Title
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THE SNS RFQ COMMISSIONING*

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Abstract

LBNL has built for the Spallation Neutron Source (SNS**) project a 402.5 MHz RFQ that is designed to accelerate up to 60 mA H^- from 65 keV to 2.5 MeV [1]. A one millisecond pulse length at 60 Hz provides a 6% duty factor. The RFQ has now been built, conditioned at full duty factor and tested with beam. This paper will present results from the final installation, tuning and beam commissioning. Beam measurements include acceleration and transport efficiencies and transverse emittances. The LEBT optics were tuned for best results. Performance testing of the RF power distribution is also discussed here.

1 INTRODUCTION

The SNS is a collaboration of six US Laboratories for the design and construction of a high power accelerator complex optimised for the production of neutrons. LBNL was responsible for the Front End (Linac injector) comprising an H^- ion source, a Low Energy Beam Transport (LEBT) line, a 2.5-MeV RFQ accelerator, and a Medium Energy Beam Transport (MEBT) line. This injector was completed and fully commissioned in the spring of 2002. The present paper is mostly concerned with construction, installation on a support structure, and commissioning of the RFQ. The discussion of RFQ beam results includes measurements with the LEBT chopper that used the RFQ cavity to obtain an appreciable degree of beam extinction.

2 CAVITY ASSEMBLY

The SNS RFQ is made of four modules which were built and individually conditioned to full power. Fabrication details of each module and of the interconnections between modules have been previously described [2-7].

The four-module assembly is supported by means of a six-strut system attached to a steel support frame. The structure also supports all cabling from the beamline equipment to the controls interfaces or the main cable trays, providing a simple configuration to reconnect at the SNS site after the shipment to Oak Ridge.

The RFQ support frame is a welded structure made from heavy tubular steel weighing in excess of 3000 pounds. For the purposes of installing and supporting the RFQ in the Front End Building at ORNL, a simpler system could have been devised. However, the requirement that the system be assembled and tested at LBNL and then lifted, loaded on a truck and shipped to ORNL without being disassembled led to the current configuration, designed to withstand significant dynamic loads. In view of the severe cost and schedule implications that damages to the RFQ during lifting or shipping would have caused for the SNS project, the support structure was subjected to extensive review and testing.

3 RF DRIVE SYSTEM

The RF power is fed into the RFQ via eight drive loops and coaxial vacuum-barrier windows located at a distance of $\lambda/4$ from the cavity walls.

The vacuum windows were purchased from CPI and conditioned in pairs using a dummy load to terminate the transmission line. The conditioning process was lengthy and eventually required an additional TiN coating on the vacuum side of the windows, performed at LBNL. All windows performed flawlessly, once the initial conditioning process was completed.

The process of setting the eight loops that couple up to 100 kW through each loop was particularly delicate. All loops are coupled to each other through the RFQ resonator. At the same time each of the four RFQ modules is powered by two loops, one per side, which are fed by hybrid rings that ensure at least 20 dB of isolation between those ports. In the final configuration, the largest difference between the highest and lowest of the coupling coefficients is about 1.0 dB.

4 BEAM COMMISSIONING RESULTS

Beam commissioning of the RFQ began in late January of 2002, with the beam successfully reaching the beam stop on the first shot.

To support beam commissioning of the entire Front End with characterisation of RFQ and MEBT [8] beams, a

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diagnostic beamline consisting of an emittance scanner using a slit and wire-harp collector configuration was built. The device is rotatable to perform measurements either in the horizontal or in the vertical plane with the same hardware. The emittance scanner was developed in collaboration with the SNS Beam Diagnostics and Controls groups.

4.1 Transmission measurements

The transmission through the RFQ was measured as a function of power. Fig. 1 demonstrates very good agreement between the measured transmission and that calculated by Toutatis [9].

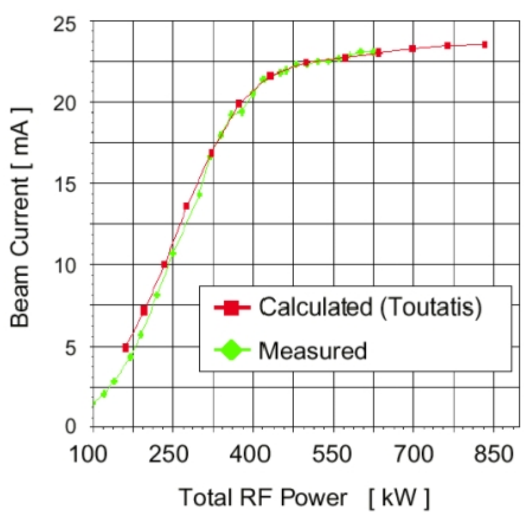

Figure 1 – Comparison between measured and calculated RFQ transmission for a 23-mA beam

4.2 Transverse emittance measurements

Using the diagnostic beamline, the transverse emittances both in the horizontal and in the vertical plane were measured. An example is given in Fig. 2.

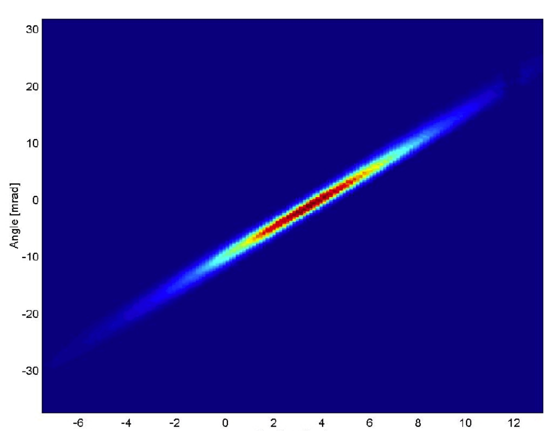

Figure 2 – Measured vertical RFQ emittance with a size of 0.260 π mm mrad, for a 20-mA beam.

