BEAM DIAGNOSTICS FOR THE HIGH ENERGY STORAGE RING AT FAIR

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Abstract

Numerous beam diagnostics systems, with the BPM system considered the most important one, are envisaged for the High Energy Storage Ring (HESR) within the FAIR Project. The BPM design, the corresponding test bench, HESR BLM studies at COSY, status of the ionization profile monitor and other subsystems are presented.

INTRODUCTION

The HESR, part of the FAIR project in Darmstadt, Germany, is dedicated to the field of antiproton and heavy ion physics. The envisaged momentum range is 1.5 GeV/c to 15 GeV/c. The ring will be 575 m long in a racetrack shape. The planned beam instrumentation within the modularized start version is:

76	Shoebox-style BPMs
118	Beam Loss Monitors
2	Beam Current Transformers
1	Ionization Beam Profile Monitor
1	Wall Current Monitor
1	Schottky Pick-up
1	Dynamical Tune-meter
1	Transverse Feedback System
1	Scraper

BPM SYSTEM

The BPM system is foreseen to measure the beam position throughout the ring. 22 BPMs are located in each arc of the ring and will be co-located to each sextupole magnet. An illustration of the elements between two dipoles in the arc sections is given in Figure 1.

The BPM units consist of two shoebox-style pick-ups rotated by 90° around the beam axis in respect to each other. The setup is shown in Figure 3. The inner diameter of the pick-ups is 89 mm and the length 77 mm with a gap of 3 mm between the electrodes using an angle of 55.5°. The expected signal levels are depending on the ion charge, the amount of ions, and the bunch length and can be calculated using

$$U_{img}(t) = \frac{1}{\beta c C_{el}} \frac{A}{2\pi\alpha} I_{beam}(t) \quad (1)$$

$$= \frac{1}{\beta c C_{el}} \frac{L_{BPM}}{2} I_{beam}(t) \quad (2)$$

The capacitance was calculated using a COMSOL Multiphysics 5.0 simulation. For the lowest case, the first injection of antiprotons with 10^7 particles in the ring, the signal level was calculated to 57 μV. For the highest intensity case, with 10^{11} antiprotons stored, the signal level is 390 mV.

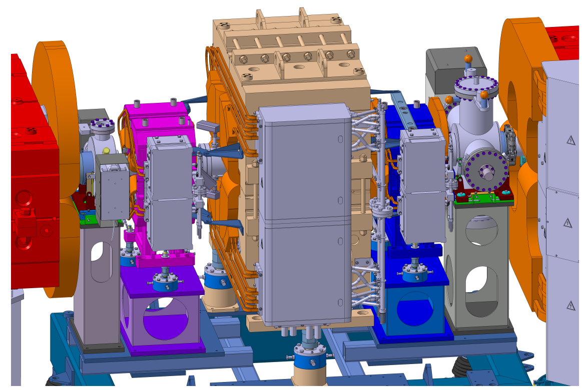

Figure 1: Illustration of the elements between two dipole magnets in the arc. From left to right: Dipole magnet (red), pumping vessel, sextupole magnet (purple), BPM, quadrupole magnet (ocher), steerer (blue), pumping vessel, dipole (red). Magnet coils are in orange.

The achievable resolution ϵ is dependent on the capacity between the pick-ups:

$$\epsilon = \frac{1}{b} = \frac{\alpha}{r_{BPM}} \quad (3)$$

$$\alpha = \frac{1 - \frac{CD}{C_{ges}+CD}}{1 + \frac{CD}{C_{ges}+CD}} \quad (4)$$

with CD the capacity between the pick-ups and C_{ges} the capacitance to ground. The capacity between the pick-ups was determined to 7.8 pF. With this value $\epsilon = 0.0146 mm^{-1}$.

The pick-up design is based upon the COSY BPMs [1]. The length and diameter is shrunk by a common factor in order to keep the length to diameter ratio. As can be seen in Figure 3 the pick-ups themselves are mounted onto a carrier tube which is then mounted within the beam pipe. In order to enhance the signal level, efforts were taken to increase the distance between the electrodes and the grounded carrier tube without changing the inner diameter of the BPM nor the outer diameter of the beam pipe as shown in Figure 2. In detail:

- Increasing the gap between carrier tube and electrodes.
- Shorten all screws to the minimum length.
- Increasing the diameter of holes in the carrier tube for the signal connections.
- Introducing bevels on the small edges of the pick-up cylinder.

