Precision Intercomparison of Beam Current Monitors at CEBAF*

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The CEBAF accelerator delivers a CW electron beam at a fundamental frequency of 1497 MHz, with an average beam current up to 200 μA. Accurate and stable non-intercepting beam current monitors are required for a number of applications. These include setup and control of the accelerator, monitoring of both beam current and beam losses for machine protection and personnel safety purposes, and providing beam current information to the experimental users. Fundamental frequency stainless steel RF cavities have been chosen for these beam current monitors. This paper reports on a precision intercomparison between two such RF cavities, an Unser monitor, and two Faraday cups, all located in the injector area. At the low beam energy in the injector, it is straightforward to verify the high efficiency of the Faraday cups, and the Unser monitor included a wire through it to permit an absolute calibration. The cavity intensity monitors have proven to be capable of stable, high precision monitoring of the beam current.

I. INTRODUCTION

At CEBAF, the electron beam current is monitored at different locations along the machine for several reasons. The beam current is measured at two locations in the injector both as a part of machine setup and for detection of beam condition changes. The machine protection and personnel safety systems rely on current measurements in the injector to set a limit on the amount of beam current input into the rest of the machine. In addition, the machine protection system also compares the beam current in the injector with the current measured at the end of the accelerator to determine and limit beam loss through the machine. Finally, the users in the experimental halls are interested in the measurement of the beam current delivered to their target.

In the injector, two Faraday cups, which also act as beam dumps, are used for current measurements. The personnel and machine protection systems, which need non-intercepting beam current information at all times during the operations, use two fundamental frequency resonant cavity beam current monitors (BCMs) in the injector. For the current measurement at the end of the machine, two BCM cavities are used in conjunction with an Unser monitor. The function of the Unser is to provide absolute calibration for the BCMs. It is difficult and costly to make Faraday cups for high energy and beam power at the end of the machine.

An experiment to determine the calibration factor and accuracy of different current monitors was performed in the injector area. In the following sections we give a brief description of different current monitors used in the experiment, explain the experimental procedure, and present our results.

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II. CURRENT MONITORS

Faraday cup 1 is a 100 keV beam dump with a power limit of 100 W. It is a copper plug 3.17 cm long with a re-entrant conical shaped cup 2.84 cm deep with a 1 cm diameter opening. The re-entrant nature of the cup allows all of the beam current to be collected as long as the beam is small and centered in the cup. Faraday cup 2 is a 5 MeV beam dump with a power limit of 1 kW. It is 7 cm long with a similar re-entrant conical shaped cup 6 cm deep and 1.5 cm diameter opening. The cups are water cooled and are designed not to move out of alignment due to heating from the beam. They can be inserted into and pulled out of the beamline remotely from the control room. To have beam on Faraday cup 2, Faraday cup 1 must be retracted; that is, the current cannot be measured at both cups simultaneously.

The Unser monitor [1] is a non-intercepting, parametric dc current transformer with a wide dynamic range and a nominal output of 4 mV per microamp. The monitor is calibrated by passing a known current through a wire inside the beam pipe. It requires extensive magnetic shielding and temperature stabilization to reduce noise and zero drift.

The beam current monitors [2] are stainless steel cylindrical resonant cavities with $Q_L \sim 1500$. The power produced in the cavity as the beam passes through it is measured using an rf power meter, and the current can then be calculated from measured calibration constant.

II. DISCRIPTION OF EXPERIMENT

The current monitor cross calibration test was performed in two phases

A. Phase I

The first phase of the experiment was to calibrate the two Faraday cups. The output current from the Faraday cups is converted to voltage and amplified by I to V amplifiers. Using LABVIEW, a digital controlled precision current source, and a digital voltmeter, the response of I to V amplifiers was mapped for different currents. The results showed very good linear response for both amplifiers.

Next, a pulsed beam was used to scan the Faraday cups in both horizontal and vertical directions. A flat plateau with 3 mm and 5 mm diameter was found at the center of cups 1 and 2, respectively (see figures 1 and 2). Then the efficiency factor for each cup was measured by measuring a pulsed electron beam current while biasing the cups with respect to ground at

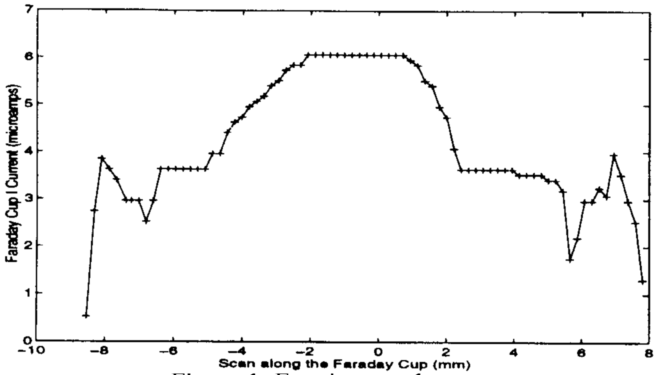

Figure 1: Faraday cup 1 scan.

