DESIGN AND FIRST COLD TEST OF BNL SUPERCONDUCTING 112 MHZ QWR FOR ELECTRON GUN APPLICATIONS*

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Abstract

Brookhaven National Laboratory and Niowave, Inc. have designed, fabricated, and performed the first cold test of a superconducting 112 MHz quarter-wave resonator (QWR) for electron gun experiments. The first cold test of the QWR cryomodule has been completed at Niowave. The paper discusses the cryomodule design, presents the cold test results, and outline plans to upgrade the cryomodule for future experiments.

INTRODUCTION

A quarter-wave resonator concept of superconducting RF (SRF) electron gun was proposed at BNL for electron cooling ion/proton beams at RHIC [1, 2]. QWRs can be made sufficiently compact even at low RF frequencies (long wavelengths). The long wavelength allows to produce long electron bunches, thus minimizing space charge effects and enabling high bunch charge. Also, such guns should be suitable for experiments requiring high average current electron beams.

A 112 MHz QWR gun was designed, fabricated, and cold-tested in collaboration between BNL and Niowave. This is the lowest frequency SRF gun ever tested successfully. In this paper we describe the gun design and fabrication, present the cold test results, and outline plans for the cryomodule upgrade for future experiments.

112 MHZ GUN DESIGN AND FABRICATION

The cavity geometry was designed using Superfish [3]. Figure 1 shows the model used to calculate the cavity RF parameters, summarized in Table 1. Since the fields will appear nearly electrostatic, a Pierce-type geometry (recessed cathode, as shown in the figure) can be used to focus the beam and compensate for the space charge of the high intensity electron beam. The Pierce electrode shape has higher electric fields away from the cathode, but these field levels are controlled in the design.

The complete cryomodule design is shown in Figure 2. The niobium cavity in a helium vessel is surrounded by the superinsulation, liquid nitrogen shield, another layer of superinsulation, and magnetic shield (mu metal).

Electron beam welding was performed by Niowave's

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Table 1: RF Parameters of the 112 MHz SRF Gun Cavity

Parameter	Value
Frequency	112 MHz
R/Q (linac definition)	126 Ohm
Geometry factor G	38.2 Ohm
Quality factor Q_0 w/o cathode insert	$> 3.5\times10^9$
Operating temperature	4.5 K
E_{pk}/V_{acc}	19.1 m^{-1}
E_{pk}/E_{cath}	2.63
B_{pk}/V_{acc}	36.4 mT/MV
Length	1.1 m
Aperture	0.1 m
Maximum diameter	0.42 m

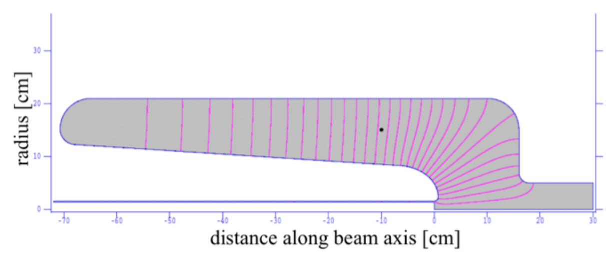

Figure 1: Cavity geometry used in Superfish calculations.

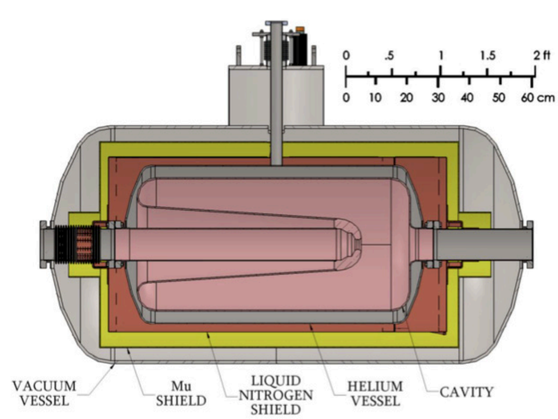

Figure 2: 112 MHz electron gun cryomodule.

vendor and included four cycles. The first involved welding the niobium beam tube shown, the second included welding of the inner and outer conductor halves, the third included welding the subassembly, and the fourth completed all niobium welding of the cavity shown in Figure 3.

