ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI050

DEVELOPMENT AND TEST RESULTS OF A QUASI-WAVEGUIDE MULTICELL RESONATOR*

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Abstract

This paper reports the successful fabrication and test results of a novel 2815 MHz superconducting deflecting cavity operating in a TE-mode trapped in a quasi-waveguide structure with extremely high shunt impedance. The waveguide structure of this cavity allows for the free propagation of all higher order modes (HOMs) out of the cavity via the beam ports, eliminating the need for HOM dampers inside the cavity when operated with high beam current. The absence of HOM dampers greatly simplifies the cavity fabrication and operation at cryogenic temperatures. This cavity with its high shunt impedance is ideal for the spatial rotation of short bunches in a small physical space, a requirement for the generation of sub-picosecond short pulse X-rays in electron storage rings or luminosity upgrades of colliders.

INTRODUCTION

The primary goal of the work described in this paper was to demonstrate a high-performance superconducting radio frequency (SRF) deflecting cavity, referred to as a Quasi-waveguide Multi-cell Resonator (QMiR). The cavity as built is shown in Figure 1. It is comprised of a rectangular waveguide perturbed from the top and the bottom by three cells that make it strongly coupled to a deflecting RF eigenmode. This eigenmode resonates at 2.815 GHz and is the highest frequency modes in the lowest frequency, 2.4-2.8 GHz, pass-band of the cavity. QMiR's electromagnetic design is described in ref. [1], it exhibits some features previously analysed in ref. [2] and it can be considered as a rather natural evolution of the parallel-bar cavity and rigid waveguide cavity proposed in ref. [3, 4]. The uncomplicated geometry of QMiR is well suited for fabrication. Table 1 summarizes the operating parameters for this cavity. It is important to note that:

1) QMiR has an extremely high shunt impedance and one cavity, shown in Figure 1, can provide the same deflecting voltage as four traditional single-elliptical-cell cavities [5] operating with the same RF frequency. The inherent waveguide properties of QMiR allow for undesirable electromagnetic modes excited by the beam to propagate via the beam tubes to higher order mode absorbers. This eliminates the need for multiple waveguide couplers to remove undesirable high order mode power and reduces the number of cryomodule penetrations and the complexity of the entire system.
2) The high shunt impedance of QMiR and simpler cryomodule significantly reduce the cryogenic loads compared to the required amount if similar deflecting voltages were generated using elliptical cell cavities.

Table 1: Electromagnetic Parameters for QMiR

Parameter	Value
Operating Frequency	2815 MHz
Deflecting Voltage	2 MV
$(R/Q)_y = V^2/2P$	521 Ω
$G = QR_s$	130 Ω
below for $V_{Deflecting}$ = 2 MV	
E_{peak}	54 MV/m
B_{peak}	75 mT

FABRICATION AND PROCESSING

Fabrication and Tuning

QMiR was machined from both high-purity, RRR > 280, niobium blocks and low-purity, RRR ~ 50, niobium sheet. The cavity body was machined from two high-purity solid blocks of niobium making an upper and lower half. These halves were welded together to make the cavity body. The half of the cavity with the waveguide welded into it was conventionally machined such that the side walls were 0.375" higher than the height required to achieve the desired resonant frequency. This extra material facilitated the tuning of the resonator during fabrication. Removal, via wire EDM, was performed in several steps to achieve the target frequency. The measured frequency dependence for the wire-EDM cuts is +32 MHz/mm and we achieved a machining tolerance of ±0.04 mm. This was verified with Coordinate Measuring Machine (CMM) measurements made after each wire-EDM step. After the tuning cuts were finished the cavity halves were welded together.

Figure 2 shows the cavity parts and hardware used to fixture the parts together for the frequency measurements. Measurements were made with capacitive probes inserted in the cavity beam ports with either indium wire or silver print between the niobium parts to facilitate uniform electrical contact during the measurements. Measurements of the cavity resonant frequency using indium wire were within 1 MHz of measurements using silver print for electrical contact as long as the thickness of the crushed indium wire was accounted for. Absolute

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*Work supported by the U.S. Department of Energy under Contract No. DE-AC02-06CH11357.