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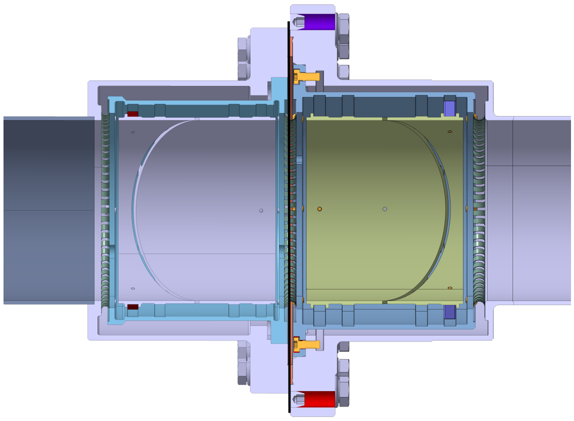

Figure 2: Comparison between the design of the COSY BPM (left) and the HESR design (right). Pictures have been scaled to fit the inner diameter of both BPMs. The gaps between the pick-up electrodes and the grounded carrier tube have been widened in order to reduce the capacitance and so increase the signal level.

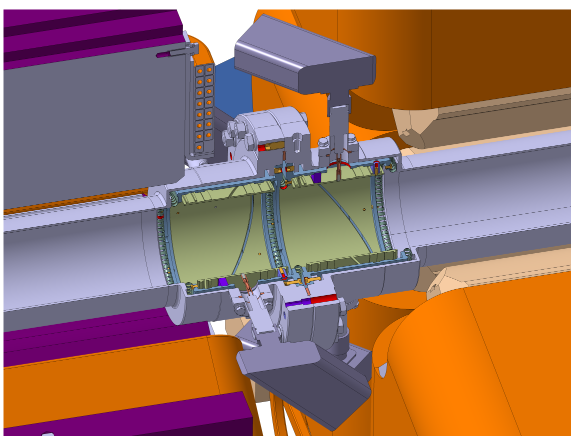

Figure 3: Illustration of the BPM between a sextupole magnet (left) and a quadrupole magnet (right).

- Removing all unnecessary holders of the carrier tube, left from production.
- Increasing the gap between the electrodes to 3 mm.

These efforts lead to an increase of about 50 % in signal level showed in simulation.

Furthermore, the XY coupling in the pick-ups was examined. The coupling reduces the position sensitivity of one plain if the beam moves in the other plain. Also the electrical center is shifted in one plain by introducing a beam offset in another plain. Simulations showed, that by moving the beam 1 mm in e.g. Y direction, the position reading in X direction changes by 2.6 μm.

A prototype of the HESR BPM is currently being manufactured. The test bench measurements are expected to start by the end of 2015.

Ion Clearing

In the antiproton mode of operation of the HESR clearing of residual gas ions trapped in the beam is seen as crucial [2]. Therefore a constant voltage should be applied on at least one pair of each BPM's electrodes. The required field strength on the location of the beam has been calculated to be higher than 2500 V/m. Simulations showed that a voltage of ± 100 V will be sufficient to fulfill this requirement. However it was also shown, that due to the pick-up geometry, the effective length of the field above 2500 V/M at ±100 V amounts to a small fraction of the pick-up length only. Therefor higher voltages might have to be applied in order to effectively clear the ions out of the antiproton beam.

BPM Prototype Wire Test Bench at COSY

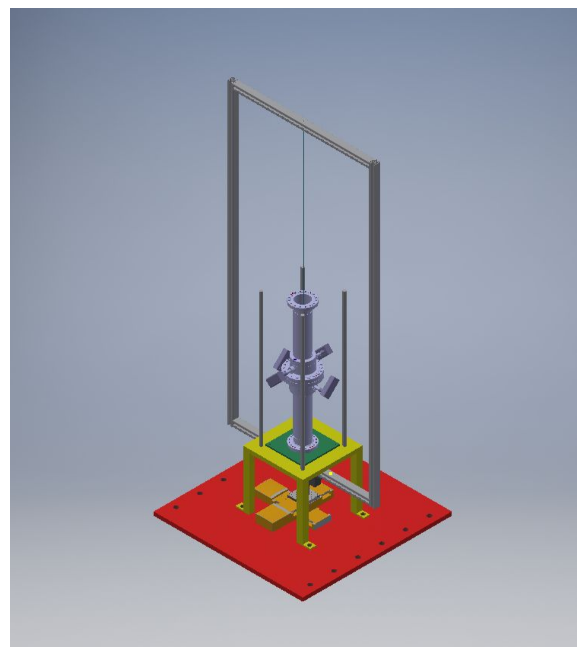

Figure 4: Isometric View of Wire type Test Bench.

