A HIGH POWER FARADAY CUP TO MEASURE EXTRACTED BEAM CURRENT FROM THE BATES SOUTH HALL RING

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Abstract

A water-cooled Faraday cup has been installed at the Bates Linear Accelerator Center in order to measure the extracted beam current from the pulse-stretcher ring in the South Experimental Hall. The Faraday cup is designed to dissipate 100kW of heat and is thus well-matched to the beam characteristics of Bates (50 μA at 1 GeV). The device has been placed on a cart-and-rail system so that it can be remotely driven into and out of the beam line. We expect the Faraday Cup to serve as an absolute calibration source for beam current measurements to better than 0.1% accuracy. This will allow for very high precision cross section measurements and the isolation of small interference response functions with reduced systematic uncertainty.

1. PROJECT PURPOSE

One of the primary experimental programs at the Bates Linear Accelerator over the next few years will be the measurement of interference response functions in (e,e'p) reactions. A system of four small magnetic spectrometers with full out-of-plane capability ("OOPS") has been constructed so that these response functions may be extracted simultaneously in one spectrometer setup. Due to the very small cross sections involved, even small systematic uncertainties may result in large errors in the extracted response function. For this reason, a program has been undertaken at Bates to minimize these systematic uncertainties. As part of this program, a water-cooled Faraday cup has been installed in the experimental hall in order to measure the incident beam charge to at least 0.1% accuracy.

Accurate measurement of the extracted beam current from the Bates South Hall Pulse-Stretcher Ring ("South Hall Ring") represents a significant challenge due to the very small beam currents involved. In the past, pulsed-beam experiments at Bates have employed ferrite toroid monitors which are ideal for measuring typical pulsed-beam currents of 1-3 mA peak. However, these devices are not sensitive enough to measure the peak currents of 5-50 μA from the South Hall Ring. In this case, an intercepting device represents the most accurate montior available.

2. HISTORY AND CHARACTERISTICS OF THE FARADAY CUP

The Faraday Cup was originally constructed thirty years ago for use at the electron linear accelerator at the National Bureau of Standards.[1] The badly damaged device was acquired as surplus material by Bates laboratory. Since then, it has been completely refurbished. Design changes have been implemented in order to modernize, and hopefully improve the reliability of, some of the key systems of the Faraday Cup.

A schematic of the Faraday Cup is shown in Figure 1. The device consists of a cylindrical lead tub with eight-inch-thick walls (nine inches at the rear of the cup). Inside the lead tub is a stainless-steel core where a large fraction of the incident beam energy is absorbed. This core consists of sixteen stainless-steel plates ranging in thickness from one-sixteenth inch in the front to one inch at the back. Water cicrulates around the plates to provide cooling. Cooling water also circulates through tubing in the lead tub. The water is provided by a closed-loop system at a rate of up to 12 g.p.m., depending on the heat load. The system can easily accomodate the 50 kW maximum heat load from the South Hall Ring (1 GeV at 50 μA). The core and tub present approximately a 41 R.L. absorption path for the incoming electrons so that a negligible fraction of the beam esacpes through the cup. Surrounding the lead tub is an aluminum shell which can be biased to several kV in order to bend low-energy charged particles back to the cup for collection. The entire assembly is housed inside an aluminum vacuum can. The vacuum is maintained at approximately 10^{-6} torr by an ion pump. The high vacuum is needed in order to prevent the incident electrons from being neutralized by positive ions, resulting in a loss of charge. The Faraday Cup must be electrically insulated from the vacuum tank to prevent excessive leakage currents. In the Bates implementation, this is achieved by four self-adjusting ceramic feet which support the weight of the tub. Ceramic standoffs are also placed on the top and sides of the vacuum tank. The water connection to the cup employs a ceramic break and a six-foot length of (rubber) hose in order to eliminate current losses through the cooling water. The zero-current of the installed Faraday cup has been measured to be 5 nA.

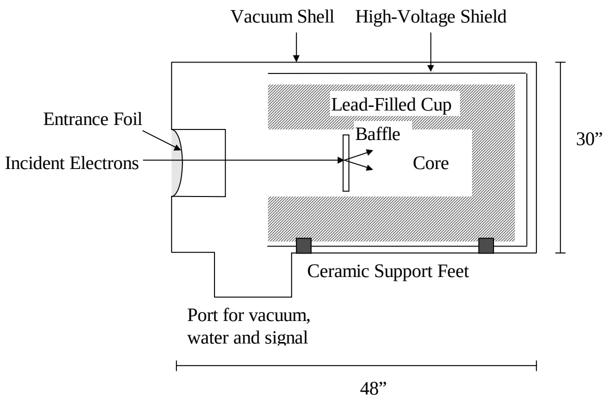

Figure: 1 Schematic of the Faraday Cup.

