

The SSCL RFQ System Integration¹

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Abstract

The integration and performance of subsystems on the Superconducting Super Collider Laboratory (SSCL) 428 MHz, 0.1% duty factor radiofrequency quadrupole accelerator is reported. Results of low- and high-power rf measurements on the RFQ cavity are compared to design specifications. Operation of the integrated RFQ vacuum, temperature and supervisory control systems are described.

I. INTRODUCTION

The radiofrequency quadrupole (RFQ) accelerator for the SSCL Linac is designed to accelerate up to 50 mA of H⁺ ions from 35 keV to 2.5 MeV. The SSCL RFQ is the first to use a ramped inter-vane voltage to maintain high transverse (focussing) field strength through the accelerating sections [1]. The vane profile was designed using an eight-term potential and the maximum peak surface fields were limited to a conservative 36 MV/m (1.8 Kilpatrick).

The SSCL requirement for a high-reliability, low-risk and low-cost RFQ design was satisfied by the choice of demonstrated technology and fabrication techniques from the Los Alamos National Laboratory (LANL) [2]. The RFQ cavity is a 2.2 m (\approx three wavelengths) structure fabricated from tellurium-copper. The structure comprises two axial segments bolted together to form the resonant cavity. Each segment is a near copy of an existing LANL cavity design, fabricated by electro-forming, at room temperature, four identical vane/cavity quadrant sections together. The resulting monolithic assembly features a stress-free integral vacuum vessel with no cross-sectional rf joints.

Following shipment from LANL in August 1992, the RFQ was assembled at the SSCL Central Facility (CF), in Waxahachie, for final acceptance low level rf tests. The structure was then integrated with the vacuum and temperature control [3], 600 kW rf amplifier [4] and computer control subsystems. After passing an integrated operational safety review in early December 1992, DOE approval was granted to start high-power rf conditioning. By the end of 1992, the cavity was rf conditioned to fields up to 115% of design (i.e., 2.1 K_p). Details of the cavity conditioning and acceptance tests on the rf amplifier are presented in a companion paper [5].

The RFQ accelerated first beam in early April of this year. Presently, the RFQ is undergoing beam acceptance testing to verify the design energy, transmission and emittance. A companion paper [6] discusses the preliminary acceptance test results and describes the ion source/LEBT arrangement.

Figure 1 is a photograph of the RFQ as installed at CF, showing vacuum, temperature control and rf connections.

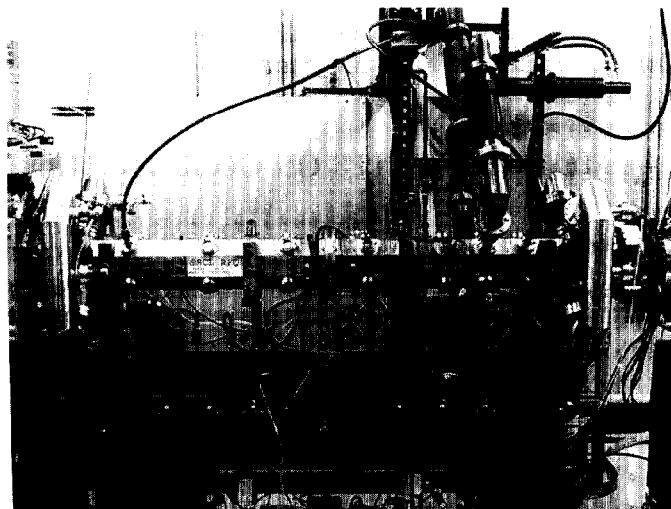


Figure 1. Photograph showing the RFQ as installed at the SSCL Central Facility.

II. RF TUNING AND SUBSYSTEM INTEGRATION

A. RF Tuning

The RFQ was first assembled at LANL for low level rf tuning of the cavity [2]. LANL personnel reverified cavity tuning after the RFQ was assembled on the support stand at SSCL. No significant post-delivery tuning deviations were measured, and the RFQ met the field balance and voltage ramp design requirements.

The design requirement for the unloaded cavity Q for the SSCL RFQ was 7500. At LANL, the unloaded cavity Q of \approx 7150 was measured. By installing aluminum and copper substitutes, it was determined that the low Q was due to the SSCL endwall assemblies. At SSCL, the highest Q value measured was \approx 6850. The assemblies are stainless steel with electro-deposited Cu rf surfaces; the quality/uniformity of the plating is suspect (the design requirement was a minimum thickness 15 μ m, or three skin depths). The lower-than-design Q values were considered acceptable as they represent, at most, a 10% increase in the rf power requirement.

