FNAL HINS BEAM MEASUREMENTS AND THE FUTURE OF HIGH INTENSITY LINAC INSTRUMENTATION*

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Abstract

The intensity frontier, having been identified as one leg of the future of particle physics, can be meet by the development of a multi-GeV high-intensity linac. In order to address the low-energy needs of such an accelerator, Fermilab started the High Intensity Neutrino Source (HINS) project. HINS is a research project to address accelerator physics and technology questions for a new concept, low-energy, high-intensity, long pulse H- superconducting linac. The development of such an accelerator puts strict requirements on beam diagnostics. This paper will present beam measurement results of the HINS ion source and 2.5 MeV RFQ as well as discuss the role of HINS as a test facility for the development of future beam diagnostic instrumentation required for the intensity frontier.

INTRODUCTION

The High Energy physics community has identified three areas of research for the future of particle physics. These areas are the energy frontier, the cosmic frontier and the intensity frontier [1]. The intensity frontier can be addressed by the development of a multi-GeV high-intensity linac. In order to address the low-energy needs of such a linac, Fermilab has started the High Intensity Neutrino Source (HINS) project [2].

Initial designs for HINS described a linac up to 60 MeV consisting of an H- source, a 2.5 MeV RFQ, a medium energy beam transport (MEBT), a room temperature acceleration section and a series of superconducting single spoke resonator cyromodules. At this time, only a 50 keV proton source, a low energy beam transport (LEBT) and the 325 MHz RFQ have been installed at HINS and tested with beam.

Initially, the HINS project identified four basic goals needed to be studied for a multi-GeV superconducting linac [2]:

1. Demonstrate beam acceleration using superconducting spoke type cavity structures.
2. Demonstrate the use of high power RF vector modulators to control multiple RF cavities by a single high power klystron for acceleration of a non-relativistic beam.
3. Demonstrate beam halo and emittance growth control by the use of solenoidal focusing.
4. Demonstrate a fast 325 MHz bunch-by-bunch beam chopper.

In addition to these goals, it is planned to also operate HINS as a low-energy, high-intensity H- beam test facility.

INITIAL HINS BEAM MEASUREMENTS

Initial beam measurements with the HINS 2.5 MeV RFQ were made this past year. The proton ion source was operated at 50 keV with 500 μs pulses at a rate of 1 Hz. The RFQ was operated without cooling. Because of this RF power was limited to 50 μs pulses at a rate of 0.5 Hz. Detailed information on the operational experience with the RFQ can be found in [3].

Beam diagnostics after the RFQ consists of a toroid, three transverse wire scanners, two BPMs and a water cooled beam dump. Figure 1 shows a block diagram of the HINS beamline during these measurements.

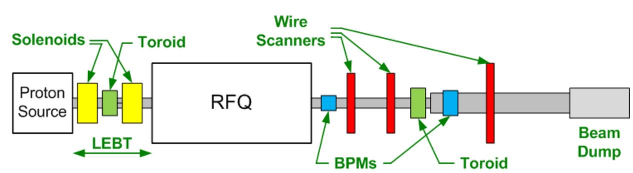

Figure 1: Block diagram of the beamline configuration used for the initial RFQ beam measurements.

Beam Current Measurements

During operation of the RFQ, beam current measurements were made with a LEBT toroid and a toroid in the RFQ output beamline. Figure 2 shows the beam toroid measurements for a single pulse. Beam currents out of the proton source through the LEBT were measured to be ~18 mA while beam current measurements out of the RFQ were ~4 mA.

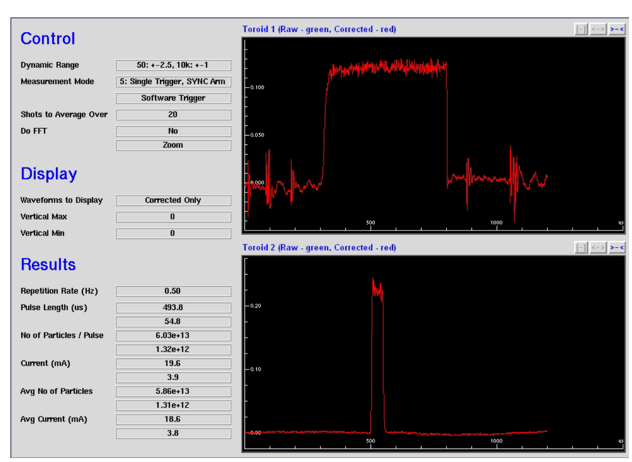

Figure 2: HINS LEBT (top) and RFQ output (bottom) beam currents. The RFQ RF power was limited to 50 μs to minimize heating issues.

