MEASUREMENTS WITH THE UPGRADED CRYOGENIC CURRENT COMPARATOR

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Abstract

In the upcoming FAIR facility, it is foreseen at several installation locations to have beam currents down to few nA. The operational mode also demands for non-destructive beam current measurement. Since standard non-disturbing beam current measurement techniques do not offer the required current resolution, Cryogenic Current Comparators (CCC) will be installed at various locations of the FAIR facility [1].

The CCC for the ion beam current measurement was first developed at GSI and was used for the current measurements at the high energy beam transport section after the GSI synchrotron SIS18. This system has now been refurbished as a prototype for the new CCC design for the FAIR facility. The refurbished CCC unit was taken into operation and first test measurements have been carried out. In this contribution we report the test measurements using the refurbished CCC unit with a simulated beam current. Since the magnetic noise field components are one of the parameters limiting the resolution of the detector system, the simulation on the field attenuation is studied is by an FEM simulation package and is also reported.

SIMULATION OF THE MAGNETIC FIELD ATTENUATION

The CCC measures the beam current by measuring the azimuthal magnetic field associated with the beam current [2]. However, this azimuthal magnetic field, in most cases will be several orders of magnitude less than the magnetic noise field present in a typical accelerator environment (for instance, a beam tube of diameter 100 mm carrying a beam current of 100 nA produces an azimuthal magnetic field of 0.4 pT, compared to an average Earth's magnetic field of 50 µT). Hence the pick-up coil is enclosed in a meander shaped superconducting magnetic shield which is shown [3,4], to attenuate any magnetic field component other than the azimuthal field carrying information about the beam current as shown schematically in Figure 1. In this work, we discuss the preliminary results from the simulations in order to optimize the geometry of the magnetic shield.

The magnetic shield geometry under investigation consists of parallel plates of circular Niobium discs arranged to form a meander structure. This shield ensures any non-azimuthal magnetic field undergoes strong attenuation before reaching the cylindrical cavity where the field is measured with a high permeability ring core and a surrounding single turn pick up coil arrangement. The dimensions of the basic simulation model were chosen from a shield prepared for the new CCC prototype having inner and outer diameters 95.5 mm and 140 mm respectively with a gap width of 0.5 mm. The assumptions for the simulations and their validity are already described in detail [1] and hence only a brief outline is given here. Comsol multiphysics simulation package is used for the simulation with its magnetic insulation boundary condition is applied to the superconducting walls so that the field will be excluded from the Niobium material boundaries and hence creates a perfect conductor boundary condition. As it is previously shown [1] that the axial component of the magnetic field undergoes very strong attenuation compared to the transverse field components, attenuation only in the transverse direction is discussed in the following sections.

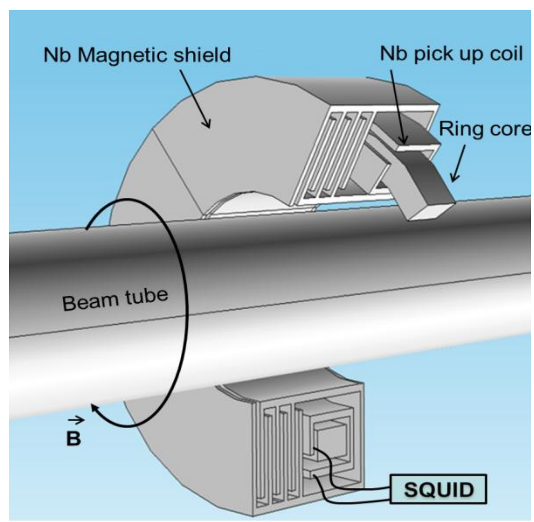

Figure 1: Schematic view of the sensor unit of the CCC system. The complete sensor part is operated at 4.2 K.

The magnetic field attenuation through meander shaped magnetic shield geometries is analytically studied by Grohmann et al [4, 5, 6]. However the analytical formulation doesn't give dependence of gap width (g) plates on field attenuation between two consecutive meander.

