CONCEPTUAL DESIGN OF THE SNS RFQ *

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Abstract

The conceptual design of the RFQ included in the front end injector of the Spallation Neutron Source is described. The RFQ operates at 402.5 MHz, with a maximum H^- input current of 70 mA and 6% duty factor. It is 3.72 m long and made out of four equally long modules. A brazed copper structure has been chosen due to the high power, high duty factor operation. The 800 kW peak r.f. power is coupled into the structure via eight ports, two per section. A set of tuners is provided for final frequency adjustment and local field perturbation correction. Quadrupole mode stabilization is obtained with a set of π-mode stabilizing loops. The conceptual design, assembly processes and status report are presented. This paper reports and updates the status of the design since it was last described [1].

1 INTRODUCTION

Lawrence Berkeley National Laboratory has been given the responsibility within the SNS collaboration of designing, building, installing and commissioning the Front End. This 2.5 MeV injector comprises the ion source, an electrostatic beam transport into the RFQ accelerator and the beam transport line that will deliver and match the beam into the linac. The radio frequency quadrupole (RFQ) accelerator is responsible for the bunching and acceleration of the beam from the energy of 65 keV after the source to the 2.5 MeV injection energy into the linac. A summary of the status of the SNS Front End is presented in another paper at this conference [2]. Intensive modeling has been done to support the RFQ conceptual design. The modeling results are in a separate paper [3].

2 PHYSICS DESIGN

The main parameters of the RFQ are summarized in Table 1. The RFQ accelerates the 65 keV H^- beam to 2.5 MeV in a 3.72 meter long cavity resonant at 402.5 MHz. The choice of operating frequency is dictated by the required peak output current, the desire of a compact structure and the need to inject into the higher energy sections of the linac (805 MHz) with an integer frequency ratio. This frequency also allows for the possibility of beam funneling in the first part of the linac.

Structure Type	4 vane
Total Length	3.723 m
RF Frequency	402.5 MHz
Input Energy	65 keV
Output Energy	2.5 MeV
Peak output Current	56 mA
Design Transmission	> 90 %
Rms Beam Size	0.7 mm
Norm. H rms Emittance	0.156 π mm mrad
Norm. V rms Emittance	0.156 π mm mrad
Vane-to-vane Voltage	83 kV
Peak Field	1.85 kilpatrick
Total Peak RF Power	800 kW
Beam loading	17 % @ 56 mA
RF Duty Factor	6.2%
Rep. Rate	60 Hz
Vacuum	< 1 10^{-6} Torr

Table 1- Main RFQ Design Parameters

The RFQ is made of 449 cells, which are apportioned as 8 in the radial matcher, 48 in the shaper, 328 in the buncher ending at an energy of 780 keV, and 65 in the final accelerator section. The parameter selection is conventional, with the exception that the buncher section is slightly longer than usual to allow the longitudinal output emittance to remain below 95 keV-degree at 60 mA output and 75 keV-degree at 30 mA output, rather than increasing due to excessive bunching at lower current.

Eight-term RFQ beam dynamics simulations have been used in optimizing the buncher and acceleration section parameters, giving a normalized rms input acceptance of 0.2 π mm-mrad. In such simulations, the beam transmission is better than 95% at 60 mA of current, increasing to better than 99% at 30 mA.

The peak vane-to-vane voltage is 83 kV for a peak surface field of 1.85 kilpatrick, with a flat field distribution along the length of the RFQ to minimize longitudinal currents at the joints between the four modules that comprise the accelerator.

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The vane tip is machined with a constant transverse cross section of .351 cm, the same as r_0, the mean vane tip displacement from the axis.

3 RF CAVITY DESIGN

The 3.723 m long RFQ is built in four modules, each 93 cm long. The vanes and vacuum shell are made of OFE copper, with each quadrant brazed to a Glidcop (C) backbone to provide bolting strength for exterior components. The modules are joined with a copper-to-copper r.f. compression joint, backed up by a canted spring ring to provide a backup rf seal and a Viton O-ring vacuum joint. All this within the OFE part of the cavity. Figure 1 shows a conceptual view of one module.

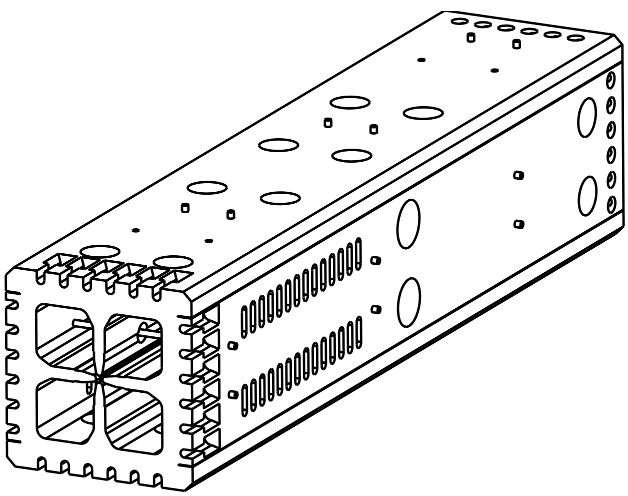

Figure 1 - Schematic view of one RFQ module

The quadrupole-dipole mode separation for the fundamental mode is 35 MHz, provided by π-mode stabilizer loop pairs [4] separated by 15.5 cm, for a total of 24 stabilizer pairs. The quadrupole mode frequency is decreased by 11 MHz and the dipole mode frequencies are increased by 36 MHz by the stabilizers. Perturbation tests show that changing the frequency of one RFQ quadrant by 1.53 MHz changes the azimuthal field symmetry by less than 2.7 percent. The RFQ is 5 free-space wavelengths long, and while no longitudinal stabilization is provided, the beam loading (for 60 mA) accounts for less-than 17% of the total power. Eight r.f. drive ports equally distributed in the four modules are expected to maintain the longitudinal field distribution within limits better than +/- 1%.

