PROTON INJECTION INTO THE FERMILAB INTEGRABLE OPTICS TEST ACCELERATOR (IOTA)*

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Abstract

The Integrable Optics Test Accelerator (IOTA) is an experimental synchrotron being built at Fermilab to test the concept of non-linear "integrable optics", based on a lattice including non-linear elements that satisfies particular conditions on the Hamiltonian. The resulting particle motion is predicted to be stable but without a unique tune. The system is therefore insensitive to resonant instabilities and can in principle store very intense beams, with space charge tune shifts larger than those which are possible in conventional linear synchrotrons. The ring will initially be commissioned with electrons, but this poster describes progress toward the injection of protons into the ring, using the RFQ originally built for the High Energy Neutrino Source (HINS) project.

INTRODUCTION

Table 1: HINS Parameters for IOTA

Parameter	Value	Unit
Particle type	proton	-
Kinetic Energy	2.5	MeV
Momentum	68.5	MeV/c
β	.073	-
Rigidity	.23	T-m
RF structure	325	MHz
Current	8	mA
Circumference	39.97	m
Total Protons	9.1×10^{10}	-
RMS Emittance (un-normalized)	4	π-mm-mrad
Tune shift	$-.51\times B$	-
Pulse rate	<1	Hz
Pulse length	1.77	μsec

This project has been described previously [1], and the motivation is summarized here. The Integrable Optics Test Accelerator (IOTA) at Fermilab [2] is being built to test the concept of nonlinear integrable optics [3]. These are optics based on nonlinear lattice elements that satisfy very particular criteria. Calculations and simulations show that such a system will have stable, analytical orbits, but not a unique tune, making it very insensitive to harmonic instabilities, and allowing the stable acceleration of intensities with space charge tuneshifts on the order of unity.

Initial tests of IOTA will use a 150 MeV electron beam from the Fermilab Accelerator Science and Technology (FAST) facility at Fermilab [4]. By varying initial conditions, this electron beam can be used to probe the optical space of the ring; however, since the space charge effects on the electron beam will be negligible, it will not serve as a direct test of the inherent stability. As a next step, we therefore plan to reuse the 2.5 MeV RFQ, which was built for Fermilab's High Intensity Neutrino Source (HINS) program [5]. This RFQ became available when the lab chose to focus instead on a CW ion source for its high intensity program.

DESIGN

IOTA

Figure 1 shows the IOTA ring. The ring is essentially an ordinary lattice with two straight sections to accommodate the non-linear elements for the proposed optical tests. A straight section is also provided for optical stochastic cooling tests, which are separate from the non-linear optics program.

The injection lines can be switched to accommodate the initial injection from the upstream electron linac, as well as 2.5 MeV protons from the RFQ which was formerly used for the High Intensity Neutrino Source (HINS) project, described below.

HINS RFQ

The High Intensity Neutrino Source (HINS) program began as R&D to develop the front end of an 8 GeV proton linac, which was being considered as an upgrade to the Fermilab accelerator complex (the so-called "Project X") [6]. To this end, a 2.5 MeV RFQ was built, with the goal of producing a beam up to several mA, with a duty factor of 1%. This was followed by a bunching cavity and a series of spoke resonators, with the goal of ultimately accelerating the beam to 10 MeV.

The source consists of a 50 kV filament proton source, capable of delivering 8 mA. The RFQ itself is a four vane design, operating at 325 MHz. The specifications were developed in a collaboration between Fermilab and Argonne National Lab. The RFQ is shown in Figure 2, while Figure 3 shows the RFQ in it's vacuum vessel as part of the original HINS beam line.

Problems related to cooling prevented the RFQ from reaching its design duty factor. In addition, Fermilab efforts were redirected to a CW ion source, as part of the PIP-II upgrade plan [7], so the HINS RFQ has become available for use by IOTA. In this application, it is planned to use the RFQ for 1.7 μsec pulses, at 1 Hz maximum. The cooling problem will therefore not be an issue.

