BEAM INSTRUMENTATION REQUIREMENTS FOR THE HINS PROGRAM AT FERMILAB*

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Abstract

A linear accelerator test facility called the High Intensity Neutrino Source (HINS) has begun operating at Fermilab. The goal of this program is to test new technology for the front end of an intensity frontier linac. Some of the new technologies that will be tested include: operation of multiple cavities from a single RF source using high-power vector modulators, round beam transport using superconducting, solenoidal focusing, accelerating beam with spoke cavities, and a transition to superconducting RF cavities at 10 MeV. The testing has been split into four different stages: 2.5 MeV beam from the RFQ alone, acceleration through six room temperature cavities with quadrupole focusing, acceleration through 18 room temperature cavities with solenoidal focusing, and acceleration through the room temperature section plus one cryomodule of superconducting spoke cavities. Each stage focuses on testing the beam quality with a particular new technology. This paper describes the instrumentation necessary to quantify the beam quality for each stage of the program.

INTRODUCTION

The Fermilab HINS program is building a low energy, linear, hadron, test accelerator for intensity frontier applications. Figure 1 shows one of the original proposed designs for HINS as the front end for an intense neutrino source [1]. The program has since been descoped to provide an accelerator that will be used as test bed to study novel, linear accelerator components and techniques. Successful designs and techniques will be utilized in the front-end design of ProjectX [2], a long-term plan to increase proton flux to MW levels for long baseline neutrino experiments at Fermilab.

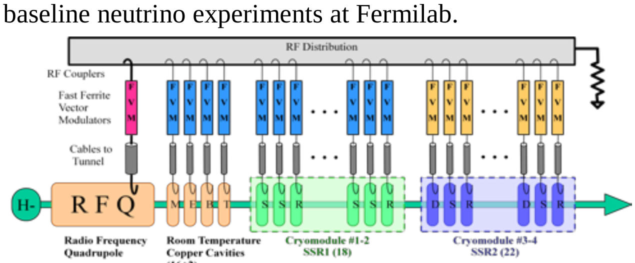

Figure 1: Original HINS proposal from 2006 showing a 90MeV beam line and four cryomodules.

There are four main concepts that the HINS program is currently prepared to test. First, it will test operation of multiple cavities from a single RF power source. One large RF power source is less expensive to procure and operate than many smaller sources. High power, ferrite vector modulators [3] (FVM) provide the fine amplitude and phase adjustments required for individual cavities. Second, it will test a lattice utilizing solenoidal focusing to propagate round beam. This lattice has been simulated to produce smaller beam halo at low energy than standard quad focusing [4]. However, the strength of the magnets needed for a practical solenoidal lattice require too much current for a normal conducting coil. These solenoid coils are superconducting. Third, the transition from normal conducting cavities to superconducting cavities will occur at 10 MeV. This is the lowest superconducting transition energy for any existing high-intensity hadron linac and is made possible by a spoke resonator cavity design [5]. This accelerator will also be the first to test any superconducting spoke resonator with beam. Fourth, the accelerator will be used to test advanced hadron linac instrumentation.

Testing of the different concepts will occur in four different stages based on resource availability. In the first stage, beam directly from the radio frequency quadrupole (RFQ) will be analyzed at 2.5 MeV. In the second stage, beam will be accelerated using six room temperature cavities with normal conducting quadrupole focusing. This will test beam operation with the FVMs. Once the cryogenic infrastructure is in place, the beam will be accelerated to 10 MeV using 18 room temperature cavities and superconducting solenoid focusing. This will test the beam halo and stability of the FVMs with many cavities. Once a spoke resonator cryostat is constructed, beam will be accelerated by the superconducting spoke cavities to test viability and stability of spoke cavity acceleration.

2.5 MEV RFQ

The 2.5 MeV beam line consists of a 50 keV proton source, a 2.5 MeV RFQ, a diagnostic line, and a beam dump. Figure 2 shows the layout of the 2.5 MeV diagnostic line. Beam studies on the RFQ were already performed with a simpler diagnostic line [6]. These studies verified the round beam profile from the RFQ. However, beam efficiency and beam energy were not precisely measured.

Ion Source

The HINS ion source is a duo-plasmatron, 50 keV, proton source [7]. The proton extractor is immediately followed by a low energy beam transport section (LEBT) consisting of two room temperature focusing solenoids, two dual plane dipole correctors, a beam stop, and a beam current toroid. Beam steering and emittance of the ion source are well characterized. The percentage of ions produced by the source that are protons is not as well

*Operated by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the United States Department of Energy.
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characterized. This parameter is important for determining the accelerating efficiency of the RFQ. The LEBT toroid measures the current due to all of the ion source ions, but the RFQ will accelerate only protons. A dedicated ion source experiment is planned to characterize the ion species before the RFQ beam studies continue.

