Beam Charge Asymmetry Monitors for Low Intensity Continuous Electron Beam*

Chris Cuevas, Jean-Claude Denard, Arne P. Freyberger, Youri Sharabian
Jefferson Lab, 12000 Jefferson Avenue, Virginia, 23606 USA

Abstract

Experimental Hall B at Jefferson Lab (JLAB) typically operates with CW electron beam currents in the range of 1 - 10 nA. This low beam current coupled with a 30 Hz flip rate of the beam helicity required the development of new devices to measure and monitor the beam charge asymmetry. We have developed four independent devices with sufficient bandwidth for readout at 30 Hz rate: a synchrotron light monitor (SLM), two backward optical transition radiation monitors (OTR) and a Faraday Cup. We present the results from the successful operation of these devices during the fall 2000 physics program. The reliability and the bandwidth of the devices allowed the control of the current asymmetry at the source laser by means of a feedback loop.

1 POLARIZED BEAM AT JLAB AND HALL B REQUIREMENTS

The JLAB polarized source generates three CW electron beams for the experimental halls (A, B & C). Two of these halls, A & C, house two-arm spectrometers and operate with beam currents between 50μA and 100μA. Hall B houses a large acceptance spectrometer which is luminosity limited to beam currents of 1 to 10nA. This small CW beam current is a challenge for beam diagnostics.

The electron beam polarization is toggled between the h^+ helicity state and the h^- helicity state at a 30Hz rate. The relative beam charge for each state must be accurately measured in order to correctly extract the physics cross sections. The measured physics asymmetries are of the order of a few percent, which was used to place a desired limit on the beam charge asymmetry; $A_Q = \frac{N^+_{e^-} - N^-_{e^-}}{N^+_{e^-} + N^-_{e^-}} < 0.1\%$.

2 BEAM CHARGE ASYMMETRY MONITORS

To monitor the relative amount of beam charge in each helicity state requires devices that are linear with respect to beam current, fast enough to be recorded at the 30Hz time scale and independent of other possible helicity dependent effects (like beam motion).

Prior to fall 2000, the Hall-B beam current instrumentation consisted of the Faraday Cup and beam position/current RF cavities. Both were of insufficient bandwidth to measure the beam charge at a 30Hz rate. Three new devices were installed along the beam-line, a synchrotron light monitor (SLM) and two backward optical transition radiation monitors (OTR), prior to the fall 2000 physics run. The Faraday Cup electronics was upgraded to work at a higher bandwidth at this time as well. The following sections describe these developments.

2.1 *Synchrotron Light Monitor*

The electron beam is transported from the "switch-yard" to Hall-B via a vertical "S" bend. The bending radius of the last dipole is 33m. Downstream of this dipole a mirror reflects the synchrotron light through an optical port. From there the synchrotron light goes through an aperture and is split, with one half of the light incident on a CCD camera and the other half is focussed via a lens onto a photomultiplier tube (PMT). The PMT current output is proportional to the beam current and is used to measure A_Q. The lens is used to focus the light onto the photo-cathode so that the synchrotron light position on the photo-cathode is independent of beam position. Beam motion in the bend plane changes the geometrical acceptance. Details of the PMT and electronics chain is found in a later section.

2.2 *Optical Transition Radiation Monitors*

Two OTR monitors were installed; each use 0.8μm Al foils[1] as the source of OTR. OTR-1 consists of a foil 2.54cm in diameter mounted at a 45^0 angle with respect to the beam and an optical port. OTR-1 is installed just upstream of the Hall-B Møller polarimeter target and is used only during Møller runs. OTR-2 consists of a foil mounted at 60^0 with respect to the beam. The foil resides just inside of an integrating sphere[2], and uniformly illuminates the photo-cathode. The integrating sphere is used to minimize reflective variations in the OTR foil and to minimize the position dependence of the light on the photo-cathode. OTR-2 is located ~5m upstream of the experimental target. The electron beam in this region is rastered in a spiral pattern approximately 1.5cm in diameter.

2.3 *Faraday Cup*

After the electron beam traverses the experimental target it is transported to the Faraday Cup. With a capacitance of

* Work supported the Southeastern Universities Research Association (SURA) which operates the Thomas Jefferson National Accelerator Facility (JLAB) for the United States Department of Energy under contract DE-AC05-84ER40150

[1] Goodfellow Cambridge Limited, Cambridge, CB4 4DJ, England

[2] Oriel Instruments, 150 Long Beach Boulevard, Stratford, CT 06615-0872

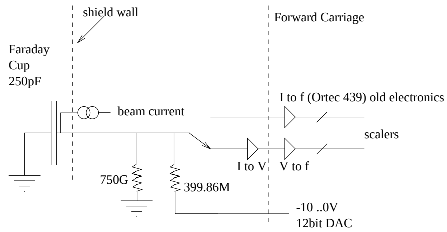

Figure 1: Schematic of the F-Cup electronics, including the old electronics as well as the calibration circuit

250 pF, the RC time constant is small enough to measure the beam current on a 30Hz time scale.

