BNL-98661-2012-CP

Gatling gun test stand instrumentation

**D.M. Gassner, I. Ben-Zvi, J. Brutus, C. Liu, M. Minty,
A. Pikin, O. Rahman, E. Riehn, J. Skaritka, E. Wang**

Presented at the International Beam Instrumentation Conference 2012 (IBIC 2012)
Tsukuba, Japan
October 1-4, 2012

Collider-Accelerator Department

Brookhaven National Laboratory

**U.S. Department of Energy
DOE Office of Science**

Notice: This manuscript has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The publisher by accepting the manuscript for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

This preprint is intended for publication in a journal or proceedings. Since changes may be made before publication, it may not be cited or reproduced without the author’s permission.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

GATLING GUN TEST STAND INSTRUMENTATON*

D. Gassner #, I. Ben-Zvi, J. Brutus, C. Liu, M. Minty, A. Pikin, O. Rahman,
E. Riehn, J. Skaritka, E. Wang
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

To reach the design eRHIC luminosity, 50mA of polarized electron current is needed. This is more than what the present state-of-the-art polarized electron cathode can deliver. A high average polarized current injector based on the Gatling gun [1] principle is being designed. This technique will employ multiple cathodes and combine their multiple bunched beams along the same axis. A proof-of-principle test bench will be constructed that includes the 220 keV Gatling gun, beam combiner, diagnostics station, and collector. The challenges for the instrumentation systems and the beam diagnostics that will measure current, profile, position, and halo will be described.

INTRODUCTION

A future electron-ion collider called eRHIC [2] is being designed at Brookhaven National Laboratory. It will utilize a polarized electron source based on an electron gun with multiple photocathodes arranged in circular configuration similar to a traditional Gatling gun. It is driven by IR lasers with circular polarization [3]. The electron bunches from individual cathodes will be funneled to a common beam-line axis by a fast combiner with a rotating magnetic field [4]. A test setup is being designed for testing the primary components of this high average polarized current pre-injector. The electron beam parameters [5] are listed in Table 1. The performance of the innovative electron gun and combiner designs will be determined by the resulting electron beam characteristics that will be measured by the diagnostic systems. Due to the challenges presented by commissioning a variety of innovative subsystems at the same facility, a phased approach will be employed. The phase one proof of principle plans include using 2 of the 20 gallium arsenide photocathodes to generate the first beams at low rep-rates (~1Hz). The diagnostics plan for this project is presently in the preliminary design stage. The present schedule for this Laboratory Directed Research and Development (LDRD) project is to demonstrate the Gatling gun for use as a practical source for an Energy Recovery Linac by 2015. Existing state-of-the-art guns can produce average current of several hundred uA. Groups at JLAB and Mainz have achieved average current of several mA but with rather poor lifetime [6]. By extrapolating past experience with future expectations we hope to achieve 149-hour cathode lifetime [7].

Table 1: Gatling gun Electron Beam Parameters

Electron Parameters	
Electron Beam Energy	220 keV
Charge per Bunch	0.1 – 3.5 nC
Electron Beam Current	2 mA/cathode
RMS Norm Emittance	17 mm-mrad
Bunch Repetition Rates	1 Hz – 14 MHz
Energy Spread (full)	22 keV
Energy Spread (97%)	8 keV
FWHM Bunch Length	1.5 ns
Trans beam size at YAG	15 mm round

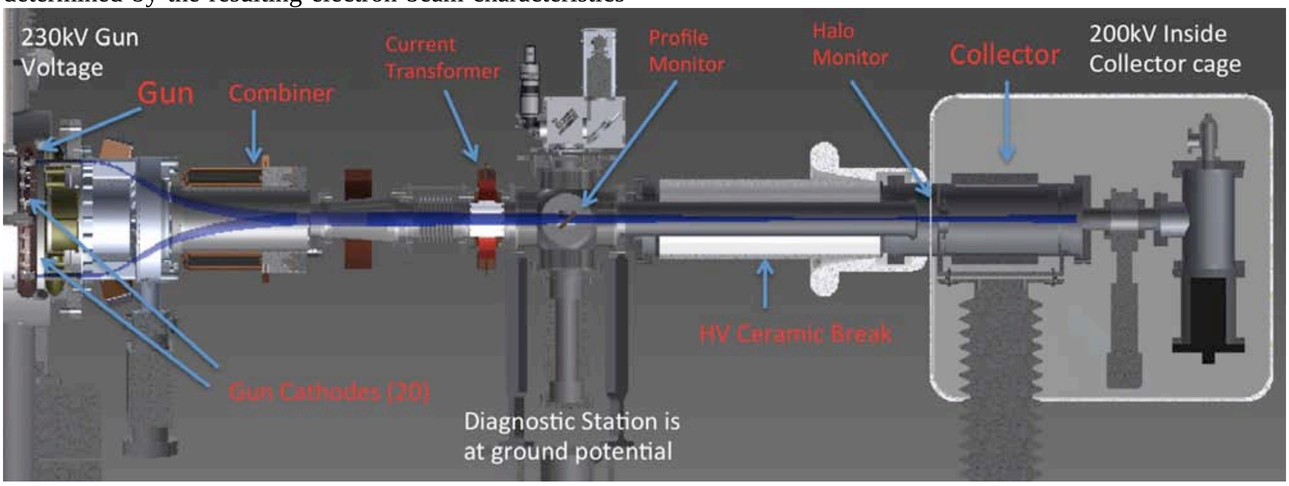

Figure 1: Gatling Gun test stand cut-away side view. Some of the transport magnets and BPM are not shown.