Figure 4 (isometric) represents a 3D design view of the test bench with its main elements and the BPM under test. A centered axial line is also depicted to represent the wire that longitudinally passes through the BPM. The fundamental design concept is the upright mounting of the BPM. A movable aluminum frame is used to support a wire, stretched through the BPM. Such an approach allows avoiding any wire sagging due to gravity. With the BPM fixed on the base bench, the aluminum frame carrying the wire is moved by linear stages. Their position readout yields the wire-BPM relative displacement. Moving the wire instead of the BPM will be preferred due to a significant weight of the BPM. The stretched wire will have SMA connectors attached to both ends.

Two linear stages [3] will be orthogonally mounted providing the wire-BPM relative displacement in (x, y) direction. On top, a Y-shaped solid frame made of cast steel will be mounted that holds the aluminum frame. The M-ILS100HA

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will be chosen for each translation stage, being a high performance precision micro-mover driven by DC motors from Newport. The maximum linear travel range is 100 mm with an on-axis accuracy of 3 μm and the smallest incremental linear motion of 0.3 μm. The maximum normal load capacity is 250N (25.5 Kg) which is enough to withstand a weight of approximately 15 Kg by the stage beneath.

The steel base platform serves as the base on which the whole setup will be mounted as shown in Figure 4. The BPM base bench will be made of cast steel and the reference plane will be made of aluminum. Both the base bench and the reference plane have a concentric hollow center for the wire-BPM relative displacement. Finally, two contact brushes will provide electrical contact between the beam pipe and the movable frame (not shown in figure). This is done to avoid the ground current loop that would otherwise form between the wire and the aluminum frame.

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 are planned to be used. Although detailed beam loss simulations are yet to be carried out, testing of different detector technologies has already begun.

- LHC-type ionization chamber from CERN [4]
- SNS-type ionization chamber from ORNL [5]
- Liquid scintillator
- Sait-Gobain scintillator crystal 2M2/2 [6]
- PIN-Diode BLMs from Bergoz
- Heliax cable

For the preliminary testing of the ionization chambers a commercially available current amplifier was used. This readout allowed to observe a slowly extracted beam in the extraction beam line of COSY using the LHC ionization chamber. The first test of the SNS type chamber was not successful due to noise dominated signals associated with the test setup. Next series of tests will be carried out using the current measurement module designed and built by iThemba LABS. It is an 8 channel version of a current measurement electronics used to readout harps in the beamlines at iThemba LABS and at COSY [7]. The specifications of both devices are very similar, both measure in the most sensitive range pA by integrating the current, up to 200 ms. Although the integration is done independently for every channel a multiplexer is used to read out the current integrators sequentially. The difference, besides the amount of channels is, that the version with 48 channels can only use the same integration time, and in consequence the same measurement range, for all channels, while the 8-channel one can use individual integration times for every channel. The 8-channel device as well as the newer versions of the 48-channel version have a built-in EPICS server for read-out and controls. In addition further tests using the ionization chambers read out by the CERN electronics to detect beam losses at COSY are planned.

Another test series was carried out using scintillation detectors and PIN-diodes to monitor the beam losses in the COSY tunnel during the JEDI beam time. Standard COSY BLM utilizing a liquid scintillator, a crystal scintillator purchased from Saint-Gobain and a Bergoz BLM based on Hamamatsu PIN-diodes were used. Both scintillation detectors have a PMT and a pre-amplifier built in.

Shown in Figure 5 are results of a comparative test of the PIN diodes and the two scintillation based detectors. These first tests were done using a digital oscilloscope. During this test the beam was slowly steered towards a target on top of the vacuum chamber. Therefor the beam intensity, represented by the BCT signal slowly decreases. As shown, the PIN diode BLM delivers the lowest count rate. This is likely due to a much smaller detector size compared to the scintillator based models. In comparison of the two scintillation based detectors the crystal one has the tendency to saturate slower, which makes this type preferable over the liquid scintillator one.

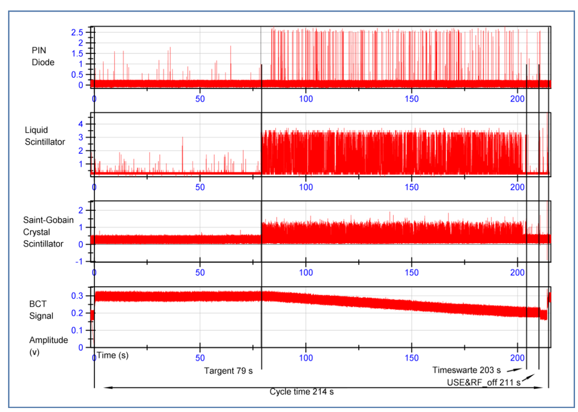

Figure 5: Test of three different Beam Loss Monitor devices. Two scintillator and one PIN diode based (upper trace) during the slow steering of the beam towards a target.

