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STATUS OF BEAM INSTRUMENTATION FOR FAIR HEBT

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Abstract

At present the Facility for Antiproton and Ion Research (FAIR) is under construction at the GSI site. As part of the FAIR project the beamlines of the High Energy Beam Transport (HEBT) section interconnect the synchrotrons, storage rings and experimental caves. The large range of beam energies (MeV to GeV) and beam intensities up to 10^{12} particles per pulse for uranium, or up to 2×10^{13} particles per pulse for protons, demand in many cases for purpose-built beam diagnostic devices. Presently, the main diagnostic components are being manufactured by international in-kind partners in close collaboration with GSI. This contribution presents an overview of the beam instrumentation layout of the FAIR HEBT and summarizes the present status of developments for HEBT beam diagnostics. We focus on the status of the foreseen beam current transformers, particle detectors, scintillating screens and profile grids.

STATUS OF FAIR ACCELERATORS

Presently, civil construction works of the northern section of the FAIR accelerator complex are progressing well [1]. This section is the first to be built and includes the underground ring building for SIS100, i.e. the main synchrotron of FAIR, as well as significant parts of the HEBT buildings. Also the interconnection between the existing GSI accelerator facility, which will serve as injector for the FAIR machines, is presently being prepared. The ring tunnel for the fast ramped super-conducting synchrotron SIS100, located 25 metres underground is already excavated and first sectors of the ring building are constructed. Construction works of the HEBT buildings have started too. The HEBT connects the synchrotrons with the super-fragment separator (S-FRS) for the production of rare isotopes, with the antiproton target and separator for the production of antiprotons, the collector ring (CR) for stochastic pre-cooling of rare isotopes and antiprotons and the high-energy storage ring HESR. In addition, HEBT beamlines provide beams to the fixed target experiments of APPA, SPARC and CBM. The main accelerator of FAIR will be SIS100, designed for production of up to 5×10^{11} U28+ ions/s with energies of 0.4-2.7 GeV/u. SIS100 beams can be extracted either in single bunches of 30-90 ns, or by slow extraction with extraction times of several seconds, for the production of radioactive ion beams in the S-FRS and various high energy experiments, like e.g. CBM or HADES. Efficient production of antiprotons will require 2×10^{13} protons per pulse at an energy of 29 GeV with a repetition rate of 0.1 Hz and a bunch length of 50 ns. After passing the large aperture antiproton separator line, secondary antiproton beams will be stored and pre-cooled in the CR and transported to the HESR for stacking, stochastic cooling and post-acceleration. The design of the FAIR facility foresees that all accelerators operate in a highly multiplexed mode, thus allowing sequential beam delivery to up to four different experiments inside one machine super-cycle. The complex modes of operation demand for well adopted beam instrumentation inside the HEBT beamlines.

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HEBT BEAM DIAGNOSTICS

Beam instrumentation for the 1.5 km long HEBT beamlines has to cover both, slow and fast extracted beams, as well as a wide range of beam intensities. Thus dedicated instruments were developed for all modes of operation. Table 1 summarizes the diagnostic equipment of the HEBT. Especially high current operation requests for non-intercepting devices, like e.g. Beam Current Transformers, Beam Position Monitors or Ionization Profile Monitors.

Table 1: HEBT Diagnostic Devices

Device	Parameter	No. of pcs.
Resonant Transformer	Bunch / batch charge	25
Fast Current Transformer	Bunch current, time structure	11
Cryogenic Current Comparator	Beam current, spill structure	4
Particle Detector Combination	Beam current	16
Beam Position Monitor	Centre-of-mass	39
Multi-Wire Proportional Chamber / Ionization Chamber	Transverse beam profile, current	34
SEM-Grid	Transverse beam profile	51
Scintillating Screen	Transverse beam profile	18
Ionization Profile Monitor	Transverse beam profile	15
Beam Loss Monitor	Beam loss	30

Diagnostic Vacuum Chambers

As part of the Indian in-kind contribution to FAIR 70 diagnostic vacuum chambers for beam diagnostic devices will be manufactured. Presently, a commercial provider has been selected by the Indian shareholder and the first two prototype chambers are ready for delivery. Prior to series

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production detailed mechanical and vacuum acceptance tests of these prototypes will be performed at the GSI site.