*Work supported by the auspices of the US Department of Energy
#gassner@bnl.gov

HIGH VOLTAGE AND ULTRA-HIGH VACUUM CHALLENGES

The gun platform will be operating at 230kV and the collector platform at 200kV. Using a depressed collector [8] will allow us to decelerate the electron beam to nearly the cathode potential and dump it at low energy at the collector. This will reduce the gas load in the vacuum chamber and reduce the power load on the gun HV power supply. The intermediate beam line will be at ground potential. Fiber optics will be used to allow diagnostics data to be transferred from the HV platforms to the receiving electronics at ground potential. The diagnostics hardware design will include protection against inadvertent discharge arcs.

Due to the sensitivity of the 20 gun cathodes to contamination, the gun chamber will be baked to 950C and its target pressure is ~10E-12 Torr. The remaining portions of the beam transport have slightly less demanding vacuum requirements. The design of the downstream components at the test bench is influenced by the goal of preserving the cathodes. All diagnostics will be designed for a 400C bake. We are working with several vendors, Atlas Technologies [9] and GNB Corporation [10], on preliminary designs to fabricate beam line components from titanium. Titanium materials have been shown to provide excellent outgassing rates after the baking process. The titanium outgassing rates are two orders of magnitude smaller than for standard vacuum materials [11].

ELECTRON BEAM DIAGNOSTICS

The electron beam diagnostics that will provide the project phase one measurements to test the Gatling gun and combiner will include current transformers, profile, position, and halo monitors as shown in Figure 1. The initial goal is to provide a set of core diagnostics for the first beams. Subsequent test phases planned will include a pepper pot for emittance measurements and a polarimeter.

Electron Beam Profile Monitor

Transverse beam profiles will be measured using a 5cm diameter YAG:Ce screen (4.5cm active) from Crytur [12]. We are investigating several types of thin conducting screen coatings used to bleed off collected charge that will not flake off after the 400C bake. The beam power will be limited by the machine protection system when the screen is inserted during measurements to avoid excessive desorption and possible screen damage. The screen thickness will be a few hundred microns.

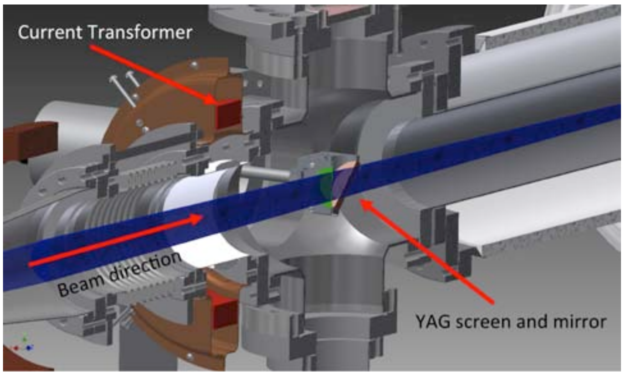

Figure 2: Profile monitor cutaway view. Electron beam path is shown in blue, the YAG screen is green.

Images from the YAG screen are transported through a mirror labyrinth to a 3-motor lens and GigE CCD camera in a local enclosed optics box. An XHV rated magnetically coupled actuator from Transfer Engineering Inc. [13] (model PMM-Lite) can be used to insert the YAG screen into the beam path.

Many other profile-monitoring techniques such as wire scanners, multi-wires, OTR, ODR, diamond screens, laser profile monitor, and pin-hole detector were considered and discounted due to complexity, reliability, high bake temperature compatibility issues, and costs.

Pepper Pot – Emittance Measurement

Pepper pot simulations were done [14] using the calculated [5] electron beam parameters (17 mm-mrad normalized emittance) to determine the dimensions needed to make a quality measurement. The results show that the best resolution is achieved by analyzing 5 beamlets produced by a 1mm thick tungsten pepper pot mask that has 1mm slits spaced 1.5mm apart. The beamlets should be imaged on a downstream profile monitor with a drift space of 0.1-0.3m.

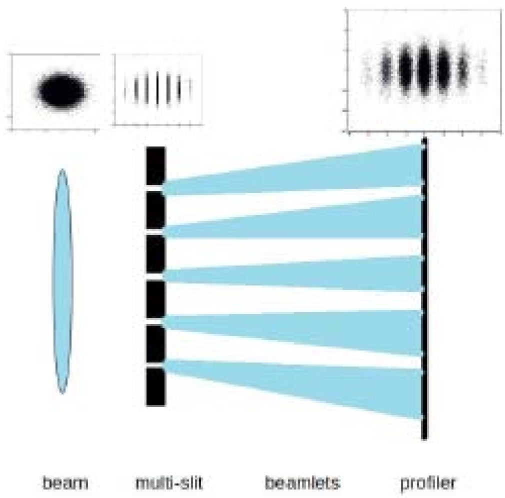

Figure 3: Pepper pot simulation data, not to scale.

