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CRYOGENIC CURRENT COMPARATORS (CCC) CUSTOMIZED FOR FAIR-PROJECT*

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Abstract

The principle of non-destructive measurement of ion beams by detection of the azimuthal magnetic field, using low temperature Superconducting Quantum Interference Device (SQUID) sensors, has been established at GSI already in the mid 90's. After more recent developments at Jena, GSI and CERN, a CCC was installed in the CERN Antiproton Decelerator (AD) and is operated there routinely as the first stand-alone CCC system. For the Facility for Antiproton and Ion Research (FAIR) a new version of the CCC with e**X**tended **D**imensions (CCC-XD) - especially with a larger inner diameter and adapted parameters - was constructed and first lab tests have already been performed. In parallel, a concept for a dedicated UHV beamline cryostat has been worked out. The CCC-XD system - together with the new cryostat - will be ready for testing in the CRYRING at GSI before the end of 2018. In this contribution, experimental results for the resolution, frequency range, slew rate and pulse-signal obtained by electrical laboratory measurements with the CCC-XD are presented.

INTRODUCTION

Cryogenic Current Comparators can compare electrical currents with high accuracy and have been used in metrology for many years. The device can be adapted for the use in beamlines, which enables the measurement of beam currents in the nA range. A big advantage of the system is the non-destructive real-time measurement. Furthermore, it is possible to measure continuous and bunched ion beams. CCC's were successfully operated at GSI and CERN to detect beam currents. The next step is to integrate a customized CCC in the CRYRING at GSI Darmstadt and optimize it there. Afterwards the installation in other locations at FAIR is planned. Therefore, the CCC-XD was developed with an enlarged niobium shielding, an inner diameter of 250 mm, a highly permeable nano-crystalline core, and a flexible SQUID cartridge. For the new CCC-XD an enlarged and improved cryostat design is necessary.

OPERATION PRINCIPLE

The operation principle of the Cryogenic Current Comparator is based on effects of superconductivity. One property that characterizes superconductors is the ideal diamagnetism below a critical magnetic field - the Meissner-Ochsenfeld effect. Placing a superconductor in a magnetic field generates an opposing field by shielding currents. These screening currents start to flow within the London penetration depth along the surface. Thus, the magnetic field cannot permeate the superconductor. This effect is used in CCCs for accelerators. Another effect used is the Josephson Effect that occurs when two superconductors are separated by a weak link. Based on quantum tunneling, it is possible that the Cooper pairs pass the normal conducting barrier. Figure 1 shows the elements of such a typical CCC for accelerators.

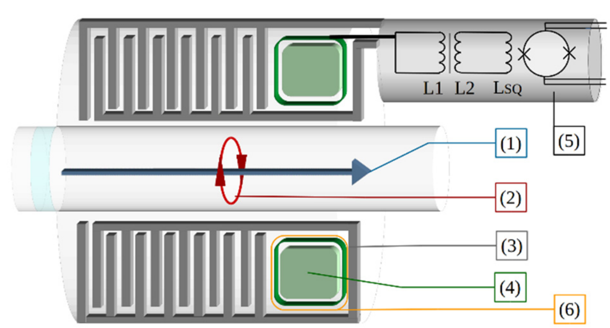

Figure 1: Components of a CCC as used in accelerators (1) Charged particle beam with (2) azimuthal magnetic field, (3) meander shielding as magnetic field filter, (4) pick-up coil and flux concentrator, (5) SQUID cartridge (6) calibration wire.

When a charged particle beam (1) enters the CCC the azimuthal magnetic field (2) triggers screening currents in the meander shielding (3), which are proportional to the beam current and propagate over the whole surface. The

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complex shaped niobium shielding attenuates any non-azimuthal field components [1]. That enables the measurement of the azimuthal magnetic field component apart from disturbing background fields. The attenuation factor increases with tube length, resp. the number of meanders. In order to minimize the space required by the CCC in a cryostat the meander shape is chosen. The pick-up coil (4) is a superconducting niobium toroid with a slit around the circumference and contains a core of a highly-permeable, nano-crystalline iron-boron-silicon alloy optimized for low-temperatures [2]. The core material for the CCC-XD, produced by MAGNETEC GmbH, is called GSI328plus. The pick-up coil creates a frequency dependent inductance of 10…100 µH. A matching transformer (MT) is used for the coupling between high-inductance pick-up coil and the low-inductance, flux-locked loop DC-SQUID (5). A DC-SQUID is a superconducting ring with two Josephson junctions operated with direct current. Figure 2 shows the completed niobium CCC-XD.