Beam Energy Measurement

The initial plan for measuring the beam energy of the 2.5 MeV beam was to use beam time-of-flight measurements with the beam position monitors (BPM). However, there are no hard edges to the beam current pulse. The RF decay time of the RFQ is about 5 us, making correlating individual 3 ns buckets across the drift space nearly impossible. The only clean energy measurement came when the RFQ was intentionally sparked to provide a sharp, beam current profile.

To help verify the beam energy measurement, a spectrometer magnet will be installed in the diagnostic line. This will provide a sufficiently accurate bend to verify the absolute beam energy to within half a wavelength of the time of flight measurement. Once the absolute beam energy is confirmed, the time of flight measurement can be used to verify the average beam energy more accurately than the magnet. Using this beam energy information in conjunction with beam centroid information from the wire scanners, the dispersion of the magnet can be measured. The dispersion and difference in beam width between the straight ahead beam and bent beam reveal momentum spread.

Table 1: Instrument Acronyms for Figures

Acronym	Description
BPM	Beam Position Monitor
BSM	Bunch Shape Monitor (Longitudinal)
FD	Faraday Cup/ Dump
FFC	Fast Faraday Cup
HM	Halo Monitor
LW	Laser Wire
Q	Quadrupole Magnet
S	Horizontal and Vertical Slits
SEM	Secondary Emission Monitor
SM	Spectrometer Magnet
T	Toroid
WS	Wire Scanner

Emittance Measurement

The 2.5 MeV diagnostic line will include a quad triplet immediately after the RFQ. This will allow the beam to travel further down the beam line before space charge forces cause beam to fill the aperture, allowing for more instrumentation options. The non-linearities of the quad triplet should not have a significant effect on beam emittance.

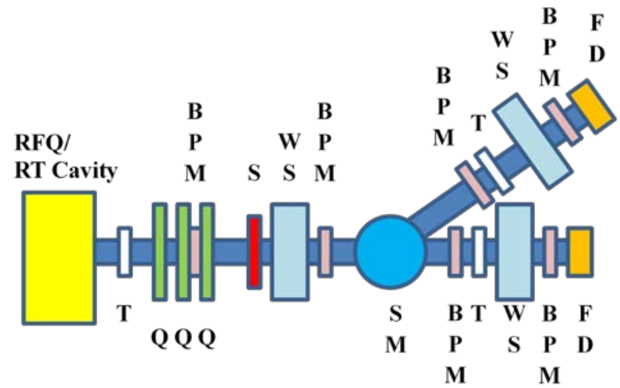

Figure 2: Proposed layout of diagnostic line for 2.5 MeV and six cavity test with protons.

Three wire scanners will be utilized for beam emittance measurements. Two other wire scanners are used downstream of the spectrometer magnet. One measures the profile of beam steered by the magnet, and the other measures the straight-ahead beam profile. This allows for possible momentum spread measurements and quantization of lower q/m particles that escape the RFQ. The upstream wire scanner also has slit scanners in front of it to allow measurement of beam emittance immediately after the quad triplet.

SIX CAVITY TEST

The next phase of the HINS program involves accelerating beam with room temperature cavities after the RFQ. The new lattice will utilize room temperature quadrupole focusing and six cavities (Fig .4). Most of the RF voltage in the cavities will go toward beam focusing. The final energy of the beam line will be approximately 3 MeV. The cavities will consist of two room temperature

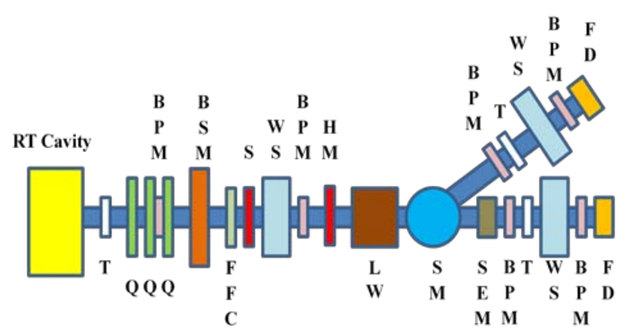

Figure 3: Proposed layout of diagnostic line for six cavity test with H^-.

buncher cavities and four room temperature triple spoke resonantors. A single klystron will power the RFQ and the six cavities, with individual phase and amplitude controlled by FVMs. The purpose of this configuration is

