

# CONTROLS AND DIAGNOSTICS FOR THE HIGH CURRENT ELECTRON BEAM ION SOURCE AT BNL \*

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## Abstract

The BNL EBIS Test Stand (EBTS), is a full electron beam power, half ion trap length prototype for an Electron Beam Ion Source (EBIS) that meet requirements for the Relativistic Heavy Ion Collider (RHIC) preinjector. [1]. The EBTS uses a 10 A, ~50 ms pulsed electron beam to produce intense pulses of highly charged ions, of ~55 nC total positive charge yield and as short as 10  $\mu$ s duration. An auxiliary ion source is used to inject primary low charged Au ions into the EBTS in ~500  $\mu$ s pulses. The EBIS controller handles all the digital timing and many analog control signals used for power supply and device control necessary, for stable, low loss EBIS operation. Diagnostics used to monitor the electron and ion beams include Faraday cups, current transformers, a Mamyrin TOF for providing high resolution ion spectra for highly charged heavy ions (e.g., Au<sup>34+</sup>) at 20 kV extraction energy, harp-type beam profile monitors and a compact emittance head. The design and operation of these devices will be discussed.

## 1 INTRODUCTION

The BNL EBTS has operated with a multi-ampere electron beam. 6-8A electron beams of duration 20- 50 ms are common. Beams from 10-13A have been propagated in pulses ~1 ms or less. Instantaneous power as high as 120 kW has been dissipated on a nominally 50 kW average power collector. Propagation losses are very low, typically < 1mA. Control of the electron beam current requires strict control of electrode voltages both in timing and amplitude. Likewise, control of the ion injection from an external auxiliary source, the confinement, extraction and sampling of the output pulse require precise control and timing to the microsecond level. The EBIS Voltage and Timing Controller and associated user interface coordinates all activities related to EBIS operation.

## 2 EBIS VOLTAGE AND TIMING CONTROLLER

An EBIS Voltage and Timing Controller has been developed to apply the time dependent potential distribution to the ion trap. The controller also coordinates the application of all time dependent voltages and timing references associated with the ion source, with a time resolution of 1  $\mu$ s. The controller is operated

through a graphical interface built using LabWindows programming software by National Instruments. At present the controller hardware allows a distribution with ~1000 time steps; however, to simplify the user interface, the software limits the distribution to 10 EBIS subcycles or “plateaus” and 10 ramps between the plateaus. At present 10 analog “function” channels are available at 12 bit DAC outputs between 0 and 10V. 24 digital outputs are also available to provide gating or timing triggers as needed by the experiment. All digital and analog

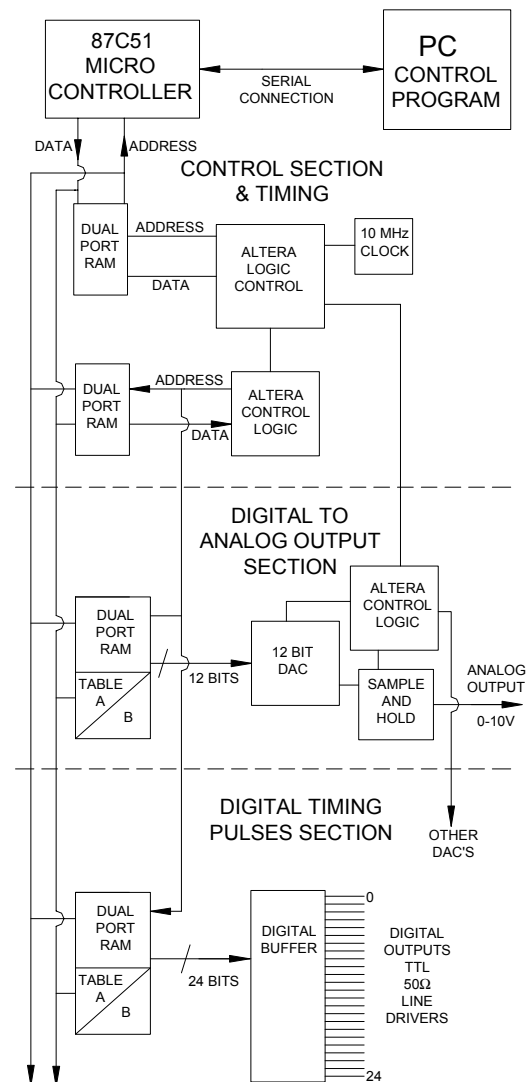


Figure 1: Simplified schematic of Voltage Controller and Timer

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channels are independently programmable with the limitation that changes can occur only synchronously with a 1 MHz clock. The user can specify three independent tables of functions (cycles) which can be executed with repeat factors up to sixteen times each, before the entire sequence (super-cycle) will repeat.