3 LIGHT DETECTION AND ELECTRONICS

Both the OTR and SLM devices produce light in the visual region of the EM spectrum. Phillips XP2262[3] photomultiplier tubes are used to detect both SLM and OTR light. These PMT's are used extensively throughout the Hall-B instrumentation. Their use in a CW light detection environment meant that the electronics would have to be different than the nominal discriminator-scaler setup. In order to avoid statistical fluctuations of detecting single photons, the PMT's are operating in current mode. The PMT output current is proportional to the number of photons incident on the photo-cathode.

The PMT's operating in current mode are a current source similar to the Faraday Cup. Measuring the current from these devices while retaining correlation with the beam helicity state is done with the following electronics chain; current to voltage amplifiers (ItoV) [4] are placed as close to the PMT's/F-CUP as possible to keep the RC time constant small. The voltage output is fed into a voltage to frequency converter (Vtof)[5] followed by a VME scaler [6]. Figure 1 is a schematic of the F-Cup circuit, including the previous electronics and the calibration circuitry.

4 LINEARITY AND POSITION DEPENDENCE

Figure 2 shows the response of the SLM and OTR's versus the beam current as measured by the Faraday Cup. Both OTR's saturated their electronics at large beam currents, this was fixed by changing the gain of the ItoV amplifier after the test. The beam position varied by $\pm 100\mu$m during this portion of the test. The non-linearity of each device is measured by determining the slope at each beam current cluster (at 0.5,1,2,5,8,10nA) The results of this comparison

[3]Phillips Photonics, BP 520, F-19106 BRIVE, France

[4]PMT5-R,Advanced Research Instruments Corporation, 1pA to 1μA sensitivity, gain selected via 3 TTL lines. Bandwidth at 1nA is 1kHz.

[5]8400series VtoF, 0.001% FS linearity, 1V input produces 100kHz output, Dymec, 27 Katrina Road, Chelmsford, MA 01824

[6]SIS3801, SIS GmbH, Moorhof 2d, 22399 Hamburg, Germany

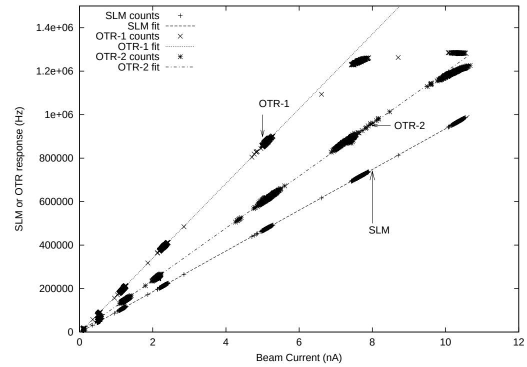

Figure 2: SLM, OTR-1 and OTR-2 light yield as a function of the beam current as measured by the Faraday Cup. The line drawn is the result of a linear fit to the data; data where the electronics on OTR-1 and OTR-2 are saturating are excluded from the fit.

are a 1%, 3% and 1% non-linearity for the SLM, OTR-1 and OTR-2 respectively. This non-linearity includes the effect $\pm 100\mu$m of beam motion and the improved response of OTR-2 compared to that of OTR-1 is presumably due to the integrating sphere reducing the effects of beam motion.

The effects of beam motion on the SLM and OTR responses was investigated by steering the beam off axis in 0.5mm steps in both x and y directions. The SLM and OTR-1 are $\sim$50m from the F-Cup and these beam motions led to beam loss as observed in the beam halo monitors. Unable to perform a direct comparison to the F-Cup, the measured asymmetry at the SLM and OTR's was compared to the F-Cup asymmetry. This is done by measuring the "double-asymmetry"; $\Delta A_{SLM-FCu} = \frac{N^+_{e^-}(SLM)N^-_{e^-}(FCu) - N^-_{e^-}(SLM)N^+_{e^-}(FCu)}{\Sigma}$. The top plot in Figure 3 shows the double-asymmetry for OTR-2 and the F-Cup and the bottom plot shows the beam position during this measurement. The double-asymmetry is fit to a Gaussian function, resulting in a mean of $(-0.6 \pm 2.2) * 10^{-5}$ demonstrating that the two devices are measuring the same asymmetry within statistics. Similar comparisons for SLM and OTR-1 showed that the measured asymmetry in all devices is independent of the beam position. While a zero double-asymmetry does not demonstrate the SLM and OTR responses are independent of position, it does show that the beam motion occurs on a slow enough time scale (compared to the helicity flip rate) that the measured A_Q is independent of beam motion.