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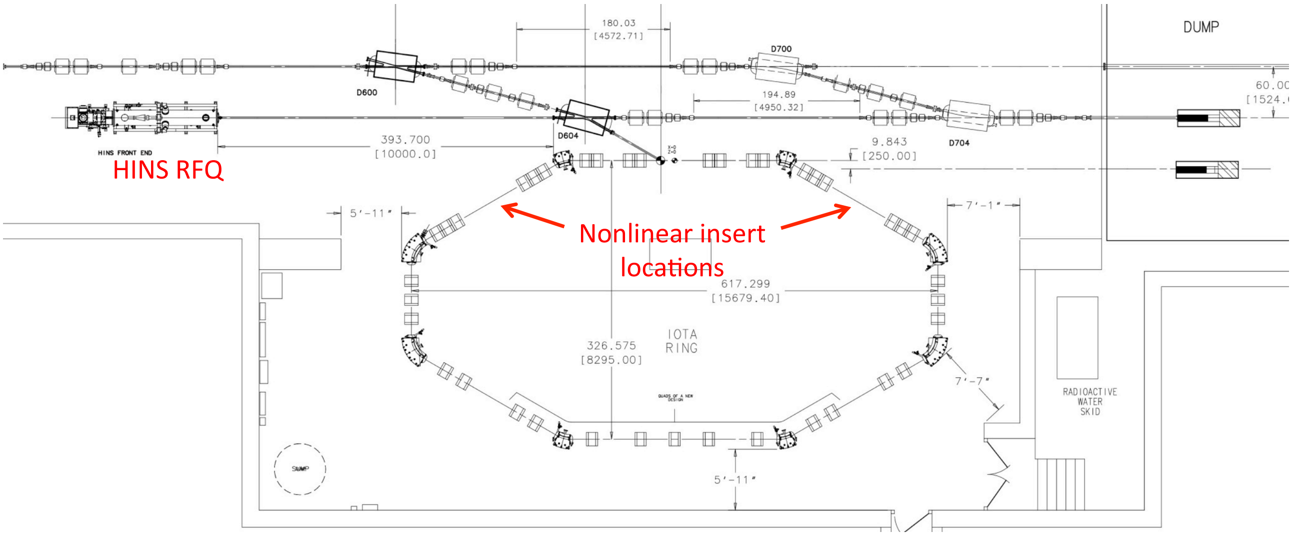

Figure 1: Layout of the IOTA ring and HINS RFQ proton source. Initial tests will use 150 MeV electron beam from the FAST test facility.

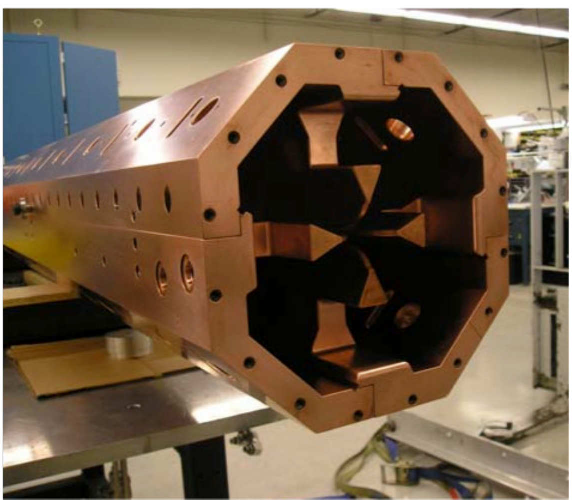

Figure 2: 2.5 MeV HINS RFQ.

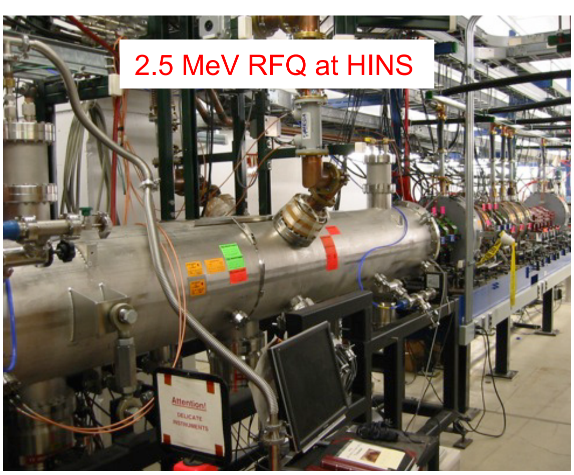

Figure 3: RFQ in its vacuum vessel.

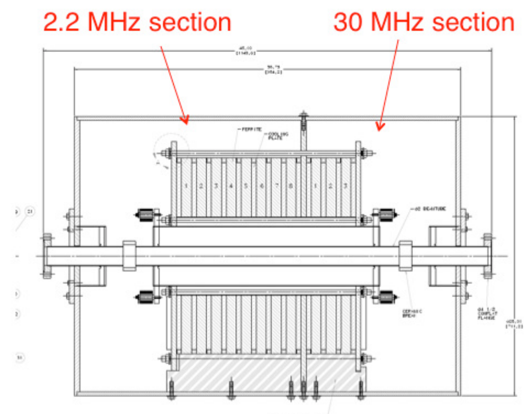

Figure 4: RFQ in its vacuum vessel.

RF System

An 1 kV, $h = 4$, 30 MHz RF system has been designed for electron operation. For protons, this corresponds to roughly $h = 56$, and 1 kV is not enough to fully bunch the beam. At 1 kV, about 1/3 of of the proton beam will be bunched. This is enough for the BPM system to operate, but if more bunching is desired, a lower frequency RF system is desirable. A second 2.2 MHz RF system is planned, which will be $h = 4$ for protons. At this frequency, 400 V is sufficient to fully bunch the beam, although higher voltages can be used to increase the bunching factor and the resulting space charge tuneshift. This will be accomplished using a dual RF cavity, which is shown in Figure 4.

