FABRICATION AND TESTING OF THE FIRST MODULE OF THE SNS RFQ ⁕

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Abstract

The 2.5 MeV injector for the Spallation Neutron Source is currently under construction at LBNL, which includes a 2.5 MeV high power, high duty factor four vane RFQ made of four modules. Transverse mode stabilization is obtained through a series of cross coupling rods. Each of the four RFQ modules is equipped with twenty fixed tuners, two active power and two vacuum ports. Fine frequency tuning is accomplished by adjusting the temperature differential in two separate cooling circuits, one on the RFQ body and the other near the vane tips. The RF drive is provided via 3-1/8 inch rigid coaxial lines and a coaxial RF vacuum barrier window. The first module has been built, confirming all fabrication, assembly and brazing techniques. This paper will cover the mechanical fabrication details as well as the early results from commissioning tests underway at LBNL.

1 INTRODUCTION AND SYSTEM DESCRIPTION

The SNS complex has been under construction for the past two years. In the collaborative effort among six US National Laboratories, LBNL is responsible for the delivery of a fully tested injector capable of 52 mA at an energy of 2.5 MeV and with the time characteristics of the SNS beam at 6% duty factor. This injector has been described extensively at previous meetings [1,2]; several reports are also being presented at this conference [3,4,5].

The RFQ is made of four modules each 93 cm long. The four vane structure is made of OFE copper with brazed on GlidCop® forming an outer shell to provide strength for all mechanical connections. No water-to-vacuum brazes are used in the design, keeping the GlidCop braze completely outside of the vacuum. Quadrupole symmetry is stabilized by means of π-mode stabilizer rods, which are water cooled and brazed into the structure[6].

The cavity has been modeled extensively, both with electro-magnetics codes, and with thermal and structural analysis software [7]. The structure is coarsely tuned by a multitude of fixed tuners, complemented by a dual temperature cooling system that performs fine tuning functions.

Each of the four modules that make up the RFQ contains twenty fixed tuners and two RF power ports. The RF is distributed by an 8-way splitter that can be configured to test individual modules or pairs as well. The RF is fed to each cavity by coupling loops after passing through commercial ceramic vacuum windows. The module is shown in Fig. 1.

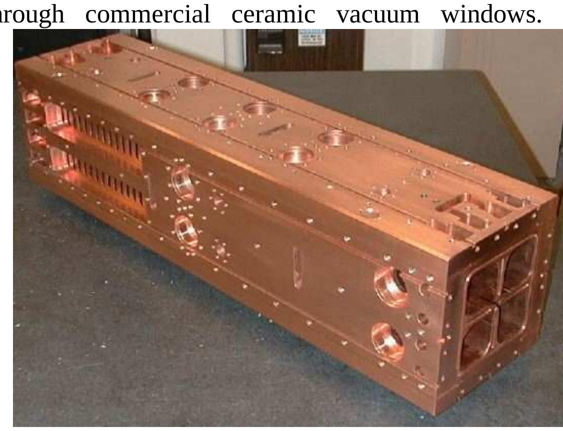

Figure 1 - The RFQ body

2 FABRICATION

After the successful fabrication of the first cavity [8] a number of conclusions can be derived from the experience.

The single most critical step in the fabrication process is the final braze, where the four vanes are joined together maintaining a the vane-to-vane spacing tolerance of less than 25 μm (1 mil). This step was monitored before and after the final CuSil braze by means of field perturbation measurements. The observed frequency shift due to the brazing was less than 215 kHz, corresponding to a motion of less than 5 μm (0.2 mils). This was also checked by a coordinate measurement machine, and the results agreed to the accuracy limit of the measuring device. Such a successful ‘zero thickness braze’ was achieved by using a clamping arrangement that kept the pressure on the four vanes well balanced.

The final braze joined the four vanes together, as well as connecting the 12 π-mode stabilizing rods to the cavity

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walls. All these braze joints were leak tight, with the exception of one rod end, which was sealed using an O-ring back-up. Fig. 2 shows the module installed in the brazing oven.

The GlidCop-to-Copper braze procedure will be modified for the remaining three modules. In the first module, the successful joint was obtained by acid copper plating (50 mils, then machined to ensure surface flatness) of the GlidCop surfaces prior to brazing and the use of a stainless steel vacuum enclosure that applied 15 psi to the joining surfaces. In the current production of the remaining three modules a few changes have already been made to simplify and improve the fabrication process. Hot Isostatic Pressed (HIP) GlidCop has replaced the extruded material used in the first unit, providing more mechanical stability. As a consequnece, the load during the braze could be reduced to 3 psi, making the use of the vacuum jacket unnecessary.

