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Brookhaven 200 MeV Linear Accelerator beam instrumentation upgrade

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Abstract

The Brookhaven National Laboratory 200 MeV H- Linac beam instrumentation has been in operation for four decades with various changes implemented over this period. There is a need to upgrade the beam instrumentation systems of the Linac to improve the diagnostics of the beam from the Low Energy Beam Transport Line through the Linac and into the Linac Booster Transfer Line and BLIP Line. Profile Monitors, Current Monitors, Beam Position Monitors, Long Radiation Monitors, and Emittance Measurement devices are to be designed and implemented over the next three years. This upgrade will improve the operation reliability, beam quality; and reduce beam losses. Additional improvements will be obtained by designing the beam instrumentation systems to integrate with other proposed diagnostics and malfunction detection and display upgrades in the Linac Control Room to improve the overall performance of the Linac.

INTRODUCTION

The Brookhaven National Laboratory 200 MeV Linear Accelerator [1] has met and exceeded performance demands and goals through changes and modifications to its design over a period of four decades. The Linac had milestone performances in 1975 achieving an average current of 60 microamps; in 1984 with the implementation of the H- Source; in 1990 with the implementation of the RFQ Pre-Injector; in 1996 achieving an average current of 90 microamps with the implementation of RF upgrades and changes in the Low Energy Beam Transport (LEBT) and Medium Energy Transport (MEBT) Lines; in 2000 with the addition of the Optically Pumped Polarized Ion Source (OPPIS) polarized proton source; in 2010 achieving an average current of 110 microamps with design changes to LEBT/MEBT; in 2013 achieving an average current of 137 microamps based on the implementation of the new Cu Bunchers, Einzel Lens and Solenoid combination implemented in recent years. An upgrade is necessary as beam instrumentation systems have aged and are not functioning at their full design capabilities.

The Linac accelerates two types of ions for users on a pulse-to-pulse basis. An H- ion beam and a Polarized H- ion beam. The instrumentation for the acceleration of the two types of ions differs primarily due to the magnitude of the currents. Polarized H- currents range in magnitude from a few hundred microamperes to 1.5 milliamperes; whereas, the H- Source provides beam currents in the range of several tens of milliamperes. In addition, the energy of the ions can be configured for each user on a pulse-to-pulse basis. This type of accelerator performance can only be accomplished at the BNL 200 MeV Linac. The beam instrumentation and diagnostics must be able to accommodate these performance requirements.

The beam instrumentation upgrade proposal will modernize hardware and software for Current Transformers (CT), Secondary Emission Monitors (SEM), the Slit Aperture Insertion Device (SAID), the Energy Measurement Absorber Insertion Device (EMAID), Harp Multi-wire Profile Monitors (Harp), Long Radiation Monitors (LRM), and Beam Position Monitors (BPM); and a Laser Profile Monitor (LPM) will be added to the BLIP beam line instrumentation. This upgrade will improve diagnosing the characteristics of the beam, its position in the accelerator, losses in the beam line, and improvements in tuning the beam.

The integration of systems will be a secondary aim of the upgrade. Methods to utilize the information obtained by subsystems are proposed to optimize beam performance, minimize down time, and improve the diagnosing of conditions observed by personnel and detected by system monitors.

The recent prototype software Linac Early Symptoms Detection (LESD) and the proposed Linac Central Malfunction User Interface System (CMUI) will be integral components in the focus of the integration of systems.

SYSTEMS UPGRADE

Hardware in good condition will remain in operation and have their electronics upgraded and signal cables replaced; other systems will have both the electronics and hardware upgraded.

All systems will have a data acquisition form that promotes systems integration. The user interface for the beam instrumentation and diagnostics will be determined by the functionality of the systems. All devices described below will have a data acquisition system upgrade in which analog to digital conversions will be completed in local stations to minimize the travel of the signal to improve reliability and signal integrity. The digital information will be transmitted via an existing network to servers for storage and for access by operators. The use and capabilities of front-end computers and the capacity of the data storage servers will be assessed to accommodate the increased demand.

Table 1. Listing of Device Quantities

Devices	Present	Upgraded
CT	25	27
SEM	14	14
SAID	1	1
EMAID	1	1
Harp	4	6
LRM	33	33
BPM	20	21
LPM	1	2

Secondary Emission Monitor

A single-wire Secondary Emission Monitor (SEM) System is utilized to obtain a vertical and horizontal profile of the beam density. They are installed at 45 degree angles in the beam line and are motor driven in steps, into and out of the beam line. There is a SEM located at the downstream side of RF Cavity 2, and in between each RF cavity through RF Cavity 9; each labeled SEM-2 to SEM-9 in a manner shown in Fig. 1.

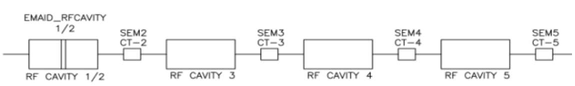

Figure 1: EMAID-RF CAVITY 1/2, SEM, CT.

