RECENT IMPROVEMENTS OF A CRYOGENIC CURRENT COMPARATOR FOR nA ION BEAMS WITH HIGH INTENSITY DYNAMICS

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Abstract

Former measurements of exctracted ion beams from the GSI heavy ion synchroton SIS showed large current fluctuations in the microsecond region with a high peak-to-average ratio. To adapt our Cryogenic Current Comparator (CCC) to this time structure the detector's electronics have been carefully modified.

The most important improvement of the new DC SQUID system affects the enlargement of the bandwidth and the slew rate of the measuring system. In addition the existing data acquisition system for e.g. SEMs (Secondary Emission Monitors) was extended to digitize the CCC signals simultaneously. Measurements of Argon beams will be shown to demonstrate the improved capabilities of the upgraded Cryogenic Current Comparator.

1 MODIFICATION OF THE SQUID ELECTRONICS

The CCC has demonstrated its excellent capabilities to measure nA beams with absolute calibration [1]. The most important component of the CCC is the new DC SQUID system developed and manufactured at the Friedrich Schiller University Jena, Germany. This device is able to detect extremely low magnetic fields, for instance, caused by the extracted ion beam of the SIS. For this reason the SQUID input coil is connected with the pick-up coil for the ion beam. This pick-up coil consists of a superconducting niobium toroid containing a special VITROVAC 6025-F core (VAC GmbH, Hanau, Germany) providing a high permeability, even at the low working temperature of 4.2 K. The large diameter of the pick-up coil of 200 mm provides a "warm" hole for the ion beam passing the dewar (see Fig. 1). Both the SQUID input coil and the pick-up coil form a closed superconducting loop so that the CCC is also able to detect DC currents.

As already known from earlier measurements the spill structure of the extracted ion beam pulses shows a strong modulation with current peaks up to 130 nA while the average current is only about 15 nA [2]. The beam consists of individual bursts with a steep rise and a slower fall. As a consequence, the current rise time of this spill structure sometimes exceeds the slew rate limit of the SQUID system, if the value goes beyond 5000 Φ_0/s or about 1 nA/μs. In those cases the feedback loop of the CCC electronics becomes unstable and negative spikes or other unpredictable effects could be observed [3]. For this reason a further development of the CCC was necessary and, above all, a new DC-SQUID system with a higher slew rate was designed and realized within the last year. The simplified block diagram of the DC SQUID Control is shown in Fig. 1.

The main improvement affects the enlargement of the bandwidth. For this reason a wide band transformer at room temperature is used instead of a cooled high quality factor resonant circuit for the readout electronics of the SQUID signal. The corresponding increase of the intrinsic noise of the SQUID system is much lower than the noise level of the CCC. It is caused, mainly, by the VITROVAC core of the antenna and can be neglected. Furthermore, the modulation frequency of the PLL-loop was essentially increased from 125 kHz in the former SQUID system up to 500 kHz using faster operational amplifiers in the SQUID controller. As a result of these design features the system bandwidth of the SQUID system was increased up to 50 kHz per 1 flux quantum (full range signal). This corresponds to an increase of the slew rate of the CCC up to 1.6×10^5 Φ_0/s or 28×10^6 nA/s. But with the detector system connected and a calibration signal as the input a reduced value of 6×10^4 Φ_0/s was measured. For this phenomena we have no electronic model up to now and further investigations are necessary to understand this.

Another important feature is the realization of a distance of 25 m between the preamplifier on top of the cryostat and the SQUID controller in order to allow the operation of the SQUID system also when the beam line is activated. To meet this requirement without decreasing the current resolution of the CCC several special buffers for most of the leads and a special double-screened cable between preamplifier and SQUID controller were used to avoid rf interferences.

A point of special interest is the coupling of the SQUID output with an A/D converter and the data aquisition unit (see Fig. 2). According to our experience this is only possible by using an optical coupler between the analog and digital circuits. Otherwise the whole SQUID system is not working at all because of the disturbances generated by the digital circuits. In addition, the analog output of the SQUID electronics is equipped with an isolating amplifier.