The average wall power density for 6% duty factor is 1.7 watts/cm^2, assuming the real losses to be about 67% of the ones in pure copper; computer simulations show that small areas near the vane end cutbacks approach 10 watts/cm^2. Each π-mode stabilizer rod will dissipate less than 10 watts.

The RFQ will be equipped with 80 tuners, 5 per module per quadrant, with a range of 2 MHz. Most, if not all, the tuners will be fixed, with the RFQ frequency fine control provided by a two-temperature water cooling system. In this scheme, the RFQ body is held fixed above ambient and the vane cooling channel temperature is kept at a lower and adjustable value.

4 MECHANICAL CONSTRUCTION

The RFQ mechanical design incorporates four separate vane quadrants containing the precision machined vane and cavity profiles. The quadrants are wire-brazed together to create the final cavity configuration. This design eliminates the need for demountable r.f. joints in the regions of high azimuthal r.f. wall currents. The vane and cavity wall surfaces are machined from solid blocks of oxygen-free copper (OFE). Since the copper is fully annealed during the brazing process, a 1" thick slab of GlidCop AL-15 is wire-brazed onto the rear surface of each copper quadrant to provide additional strength. This joint is obtained by brazing the copper cladding of the Glidcop to the OFE inner part. Provision has been made that no vacuum joint will cross the OFE-Glidcop braze. Figure 2 shows the final assembly of the four quadrants, as well as the external GlidCop layer.

The four completed modules are joined by means of a bolted connection. Rather than incorporating flanges at the ends of the RFQ modules, the joint design is preloaded by axial bolts recessed into the GlidCop outer layer, as shown in Fig. 1. Benefits of this type of joint include higher strength, reliable seal loading and a low profile. A slightly raised surface at the module ends around the perimeter of the cavity is used to provide a copper-to-copper r.f. compression joint. A canted spring ring seal provides back up to the r.f joint and protects an outer Viton O-ring vacuum. Canted springs are also used to ensure good electrical contact between adjoining vane tips. The r.f. and vacuum seals are all contained within the OFE portion of the cavity.

To conduct cooling water along the structure, the RFQ design uses milled channels in the back side of the OFE quadrants which are covered by the brazed-on GlidCop layer. This configuration allows internal manifolding and increased flexibility in the routing of the cooling passages. The integrity of the RFQ vacuum is maintained since no passages penetrate the ends of the modules.

This design has been studied with regards to cooling and stresses. Preliminary 2D finite element analyses have shown the RFQ operating temperature to be uniform within 3^o C and thermal stresses to be 1200 psi or less.

Although the RFQ operating parameters call for a 6.2% duty factor, all thermal analyses are performed for operation at 10% to allow for possible future upgrades to a longer pulse length.

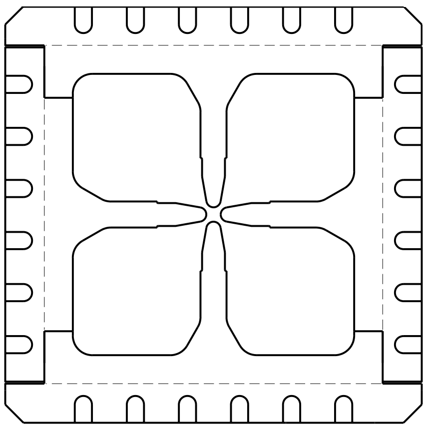

Fig. 2 – Four Quadrant RFQ cavity assembly

Vacuum ports are arranged in arrays of slots designed to attenuate the r.f. transmission into the vacuum system. The ports are incorporated identically in all four quadrants to ensure r.f. symmetry. In addition, nearby tuners are used to compensate the locally depressed cutoff frequency near the pumping ports, leveling out local variations in the vane tip voltage distribution. The RFQ vacuum level is maintained in the low 10^{-7} Torr range. All penetrations into the RFQ vacuum have been designed such that the GlidCop-to-OFE braze joint is not exposed to vacuum.

5 RF POWER SYSTEM

The peak power calculated is approximately 800 kW, including beam loading, when an additional 50% of power is allowed as the difference between the theoretical model of the RFQ and the real device built. This power is delivered by a single klystron, capable of 1.25 MW, that feeds the coupling ports via a circulator and a commercial eight-way power splitter. This splitter provides better than 40 dB of port-to-port isolation; at present no external longitudinal stabilization is planned.

The power is coupled in the cavity with a set of two coupling loops per module, with a total of eight ports. Each port will therefore carry a peak rf power of 100 kW, at a 6.2 % duty factor.

6 STATUS

A separate paper in this conference describes in detail the ongoing modeling efforts to support the conceptual design of the RFQ [3]. Benefiting from the results of such modeling, the detailed design of the first test module has begun. In the next months, a full cross-sectional size 93 cm long module will be built; it is designed with full capabilities, including vacuum, rf power, tuning and cooling. This module is intended to be identical to any of the four modules of which the RFQ will be built, apart from the specific vane modulations. The RFQ design and manufacturing procedures, as well as the operation under full r.f. power, will be tested with this device. A 1 MW klystron has been made available from the LANL collaborators and has been recently delivered to LBNL; its installation at LBNL is underway.

Upon successful completion of the first module's test, a full size prototype will be built incorporating the necessary changes that might be needed. This prototype RFQ will also be tested with beam.

7 ACNOWLEDGMENTS

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