Figure 3: Electron beam welded 112 MHz Nb cavity.

The stainless steel helium vessel was welded onto the cavity prior to chemical etching of niobium and acted as a cooling jacket. The cavity was chemically etched and high pressure rinsed in the Class 100 cleanroom. Due to the size of this cavity, testing in the cryomodule was easier and more efficient than trying to carry out an intermediate test before cryomodule assembly. The cavity was hermetically sealed in the cleanroom with the cathode assembly, power coupler, pick-up probe and beamline vacuum components (Figure 4).

The cryomodule's vacuum vessel is made from low carbon steel. The vessel is demagnetized and acts as a magnetic shield. Once the cryomodule was complete, it was vacuum leak checked and cold shocked with liquid nitrogen.

Figure 4: The cryomodule in its test configuration.

FIRST COLD TEST

The cooldown began with opening liquid nitrogen supply to the thermal shield. It was cooled stably overnight with exhaust gas from the shield tubes at approximately 150 K. This procedure cooled the cavity flanges to just below 200 K. This was followed by the liquid nitrogen pre-cool of the helium vessel. The cavity flanges were cooled at a rate of 10 K/min down to around 130 K, with the temperature monitors on the vessel itself reaching 100 K in about 2 hours. The switchover to liquid helium took place after that. The cavity flanges were cooled at a rate of 2 K/min from 130 K to 10 K, limiting the time in the "Q disease" range. The liquid helium vessel sensor reached 4.4 K in approximately one hour and the liquid helium vessel was full in 1.5 hours. In summary, the cavity was cooled to the superconducting transition in approximately 3.5 hours from the beginning of the liquid nitrogen pre-cool. The efficiency of the cavity cooldown (in terms of time and liquid helium lost to boiling) was therefore excellent.

For this test, a copper cathode rod was also used as an input RF power coupler (Figure 5). An external (to the cryomodule) RF network was used for fine-tuning the coupling and search for resonant modes. The fundamental cavity mode was observed at 113.0 MHz within 2 hours of the cooldown. The difficulty in locating the mode frequency was due to the extremely narrow bandwidth of the mode. The "5λ/4" mode was also observed at high Q and located at 476.5 MHz. The adjustability of the coupling to the fundamental mode was measured by changing the position of the cathode and observing the loaded Q of the cavity. Results are shown in Figure 6.

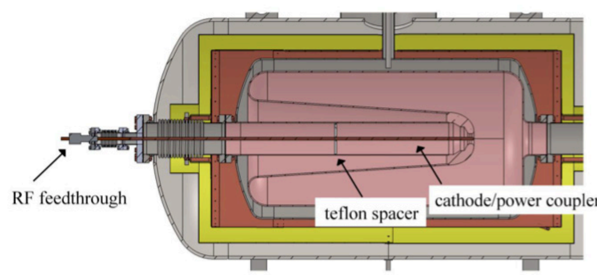

Figure 5: Testing setup for first cryogenic RF test.

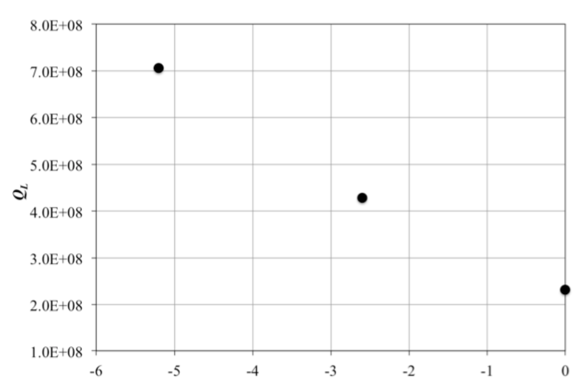

Figure 6: Loaded Q vs. cathode position.

