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CRYOGENIC CURRENT COMPARATORS FOR 150 mm BEAMLINE DIAMETER*

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Abstract

New versions of Cryogenic Current Comparator (CCC) sensors with eXtended Dimensions (CCC-XD) for beamline diameters of up to 150 mm – necessary for the planned Facility for Antiproton and Ion Research (FAIR) at GSI (Gesellschaft für Schwerionenforschung) – have been realized. These non-destructive charged particle beam monitoring systems are able to measure intensities in the nA-range with a white noise level below 5 pA/√(Hz). The systems are sensitive from DC to several hundred kilohertz and can be linked up in a traceable way with national and international ampere-standards.

In its present design, the base body consists of a highly-permeable, nano-crystalline core optimized for low-temperatures (ready for superfluid He-II applications) [1] and a niobium shielding/pickup-coil unit. The flexible SQUID (Superconducting Quantum Interference Device) - cartridge allows tuning for application. Three cartridge versions (direct, balanced and enhanced) are presented, discussed and results of electrical laboratory measurements of the noise behaviour and the frequency response are given.

OPERATION PRINCIPLE

The key to measure the beam intensity non-destructively is to measure the magnetic field component created by the charged particle. The main parts of a CCC are shown in Fig. 1.

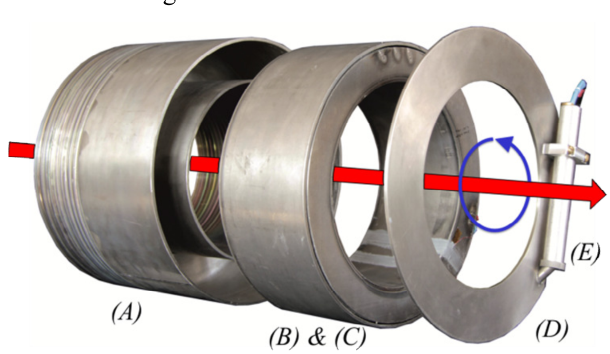

Figure 1: Exploded view of classical meander design CCC as used at CERN; red: charged particle beam; blue: magnetic field, courtesy of R. Geithner.

(A) Superconducting Meander Shielding

This shielding separates the concentric magnetic field component created by the charged particle from the interference created by surroundings. Two long coaxial tubes – shorted by a complex meander structure – act as a filter [2, 3]. The meander structure has no electrical connection between both parts and creates a frequency-independent parasitic capacity C_m in the nF-range. For the CCC-XD shielding – consisting of about approximately 65 kg niobium – the measured parasitic capacity is about 40 nF.

(B) Flux Concentrator

A special, highly-permeable, nano-crystalline core – optimized for low-temperature applications – concentrates the magnetic field at the end of the tubes. In cooperation with MAGNETEC GmbH the GSI328plus core was developed and used for CCC-XD [4].

(C) Superconducting Pickup Coil

A full faced, one-turn, superconducting pickup coil covers the flux concentrator and creates a frequency-dependent inductance L_{pu} in the range of (10 to 100) µH at a temperature of 4 K. The pickup coil inductance of the CCC-XD is about 80 µH at 4.2 K and 1 kHz.

(D) Top Cover

A superconductive connection between both parts of the meander shielding tubes completes the shielding and also creates a full faced, one-turn frequency-dependent coupling coil inductance L_m – similar to the pickup coil. This inductance and the parasitic capacity C_m produce a LC-resonator which can be simulated for example with LTspice.

(E) SQUID-Cartridge

The cartridge includes the SQUID as the current meter and additional components like the matching transformer for inductance coupling.

Benefit of Superconductivity

The superconductivity with Meissner effect, Josephson effect and the flux quantization are necessary to realize shielding, DC-transformer and an extreme high sensitive current meter [5].

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EVOLUTION OF CCCs

The development of CCCs for beam instrumentation started in the 90s. The first systems (1996 at GSI and 2009 for BESSY) were Pb-based. The current running system at CERN-AD and the new larger CCC-XD for GSI/FAIR are Nb-based. Optimization is still in progress and the new designs and materials are under investigation [2]. The CCC-XD sensor as shown in Fig. 2 – manufactured in classical radial meander design – is now ready and the first lab measurements with different SQUID-cartridge versions are done.

