THE FABRICATION AND INITIAL TESTING OF THE HINS RFQ*

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Abstract

Fermilab is designing and building the HINS front-end test facility. The HINS proton linear accelerator consists of a normal-conducting and a superconducting section. The normal-conducting (warm) section is composed of an ion source, a 2.5 MeV radio frequency quadrupole (RFQ), a medium energy beam transport, and 16 normal-conducting crossbar H-type cavities that accelerate the beam to 10 MeV. Production of 325MHz 4-vane RFQ is recently completed. This paper presents the design concepts for this RFQ, the mechanical design and tuning results. Issues that arose during manufacturing of the RFQ will be discussed and specific corrective modifications will be explained. The preliminary results of initial testing of RFQ at the test facility will be presented and comparisons with the former simulations will also be discussed.

INTRODUCTION

Within the framework of the High Intensity Neutrino Source (HINS) program at FNAL, we plan to build and operate a portion of the Front End (up to energies of 90 MeV) as a technical feasibility proof of the proposal. A detailed description of the project and the current status is given in [1]. In the Front End test stand a four vane 325 MHz Radio Frequency Quadrupole (RFQ) will be used for bunching the beam and accelerating it from 50 keV to 2.5 MeV.

The technical specifications for the RFQ were developed by ANL/FNAL collaboration and are presented in Table 1.

Table 1. Initial Specifications for the RFQ Design

Input energy	50 keV
Output energy	2.5 MeV
Frequency, MHz	325
Accelerating beam current, mA	40
Peak surface field, kV/cm	<330
Acceleration efficiency,%	>95
Pulsed power losses in copper, kW	<450
Duty factor, %	1
Total length of vanes	302.428 cm
Average bore radius	3.4 mm
Input rms transverse emittance, normalized π mm mrad	0.25
Transverse emittance growth factor	<1.1
Longitudinal rms emittance, π keV deg	<150
Separation between operating and nearest dipole modes	>4 MHz

In this collaborative effort ANL was responsible for complete beam dynamic design resulting in a vane tip modulation table for machining. RF design with computational support from FNAL, mechanical design and manufacturing, preliminary tuning were delivered by AccSys Technology, Inc. Serious issues arose during manufacturing of the RFQ that prevented proper preliminary tuning. Intensive study has been undertaken to address the problem and specific corrective modifications have been done. Final RF measurements and testing of recently arrived RFQ have been performed by FNAL. The preliminary results of initial testing of RFQ at the test facility are presented.

DESIGN FEATURES

Similar to many other linear accelerators, the HINS proton accelerator requires an RFQ for initial acceleration and formation of the bunched beam structure. The HINS RFQ will operate at 325 MHz. The initially projected acceleration of ~40 mA pulsed current is considered a relatively moderate problem in the physics design of the RFQ. The design of the RFQ, MEBT and whole proton accelerator lattice has been iterated several times to satisfy more advanced RFQ beam specifications. Particularly, the longitudinal phase space beam emittance must be halo free to avoid excessive beam loss in the high energy section of the accelerator. As a part of this approach, axial-symmetric beam was requested at the RFQ output.

For RFQs longer than ~31 rf wavelengths, it is difficult to stabilize the operating field and damp field errors. To address this problem, modern RFQ designs include p-mode stabilizing loops (PISLs) [2]. PISLs complicate the resonator design and increase its cost; therefore we proposed to minimize the length of the RFQ resonator to allow using the end-wall dipole mode tuners for field stabilization that were successfully applied to several RFQs.

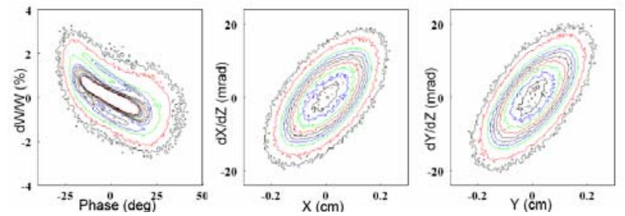

Figure 1: Phase space plots of accelerated beam. The outmost isoline contains 100%, the next one contains 99%.

For the beam dynamics design, the RFQ is divided into three main sections: an input radial matcher, a main modulated vane section where bunching and acceleration

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occur, and an output radial matcher. The emittance and profile of the beam exiting the RFQ obtained from TRACK simulation of 10^6 particles are shown in Fig. 1

The complete beam dynamics design, resulting in a vane tip modulation table for machining, is described in [3].