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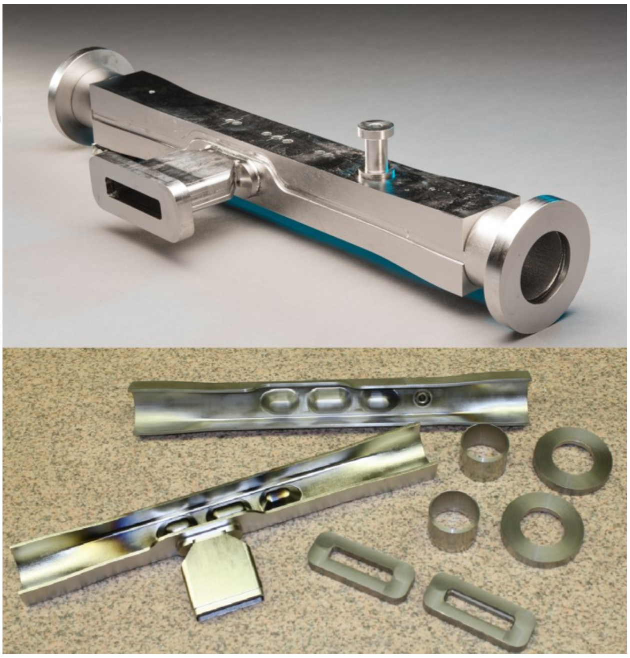

Figure 1: (Top) QMiR 21.75' Long, (Bottom) Niobium parts just before final welding.

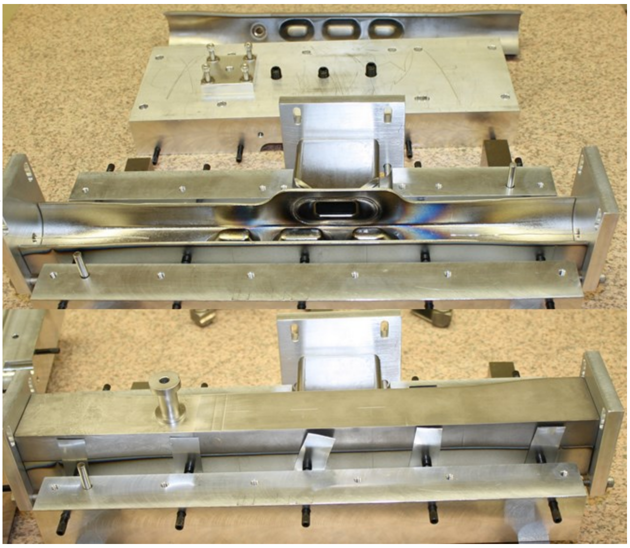

Figure 2: Tuning measurements with QMiR. (Top) all of the parts. (Bottom) The top half of the cavity installed.

frequency errors of less than 2 MHz were observed for separate assemblies of the parts.

Cavity Processing

The ANL low-beta cavity EP tool [6] was modified to enable the horizontal electropolishing of QMiR. Figure 3 shows the cavity in the EP tool prior to the final light electropolish.

Functionally the system is identical to that used to horizontally polish elliptical cell cavities, except that the aluminium cathode for QMiR is a flat plate of high purity aluminium with 0.063” x 1” cross section dimensions. During EP the cavity rotates at ~1/5 RPM and the anode to cathode voltage is fixed at 18 V. The aluminium cathode was masked to achieve an anode-to-cathode surface area ratio of ~6:1 and to maintain a minimum distance of ~0.5” between the anode and cathode along the entire length of the cavity.

Due to the unique cavity geometry the cavity was processed in several steps to ensure adequate niobium material removal during the polishing. A total surface removal of 180 µm of niobium was achieved in the following sequence:

1) An 80 µm 1:1:2 (Hydrofluoric:Nitric:Phosphoric acid) Buffered Chemical Polish @ T < 15^0C.

2) An 80 µm 1:9 (Hydrofluoric:Sulphuric acid) Electropolish @ T < 35^0C.

3) 3 hour 800^0C hydrogen degassing at Fermilab.

4) A final, 20 µm 1:9 (Hydrofluoric:Sulphuric acid) Electropolish @ T < 30^0C.

After the final light-electropolish the cavity was ultrasonically cleaned, high-pressure water rinsed and assembled in a class 100 clean room.

2 K CAVITY PERFORMANCE

RF Performance

Preliminary cold testing of the cavity at 2 K was finished on 12 June 2014. The cavity was fully submerged in the superfluid helium bath and surrounded with two layers of magnetic shielding which, at room temperature, reduced the ambient field around the cavity to < 0.02 mG. The magnetic field at 2 K was not measured but is expected to be less than 0.1 mG which corresponds to an additional residual resistance of 0.05 nΩ, which is negligible. Work on QMiR is ongoing but preliminary results from the 2 K RF test, shown in Figure 4, already demonstrate that QMiR can achieve deflecting voltages more than 33% greater than the design requirement and no field emission was observed.

