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CRYOGENIC TESTING OF HIGH-VELOCITY SPOKE CAVITIES*

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Abstract

Spoke-loaded cavities are being investigated for the high-velocity regime. The relative compactness at low-frequency makes them attractive for applications requiring, or benefiting from, 4 K operation. Additionally, the large velocity acceptance makes them good candidates for the acceleration of high-velocity protons and ions. Here we present the results of cryogenic testing of a 325 MHz, β_0 = 0.82 single-spoke cavity and a 500 MHz, β_0 = 1 double-spoke cavity.

INTRODUCTION

High-velocity single- and multi-spoke cavities have been suggested for applications including high energy proton accelerators [1] and the acceleration of electrons in compact light sources [2, 3]. To this end, we have designed, fabricated (along with Niowave, Inc.), and cryogenically tested a single-spoke cavity with a geometric β_0 = 0.82 and operating at 325 MHz and a double-spoke cavity with a β_0 and operating frequency of 1.0 and 500 MHz, respectively. Table 1 shows some of the rf properties for these cavities. The reference length is $\beta_0\lambda$ and $3\beta_0\lambda/2$ for the single- and double-spoke cavity, respectively, while E_{acc} = 1 MV/m for both.

Table 1: RF Properties

Parameter	325 MHz Single	500 MHz Double
β_0	0.82	1.0
E_p/E_{acc}	3.6	3.7
B_p/E_{acc} [mT/(MV/m)]	6.0	7.6
R/Q [Ω]	449	675
$Q \cdot R_s$ [Ω]	182	174

CAVITY FABRICATION AND PROCESSING

The 325 MHz single-spoke cavity was designed at ODU while the fabrication was done at Niowave, Inc. A 150 μm bulk BCP and 30 μm light etch was also performed by Niowave, Inc. In between these processing steps, a 600° C heat treatment was preformed at FermiLab. When the cavity arrived at Jefferson Lab, a 3-pass high pressure rinsing with deionized water at 1250 psi followed by class 100 cleanroom assembly and 25 hour 120° bake were all carried out.

The 500 MHz double-spoke cavity was designed at ODU while the complete fabrication, processing, and cryogenic testing were done at Jefferson Lab. The fabrication details can be found in [4]. The processing was similar to that described above. A bulk BCP removing 150 μm was initially done. This was done in two steps- 75 μm was removed, the cavity was rotated 180° within the BCP cabinet, and the remaining 75 μm was removed. The cavity thickness (between the spokes, at the center) is measured in real time to ensure accurate removal. The BCP mixture had a volume ratio 1:1:2, which gave an etch rate of roughly 0.5 μm per minute, at this particular point. The complicated geometry of the double-spoke cavity resulted in more material being removed from the end cap regions.

The 500 MHz double-spoke cavity then received a heat treatment of 600° for 10 hours, followed by a light etch of 10 μm, manual high pressure rinsing through the cleaning ports and three passes through the beam ports in the HPR cabinet, finishing with a low-temperature bake of 120° for 48 hours.

HIGH POWER TESTING

The cryogenic testing of both cavities was carried out at Jefferson Lab which houses the Vertical Test Area (VTA). While calibrating the cables, a low power amplifier (1 W) was used and a 500 W amplifier was used to drive the cavities during the high power tests. The VTA operates with a closed cycle LHe supply capable of cooling from 300 K to 4 K in a matter of hours. The 4 K test is then performed and the dewar is refilled and cooled from 4 K to 2 K. During this cool down, frequency and Q_0 measurements are taken in order to determine the residual resistance. Finally, the 2 K tests are carried out.

Gradient Measurements

A fixed-length input coupler installed in one of the cleaning ports was used for both tests. The 325 MHz single-spoke cavity was calibrated to have a Q_{ext} of $6{\times}10^9$ while that of the 500 MHz double-spoke cavity was $1{\times}10^{10}$. In both cases, the pickup probe Q_{ext} was roughly $2{\times}10^{11}$.

The initial tests of the 325 MHz single-spoke cavity exhibited soft multipacting barriers which were predicted quite accurately by TRACK3P (within the SLAC ACE3P code suite [5]). Below 2.5 MV/m, strong multipacting was expected and it was indeed observed, as shown in Fig. 1. After a relatively short amount of processing, it was found that these barriers could be eliminated.

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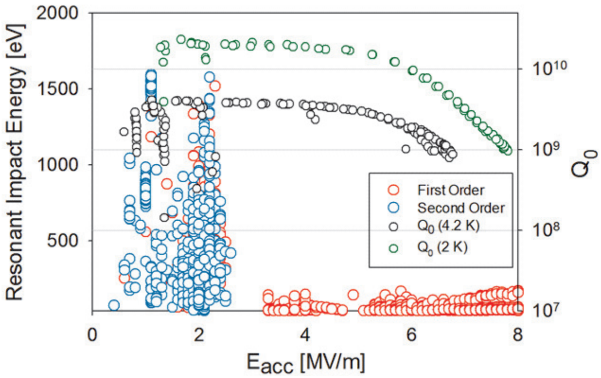

Figure 1: 325 MHz single-spoke cavity initial test results showing simulated multipacting events.