As the result of all improvements the CCC is now working at a sufficiently high slew rate so that we can mea-

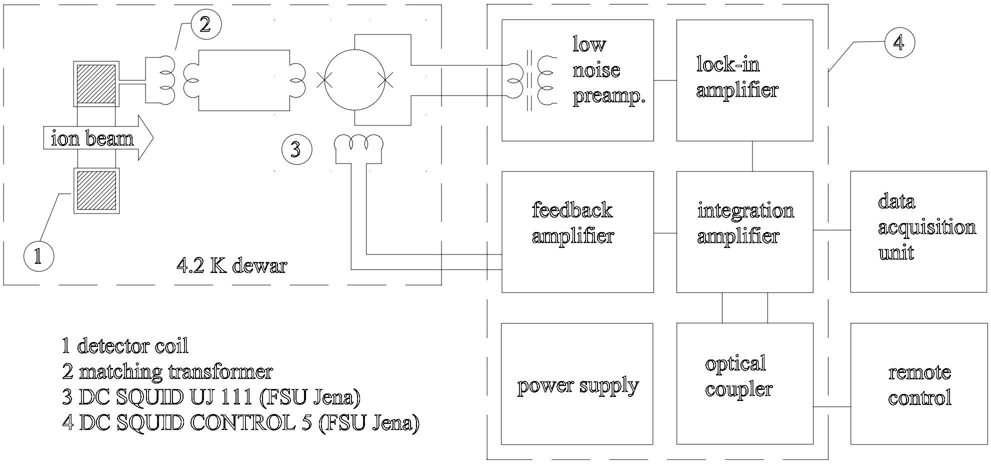

Figure 1: Block diagram of the modified DC SQUID electronics

sure also short current peaks at a level of several hundred nA with an extreme high current resolution of about 250 pA/$\sqrt{Hz}$.

2 DATA ACQUISITION SYSTEM

For the data acquisition of other beam diagnostic detectors like scintillators, ionization chambers and secondary emission monitors (SEM) a GSI product called **M**ulti **B**ranch **S**ystem [4] is used.

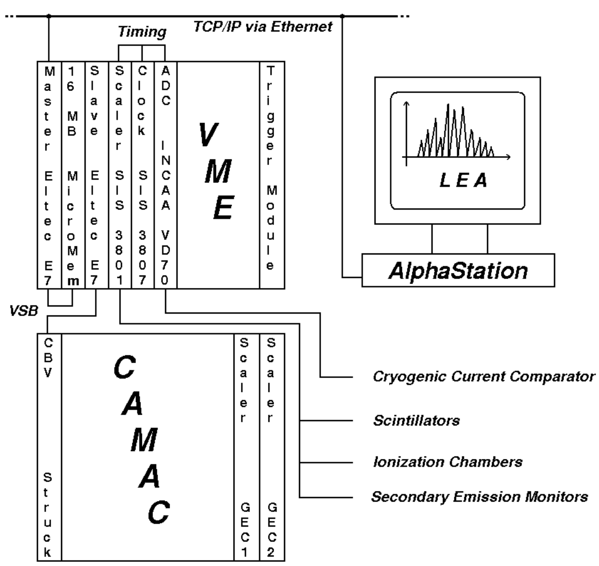

Figure 2: Schematic drawing of the data acquisition system

To digitize the output signal of the CCC the existing VME system was extended by a 12-bit ADC with 2 MSamples memory [5]. A clock module in the VME crate provides the timing for the simultaneous acquisition of the scaler inputs as well as the ADC data up to 10^5 datasets per second. The whole acquisition process is controlled by two ELTEC E7 VME processors running under Lynx-OS, which share a 16 MByte VME/VSB memory (see Fig. 2). The slave processor collects the data from all VME and CAMAC modules and writes them to the shared memory via VME. The master processor reads the shared memory via VSB, formats the data and handles all kind of transport, e.g. via network or to a tape drive.

For the on-line control of the measurements a special software package called LEA [6] is used. The data are received over the network via TCP/IP and can be displayed on a VMS or UNIX workstation. For an off-line analysis the data are stored in ASCII format on disk.

3 SPILL MEASUREMENTS WITH HIGH DYNAMICS

With the upgraded SQUID electronics and the extended data acqusition system enhanced measurements of the ion beam extracted from the SIS are possible. Fig. 3 shows such a measurement of a 300 MeV/u $^{40}Ar^{11+}$-beam, where 7×10^9 ions are extracted in about 1.2 seconds effectively. The mean current is only 11.2 nA but the peak-to-average ratio is in the order of 26 (!). Thus the single beam bursts have an enormous current slew rate, up to 290 nA in 40 μs were observed. This measured value is equivalent to a slew rate of about 4×10^4 Φ_0/s, which is in good correspondence to the measured performance of the enhanced CCC detector electronics.

This allows to make further studies of the spill structure with high resolution. These measurements will start again in winter 1999 when the new high current injector at GSI will deliver beams for the synchroton reaching the incoherent space charge limit [7].

