Rf Commissioning of the Superconducting Super Collider Radio Frequency Quadrupole Accelerator*

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Abstract

The SSC 2.5-MeV H^- RFQ is powered by a 600-kW, 428-MHz pulsed rf amplifier system [1]. The results of the SSC RFQ rf commissioning, including the measurements of cavity field stability (phase and amplitude) are presented.

INTRODUCTION

The SSC RFQ is required to accelerate a 30 keV H^- beam to 2.5 MeV. The beam design requirement, at the exit of the RFQ, is 25 mA, 7-35 μs-long macropulse, with a repetition rate of 10 Hz. The RFQ uses a 100 μs-long rf pulse to establish its accelerating fields. The 100 μs rf pulse length allows ample time for cavity filling and field stabilization, so that the very stringent rf field control requirements of +/- 0.5% of amplitude and +/- 0.5° of phase during the beam pulse can be achieved. The RFQ cavity [2] is a 2.2 m long structure with a design peak field strength of 36 MV/m (1.8 Kilpatrick). The rf system for the RFQ consists of a 600-kW, high-power rf amplifier at 427.617 MHz [3], a low-level rf control system (LLRF), and a supervisory control system. This paper describes the initial RFQ cavity conditioning process, and the rf phase and amplitude stability measurements performed with the RFQ cavity at design field levels.

RF CONDITIONING

Rf conditioning is the process of achieving the design field level in an rf cavity. This is usually done by slowly raising rf field levels in the cavity, the rate of rise being limited by the sparking rate and the vacuum levels. As rf fields in a cavity are increased, electrons and ions are accelerated into the cavity walls, devolving more ions and free electrons. This causes a pressure rise, and sometimes a spark or discharge. These sparks are most likely to occur at local high field points, caused by surface irregularities in the cavity. Sparking usually eliminates these points. Eventually, the walls of the rf cavity are cleaned by the ion and electron bombardment, and the rf power levels can be raised to the design value. Each rf cavity has a unique conditioning history, due to microscopic differences in the surfaces of the cavity.

Conditioning of the RFQ cavity was performed at the design frequency of 427.617 MHz. The cavity is maintained on resonance by circulating heated, low-conductivity water (LCW) through channels in the vanes of the RFQ cavity.

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The proper resonant cavity temperature was determined by varying the temperature to produce a minimum reflected power as measured with a network analyzer. This temperature was found to be 47.0°C. This was a deviation from the design value of 40.5°C, but was within the temperature tuning range of the RFQ Temperature Control Unit (TCU).

At the start of rf conditioning, a 50 μs rf pulse was used at 10 Hz. To prevent excessive power during sparking, rf power was controlled open loop - ie. constant input power to the cavity. Base upon Q measurements and SUPERFISH calculations, the expected rf power level to establish the design rf field was 320 kW. Power was initially applied at the 17 kW level, and continuous multipactoring was observed. The power was then raised to the 85 kW level, where intermittent multipactoring and sparking ceased after about 5 minutes.(This power level, as are all power measurements in this paper, has an absolute accuracy of +/- 5% and a relative accuracy of +/- 1%.)

After the initial clean-up of the cavity, the RFQ ran stably at the 85 kW power level. The cavity reflected power (after the rf fill time) was about 1 kW. The water temperature was varied to ensure that the cavity was at the proper resonance, and 47.0°C produced the minimum reflected power levels. The rf pulse length was then lengthened to 100 μs, and the rf power was slowly raised over the course of four hours to 340 kW, slightly above the expected nominal field levels. Only slight sparking was observed during this time interval.

The RFQ vacuum level was 7×10^{-5} Pa at the start of commissioning. After the initial clean-up, the pressure level in the cavity dropped to 1×10^{-5} Pa, and did not exceed 3×10^{-5} Pa during the course of conditioning to 340 kW. At this point, the rf power was lowered to 280 kW, and the LLRF closed loop control system, which insures constant field level in the rf cavity, was activated.

An intrinsic Germanium detector was used to measure the bremsstrahlung x-rays produced by free electrons accelerated into the RFQ vanes. These x-rays have an endpoint energy corresponding to the maximum intervane voltage in the RFQ cavity, and thus determine internal cavity voltage levels.(The accuracy of these field level measurements is estimated to be a few percent.) The voltage levels measured verified that the design field level was produced at 330 kW [4].

Rf conditioning was continued for a total of about 8 hours (not continuously) until 430 kW was reached, which is 136% of the design power level (117% of design field levels). When the spark rate at this power level was reduced to one spark/2000 pulses, conditioning was considered complete.

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PHASE AND AMPLITUDE STABILITY MEASUREMENTS

Once the RFQ cavity was conditioned, phase and amplitude stability measurements were made at the nominal cavity field level (335 kW) and at plus and minus 10% cavity field levels (400 kW and 260 kW, respectively). The rf system requirements are +/- 0.5% cavity field amplitude stability and +/- 0.5° cavity phase stability as measured in a 50 µs window within the total 100 µs rf pulse. A stability run of four hours duration was made at the design power level of 335 kW at 10 Hz. Phase and amplitude were monitored using the LLRF monitoring system to record the phase and amplitude 55 µs into each pulse. The amplitude of the total pulse was also monitored using a differential input oscilloscope. The oscilloscope trace was photographed every 15 minutes to check amplitude stability in the 50 µs window. The phase of the total pulse was also monitored using an oscilloscope. The phase waveform was recorded every 15 minutes. A counter was used to record the number of cavity arcs during the four hour run. The results of these measurements are listed in Table 1.

Table 1
Rf Stability Measurements at RFQ Nominal Field Levels

Cavity power level	335 kW
Frequency	427.617 MHz
Pulse length	100 µs
Repetition rate	10 Hz
Phase stability:	+/- 0.2°
Amplitude stability:	+/- 0.2%
Total number of cavity arcs	109 (18 during last hour of test)
Total number of amplifier crowbars	2 (both within one minute of each other)
Total number of pulses (approx)	144000
Total number of pulses out of tolerance	17 (plus sparks)

These measurements were performed just after the initial cavity conditioning. Since then, the spark rate has dropped considerably, to less than 1 spark/10000 pulses. As can be seen from Table 1, the phase and amplitude control is within specifications for this rf system.

The stability tests were also performed for +/- 10% RFQ field values (+/- 20% in power) for two hours and one hour respectively. The results are summarized in tables 2 and 3.

Table 2
Rf Stability Measurements at 110% of RFQ Nominal Field Level

Cavity Power Level	400 kW
Frequency	427.617 MHz
Pulse Length	100 µs
Repetition Rate	10 Hz
Phase stability:	+/- 0.1°
Amplitude stability:	+/- 0.1%
Total number of cavity arcs	278
Total number of Amplifier Crowbars	0
Total number of pulses (approx)	72000

Table 3
Rf Stability Measurements at 90% of RFQ Nominal Field Level

Cavity Power Level	260 kW
Frequency	427.617 MHz
Pulse Length	100 µs
Repetition Rate	10 Hz
Phase stability:	+/- 0.1°
Amplitude stability:	+/- 0.1%
Total number of cavity arcs	109
Total number of Amplifier Crowbars	0
Total number of pulses (approx)	40000

The rf system has again met stability requirements.

SUMMARY

The SSC RFQ was rf conditioned in only 8 hours to 117% of the design field level. The rf system has achieved the design stability values for amplitude and phase control, and the RFQ rf system is operating reliably at the SSC.

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