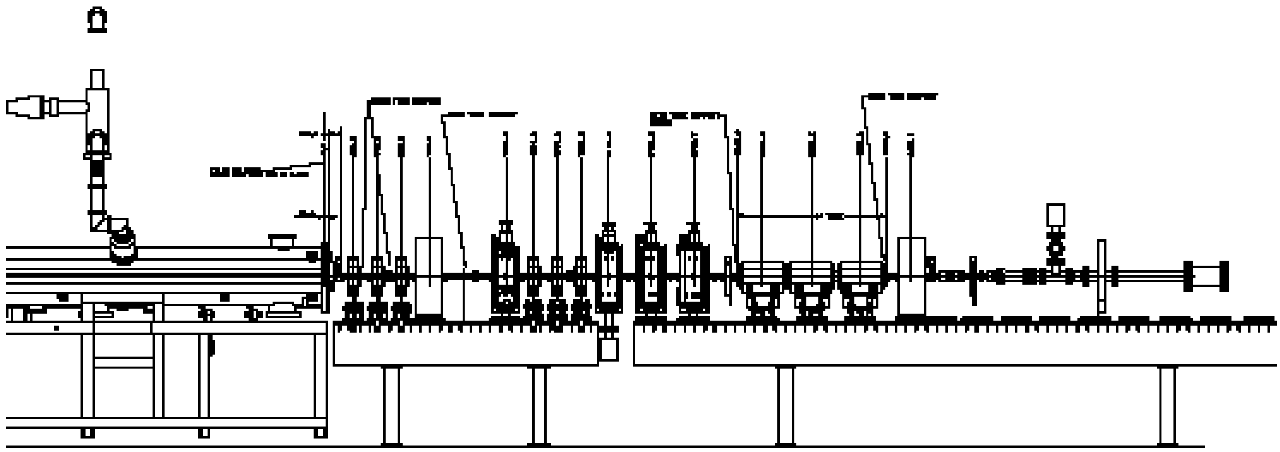

Figure 4: Proposed beam line layout for the six cavity test. The first large component is the RFQ, followed by three quadrupole magnets. The next item is a buncher cavities which is followed by the first of four room temperature triple-spoke resonators. This is followed another quadrupole triplet, three more spoke resonantors, and another quadrupole triplet. A second buncher cavity, diagnostic line, and dump finish out the beam line.

to verify beam operation through spoke resonators and to verify beam energy stability with FVM operation.

Initial Phase Instrumentation

The diagnostic line for the 2.5 MeV test will be repositioned to the output of the six cavity beam line. All of the measurements performed with the 2.5 MeV test will be repeated for the six cavity test. There will be special emphasis on the time of flight measurements because of between the BPMs will be operational for the six cavity test.

H^- Operation

The second phase of the six cavity test involves commissioning an H^- source. All of the present manifestations of ProjectX involve injecting multiple turns of beam into a synchrotron. This will require H^- acceleration and stripping at injection. There are few components of the six cavity test that operate differently with H^- or protons. However, the H^- operation offers a richer test bed for advanced accelerator instrumentation. For example, the spectrometer magnet may be used in conjunction with the straight ahead wire chamber to quantify ion neutralization. With H^-, there are plans to install and test a laser wire [8], longitudinal bunch shape monitor [9], secondary emission monitor, and halo monitor [10] (Fig. 3).

SUPERCONDUCTING LINAC TEST

As the specifications for ProjectX settle, the HINS program will need to align itself with the project's accelerator R&D. The next phases defined for the HINS program involve superconducting components and will require significant infrastructure investment. It will be important that these investments provide the tools to move Project-X forward. The following items are likely to be tested in some mode.