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The low output current from the RFQ may be attributed to (1) the ion source consisting of mostly non-proton species (H_2+, H_3+), which do not propagate through the RFQ, and (2) RFQ output beam blow-up before reaching the downstream toroid. Species characterization of the ion source and moving the output toroid closer to the RFQ will improve future measurements.

Transverse Profile Measurements

Transverse beam profiles were made with three wire scanners downstream of the RFQ. Figure 3 show a typical set of horizontal profiles. As figure 1 shows, there are no focusing elements after the output of the RFQ to minimize transverse beam blow-up. Profile measurements indicate that there is indeed beam loss between the first and second wire scanner. Our proposed upgrade to this diagnostic beamline will include quadrupole focusing to reduce beam blow-up and allow for quadrupole scan emittance measurements.

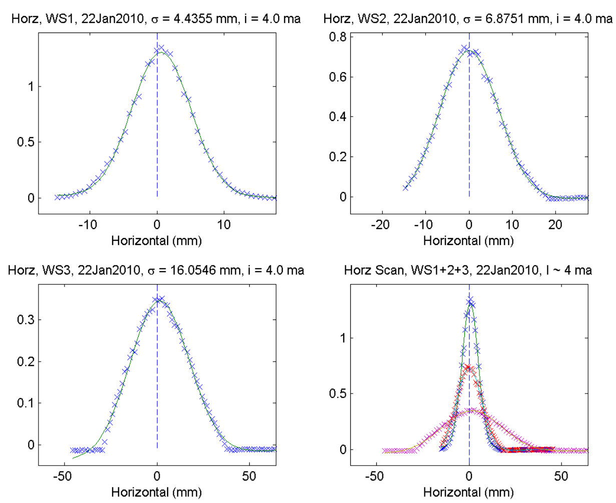

Figure 3: Transverse beam profile measurements from three wire scanners after RFQ. Solid lines are Gaussian fits to measured data points. Lower right plot is a overlay of all three scanner profiles.

Energy Measurements

Initially, it was intended to use the two BPMs, shown in figure 1, as a method to determine the RFQ beam energy by measuring the time-of-flight of a unique bunch. However, because the beam had no unique structure, it was impossible to distinguish a single bunch at both BPMs. It was determined that causing the RQF to spark would quickly extinguish the beam and produce a relatively sharp edge which could be identified at both BPMs. Figure 4 shows the beam structure from both BPMs during the sparking of the RFQ. The time-of-flight is approximately 45 ns which is consistent with the RFQ design beam energy of 2.5 MeV. Upgrades to the RFQ output diagnostics will include a spectrometer magnet to provide energy and energy spread measurements.

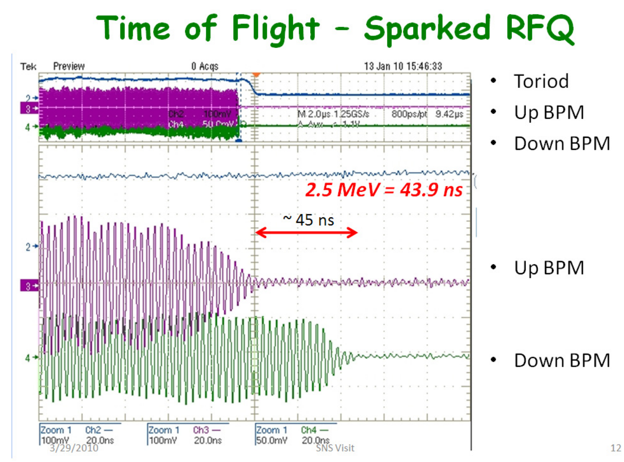

Figure 4: A measure of the RFQ beam energy derived from time-of-flight between two BPMs.

HINS AS A LOW-ENERGY, HIGH-INTENSITY TEST FACILITY

The development of high-intensity hadron linacs is placing strict requirements on possible beam diagnostics, especially for beam intercepting diagnostics. HINS is a uniquely accessible low-energy, high-intensity linac injector. The potential exists to operate HINS as a test facility during the Project X R&D phase [4]. This will allow for the development of Fermilab projects as well as a facility for external collaborators. Fermilab intends to use HINS to (1) investigate beam dynamics at low energy, (2) develop and test high bandwidth beam chopper concepts and (3) develop and test beam diagnostics for Project X.

