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MEASUREMENT OF THE LONGITUDINAL ACCEPTANCE OF THE REA RFQ*

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Abstract

The reaccelerator facility (ReA) at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) will provide a unique capability to study low-energy beams of rare isotopes. A beam from the coupled cyclotron facility is stopped in a gas stopping system, charge bred in an Electron Beam Ion Trap (EBIT), and then reaccelerated in a compact superconducting LINAC. The beam is injected into the LINAC by a room-temperature Radio Frequency Quadrupole (RFQ) combined with an external Multiharmonic Buncher (MHB). In preparation for future upgrades to the capabilities of ReA, an accurate determination of the longitudinal acceptance of the RFQ was conducted using a stable ion beam from a test source. This paper presents the results of the acceptance measurement, including empirical confirmation of a predicted asymmetry in the shape of the acceptance window.

INTRODUCTION

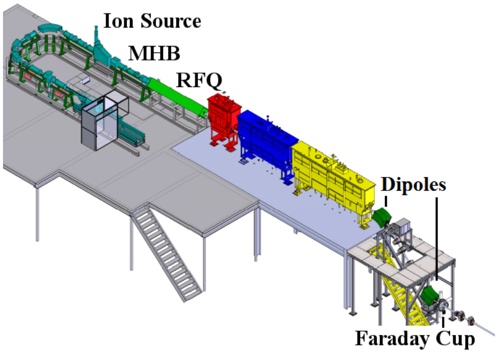

Figure 1: Experimental Layout.

Figure 1 shows the layout of the ReA accelerator facility. The first stage of acceleration at ReA is provided by a room temperature RFQ, specified to accelerate ions with charge to mass (Q/A) ratios in a range from 0.2 to 0.5 from an injection energy of 12 keV/u to 600 keV/u [1]. At present, the beam is bunched longitudinally into the RFQ by the MHB at the RFQ frequency of 80.5 MHz [2]. A proposed future upgrade to ReA would include a prebuncher operating at the 5th subharmonic of 16.1 MHz [3]. Since such a buncher will increase the energy spread of the injected beam, an empirical verification of the longitudinal acceptance of the RFQ is a critical first step in the planning for this device.

MEASUREMENT PROCEDURE

All measurements were performed using a stable H_2^+ beam from an offline test source. The beam from this source has an extremely narrow energy spread (~18 eV RMS for H_2^+). For the purpose of using this narrow energy spread as a sensitive probe of the RFQ energy acceptance, the MHB was turned off for the first part of the measurement. This would never be done in normal operation of the machine, as the unbunched beam has a much lower transmission through the RFQ. However, for this measurement, a higher importance was placed on minimizing the energy spread of the probe beam than on maximizing total transmission.

This beam was tuned through the LINAC, with the accelerating cavities turned off, and through two bending dipoles to ensure that any unaccelerated beam transmitted through the RFQ would not be counted towards the total transmission. The transmission was measured using a Faraday cup after the second dipole.

An initial tune was established at the RFQ design injection energy of 12 keV/u, and optimized for maximum transmission to the Faraday cup to establish a baseline reference. Then the energy of the test source was varied up and down while the beam transport devices were scaled to match the source energy. At each energy level, the beamline was once again optimized to maximize transmission to the Faraday cup, and the beam current was compared to the reference level.

At each energy level, once the overall transmission was established the MHB was turned back on, and the phase of the RFQ was scanned relative to the MHB phase. This allowed for a measurement of the phase dependence of the RFQ acceptance at each energy level. No other RF elements were active during the measurement besides the MHB (when indicated) and the RFQ. Since the MHB has been demonstrated not to affect transverse beam parameters, no retuning was required.

RESULTS

Energy Acceptance

The overall transmission efficiency of the RFQ versus relative energy (dE/E) with the MHB off is shown in Fig. 2. No decrease in transmission was observed until the beam energy was varied more than 5% from the design energy in either direction. The only likely source of potential error in the energy of the beam is from variations in the ion source regulation, which is measured to be less than ~0.1%.