The electron beam enters the Faraday Cup through a 12 mil thick aluminum entrance foil. The foil is separated from the scattering baffle by a distance of approximately 24 inches in order to minimize the solid angle in which backscattered electrons may leave the cup. A series of permanent magnets (“catcher magnets”) also help to reduce the number of escaping backscattered electrons.

The entire Faraday Cup has been placed on a moveable cart so that it can be remotely driven into and out of the beamline.

3. SOURCES OF ERROR AND FARADAY CUP CALIBRATION

The main source of error in the beam charge measurement is expected to be due to secondary electrons produced by scattering in the entrance foil. It has been known for a long time that the fractional error for this process follows a 1/E law, where E is the incident electron energy.[1] At the NBS, the beam energy was limited to 120 MeV and, at this energy, the error from this source was just 0.1%.[1] The higher energy beam employed at Bates will lead to correspondingly lower errors.

We plan to calibrate the Faraday Cup using pulsed beam and one of our ferrite toroids as a null monitor. This method has been employed elsewhere.[1,2] Briefly, the method is as follows. The output from the ferrite toroid is directly proportional to the beam current. We define the integrated, pedestal-subtracted, output from the toroid per unit charge collected from the Faraday Cup as:

$$C = k\frac{Q_T}{Q_{CUP}} \tag{1}$$

Now, suppose that we feed the current from the cup back through the toroid. We may then write,

$$\delta C = k\frac{(Q_T - Q_{CUP})}{Q_{CUP}} \tag{2}$$

The fractional Faraday Cup error is then given simply by,

$$\frac{\delta C}{C} = \frac{(Q_T - Q_{CUP})}{Q_T} \tag{3}$$

The third equation follows only if the constant, k, is the same in equations (1) and (2). This is not strictly correct as k has a small current dependence. Therefore, the result of equation (3) is exact only when the measurements implied by equations (1) and (2) are extrapolated to zero current.

Although we have not fully commissioned the Faraday Cup, an early test measurement appears promising. Figure 2 shows the response for a beam pulse for both the toroid and the Faraday Cup. The total charges measured by each device agree to within five percent.

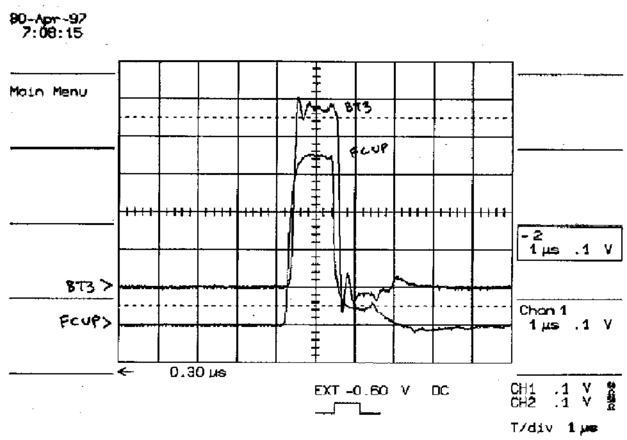

Figure: 2 Oscilloscope trace of the Faraday Cup signal (FCUP) and a ferrite toroid (BT3) for a beam pulse. The veritcal scale is 2mA/division while the horizontal scale is 1 microsecond/division.

4. FUTURE PLANS

In the near future, we will fully commission the Faraday Cup using the method outlined above. The availability of pulsed beam at Bates will allow us to quickly and accurately calibrate the Faraday cup for use in continuous-beam experiments which use extracted beam from the South Hall Ring. Due to the much higher beam energies at Bates as compared with NBS, secondary foil scattering should be greatly reduced, leading to improved accuracy in the beam charge measurement. We expect to achieve accuracies of better than 0.1%, thus practically eliminating the beam charge measurement as a source of systematic error in the OOPS physics program.

REFERENCES

[1] J.S. Pruitt, NIM **92**, 285, (1970).
[2] J.F. Hague, R.E. Jennings and R.E. Rand, NIM **24**, 456, (1963).