Pressure and temperature dependence of Cryogenic Current Comparator measurements

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One of the key features of the Cryogenic Current Comparator (CCC) is its ability to measure extremely small magnetic fields associated with the beam current [1]. However, in a typical accelerator environment, a number of unavoidable noise sources limit its current sensitivity. Main sources of noise are mechanical vibrations, magnetic stray fields including Earth's magnetic field, electromagnetic interferences and temperature fluctuations.

A low T_C dc SQUID (Superconducting Quantum Interference Device) is used in the CCC as magnetic flux detector. It is operated at 4.2 K which is favourable due to low thermal noise. However, as already observed in former measurements [2], the CCC readout is affected by a drift that is correlated with the pressure inside the CCC cryostat (i.e. pressure of the liquid Helium (LHe) vapours above the LHe surface).

The influence of pressure and hence temperature fluctuations were studied for the refurbished CCC system, installed in the beam diagnostics test bench at HTP [1]. A differential pressure sensor connected to an oscilloscope was used to measure the pressure inside the CCC cryostat. The resolution of this measurement was 0.13 mbar with a signal to noise ratio of 2. The absolute calibration of the sensor is 4.86 mV/mbar and was made by means of a mechanical manometer. A needle valve installed at the cryostat exhaust was used to control the pressure of the boiling LHe. The temperature of the superconducting magnetic shield which includes the ring core and pick up coil, was measured by a silicon-diode temperature sensor (Lakeshore, DT-670B) with an accuracy of 1 mK. The temperature of the SQUID was not monitored directly which is a drawback, as mentioned below.

The CCC was operated in its most sensitive range with a current sensitivity of 118.2 nA/Φ_0 and a current resolution of 6 nA, where Φ_0 is the magnetic flux quantum (Φ_0 =h/(2e) = 2.068×10^{-15} Wb). The CCC was calibrated with a known dc current applied to a built-in current loop.

Figure 1 shows the variation of the offset in the CCC measurement and temperature changes with respect to the pressure variation inside the LHe cryostat. The needle valve at the exhaust of the cryostat is closed for about 50 seconds to create an overpressure of 15.3 mbar inside the cryostat by LHe boil-off. This causes a temperature rise of 36.0 mK on the superconducting magnetic shield. The pressure increase of 15.3 mbar result in an instantaneous drift on the CCC output corresponding to an equivalent current of 1.107 µA which is 70% of the full CCC range. The delay of 5 sec in the temperature readout with respect to pressure and CCC readout is due to the bulky magnetic shield that needs more time to reach the same temperature as the SQUID.

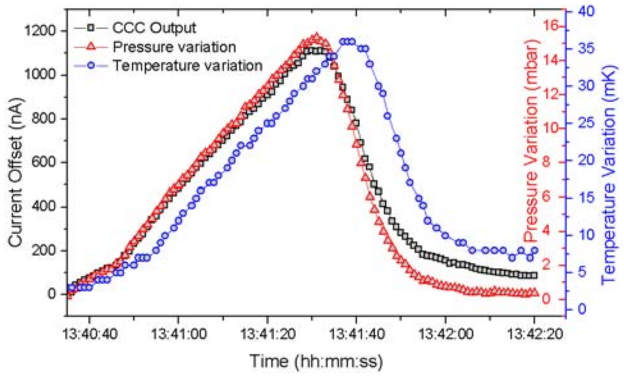

Figure 1: Current offset (black squares) as the result of pressure increase (red triangles) in the LHe cryostat and corresponding temperature variation (blue circles).

The offset of the CCC readout has a linear pressure dependency of 73.7 nA/mbar (0.62 Φ_0/mbar). The corresponding temperature dependence of the CCC offset is 33.5 nA/mK (0.28 Φ_0/mK).

The strong and non-linear temperature dependence of the SQUID drift in presence of an external magnetic field was already observed in other experiments [3], however, only at temperatures lower than 600 mK and explained as an effect of surface defect spins [3 and Refs. therein]. On the contrary, present measurements show by factor of ten stronger and nearly linear drift dependency but at LHe temperature. This may be rather addressed to thermal motion of magnetic flux and/or temperature-dependent critical currents [4].

Since the pressure of the LHe vapour is perfectly correlated with the CCC readout there are two extremely important issues for any future CCC design:

- The pressure of the CCC exhaust must be stabilized (e.g. by means of a pressure regulator) with a precision of better than 1 mbar.
- By simultaneous measurement of the vapour pressure one can calculate and compensate this drift.

References

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