The current state of their motors and wires limit their functionality. They are presently not utilized due to the status of their reliability. The motors and the 50.8 μm thick tungsten wires will be replaced as necessary. The required stepping motor increment is 0.25 mm for each SEM. The SEMs H1 through H6 are distributed in the HEBT Line. They have a stepping motor resolution of 0.50 mm. There are no SEMs in the BLIP Line. The required rate of the motion of the SEMs will range from 100 milliseconds to 5 seconds.

The signal cabling for the HEBT SEMs will be replaced with shorter length cables to improve the analog signal reliability and performance prior to the conversion to a digital signal. This will require that the analog to digital conversion occur as close to the HEBT Line as possible outside of the tunnel.

Six SEMs in the HEBT Line are required for a beam emittance measurement. SEM-H6 is also used for momentum and momentum spread measurements of the H- beam.

Slit Aperture and Absorber Insertion Devices

There is a Slit Aperture Insertion Device (SAID) and an Energy Measurement Absorber Insertion Device (EMAID) utilized at the Linac. The SAID, SAID-BM4, is located upstream of Bending Magnet BM4 in the HEBT Line. The EMAID-RFCAVITY1/2 is located in between RF Cavity 1 and RF Cavity 2. EMAID-RFCAVITY1/2 has a highly precise thickness for use in optimizing the energy of the RF Cavity 1. It is used in conjunction with the Current Toroid CT-2, as shown in Fig. 1, to optimize the RF cavity amplitude to 10.4 MeV. The H- beam must have an energy of 10.4 MeV to transit the EMAID-RFCAVITY1/2 and be measured by CT-2. The controls for EMAID-RFCAVITY1/2 will provide a status indication to the CMUI System.

SAID-BM4 is used to reduce the beam size of the H-beam for energy and energy spread measurements in the HEBT Line as shown in Fig. 2. This SAID is precisely positioned to have the H- beam travel on the center of the beam line through Bending Magnet BM4 and the center of the beam line of SEM-H6 located downstream of BM4. The BM4 magnetic field has a precision of +/- 0.025%.

The motors for SAID-BM4 and EMAID-RFCAVITY1/2 will be replaced to improve the reliability of the operation of the devices.

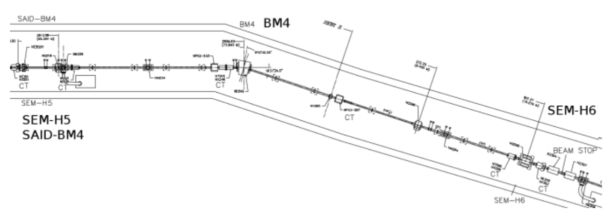

Figure 2: HEBT SEM-H5, SAID-BM4, and SEM-H6.

Harp Multi-Wire Profile Monitor

There is currently a Harp multi-wire profile monitor permanently stationed in the path of the beam in the BLIP Line and HEBT Line. The resolution of these Harps is 3.175 mm with 32 wires in the horizontal plane and 32 wires in the vertical plane. Note the fixed Harp in the BLIP Line will be replaced at the same location with a Laser Profile Monitor as indicated in Fig. 3.

There are two new plunging Harp multi-wire profile monitors proposed for the BLIP Line. One Harp monitor will be at the 7.5 degree bend of the BLIP Line and the other will be at the 22.5 degree bend of the BLIP Line. The spacing of the wires for each of the Harps will be 3.175 mm.

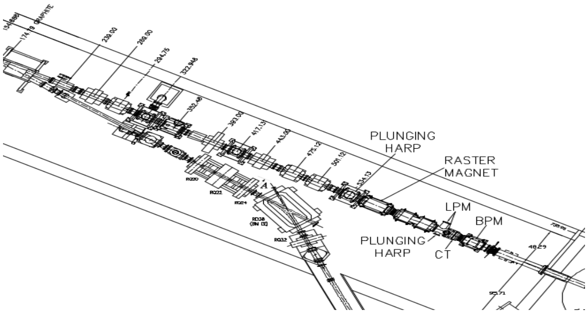

Figure 3: BLIP LPM, Harps, CT, BPM.

The Polarimeter Harp in the HEBT Line will be assessed for replacement. The motor and electronics of this Harp will be upgraded.

Laser Profile Monitor

The BLIP Line will have the Laser Profile Monitor (LPM) installed as part of the Raster Project. This project will provide a more uniform current density on the target. The project is currently under review. This LPM will replace the existing fixed Harp in front of the BLIP Target as shown in Fig. 3. There is an existing LPM downstream of RF Cavity 9 which does not need to be upgraded. It is also used for energy and energy spread measurements.

The LPM utilizes a las signal to neutralize a cross section of the H- beam [2]. Stripped electrons will be measured as a function of the laser position. The data acquisition of the LPM will depend on a Faraday Cup (FC) which is located at 90 degrees from the H- beam.

Current Transformers

The CTs located in the vacuum of the beam line throughout the Linac have deteriorated in performance or are not functioning due to damage and aging of the devices. New CTs are required for all locations. Vacuum CTs are utilized due to limited space. The current transformers should be able to detect a minimum current of 100 μA and a maximum current of 100 mA. There are various beam pipe sizes that needs to be accommodated.