5 SLM AND OTR LIGHT YIELDS

The PMT gain can be determined by measuring the widths of the ratio groups [SLM/F-Cup, OTR-1/F-Cup, SLM/OTR-1] and [SLM/F-Cup, OTR-2/F-Cup, SLM/OTR-2][7] and comparing with the calculated widths

[7]Only one OTR could be inserted at a time due to control issues. This led to two datasets, one with SLM, OTR-1 and F-Cup data and the other

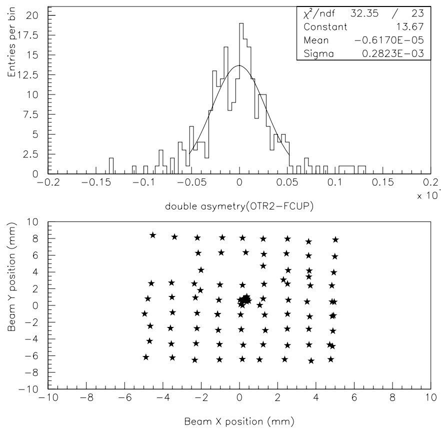

Figure 3: The top plot shows the double-asymmetry for OTR-2 and F-Cup and the bottom plot shows the x and y beam position during the measurement.

	Coefficient	$\frac{n_\gamma}{e^-_{beam}}(mea.)$	$\frac{n_\gamma}{e^-_{beam}}(cal.)$ [1, 2]
SLM	5.28(set 1) 5.18 (set 2)	$0.32 * 10^{-3}$	$0.64 * 10^{-3}$
OTR-1	11.1	$1.2 * 10^{-3}$	$5.6 * 10^{-3}$
OTR-2	5.91	$0.44 * 10^{-3}$	$1.9 * 10^{-3}$

Table 1: Table listing the results of constraining the $(measuredwidth)/(calculatedwidth) = 1$ at the 1nA data point. Using 0.25 for the photo-cathode efficiency the number of photons per electron of beam is determined.

based on Poisson statistics. Each group of ratios results in three equations with three unknowns at each beam current point. The coefficients for the 1nA data are listed in Table 1.

As expected OTR-2 looses some light as compared to OTR-1 due to the integrating sphere. The discrepancy between the calculated light yield and the measured yield for the OTR's suggests that there is an additional noise term contributing to the measured width. This discrepancy increases as a function of beam current and might be due to the presence of UV light on the photo-cathode[3]. The SLM light yields for all beam currents are constant. The light splitter in the SLM optics does not transmit in the UV region ($\lambda < 350n$m) so this PMT is protected from UV light.

6 SUMMARY

Using the results in the previous section the time needed to measure the beam charge asymmetry with 0.05% error at 1nA of beam current are determined to be (1.4, 8, 2, and 6s) for the (F-Cup, SLM, OTR-1 and OTR-2). The limiting factor on the F-Cup is the *digital* error as the F-Cup count

with SLM, OTR-2, F-Cup data.

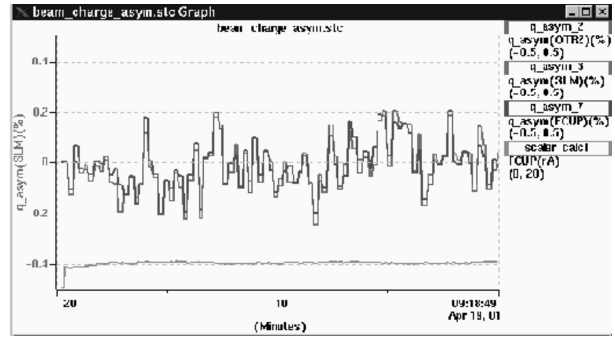

Figure 4: Screen capture of a real-time plot of A_Q as measured by the F-Cup and SLM as a function of time. A_Q was calculated using 10s worth of data. The lower trace (not fluctuating) is the beam current as measured by the F-Cup.

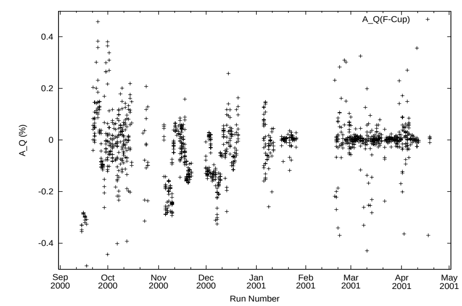

Figure 5: Beam charge asymmetries, one hour samples, corresponding to a data run in the hall. One can easily see the improvement when the feedback loop was enabled in Jan. 2001.

rate is only 309 pulses per helicity bin. Real-time plot of A_Q as a function of time for the SLM and F-Cup are shown in Figure 4. Actual fluctuations of the beam charge asymmetry are measured accurately within a 10s time frame as shown by the agreement between the F-Cup and SLM measurements. The helicity uncorrelated noise of the injector is the likely source of these fluctuations.

All these devices have been reliably used since Sept. 2000. Starting in Jan. 2001 the measured asymmetry is used to control the laser power at the injector to constrain the charge asymmetry to the Hall's requirements (see Figure 5).

7 REFERENCES

[1] Helmut Wiedemann, "Particle Accelerator Physics", Springer-Verlag, 1993.

[2] V.L. Ginzburg and V.N. Tsitovich, "Transition Radiation and Transition Scattering", Adam Hilger, 1990.

[3] "Photomultiplier Tubes, Principles & Applications", Phillips Photonics, 1994.