ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWA055

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". These optics are 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 tested with pencil electron beams, but this poster describes the ultimate plan to install a 2.5 MeV RFQ to inject protons, which will produce tune shifts on the order of unity. Technical details will be presented, as well as simulations of protons in the ring.

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

All particle optics to date have been based on linear magnetic systems of quadrupoles and dipoles. Higher order multipoles are treated perturbatively, and generally lead to instabilities if they are large enough. It has long been known that very specific conditions can produce stable orbits in non-linear magnetic systems [1] [2]; however, it was not until fairly recently that specific magnetic lattices were proposed that satisfy these conditions [3]. Such systems have stable orbits, but not unique tunes. They are therefore extremely insensitive to harmonic instabilities, thereby allowing the storage of beams with intensitities beyond those which would otherwise be limited by space charge tune shift.

The Integrable Optics Test Accelerator (IOTA) at Fermilab is being built to test this concept, and is described in detail elsewhere [4]. Initial tests will use a 150 MeV electron beam from the Advanced Superconducting Test Accelératator (ASTA) facility at Fermilab [6]. 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.

Initial tests of the IOTA ring will use the 150 MeV electron beam from the ASTA test facility. This facility was built primarily to test 1.3 GHz cryomodules, of the sort that could be used for a linear electron collider. It is also used to support an electon-based R&D program. In the figure, the elecron beam is seen entering from the upper left. A system of dipoles can selectively direct the electron beam to the IOTA ring, a beam dump, or potentially other electron experiments.

Because space charge is not an issue for an electron beam of this energy, the non-linear optics will be probed by varying the initial position and trajectory of the beam and observing the orbit.

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 the the Fermilab accelerator complex (the so-called "Project X") [7]. 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

* Work supported by the United States Department of Energy under Contract No. DE-AC02-07CH11359

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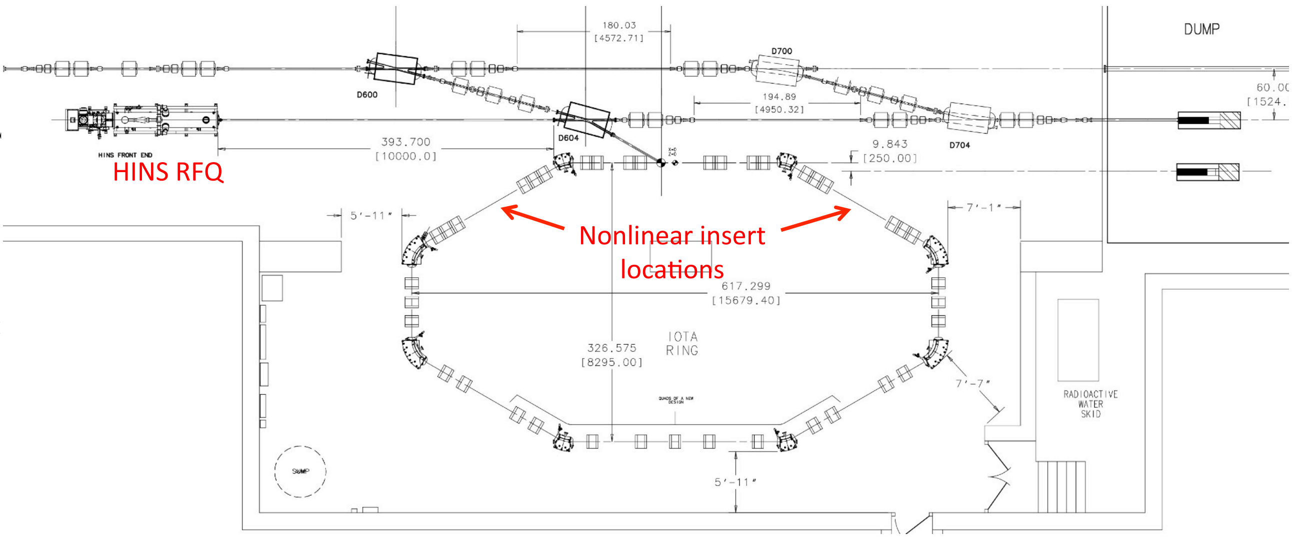

Figure 1: Layout of the IOTA ring and HINS RFQ proton source. Initial tests will use 150 MeV electron beam from the ASTA test facility.