RFQ MECHANICAL DESIGN

The RFQ resonator was fabricated using AccSys patented Univane technology [4]. The four identical univanes were each fabricated from solid copper billets (Fig. 2). The univanes are bolted together (Fig. 3) and can be disassembled and re-assembled to facilitate repairs, surface cleaning etc, if necessary. This mechanical design feature turned out to be very useful.

Figure 2: CMM measurements of the univane at SLAC.

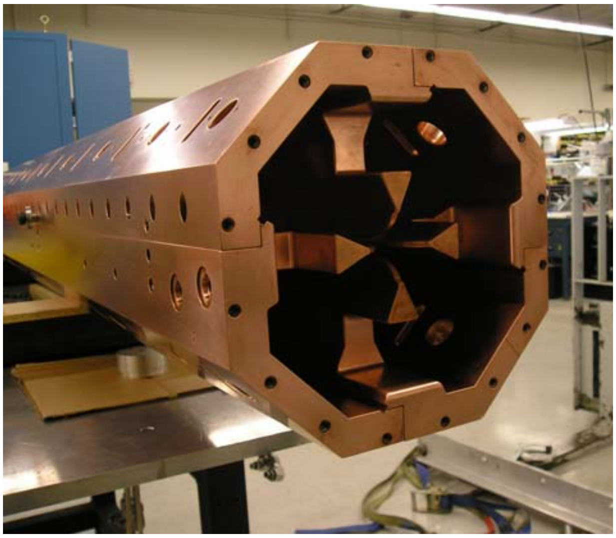

Figure 3: Assembled RFQ resonator. Output end.

Twelve cooling water passages were gun-drilled through the full length of the structure. The cooling passages near vane tips are isolated from passages in outer part of the body to allow RFQ resonant frequency control by adjusting the differential water temperature between the two circuits. The RFQ resonant frequency may also be adjusted using a moveable slug tuner located at the midpoint of the cavity.

Two 3 1/8 inch RF drive loops are used to keep the RF losses in the loops low and also to allow the coupling to be easily adjusted. To operationally monitor and control field distribution in the RFQ, 12 pick-up electrodes (3 per quadrant) are provided. Tuning of the structure at assembly is achieved by means of 64 fixed slug type tuners (16 per quadrant at evenly distributed locations).

Since RFQ resonator cavity does not serve as a vacuum chamber, it is placed in a stainless steel vacuum chamber with vacuum feedthroughs for the RF drive loops, the water cooling and RF pick-up loops (see Fig. 4). Two ports are located on the bottom for mounting vacuum pumps to maintain an operating pressure in the chamber less than $1\text{x}10^{-8}$ Torr.

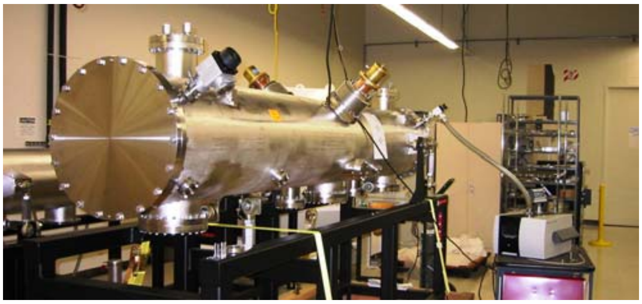

Figure 4: RFQ in the vacuum chamber.

DESIGN CORRECTIONS AND TUNING

During the initial tuning of the RFQ it turned out impossible to correct (flatten) the resonator's quadrupole field without exceeding the nominal operating frequency by 2-3 MHz. The quadrupole field measurements showed an extreme tilt of field distribution along the resonator, approx. 80%. This was beyond the range of normal correction (i.e. end tuners and slugs) and indicated a fundamental geometry error in the RFQ.

Extensive numerical simulations of the RF properties of the RFQ were performed at FNAL with the use of MWS and HFSS to understand the problem and find a solution [5, 6, and 7]. It was determined that the main problem was the result of a mis-tuned output matcher. The output radial matcher is designed to form axially symmetric beam exiting the RFQ, and because of this special function it is different than the input radial matcher. An error in the final dimensions of the matcher was not realized before univane machining and the resultant matcher local frequency went too high. Simulations indicated that fixing the problem without affecting fields in the matching area meant disassembly and re-machining of the univanes (see Fig. 5).

