Beam intensity monitoring with nA resolution – the Cryogenic Current Comparator (CCC)

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IBIC18, GSI, AVA – Accelerators Validating Antimatter - Beam charge and current monitors d.haider@gsi.de

The **storage** *of low current* beams as well as the **slow extraction** from the synchrotrons at FAIR require **non-destructive** beam intensity monitoring with a current **resolution of nano-ampere**. To fulfill this requirement, the concept of the Cryogenic Current Comparator (CCC) based on the low temperature SQUID is used to obtain an extremely sensitive beam current transformer.

The main challenge of the ongoing research is to improve the **robustness against external interference** and to develop a cost-efficient **concept for the superconducting shield** and the cryostat.

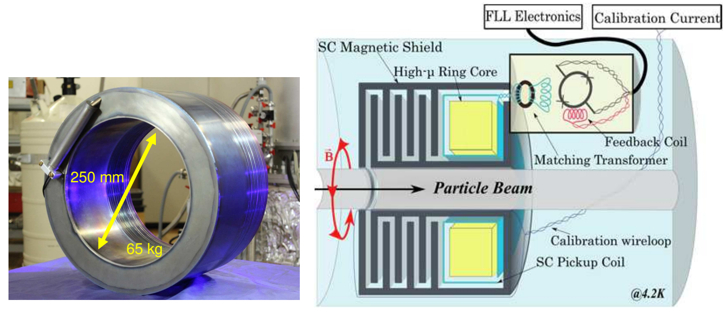

Figure 1: The FAIR prototype CCC-eXtended-Dimensions (GSI-CCC-XD)

Features

- **Non-destructive**
- **Intrinsic absolute calibration**
- **Independent of energy, position and particle species**

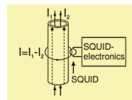

Fig. 2: Concept (1972)

Fig. 3: First accelerator application (1996)

Applications

Offers relative resolution down to 5.8 nA for beam currents below 12 µA in accelerator applications [1] and slew rates of up to 0.16 µA/µs in a clean lab environment [2].

- **Storage rings** (Antiproton Decelerator at CERN, TARN II at KEK)
- **Transfer lines** (SIS18 extraction line at GSI)
- **Dark currents of superconducting cavities** (DESY)

Measurement principle

- **Superconducting magnetic shield:** Attenuates non-azimuthal components.
- **High-µ ring core:** Concentrates the beam's azimuthal magnetic flux.
- **Superconducting pick-up coil:** Detection of the beam's azimuthal magnetic field.
- **Matching transformer:** Coupling of the signal from the pick-up coil to the DC-SQUID.
- **DC-SQUID + Flux-Locked-Loop electronics:** The flux through the SQUID is kept constant by a feedback loop (Flux-Locked Loop).

Institute	Date	Comment
GSI, Germany	2014	Measurement of **SIS18** slow extraction.
CERN, Switzerland	2016	Current monitor for the **Antiproton Decelerator** with a closed refrigeration system.
FAIR, Germany	est. 2019	Installation of the **FAIR** prototype.

Storage rings

Perturbations from magnet ramps, cryocoolers and other components can be filtered during data processing to obtain **absolute current** readings **for many seconds**.

- **Resolution:** 5.8 nA for currents below 12 µA over >85 s [1].

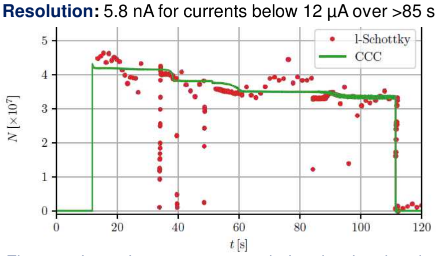

Figure 4: Intensity measurement during the deceleration cyle of the Antiproton Decelerator (CERN) and comparison with the longitudinal Schottky monitor [1].

Shield design

New shield designs and modern SQUID technology can remove the need of a flux-concentrating core.

- **Higher shielding factor (135 dB)**
- **Remove magnetic noise of core**

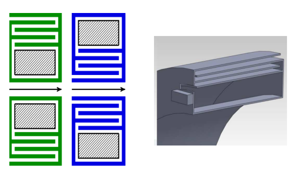

Figure 5: Alternative shield designs to further increase the current resolution.

Extraction lines

Spill structure of the slow extraction from SIS18 at GSI was measured and lead to the improvement of the spill quality.

- **Resolution:** 2.3 nA rms with average currents of 5.34 nA for 65 ms [3]

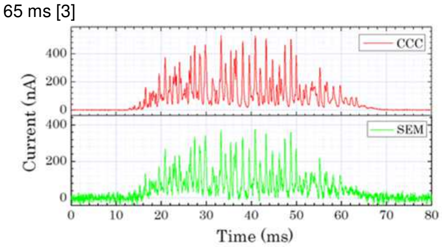

Figure 6: Spill structure of 1.6 x 10^9 Ni^{26+} ions from SIS18 (GSI) measured with 10 kHz by both the CCC and the Secondary Electron Monitor (SEM) [3].

Characterization of the CCC-XD for FAIR

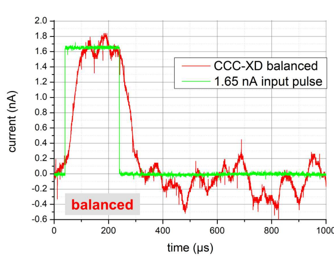

Figure 7: Response of the CCC-XD (red) to a 1.65 nA (200 µs) current pulse (green), measured with a 10 kHz low pass filter [4].

- Intensities of 1.65 nA (200 µs) [4] can easily be detected.
- A slew rate of 0.16 µA/µs can be achieved, at a bandwidth of 200 kHz [2].

Beamline cryostat for FAIR

- Challenging design because of warm beam line.
- Helium re-liquefier for continuous operation.
- Careful consideration of the **resonant frequencies**.

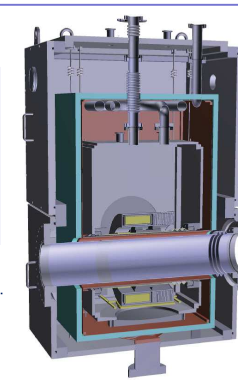

Figure 8: Preliminary design of the cryostat for FAIR.

Summary and Outlook

- The manufacturing of the **CCC cryostat** is accompanied by ANSYS© calculations to avoid critical **resonances** (e.g. 50 Hz) and to provide sufficient damping.
- Tests on alternative **shielding geometries** and coreless designs are ongoing.
- **Irradiation tests** of the SQUID sensors up to 700 Gy at the CHARM irradiation facility at CERN to confirm radiation hardness of the SQUID sensors.
- In 2019 the GSI-CCC-XD will be installed in **CRYRING** where the **new shield geometries** will be tested.

References

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[1] M. Fernandes, Ph.D. thesis, University of Liverpool, UK, June 2017
[2] P. Seidel et al., IEEE Trans. Appl. Supercond., vol. 28, no. 4, p. 1601205, June 2018
[3] F. Kurian, Ph.D. thesis, University Frankfurt, Germany, 2015
[4] V. Tympel et al., Proceedings of IBIC 2017, Grand Rapids, MI, USA

Further information at: https://www-bd.gsi.de/dokuwiki/doku.php?id=instruments:overview:ccc

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