The 2 K performance in Figure 4 was measured with a fixed coupler and extends to the limit of the RF power source available for testing. The low field residual resistance for this cavity was measured to be several hundred nΩ and is thought to be due to the non-negligible

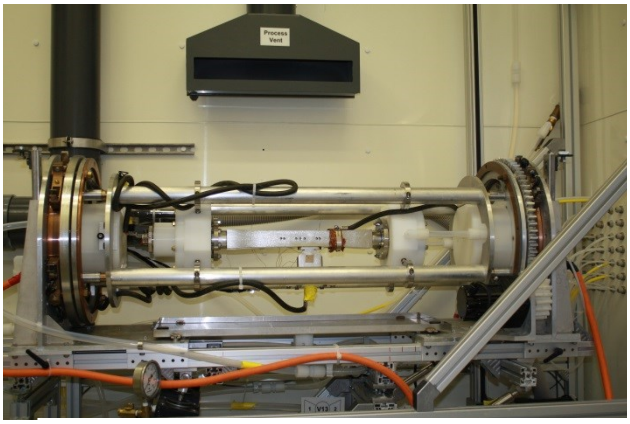

Figure 3: QMiR in the ANL low-beta cavity EP tool.

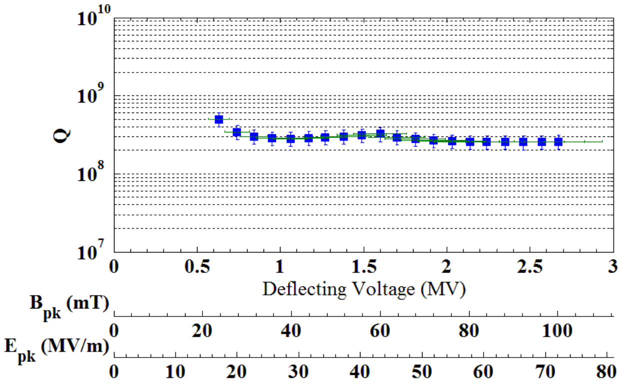

Figure 4: Preliminary 2 K Q-curve measured for QMiR. Decay curves were measured at deflecting voltages of 0.7 MV and 2.6 MV and all give the same calibration. Future testing is planned to eliminate the temporary cover used on the waveguide port to improve the residual resistance.

RF fields at the waveguide flange on the side of the cavity. Care was taken to reduce the RF surface losses by making the blank covering this port from high-RRR niobium, but RF losses in the indium joint between the cavity and the blank were present and have not been quantified yet. Future tests are planned where this RF joint will be modified to make both a hermetic and RF seal to improve the performance of QMiR.

It is interesting to note that the cavity never quenched during the first set of tests. Brief periods of conditioning were observed but none lasted longer than a approximately 2 seconds and the cavity was easily excited to higher stored energies at each step. Total conditioning time was less than one hour to reach the field levels reported in Figure 4.

Mechanical Properties

Microphonic noise which couples to the deflecting RF mode is an important issue for QMiR. Beam loading of QMiR in bunch rotation applications will be relatively small and additional RF bandwidth required for microphonic noise compensation could greatly increase the size, cost and complexity of the RF system.

QMiR is currently being evaluated for continuous wave applications and the relevant acoustic properties are summarized by the cavity's sensitivity to changes in the external pressure. A measure of this, df/dP, was taken by comparing the cavity resonant frequency at 12 torr, 23.5 torr, 400 torr and 760 torr. df/dP was found to be +313 Hz/mbar for the deflecting mode (π -mode) and +450 Hz/mbar for the $2\pi/3$-mode. These numbers will decrease in magnitude with the installation of the cavity helium jacket.

CONCLUSIONS

In the preliminary 2 K cold tests of QMiR the measured deflecting voltage (2.7 MV) exceeded the design goal of 2.0 MV. This measurement demonstrates the excellent electromagnetic and mechanical properties of QMiR, the viability of the design and fabrication techniques. We believe such a cavity may be used at the end of a linac in a beam switchyard for the distribution of high-bunch repetition rate beams to multiple applications. Electron storage rings may use this cavity for the production of picosecond X-ray pulses with high repetition rates according to a proposal described in ref. [7].

ACKNOWLEDGMENTS

We would like to thank A. Lunin of FNAL for the many RF simulations he performed in developing the QMiR cavity geometry and A. Rowe and M. Merio of FNAL for the hydrogen degassing bakes which were performed on this cavity. We acknowledge the support from the ANL LDRD program used to finish this work.

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