The Next Generation of Cryogenic Current Comparators for Beam Monitoring

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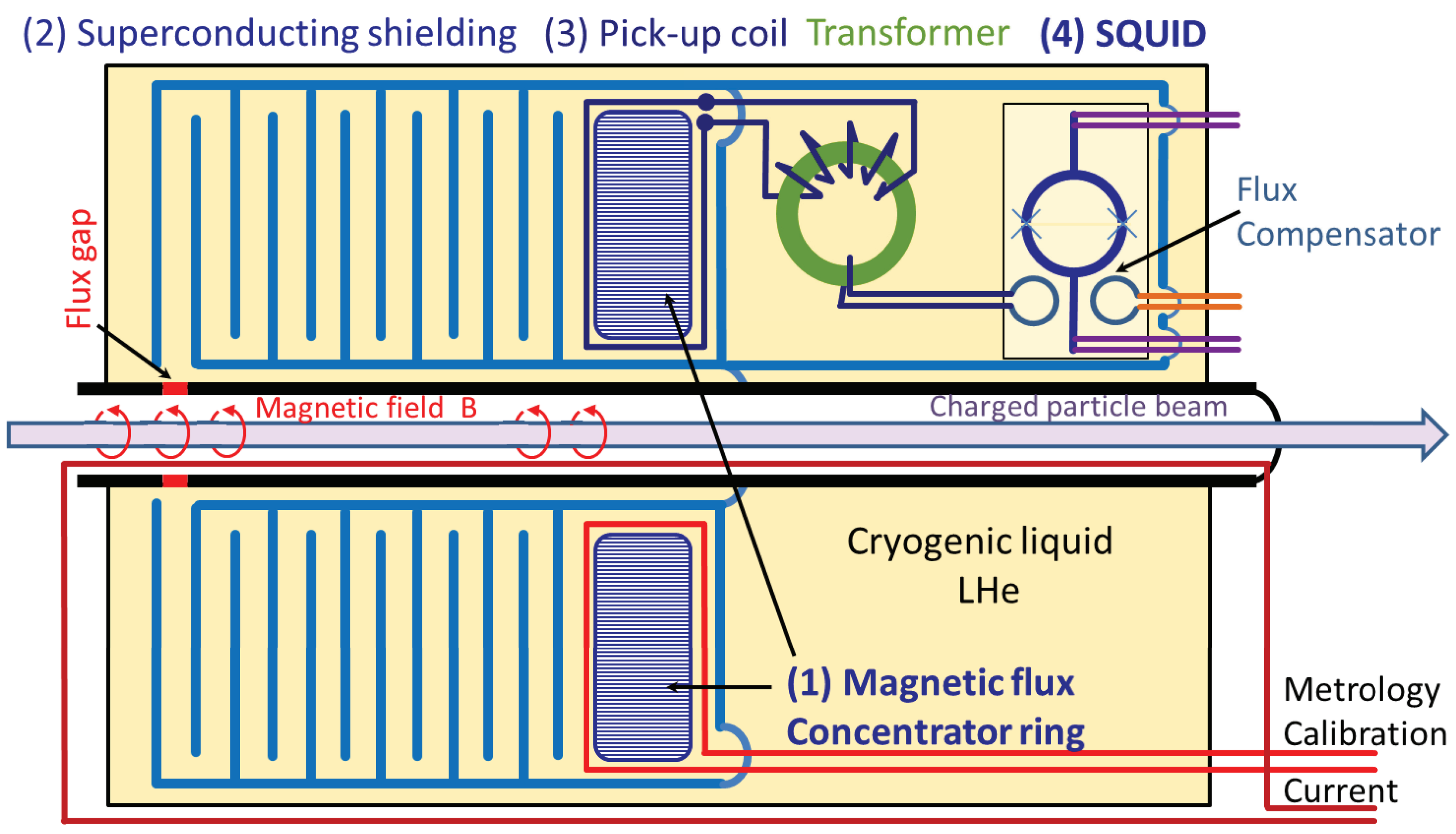
Abstract

A new ***C****ryogenic* ***C****urrent* ***C****omparator* with *e****X****tended* ***D****imensions* (***CCC-XD***), compared to earlier versions built for GSI, is currently under development for a non-destructive, highly-sensitive monitoring of nA-intensities of beams for larger beamline diameters planned for the new FAIR accelerator facility at GSI. The *CCC* consists of a:

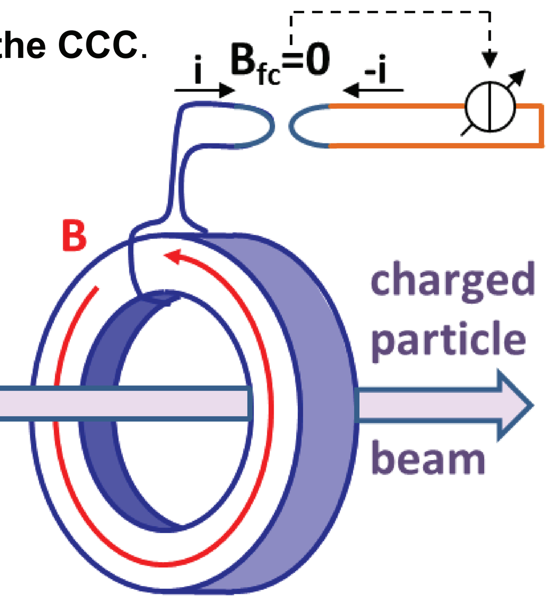
(1) flux concentrator,
(2) superconducting shield against external magnetic field and
(3) superconducting toroidal coil of niobium which is read out by
(4) *Superconducting Quantum Interference Device* (*SQUID*).

The new flux concentrator (1) comprises a specially designed highly-permeable core made of nano-crystalline material, in order to assure low-noise operation with high system bandwidth of up to 200 kHz. The superconducting shielding of niobium (2) is extended in its geometric dimensions compared to the predecessor *CCC* and thus will suppress (better -200 dB) disturbing magnetic fields of the beamline environment more effectively. For the *CCD-XD* readout, new SQUID sensors (4) with sub-µm Josephson junctions used which enable the lowest possible noise-limited current resolution in combination with a good suppression of external disturbances.

The *CCC-XD* system, together with a new dedicated cryostat [IBIC2016-Poster WEPG40], will be ready for testing in the CRYRING at GSI in spring 2017. For the application of a *CCC* in the antiproton storage ring at CERN a pulse shape correction has been developed and tested in parallel. Results from electrical measurements of two components (1 and 4) of the new *CCC-XD* setup will be presented in this work.



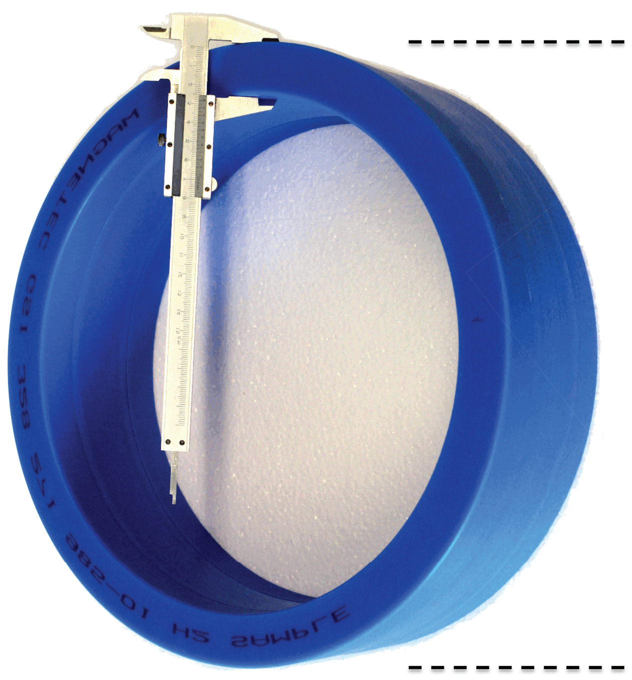
Schematic of the CCC.



