EVENT DRIVEN AUTOMATIC STATE MODIFICATION OF BNL'S BOOSTER FOR NASA SPACE RADIATION LABORATORY SOLAR PARTICLE SIMULATOR*

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Abstract

The NASA Space Radiation Laboratory (NSRL) was constructed in collaboration with NASA for the purpose of performing radiation effect studies for the NASA space program. The NSRL makes use of heavy ions in the range of 0.05 to 3 GeV/n slow extracted from BNL's AGS Booster. NASA is interested in reproducing the energy spectrum from a solar flare in the space environment for a single ion species. To do this we have built and tested a set of software tools which allow the state of the Booster and the NSRL beam line to be changed automatically. In this report we will describe the system and present results of beam tests.

INTRODUCTION

The NSRL provides a high quality source of high energy, high charge state (HZE) particles within the high linear energy transfer (LET) ranges of most interest to scientists who want to study the kinds of radiation a spacecraft would be exposed to outside the earths protective envelope. Since the radiation environment beyond the earth/moon system is so varied and dynamic the NASA investigators need to reproduce in the laboratory many different conditions. To this end the NSRL was designed to accept a large range of ions over a large range of beam energies [2]. For more details on the NSRL facility see [1, 2, 3, 4, 5].

NSRL scientists are interested in being able to rapidly expose samples to a range of energies. This would allow scientists to reproduce the conditions of specific solar flare events. The energy range of the NSRL is sufficiently high for nuclear interactions to contribute significantly to backgrounds and to degrade the beam purity. For this reason the NSRL operates with a minimum of material in the beam. The energy changes for the solar particle simulator must be performed without using an energy absorber, which will create fragments and other types of ionizing radiation. The only way to change the energy rapidly is to change the accelerator and beam-line state automatically and without feedback.

In table 1 is listed the ion species, maximum beam intensities, beam sizes, and maximum dose rates that have been delivered to the NSRL experiments. The minimum intensities operated are on the order of $10^2/\mathrm{cm}^2/\mathrm{cycle}$. The solar particle simulator is an added capability to the NSRL and any of these states will be available to users of this system.

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Table 1: Typical NSRL Beam Parameters

Ion	Intensity (ions/cycle)	Beam Size (cm^2)	Dose Rate (Gy/min)
Fe (1 GeV/n)	1×10^9	20x20 7x7	7 50
Ti (1 GeV/n)	0.8×10^9	20x20 10x10	3 15
Si (0.6 GeV/n)	3×10^9	20x20 5x5	5 25
C (0.3 GeV/n)	12×10^9	20x20 10x10	4 15
p (1 GeV/n)	34×10^9	20x20 7x7	0.2 1.5
O (1 GeV/n)	4×10^9	20x20	2.5

SOLAR PARTICLE SIMULATOR

To produce the desired energy spectrum requires a user specified dose versus energy request. The NSRL operates with a high precision, calibrated dosimetry system that controls the amount of exposed dose for a given energy and particle species. The dosimetry system provides an asynchronous event to the accelerator that turns off the slow extracted beam very fast, cutting off the exposure. The speed of this cut-off is sufficiently fast to contribute less than 0.1% uncertainty to the exposure, for low dose exposures, and an even smaller uncertainty for high dose exposures. For the solar particle simulator this asynchronous event can also be used to signal a change in state of the accelerator and NSRL beam line.

The main challenge for this system is the requirement that the beam size and intensity not vary too greatly over the exposure. Our design takes advantage of the sequencing infrastructure built into the controls system for the purpose of RHIC operations [6]. We then use the Booster main magnet program as a scaling reference and scale elements from some well established known state (or set of states). Scalings will make use of magnet excitation maps and experimental verifications of accelerator parameters, as well as established models of the accelerator parameters [7].

The specifications for the solar particle simulator are the

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same as for normal NSRL operation, with the added requirement that the dose be delivered over a range of energies and in as short a period as in one hour. Although this isn't very specific, it provides a clear framework within which the design of the system must adhere. Shorter timescales would have required actual hardware modifications to certain accelerator sub-systems. Longer timescales would have made many of the software requirements unnecessary. Fortunately much of the infrastructure required already exists.

SUBSYSTEM CONSIDERATIONS

Software

The most important modifications required to meet the solar particle simulator specifications are in the software systems used for Booster and NSRL operations.

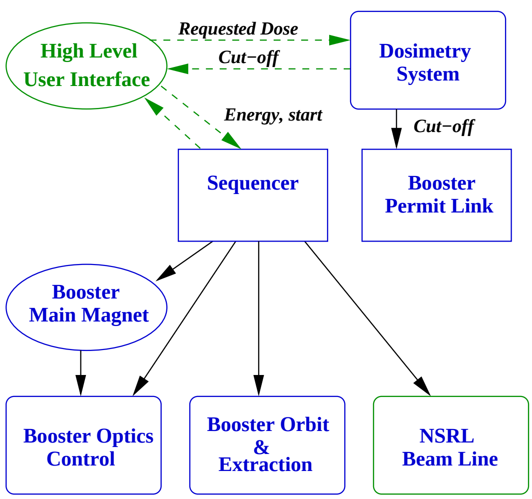

Figure 1: Solar particle simulator software system diagram.

