COMMISSIONING OF THE NEW SNS RFQ AND 2.5 MeV BEAM TEST FACILITY

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Abstract

The SNS injector uses a four-vane 402.5 MHz RFQ for accelerating the H- beam with 38mA peak current and 7% duty factor to 2.5 MeV. The original RFQ, commissioned in 2002, has been able to support SNS operation up to the design average beam power of 1.4 MW. However, several problems have developed over almost fifteen years of operation [1]. A new RFQ with design changes addressing the known problems has been built and commissioned up to the design beam power at the new SNS Beam Test Facility (BTF). The BTF consists of a 65 kV H^- ion source, a 2.5 MeV RFQ, a beam line with advanced transverse and longitudinal beam diagnostics and a 6-kW beam dump. This presentation provides results of the RFQ commissioning and the BTF beam instrumentation commissioning. We also discuss progress of the ongoing multidimensional phase space characterization experiment and future beam dynamics study planned at the SNS BTF.

INTRODUCTION

The SNS Beam Test Facility (BTF) functionally replicates the SNS Front End systems to ensure relevance of beam measurements at the BTF for SNS operation. A layout of the BTF is shown in Fig. 1. A detailed description of the BTF systems can be found in [2].

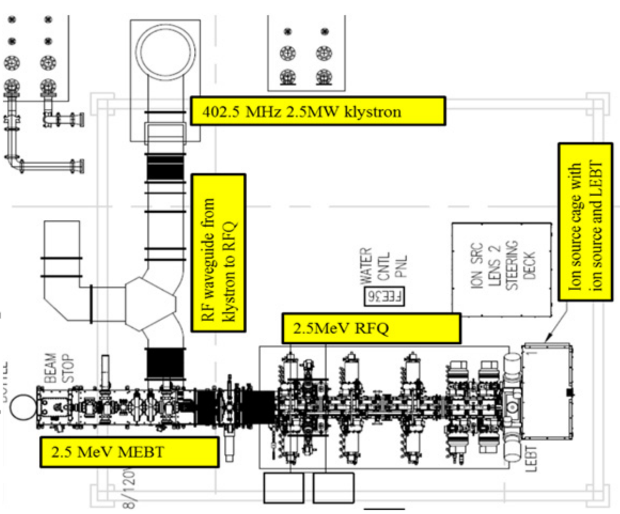

Figure 1: General layout of the SNS Beam Test Facility.

The main goals of the SNS BTF are:

- To verify operation of the spare RFQ with beam.
- To provide a facility for testing existing equipment and developing new equipment for improving SNS reliability and power capability.
- To provide a facility for conducting R&D for novel accelerator physics and technological concepts related to high intensity hadron beam generation, acceleration, manipulation and measurement.

This document describes the results of the BTF commissioning and the new SNS RFQ characterization. The ongoing R&D efforts to measure the 6-dimensional bunch phase space are described in [3] and the design of an experiment to study development of a halo in high intensity hadron beam is presented in [4].

NEW RFQ COMMISSIONING

RFQ RF Field Calibration

The RFQ cavity was RF conditioned to the RF power of 600kW at the design duty factor of 6% prior to the commissioning with beam. The amplitude of the RFQ inter-vane voltage was calibrated using the X-ray spectrum cut-off technique [5]. A typical measured X-ray spectrum is shown in Fig. 2 and the resulting calibration curve is shown in Fig. 3. All the subsequent measurements with beam were done with the design RFQ inter-vane voltage of 83 kV.

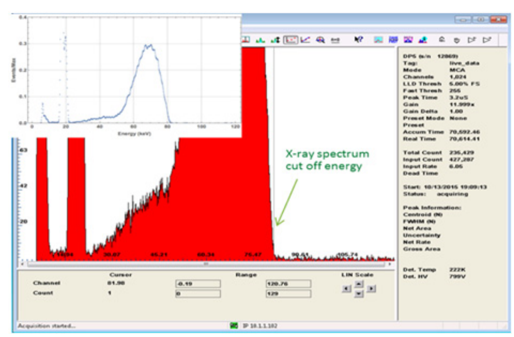

Figure 2: Measured energy spectrum of X-rays coming out of the RFQ cavity.

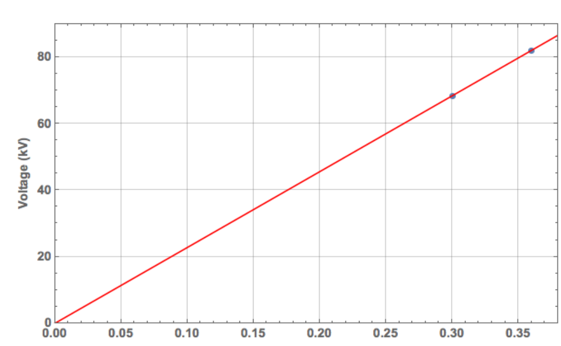

Figure 3: The RFQ inter-vane voltage calibration curve obtained by the X-ray spectrum cut-off measurements.