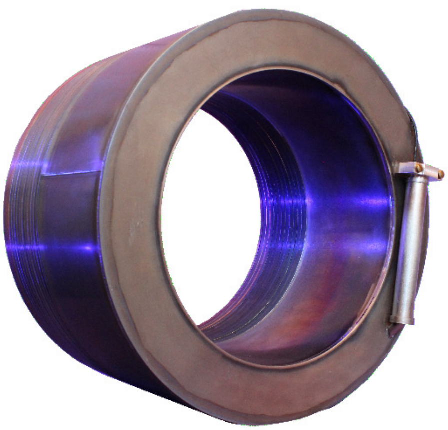

Figure 2: Completed niobium CCC-XD with anodized surface, an inner diameter of 250 mm, an outer diameter of 350 mm, a thickness of the niobium walls of 3 mm, a height of 207 mm, and a weight of 56 kg.

FIRST MEASUREMENTS

The functionality of the CCC-XD was tested in a lab environment at FSU Jena. Noise measurements over a wide frequency range and various pulse response measurements were performed. During the measurements the device was placed in a wide neck cryostat filled with liquid helium. In order to guarantee the best performance of the system it was important to wait 72 hours after the cool down.

Noise Measurements

Figure 3 shows the noise measurement performed in a frequency range between 50 mHz and 300 kHz. The measurement was performed at night to avoid disturbing influence of the lab environment. Nevertheless, acoustically induced noise caused by the air condition engines of the clean room – located in the same building – is visible between 10 Hz and 100 Hz. The CCC-XD white noise is <3 pA/√Hz at 10 kHz. A resonance peak can be observed at 170 kHz because the inductance of the coupling coil L_m and the parasitic capacity C_m of the meander shielding form a LC-parallel resonant circuit.

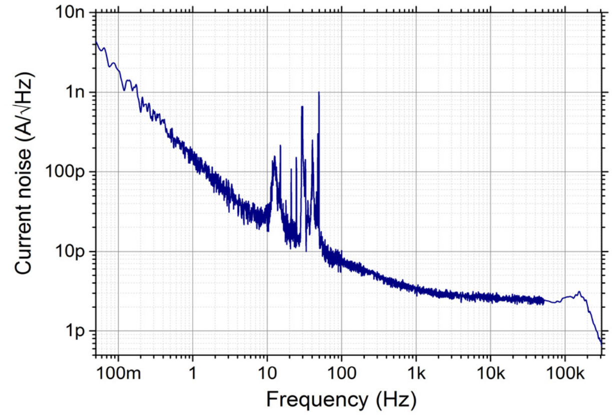

Figure 3: Noise measurements (Devices: HP 35670A Signal Analyzer 50 kHz, HP 89410A Vector Analyzer 10 MHz).

Pulse Measurements

Pulse measurements are performed by applying a well-known pulse signal to an additional wire wound around the pick-up coil, see Fig.1 (6). The wire is used to simulate the beam and can be used to calibrate the device easily when it is mounted in the cryostat. R. Geithner showed in [3] that a wire around the pick-up coil gives the same results as a wire along the beam axis.

Figure 4 shows the pulse measurement with the 10 kHz SQUID-filter disabled. The full slew rate is available and a pulse of 200 µs duration and a current of 6.6 nA can be measured.

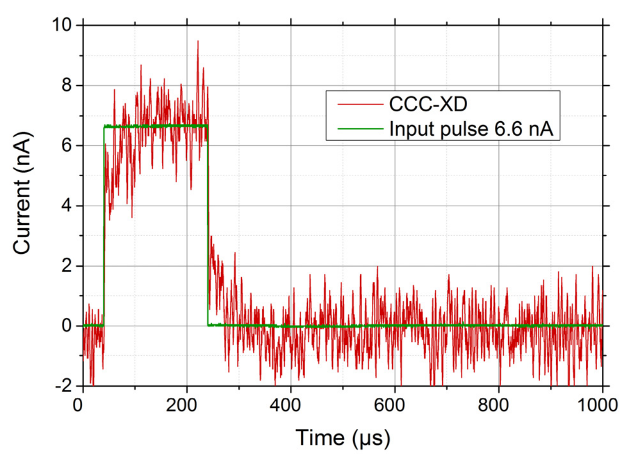

Figure 4: Single pulse signal response of the CCC-XD (SQUID electronics without 10 kHz low-pass filter) compared to the 6.6 nA input signal (Device: Data Sys 7000 Digital Storage Oscilloscope) [4].

