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HEAVY ION BEAMS FROM THE SIS

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Intensity Measurements of slowly extracted Heavy Ion Beams from the SIS

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Abstract

The paper reports about performance tests of newly designed Secondary Electron Monitors (SEM), Ionization Chambers (IC) and Multi Diode Counters (MDC). Especially the linearity of the detectors with respect to the specific energy loss will be discussed. Calibration has been performed by means of scintillation particle counters at the lower end of the intensity region. The status of the Cryogenic Current Comparator (CCC), which is provided for absolute measurements and calibration of detectors above some nA of beam current is reported, too.

DETECTORS FOR INTENSITY MEASUREMENTS

Since absolute particle fluxes have to be known to determine cross sections of measured nuclear reactions as well as to optimize the efficiency of particle extraction and beam transportation a great variety of detector devices are in use around the laboratories. Table 1 gives a selection of commonly used principles for particle detection.

Table 1. Principles of intensity measurements

Detector Principle	on-line	nondestructive	radiation resistant	intrinsic calibration	Vacuum compatible	Output signal
Track Counting	-	-	-	+	-	$= N$
Faraday Cup	+	-	+	+	+	$= N\zeta e$
Ionization Chamber	+	-	+	-	-	$= Ne\Delta E/W$
Scintillation Pulse Counter	+	-	-	+	-	$= N$
Scintillation Current Monitor	+	-	-	-	-	$\sim N\Delta E$
Secondary Electron Monitor	+	o	+	-	+	$\sim NdE/dx$
Residual Gas Monitor	+	+	+	-	+	$\sim Np\Delta E$
Nuclear Reaction Monitor	+	o	+	-	-	
Beam Transformer	+	+	+	+	+	$\sim N\zeta e$

$+$ = yes; o = only under favorable conditions; $-$ = no; N = Number of ions; ζ = ionic charge; e = elementary charge; W = the effective average energy to produce one ion pair; p = pressure

Fig. 1 shows the SIS intensities achieved at present. They will be improved in the next years to reach the incoherent space charge limit of the SIS. Most of high energy experiments with the SIS use the slow extraction mode. In this mode the ratio between the revolution time of the particles in the SIS and the extraction time is in the order of $1\mu s$ to 1-10 s which means that typical SIS currents of some mA correspond to external electrical currents below 1 nA.

Figure. 1. Achieved and planned SIS intensities (1)

Considering the intensity ranges as well as the ion species which have to be covered it becomes evident that various types of detectors have to be used to determine the extracted particle fluxes. Furthermore, at present there is no detector available which can measure absolutely particle fluxes in the current range between about 10^{-12} - 10^{-6} A for all kinds of ion species.

Obviously, at the low intensity end up to about 10^6 particles per second (pps) calibration can be performed by reference to particle counters, while at the high intensity end a current of about $1\mu\text{A}$ ($10^{11} \dots 10^{13}$ pps depending on ζ) is the lower limit where beam transformers of fluxgate type can be used for calibration and nondestructive absolute flux measurements. To extend the region below $1\mu\text{A}$ down to about 1 nA a new type of beam transformer using the principle of a Cryogenic Current Comparator (CCC) has been developed at GSI. The monitors which have been investigated for the determination of flux rates in the medium intensity region are: The scintillation current monitor, the ionization chamber and the secondary electron monitor.

Scintillation Current Monitor (MDC)

To extend the range of scintillation particle counters up to about 10^9 pps an attempt has been made to read out the scintillation light in current mode by photodiodes (2),(3),(4). In this mode the dependence of the light output on the deposited energy becomes important, in contrast to the pulse counting mode. Therefore, supposing the energy loss of the heavy ions can be taken from tables of stopping power, a linear relation between the light output and the energy loss will simplify the calibration of such a detector very much since

only one calibration is necessary for all ion species and different energies.

Figure. 2. MDC output as a function of the beam intensity.

This has been studied with a detector consisting of a round plastic scintillator sheet of NE108(5) surrounded by 15 photodiodes SFH100(6), a geometry which minimizes the position dependence of the output evaluating the sum signal.

A series of measurements (4) has been performed in the energy range between 200 and 1800 MeV/u for ions of C, Ne, Ar, Kr, Xe and U. Figure 2 shows the detector output as a function of the beam intensity determined by a particle counter. In the Figure the elements and energies (MeV/u) are from bottom to top Ne (1800), Ne (1200), Ne (700), Ne (300), C (270), Ar (800), Kr (800), Kr (500), Kr (300), Xe (1095), Xe (200), U (900), U (600), U (300). The relation between the slope of the fitted straight lines and the corresponding energy loss will be discussed in Fig. 4.

