THE DESIGN OF A HIGH CURRENT, HIGH DUTY FACTOR RFQ FOR THE SNS[*]

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Abstract

The Lawrence Berkeley National Laboratory (LBNL) is presently designing and building the 2.5 MeV injector for the Spallation Neutron Source (SNS). This injector comprises an H$^-$ ion source, a radio-frequency quadrupole (RFQ) and a beam transport line including a fast chopper. This paper will briefly describe the injector components and then focus on the design and fabrication details of the RFQ, from the beam dynamics, to the mechanical and electrical engineering design. The first module of the RFQ has been built and is presently undergoing tests at LBNL. A status report of the first module is included, describing the completion of the fabrication and low power testing.

1 INTRODUCTION

The SNS facility is under construction for the US Department of Energy (DoE). The Oak Ridge National Laboratory (ORNL) and the DoE have formed a collaboration of six US national laboratories that includes Argonne (ANL), Berkeley (LBNL), Brookhaven (BNL), Jefferson Lab (TJNAF), Los Alamos (LANL) and ORNL. LBNL is responsible for the design and construction of the Front End [1], an H$^-$ injector that is designed to deliver 52 mA at 2.5 MeV of beam current. The SNS linac delivers 650 ns pulses to the ring and target and it is designed to operate at a 60 Hz repetition rate, for a beam duty factor of 6%.

The Front End comprises of an Ion Source, an electrostatic beam transport line (Low Energy Beam Transport – LEBT), an RFQ and a Medium Energy Beam Transport line (MEBT). The RFQ accelerates the beam from 65 keV to 2.5 MeV.

LBNL has a long tradition in RFQ and cavity design and fabrication both for use in accelerators at Berkeley and for other laboratories worldwide. Previous RFQ systems were built for CERN [2] and Brookhaven [3]. Similarly the LBNL has recently been responsible for the design and fabrication of the cavities for the PEPII B-Factory and is now contributing to cavity design efforts for the Muon Collider collaboration.

2 SYSTEM DESCRIPTION

The SNS RFQ is designed to accelerate the H$^-$ ions from 65 keV to the final front end energy of 2.5 MeV. The physics design parameters are summarized in Table 1 [4]. The RFQ is made of 499 cells apportioned in the successive sections in a conventional way. The field is kept constant along the cavity to minimize the RF current through the module-to-module joints. The buncher section is slightly longer than usual to keep the output longitudinal emittance below 95 keV-degree at full current. The beam transport has been simulated using eight-term beam dynamics codes, and the calculations show an expected transmission better than 90% at full current. The choke current for this RFQ is slightly above 100 mA.

Table 1 - Physics Parameters of the RFQ

Species	H$^-$
Input Energy	65 keV
Output Energy	2.5 MeV
Peak output Current	52 mA
N. of cells	449
Design Transmission	> 90 %
RMS Beam Size	0.7 mm
Long. Emittance	103 π keV-deg
Norm. H rms Emittance	0.21 π mm mrad
Norm. V rms Emittance	0.21 π mm mrad
Pulse Length	1 ms
Repetition Rate	60 Hz

The cavity has been modeled extensively and designed in iterative steps. The general cross-sectional shape and frequency sensitivity have been determined with Superfish, whereas MAFIA has been used to study the end and mode stabilizer geometry. A cold model was used to verify these simulations and determine the final cavity shape as well as the tuning of the module terminations [5].

The SNS RFQ is a 4-vane structure. The separation between dipole and quadrupole modes is obtained by using straight rods, called π-mode stabilizers (PISLs) that

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couple opposing quadrants. These rods are an evolution of the coupling rings adopted in earlier RFQs built at LBNL and have been implemented successfully at KEK [6].

Because of the high duty factor operation, the four quadrants are brazed together, whereas the end-to-end bolted connections between the four modules include RF seals. A summary of the cavity design parameters is listed in Table 2.

Table 2 - Engineering Parameters of the RFQ

Structure Type	4 vane
Total Length	3.723 m
RF Frequency	402.5 MHz
Vane-to-vane Voltage	83 kV
Peak Field	1.85 Kilpatrick
Total Peak RF Power	800kW (incl. beam)
Beam loading	17 % @ 56 mA
RF Duty Factor	6.2%
Theor. (2D S-Fish) Q	10400
Measured Q	6350

The RF power is fed via eight coupling loops through coaxial RF windows. Both the RF power distribution system and the windows have been commercially manufactured. The low-level RF system as well as the final power system will be provided by Los Alamos and is designed to be operated by the EPICS control system. LBNL has an existing klystron (also thanks to LANL) in house that will be used for doing cavity testing and conditioning as well as beam tests of the entire front end. An overall layout of the RFQ is shown in Fig. 1.

The primary RF seals are metal: The module-to-module joints are achieved by compressing a raised copper surface against the adjacent module, whereas all penetrations use tin seals, which serve also as primary vacuum seals. The tin seal method, has been qualified and tested for RF performances at these frequencies. All metal seals are designed to accommodate a backup viton seal with an RF spring-ring.

The π-mode stabilizer rods shift the dipole mode about 35 MHz above the quadrupole mode, while lowering the quadrupole mode frequency by about 11 MHz. Computer simulations using MAFIA were used to optimize the rods spacing and to estimate the expected power dissipation on the rods. These rods are water cooled.

The cavity tuning scheme comprises a set of 20 fixed tuners per cavity. The design of the fixed tuners allows for a tuning range of ±2 MHz around the center frequency of the cavity body. The dynamic tuning of the RFQ will be achieved by the use of a dual temperature tuning system, where the water cooling the vane tips is maintained at a different temperature than the water cooling the RFQ body. This tuning system will also accommodate the cavity turn-on transient.