BEAM DIAGNOSTICS R&D AT HINS

Initial measurements of the HINS RFQ show that changes to the diagnostic beamline are needed to improve our measurement capabilities. Figure 5 shows a new improved diagnostics beamline that also includes new diagnostic instruments under development.

Transverse Profile Diagnostics

Traditionally, transverse beam profiles have been measured with wire scanners or multiwire monitors. However, beam intercepting wire monitors pose a danger for superconducting cavities. Transverse profile measurements of H- beams have been made with lasers, utilizing photo-detachment, with minimal interaction with the beam [5]. Fermilab will use HINS as a test facility for development of a "standard" transverse laser profile monitor for Project X.

Laser-based transverse profile monitors can also be used to directly measure transverse emittance. Figure 6 shows a proposed laser slit emittance monitor under development at HINS. In this monitor, the laser acts like a slit and changes H- to neutral hydrogen. The collected electrons from neutralization give a measure of phase-space x while a measure of the neutral hydrogen angular distribution gives a measure of x'.

Longitudinal Profile Diagnostics

Fermilab is investigating longitudinal bunch measurements using beam intercepting and non-intercepting techniques. We will use HINS to develop the use of a high-bandwidth faraday cup and also a scanning wire bunch shape monitor [6]. While both of these techniques are beam intercepting, they have the advantage of having a history of development.

Similar to laser-based transverse profile measurements, longitudinal profile monitors based on lasers offer the possibility of non-intercepting monitors. The Spallation Neutron Source (SNS) has made longitudinal profile measurements in their MEBT using a femtosecond Ti:Sapphire laser [7]. Fermilab is collaborating with LBNL to develop and test a longitudinal profile monitor with short-pulse (~ ps) laser systems.

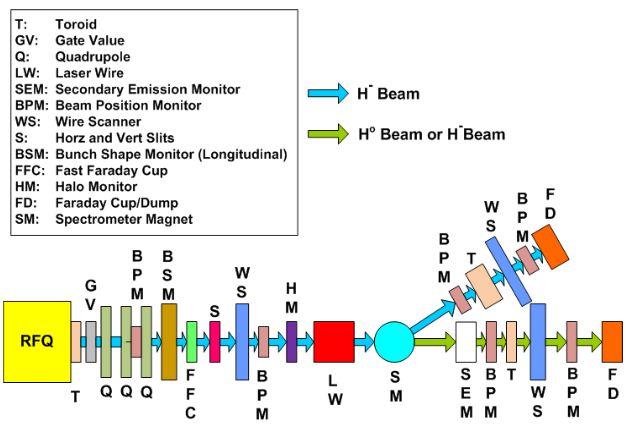

Figure 5: Proposed layout of HINS beam diagnostic R&D beamline.

Beam Halo Diagnostics

Measurement of transverse, as well as longitudinal, beam halo will be critical for future high-intensity linacs. HINS will install a vibrating wire system from Bergoz Instruments to study transverse halo measurements [8]. In addition, we will investigate longitudinal halo measurements utilizing the longitudinal bunch shape monitor and the longitudinal laser profile monitor.

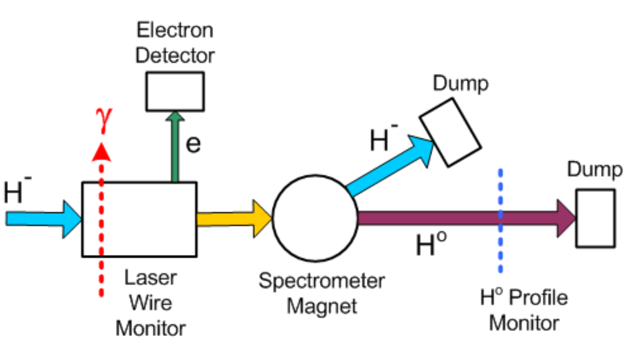

Figure 6: A block-diagram of a proposed laser transverse emittance monitor.

SUMMARY

Initial beam measurements have been made on the HINS 2.5 MeV RFQ. These basic measurements indicate that the RFQ is operating within the design specifications. HINS has also been presented as a possible low-energy, high-intensity accelerator test facility for R&D activities. A number of beam diagnostic R&D projects have been presented.

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