Beam current monitors for Hall C

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Abstract

We summarize the precision of beam current measurements required by those proposed experiments which may run in Hall C. Four different technologies are examined which in combination would allow measurements over 4 orders of magnitude in current. In spite of the complications produced by the otherwise excellent characterisitics of the CEBAF beam (100% duty factor, 100μm diameter, and power levels near 1MW) there appear to be no obstacles to $\simeq$ 1% charge measurements at the start of physics.

Introduction

In principle this talk should be about beam charge measurements rather than beam current measurements since measurements will be normalized to charge. However, the technology needed for a particular experiment is strongly dependent on the magnitude of the beam current rather than the total charge. Thus, I will use the beam current and charge in the following discussion interchangeably.

The Hall C experimental program requires monitors covering 4 orders of magnitude in beam current. At the lower end of this range, the G_{En} measurement using a polarized ND_3 target will run with as little as 10 nA.[1] At the higher end, deuteron photodisintegration experiments will use 100μA beams.[2] The experiments consist of two very different types: cross-section measurements which require the absolute charge Q, and asymmetry measurements which require the ratio of charges of the different beam helicity states, Q^+/Q^-. The most restrictive of the cross-section measurements (squares) require current measurements of $\leq$ 1% relative error $\Delta I/I$ or absolute errors of $\leq .1\mu A$. (See Figure 1.) The asymmetry measurements (circles) require that $\Delta(Q^+/Q^-)$ be as low as $1\mathrm{x}10^{-5}$.

Available Technology

1. CEBAF 1.5 GHz Beam Current Monitor

The 1.5 GHz Beam Current Monitor is already the standard current measuring device in the accelerator.[3] Four small antennae pick up signals from the charge bunches in the beam. The sum of these four signals produces a signal proportional to the beam current. Fortunately, the same beam current monitor and associated electronics can be used in the endstations where the charge bunches will typically be separated by 2 nsec (500 MHz).

The noise level is about 0.1μA using an integration time of one second. Thus, a properly calibrated 1.5 GHz monitor would allow the entire range of cross-section measurements to be made in Hall C. (See Fig. 1) Longer integration

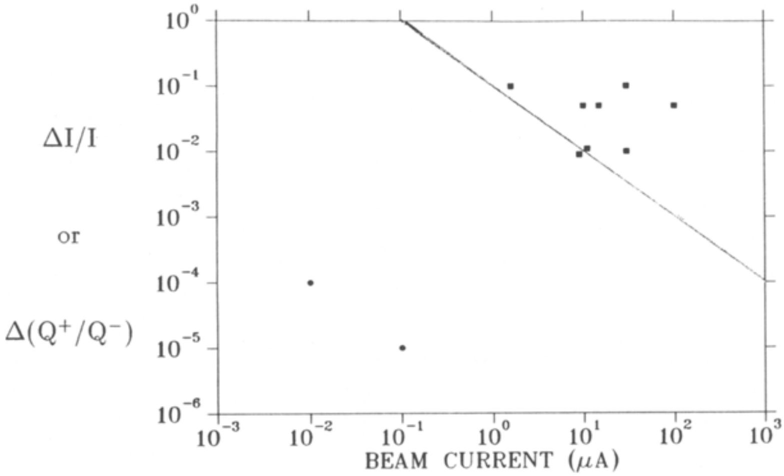

Figure 1: Required $\Delta I/I$ versus I (squares) and required $\Delta(Q^+/Q^-)$ versus I (circles) for proposed cross-section and asymmetry experiments, respectively. The solid line represents $\Delta I = .1\ \mu A$.

times might improve this accuracy as 1/sqrt(time) if systematic effects like beam motion or electronics drifts are small enough. The device looks very promising, but the linearity and long term stability need to be better understood by the physics division personnel who will be placing the greatest demands on it. One drawback of the device is that it needs to be calibrated with beam using a separate absolutely calibrated beam current monitor. This other beam current monitor should function over the greatest dynamic range possible in order to test the linearity of the 1.5 GHz monitor.

2. Parametric Current Transformer

Manufactured by the company Bergoz, these are also called Unser monitors after the developer of the technology at CERN. The shape is toroidal, but the principle of operation is completely different than that in the so-called toroidal monitors found at low duty factor facilities. In the Unser monitor the small magnetic field of the beam tries to magnetize circular strips of an extremely permeable material. A modulator-demodulator circuit senses this magnetization and sends a current to a compensating coil to cancel the field. This compensating current is proportional to the beam current.

