THE SNS RFQ PROTOTYPE MODULE*

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Abstract

The RFQ included in the Front End [1] injector for the Spallation Neutron Source (SNS) operates at 402.5 MHz, with a maximum H^- input current of 70 mA at a 6% duty factor. It is 3.72 m long and consists of four equally long modules. A brazed copper structure has been chosen due to the high power, high duty factor operation. The 1 MW peak r.f. power is coupled into the structure via eight ports, two per module. Quadrupole mode stabilization is obtained with a set of π-mode stabilizing loops. The conceptual design has been completed, and a single, full size prototype RFQ module has been designed and is under construction to test the fabrication processes and r.f. performance. It will be operated at full r.f. power in order to test its cooling scheme, dual temperature water tuning, mode stabilization and beam acceptance. The detailed design, assembly processes, thermal analyses and a status report for the prototype module are presented.

1 INTRODUCTION

The preparation for construction of the SNS RFQ, scheduled for completion by the second half of the year 2001, has begun. An initial step is the fabrication of a single, 93 cm long prototype module. This unit will test and validate all construction techniques, as well as the r.f., vacuum, cooling and tuning performance of the cavity. This paper outlines several details of the design and analysis of the prototype RFQ cavity. In particular, the module-to-module joining and sealing technique, the cavity penetration designs (r.f. ports, vacuum ports, r.f. tuners) and the thermal static and transient response analyses will be described. A schematic view of the prototype module is shown in Figure 1.

2 CONCEPTUAL DESIGN

The SNS RFQ [2] is a high power, high duty factor accelerator designed to capture, accelerate and transport up to 70 mA of H^- beam at a 6% duty factor, with a 60 Hz repetition rate. A four vane configuration has been chosen which will use π-mode stabilizer loops to achieve quadrupole-dipole mode separation [3].

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The RFQ operates at 402.5 MHz and will require up to 1 MW of r.f. power to provide the 83 kV vane-to-vane voltage (corresponding to a 1.85 Kilpatrick peak field). The power will be fed into the cavity through 8 coupling ports equally distributed along the RFQ. Most of the power is required to compensate for cavity wall losses with only about 17% of the total power transferred to the beam.

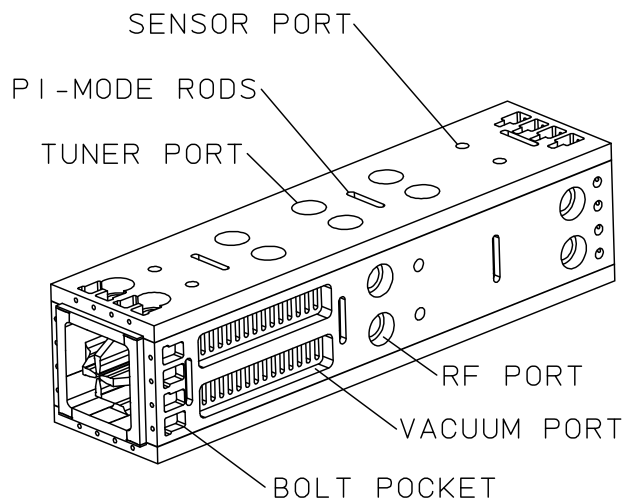

Figure 1: Schematic view of prototype RFQ module

The full RFQ consists of four 93 cm long modules and is constructed of a combination of GlidCop AL-15 and C10100 oxygen free copper (OFE). These materials have been chosen to take advantage of the structural strength of GlidCop and the superior brazing characteristics of OFE copper. The GlidCop is attached to the outer surfaces of the OFE by a braze which is kept completely outside of the vacuum shell. All penetration (r.f. ports, tuners, vacuum ports) vacuum seals are recessed beyond the outer layer of GlidCop and applied directly to the OFE. In order to maintain the very tight tip-to-tip vane tolerances (±0.001 inches) during the final, four vane brazing cycle, a zero-thickness brazing process has been selected. With this technique, the two copper surfaces are brought into direct contact, and the brazing alloy is fed to the adjacent surfaces by means of capillary action. The cavity wall heat is removed by a dual temperature water cooling system, which has been chosen to allow fine tuning of the structure in operation as well as during the initial r.f. power transient after start-up.