Since the magnetic field gradually tends to take azimuthal direction while passing through the shield geometry, a 180 degree rotation of the cylindrical geometry has to be taken into the simulating model. This

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makes the number of mesh cells too large for the simulation package to solve for field attenuation. Due to these reasons, we present an analysis on the attenuation of the external magnetic field in radial and axial directions along with the dependence of the gap width on the attenuation.

Magnetic Field Attenuation in Radial Directions

The radial dependence of the field attenuation is studied by plotting attenuation against the radial distance the shield. While passing through $+\vec{r}$ direction, the field undergoes exponential attenuation as shown in Figure 2(a). It should be noted here that the outer radius of the shield is increased and the radial distance is measured from a constant inner radius of 95.5 mm.

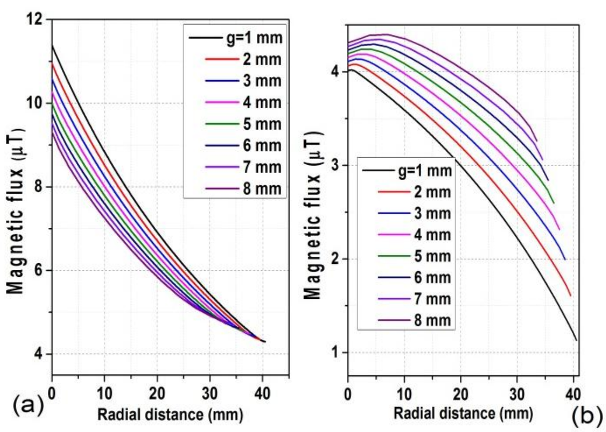

Figure 2: Attenuation of the magnetic field in $+\vec{r}$ direction (a) and $-\vec{r}$ direction (b) plotted for various gap widths.

In case of passing through $-\vec{r}$ direction, the field undergoes a relatively smaller attenuation compared to the former case as shown in Figure 2(b). An exponential fit shows that in both directions attenuation follows a relation,

$$B_{in} \propto B_{out}.\exp(-k.r)$$

where k is a function of the gap width g and inner radius r_i. Further detailed analysis is required to introduce the dependence of each geometrical variable into the relation. In the $-\vec{z}$ direction, the field components undergo an exponential attenuation given by the equation as already shown [2],

$$B_{in} = B_{out} \exp\left\{\left(\frac{-2}{1 + {r_i}/{r_o}}\right) {z}/{r_o}\right\}$$

where r_i and r_o are the inner and outer radius of the coaxial cylinder.

Dependence of Gap Width on Field Attenuation

Taking into account of the individual components in the total attenuation of the magnetic field, variation of field attenuation as a function of the gap width is shown in Figure 3. Simulation results shows that as the gap width of the meander plates is reduced, the attenuation shows an exponential increase. For the magnetic shield manufactured for the new CCC prototype, great care has been taken to keep the gap width minimal. A gap width of 0.5 mm has been successfully introduced without any electrical contacts between the consecutive plates.

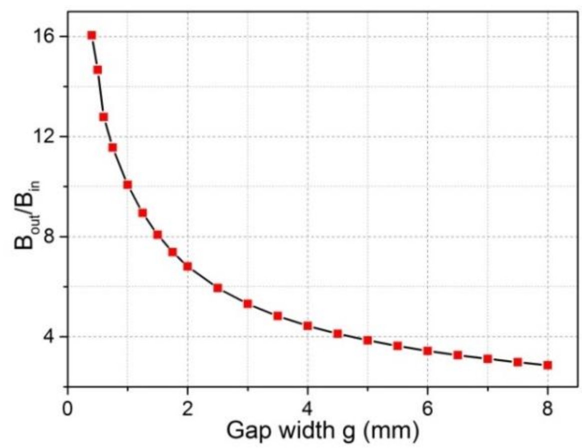

Figure 3: Variation in field attenuation while passing through a single meander curve as a function of gap width, g.

