FIRST BEAM MEASUREMENTS OF THE FNAL HINS RFQ*

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Abstract

The High Intensity Neutrino Source (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. HINS will consist of a 50 kKeV ion source, a 2.5 MeV Radiofrequency Quadrupole (RFQ), and a 10 MeV room temperature spoke resonator acceleration section, followed by superconducting spoke resonator acceleration sections. To date a proton ion source and the RFQ module have operated with beam. This paper presents the results of first beam measurements through the HINS RFQ.

INTRODUCTION

The HINS accelerator project is a DOE approved and funded avenue to pursue advanced low-energy linac technologies. HINS has undergone various changes, as its development is vital for the testing and design of Project-X [1]. Details of the HINS program can be found in [2].

The HINS project has identified four basic goals [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.

Figure 1 shows an early block diagram of a 60 MeV version of the HINS accelerator. This version of HINS consists of an ion 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. For this paper, only a proton ion source and RFQ have operated with beam.

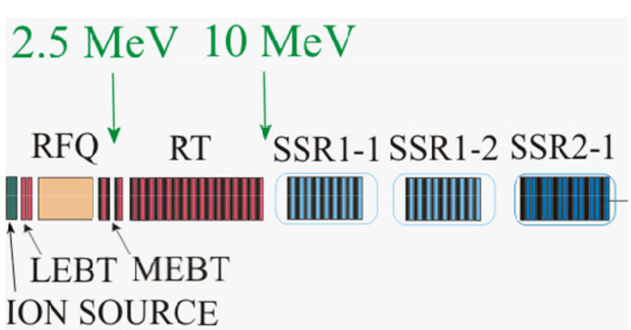

Figure 1: An early proposed HINS layout for a 60 MeV beam line and three superconducting cryomodules.

RFQ BEAMLINE

Figure 2 shows a block diagram of the present HINS beamline with its 2.5 MeV diagnostics section. This section consists of a pair of BPMs, a toroid, three transverse wire scanners and a water cooled beam dump. Figure 3 is a photograph of this 2.5 MeV diagnostic section used for the measurements in this paper.

Ion Source

The present HINS ion source is a 50 keV proton source and a low energy beam transport line (LEBT) with solenoid focusing. This proton source is capable of up to 30 mA beam in 3 ms pulses at a rate of 5 Hz [3].

RFQ

The HINS RFQ is designed to accept 50 keV beam and accelerator it to 2.5 MeV. The RFQ operates at 325 MHz and has been tested to a peak power of 450 kW, without beam, for up to 1 ms [2]. Details of the RFQ design can be found in [4].

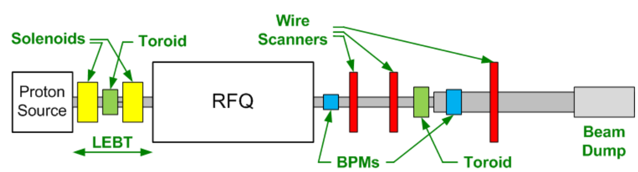

Figure 2: Original HINS proposal from 2006 showing a 90 MeV beam line and four cryomodules.

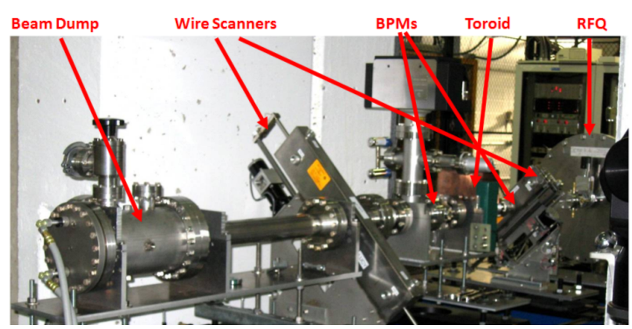

Figure 3: Original HINS proposal from 2006 showing a 90M eV beam line and four cryomodules.