4 CALIBRATION OF SEM DETECTORS AT HIGH INTENSITIES

A SEM made of three Al foils [8] is mounted closely behind the CCC to provide a comparable measurement device. Again for a $^{40}Ar^{11+}$-beam at 300 MeV/u the particles per spill were determined with the SEM and the CCC. A plot of these data is shown in Fig. 4. The output current of the CCC is converted to particles by numerical integra-

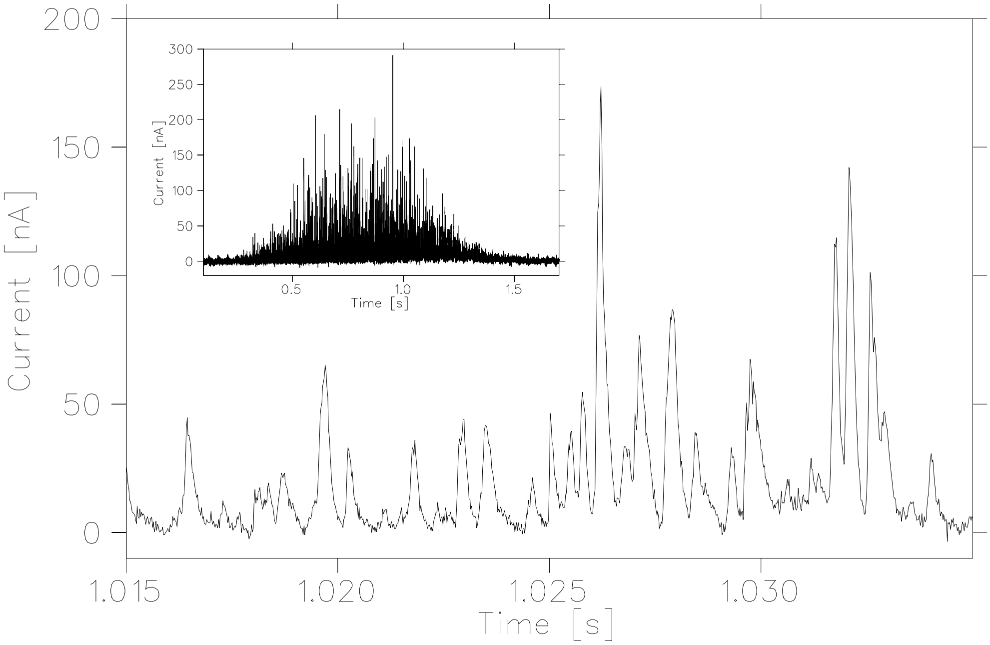

Figure 3: Spill structure of a 300 MeV/u $^{40}Ar^{11+}$-beam. An enlarged view (20 ms) of the spill with the typical burst-structure is displayed. The inset shows the whole spill of 7×10^9 ions extracted in about 1.2 seconds. The data were taken with a sampling frequency of 50 kHz.

tion of each measured spill and plotted against the SEM output. The data show a good linear correlation over one order of magnitude. This overlap is sufficient to calibrate the SEM detectors at high intensities. Further comparative measurements with various ion species will be carried out whenever the beam time schedule will permit this.

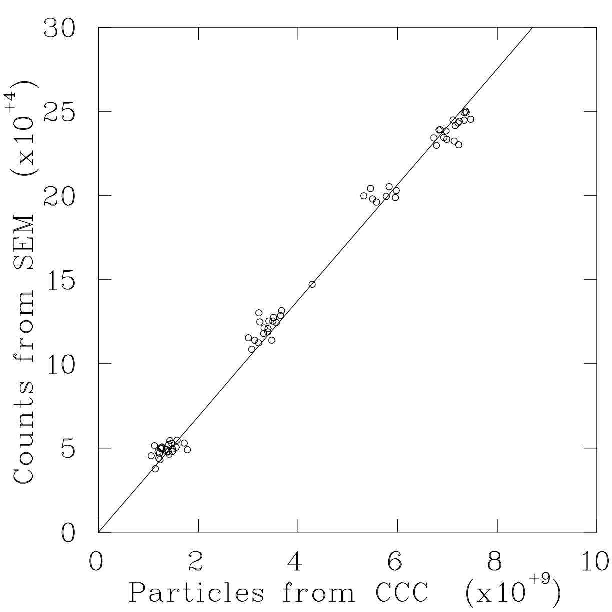

Figure 4: Comparison of CCC and SEM data. Each point represents one spill measured simultaneously. The CCC output is converted into particle numbers by numerical integration of the spill current.

5 ACKNOWLEDGEMENT

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