Upper limit of the electron beam energy at the CEBAF 2D injector spectrometer and its functionality

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1 Introduction

Two areas of research at the CEBAF injector (study of the polarization transfer from electrons to positrons and study of the absolute uncertainty of Mott polarimetry) benefit from an electron beam with an energy up to about 10 MeV. The electron beam receives 0.5 MeV from the combined gun high voltage and room temperature radiofrequency (RF) "capture" cavity. Acceleration to higher energy is achieved by the cryounit (see Fig. 1), the initial superconducting RF element (SRF) in CEBAF. The cryounit, composed of two standard 5-cell CEBAF cavities, is routinely used to increase the electron beam energy to 5 MeV. To do this, each cavity with an effective accelerating length of 0.5 m, is operated at a gradient of 5 MV/m, although off crest. The cavities, however, may be run at higher gradient and potentially closer to crest to further increase the beam energy.

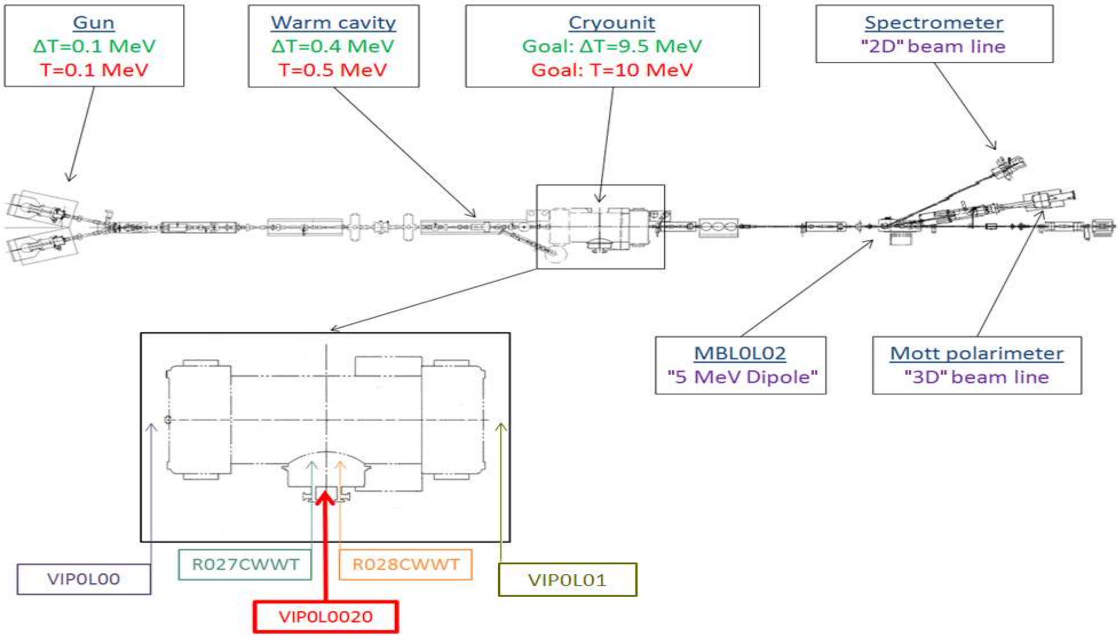

Figure 1: *The standard "5 MeV" CEBAF injector region, electron gun to "2D" spectrometer. The cryounit insert refers to elements described in the text.*

The purpose of the present work is to (a) determine the maximum sustainable gradient of each cavity (goal: ∼10 MV/m), and (b) determine the operational status of the "2D" electron spectrometer which will be used to measure the electron beam momentum at the maximum energy.

2 Maximum Gradients Of The Cryounit Cavities

The first part of this test does not require beam. The purpose is to determine the maximum gradient that each cavity in the cryounit will sustain before either:

a) exceeding acceptable radiation level due to field emission, or

b) exceeding acceptable vacuum level due to desorbed gas.

The two cavities are referred to as 0L02-7 and 0L02-8. Power is distributed from a klystron in a ground level service building, into the accelerator enclosure via an RF waveguide under vacuum and through a ceramic vacuum window to the cavity itself. The cavity is directly part of the accelerator beam line through which the electron beam passes. The power to each cavity is controlled by a gradient setpoint (GSET) and monitored by a gradient readback(GMES). We intend to use a spectrometer to measure the electron momentum and calibrate each.