The analog functions are used to control drift tube power supplies, ramping and pulsing of the electron gun voltages, and ramping of the electron gun solenoidal field. Functions can be transferred to high voltage platforms using fast analog light links developed in our laboratory. An important design consideration of the Voltage Controller is that it should be very dependable in the relatively hostile laboratory environment.

A simplified schematic of the controller is given in figure 2. The device is table driven from data that is pre-loaded into dual port RAM located in the address space of a single micro-controller. The memory is divided into two spaces A and B, which allows a new table to be generated while an old one is executed. Swapping between tables is achieved in a single microsecond at a predetermined point in the cycle. This insures that the EBIS never dwells in an unknown state during table loading, which could be detrimental to the vacuum conditions, especially for a high current electron beam. Data in the control section specifies data starting addresses, dwell and ramp times, and cycle repetition rates. Data in the analog output stage and digital timing sections specify DAC output levels and TTL pulse characteristics, respectively.

All calculations are made in the PC which displays the user interface. The micro-controller is responsible only for transferring data from the PC to the dual port RAM, and issuing the command to initiate the switching of execution between tables A and B.

The user interface program is extremely versatile, allowing the operator the possibility to add and configure new hardware quickly. Some notable features of the interface are:

- It is fully configurable and persistent on restart. (All DAC ranges, device (channel names, subcycle names, etc. can be specified and changed).
- It is a multithreaded application in order to be able to stop an action such as data transfer to the microcontroller.
- The program makes all data available to other programs (DDE clients) as a network DDE server. This is useful, for example, in the case of the EBIS to calculate and display the potential on the axis of the electron beam as various control parameters are changed.

### 3 ION BEAM DIAGNOSTICS

In many locations in the beamline we use traditional faraday cups, or segmented faraday cups to determine beam current and position. However, the Faraday cups must be inserted into the beam, and therefore prevent further analysis of the same beam pulse downstream. In

the case of ion injection into the EBTS a non-destructive measurement method is favorable to be able to monitor the injection and extraction process simultaneously. Recently, we have installed both a current transformer (toroid) [2] and a harp on our beamline near the EBIS exit.

#### 3.1 Toroid Beam Current Monitor

A high permeability 6.5" core with 40 turns comprises the secondary of a toroid that has been installed at the EBIS exit. The ion beam acts a single turn primary to the toroid and coupling is allowed by the insertion of a 4" diameter ceramic break into the 4" stainless steel beamline. The toroid secondary output is terminated in 50 ohms to produce a high bandwidth low noise signal. A voltage amplifier transmits the signal to where the level is recorded as one volt per mA of ion beam current. BNL EBTS signals with fast extraction are ~1 mA and 10-50 $\mu$ s FWHM and are transmitted without much a.c. distortion.

#### 3.2 Harp beam profile monitors

Harp-type beam profile monitors are useful for determining the ion beam location and shape especially in the case in which non-destructive measurement is necessary. This allows us to examine both the low charge state ion beam from the auxiliary ion injector and the extracted EBIS beam without interrupting the injection process. Observation of the transverse beam profiles is useful for example, to help optimize ion injection or for choosing appropriate focusing conditions during emittance measurements. Two compact harps were developed at BNL in collaboration with the CRYSIS EBIS group at Manne Siegbahn Laboratory (MSL) in Stockholm. Both harps consist of two closely spaced planes of vertical and horizontal 0.001" gold plated tungsten wire. Harp I has a 16mm aperture, 0.5mm wire spacing, and 90% transparency; and Harp II has a 28mm aperture, 1 mm wire spacing, and 97.5% transparency. Both harps were designed to be retractable into the arms of 4" diameter beamline crosses. The electronics were developed at MSL, and consist of a 32-channel preamplifier mounted directly to the high vacuum feedthrough, in order to minimize the capacitance in the detection circuit, which could limit the response. The preamps are followed by independent track and hold circuits to insure sampling within a microsecond of the specified trigger. Figure 2 shows transverse beam profiles for an ion beam extracted from the TestEBIS, [3] a test stand at BNL. In the oscillograms, the central peak is the sum of the currents collected on the harp electrodes and is proportional to the total instantaneous beam current. The signals recorded on either side of the sum peak are the horizontal and vertical beam profiles. In this example, the extracted EBIS ion beam diameter was about 2mm.