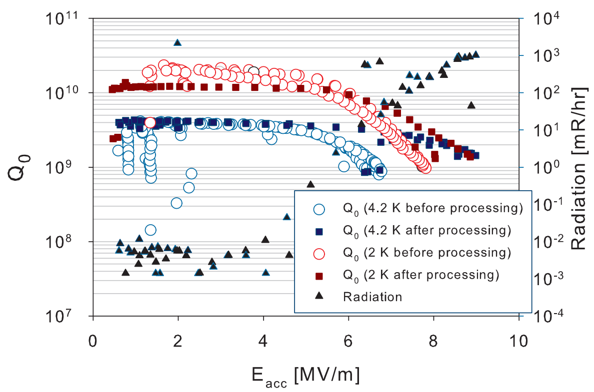

Figure 2: 325 MHz single-spoke cavity test results before and after helium processing.

The single-spoke cavity suffered from abundant field emission, which limited the gradient to roughly 8 MV/m at 2 K, corresponding to $E_p \approx 30$ MV/m and $B_p \approx 50$ mT. Helium processing was employed to try to improve the performance. While a slight improvement was observed (see Fig. 2), the achievable gradient is still quite low. One possible contributor is that the surface of the cavity had a number of stains (possibly from insufficient rinsing after chemical etching) which could not be eliminated through high pressure rinsing alone. Also, because of the large size of the cavity, a production-quality HPR could only be done through the beam pipes. The parts of the spoke and outer conductor that could not be reached, therefore, had to be rinsed manually through the cleaning ports. This cavity has now received an additional light etch at Niowave and is awaiting another round of testing at Jefferson Lab.

The gradient measurements of the 500 MHz, $\beta_0 = 1$ double-spoke cavity are shown in Fig. 3. The low-field Q_0 of this cavity are 2.5×10^9 and 1.1×10^{10} for 4.3 K and 2.3 K, respectively. A cold leak appeared when the cavity was cooled. Because of this, the cavity vacuum was in the 10^{-7} range and prevented cooling to 2 K. A great deal of

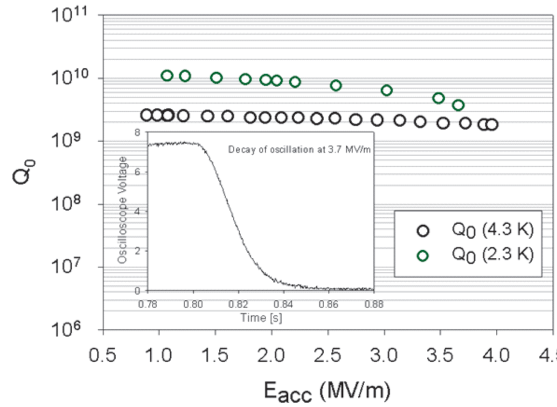

Figure 3: 500 MHz double-spoke cavity initial test results. The inset shows the oscilloscope trace of the transmitted power decaying during one oscillation at 2.3 K and 3.7 MV/m.

multipacting between 1 and 4 MV/m had to be processed, which is consistent with the TRACK3P simulations. A gradient of 4 MV/m (4.3 K) and 3.7 MV/m (2.3 K) marked the onset of oscillatory behavior. The decay time was on the order of tens of milliseconds, which suggests that the cause is not magnetic in nature. It is more likely that the cavity is experiencing thermal breakdown, but further testing is needed to confirm this. These tests, along with additional processing are presently being planned.

Residual Resistance

The surface resistance of a superconducting cavity can be described using BCS theory as $R_s = R_{BCS} + R_{res}$, where R_{BCS} is temperature and frequency dependent, while R_{res} depends on the quality of the surface [6]. Knowing the geometry factor, $G = Q_0 R_s$ (given in Tab. 1) and R_{BCS}, we can then measure the intrinsic quality factor as the cavity is being cooled from 4 K to 2 K, and find the best fit of the data with

$$R_s[n\Omega] = \frac{a}{T[K]} \exp\left[-\frac{b}{T[K]}\right] + R_{res}, \qquad (1)$$

where a and b are constants.

The surface resistance vs. $1/T$ for both cavities is shown in Fig. 4. The residual resistance of the 325 MHz single-spoke cavity is 12.5 nΩ. The 500 MHz double-spoke cavity was more difficult to estimate in this way because the cold leak only allowed for cooling to a safe temperature of 2.3 K. It is clear in Fig. 4 that the 500 MHz cavity R_s curve may not be the most reliable estimate for R_{res}. The value obtained is likely not higher than $R_{res} = 13.4$ nΩ.