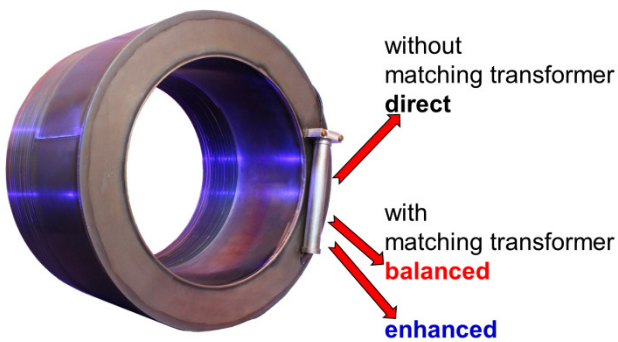

Figure 2: CCC-XD and the three different types of SQUID-cartridge configurations.

SPICE Electronic Simulations

A task of system understanding and application optimization is the electronic design of the SQUID-cartridge. Usually a balanced matching transformer (MT) is used coupling the high inductance pickup coil with the low inductance SQUID input coil [6]. Figure 3 shows a circuit diagram of the balanced MT-version, but also versions without MT or with MT and a higher current magnification. So, the MT influences the additional current magnification and the frequency response as shown in Fig. 4.

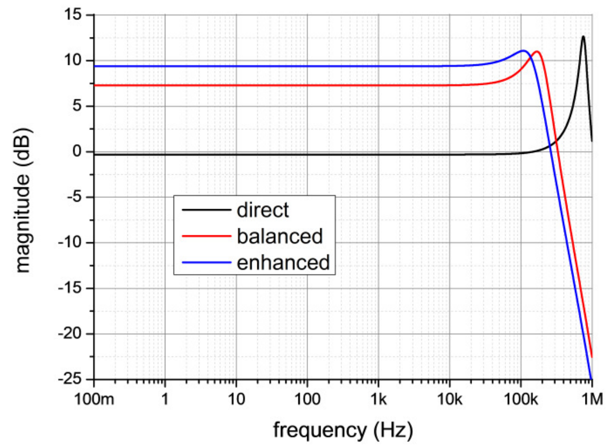

Figure 4: LTspice simulation of amplitude frequency responses. Black (direct): resonance peak at 760 kHz, red (balanced): resonance peak at 170 kHz, blue (enhanced): resonance peak at 115 kHz.

Using L_sR_s inductance measurements of the GSI328plus published in [1] and calculated into the L_pR_s model suitable for higher frequencies it is possible to calculate the LC-resonator frequencies of the cartridge versions. Measurements of the balanced version should have a small resonance peak at 170 kHz and the direct version should have a clear peak about 760 kHz.