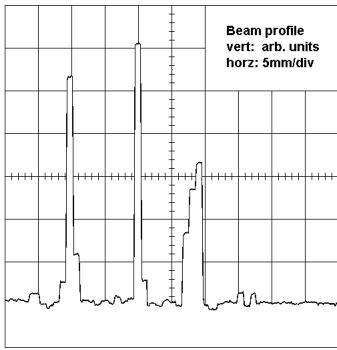


Figure 2: Transverse beam profiles of and extracted ion beam pulse from the TestEBIS

Recently, at the high current BNL EBTS, we have installed a third harp version developed by Nuklear Technik and distributed by Princeton Scientific Corporation. Harp III uses 0.004" W-Re wire at a spacing of 1mm in the 22 mm central area, transparency ~81%. This harp has a 80mm aperture, is quite rugged, and it well suited for the higher current, higher energy heavy ion beams (~10mA, 50kV, 10μs pulses) to be produced by the EBTS.

### 3.3 High Resolution Time-of-Flight (TOF)

The EBTS TOF mass-spectrometer is based on Mamyrin's [4] concept of using an electrostatic mirror to reflect a beam back to a detector. Higher energy ions travel further into the mirror before reflecting, providing an energy focusing effect. This is especially important for a high current EBIS in which the extracted ions can have ~1kV energy spread due to the deep potential well and the fast extraction process. The existing TOF has been modified to accommodate a higher energy ion beam, improve transmission of ion beam to the detector and possibly extend its function to the energy analysis. These modifications are:

- A new fast chopper assembly with improved electrical insulation was installed. This provides

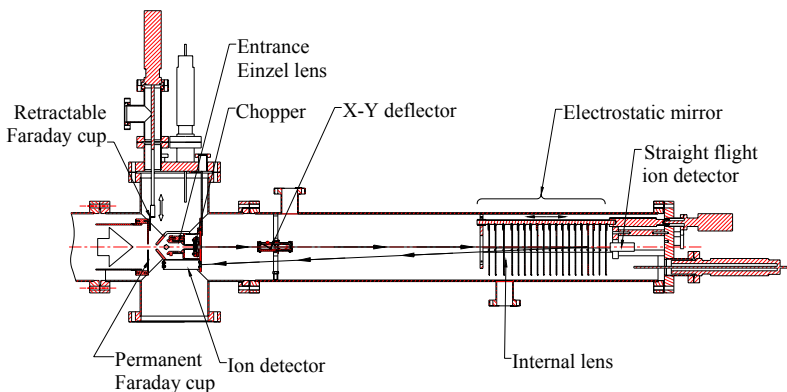


Figure 3: Schematic of the Mamyrin TOF spectrometer

the capability to analyze ion beams with energy 35 keV without loss in resolution.

- A new X-Y deflector for the incoming beam was installed in a drift space.
- One of the electrodes of the electrostatic mirror has been equipped with an independent voltage control to serve as an electrostatic lens for both incoming and reflected ion beams.
- An additional channeltron has been installed behind the mirror, providing the capability to detect and energy analyze the direct beam.
- An additional Einsel lens has been installed at the entrance of the TOF.

### 3.4 Compact Emittance Head

Figure 4 shows the compact emittance measuring device built in our laboratory. It is a slit and collector unit, with 30 etched tungsten mesh collector foils and 31 kapton foils, (each foil 0.002" thick). The signal from each strip is sampled at any selected time during the beam pulse before digitization. The emittance head can fit into a four inch cross and scans across the beam in one direction. The slit to detector distance was recently decreased from 76.2 mm to 38 mm in order to provide a larger angular acceptance necessary to accommodate the relatively high current (1-10mA), low energy (<20qkV) ion beams produced at EBTS.

## 4 REFERENCES

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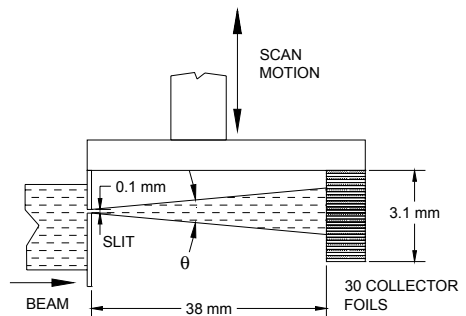


Figure 4: Schematic of the emittance head