Also during simulations it became understood that there is an additional distortion of the quadrupole field distribution due to the local frequency variation along the RFQ associated with very specific vane tip modulation. This frequency variation was a potentially serious problem as well, but could be avoided by proper assembly and tuning. This meant reducing the bore radius by 50-70 microns using shims of appropriate thickness (see Fig. 6).

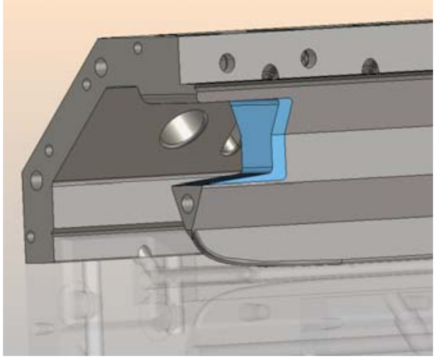

Figure 5: The blue volume has been removed during the univanes re-machining to tune output matcher.

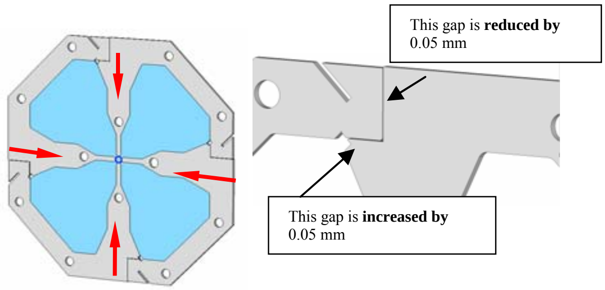

Figure 6: The shims of appropriate thickness reduced bore radius by 50 microns.

After all recommended corrections were done, the tuning went smoothly and RFQ met all design requirements. Fig. 7 shows the evolution of the field distribution. Overall final flatness of field distribution is in ±2% interval.

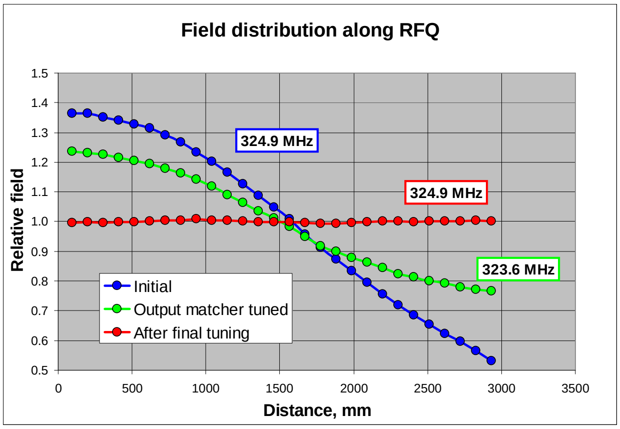

Figure 7: Measurements of field distribution along RFQ resonator at different stages of tuning (average over four quadrants).

Frequency spectra measured at room temperature of 22°C and air filled cavity are given in MHz in Table 2.

Table 2

Mode	Q	D1	D2
0	324.942	313.249	312.731
1	328.693	319.226	319.594
2	339.837	330.378	330.608
3	357.102	348.062	347.797

Nearest dipole modes are located symmetrically in respect to operating frequency with separation more than 5 MHz. Measured unloaded quality factor was Q=9650 compare to the simulated figure of 10750.

TESTING

The RFQ was delivered to Fermilab this month. Receiving inspections, alignment measurements, and final cold tests are now under way prior to high power RF conditioning expected to commence in October 2008.

The HINS 325 MHz RF power system is operational and ready for the RFQ. A proton ion source and low energy beam transport line is installed and waiting. Following RF conditioning, the source and RFQ will be coupled. The first 2.5 MeV beam is expected by December this year.

CONCLUSIONS

The HINS RFQ has been fabricated and has passed all mechanical and low power RF tests. The excellent agreement between comprehensive numerical simulations and the RFQ structure's behavior in response to re-machining and during final assembly and tuning offers confidence that the RFQ will perform as designed with beam.

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