TUNABLE 28 MHZ SUPERCONDUCTING CAVITY FOR RHIC*

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Abstract

Replacement of the normal conducting 28 MHz accelerating cavities in the RHIC ring with superconducting structures offers a number of advantages for the machine operation, including reduction of the number of cavities required and lower impedance. A prototype folded quarter wave structure has been constructed at Niowave, Inc. to meet this need. This novel cavity geometry achieves the very low resonant frequency required with a relatively compact structure, and can provide the large tuning range required (~1% of the cavity frequency). Results of the cavity fabrication are presented along with room temperature RF measurements.

ACCELERATING CAVITIES IN THE RHIC MAIN RING

Brookhaven National Laboratory (BNL) has operated the Relativistic Heavy Ion Collider (RHIC) since 2000 to probe the structure of the nucleus and its transition to a quark-gluon plasma [1]. Significant advances in nuclear physics have been made at RHIC, and the potential for future breakthroughs warrants continued operation and upgrades of the facility. The 28 MHz accelerating system currently operating in the RHIC storage rings is based on copper structures and high power tetrodes [2]. One potential upgrade is the replacement of the existing 28 MHz accelerating cavity system with superconducting RF structures driven by solid state amplifiers. This system could reduce maintenance, save power and improve performance of the RHIC complex.

The advantages of upgrading to a superconducting RF system include:

- increased voltage per cavity so one SRF cavity replaces two copper cavities, thereby reducing the number of cavities or maintaining the second cavity as a spare;
- improved beam-line vacuum;
- reduced electrical and RF power requirements due to lower RF power loss in superconducting material;
- solid state power amplifier;
- reduced delay in the fast-feedback loop due to the simplified power amplifier;
- reduced parts inventory due to elimination of tetrode and high power coupler, and possible reduction in number of cavities;
- multipactor-free design over the broad range of voltages required – the existing cavities suffer from this phenomenon.

Liquid helium (4.5 K) is already available in the RHIC tunnel for use in the cavity system, and the low losses at the very low frequency allow for operation at this temperature.

A number of challenges have been addressed in this design. The novel superconducting cavity geometry which has been realized is one of the lowest frequency niobium cavities to ever be built. The tuner concept will allow the large tuning range required, and the folded quarter-wave design has greatly reduced the size of the structure. This cavity is now a prototype for a system which could replace the current normal-conducting accelerating system in the RHIC main ring.

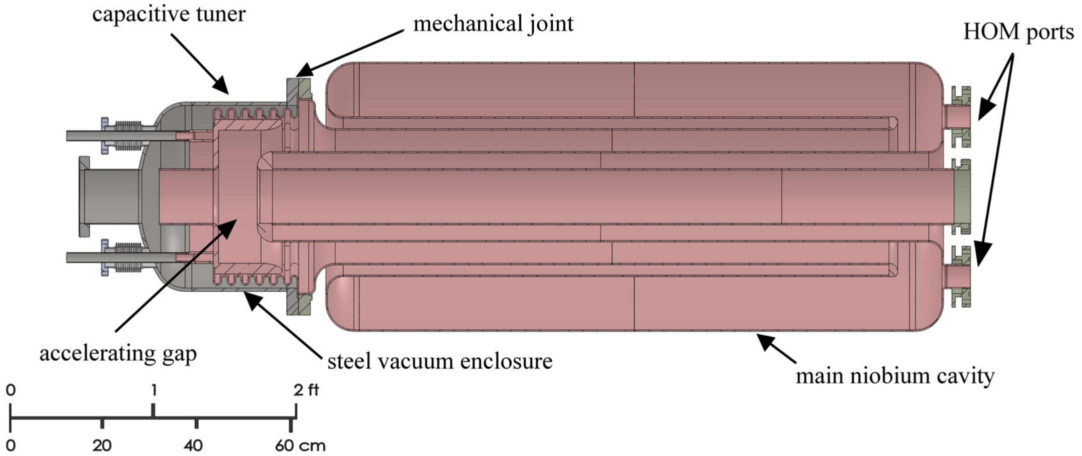

Figure 1: The folded quarter-wave cavity structure with the proposed capacitive tuner.

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FOLDED QUARTER WAVE CAVITY DESIGN

A simple quarter wave structure was initially proposed as a superconducting RF replacement for the existing normal-conducting copper cavity. [3] Calculations of the cavity frequency using Superfish showed that a much larger capacitive section and a longer inductive section are required to bring the cavity frequency to 28.1 MHz, and the overall cavity length in that model was greater than 2 m. Significant space savings can be achieved by folding the inductive section back onto itself. Figure 2 shows the Superfish model of the accelerating gap of the cavity, and the relevant electromagnetic parameters calculated by Superfish are shown in Table 1. The required RF power remains under 5 W, easily supplied by a solid state amplifier, and the reduced impedance (compared to the basic quarter wave) presented to the beam traveling in the RHIC ring is preferred.

The full folded quarter-wave design is shown in Figure 1. As shown here, the main superconducting cavity is separated from the tuning section by a large mechanical joint, allowing for testing of the main cavity section separately.

As part of the SBIR Phase I project, a preliminary multipacting analysis was carried out at Brookhaven National Laboratory using the multipacting code Fishpact_10ps written by Genfa Wu. [4] From this analysis there appeared to be no sites that produced any strong multipacting. Several sites did lead to electrons that survived 10 impacts, however the trajectory began from the site of interest and then proceeded to propagate back and forth in the beampipe of the cavity at very low energy. This analysis suggests that these multipacting sites should not pose a serious problem.