Figure 1 shows a simplified diagram of the software systems and the lines of communication between the different sub-systems. The Sequencer is basically a listing of commands to perform in order to achieve the desired energy change. Most of the sub-systems already exist as part of the Booster controls system. Some modifications were required. Both the Booster Main Magnet and the Booster Optics Control needed modifications to allow the sequencer to change those states and then calculate and load the new functions. The sequencer infrastructure required some modifications to allow applying a scaling factor and to control specific function generators. The Optics Control sub-system required some modifications to allow specifying higher precision reference functions and matrix transformations and to improve in diagnostics. Currently the Dosimetry system sends a cut-off signal to the Booster permit link to turn off the beam at the end of an exposure. This system is completely independent from the sequencer system at this time. The figure shows a High Level User Interface, which currently does not exist. This is envisioned to be a thin client that will act as an arbitrator between the user, the dosimetry system, and the sequencer. A user will specify a table of energy versus dose and through communications with the dosimetry system the sequencer will step through that table. The NSRL Beam Line is in a different colored box, since currently the beam line elements are operated directly by the control system. A higher level application to manage the beam line elements using optics parameters and known excitation data for each magnet is planned to be built, which will enable the beam line to be more easily managed and operated.

Instrumentation

The most significant instrumentation consideration is the energy response of the dosimetry system. The calibration of the system changes as a function of beam energy and so software needs to include this energy dependence in the calculation of the dose. The existing dosimetry system already has this capability.

A second consideration is a method of monitoring the beam quality during an exposure. Again, existing instrumentation in the NSRL target area will provide transverse and longitudinal beam quality measurements during an exposure. For transverse uniformity a scintillating screen and camera system will capture and store the uniformity for each energy in an exposure. An ion chamber or scintillator are available for longitudinal monitoring. Both these monitors are located downstream of the samples, and thus will not contaminate the beam quality. The calibration of the transverse monitor is independent of the beam energy. There is no requirement that the longitudinal monitor be calibrated, since the dosimetry system is independent and provides the dose measurement.

Beam Optics

Part of the NSRL beam studies program has been detailed studies of the beam optics in the beam-line. The focus of the beam optics studies were on understanding emittance and initial twiss parameters. In addition significant effort has gone into studies of generating uniform beams. More details can be found on the beam line, beam measurements, and non-linear optics in [2, 4].

In our models we have assumed that the beam parameters of the extracted beam at the beginning of the NSRL beam transport line are identical to the beam parameters of the circulating beam at the same location apart from the effect of the D3 thin septum magnet which provides a kick to the circulating beam to send it into the aperture of the D6 septum magnet. Table 2 shows the assumed horizontal and vertical beam parameters at the beginning of the NSRL beam transport line in the top row and the parameters from measurements in the bottom row. The measured data was taken using 1 GeV/n Ti and the 0.05 mm Cu stripping foil. η and η' are 0 in both planes.

In order to ensure that the slow extracted beam acquires a more normal distribution we scatter the beam through a

Table 2: NSRL Beam Parameters

	α_x	β_x (m)	α_y	β_y (m)
Model	1.87	10.0	0.63	4.39
Measured	1.1	10.0	0.45	7.0

thin foil or wire at the entrance of NSRL (which also acts to strip off any electrons, since ions are typically not fully stripped in the Booster). The electron stripping reduces the rigidity of the transported beam. In the models we use a 10 π[mm mrad] 95% normalized beam emittance for both the horizontal and vertical planes. Measured emittances are consistent with this. The magnitude of the measured beam emittances and the beam parameters, for the various extracted beams depends on the thickness of the foils used at the entrance of NSRL.

For the scaling of the beam-line, the effect of the foil needs to be considered, since at lower energies the energy loss through the foil becomes significant. This is easily calculated and will be incorporated into the final scaling of the beam-line, along with any charge state change at the foil. The emittance growth due to the multiple Coulomb scattering will affect the optics and final beam quality, but tests have shown that this effect does not significantly degrade the quality of the beam on target.

Spill Control

As is always the case with slow extraction systems the time dependent spill structure is a major concern. Figure 2 shows a 1 GeV/n Titanium beam spill.

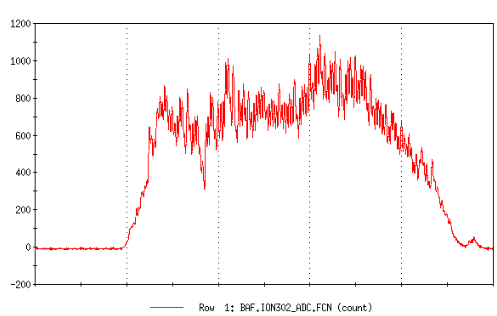

Figure 2: Normal slow extracted beam spill using rf phase displacement to smooth spill harmonics.

The most successful method of reducing the power supply harmonics from the spill has been the use of rf phase displacement. In this method the main RF is brought back on after the beam has been debunched, at a non-beam-synchronous frequency that corresponds to the revolution frequency for a particle in resonance. This causes the particles to be accelerated through the resonance between empty RF buckets. This method is a completely open loop operation. It scales automatically, since the RF system uses the Booster Gauss clock as the frequency reference for the radial control of the beam, and does not use any beam position monitors for feedback. Initial tests have shown the spill structure will remain at a good quality for the different energy beams of the solar particle simulator.

SUMMARY

The ability to quickly and reliably change the energy of the NSRL beam will provide a significant enhancement to the capabilities of the facility and the science that can be accomplished. The solar particle simulator is really just a set of tools that allow for this to be done. Although the system is not yet complete we have performed initial tests that suggest the design is sound and the system will work well.

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