Superconducting Solenoids

The next phase of the HINS program, as heretofore

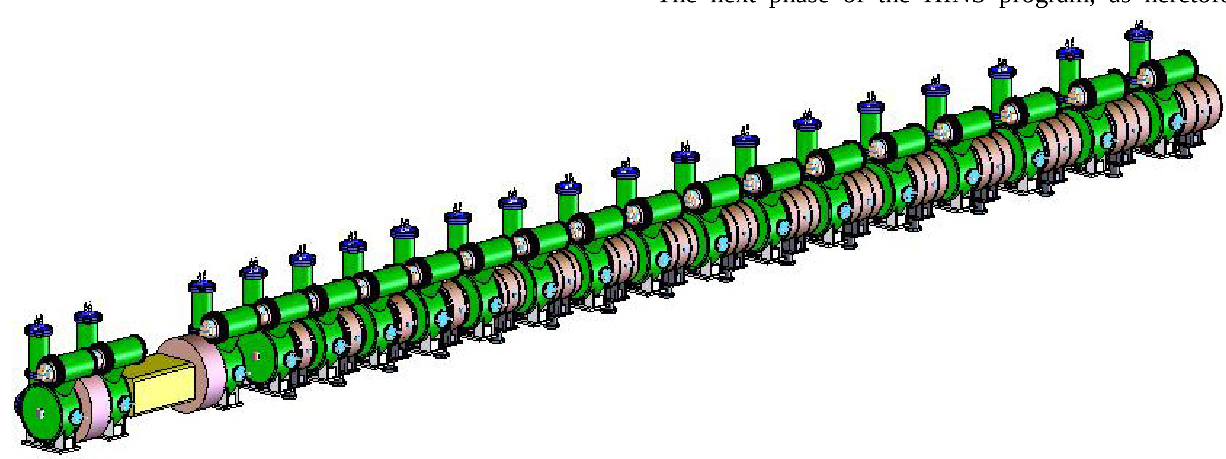

Figure 5: Proposed solid model of HINS 10 MeV room temperature cavity section. Green components are the superconducting solenoids.

planned, involved constructing a 10 MeV beam line with 18 room temperature cavities and superconducting solenoids as the focusing elements (Fig. 5). The solenoidal focusing keeps the beams round and minimizes the beam halo generation at low energies. Maintaining low emittance growth in the presence of space charge requires fast acceleration and strong focusing. The solenoid magnets required to maintain such a lattice have strengths on the order of 6T. Small errors in these magnets can have a substantial effect on the steering of such low energy beam. The main focus of this phase is to verify that the magnets can be aligned and/or corrected well enough to maintain stable beam position.

It is highly likely that some form of solenoid testing will occur within the scope of the HINS program. There are three possible versions that may be tested: a solo solenoid, a solenoid with dipole correctors, and a solenoid with a BPM. Regardless of the type(s) of solenoid(s) tested, correctors and BPMs will be a necessary part of the experiment. The BPMs will be used to verify the beam path through the center of the solenoid(s) and may also be used to help align multiple solenoids.

Figure 6: Picture of completed superconducting spoke resonator.

Superconducting Spoke Resonator Cryomodule

The final phase of the HINS program involves accelerating beam through a superconducting spoke resonator cryomodule. These cavity designs have never been tested with beam and could be very useful for high intensity, low energy acceleration. The HINS linac design called for pulsed cavity operation (1 ms at 10 Hz), however ProjectX has diverged from this and is likely to run continuous wave (CW). At present, any spoke resonator cryomodule test performed in the HINS facility will occur with a pulsed beam injector and the superconducting cavities running CW RF.

This phase is the culmination of the project. The cryomodule will include superconducting solenoid magnets that are similar to the magnets used in the room temperature section. The BPMs inside the cryomodule will be critical devices for determining proper beam steering and magnet alignment within the cryomodule. Measuring real time beam energy, halo formation, and beam neutralization (for H^-) are also critical measurements for extrapolating the efficiency and utility of a higher energy accelerating chain. All of the instruments used in the six cavity test will be used for the cryomodule test.

REFERENCES

[1] R. C. Webber et al., “Overview of the High Intensity Neutrino Source Linac R&D Program at Fermilab”, LINAC08, Victoria, BC, Canada, September 2008, pp 36-40.

[2] S. Holmes, “Project X at Fermilab: Prospects and Plans”, PAC09, Vancouver, BC, Canada, May 2009.

[3] R. Madrak & D. Wildman, “High Power 325 MHz Vector Modulators for the Femilab High Intensity Neutrino Source (HINS)”, LINAC08, Victoria, BC, Canada, September 2008.

[4] P.N Ostroumov et al., “Beam Dynamics Studies of the 8 GeV Linac at FNAL”, LINAC08, Victoria, BC, Canada, September 2008, pp 760-764.

[5] I. Gonin et al., “High Gradient Tests Results of 325 MHz Single Spoke Cavity at Fermilab”, LINAC08, Victoria, BC, Canada, September 2008.

[6] V. Scarpine et al., “First Beam Measurements of the FNAL HINS RFQ”, these proceedings.

[7] W.M. Tam et al., “Fermilab HINS Proton Ion Source Beam Measurements”, PAC09, Vancouver, BC, Canada, May 2009.

[8] R. Connolly et al, “Laser Profile Measurements of an H- Beam”, DIPAC01, Grenoble, France, May 2001.

[9] E. McCrory et al., “Longitudinal Emittance from the Fermilab 400 MeV Linac,” LINAC96, Geneva, Switzerland, August 1996.

[10] S.G. Arutunian, “Vibrating Wire Sensors for Beam Instrumentation”, BIW08, Lake Tahoe, CA, May 2008.