The SRF group recommended [1] cryounit parameters to monitor as we processed each cavity beyond its usual operating gradient. The parameters included the beam line vacuum, RF waveguide vacuum, ceramic window temperature and cryogenic flow and capacity, described here:

- Beam Line Vacuum - The beam line vacuum signals upstream (VIP0L00) and downstream (VIP0L01) were monitored. The acceptable limit is 3×10^{-9} Torr [2].

- Waveguide Vacuum - The waveguide vacuum signal (VIP0L0020) that conducts the RF power from the klystron to the cavity is monitored. The vacuum is monitored to determine if the waveguide is safely sealed, however, the signal is a useful indicator of RF induced gas desorption. The acceptable limit is 1×10^{-7} Torr [2].

- Ceramic Window Temperature - Ceramic windows isolate, the vacuum between the waveguide and the cavity, yet transmit RF power. The temperature of the windows are monitored using infra-red detector signals for cavity 7 (R027CWWT) and cavity 8 (R028CWWT) and correspond to field emission intercepted by the window. The acceptable limit is 3.5 V for R027CWWT and 2.94 V for R028CWWT [3, 4].

- Cryogenics - The superconducting cavities operate in a bath of 2K liquid helium (LHe) which is maintained by a cryogenic control circuit. The circuit was monitored to detect increased heat load at higher gradient. These included the helium liquid levels signal (CLL0L0050), the Joule-Thompson valve regulating LHe flow to the cryounit (CEV0L00JT.ORBV) and the helium cryostat pressure signal monitoring formation of GHe (CIP0L0060). The helium liquid level is kept at 90.2% [3] and the helium pressure at 0.039 atm [3].

The test of maximum gradient was performed on May 5, 2008 and documented in ELOG # 1428074. The sustainable gradients from prior cryounit measurements were 0L02-7GSET=8.1 MV/m and 0L02-8GSET=5.9 MV/m. Beginning with these values we increased the gradient setpoint for one cavity at a time by 0.1-0.2 MV/m and monitored the measured gradient and performance parameters signals.

2.1 Testing 0L02-7

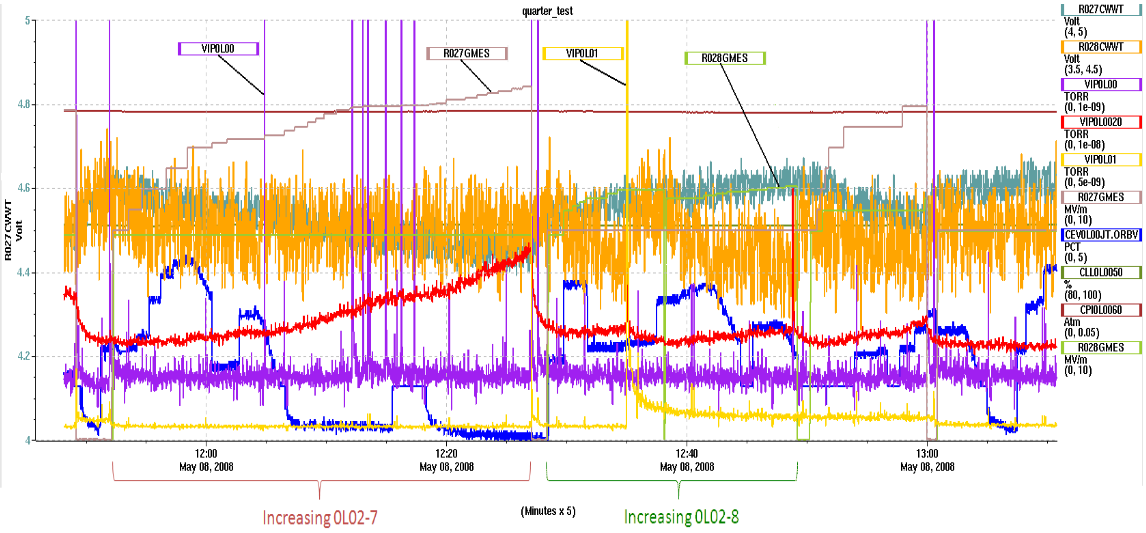

Figure 2: *Cryounit conditions while first increasing 0L02-7 gradient (left) and then 0L02-8 gradient (right).*