Figure 2 - The RFQ module ready for the final braze

3 ELECTRICAL MEASUREMENTS AND TUNING

For RF power testing a single module must be properly terminated at both ends. While the entrance end has been designed to mount on the ion source and has the final vane undercut geometry, the end of this module is flat to mate directly to the vanes of the second module. A vane termination block with appropriate cut-backs has been built with full vacuum and cooling capabilities to support both low level and high power testing of the first module.

Once the module was completed, the manufacturing process was checked with frequency measurements. The following table summarizes the measured frequencies and frequency shifts.

Cavity body (w/o tuners)	403.8 MHz
Fixed tuner displacement	415 kHz/mm
Vane tip Displacement	43 MHz/mm

Table 1 - Measured RF frequency and tuning effects

The measured Q is about 6750, or 65% of the value for pure copper as resulting from Superfish calculations neglecting losses on the ends, π-mode stabilizers or tuners. This is in agreement with the assumptions made on power dissipation for the thermal analysis and RF drive design.

The cavity was then tuned to the desired frequency by cutting the fixed tuners to size. In order to allow for a small correction of all tuner lengths when all modules of the cavity are installed together, the tuners were for now cut to have an operating frequency of this module at 402.850 MHz. This frequency will be reduced to the final operating frequency of 402.5 MHz when the additional modules have been added. The set of 20 tuners can change the cavity frequency by more than ±2 MHz.

Once installed on the test stand, the tuning sensitivity to the dual temperature water cooling system was verified and showed good agreement with the calculated value of –33kHz/deg C [9].

4 HIGH POWER CONDITIONING

The LBNL team has developed a test facility to support testing and commissioning of the RFQ at high power. Thanks to the support of LANL staff, a 1 MW tunable klystron has been installed and commissioned. The setup has been completed with the installation of a circulator and dummy load. This power system can be configured to feed the RFQ or an RF windows test stand. The RFQ test stand offers the possibility of closely monitoring water flow and temperatures in the separate cooling channels. Such expanded features will not to be available in the complete RFQ but can be used to verify the cooling design and dual temperature tuning system.

The cavity has been conditioned to full power for a 1 ms pulse length and a high duty factor of 3%, operating at 30 Hz. The testing was performed using a single RF vacuum window, which was run at 150 kW, corresponding to full gradient in the cavity. During operations the temperature across the ceramic window was routinely monitored and air cooling applied when the higher duty factor was reached at full power. The addition of a second window will allow testing at full duty factor.

The vacuum system uses two Cryotorr 8 pumps, supplemented by a VacIon15 that provide an additional 15 l/s of pumping in proximity of each vacuum window. Both the pumping system and the vacuum seals (tin seals on tuners and RF pick-up loops, and O-rings on the end blocks) are performing well. During RF conditioning, the vacuum level and its multipactoring or spark induced bursts both in the resonator and near the RF window were monitored. Each window is equipped with an arc detector. The RFQ module test stand is shown in Fig. 3.

Figure 3 - The RFQ module test stand

5 TUNING LOOP AND INTERFACE WITH THE CONTORLS SYSTEM

The EPICS control system is not part of the testing setup at LBNL. However, EPICS is actively used to monitor the RF frequency and execute the tuning correction. The local tuning loop has successfully been implemented and commissioned during the operation of the conditioned cavity.

The resonant frequency of the RFQ is adjusted by changing the water temperature of the vane water circuit. A software regulation loop is employed to keep the tune within a few kHz of the nominal frequency. This system relies on the accurate measurement of the frequency error of the RFQ resonance relative to the stable oscillator that drives it.

In our pulsed system, where the input drive turns off much faster than the decay time of the fields in the cavity, the decay waveform contains unambiguous tuning information. A pair (I/Q) of mixers are used to convert that signal to baseband, and are connected directly to a Tek TDS210 oscilloscope. 25 μs of the decay signal are digitized and sent to the local controls computer over an RS-232 link. Once per second, that waveform is fit to a decaying complex exponential, where the imaginary term in the exponent represents frequency shift. The output represents the frequency offset between the cavity and the reference oscillator. Changes in phase lengths of cables, or other adjustments typical of phase feedback loops, are irrelevant to the measurement.

The system has been demonstrated to operate stably. The frequency is measured with rms scatter of about 1 kHz, much smaller than the cavity bandwith. When RFQ fields change, the regulation loop shows corrections on a time scale related to the water transit time from the chiller to the RFQ (36 seconds).

6 STATUS AND PLANNING

After the successful commissioning of the first module, the cavity will be connected to the ion source and LEBT structures. This will allow testing with beam, measuring capture and LEBT chopper performance.

The production of the remaining three modules has started, and the present test stand will be used for the commissioning of each individual module as it comes out of production.

7 ACKNOWLEDGMENTS

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