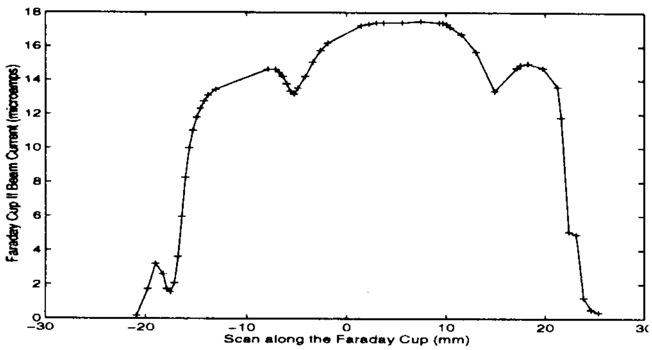

Figure 2: Faraday cup 2 scan.

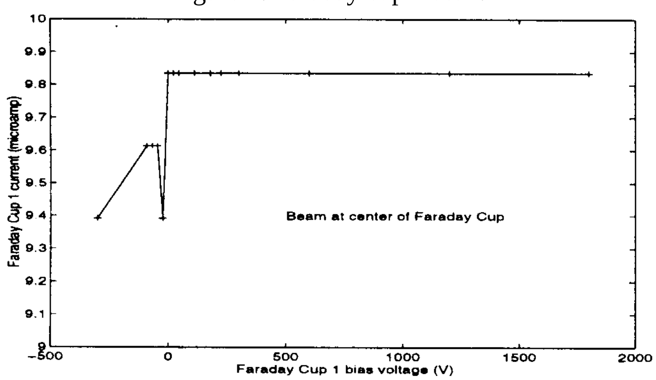

Figure 3: Faraday cup current vs bias voltage

different voltages from -300 V to +18000 V. This experiment showed no significant change of current measured between the biased and unbiased cups when beam was centered in the cups (see figure 3). This measurement confirms essentially 100% collection efficiency for the cups. Therefore, the I to V amplifier response curves can be used to determine the beam current on the Faraday cups.

B. Phase II

In phase II of experiment, the Unser monitor, the BCMs and the Faraday cups were used to measure cw beam current simultaneously. A beam to the second Faraday cup has to pass through the location of Faraday cup 1, the Unser and both BCM monitors in that order. The equivalence of the current signal on both Faraday cups, plus the absence of signals on the beam loss monitors (photomultiplier tubes) in the region between the two cups, indicated no beam loss between the cups. Therefore all current monitors would detect the same current.