Pressurized Air Drives

All pressurized air drives of the HEBT beamlines will be produced and delivered as Slovenian in-kind contribution to FAIR. This includes drives for particle detector combinations, scintillating screens, multi-wire proportional chambers and SEM-grids. At present first prototypes have been produced by the Slovenian contributor Vacutech [2] and series production will start in autumn 2019.

Beam Intensity Measurement

In total 25 Resonant Transformers (RT) are foreseen in the HEBT for online measurement of fast extracted beams with high accuracy. The RTs developed and manufactured by GSI are based on the excitation of a damped oscillation of the passing ion beam inside the RT electronic circuit [3]. The amplitude of the oscillation, proportional to the total bunch charge will be recorded and post-processed with a 14 bit 105 MSa/s ADC based on µTCA form factor. This device has a typical resolution of ~10 pC_{RMS} (i.e. 6×10^7 protons). To achieve an absolute accuracy of 1-2% as required for FAIR an in-situ calibration generator was designed. At the moment prototype development is finished, the sensor was successfully tested and the purchase order is prepared for the RT sensor.

For the measurement of the bunch structure of fast extracted beams 11 commercially available Fast Current Transformers (FCT) have already been purchased [4] and will be inserted in the same magnetic shielding as for the RT. Data Acquisition of the FCT signals consists of a 2.5 GSa/s 14 bit µTCA ADC board by SIS [5].

In order to cover a large range of beam intensities during slow extraction so-called Particle Detector Combinations (PDC) will be installed. These combined detectors are mounted on a pocket drive and consist of a plastic scintillator for the detection of very low beam currents, and a secondary electron emission monitor (SEM), which is mounted on the identical pneumatic drive [6]. The installation location for the PDC is chosen in such a way that at all positions there is an ionization chamber nearby. In the low intensity region, e.g. below 10^5 particles/s, the measurement ranges of plastic scintillators and ionization chambers overlap, thus allowing for direct calibration of the ionization chamber by the plastic scintillator. In turn, this method will be used to calibrate the adjacent SEM detector. The GSI-built SEM consist of a stack of 3 circular foils (24 µm thickness, 107 mm diameter) mounted on a common support, where the outer two foils are kept on high positive potential. Figure 1 depicts the prototype SEM stack. For a given foil material the yield of secondary electrons emitted by the ion beam passing the foils is proportional to the beam intensity. A dedicated development of a SEM detector was accomplished and is now ready for series production. The SEM current signals will be converted to logic pulses using GSI-built current-to-frequency converters (IFC) and pulses will be recorded by the 'LASSIE' DAQ system [7], a µTCA-based multi-channel acquisition system already in operation at GSI.

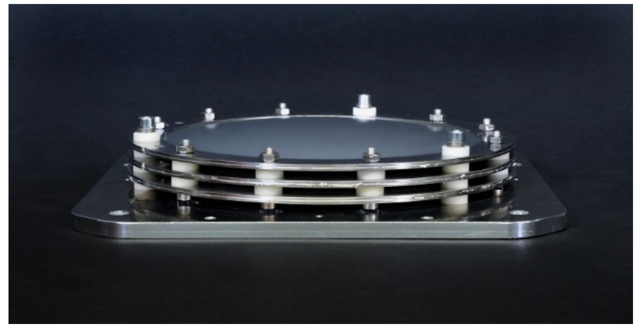

Figure 1: SEM detector developed for FAIR.

For the precise measurement of slow extracted beams a long-term development for the design and manufacture of a Cryogenic Current Comparator (CCC) meanwhile yielded excellent results [8, 9]. The measurement principle of this world-unique instrument is based on the precise detection of the beam's magnetic field by a super-conducting quantum interference device (SQUID). The goal is to achieve the highest current sensitivity for dc beams in the nA region. At present an optimized CCC pre-series model is under construction and first beam tests at CRYRING are foreseen for end of 2019.

Transverse Profile Measurement

For the measurement of the transverse profile of fast extracted beams in total 51 SEM-Grids will be installed in the FAIR HEBT. The standard SEM-grid features 64 W-Rh wires (0.1 mm diameter) per plane at a typical spacing of 1 mm. For the readout of both, SEM-Grids and MWPCs, dedicated acquisition electronics based on a purpose-built ASIC has been developed. The digitization is performed by charge-to-frequency conversion (QFC), with a sensitivity of 0.25 pC/Count for each wire channel. The POLAND electronics (PrOfiLe Acquisition Network Digitizer) has a modular structure and will allow fast digitization of 64x64 channels. The system layout was optimized with respect to radiation hardness, rigorously tested during several beam times and is presently in series production [10] at GSI Experiment Electronics Department. In addition, a charge-sensitive amplifier is presently under development to further enhance the dynamic range of the SEM-Grids.