A multi-position linear actuator can be used to insert a mask with two separate sets of slits, horizontal and vertical, to allow separate measurements because the respective emittances may be different.

Electron Bunch Charge

Bunch-by-bunch and bunch train charge will be measured by a Bergoz [15] Integrating Current Transformer (ICT). Beam charge signals will be processed by standard BCM-IHR (Integrate-Hold-Reset) electronics feeding a beam synched triggered digitizer. A 178mm ID ICT will be installed upstream of the centrally located profile monitor around a 3.67" ID ceramic break. The image current shroud will be designed to be removable without breaking vacuum, and a cooling coil will be installed to avoid overheating during the 400C bake.

Provisions will be included in the mechanical design of the ceramic break and image current shroud to allow an FCT sensor (300ps rise time, 1GHz bandwidth) to be installed adjacent to the ICT so long bunch train measurements can be acquired. A synchronized fast digitizer will be used to measure the individual bunch charges. This information can be used to track the evolution of each photocathode quantum efficiency independently.

Current transformers mounted around the high voltage cables are planned to be located at three locations as shown in Figure 4; at the grounded side of the gun high voltage power supply, near the gun cathodes, and near the collector. These will be used to measure the beam related current signals in the wires. We are working on overcoming the practical challenges of making these measurements that include the mechanical installations around the HV wires and resolving the low level signal in a high-noise environment.

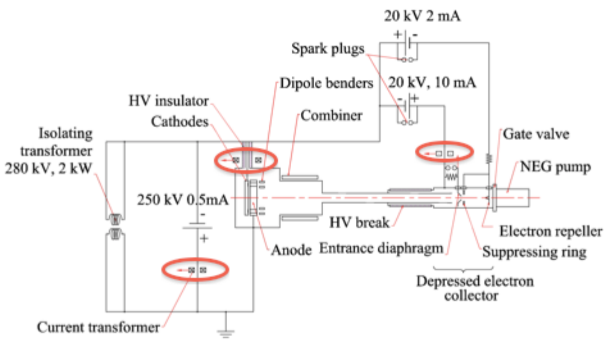

Figure 4: Gatling gun test stand schematic [12]. Current transformers are indicated by red ovals.

Beam Position Monitor

A beam position monitor using four 9.3mm diameter button pick-ups will be installed to allow nondestructive measurements. Times Microwave Systems [16] has provided a quote for an upgraded version of a previously provided similar button that can be baked to 600C. The buttons are delivered welded into a mini-Conflat flange. They will be installed on mating flanges that are welded to a section of the beam pipe.

Halo detector

Isolated molybdenum jaws with a 30mm ID beam passage aperture, separated in a quad configuration mounted just upstream of the collector will be used as a halo detector. These jaws will be biased up to the 200kV collector potential. Special care will be taken to reduce arc discharge damage from the nearby grounded beam line shield. Gated integrator electronics located on the HV platform will be used to readout the signal from each of the isolated jaws.

ACKNOWLEDGMENTS

The authors would like to thank the members of the eRHIC Research & Development Group for valuable contributions and discussions.

REFERENCES

[1] V. N. Litvinenko, "Gatling gun: High average Polarized Current Injector for eRHIC". C-A/AP/#417, Jan. 2011

[2] V. Ptitsyn, et al, "High Luminosity Electron-Hadron Collider eRHIC," PAC 2011, TUOAN2

[3] X. Chang, et al, "A Multiple Cathode Gun Design for the eRHIC Polarized Source", PAC 2011, p.1969.

[4] I. Ben-Zvi, et al, "Generating High-Frequency, Rotating Magnetic Fields with Low Harmonic Content", Phys. Rev. ST Accel. Beams 14, 092001 (2011)

[5] E. Wang, et al, "Beam Dynamics of Funnelling Multiple Bunches of High Charge Polarized Electrons", submitted to Physical Review Special Topics.

[6] E. Tsentsalovich, "Status of High Intensity Polarized Gun Progress at MIT Bates", PSTP2011, page 29.

[7] K. Aulenbacher, "High Average Photocurrent Research at MAMI", 2011 Journal of Physics, Conference Series Volume 298 Number 1.

[8] A. Pikin, et al, "Depressed Electron Collector for the Gatling Gun Test Stand" submitted to Physical Review Special Topics.

[9] www.atlasuhv.com

[10] www.gnbvalves.com

[11] K. Ishizawa, et al, "Titanium Materials for UHV/XHV Systems", XXIInd Int. Symp on Discharges and Electrical Insulation in Vacuum-Matsue- 2006, p. 805.

[12] www.crytur.com

[13] www.transferengineering.com

[14] C. Liu, et al, "Multi-slit Emittance Measurement Study for BNL ERL", August 13, 2012, BNL C-AD Tech Note.

[15] www.bergoz.com

[16] www.timesmicrowave.com