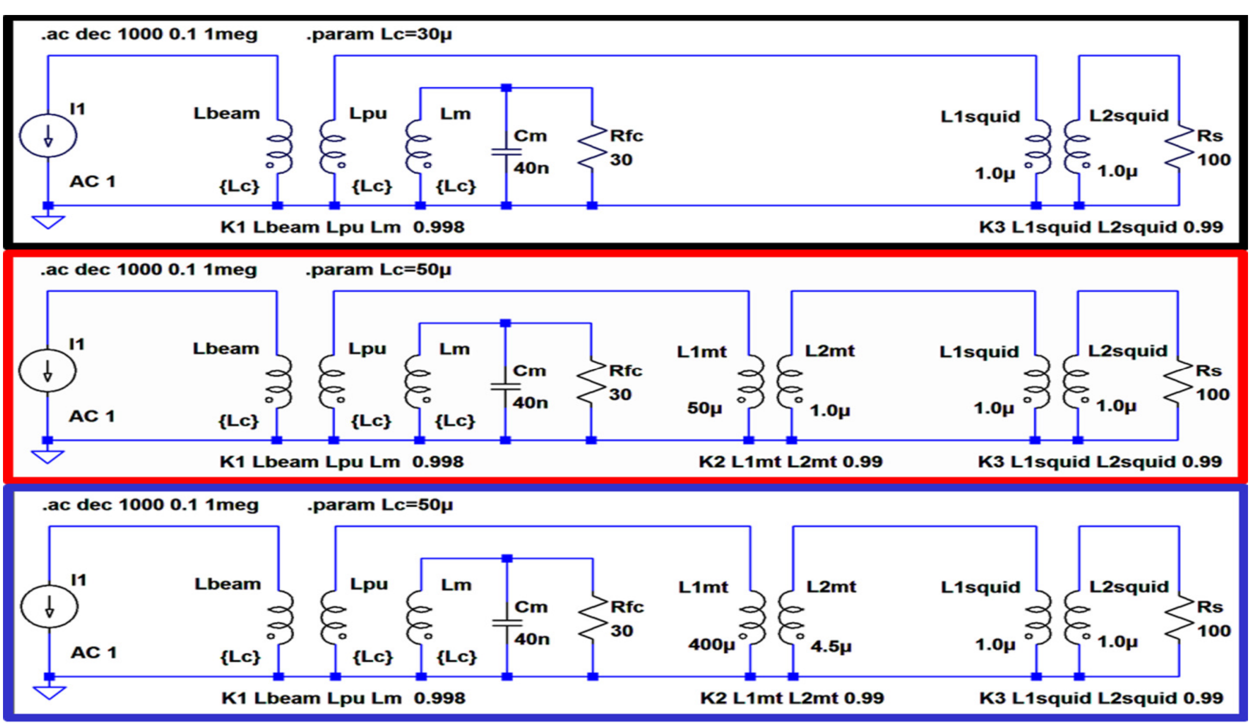

Figure 3: CCC-XD LTspice circuit diagram of the three cartridge versions. Top: direct without MT, middle: balanced with MT and inductance matching, down: enhanced with matching transformer and a higher current magnification.

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THE CCC-XD FOR GSI/FAIR

The first measurements are done in a wide-necked cryostat inside and outside a magnetic shielded chamber in a lab environment. A wire with an electrical current flow is simulating the charged particle beam if necessary.

Noise Measurement

Figure 5 shows that the white and 1/f input noises of the direct and balanced version are nearly identical and dominated by the core noise which is ten times or more above the SQUID noise. It also shows that there are interference problems between 5 Hz and 100 Hz and that the acoustical noise within the magnetic shielded chamber is not helpful. Clearly visible are – expected by the simulation – resonance peaks measured at 170 kHz (balanced version) and 770 kHz (direct version).

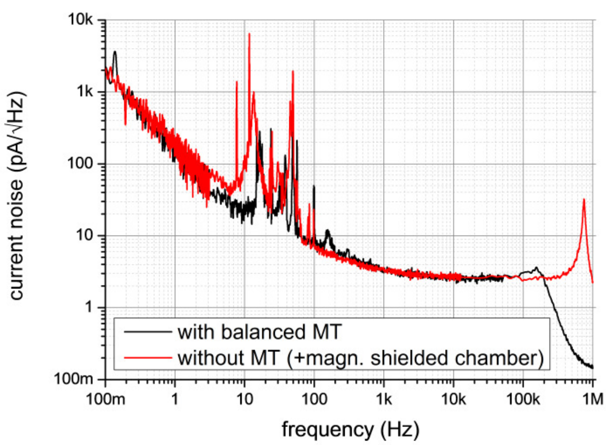

Figure 5: CCC-XD noise measurement, red: direct version with resonance peak at 770 kHz, black: balanced version with resonance peak at 170 kHz.

Sinus Signal Measurement

The small-signal response of the CCC-XD system shows a strong correlation between the signal response and the noise (see Fig. 6). The small-signal frequency bandwidth is about 200 kHz without data processing and it should be feasible to achieve 1 MHz with data processing.

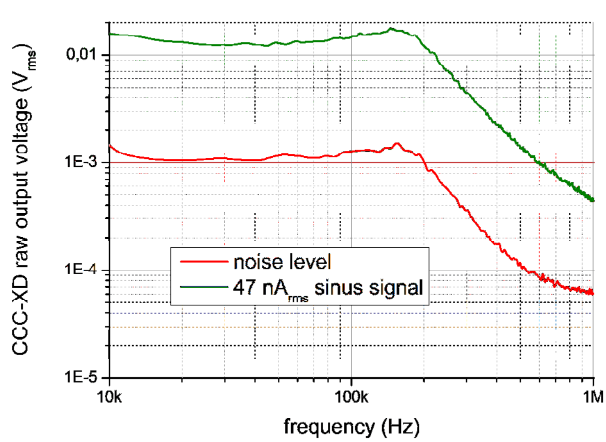

Figure 6: Small-signal response compered to noise level.

The large-signal response (slew-rate) achieved 0.16 µA/µs for the balanced version and 0.32 µA/µs for the direct version at 200 kHz.

Pulse Signal Measurement

Especially the pulse signal response is important for the application in a beamline. Figure 7 shows that in a low-frequency application – like a storage ring with signal integration – it is possible to detect pulses of a few nanoamperes. The used analogue 10 kHz low-pass filter enables the detection of very low-level pulses. Unfortunately the slew rate is also dominated by the low-pass and is reduced to only about 16 pA/µs.