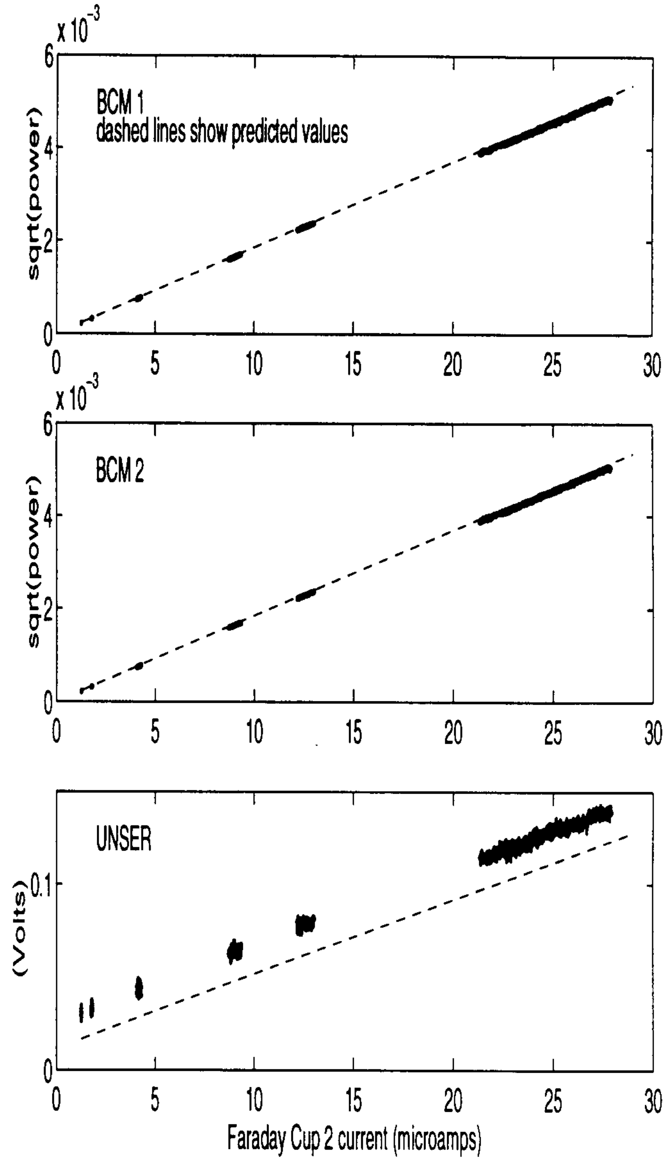

Figure 4: BCM1, BCM2, and Unser voltages vs. FC2 current

Plotting the Unser and the BCMs signals vs. the Faraday cup 2 signal and using Faraday cup 2 calibration curve gave us the calibration factor for the monitors (see figure 4, there are 2677 points in each plot). The dashed lines show the predicted response of the monitor. For the BCM cavities, the predicted lines are based on Q_L , the shunt impedance as calculated using MAFIA, and cable attenuation measurements. For the Unser monitor the predicted line is based on calibration measurement using the calibration wire inside the monitor.

III. ANALYSIS OF THE RESULTS

Table 1 shows the slope and offsets for the best fit and predicted lines for the Unser and the BCM vs.Faraday Cup 2 current. The measured slopes and offsets from beam data obtained in phase II match closely with predicted values. The data also show that the offset value for the Unser was relatively high and changed over time. The reason is that the Unser monitor is very sensitive to nearby magnetic fields and day to day temperature changes. However, only slope of the Unser response is important to us, since the offset value can be obtained by turning the beam off and measuring the output signal.

The data points for figure 4 were obtained by measurement of the instantaneous signal from the different devices at a rate of approximately 1 Hz. Table 2 lists the values of these fluctuations for each monitor.To obtain the BCM fluctuations independently of the beam noise, a graph of BCM 2 vs BCM1 is plotted and the best linear fit through the data is calculated. The percent difference between BCM 2 values and the fitted line show the level of voltage fluctuations of the BCMs. (see Figure 5).

Table 1

	Phase II Data (Linear Fit)	Predicted results
BCM1 vs FC2	slope: 1.828e-4 $V/\mu A$ offset: -6.13e-6 V	1.853e-4 $V/\mu A$ 0.0 V (MAFIA)
BCM2 vs FC2	slope: 1.820e-4 $V/\mu A$ offset: -9.16e-6 V	1.845e-4 $V/\mu A$ 0.0 V (MAFIA)
Unser vs FC2	slope: 4.11e-3 $V/\mu A$ offset: 2.6e-2 V	4.012e-3 $V/\mu A$ 1.2e-2 V (Calib. wire)

Table 2

Device	rms fluctuations
Faraday cup 2 current	0.05 μA
BCM 1 voltage	0.5%
BCM 2 voltage	0.5%
Unser current	1.0 μA

IV. CONCLUSION

This experiment has allowed us to cross compare different current monitoring devices at CEBAF. We have calibrated our Faraday cups by measuring their I to V amplifier responses and demonstrated that there is no secondary emission loss. Using these results we established lossless transmission to Faraday cup 2 and calibrated the rf cavity current monitors and the Unser monitor. These measured calibration factors

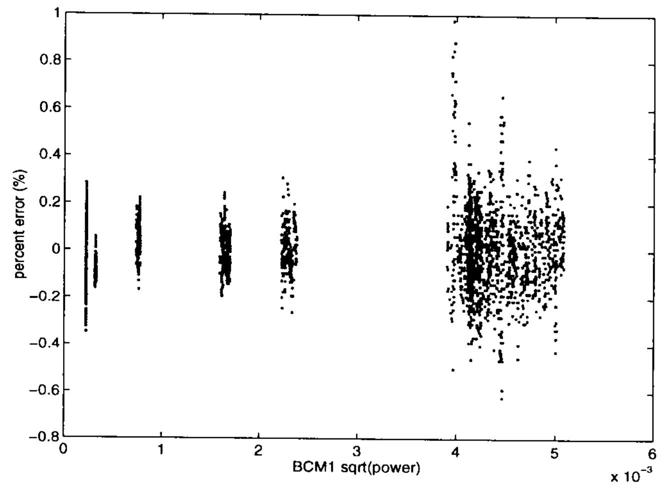

Figure 5: BCM2 vs BCM1 percent difference

agreed well with the predicted values. The results of the study are presently being used for current measurement and for establishing safe operating currents for personnel and machine safety systems. Improvements can be made on increasing the accuracy and reducing the noise level of the monitors. The I to V amplifiers can be redesigned to reduce the noise due to interference and ground loop effects.

Another area of improvement would be to integrate the output signal of the monitors. For safety system purposes, the instantaneous current measurement is important and the accuracy of a few percent is sufficient. The experimental users of the accelerator are more interested in integrated current and high accuracy. We are planning to continue research on this subject and will use lessons learned in future experiments.

V. REFERENCES

[1] K. B. Unser, The Proceedings of IEEE 1989 Particle Accelerator Conference, p 71.

[2] R. Ursic, these proceedings.