Enabling the 10 kHz low-pass filter makes it even possible to measure a pulse signal of a current of 1.65 nA. But using the filter restricts the slew rate to 0.16 µA/µs, see Fig. 5. The measurement requirements define weather it is better to use the low-pass filter or not. Spill structure studies for instance need a high slew rate and the use of the filter is not recommended. Without using the filter the pulse signal should be at least 5 nA. For measurement in a storage ring with signal integration the use of the filter might be advantageous.

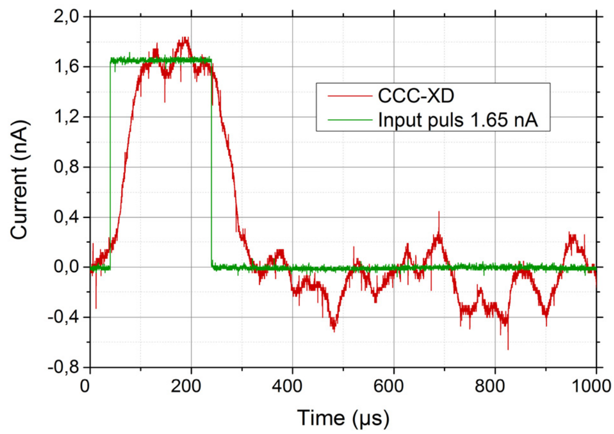

Figure 5: Single pulse signal response of the CCC-XD (SQUID electronics with 10 kHz low-pass filter) compared to the 1.65 nA input signal (Device: Data Sys 7000 Digital Storage Oscilloscope) [4].

BEAMLINE CRYOSTAT

The design for a beamline cryostat hosting the CCC-XD has been developed by GSI Darmstadt. The beamline cryostat shown in Figure 6 has an inner diameter of 150 mm (a) and can accommodate a warm UHV tube.

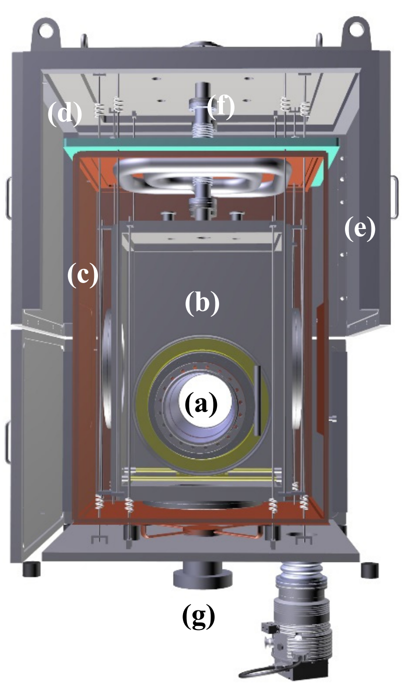

Figure 6: Beamline cryostat for CCC-XD. With (a) 150 mm beam tube surrounded by CCC-XD, (b) liquid helium container, (c) copper shield, (d) titanium suspensions, (e) vacuum chamber, (f) helium lines, and (g) connection to refrigerator.

The beam tube has a ceramic gap to avoid mirror currents from the beamline. The CCC-XD surrounds the beam tube and is immerged in liquid helium. The liquid helium container (b) encompasses a polished copper shield wrapped in multi-layer insulation to minimize heat loads by radiation (c). For an excellent vibration damping the elements are mounted via titanium suspensions (d) in the vacuum chamber. To enable easy access to the elements in the insulation vacuum chamber, it consists of a stainless steel frame covered with O-ring sealed aluminum windows (e) [5].

CONCLUSION

The first laboratory measurements with the new state-of-the-art CCC-XD were successful. The noise study of the system showed a white input noise of only 3 pA/√Hz at 10 kHz. The acoustic noise between 10 Hz to 100 Hz was identified and has its origin in the air conditioning of the laboratory environment. Pulses of 6.6 nA can be measured with the system without any slew rate restrictions. Using the 10 kHz filter of the SQUID system even measurements of 1.65 nA pulses are possible. Furthermore, the beamline cryostat design has been finalized [5]. Integration of the CCC-XD in the cryostat and measurements in the beam of GSI CRYRING are in preparation.

ACKNOWLEDGMENT

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