RFQ BEAM MEASUREMENTS

RFQ Beam Current and Transmission Efficiency

RFQ beam current measurements were taken with a toroid in the 2.5 MeV diagnostic line. The maximum current measured was 4 mA for an input source current of 20 mA. However, these current values cannot give a measure of the RFQ transmission efficiency for two reasons. First, the present proton source consists of an unknown percentage of other charged species, i.e., H_2^+, etc. Second, beam emerging from the RFQ rapidly expands transversely, such that beam is lost before reaching the downstream toroid.

A number of beamline improvements are being implemented in order to improve the measurement of the RFQ transmission efficiency. First, the present ion source species will be characterized to determine the percentage of protons. Second, the downstream toroid will be moved to the output flange of the RFQ. This will allow measurement of the entire RFQ beam current.

Beam Transverse Size

Beam profile measurements are made with three wire scanners in diagnostics line. These wire scanners obtain horizontal, vertical and diagonal beam profiles over many ion source beam pulses. Figure 4 shows a typical set of horizontal wire scans at a beam current of 4 mA. The data points are fitted with Gaussian profiles. The bottom right plot in this figure shows data and fits for all three wire scanners.

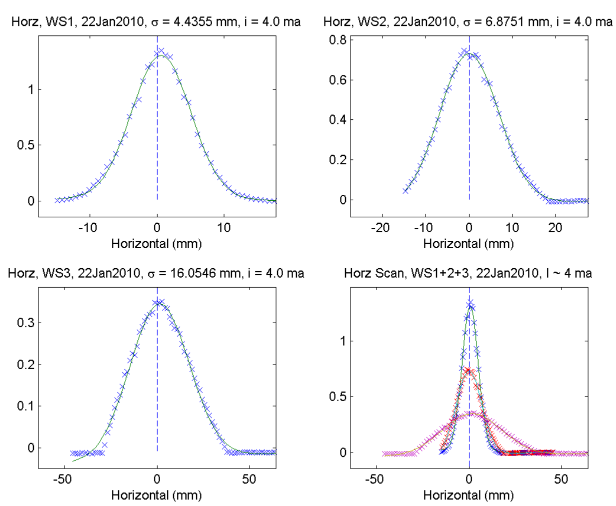

Figure 4: Typical horizontal profile measurements for all three wire scanners. Bottom right is an overlay of all three scanner measurements on one plot.

Initially, the three wire scanners were to give a measure of the RFQ beam transverse emittance. Figure 5 shows the horizontal, vertical and diagonal profile sizes as a function of beamline location. The figure also shows a linear best fit and extrapolated beam sizes at the exit of the RFQ. However, it appears that there is significant beam loss after the first wire scanner position. Table 1 gives the beam profile Gaussian-fitted sigma values and the integrals of these profiles. The integral values show that there is beam loss after the first wire scanner. This beam loss does not allow a measure of the RFQ beam emittance from the three wire scan measurements.

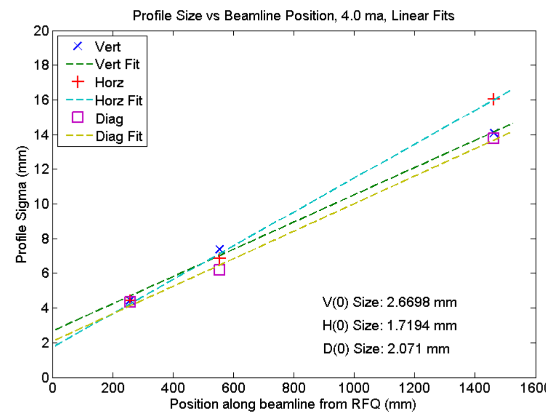

Figure 5: Beam profile sizes versus wire scanner position. The data are overlaid with linear best fit.

Table 1: Beam profile sizes and integrated areas for 4 mA beam current.