There will be a new replacement CT in a vacuum upstream of RF Cavity 2 and upstream of each RF Cavity thereafter through RF Cavity 9; 8 new vacuum CTs in the HEBT Line; and 4 new vacuum CTs in the BLIP Line. There will be two additional vacuum CTs implemented in the BLIP Line for the Raster Project.

The Low Energy Beam Transport (LEBT) Line and Medium Energy Beam Transport (MEBT) Line have CTs that are fully functional. These CTs are at atmospheric pressure.

The installation of the CTs and SEMs should be completed simultaneously as the RF Cavities will need to go from a vacuum state to an atmospheric pressure state.

Beam Position Monitors

There is a BPM upstream of RF Cavity 2 and upstream of each RF cavity thereafter through RF Cavity 9; there are 9 BPMs in the HEBT Line; and there are 3 BPMs in the BLIP Line currently. These BPMs utilize a copper pick-up loop for which a ferrite wraps around the loop to improve the linearity of the detection with respect to position. The position resolution requirement for the BPMs is 1 mm. The typical peak current for BLIP is 40 mA independent of the energy of the H- beam. A maximum current of 100 mA and a minimum current of 100 μA are to have their positions detected in the beam lines.

There will be a new BPM installed in the BLIP Line as part of the Raster Project to verify the operation of the Raster magnet. The existing BPMs are not currently utilized as they do not have data acquisition electronics and RF electronics to obtain the RF phase of the beam.

Fast Pickup Beam Monitor

The Fast-Pick Beam Monitor (FBM) is a beam monitoring design that acquires signals in the 200 MHz range. The status, benefits, and viability of the Fast Pickup device will be evaluated as part of the upgrade; and ideas on how to achieve the goal of reading signals in the 200 MHz range for the H- beam will be explored.

Radiation Monitors

There are Long Radiation Monitors comprised of Argon gas filled 3.175 mm diameter tubes 3 meters in length lining the tunnels of the beam line. The pressure of the tubes is lower than their design pressure of 10 psi due to a deterioration of the material of the tube. New tubes will replace the existing tubes. The addition of a new radiation detection system utilizing a Neutron Detector is currently being explored. The goal of this method is to detect radiation levels produced by beam energies at or below 100 MeV throughout the Linac.

All radiation monitoring schemes will have new cables installed, electronics upgraded, and a new data acquisition scheme implemented to integrate the data with existing systems as described in the Systems Integration section.

Temperature measurements are made at locations in the HEBT beam Line and BLIP beam Line that are proportional to the magnitude of the H- beam currents colliding with the beam line. This system consists of thermocouples attached to the exterior of the beam line. New thermocouples will be installed based on the condition of the existing thermocouples.

SYSTEMS INTEGRATION

Currently some of the beam instrumentation systems described and other existing related systems operate in a stand-alone fashion. The implementation of new data acquisition hardware will allow for access to available database servers and software for data analysis from networked resources. This will improve the diagnostic capabilities of operators. The centralized and universal access of data will be one of the focuses of this upgrade. A related focus will be to utilize the LESD system to automate aspects of tuning for the H- Source and Linac; and to integrate all instrumentation statuses into the CMUI system.

Data Acquisition

The sampling rate of the data acquisition required for the beam instrumentation and beam diagnostics will need to be 6.67 Hz typically; and have the capability of being increased up to 10 Hz. There is a micro-sampling rate to reconstruct the characteristics of the beam current which can have a pulse width of a few microseconds or 500 milliseconds; the minimum sampling rate is to be 1 MHz. An assessment of the analog-to-digital conversion requirements, the capabilities of front-end computers and storage servers available in the existing Controls System will need to be completed for this upgrade.

Software

The current software utilized for several of the beam instrumentation systems operate off-line and are not capable of being placed on the network due to an incompatibility of their operating systems and the network requirements. The upgrade of the software for the SEM operations, and other beam instrumentation software as well as the addition of new software will improve the beam instrumentation and diagnostics for the Linac. Resources for software and operating system maintenance will be managed through the Controls System. The software requiring unique operations will be designed in-house with the existing software platform tools available such as Java, C/C++, etc.

A current software development is the Linac Early Symptoms Detection (LESD) system. This is a prototype software design that accesses the database of information collected from data acquisition systems and compiles the data in a manner that assists the operators in understanding the behavior of the machine. This software, currently under development, monitors the available data of the Quadrupole Magnets, RF Cavities, and additional systems to check for 'symptoms' of potential failure or trends that could lead to failure. The software is proposed to include the beam instrumentation data and diagnostics data to automate the tuning of the machine and adjustments to the parameters of the H- Source.

SCHEDULE PROJECTIONS

The completion of the performance specifications of this upgrade is expected by the end of the calendar year 2013. An assessment of the required software operations and the data acquisition sampling rate, the storage of data, and the movement of this data for use by operators will be completed in February 2014. The goal is to complete this upgrade by November 2016.

ACKNOWLEDGMENT

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