We began at 5 MV/m. As the gradient increased, the heat load increased and the Joule-Thomson valve opened to maintain LHe pressure and liquid level (see Fig. 2.1). The RF window temperature fluctuated between 4.70 V and 4.46 V, but remained above the limit (signal decreases when heat increases). The vacuum in the waveguide increased (to 5×10^{-9} Torr) but did not exceed the waveguide limit. At 7.9 MV/m the RF tripped off because of a beam line vacuum fault indicating that the vacuum threshold signal(VIP0L00) had been reached (see Fig. 3). The vacuum recovered after 4 minutes, we reset the RF and were able to reach and sustain 8.4 MV/m. The waveguide vacuum continued to increase, however we did not have sufficient time to determine the equilibrium waveguide vacuum.

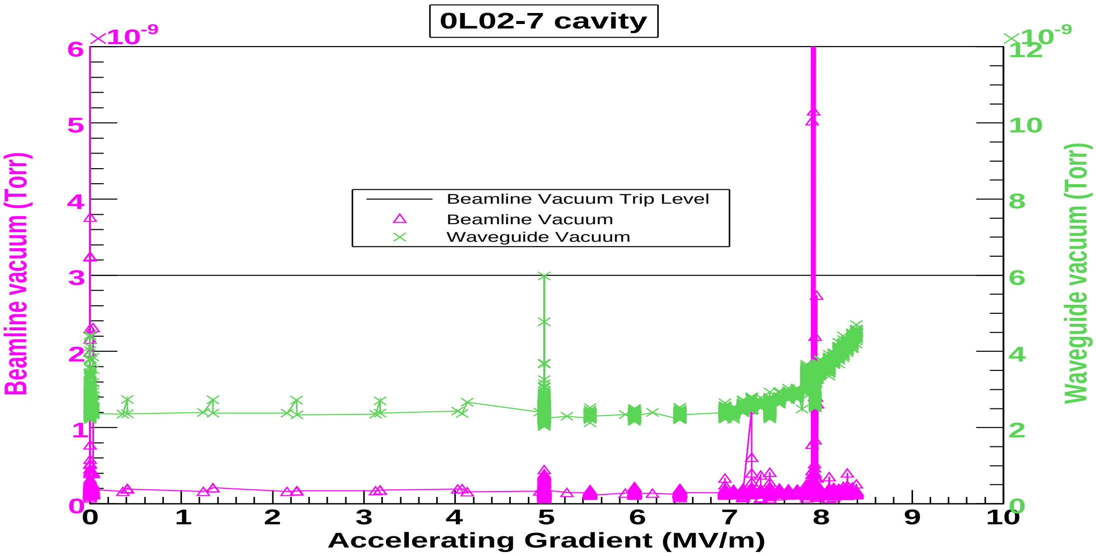

Figure 3: *Beam line and waveguide vacuum vs. cavity gradient.*

2.2 Testing 0L02-8

We began at 5 MV/m. As we increased cavity gradient the cryogenic signals remained steady; helium liquid pressure at 0.039 atm and level 90.2% (see Fig. 2.1). The temperature signal of the RF windows oscillated between 3.8-4,2 V and the waveguide vacuum remained below threshold (4×10^{-9} Torr). The first fault was the beam line vacuum signal at a gradient of 6.1 MV/m (see Fig. 4). Attempts to further gradient increase failed, due to beam line vacuum signal limit.

3 Status Of The 2D Beam Line Spectrometer

The electron beam exiting the cryounit may be deflected by a dipole magnet to the "2D" spectrometer beam line (Fig. 1). The relation between momentum, magnetic field and deflected angle is given by:

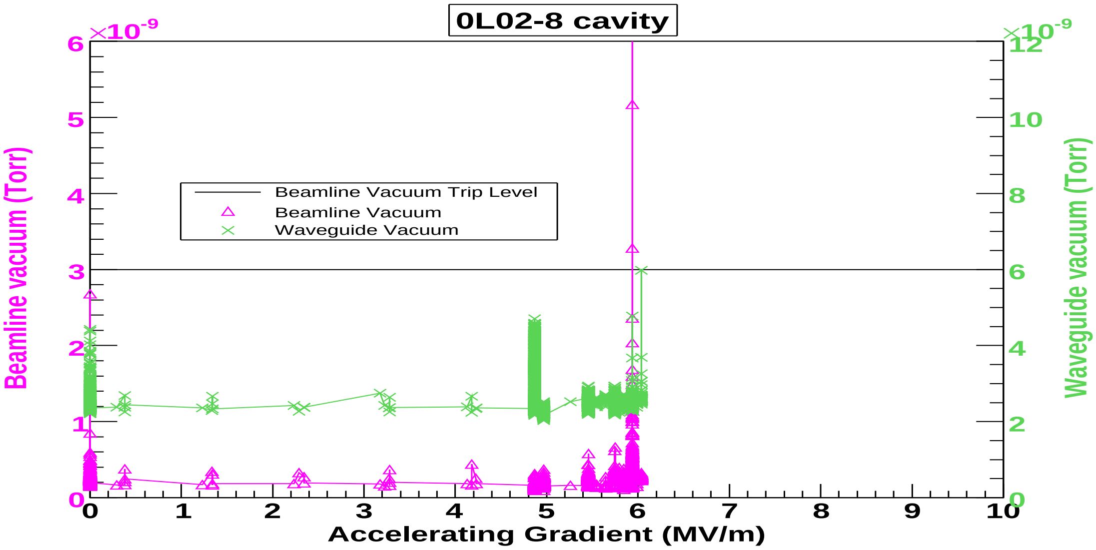

Figure 4: *Beam line and waveguide vacuum vs. cavity gradient.*

$$\frac{pc}{e} = \frac{\int Bdl}{\theta}, \tag{1}$$

where e is the electronic charge (1.602×10^{-19} C), c is the speed of light (2.99×10^{8}m/s), θ is the deflection angle in radians and $\int Bdl$ is the integrated magnetic field along the deflected orbit. This section addresses (a) whether the dipole magnet (MBL0L02) is capable to deflect the beam to the spectrometer at the maximum gradients of the cryounit and (b) whether the beam diagnostics (beam line BPM's and harp) are operational and may be used to determine the deflection of the beam.

3.1 Dipole Magnet

We assume the kinetic energy of the electron beam exiting the cryounit is 5 MeV. The undeflected dipole setpoint is -0.070 A (-290 G.cm). The dipole setpoint used to deflect the electron beam to 2D line is -2.307 A (-9794 G.cm). Assuming the energy is 5 MeV and the setpoints are correct, the required dipole current ($\int B.dl$) may be calculated for different cryounit gradients:

$$\int Bdl[G.cm] = p\cdot\left(\frac{\int Bdl}{p}\right)_{T=5MeV} = p[MeV/c]\cdot\left(\frac{-9504[G.cm]}{5.49[MeV/c]}\right). \tag{2}$$

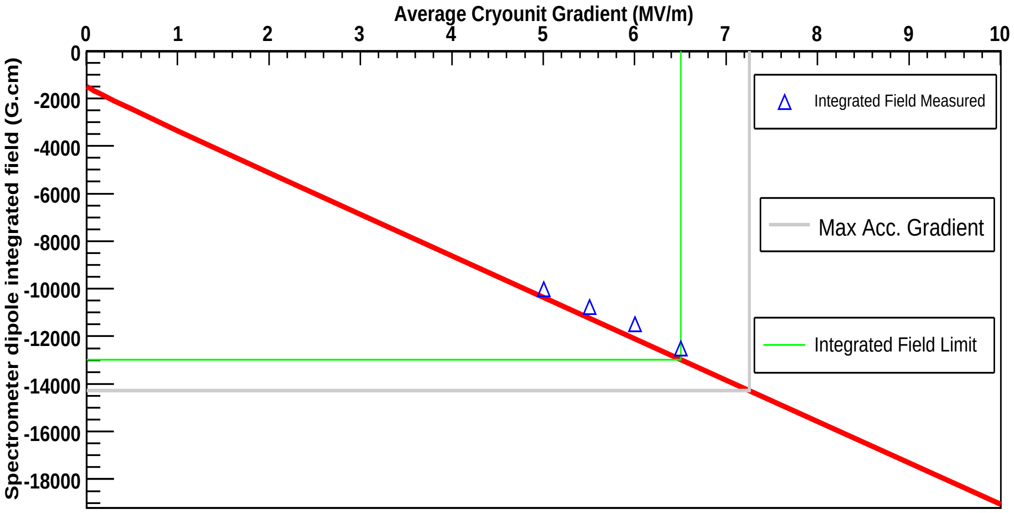

Figure 5: *intBdl as a function of the average cryounit gradient.*

The integrated field was also recorded at a few gradients (assuming that the gradient was calibrated). The dipole limit of -3 A was reached at average cryounit gradient of 6.5 MV/m. We expect to operate at a higher gradient and estimate at least -3.35 A.

