifier is shown in Figure 2.

The specification of this amplifier is:

Amplification:	20 dB
Noise:	6 $\mu$ V at 50 pF input capacitance and 10 MHz bandwidth
Bandwidth:	10 MHz default, configurable up to 70 MHz
Input Impedance:	500 k $\Omega$
Power supply:	+8 V and -8 V
Output range:	$\pm$ 1.5 V at 50 $\Omega$



Figure 2: Picture of the head amplifier developed for the HESR BPM system. The N-type plug is main signal input, calibration ports and signal output ports are facilitated via SMA connectors. The power is connected through the D-Sub plug.

**Hadron Pre-Amplifier (AMPLIFIER 110)** Within the FAIR project the decision was made early that a common amplifier solution should be developed for all accelerator structures. Therefore the AMPLIFIER 110 (A110) was developed [5] in cooperation of the GSI and Instrumentation Technologies d. d., Slovenia. The A110 is now commercial available.

The A110 has a gain range of +60 dB to -60 dB and is equipped with an overload protection which has been seen necessary especially for the SIS100. It is equipped with a 50  $\Omega$  input.

For the above listed arguments the HESR deviated from this concept by introducing active head amplifiers instead of the passive impedance transformer. Still the A110 remains part of the signal chain, as the head amplifier will have a fixed gain. An adjustable gain amplifier is seen necessary to adapt for different beam properties.

The electric power needed for the head amplifiers will be supplied from the A110, as the necessary voltages are available within the A110 and therefore additional power supplies and cables from the power supply rooms are not needed. The necessary modifications to the A110 are designed to be minimal, only one additional card has to be installed within the A110 into a pre-existing empty slot, which can be removed easily if the device would have to be installed at a different location. For signal and power distribution to and from the 4 head amplifiers an additional 1 RU module was designed and has to be installed in addition to the A110 per BPM. Another feature of the distribution unit is the precise splitting of a test signal generated by the A110 to the 4 head amplifiers, which can be used for a relative calibration of the 4 head amplifiers towards each other.

The design is to be adopted by other machines within FAIR, that face low signals levels. The total amount of systems foreseen, consisting of one distribution unit with 4 head amplifiers, is 64 for the HESR, 20 for the collector ring (CR), 10 for the HEBT, and additional 10 for the CRYRING, totalling in 104 units. The production will be done for all systems at once.

### Beam Processor

For the readout and calculation of the beam position. the LIBERA Hadron was chosen for all FAIR BPMs. 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.

## 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 with the FESA test system.

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 [6]. It was developed by GSI and will be used in other

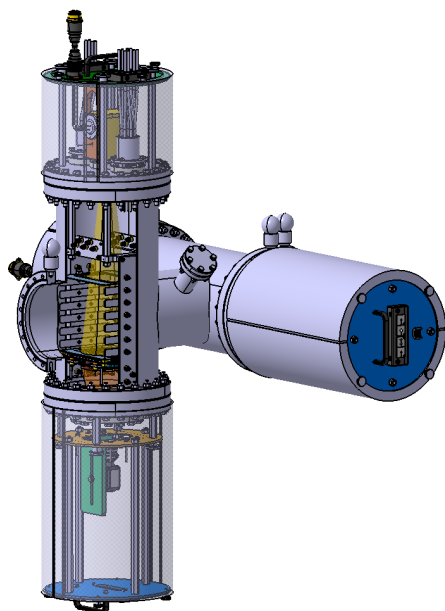


Figure 3: Drawing of the 1st of series IPM [7]. On top a UV lamp is installed in order to perform a relative calibration of the microchannel plates (MCPs), with the simulated light path depicted in yellow. The signals generated by the beam ions ionizing the residual gas, and therefore representing the profile, are amplified utilizing two MCPs and then transformed to a light signal utilizing a phosphor screen. This signal can be transported out of the vacuum vessel through a standard vacuum window and is detected by a standard CCD camera, located in the bottom in the picture. Two identical setups, rotated by 90°, are installed to measure the vertical and horizontal profile.

parts of FAIR as well, e.g. the High Energy Beam Transport (HEBT).

For the readout of the BLMs a  $\mu$ TCA system will be used utilizing scaler SIS8800 and counter SIS8980 from Struck Innovative Systeme GmbH. Both cards are connected to each other via the  $\mu$ TCA 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 System Test System*

In order to have a 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. Besides this test setup, the system is also designed as a reference for further FESA development and testing.

## IONIZATION BEAM PROFILE MONITOR

An Ionization Beam Profile Monitor (IPM) was built and tested in cooperation with the GSI in 2007 [8]. Since then it became a very valuable instrument in beam diagnostics at COSY and GSI [9]. Based on both experiences a similar device is under development for the HESR. Depicted in Figure 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. Within the HESR and high energy beam transport (HEBT) an amount of 17 devices are foreseen, although some of them only for one plane.