Transverse profiles of both, fast and slow extracted beams will be monitored using 20 Scintillating Screens. A detailed study of various scintillator materials yielded that Al_2O_3:Cr is the most adequate material for FAIR beam parameters. The readout of the scintillating screens has been standardized as CUPID system [11], featuring a combination of µTCA-based readout of the distributed gigabit-ethernet CCD cameras and PLC for I/O control. It comprises the remote-control of LED light for calibration and the lens iris for intensity adaptation, using commercial PLC components. The FESA-based CUPID system is already in use at more than 35 positions inside GSI beamlines and became an important standard device during routine operation. Figure 2 depicts the graphical user interface of a scintillating screen in the GSI high energy beam transport section including hor. and vert. projections of the profile.

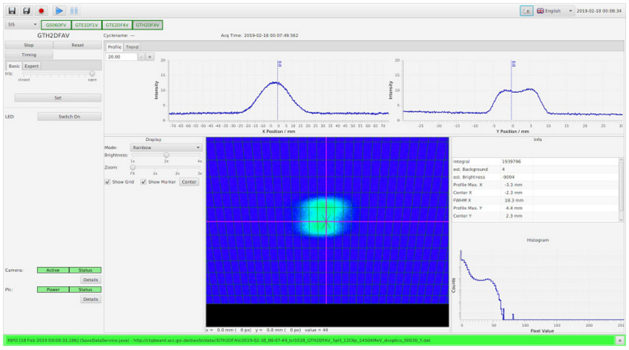

Figure 2: Online SCR display of the CUPID system.

In close collaboration with GSI detector laboratory combined multi-wire proportional chambers (MWPC) / ionization chambers (IC) are being manufactured. In order to determine the profile and intensity of slow extracted beams a total of 34 MWPC/IC combinations are foreseen for the HEBT. The MWPCs have a large dynamic range of 50 dB and will be readout using the identical electronics as used for profile grids. Beam profiles of the MWPCs will be recorded using the POLAND electronics described above. As for the SEM, the IC current signal will be fed into IFCs to provide logic pulses for the LASSIE scaler boards.

For non-intercepting beam profile measurements during high current operations 15 Ionization Profile Monitors (IPM) are foreseen. These devices, however, will not be used during beam commissioning and are presently still in the development phase.

Beam Position Monitors

The beam position of fast extracted bunches will be monitored using 39 Beam Position Monitors. The mechanical layout of these BPMs is kept identical to the SIS100 BPMs in order to gain synergies and reduce spare parts. The pick-up consists of a ceramic tube with a structured, shoe-box type metallized inner surface. The production of the ceramic tubes has recently been contracted. For impedance matching the pick-ups are directly connected to purpose-built matching transformers. As for SIS100 the BPM pre-amplifiers are developed and manufactured by the Slovenian in-kind provider Instrumentation Technologies [12], who is also responsible for the delivery of fast (250 MSa/s) digitizer units (Libera Hadron). All Libera units are already delivered to GSI and have been thoroughly tested during extensive Site Acceptance Tests. The DAQ software is presently being implemented by the Slovenian in-kind contributor Cosylab [13] and will soon be tested at a dedicated BPM testbench.

Beam Loss Monitors

A set of 30 movable Beam Loss Monitors (BLM) will be used in the HEBT to detect beam losses at critical locations, e.g. at septa, switching magnets or quadrupoles at locations with large beam envelopes. In order to monitor slowly extracted beams plastic scintillators will be used for beam loss detection, due to their high sensitivity. The BLMs developed for FAIR are based on 2x2x7.5 cm^3 BC400 scintillators with photomultiplier readout. Again, LASSIE will be used for BLM data acquisition. Details on the BLM development are given in [14]. Identical BLMs will also be used for SIS100 and the High Energy Storage Ring (HESR) of FAIR. After successful beam tests during the 2018 beam time, the BLM design is ready for series production.

CONCLUSION AND OUTLOOK

The technical design of all 'day-zero' diagnostic devices for FAIR HEBT was fixed and the prototypes were successfully tested with beam. Currently, all purchase and manufacturing works are progressing well.

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