Hall A Beam Charge Calorimeter Overview

R. Gilman

Abstract / Executive Summary

Jefferson Lab Hall A / Rutgers project to improve precision of current measurements to ~ 0.5 - 1 % at currents near 1 μA

- R Gilman: Overview, requirements, use
- P Degtyarenko: Tungsten modelling and radiation issues
- M Bevins: Mechanical design
- A Freyberger: Instrumentation and controls

The Problem

- At present, beam current / integrated charge is determined in Hall A using non-invasive BCMs, calibrated by the Unser monitor
  - Unser has noise levels of ~ 0.2 - 0.3 μA
  - Calibration < 1 % above ~ 30 μA, but 20 – 30 % at low current, ~1 μA; 1 % not easily reached by statistics
- E02-004 needs 0.5 - 1 % (absolute) and 0.2 % (relative) BCM calibration for ~ 1 μA currents at 0.6 – 0.8 GeV beam energy
- Proposed Solution: 0.5 - 1 % absolute calorimeter - builds on experience from SLAC, Charlie Sinclair's study of silver calorimeter for Jefferson Lab

Calorimeter Basics

- Absorb energy into calorimeter, measure rise in temperature: charge $Q = e\, C_{heat}\, \Delta T / E_{K\,beam}$ (+ small corrections)
  - As-proposed W calorimeter slug has a heat capacity of ~ 8 kJ/K, or ΔT ~ 126 K/MJ
  - 2.4 μA current with 100 s exposure at 1 GeV beam leads to 240 kJ energy deposition, and ΔT ~ 30 K
  - 0.5 % precision implies ΔT ~ 0.15 K
- Beam put through BCMs upstream of calorimeter to calibrate them
- Also plan to instrument calorimeter as a Faraday cup for crude consistency check – note we have not studied this with any precision

Why Tungsten rather than Silver?

- For two calorimeters with roughly the same time constant:
  - W costs less than Ag, 10 k vs 30 k
  - W has smaller estimated EM shower and hadronic losses, 0.46 % vs 1.44 % for Ag
  - W is physically smaller (shorter) than silver, and easier to handle, although its mass is slightly larger
  - ALARA
- Expansion coefficient four times smaller for W than for Ag, 5×10^{-6} vs 19×10^{-6}
- W has much higher melting point than Ag, 3695 vs 1235 K, but its conductivity is lower, 170 vs 430 W/m·K

Requirements

- 0.5 – 1 % absolute accuracy, limited by knowledge of EM + hadronic losses; ~0.2 % precision / repeatability
- Operating range from ~1/2 kW up to ~5 kW
- Measurements take few minutes of beam time, repeatable within ~1/2 hour (allows measurements to be done during hall configuration changes)
- Modest requirements on accelerator operation, discussed later

Controlling Calorimeter Uncertainties

- Use dead reckoning (~1 %) and built-in heaters (~0.2 %) to calibrate heat capacity C_{heat} of the calorimeter
- Use redundant thermometry to calibrate thermal model for and temperature rise of calorimeter (~0.2 %) - minimize thermal losses with vacuum insulation and gold plating (ϵ ~ 0.03); few tenths of a percent thermal losses appear achievable
- Hall A beam energy (ep + ARC) good to < 0.02 %
- Set size of calorimeter to reduce EM shower, hadronic reaction loss: W-Cu slug 16 cm x 16 cm ϕ has hadronic + EM losses ~ 0.46 + 0.2 % at ~1 GeV

Development and Heat Capacity Calibration

- Initial tests:
  - Use heater to determine calibration, compare with calculation, check thermal model
  - Check repeatability, sensitivity to varying conditions (initial temperature, energy/power deposition, noise, ...): determine test-bench precision limits
- Install calorimeter in Hall A, check out controls and repeat subset of repeatability tests
- Start series of with-beam studies, as testing time available: tests as above, plus sensitivity to beam energy, stability and linearity of BCMs

BCM Calibration Procedure

- Calorimeter out of beam
- Set up desired (energy) current, luminosity (agree with MCC on exposure time in advance)
- Beam off, move calorimeter to in-beam position
- Start ``calibration data run'', expose to beam
- Beam off, move calorimeter to out-of-beam position, have MCC et al reset up experiment
- Monitor T(t) for several minutes
- Move calorimeter to cool position
- Analyze data

Accelerator Requirements

- No trips!
- Insensitive to spot size, position: plan to use 2 mm raster – SLAC had 1 cm spot, ~ ½ % effects for 1 cm position changes
- Beam energy determined with ARC and ep systems to < 0.2 x 10^{-3}
- I within ~ 10 % of requested value
- Current stability is not crucial as long as calibration and running conditions similar – but - would like rms variations below ~1 % over ~1 minute exposures for some initial studies, as linearity of BCMs and noise levels in Hall A are not established for low currents

Uncertainties and Corrections

- Thermometry, heat capacity
- Heat loss/gain from radiation, conduction – calculations by M Bevins
- Energy loss from showering particles exiting sides and/or end of calorimeter – calculations by E Chudakov, P Degtyarenko, and A Freyberger
- Energy loss from hadrons escaping calorimeter – calculation by P Degtyarenko

Radiative Heat Losses

- $P = \epsilon\sigma AT^4$, with emissivity ϵ, $\sigma = 5.67\times10^{-8}$ W/m^{2}K^4, and area A ~ 0.153 m^2
- For gold finish (which does not oxidize), various sources report ϵ ~ 0.02 – 0.03
- For $T = T_{room} + 30$ K, P ~ 1.0 W (net loss)
- Conductive losses are similar in size
- Over a ~ 500 s measurement, the integrated heat loss is ~ 1 kJ / 250 kJ = 0.4 %
- The thermal model can be well calibrated, by monitoring temperature as a function of time
- The loss can be reduced, by pre-cooling the slug

Uncertainty Budget

- Knowledge of beam energy: σ ~ 0.02 %
- Knowledge of temperature change: σ ~ 0.2 %
- Knowledge of heat capacity: σ ~ 0.2 %
- Radiative plus conductive heat loss: 0.4 ± 0.1 %
- EM shower loss: 0.15 ± 0.05 % [1.1 ± 0.2 % (silver)]
- Hadronic energy loss: 0.3 ± 0.15 % [0.34 ± 0.17 % (silver)]
- Estimated total (absolute) uncertainty: ~0.3 %
- For repeatability, at the same beam energy with similar exposure (integrated charge), there is only the temperature uncertainty

Issues

- We cannot at this point prove the calorimeter will be repeatable at the 0.2 % level: tests of the device are needed
- An extensive test program is needed: Rutgers will devote ~1 FTE later this year
- BCM operations in Hall A at low current are unreliable at present, but there is no fundamental reason why they should not work and be linear; new nA BCMs are also being installed
- We are discussing ways to try to better quantify the uncertainties on the calculated hadronic and EM shower losses. We would rather *not* have a second, much bigger calorimeter.

Summary

- ~ 0.5 % beam current calorimeter looks very feasible
- Tungsten has smaller EM + hadronic losses, smaller cost, and similar time constant in comparison with silver; we conclude it is a better choice of material
- Pavel Degtyarenko, Mike Bevins, and Arne Freyberger will now present more complete descriptions and justification