RF power scans were performed at two extreme values of loaded Q. The observed multipacting barriers proved to be easily conditioned away. As shown in Figure 7, cavity

Q of as high as 10^9 was observed at fields corresponding to the gap voltage up to about 0.5 MV. The limit was imposed by the radiation safety requirements of 2 mrem/hr, as there was no dedicated radiation shielding around the cryomodule. The cavity Q is reduced when the cathode/coupler is inserted further into the high field region as shown in the lower curve. The reduction is consistent with the one expected from computer simulations. Further, very little degradation of the cavity Q at ~ 0.5 MV due to field emission was observed and no cavity quenches at high field were seen. Conditioning of field emission sites could potentially eliminate all cavity Q degradation at these field levels, giving good confidence that this gun can perform in the desired range 1.5 to 2.5 MV.

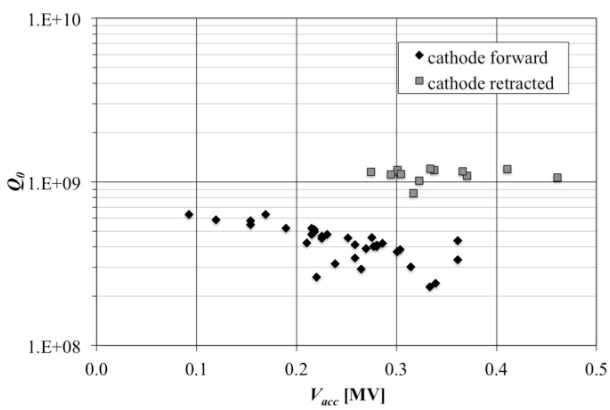

Figure 7: Cavity Q vs. gap voltage with the cathode/coupler in two different positions.

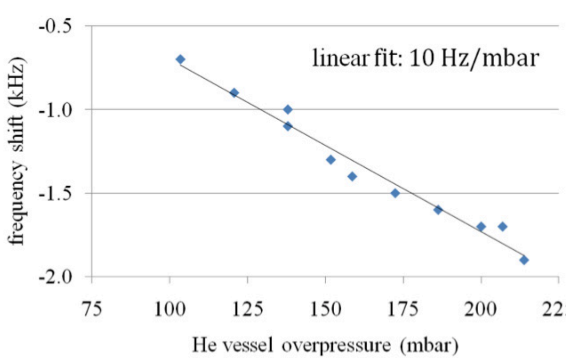

Figure 8: Cavity frequency shift vs. helium vessel overpressure (mbar above atmospheric pressure).

The sensitivity of the cavity frequency to the helium bath pressure variations is another important figure of merit for the cavity performance. It was measured by pressurizing the helium vessel. As shown in Figure 8, the cavity frequency was observed to shift by 10 Hz/mbar of pressure change. From the liquid helium boil-off rate we have estimated the static heat leak to be less than 7 W.

SUMMARY AND FUTURE EXPERIMENTS

We have successfully designed and cold-tested the 112 MHz SRF gun based on a quarter-wave resonator. The gun cryomodule demonstrated good cryogenic performance. RF losses are consistent with simulations. The observed multipacting barriers were easy to process. There was no cavity quenches and the achieved gap voltage of ~ 0.5 MV was limited only by the radiation safety requirements.

The near future experiments with the 112 MHz SRF gun will concentrate on studying different photocathodes: multi-alkali and diamond-amplified ones. For these studies we plan to separate RF power coupler from the cathode insert and use a coupler similar to what been used in a recent test of the NPS prototype 500 MHz SRF gun [4]. The new RF power coupler and the cathode stalk assemblies for photocathodes are being designed. Prior to photocathode experiments, the gun will be cold-tested again to process field emission and demonstrate its ability to reach higher voltages. The 112 MHz gun might also be used in the coherent electron cooling proof-of-principle experiment at BNL [5]. For the latter experiment a way to tune the cavity frequency will have to be developed.

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