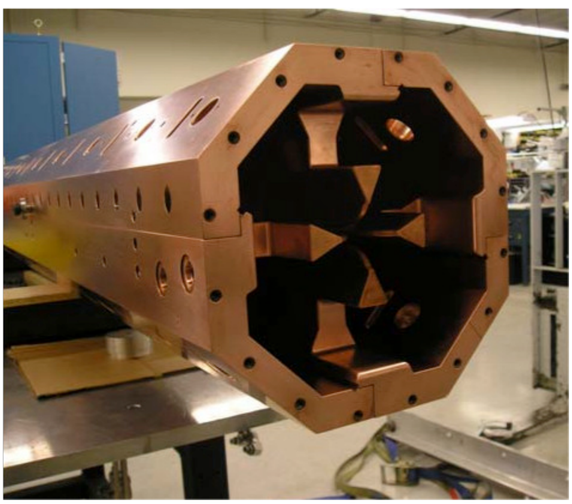

Figure 2: 2.5 MeV HINS RFQ.

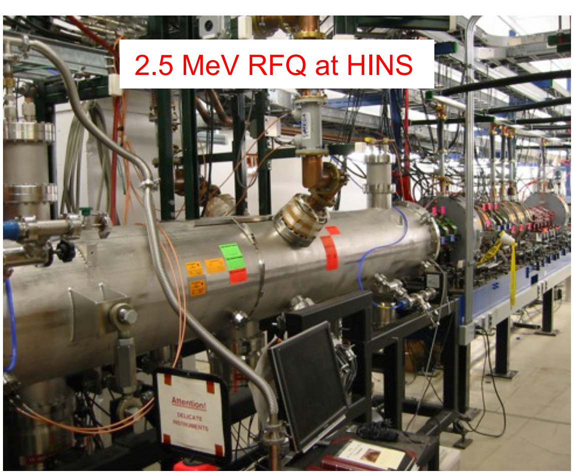

Figure 3: RFQ in its vacuum vessel.

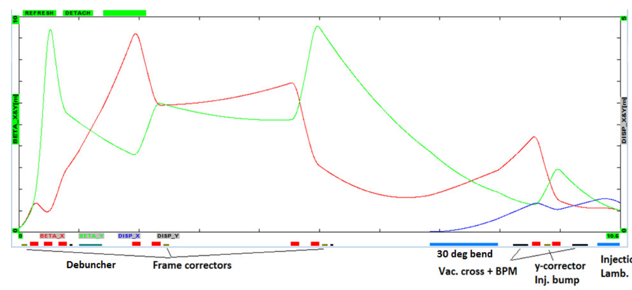

Figure 4: Optics of proton transport line, with key components indicated. It includes a debuncher cavitiy, indicated by "RF" to reduce the momentum spread.

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 [8], 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.

Integration

Figure 1 shows the approximate location of the HINS RFQ in the IOTA test area. Table 1 shows the parameters of the proton RFQ as related to the experiment. A dipole will allow the IOTA ring to switch between 150 MeV electrons and 2.5 MeV protons, and the 2.5 MeV proton beam corresponds to roughly half the magnetic rigidity of the electron beam.