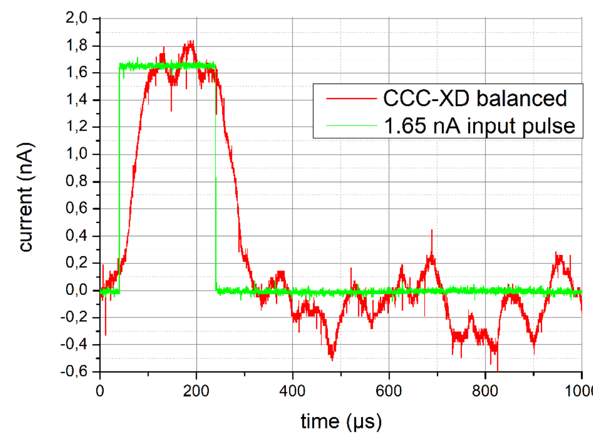

Figure 7: Balanced system response (red) of a low-level 200 µs pulse signal (green), without digital data processing, an analogue 10 kHz low-pass filter is used.

In the case that the full bandwidth is necessary – like in an accelerator line or trigger application – the pulse level should be greater than 5 nA as shown in Fig. 8. Certainly the full CCC-XD slew rate is available again. The source of the lower slew rate for the last 25% is currently under investigation.

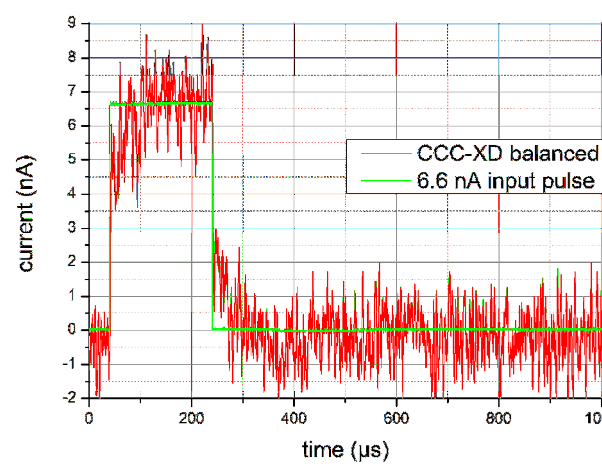

Figure 8: Balanced system response (red) of a low-level 200 µs pulse signal (green), without digital data processing, the full bandwidth of 200 kHz is used.

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CONCLUSION

We showed that CCC with lager inner diameter can be manufactured. The CCC-XD sensor has been tested in a lab environment and is ready for the integration into its own new beamline-cryostat. Using electronic circuit simulation software it is possible to forecast the frequency response of the complex CCC-system part: beam coil, meander resonator, pickup coil, matching transformer and SQUID input coil. The matching transformer can be used to generate additional current magnification. For the CCC-XD the usable magnification starts at 0.98 (direct version) and ends at 3.7 (enhanced version). Because of dominating core noise the additional magnification is currently not important and it is possible to use a balanced version (magnification 2.8) and a moderate bandwidth of 200 kHz.

ACKNOWLEDGEMENT

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REFERENCES

[1] V. Tympel *et al.*, "The next generation of Cryogenic Current Comparator for Beam Monitoring," in *Proc. IBIC'16*, Barcelona, Spain, Sep. 2016, paper TUPG43, pp. 441-444.

[2] F. Kurian, "Cryogenic current comparators for precise ion beam current measurements," Ph.D. thesis, Dept. Phys., University of Frankfurt, Frankfurt, Germany, 2015.

[3] T. Sieber *et al.*, "Optimization of the Cryogenic Current Comparator (CCC) for Beam Intensity Measurement," presented at IBIC'17, Grand Rapids, MI, USA, Aug. 2017, paper TH2AB03, this conference.

[4] Magnetec, `http://www.magnetec.de`

[5] W. Vodel, R. Geithner and P. Seidel, "SQUID-Based Cryogenic Current Comparators," in *Applied Superconductivity Handbook on Devices and Applications Volume 2*, P. Seidel, Ed. Weinheim, Germany: Wiley-VCH, 2015, pp. 1096-1110.

[6] R. Geithner, "Optimierung eines kryogenen Stromkomparators für den Einsatz als Strahlmonitor," Ph.D. thesis, Dept. Phys., F. Schiller University Jena, Jena, Germany, 2013.