Further evaluations of detectors are planned. Tests of the coaxial cable method [8] are planed using the slowly extracted beam in the extraction beamline. In addition experiments with optical fibers [9] will be performed.

IONIZATION BEAM PROFILE MONITOR

An Ionization Beam Profile Monitor (IPM) shown in Figure 6 was built and tested together with the GSI in 2007. Since then it became a very valuable instrument in beam diagnostics at COSY and GSI [11]. The COSY experience shows, that besides the data acquisition a lot of work goes into reliable automated setting of the voltages needed to

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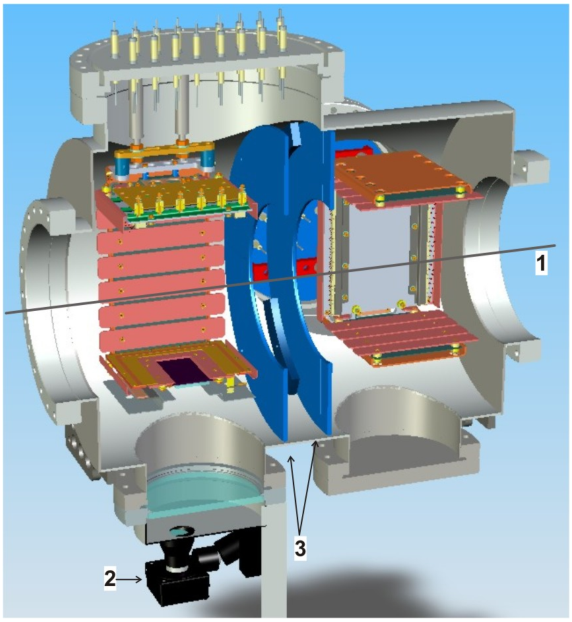

Figure 6: Drawing of the IPM prototype built together with the GSI [10]. The ion beam (1) ionizes residual gas which is accelerated towards a detector and read out by a standard GiGE camera (2). To minimize the effect of the electrical fields towards each other, shielding plates have been inserted between both devices.

operate the instrument at a level where the profiles can be detected, while making sure the built-in micro-channel plates are not damaged. This is due to a wide range of beam densities routinely present in the COSY ring, in particular when beam cooling is applied. The development of automation and interlocks is an ongoing effort to achieve an unattended operation of the IPM. Based on COSY experience a similar device will be developed for the HESR.

CONCLUSIONS

Using anti-protons with a longitudinal stacking injection within the HESR of the FAIR project the beam instrumentation has to be able to measure the beam position with as low as 10^7 particles stored after the first injection. Therefore results from simulations have been used to optimize the design of the shoebox BPM. The manufacturing of the BPM prototype is in progress. The design of the BPM test bench is being finalized. The BPM readout electronics will be provided by Instrumentation Technologies as an in-kind contribution to FAIR. This electronics will also be used for tune measurements and orbit feedback.The first test of BLMs was performed, in order to find a system that best fits HESR needs. Further BLM technologies need to be tested. For dc and bunched beam current measurements commercially available systems will be used. The GSI/COSY IPM utilizing collection of ions will be adopted for HESR.

REFERENCES

[1] R. Maier et. al., "Non-Beam Disturbing Diagnostics at COSY-Jülich," EPAC'90, Nice, France, June 1990, p. 800.

[2] F. Hinterberger, "Ion Trapping in the High-Energy Storage Ring HESR," Berichte des Forschungszentrums Jülich 4343, ISSN 0944-2952, October 2011.

[3] Manual of ILS Series, "High-Performance Mid-Range Travel Linear Stages," MILS100CCHA, Newport Corporation, Irvine, California, USA.

[4] M. Stockner et. al., "Classification Of The LHC BLM Ionization Chamber," DIPAC 2007, Venice, Italy, WEPC09.

[5] A. Zhukov et. al., "SNS BLM System Evolution: Detectors, Electronics, and Software," PAC09, Vancouver, BC, Canada, FR5REP038.

[6] Saint-Gobain Ceramics & Plastics, Inc. "Scintillation Detectors with Integrally Mounted PMT," 05-14.

[7] iThemba LABS, Annual Report 2008, p. 50.

[8] G. W. Bennett et. al., "The Upgraded Ring Loss Radiation Monitoring System at the AGS," PAC89, Chicago, USA, p. 1477.

[9] F. Rüdiger et. al., "Beam Loss Position Monitoring with Optical Fibres at DELTA," EPAC08, Genoa, Italy, TUOCM03.

[10] T. Giacomini, GSI Gesellschaft für Schwerionenforschung mbH, Darmstadt, Germany, private communication.

[11] V. Kamerdzhiev et. al., "Results of Electron Cooling Beam Studies at COSY," RuPAC-2010, Protvino, Russia, WECHZ04.

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