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RFQ Transmission

The input beam current to the RFQ was measured by deflecting the beam on the insulated electrode mounted on the RFQ entrance wall ("chopper target") as illustrated in Fig. 4. A short 1 us high-voltage pulse was applied to the LEBT steering electrodes to deflect the beam and the beam current from the chopper target was measured.

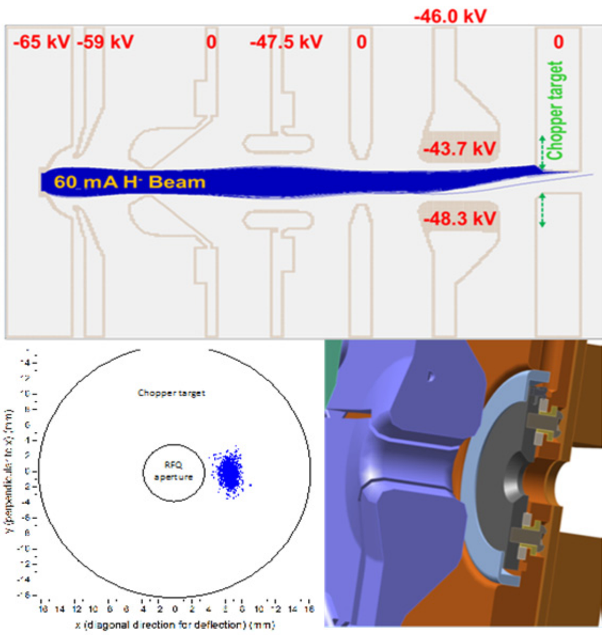

Figure 4: The ion beam envelope in the LEBT with deflecting voltage applied to the steering electrodes (top); simulated distribution of the deflected beam on the chopper target (bottom left); layout of the deflecting electrodes and the chopper target (bottom right).

The RFQ output beam current was measured by a current transformer in the beginning of the MEBT (BCM) and by collecting charge at the beam dump. Typical signals from the BCM and the beam dump are shown in Fig. 5. The location of the diagnostics is shown on the MEBT layout in Fig. 6. A transmission of 88% was measured with 44mA output beam current. We lost ability to measure the transmission in the later part of the commissioning due to damage of the chopper target.

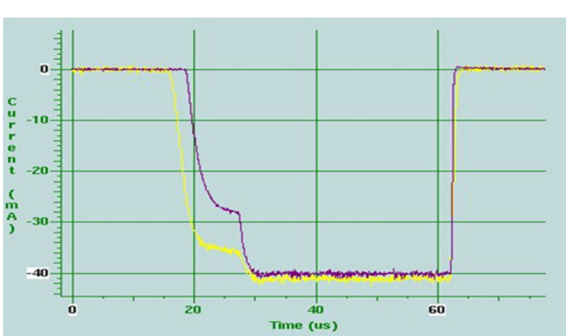

Figure 5: Beam current pulse measured by the BCM (yellow) and at the beam dump (brown).

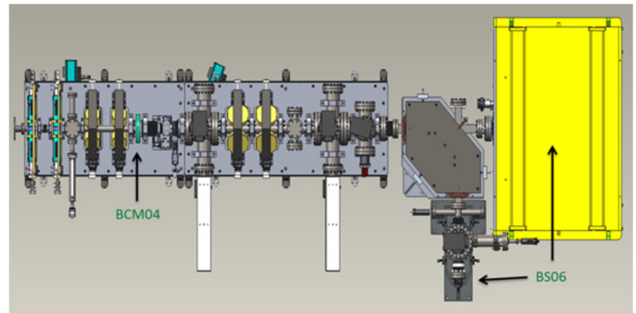

Figure 6: A layout of the BTF MEBT.

The dependence of the RFQ output current on the RF field amplitude is shown in Fig. 7. It is worth noting that the RFQ transmission is not fully saturated at the design set point of .36 (arbitrary units) and there is a significant variation from one ion source to another.

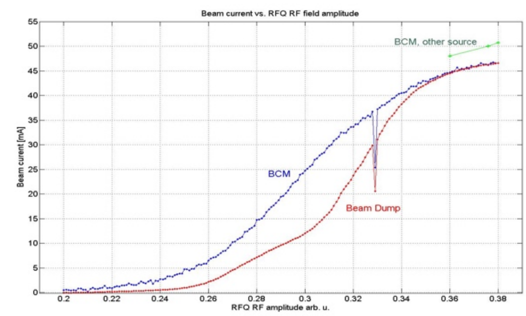

Figure 7: RFQ output current vs. RF field amplitude.

RFQ Output Beam Energy

The output beam energy was measured by time-of-flight technique using a movable phase detector. The measured dependence of the beam phase on the detector displacement is shown in Fig. 8. The beam velocity is linearly proportional to the slope of the curve. The measured beam energy of 2520±20 keV is close to the design value. The beam energy was measured at different beam currents with several different sources and did not show any appreciable variation.