Relative error in the measured transmission rate is more difficult to estimate. The accelerator was tuned at each en-

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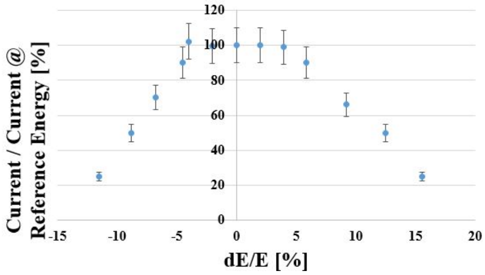

Figure 2: RFQ Transmission vs. Source Energy (MHB Off).

ergy level by an experienced operator, but there is nonetheless a possibility that greater transmission could have been achieved at each level, including the reference energy. It is estimated that the transmission achieved at each level is within 5% of the maximum achievable. The transmission at each level should be treated as a minimum, and the error in the ratio has been calculated accordingly.

Phase Acceptance

Figure 3 shows the results of three scans of the RFQ phase at different energies with the MHB on. The width of the time acceptance is narrower away from the reference energy, as show in in Fig. 4. The peak of the phase scan is offset due to the change of particle velocities, which changes the time of flight from the buncher to the RFQ and thus the measured phase.

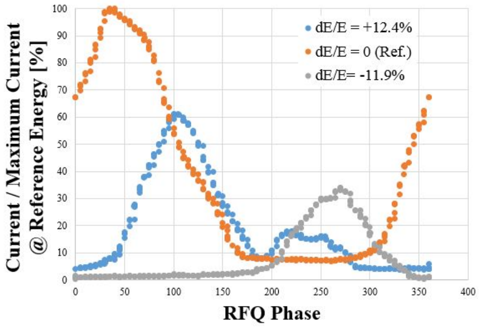

Figure 3: RFQ transmission vs. measured phase for beams at the +0.124, 0, and -0.119 times the reference energy.

One interesting result is that the phase scans at energies greater than 5% above the reference energy have a double peaked structure with two transmission maxima. This matches the prediction of the simulated phase space (see below) but had not previously been directly observed.

Comparison with Simulation

The initial simulation of the longitudinal acceptance for the RFQ was made by generating a simulated beam with minimal transverse emittance and large longitudinal emittance and transporting it through the simulated RFQ [4]. In Fig. 5, the particles which were not successfully transported through the model are shown in red, and the longitudinal acceptance consists of the white area in the center of the distribution.

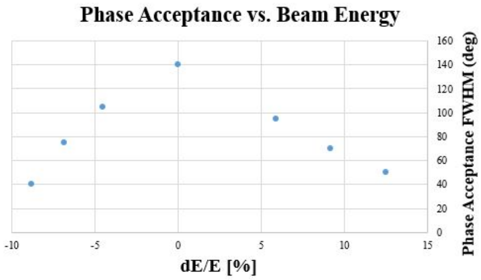

Figure 4: FWHM phase acceptance relative to beam energy.

Overlaid on this plot is the measured acceptance window calculated as follows: The energy peak of the phase scan taken at each energy level with the MHB on (for maximum time precision) was normalized to the energy level relative to the reference determined with the MHB off (for maximum energy precision). The maximum phase for each phase scan was offset in time by the calculated phase advance for each beam velocity.

Since the absolute RF phase of the RFQ is not known, the measured acceptance window is shown here overlaid on the simulation such that the peak of the transmission curve at the reference energy coincides with the center of the simulation window. The blue points indicate the edges of the FWHM transmission relative to the maximum transmission at each energy level, with an estimated +/- 10° error in phase.

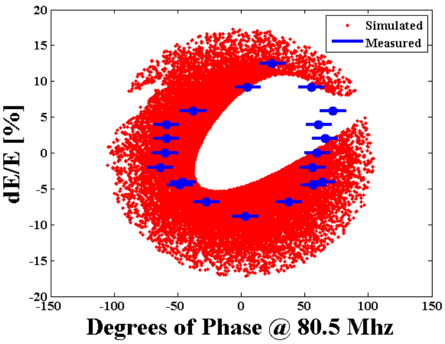

Figure 5: RFQ Longitudinal Acceptance.

A complete determination of this window would require a full measurement of the time structure of the probe beam, which could then be deconvolved with the phase scan. Without such a measurement, this window may be regarded as a minimum phase acceptance. Since the energy width of the beam used for the measurements is <0.1%, the same concern does not apply in the vertical direction.

CONCLUSION

A series of measurements was undertaken in November 2013 to characterize the longitudinal acceptance of the ReA RFQ. It was determined that the range of beam energies transmitted at optimum phase with minimal loss is +/- 5% relative to the design energy of 12 keV/u. This acceptance width is consistent with simulation, and should allow for the construction of a low frequency prebuncher with an energy spread of +/- 3-4%.

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