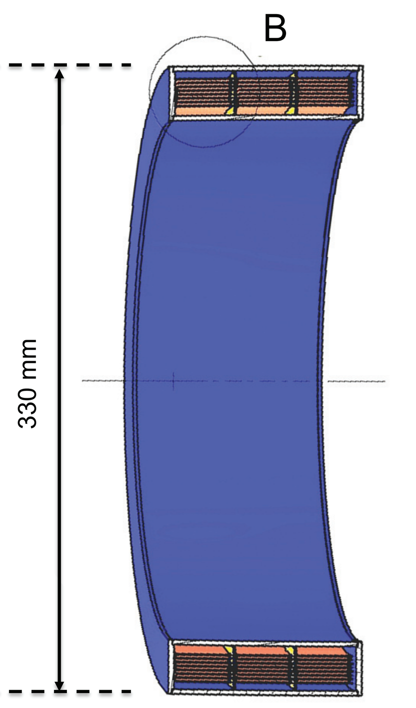
The **general principle of a CCC** as a closed loop current measurement system with compensation current as measurement value.

(1) The advanced flux concentrator

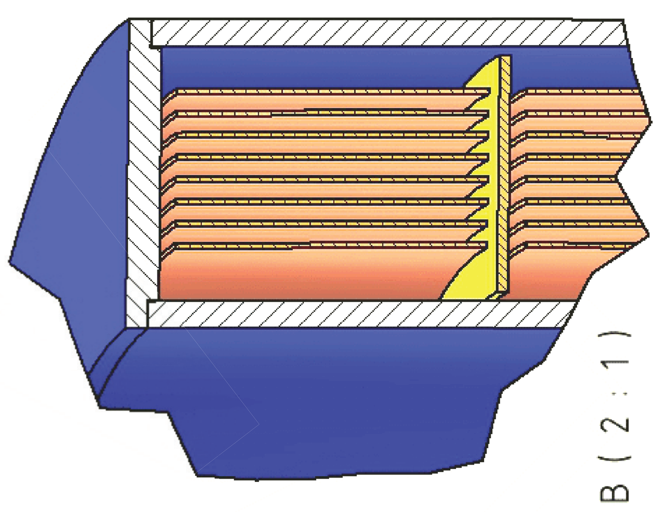
The larger beamline diameter of the new FAIR accelerator facility leads to an inner diameter of 274 mm for the flux concentrator. A special three-piece core package was composed by wrapped ribbons of nanocrystalline Soft Magnetics. The ribbon thickness itself is very small – on about 15 µm. The material is produced by a specific thermo-magnetic annealing process of amorphous Fe-alloy (NANOPERM® $Fe_{73.5}$ Cu_1 Nb_3 $Si_{15.5}$ B_7 [1]) ribbons which defines the magnetic parameters and the temperature dependencies. More than 1000 layers are necessary to create a single core.



Real core package GSI328plus.

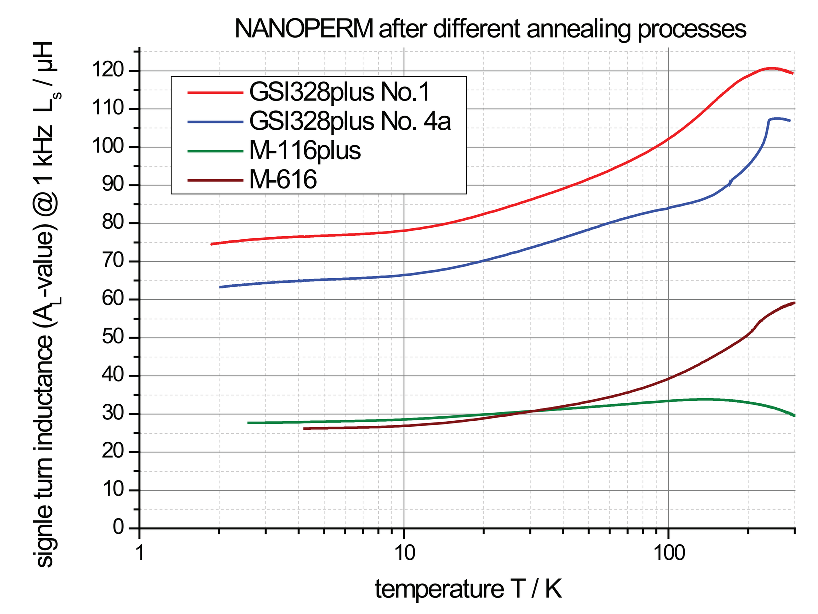


Virtual cut through the core package.