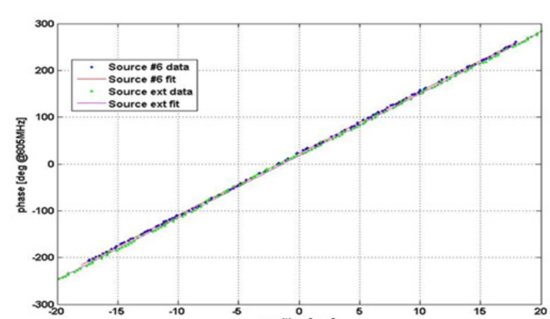

Figure 8: The measured dependence of the bunch phase on the detector displacement.

RFQ Output Beam Transverse Emittance

The RFQ output beam transverse emittance was measured using two pairs of slits separated by a ~1 m drift as shown in Fig. 6. The horizontal and vertical slits at the same location are offset by ~10mm longitudinally and, therefore, can move simultaneously without collision. The beam charge coming through the slits is measured at the downstream beam dump. This system allows measuring conventional 2D horizontal and vertical emittances, transverse 2D x-y distribution and full 4D phase space [3]. A typical result of horizontal and vertical transverse emittance measurement is shown in Fig. 9. The measured RMS emittance value is in the range of 0.25÷0.35 π·mm·mrad, depending on the beam current, the MEBT optics and the ion source used.

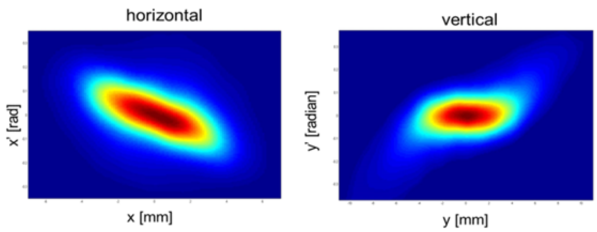

Figure 9: Horizontal and vertical transverse beam emittance measured with slit-slit system.

RFQ Output Beam Longitudinal Emittance

Diagnostics for measuring longitudinal bunch parameters include a view screen located in the dispersion region after the 90° dipole magnet, and a Beam Shape Monitor (BSM). The beam energy spread can be derived from the horizontal profile of the image on the screen. The view screen has a vertical slit to allow a narrow slice of the beam energy spectrum to go through to the BSM, where the temporal distribution of the slice is measured. By scanning the energy slit over whole beam energy spectrum the longitudinal emittance of the bunch can be reconstructed. The BSM screen images with the deflector RF off and on are shown in Fig. 10. An example of the reconstructed longitudinal emittance is shown in Fig. 11. The measured RMS emittance value is ~0.25 MeV·deg @402.5MHz

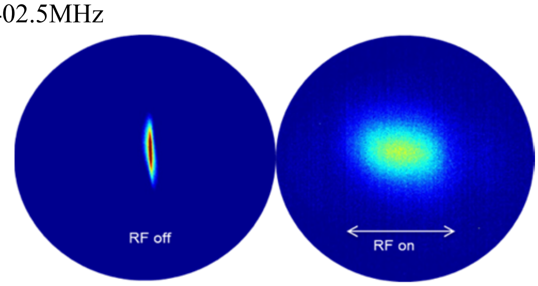

Figure 10: Image on the BSM screen with the deflector RF off (left) and on (right). Projection of the right image on the horizontal axis is the temporal bunch profile.

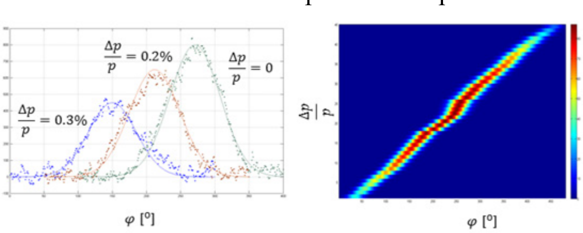

Figure 11: Longitudinal bunch emittance (right) constructed of multiple temporal profiles from BSM (left) measured with different energy slit positions.

High Power Beam Test

A two-hour high power beam test at the design SNS duty factor of 6% was conducted to verify the RFQ stability under the nominal production beam loading. A strip-chart of the most important parameters during the test is shown in Fig. 13. The new RFQ demonstrated good stability and fast recovery after RF power and/or input beam interruption. A maximum peak beam current of 50mA was achieved by maximizing the ion source current and increasing the RFQ RF amplitude by ~2%. The beam current measured during the high-power test and the maximum peak current demonstration are shown in Fig. 12.

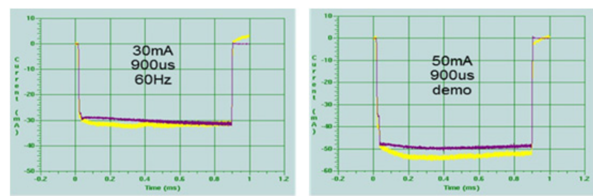

Figure 12: The beam current measured at the BCM (yellow) and the beam dump (red) during high power and high peak current tests.

Figure 13: Strip-chart of the beam current (blue), the RFQ resonance error (brown), RF amplitude (green), and the RFQ vacuum during 2 hours high power beam test.

ACKNOWLEDGMENT

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