The first of series device is right now being build at the Reserach Center Jülich and it is planned to be ready by the end of this year. Extensive testing of the device is planned to be performed within the COSY synchrotron. Once the testing is completed, which is foreseen to be mid 2023, mass production will be started. Although the vacuum chambers for HESR and HEBT will be different and therefore produced separately, the actual IPM parts, e.g. the parts inside the vacuum chamber or the mounting of the UV lamp and camera, are planned to be produced together. First parts, like a metal mesh to, on one side let through the UV light but have a flat E-field within the E-field cage, and on the other side to protect the MCPs, are already under production at the Research Center Jülich, also for the IPMs in other FAIR machines using a different design, like in SIS100.

## VIEWER

There will be 5 viewers installed in the HESR. One at the beginning and end of each telescope and an additional one directly after the injection septum magnet. As shown in Figure 4, the viewer consists of a scintillation screen mounted at 45° and will be moved by a pneumatic drive. As a speciality at the HESR, if the viewer is not used an 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. The first of series is already tested, the remaining 4 devices are right now being produced.

## SCRAPER

The scraper system is shown in Figure 5. There will be 2 scraper systems installed in the HESR. Each system consists of 2 vertical and 2 horizontal jaws. Each jaw of 10 copper rods which are placed in an alternating manner and are each 25 mm in diameter. This layout assures 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 on its out position. Each jaw can move in farther than the middle of the beam pipe. As a safety measurement the jaws are therefore placed not directly facing

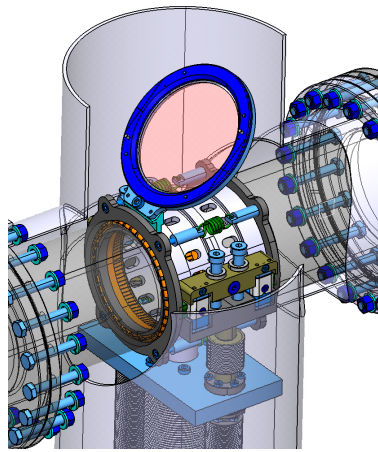


Figure 4: Drawing of the viewer. A scintillator screen is moved into the beam with 45°. While being moved out, a RF cage will be moved into it's position.

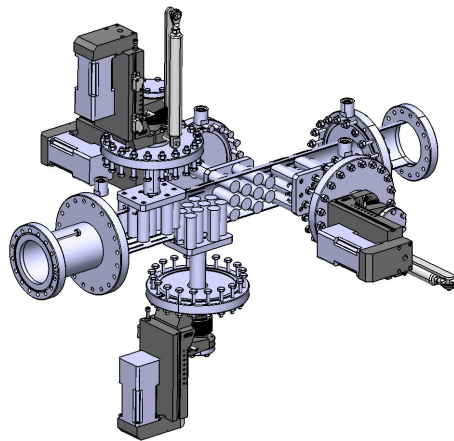


Figure 5: Drawing of the scraper [7]. On each side of each plane the scraper consists of 10 rods of 25 mm diameter. The scraper can move in further than the middle of the beam pipe. To avoid damage, rods for one plane are physically located behind each other.

each other but longitudinally behind one another. If both jaws are moved in fully they will not touch each other and so not being damaged. The mechanical construction of this system is finished, tests of the stepper motor control within the control system are underway.

## PHASE PICK-UP

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

## IN-GAP PARTICLE MEASUREMENT

The injection scheme of the HESR is planned in a way, that by the use of a barrier bucket RF-mode the circulating beam will be squeezed in about half of the longitudinal space [10].

The so generated cleared region will be used to inject the next bunch of antiprotons into the HESR. For the seamless injection, as few as possible particles should remain in the cleared region, as they will be lost during injection of the next bunch. In order to adjust the RF mode, the amount, or percentage, of remaining particles within the cleared region should be measured. Initially a wall current monitor (WCM) was requested for this task. During the detailed specification it was found the WCM is not capable of performing such measurement.

Further investigations led to a modified design of an IPM, in which the camera was replaced by a photomultiplier and the replacement of a phosphor screen with another form of scintillation screen was discussed. After calculating the particle yield of the residual gas interaction, the yield was found to be in the region of only few particles per second, and therefore within the expected noise background.

Therefore further investigations towards a suitable measurement method are required.

## OUTLOOK

At this point in time the production and delivery of the BPM pick-ups are almost completed. The measurement of the BPMs on the designed test stand is also well underway. As well as the calculation of the individual geometrical factors and offsets. The beam current transformers and the scrapers are completely manufactured, while testing is still ongoing. The viewers are in production, with the first of series already tested. For the IPM the design phase is finished, with the first of series right now under construction. Other systems are still in the design phase, like the Schottky Pick-up, or the Beam In-Gap measurement.

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