Preliminary results from simulations show an attenuation factor of 115 dB for the magnetic shield geometry having 10 meander plates (which is the case for the shield prepared for the new CCC prototype). However for the practical CCC sensor unit, the high permeability ring core inside the magnetic shield is covered by single turn Nb pick up coil. This will introduce further attenuation of the field components.

Figure 4 shows the attenuation of an externally applied magnetic field through magnetic shield geometry with 10 meander shaped plates having a gap width of 2 mm.

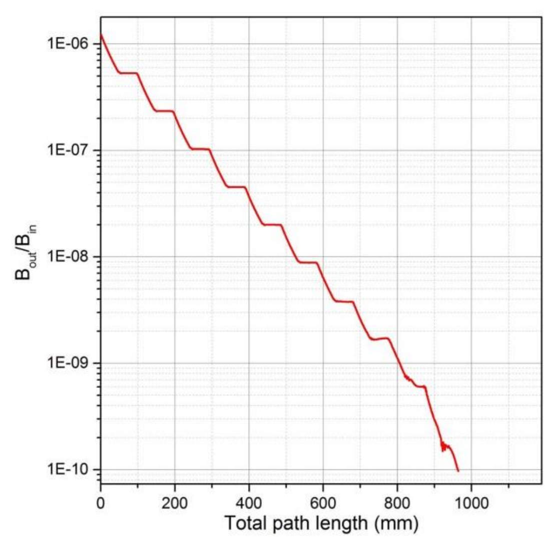

Figure 4: Field attenuation through a meander shaped magnetic shield geometry. The attenuation is plotted against the total path the field has to propagate through the shield geometry.

TEST CURRENT MEASUREMENT WITH CCC PROTOTYPE

In order to meet the installation requirements at various locations, CCC systems for the FAIR facility will have a number of upgrades from the present system at GSI in the sensor units to cryogenic and vacuum components. Hence for the optimization studies and test measurements, the existing CCC system was recommissioned as a prototype for the new installations. The re-furbished CCC was taken in to operation to measure a simulated test current applied through a current carrying loop around the magnetic sensor unit as shown schematically in Figure 6. The current sensitivity of the SQUID sensor corresponding to unit flux quantum (ϕ_0) is found to be 175 nA/ϕ_0. This was the same value reported during the test measurements throughout the previous operations [2] of the CCC which also shows the excellent stability of the SQUID system over long periods.

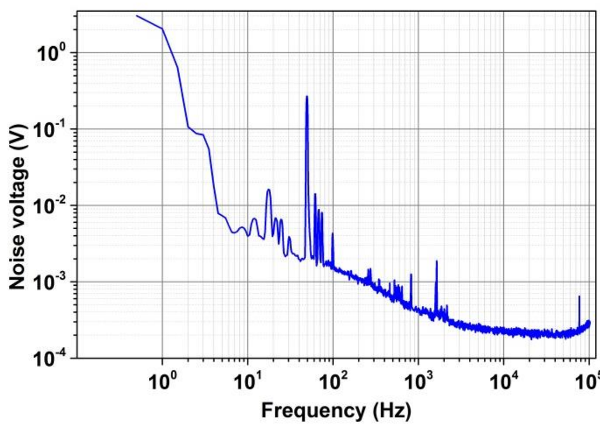

Figure 5: Noise spectra given by the SUQID sensor.

The noise spectrum given by the SQUID sensor (UJ 111, developed in FSU, Jena) is shown in Figure 5. A noise signal of 1.5 to 3.5 $mV_{RMS}/\sqrt{Hz}$ corresponds to a current resolution of 26 to 60 $pA\sqrt{Hz}$ at lower frequency range (<100 Hz). The spectrum shows a number of characteristic lines corresponding to various noise sources. The strongest noise influence was from the electrical disturbances caused by the roughing pump at 49.5 Hz, which was switched off during further measurements. The turbo molecular pump frequency (820 Hz) and its harmonics also show noticeable noise amplitude in the noise spectrum. Three different peaks were found around 70 Hz which were due to the mechanical resonances of the dewar which were also found during the previous vibration analysis tests [2].