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3 DESIGN AND FABRICATION DETAILS

The RFQ cavities are constructed of OFE copper with an outer layer of GlidCop. The GlidCop plates are machined flat, and rough openings for the vacuum, tuner, r.f. feed and sensing loop ports are added. A rough vane profile is machined on one side of the OFE copper, and 5 mm by 5 mm cavity wall cooling channels are milled into the opposite side. The vane cooling channels are formed by cutting a 6 mm wide by 50 mm deep slot into the back surface of the OFE with a slitting saw. An appropriate filler piece of copper is brazed into place to complete the vane cooling channel. The filler includes squirt tubes at the ends to ensure sufficient cooling where the vanes are cut back at the entrance and exit of the RFQ. The details of the filler piece and squirt tube are shown in Figure 2. Next, the GlidCop is brazed to the OFE using a gold/copper foil to provide a structural connection and to cover the milled cooling channels. This braze is completely outside of the cavity vacuum. Since the cooling channels do not penetrate the ends of the modules, there are no water-to-vacuum joints in the system.

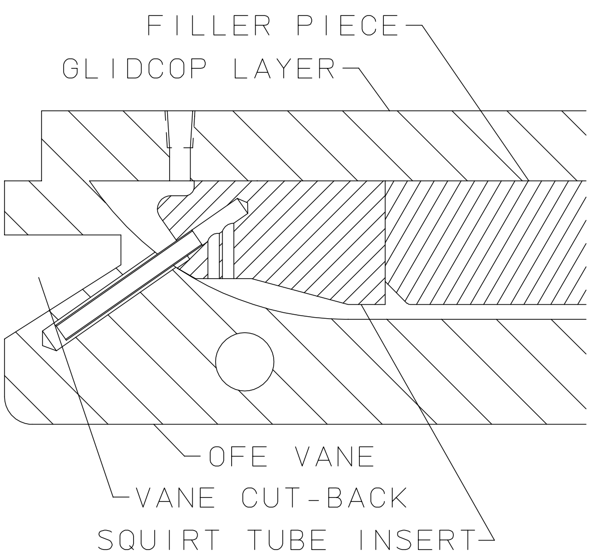

Figure 2: Vane cooling channel and squirt tube details

After brazing, the final vane and cavity profiles are machined into the OFE work piece using custom-made form cutters and end mills. A tolerance of less than ±0.001 inches between the quadrant mating surfaces and the vane tips is maintained during this process. The final braze of the four vane quadrants consists of a 'zero-thickness' vacuum braze using Cusil wire. This method allows the RFQ modules to be assembled and the cavity frequency measured prior to the completion of the final braze to allow for adjustments, if necessary. Grooves are machined into the mating surfaces to allow insertion of the braze wire which melts and flows via capillary action between the preloaded contact areas. The OFE copper π-mode stabilizer rods will also be inserted and brazed into position during this step. The rods are constructed from hollow tubing to allow for active cooling.

The module-to-module r.f. connection will be accomplished by means of a 3 mm wide, 250 μm high raised surface machined into the module ends around the periphery of the cavity. This sealing surface is backed up by a canted coil spring which will absorb any r.f. that leaks past the primary seal. Outside of the canted spring is an O-ring which provides the vacuum seal. The load on these seals will be provided by bolts which are recessed into the outer layer of GlidCop by means of bolt pockets and barrel nuts (refer to Figure 1).

The numerous penetrations into the RFQ cavities also require both r.f. and vacuum sealing. The vacuum, tuner, r.f. feed and sensing pick-up ports have sealing surfaces which are recessed beyond the GlidCop and into the OFE in order to keep the GC/OFE joint out of the vacuum. The vacuum ports consist of slotted holes penetrating the OFE copper of the RFQ cavity. The slots are designed to maximize gas conductance while preventing r.f. leakage into the pumps. An O-ring will provide the vacuum sealing for these ports. The tuner, r.f. feed and sensing pick-up ports will use a 250 μm thick tin gasket to provide both r.f. and vacuum sealing against the OFE. The tuner ports will use a large snap ring embedded in the GlidCop along with a loading disk to transfer the sealing forces to the RFQ body. This is shown schematically in Figure 3.