The RFQ cavity is required to operate at a resonant frequency of 427.617 MHz. The cavity was tuned to resonate at this frequency at 40.5°C. Figure 2 shows a plot of the resonant frequency versus cavity temperature for the completed cavity assembly. At 40.5°C, the resonant frequency

¹Operated by the University Research Association, Inc. for the U.S. DOE, under contract No. DE-AC35-89ER40486.

is ≈ 50 kHz higher than the design value. The difference is attributed to vacuum isolation plugs, in the endwall bead-pull holes, which were not installed when the cavity was tuned. Unless the cavity is retuned, an operating temperature of $\approx 46.5^\circ\text{C}$ is required to operate at the required frequency.

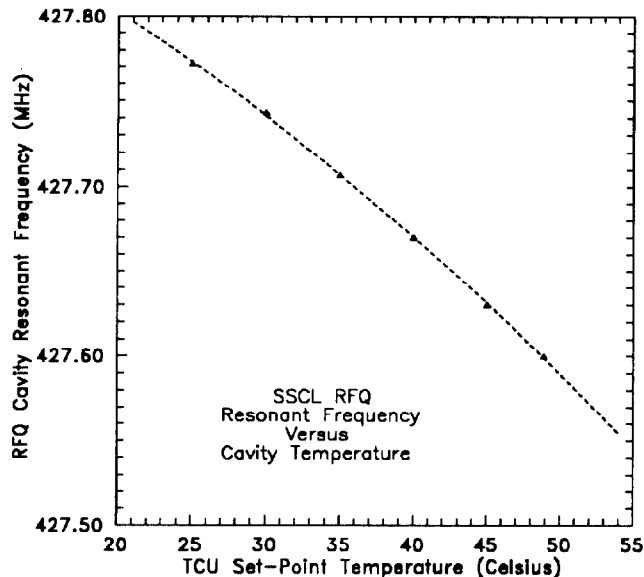


Figure 2. SSCL RFQ resonant frequency versus cavity temperature.

B. Vacuum and Temperature Control

Two parallel 450 l/s turbopump systems provide vacuum pumping on the RFQ [3] through vacuum manifolds at the high- and low-energy ends. The manifolds connect through bellows to 143 l/s conductance vacuum pumping ports on each of the four cavity quadrants. Gate valves provide vacuum isolation between the pump systems and the manifolds. Sentry valves and molecular sieves prevent migration of oil from the backing pumps to the RFQ cavity. Beam-line isolation valves were custom-designed to fit in to the tightly-confined endwall spaces at the entrance and exit of the RFQ.

At the operating temperature, the base vacuum pressure (measured in the manifolds) is typically $\approx 5 \times 10^{-6}$ Pa, well within the 1.3×10^{-5} Pa base pressure design requirement (at room temperature, the pressure falls by a factor of five). The pressure is also within the 6.5×10^{-5} Pa operating pressure design requirement when the isolation valve to the source is open. The system has operated now for over 3000 hr, and base pressures are routinely achieved within 15 minutes of starting a pump down from atmosphere (the RFQ is only back-filled with dry N_2). The endwall isolation valves provide an adequate vacuum seal, and total cavity leak rates are less than the 2×10^{-10} Pa m^3/s design requirement.

A temperature control unit (TCU) [3] supplies temperature-controlled, low-conductivity water (LCW) to the RFQ to frequency-stabilize the resonant cavity. The TCU system comprises a pump and heater to recirculate heated

LCW through a network of channels in the RFQ vanes. An elevated LCW temperature, 40.5°C design, was chosen to simplify the system by eliminating the need for a chiller. A temperature controller regulates the LCW temperature by operating a heater or by bleeding in cooler water ($30^\circ\text{C} - 35^\circ\text{C}$) from the primary LCW supply. Resistive temperature devices (RTD's) in the cavity walls monitor the temperature of the RFQ structure.

The TCU was designed for a $35^\circ\text{C} - 45^\circ\text{C}$ operating range. However, satisfactory operation has been demonstrated at operating temperatures up to 50°C . To avoid retuning the cavity, a 46.5°C operating temperature was established as the nominal operating temperature (see Section II A). Temperature stability is well within the $\pm 0.5^\circ\text{C}$ design requirement and the cavity temperature can be raised from ambient to the operating setpoint within one-half hour (better than the one hour design requirement).

C. Computer Control

The vacuum system and TCU are computer controlled through a UNIX/CAMAC based, distributed control system. The system is based on TACL (Thaumatugic Automatic Control Logic) software, developed at the Continuous Electron Beam Accelerator Facility [7]. The system provides the operator with control/monitoring functions including: display screens, hardware access routines and datalogging.

To simplify operation, the vacuum system is fully automated. TACL provides a set of start-up, shutdown and valve control sequences through "point-and-click" buttons on a display screen. System pressures, valve positions and vacuum pump conditions are also displayed. The TCU recirculating pump and temperature set-point are computer controlled, and LCW flows and temperatures are monitored. Note: All safety interlock functions are hardwired.