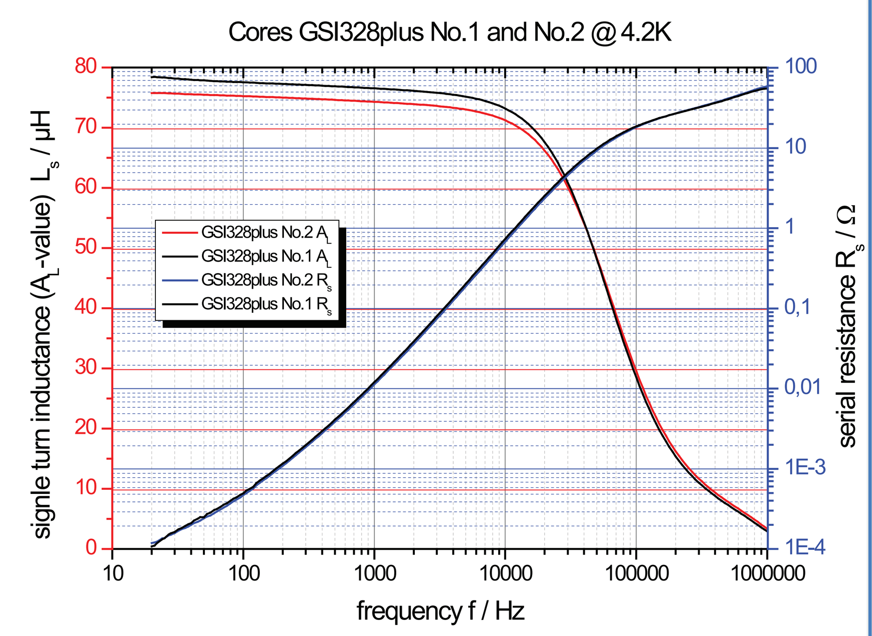


Enlarged cut through a NANOPERM® ribbon core (only schematic: real ribbon thickness ≈ 15 µm).

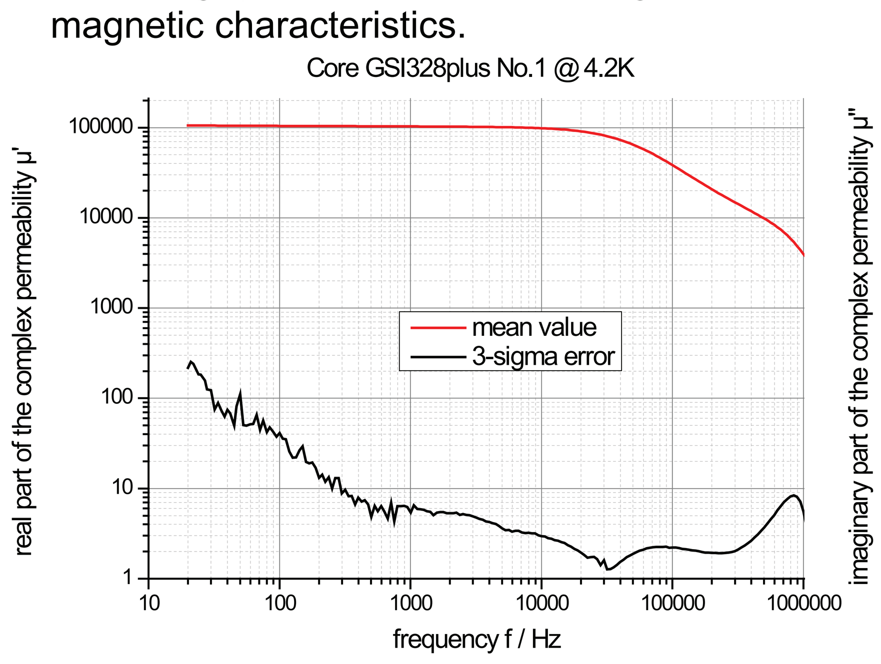
A precision L_S-R_S-measurement setup and a wide-neck cryostat with a temperature range from 2 K to 300 K was developed to characterise the core packages concerning the variation of the electrical parameter due to annealing process.