The vacuum design is based upon tin seals on all penetrations and viton seals between modules. All vacuum-to-water braze joints have been avoided.

3 FABRICATION

The RFQ consists of four modules of nearly equal length. Each module is joined to the next section using recessed bolt-pockets.

Each cavity module is built in four sectors, each containing one vane, made of a layer of GlidCop® brazed to an inner layer of oxygen-free OFE copper. The GlidCop is used because its good residual strength after brazing allows for a strong support and connection of all devices like RF and vacuum ports or fixed tuners. It also provides the structural strength in the joints between the modules.

In the first fabrication step, all penetrations are machined both in the OFE and the GlidCop. The vane tip

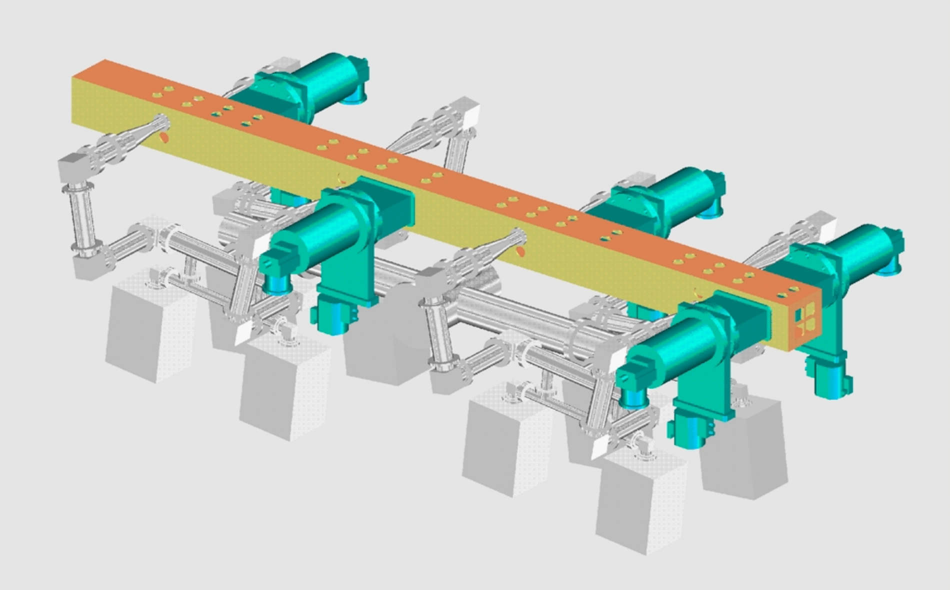

Figure 1: General layout of the RFQ

cooling passage is machined into the OFE copper using a deep saw. A filler piece is then used to complete the channel. All cooling passages are machined into the OFE surfaces and are sealed during the first brazing cycle, when the GlidCop is brazed to the OFE. This gold foil braze is done in a hydrogen oven after the GlidCop is acid copper plated to prevent diffusion of the gold alloy in the material. An exploded view showing the assembly of each module is shown in Fig. 2.

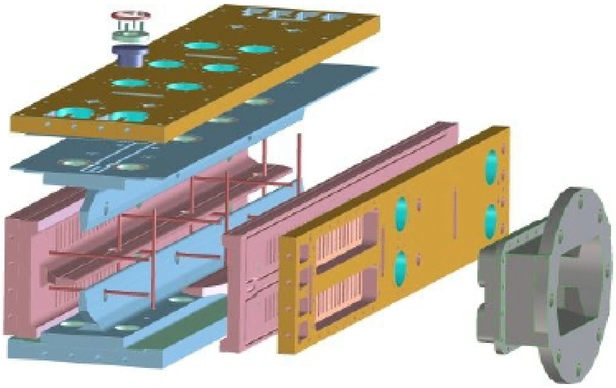

Figure 2: RFQ exploded view

After the first brazing, each vane profile is rough machined. The final modulations are machined in the vane tips using a constant radius form cutter and a numerically controlled mill that is computer driven and uses the parameters directly derived from the beam dynamics software. The machining of the vane tip modulations was extensively tested to determine cutting speed and compliance with machining tolerances.

The final braze is very critical since the vane tip-to vane tip frequency sensitivity is very high (43 MHz/mm). The ‘zero thickness’ braze method has been implemented, whereby the silver braze alloy is diffused in along the mating surfaces by capillary action. The RFQ is brazed in a vertical configuration to minimize possible cavity deformations. During this step all stabilizer rods are also brazed in the cavity using the same capillary technique. The stabilizer rods design allows for the installation of a back-up O-ring in case of a leak.

After the second braze, the cavity end surfaces are machined to final dimensions and the fixed tuners are cut to the dimensions determined by the cavity perturbation measurements.

4 STATUS AND TEST RESULTS

The fabrication of the first module has now been completed [7]. A full set of measurements proves that the final brazing step changed dimensions by less than 5μm (0.2 mils). This was verified both by frequency and field measurements and a coordinate measurement machine. The cavity design parameters such as the frequency sensitivity due to vane tip spacing and tuners displacement of 43 MHz/mm and 415 kHz/mm respectively have been validated with direct field measurements and are in very good agreement with the predictions based upon Superfish. The final size of the fixed tuners has also been determined.

The quality factor Q of the cavity is about 6750. This is approximately 65% of the theoretical Q as calculated by Superfish, not including any tuners, stabilizer rods or end flanges.

The first module is currently under preparation for high power testing. The cavity is connected to an end block that properly terminates the vanes at the exit end of the cavity. The RF system has been commissioned and the windows have been conditioned for operation at full power (100 kW each).

Full high power operation of the RFQ, including frequency tuning and RF conditioning is planned for summer 2000.

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