3.2 Beam Diagnostics

To determine the bend angle θ, we must know the initial reference orbit and the deflected orbit. The reference orbit is defined using BPM's (IPM0L02 and IPM0L03) on either side of the dipole, whose absolute position is calibrated against surveyed adjacent quadrupoles (MQJ0L02 and MQJ0L03A)that are surveyed into position. A harp (IHA2D00, see Fig. 6) is used to measure the bend angle. The harp was tested in December, 2008 and did not work.

4 Conclusions

The maximum stable cryounit cavity gradients achieved were, respectively, 8.4 MV/m and 6.1 MV/m (7.25 MV/m average) under optimum conditions. The vacuum in the

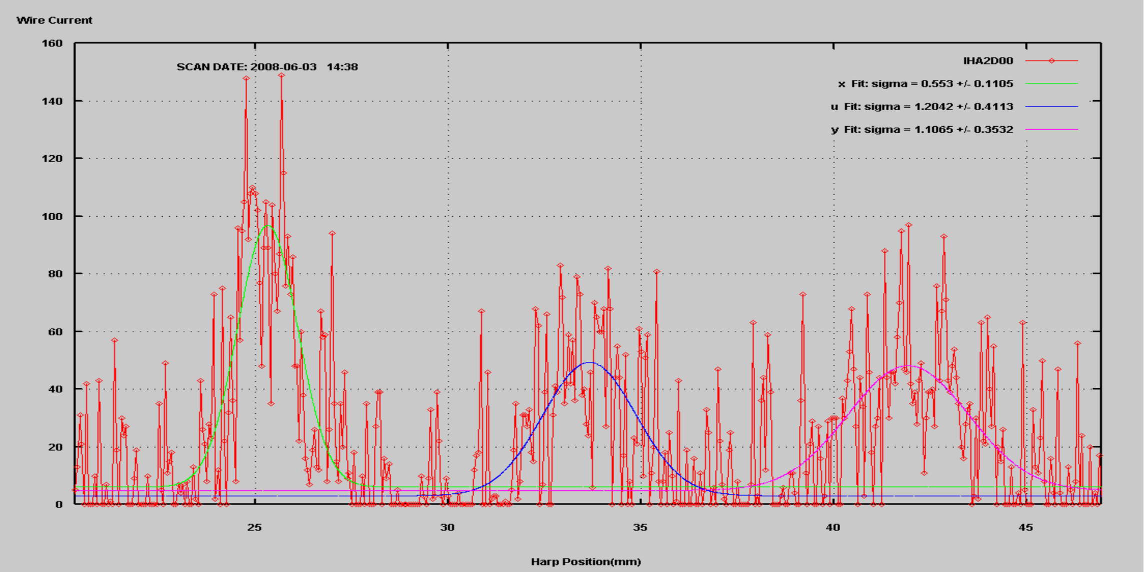

Figure 6: *Harp scan on June 3, 2008. The position of the beam is monitored with 3 wires. The left fit represents the signal for the horizontal "x" wire, the signal on the right for the vertical "y" wire and in the middle, the signal for the* 45° *"u" wire.*

beam line indicates that field emission and desorbed gas are the most problematic, but improve with processing.

The spectrometer dipole current is limited to a corresponding gradient of 6.5 MV/m. A new current limit for the dipole is necessary to reach the maximum beam energy of the cryounit. Further work to make a precision spectrometer requires a survey of the "5 MeV" dipole, the IHA2D00 harp and to measure the magnetic field of the dipole with increased limits (±3.5 A).

References

[1] Micheal Drury, private communication.

[2] Ron Lauze (lauze@jlab.org), private communication.

[3] Clyde Mounts (mounts@jlab.org), private communication.

[4] Larry King (king@jlab.org), private communication.