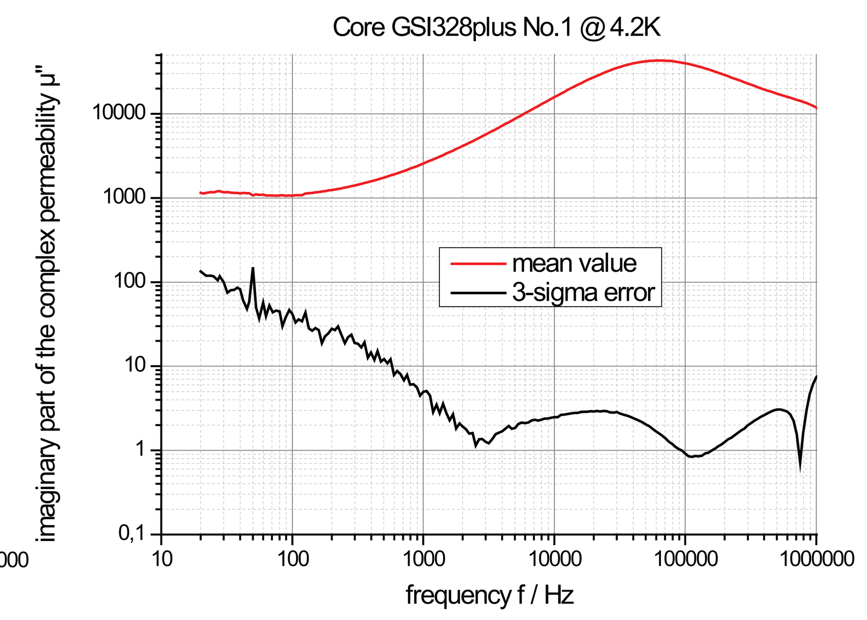
Different recipes of the thermo-magnetic annealing process lead to changed electro-magnetic characteristics.



The same recipes does not lead to identical electro-magnetic characteristics.

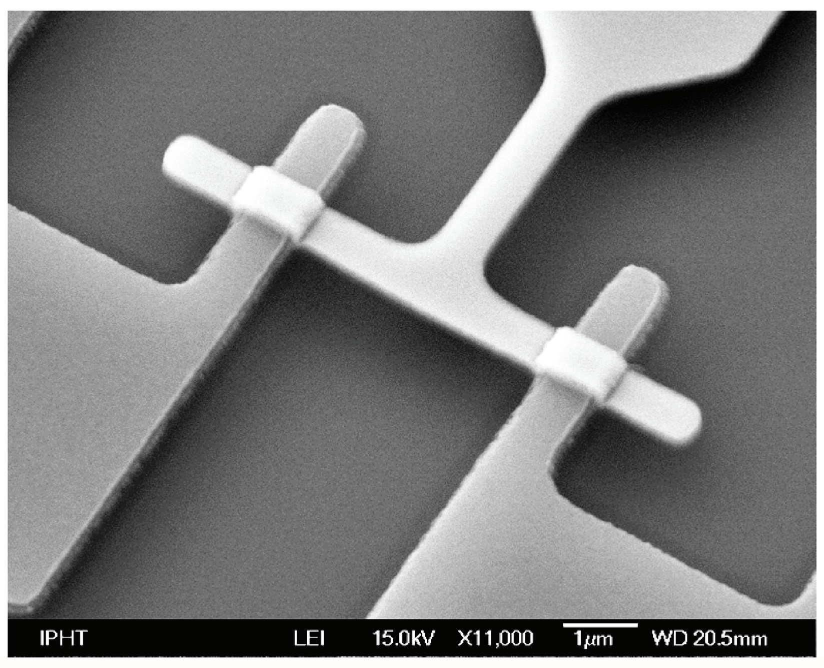


Precision measurement of the real part µ' of the complex permeability µ = µ' - i·µ'' of a core package @ 4.2 K.



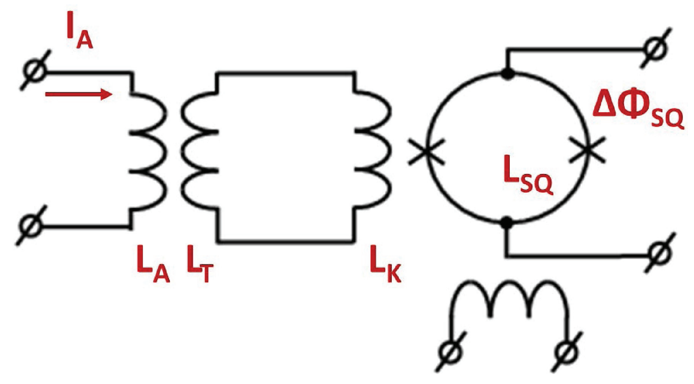
Precision measurement of the imaginary part µ'' of the complex permeability µ = µ' - i · µ'' of a core package @ 4.2 K.