Figure 4 shows the optics of the proton transport line from the RFQ to the IOTA ring, including the bend dipole and

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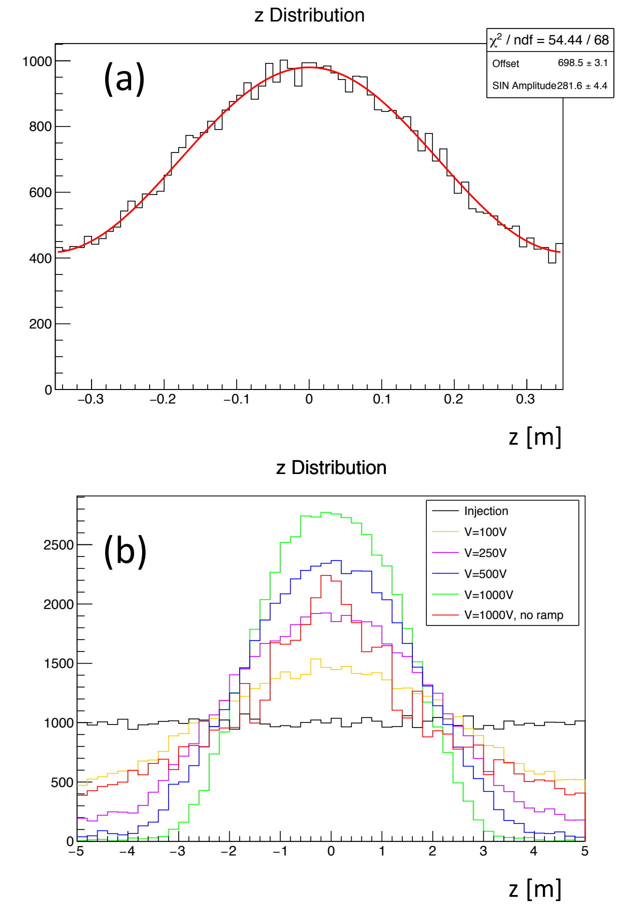

Figure 5: Bunched beam z distributions for (a) $h = 56$ and (b) $h = 4$ RF systems.

injection Lambertson. The total length is 10.6 m. The beam line consists of 9 quadrupoles, which are used to match the output optics of the RFQ to the injection optics of the IOTA ring. It includes a debuncher cavity to reduce the momentum spread of the beam.

The plan is to use the same injection septum and kicker for protons and electrons, allowing single turn injection. Given the momentum spread and the low β, the 325 MHz structure of the proton beam will completely debunch in the first turn, making it effectively DC.

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. Figure 5 shows bunch distributions for both of these frequencies, as simulated by Synergia [9].

STATUS AND PLANS

The ASTA electron source has recently been commissioned. Plans for the IOTA ring are moving forward, with plans to begin electron operation in late FY16 or early FY17, and proton operation some time in FY17.

Work is going on in parallel to reestablish beam in the HINS RFQ. This year, vacuum will be restored and the proton source will be restarted. Next year, work will begin on restarting the RFQ. Once beam has been established, the whole system will moved to the IOTA enclosure, with the hopes that proton beams can be injected into the IOTA ring approximately one year after electrons.

RELATED CONTRIBUTIONS

Several contributions have been submitted related to this paper, including “Status of the IOTA Experimental Beam Physics Program at Fermilab" (MOPMA021), “Electron Lenses for Experiments on Nonlinear Dynamics with Wide Stable Tune Spreads in the Fermilab Integrable Optics Test Accelerator" (MOBC3), “Longitudinal Bunch Shaping at Picosecond Scales using Alpha-BBO Crystals at the Advanced Superconducting Test Accelerator" (MOPMA043), “Development of a Single-Pass Amplifier for an Optical Stochastic Proof-of-Principle Experiment at Fermilab’s IOTA facility" (MOPMA049), “Development of a Versatile Bunch-length Monitor for Electron Beams at ASTA" (MOPWI016), “First Beam and High-Gradient Cryomodule Commissioning Results of the Advanced Superconducting Test Accelerator at Fermilab" (TUPJE080), “Stripline Kicker for Integrable Optics Test Accelerator" (WEPTY051), and “Beam Physics Research Towards Future Multi-MW Proton Accelerators" (THPF128).

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