With the Unser monitor it should be possible to routinely measure beam currents to few μA accuracy. Unfortunately, the list of systematic errors which may contribute at the 1μA level is sufficiently long that it may not be possible to improve the performance by using longer integration times. The permeable material is magnetostrictive, and is therefore sensitive to temperature drifts and vibration. Magnetic shielding is provided, but care must be taken that the installation environment is not magnetically dynamic. These problems cause zero drifts rather than gain drifts, and can be attacked on two fronts. First, the device can be isolated as much as possible from environmental changes, and second, the zero of the device can be remeasured during a short beam off period as frequently as needed. The great advantage of this device is that it can be calibrated by passing a known current through a wire. This calibration can then be transferred to the 1.5 GHz monitor. Finally, both the PCT and the 1.5 GHz monitors are slightly sensitive to beam motion and will ideally be located upstream of the beam raster.

3. Faraday Cup

A faraday cup could play a useful role. First of all, it would provide another beam current monitor which could easily be calibrated using a precision current source. Secondly, it would extend the range of such "absolute" monitors to well below 1μA, where the Unser monitor could not be used. This would be particularly important for calibrating or checking the linearity of the 1.5 GHz monitor at low beam currents.

To continuously operate a Faraday cup using the full 1.2 MW CEBAF beam would be a formidable task. Ideally, one would like to remove the heat, contain the residual radioactivity, and use as little coolant as possible. The buildup of the electromagnetic shower produces a hot spot or point of maxiumum dE/dz in the bulk. The equilibrium temperature of this spot can be reduced by using material of longer radiation length or higher thermal conductivity. However, since many radiation lengths are needed to completely contain the shower (the SLAC cup used 72 in the longitudinal direction and 46 in the radial direction)[4], and since the beam dump tunnel is less than 3 meters wide, a faraday cup using material with a radiation length greater than roughly 2 cm would be unacceptably large. Copper appears to be a good material for the central region with respect to radiation length, thermal conductivity, melting point, and cost.

If one is willing to accept a much lower continuous beam power level, say 100KW, then the early SLAC report suggests that it is possible to build a radiatively cooled faraday cup with a copper core. It was estimated that melting of the copper would occur at about this power level. To keep well below the melting point one might consider reducing the average radiation length of the core by alternating sheets of copper and aluminum. At 100KW continuous power level one could run up to 25μA beams at 4 GeV. This would be satisfactory for the majority of the proposed experiments. Alternatively, such a faraday cup could be used for short times at any CEBAF power level in order to calibrate other monitors. The cup could then be moved to the side to allow the capture of higher power beams in a beam dump.

4. Ion Chamber

An ion chamber is a device which collects but does not amplify ions produced in a gas by the beam. The principle advantages of an ion chamber are that it has great sensitivity to small beam currents, and is relatively straightforward to design and build. The smallest proposed beam current for Hall C is 10nA, which is well below noise level of the 1.5 GHz monitor or the PCT using 1 second integration times. In the most optimistic scenario, a 10% measurement of this beam current (1nA) could be made with the 1.5 GHz monitor in t=((100nA/sec) /1nA)^2= 1x10^4 seconds, which is completely unacceptable. On the other hand, if a 4 inch thick hydrogen ion chamber at one atmosphere pressure were used, an easily measured collector current of 2.5μA would result.

An ion chamber can also be used at higher currents provided the space charge density does not become so large that significant recombination occurs. For hydrogen gas at one atmosphere pressure and an electric field of a few hundred volts/cm, the maximum areal current density at full efficiency was found to be 10μA/cm^2.[4] One can presumably increase the critical current density by at least one order of magnitude by some combination of lowering the pressure of the gas and increasing the electric field between the collector plates. The choice depends on the size of the currents being measured and the maximum output current of the high voltage supply. Thus, for beam spot sizes $\geq$1cm^2, it appears possible to build a low pressure ion chamber which will work at 100μA. Multiple scattering in the target and possibly a downstream helium bag will be sufficient to give beam spot sizes of many centimeters at the entrance to the beam dump tunnel. Of course, the 1.5 GHz and Unser monitors will work very well at such high currents, but an ion chamber is likely to be the superior relative monitor due to the high signal to noise ratio.

Summary

At startup the standard beam current measuring devices in Hall C will consist of 1.5 GHz and Unser monitors. These are off-the-shelf items, but some effort must go into shielding the Unser monitor from thermal drifts, vibration, etc. It will also be necessary to be able to quickly calibrate the Unser monitor in the beamline with a precision current source. Both monitors will be located at the entrance to the endstation, before the beam raster.

An ion chamber will be built for the two polarized target experiments. The ion chamber will be located downstream of the target, near the entrance to the beam dump tunnel. It is possible the ion chamber will be useful in the 1-100μA range, especially as a relative monitor. The design of a suitable ion chamber is in progress and is being performed in collaboration with Mike Niczyporuk, our summer student.

There are presently no plans to construct a faraday cup, although this would clearly be very useful.

References

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3. Robert Rossmanith, private communication.
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