Ionization Chamber (IC)

The output of an ionization chamber should be proportional to the energy loss of the heavy ions, too. An ionization chamber of only 5 mm length, two $1.5 \mu\text{m}$ Mylar windows, filled with a mixture of 90% Ar and 10% CO_2 at 1 bar has been tested (7). Since the "target thickness" corresponds to about 1 mg/cm^2 , the number of created electrons in the gas is in the order of 10^4 electrons/particle which means that secondary electrons from the foils can be neglected. Furthermore, assuming that losses by recombination and escaping electrons are also small, the chamber output should not only scale with the energy loss but can even be calculated using the well known W-values (8),(9) of gases. Figure 3 gives the results, extracted from a series of calibration measurements using again the particle counters. A straight line with a slope of 1.0 has been drawn to demonstrate the excellent agreement between calculated and measured values. In the near future further measurements will be performed to study the dependence on the beam energy and higher intensities more in detail as well as to test the dependence on the beam spot size.

Figure. 3. Measured calibration factor for the ionization chamber versus calculated values

Secondary Electron Monitor (SEM)

Probably the SEM (10),(11) is the most used monitor to measure intensities with a relative method. A prototype consisting of nine 25 μm Aluminum foils has been built. The foils are slightly curved to increase the mechanical strength which reduces microphonic noise signals due to vibrations. With a spacing of 10 mm between the foils the overall lengths of the monitor is below 120 mm. The dependence of the output signal on the collecting voltage has been tested and no change beyond 20 Volts could be detected. In routine operation a collecting voltage of 100 Volts is applied. Since the detector consists only of metal and Al_2O_3 -ceramics, it is even bakeable up to 300°C. Again there should be a proportionality between the output signal and the specific energy loss of the heavy ions. Since only about 30 electrons / (MeV/mg/cm²) can be expected (12) the gain of the SEM is low taking into consideration that only highly charged ions are accelerated in the SIS. To com-

Figure. 4. Response of the detectors

pare the SEM with the monitors discussed above and to test the linearity with respect to the specific energy loss a similar series of calibration measurements as described above has been performed. Defining the detector response as the output charge per incoming ion (for the MDC it is the slope in Fig. 2), Fig. 4 shows the response of the SEM and the other detectors as a function of the specific energy loss calculated according to (13). The straight line through the data of the SEM results from a fit and corresponds to 23 electrons/(MeV/mg/cm²).

Discussion of the Results for the MDC, IC and SEM

The significant differences of the three detector principles consist in the dependence of the response from ion species and their energy: while the IC output *equals* $N\Delta E/W$, the MDC output is only *proportional* to $N\Delta E$, the energy deposited into the detector. The SEM output scales with the *specific* energy loss which is independent from the target thickness.

Obviously, the MDC gives the highest output signal due to the high target thickness. But, keeping in mind table 1 an essential shortcoming of the MDC is the low radiation resistance which will result in a very short lifetime at the planned high intensities. While the ionization chamber delivers only a slightly smaller output signal the linearity is excellent in the considered intensity region and, as discussed above there is no need for an experimental calibration. The SEM has the lowest output, but due to the high radiation resistance and the excellent vacuum compatibility this monitor and the IC will be further developed for their use in routine operation.

THE CRYOGENIC CURRENT COMPARATOR (CCC)

Obviously, for further detector developments based on relative methods and their calibration it is essential to decrease the gap in the intensity region where no absolute methods are available. Therefore at GSI a new type of beam transformer has been developed (14),(15), using the principle of the CCC(16), with the attempt to cover the current region above some nA with a non-destructive absolutely calibratable current measurement. The main components of the device are shown in Fig. 5.

Figure. 5. Principle of the GSI Cryogenic Current Comparator

A current of some nA produces a magnetic field in the order of 10^{-14} T at a distance of 10 cm. The superconducting flux transducer shields this small azimuthal field from stray fields of bending magnets or the earth's magnetic field. A flux coupling coil with a SQUID is able to detect this small magnetic field. In the meantime the cryostat has been extensively tested and optimized leading to a Helium boil-off rate of 5.6 l LHe/d which corresponds to a heat loading of 170 mW and is in good agreement with the calculated value.

Figure. 6. Output of the CCC for a 10 nA test pulse, taken with a bandwidth of 100 Hz (x-axis 1s/div, y-axis 50 mV/div)

Using a one wire loop around the flux transformer to simulate the ion beam, a sensitivity of $175 \text{ nA}/\phi_0$ has been achieved, where $\phi_0 = h/2e \cong 2 \cdot 10^{-11} \text{ T} \cdot \text{cm}^2$ is the flux quantum and $1 \phi_0$ corresponds to 2.5 V in the most sensitive range of the SQUID system.

Figure 6 shows the output signal for a 10 nA test pulse. The slight zero drift of about 0.1 nA/s is probably caused by imperfect superconducting contacts. In the early spring of 1995 the whole CCC equipment will be installed in a test beam line behind the SIS, together with various other detectors for comparative measurements.

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