ZERO CURRENT DRIFT

During the current measurement, the CCC showed a zero current drift which was found to be decreasing as the cryostat became thermalized. Any mechanical disturbance to the liquid helium cryostat was found to introduce current drifts which as A. Peters et al [2] reported to have exponential decrease over time. This was assumed to be evolving from the remnant flux trapped inside the superconducting magnetic shield since it is cooled from a 'non-zero field' condition. However during our measurement, any temperature fluctuation inside the dewar showed direct influence in the SQUID signal. By connecting a flexible tube at the exhaust of the liquid helium boil-off, the ambient pressure inside the cryostat was changed hence introducing a temperature fluctuation and this caused immediate zero current drifts. The current measurements were taken with a stable system without a measurable zero current drifts as shown in Figure 7.

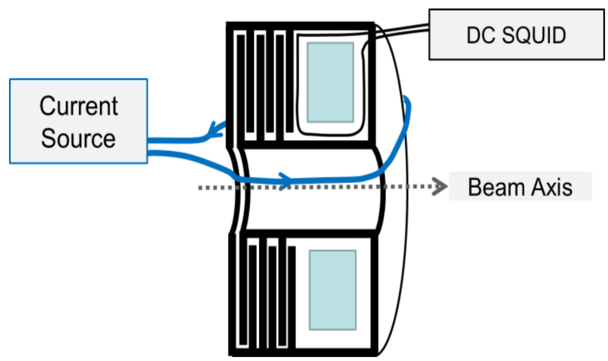

Figure 6: Schematic of the current measurement set up with wire loop wound around the magnetic shield to apply a known current to stimulate beam current. The CCC sensor unit was maintained at 4.2 K during the measurements.

Since the current measurement using CCC is position independent, by applying a known current from "Keithley 261 picoampere current source" to a wire loop around the detector unit, beam current was easily simulated. The equivalent SQUID signal was measured as shown in Figure 7 where 5 nA current signal is measured.

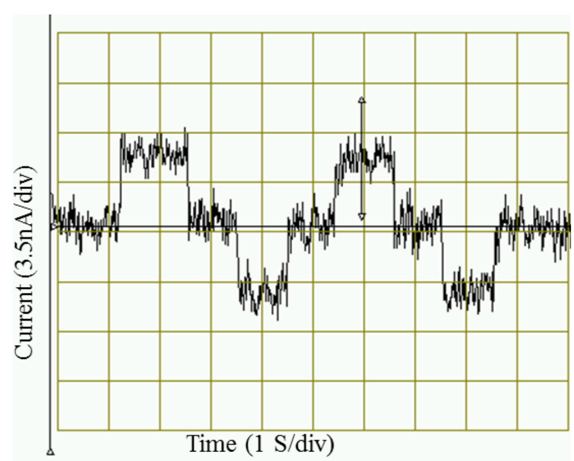

Figure 7: 5 nA peak to peak signal in full bandwidth.

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CONCLUSION AND OUTLOOK

Simulations on the field attenuation through the superconducting meander shaped magnetic shield were carried out and the preliminary results are reported. However, further investigations will be performed to introduce the pick-up coil and the high permeability ring core into the simulation to estimate the total attenuation of the external non-azimuthal magnetic fields.

It is planned to replace the present SQUID sensor and read out electronics with commercially available parts for the upgraded CCC for FAIR. These components will be tested in the prototype for the beam current measurement at a GSI beam line. Hence the current noise performance of the sensor unit will be compared. Preliminary design of the CCC unit has been prepared taking into account of the boundary conditions at various installation locations. The current drift of the SQUID signal will also be analysed in detail.

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