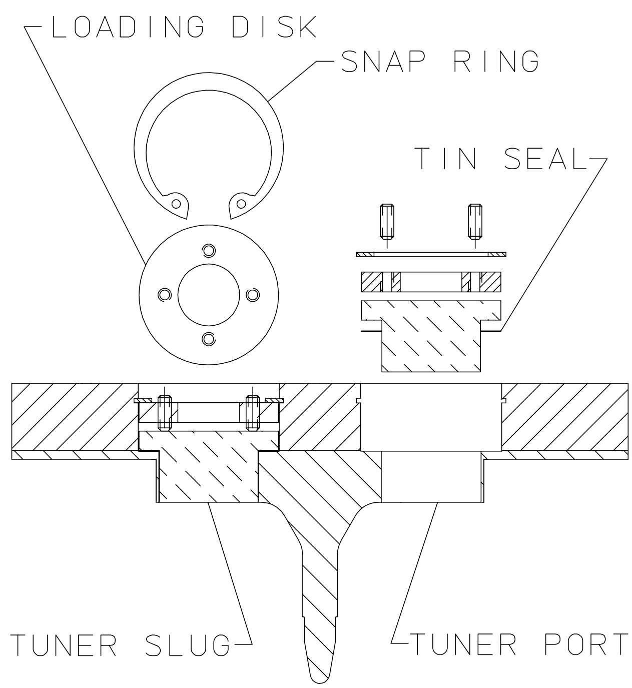

Figure 3: RFQ vane section view showing tuner details

4 THERMAL ANALYSES

A thermal model of the RFQ has been created with ANSYS consisting of a 3-D slice of one quadrant of the RFQ cross section. The surface nodes on either side of the slice are constrained to remain coplanar such that the longitudinal stresses are appropriately calculated while allowing for overall thermal growth in the z-direction. This could not be achieved with 2-D plane strain elements which would over-constrain the model longitudinally and result in artificially high z-component compressive stresses. The loads and constraints applied to the model include cavity wall heat from the r.f., vacuum pressure on the cavity walls, convective heat transfer and water pressure on the cooling passage walls and boundary conditions imposed by symmetry constraints.

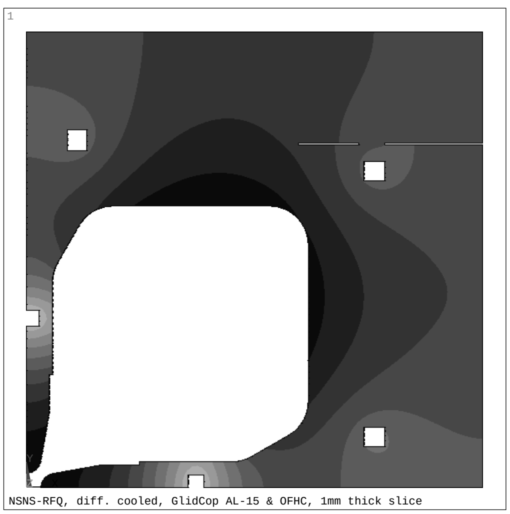

Figure 4: Predicted RFQ cavity wall temperature profile

With 18°C water in the vane channels and 24°C water in the cavity walls, the resulting temperature profile ranges between 25 and 29°C as shown in Figure 4. The highest stresses occur around the cooling channels and are in the range of 800 to 900 psi. In order to predict the frequency shift of the RFQ cavity due to thermal loading, a model was developed which combines the ANSYS displacement results with SUPERFISH calculations of frequency sensitivity. It was determined that the RFQ frequency can be shifted by –33.2 kHz for every 1°C rise in the vane cooling water temperature. This sensitivity to vane water temperature will be used to fine tune the RFQ frequency during operation.

The calculations described above were based on the nominal input temperatures of the vane and wall cooling water. However, as the water flows from the input to outlet end of one RFQ module, its temperature will rise as it absorbs heat. The vane water temperature rises by 3.7°C and the wall water by 1.6°C, thus creating a different cross section temperature profile at the end of the RFQ module. The calculated frequency error due to the higher water temperatures is –80 kHz. This error will be corrected by adjusting the position of the fixed slug tuners along the length of the RFQ modules.

A series of transient analyses were performed using the same FEA model to determine the frequency performance of the system during turn on of the r.f. power. With 18°C water in the vanes and 24°C water in the walls and no heat on the cavities, the frequency of the system is 216 kHz higher than the nominal 402.5 MHz. To correct this situation, the vane water is initially run at about 23.7°C and immediately switched to 18°C as the r.f. power is turned on. However, since the system responds faster to the wall heat than to the change in coolant temperature, a peak frequency error of –90 kHz occurs about 20 seconds after the r.f. turn-on, with the nominal frequency being achieved after 4 minutes. To minimize the frequency error, the r.f. is initially applied at 70% of full power and ramped up to 100% over the next 150 seconds, resulting in a maximum error of less than 15 kHz.

5 STATUS

Most of the manufacturing steps have been successfully tested in small samples and models, including vane profile, modulation cutting and module-to-module r.f. and vacuum sealing. The machining of the material of the prototype module has started. Testing of this unit is expected to begin this fall.

6 ACKNOWLEDGMENTS

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