CAVITY TUNING

The required tuning range for this cavity in operation at RHIC is 200 kHz, with a tuning rate of 22 kHz/s. At more than 0.5% of the fundamental frequency, this tuning range is a challenge. A simple tuning method for quarter wave cavities is the lengthening of the capacitive section. This could be done using flexible bellows to move the inner or outer conductor to increase the area of the cylindrical capacitor, but reliable motion of a 1-m long, 20-cm diameter niobium tube is a significant engineering challenge.

We propose an alternate tuning scheme, the addition of a second capacitive section to the upstream end of the cavity. As shown in Figure 2, the short section (to the left in the Figure) will be adjustable in position parallel to the beam axis, changing the frequency by increasing the capacitance between the tuning section and the nose of the inner conductor of the main cavity. Results from Superfish modeling of the tuning section are shown in Figure 3, demonstrating that the range of 200 kHz can be achieved with acceptable peak fields on the niobium surfaces.

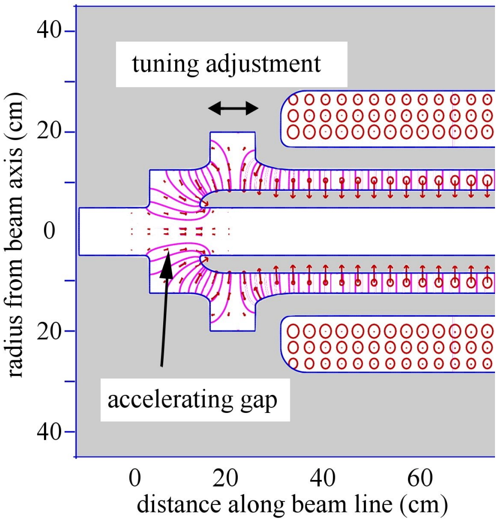

Figure 2: Superfish model of the 28 MHz cavity showing the accelerating gap and the capacitive tuning region.

Table 1: Parameters and Cavity Performance Figures of Merit for the Folded Quarter-Wave Cavity

resonant frequency	28.1 MHz
gap voltage	650 kV
cavity Q	1.6×10^{9}
geometry factor	8.2 Ω
R/Q (accelerator definition, V^2/P)	66 Ω
peak electric field on the niobium surface	26 MV/m
peak magnetic field on the niobium surface	44 mT
dissipated power	4.1 W
operating temperature	4.2 K

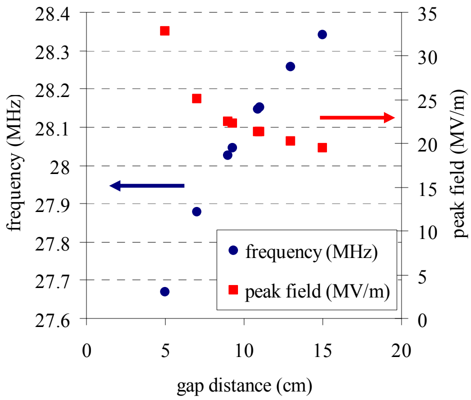

Figure 3: Superfish calculations of cavity tuning with capacitive tuning section. Blue circles show the cavity frequency with gap distance, and red squares show the change in the peak cavity fields.

Figure 4: Three main cavity subassemblies shown before final electron-beam welding (above) and the welded cavity shown being fit with a niobium test head and stainless steel vacuum head for initial RF measurements and testing (below).

CAVITY FABRICATION

The main cavity section has been fabricated at Niowave, following standard SRF cavity production techniques. The cavity component parts have been made from a combination of machined niobium ingot and stamped niobium sheet. The three main subassemblies are shown in Figure 4 before the final electron beam welding. Also shown in the Figure is the completed niobium structure being fit with a niobium test head and stainless steel vacuum head suitable for initial testing without the full tuner assembly.

The integrity of the cavity welds was verified with a cavity leak check. No leaks were detected down to a level of 10^{-10} Torr-L/s.

RF MEASUREMENTS

At room temperature, the cavity fundamental mode frequency was measured to be 27.95 MHz with the niobium test head. The predicted cavity Q factor for the folded quarter-wave structure at room temperature is 1970, based on the bulk conductivity of niobium (approximately 6.2×10^6 per $\Omega\cdot$m, [5]), which gives a surface resistance at 28 MHz of 4.2 mΩ. The measured cavity Q factor in the fundamental mode at room temperature was 2100, very close to the prediction.

Because the HOM spectrum of the quarter-wave structure is sparse, the next mode measured was at 95.6 MHz, in agreement with Superfish predictions. The next three HOMs measured (149.7 MHz, 218.7 MHz, and 269.6 MHz) also agree with the model. Significant coupling was attainable to all of the measured modes with loop couplers at the higher-order-mode ports.

CONCLUSIONS AND NEXT STEPS

A novel superconducting cavity geometry has been realized and is one of the lowest frequency niobium cavities to ever be built. This cavity is a prototype for a system which could replace the current normal-conducting accelerating system in the RHIC main ring.

Next steps in the development of the prototype SRF accelerating system for the RHIC main ring include: cavity surface preparation by chemical etch, initial cryotesting without a tuner to verify the performance of the main cavity and the large mechanical joint, observation and mitigation of multipacting, construction of a prototype tuner, and a full cryotest with the tuner. Topics to be addressed in parallel include the stability of the cavity against microphonics and requirements on additional mechanical supports.

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