(4) The new sub-µm SQUID

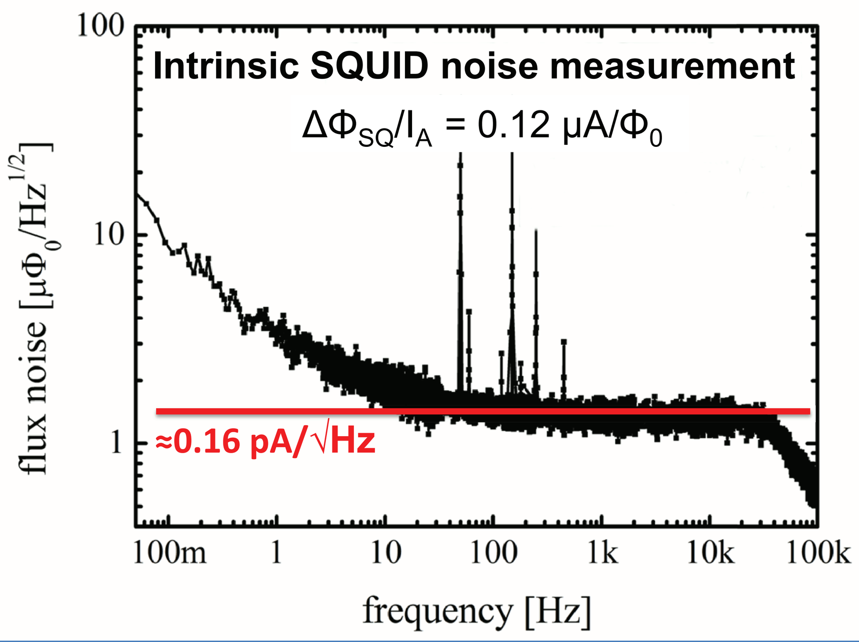


SEM image of sub-µm sized Josephson junctions of the new IPHT CE1K SQUID with critical dimensions below one micron.

Estimation of the CCC performance:



$$\frac{\Delta\Phi_{SQ}}{I_A} = \frac{\sqrt{L_A \cdot L_T \cdot L_K \cdot L_{SQ}}}{L_T + L_K + L_{par}}$$



SQUID	Standard CSBlue	Sub-µm CE1K
L_{SQ} [nH]	0.30	0.18
L_K [µH]	0.32	2.7
$\Delta\Phi_{SQ}/I_A$ [µA/Φ_0]	0.21	0.10
Φ_n [µΦ_0/√Hz]	≈ 5	≈ 2
Noise performance [pA/√Hz]	1.0	0.2

Conclusion and Outlook

The CCC in operation already have demonstrated their potential at beam lines at GSI and CERN [2], [3]. The newly developed core materials will allow for higher signal frequencies and lower noise. The use of new sub-µm-SQUIDS will enable a decreased noise and higher system bandwidth. Within the current research project supported by the BMBF the magnetic and acoustic disturbing signals shall be reduced to improve the CCC operations in critical environment. Alternative shielding constructions and their magnetic field suppression will be evaluated.

In the meantime the CCC-XD for CRYRING is still under construction, the related cryostat - considering AD CCC measuring results - is in preparation (see Posters WEPG40, TUPG50).

References

[1] Magnetec, Softmagnetic High-Tech material NANOPERM, *http://www.magnetec.de/fileadmin/pdf/pb_np.pdf* (30-Aug-2016).
[2] W. Vodel et al., *Applied Superconductivity, Handbook on Devices and Applications, Volume 2*, Wiley-VCH, Weinheim, p. 1096 (2015).
[3] R. Geithner et al., *Cryogenic current comparator for storage rings and accelerators*, MOPB013, Proc. of IBIC2015, Proc. of IBIC2015, Melbourne, Australia - Pre-Release Snapshot (17-Sep-2015)

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