To date, TACL has provided satisfactory control and monitoring functions for the RFQ vacuum and TCU subsystems. However, TACL will be replaced by an VME based EPICS² global control system which will be the SCCL standard. EPICS is currently used to control the rf amplifier.

D. RFQ Beam Diagnostics

Diagnostic instrumentation consisting of segmented apertures, Faraday cups and wire scanners are installed in the RFQ endwalls. A companion paper describes these devices and outlines the current commissioning status [8].

III. RFQ CAVITY HIGH POWER OPERATION

The RFQ cavity was successfully conditioned to cavity fields up to $\approx 115\%$ of the 1.8 Kilpatrick design after only 10 hr [5]. Once conditioned, cavity power can be raised to design

²Software produced under US Government Contracts: W-7405-ENG-36 at LANL and W-31-109-ENG-38 at Argonne National Laboratory.

levels almost immediately. Presently operation is virtually spark free, and spark-rates are unaffected by the source gas load. A reflected power trip on the rf amplifier (active after the cavity fill time) has proven critical to maintain cavity conditioning; the trip level is typically set at 10%.

Figure 3 shows a plot of the RFQ peak inter-vane voltage at the high-energy end versus peak cavity power (the dashed curve is a fitted square root function). The peak voltage was determined from measurements of the vane-tip, x-ray bremsstrahlung endpoint energy (viewed through an exit end vacuum port) using a collimated, Ge spectrometer system. Cavity power was determined from the rf amplifier forward and reverse power, and is in agreement with measurements using the calibrated rf cavity probes [2]. Absolute errors on the plotted values are estimated to be $\pm 5\%$ on power and a few percent uncertainty in voltage.

At the 1.8 Kilpatrick design field, the inter-vane voltage at the high-energy end is 89 keV. Figure 3 shows that 330 kW of cavity power is required to establish design field levels. Considering measurement errors, and the lower than design Q (Section II A), the required power of 330 kW is within acceptable limits of the < 300 kW design power requirement. Low- to high-energy end ratios of the x-ray endpoint energies are in good agreement with the 0.62 value calculated from the design voltage ramp.

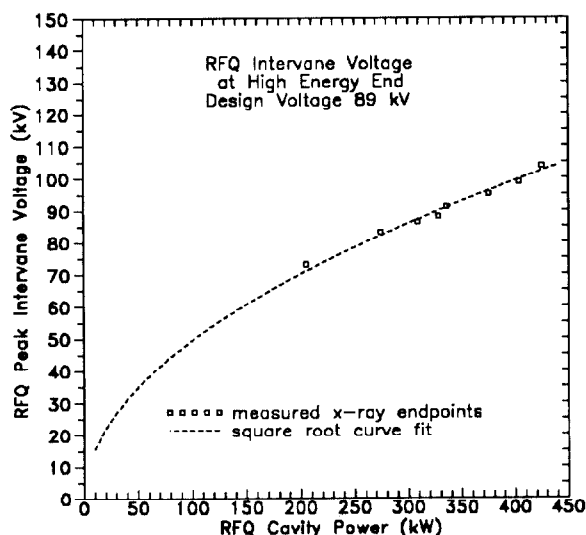


Figure 3. SSCL RFQ peak inter-vane voltage, at the high-energy end, versus peak cavity power.

The low ($< 0.1\%$) duty-factor of the RFQ results in low average x-ray field emissions from the structure. In general, contact dose-rates are $< 0.5 \mu\text{Sv/hr}$. Higher dose-rates are measured at the vacuum port manifolds where the cavity shielding is minimal. At the high-energy end manifold, where inter-vane voltages are the largest, dose-rates are $< 10 \mu\text{Sv/hr}$.

Due to the low duty-factor, there is little effect on the cavity temperature from rf power. At design power levels, only a slight ($\approx 0.3^\circ\text{C}$) temperature increase in the cavity wall is measured, due to differential heating. This temperature

increase is well within the $\pm 0.5^\circ\text{C}$ design stability requirement. At design power, the increased cavity pressure is within a factor of three of the 5×10^{-6} Pa base pressure (well within the 6.5×10^{-5} Pa operating pressure design requirement).

IV. CONCLUDING REMARKS

The SSCL RFQ has been successfully assembled and integrated with its ancillary supports, rf amplifier and computer control systems. High-power operation of the RFQ has been demonstrated to 130% of the design power and beam operation has commenced. Operations at the SSCL Central Facility will continue until the RFQ injector is moved to the permanent tunnel location later this year.

V. ACKNOWLEDGEMENTS

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