Pressure Sensitivity

Both of the cavities discussed here were intended to only be tested in the VTA, and therefore only need to withstand a vacuum load of roughly 1 atm. The 500 MHz double-spoke cavity is able to do this without any external stiffen-

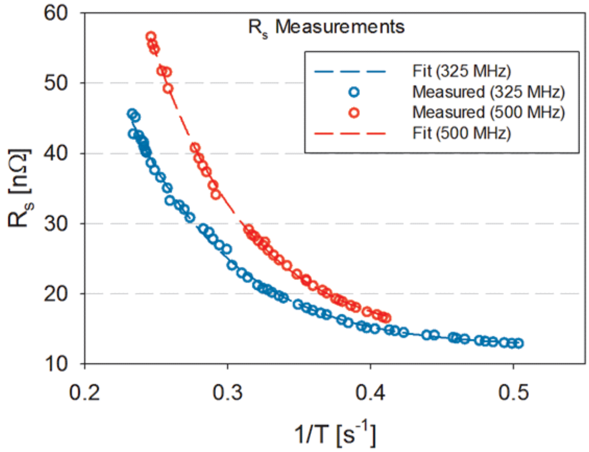

Figure 4: Surface resistance measurements for both the 325 MHz single- and 500 MHz double-spoke cavities.

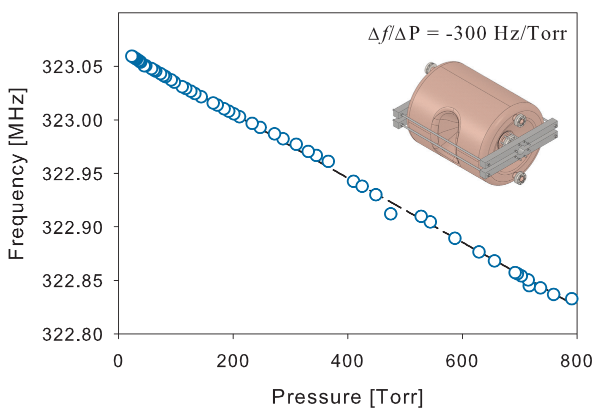

Figure 5: Pressure sensitivity of the 325 MHz single-spoke cavity.

ing, however the 325 MHz single-spoke cavity is not. A simple structure was designed and fabricated by Niowave, Inc. to stiffen the cavity sufficiently for testing (shown in Fig. 5).

The double-spoke cavity was completely bare, so a much greater sensitivity to pressure was observed, as shown in Fig. 6.

CONCLUSION

These are some of the first high-velocity superconducting spoke cavities fabricated and tested, to date. Both the $\beta_0 = 1$ and 0.82 cavities reached a high Q_0 and were found to have a reasonable residual resistance. Multipacting was encountered, but easily processed. The single-spoke cavity was limited by field emission while the double-spoke may be experiencing some sort of thermal breakdown. Each of the limitations are not fundamental to the design. The single-spoke cavity has now received another light etch to remove the residue and is being prepared for imminent testing at Jefferson Lab. The cold leak in the 500 MHz double-spoke cavity has been found and fixed and more processing and testing to identify the source of 4 MV/m limitation is underway.

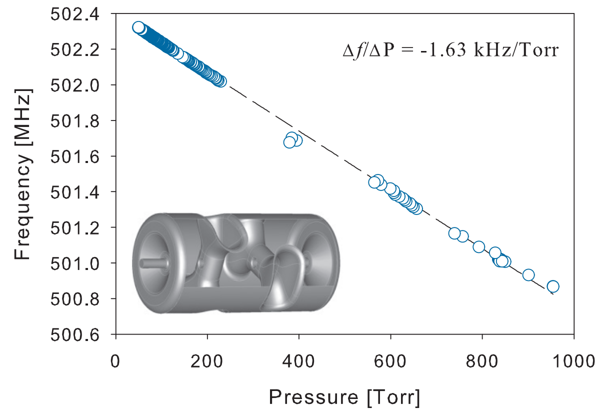

Figure 6: Pressure sensitivity of the 500 MHz double-spoke cavity.

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REFERENCES

[1] P. Ostruomov, "The Whole SC Linac", Presentation at the 4^{th} Meeting of the ESSS Linac Reference Group.31 (1996).

[2] T. Satogata and K. Deitrick and J. R. Delayen and B. R. P. Gamage and K Hernandez-Chahin and C. S. Hopper and G. Krafft and R. G. Olave, "Compact Accelerator Design for a Compton Light Source," IPAC13, Shanghai, China, (2013), pp. 2292-2294.

[3] W. S. Graves, W. Brown, F. X. Kaertner, D. E. Moncton, "MIT Inverse Compton Source," NIM A, **608**, 1, pp. S103.

[4] HyeKyoung Park, C. S. Hopper, and J. R. Delayen, "Fabrication and measurements of 500 MHz Double Spoke Cavity," These proceedings.

[5] K. Ko et al, "Advances in Parallel Electromagnetic Codes for Accelerator Science and Development," LINAC2010, Tsukuba, Japan, (2010), pp. 1028-1032.

[6] J. Bardeen, L. N. Cooper, and J. R. Schrieffer, "Theory of Superconductivity," Phys. Rev., **108**, 5, p. 1175, (1957).

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