Sigmas	Horizontal	Vertical	Diagonal
Scanner 1	4.5 mm	4.2 mm	4.3 mm
Scanner 2	7.0 mm	6.8 mm	6.2 mm
Scanner 3	16.2 mm	13.2 mm	13.4 mm

Integrals	Horizontal	Vertical	Diagonal
Scanner 1	14.8 V*mm	14.9 V*mm	14.7 V*mm
Scanner 2	11.8 V*mm	10.5 V*mm	10.2 V*mm
Scanner 3	11.6 V*mm	10.1 V*mm	10.7 V*mm

Beam Energy

Initial RFQ beam energy measurements were intended to come from the time-of-flight between two BPMs in the diagnostics line. Calculations show that, for protons, a 43.9 ns time-of-flight would indicate a 2.5 MeV beam energy. However, because of the continuous nature of the beam through the RFQ, it is impossible to determine the same beam feature in both BPMs. In order to get a measure of the beam energy, we purposely sparked the RFQ to kill the beam quickly, thus generating a sharp beam edge that could be seen in both BPMs. Figure 6 shows these BPM signals and the time-of-flight difference. These data show that the RFQ beam energy is ~2.5 MeV.

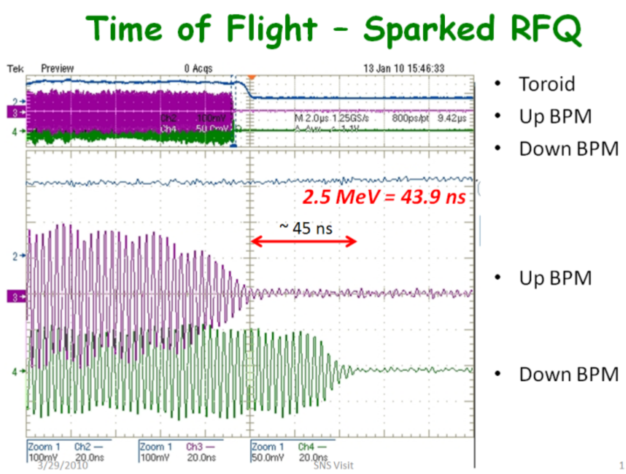

Figure 6: BPM signals showing time-of-flight time difference. Time-of-flight is consistent with 2.5 MeV beam energy.

RF Measurements

We tested the RFQ under different RF conditions in order to characterize it. Figure 7 shows the beam energy stability over a 50 µs RF pulse. The energy variation, measured by the phase difference between the two BPMs in the diagnostics beamline, is less than 8 keV, or ~0.3%, after the RFQ turn-on.

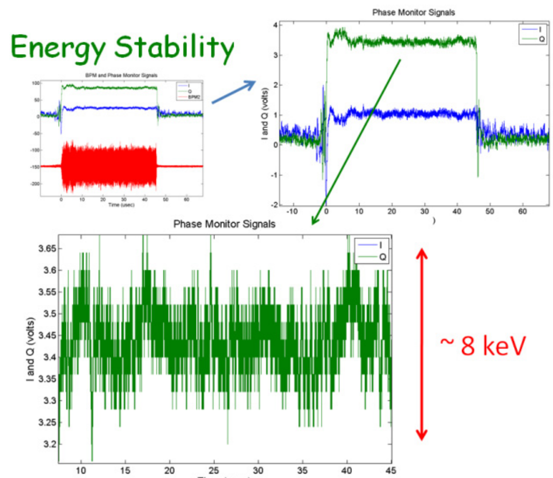

Figure 7: A measure of the beam energy stability from the BPM phase monitor I and Q values.

We also measured the RFQ efficiency versus RF power. Figure 8 shows the downstream toroid beam current as well as the magnitude of the 325 MHz frequency component of the first BPM signal as a function of RF power. The plot shows that the RFQ turns on at approximately 270 kW. In addition, the plot shows that the RFQ starts to transmit beam at a lower power, but that it has less 325 MHz bunch structure than at higher RF power levels.

We measured the change in beam transverse profile size as a function of RF power. Figure 9 shows that there is little change in the beam size when the RF power is above the 270 kW turn-on power.