PROGRESS

Except for the rate problems, the HINS RFQ was fully operational approximately five years ago; however, because it was believed would never be used again, many important components were removed and reused in the PIP-II Injector

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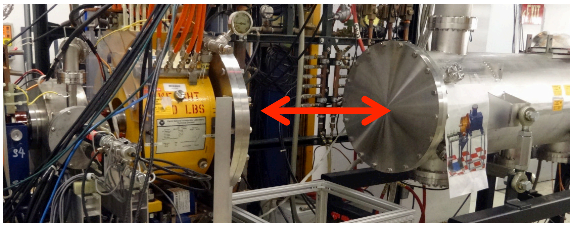

Figure 5: Ion source detached to make room for Allison Detector.

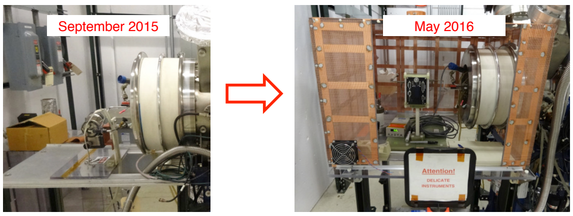

Figure 6: The state of the Hydrogen and HV systems at the start of this project, compared to the present.

Experiment (PXIE) [8]. It has therefore been a rather major undertaking to bring the system back into operation.

The HINS RFQ only achieved 8 mA, which was well short of its 40 mA design. To fully understand the operation of the ion source, it has been separated from the RFQ, as shown in Figure 5, to accommodate an Allison Detector to fully characterize the beam from the source.

The Hydrogen and HV systems for the ion source were removed and reused for PXIE. Figure 6 shows the input stage of the ion source at the beginning of this project, compared to the present.

Test have begun on the dual harmonic RF cavity. Figure 7 shows the cavity core, which will be loaded with ferrite disks.

STATUS AND PLANS

The progress of this activity is entirely resource limited. The electron beam at FAST has been recently commissioned. During fiscal fear 16, the IOTA ring will be constructed. In parallel, the ion source will be recommissioned at the Fermilab Meson Detector Building (MDB). In fiscal year 17, commissioning of the IOTA ring will begin with electrons. During that time, the HINS RFQ will be recommissioned in situ at the MDB. In fiscal year 18 or 19, the HINS RFQ and

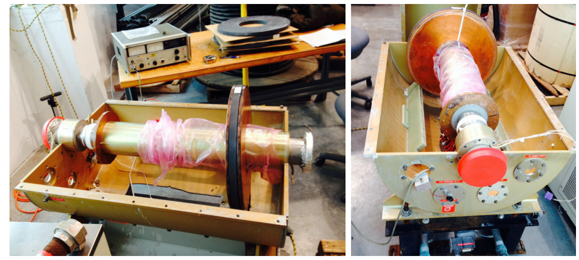

Figure 7: Ferrite tests beginning on dual harmonic RF cavity.

supporting RF hardware (klystron, modulator, PFN, etc) will be moved to the FAST facility to establish proton injection into the IOTA ring.

RELATED CONTRIBUTIONS

The following contributions to this conference are related to this topic:

- “Long Term Plans to Increase Fermilab’s Proton Intensity to Meet the Needs of the Long Baseline Neutrino Program” (contributed oral TUOAA03)
- “Electron Lens Construction for Integrable Optics Test Accelerator at Fermilab" (poster WEPMR007)
- “Mechanical Stability Study for Integrable Optics Test Accelerator at Fermilab” (poster WEPMR008)

REFERENCES

[1] E. Prebys *et. al.*, “Proton Injection into the Fermilab Integrable Optics Test Accelerator (IOTA)", WEPWA055, Proceedings of IPAC15 (2015).

[2] A. Valishev *et. al.*, “Status of the IOTA Experimental Beam Physics Program at Fermilab", MOPMA021, Proceedings of IPAC15 (2015).

[3] V. Danilov and S. Nagaitsev, Phys. Rev. ST Accel. Beams 13, 084002 (2010).

[4] `http://fast.fnal.gov/`

[5] R. Weber, *et. al.*, “Experiences with the Fermilab HINS 325 MHz RFQ", `http://arxiv.org/abs/1202.1550`, (2012).

[6] S. Holmes, “Project X: A Multi-MW Proton Sourse at Fermilab ", Proceedings of IPAC’10, Kyoto, Japan, TUYRA01, (2010).

[7] `http://pip2.fnal.gov/`

[8] `http://pxie.fnal.gov/`