Representative results are shown in Table 1, together with results of Toutatis simulations. The agreement between measured and expected values is very good.

Table 1 – Measured and calculated normalised rms emittances and Twiss parameters for the RFQ

Current mA	Emittance π mm mrad	α	β m	Remark
				Horizontal
14.0	0.210	-11.86	5.4	Measured
21.8	0.272	-12.91	6.47	Measured
32.0	0.282	-12.75	6.41	Measured
20.0	*0.296*	*-11.13*	*5.32*	*Simulated*
				Vertical
13.4	0.204	-6.69	2.52	Measured
21.8	0.286	-6.94	2.62	Measured
29.8	0.298	-6.00	2.29	Measured
20.0	*0.254*	*-8.17*	*3.15*	*Simulated*

5 LEBT CHOPPING

The last lens in the LEBT is split into four quadrants to allow for electrostatic steering and pre-chopping before the beam enters the RFQ. For the chopping function, the lens segments are pulsed with bipolar signals up to ±3 kV supplied by commercial bipolar solid-state active switches. An FPGA-driven clock distribution-system was built and programmed to provide triggers to the switches.

Proof-of-principle LEBT chopping experiments demonstrated rise and fall times around 25 ns, as shown in Fig. 3. These times are driven by the capacitive loads presented by the lens segments. The pre-chopping system is complemented by a strip-line chopper in the MEBT that provides faster rise/ fall times and further attenuates the beam in the gap. Fig. 4 illustrates the beam attenuation after the full RFQ.

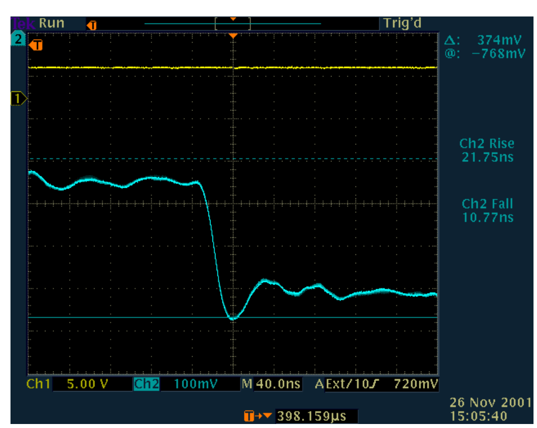

Figure 3 – Rising flank of the negative ion beam at the end of a chopping pulse. 400 ns full horiz. scale.

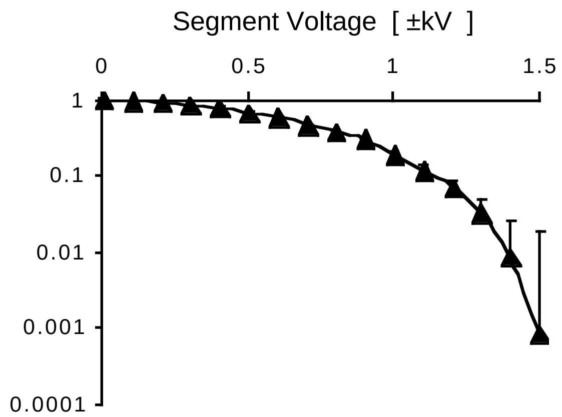

Figure 4 – Transmission of a pre-chopped beam with error bars, as a function of the applied voltage.

6 SUPPORT OF MEBT COMMISSIONING

Upon completion of the RFQ beam commissioning, this accelerator structure became the injector for the MEBT and supported the testing with beam of this transfer line [8]. The RFQ performed well throughout the whole front end commissioning and helped achieve results that went well beyond the specified and required performance.

Among the results achieved, a peak current of 50 mA was recorded at the end of the MEBT, much in excess of the design value of 38 mA, but still well within the design "choke" current of the RFQ.

The system was also successfully operated at the 6% nominal duty factor, and fully supported a weeklong round-the-clock endurance test held in early May.

7 SHIPMENT TO SNS

To prepare for shipment to Oak Ridge in June, the RFQ was separated from the beamline and power systems. Vacuum pumps and selected ancillary systems were also removed, including the RF windows. In order to prevent damage to the RFQ and its auxiliary components during shipping, the support was mounted on a series of high density foam blocks and attached to a large shipping skid that was then tied to the truck bed. Lateral movement of the structure was restrained by a series of turn buckles placed between the skid and RFQ support at a slight vertical angle. The size and placement of the foam blocks were engineered to significantly reduce the shock and vibration loading on the RFQ during shipping.

Upon arrival, the system has been reassembled and vacuum leak-checked to confirm the integrity of all components, including windows. No leaks were found. Low level RF measurements also confirmed the proper positions of all drive loops which had remained installed in the cavities during shipment.

8 PLANS FOR OPERATION AT SNS

The SNS Front End will be commissioned again after final installation at ORNL in the fall of 2002. This effort includes the integration of the RFQ with the final high power rf system currently under development and fabrication at LANL. The commissioning of the front end at Oak Ridge is due to be completed in December of 2002.

9 ACKNOWLEDGEMENTS

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