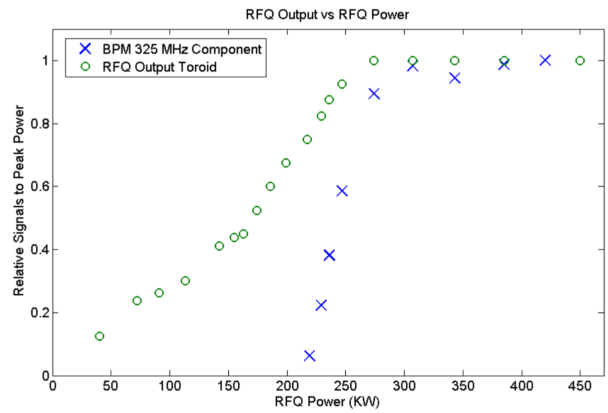

Figure 8: Relative RFQ beam output versus RFQ power.

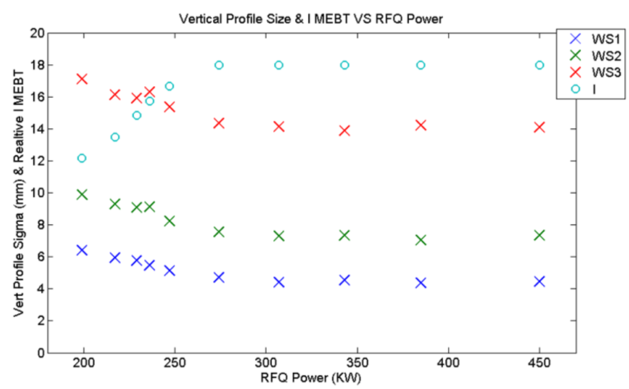

Figure 9: Vertical beam profile size at each wire scanner position versus RFQ power. The figure also shows the relative RFQ beam output current.

MEASUREMENT IMPROVEMENTS

From this initial set of beam measurements, it is apparent that improvements are needed to fully characterize the RFQ and any future HINS configurations. A number of improvements and new instruments are being implemented for HINS [5]. Figure 10 shows a schematic of a proposed new diagnostics beamline.

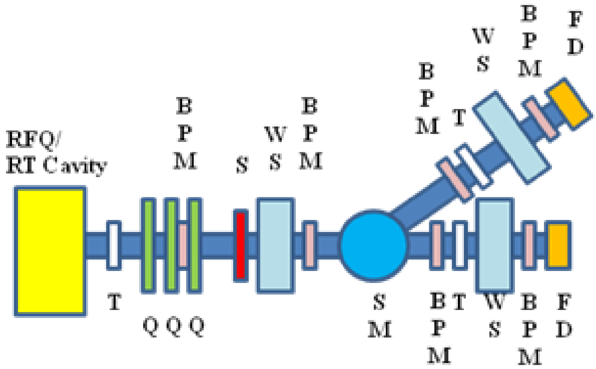

Figure 10: A schematic of an improved diagnostics beamline for HINS beam measurements. (Q) quadrupole, (T) toroid, (S) slit scanner, (WS) wire scanner, (SM) spectrometer magnet, (FD) Faraday cup/beam dump.

RFQ Efficiency

A measure of the RFQ transmission efficiency suffers from the unknown input ion source species content and the output beam loss. The present ion source is undergoing additional characterization to determine its species content. Also, a toroid is being integrated into the output flange of the RFQ to measure its output current properly.

Beam Energy

In order to measure the HINS beam energy, a magnetic spectrometer will be added to the diagnostics beamline along with downstream wire scanners. This will allow for an absolute energy measurement and a measure of the energy spread of the HINS beam.

Transverse Emittance Beam Measurements

The present diagnostics beamline has no transverse focusing and suffers from beam loss. Quadrupole focusing magnets are being added to reduce this beam loss. This focusing will also allow for transverse beam emittance measurements from quadrupole scans and a wire scan profile monitor. In addition, a slit scanner will be installed to allow for direct emittance measurements.

Longitudinal Beam Measurements

Initial beam measurements did not include any measure of the longitudinal structure of the RFQ output beam. Although not shown in figure 10, a longitudinal wire monitor, to measure bunch shape, will be added to the diagnostics beamline. In addition a high-bandwidth fast Faraday cup will also be tested to measure the longitudinal structure of the beam pulses.

CONCLUSION

Initial beam measurements have been made on the new HINS RFQ. These basic measurements indicate that the RFQ is operating within the design specifications. However, additional improved measurements will be needed to characterize fully the RFQ.

REFERENCES

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