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DEVELOPMENT AND TESTING OF A 325 MHZ β_0 = 0.82 SINGLE-SPOKE CAVITY*

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Abstract

A single-spoke cavity operating at 325 MHz with optimum beta of 0.82 has been developed and tested. Initial results showed high levels of field emission which limited the achievable gradient. Several rounds of helium processing significantly improved the cavity performance. Here we discuss the development process and report on the improved results.

INTRODUCTION

High-velocity single- and multi-spoke cavities are being investigated for a number of applications [1–4]. A single-spoke cavity operating at 325 MHz with $\beta_0 = 0.82$ has been designed, fabricated, and cryogenically tested. Figure 1 shows the fabricated cavity with the stiffening structure attached.

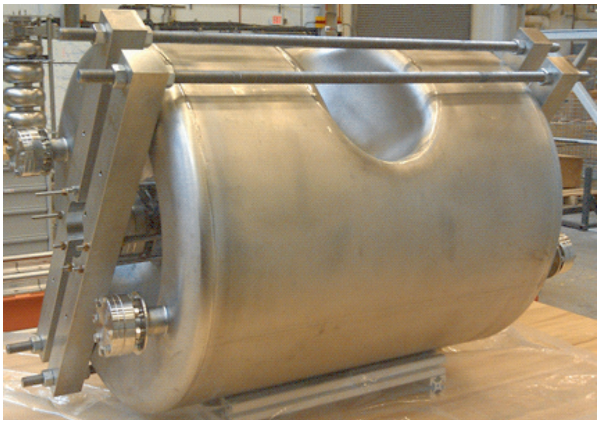

Figure 1: 325 MHz, β_0 = 0.82 single-spoke cavity with stiffening bars.

ELECTROMAGNETIC OPTIMIZATION

The primary goals of electromagnetic optimization are to reduce the peak surface electric and magnetic fields while increasing the shunt impedance. However, it is important to point out that there is no "optimal" design for all applications [5]. For this particular cavity, minimizing the peak surface fields was a priority [6]. Table 1 shows some of the geometric and rf properties for this cavity. The reference length used to define E_{acc} is $\beta_0\lambda$ = 757 mm and E_{acc} = 1 MV/m.

Table 1: Geometric and RF Properties

Parameter	325 MHz	Units
Frequency	325	MHz
Cavity diameter	609	mm
Cavity length	717	mm
Aperture diameter	60	mm
β_0	0.82	-
E_p/E_{acc}	3.6	-
B_p/E_{acc}	6.0	[mT/(MV/m)]
R/Q	449	[Ω]
$Q \cdot R_s$	182	[Ω]

There are a number of other analyses which are typically performed prior to fabrication. Multipacting reduction, particularly with the complex geometry of the spoke cavity [7] is one of the most important. Doing so resulted in minor modifications to the geometry which are reported elsewhere [6, 8]. It is also necessary to understand how the cavity will respond under various pressure scenarios. ANSYS [9] was used to evaluate the von-Mises stress under 1 and 1.4 atm vacuum load. It was determined that the cavity would experience plastic deformation even at 1 atm if not properly stiffened. Figure 2 shows the location of the high stress areas on the end caps. Even with the stiffening structure shown in Fig. 1, there was additional support which needed to be introduced. When the beam pipe is fixed, a great deal of stress appears on the curvature where the beam pipe meets the end cap. For this reason, that area was made of thicker material. This was also necessary for the spoke; the large flat areas perpendicular to the beam line experience significant bowing which can be alleviated with 4 mm thick niobium and stiffeners.

CAVITY FABRICATION AND PROCESSING

The 325 MHz single-spoke cavity was designed and optimized at Old Dominion University's Center for Accelerator Science. The fabrication and chemical processing were carried out at Niowave, Inc. The chemical processing involved a 120 μm bulk BCP and 30 μm light etch. In between these processing steps, a 600 °C, 10 hour heat treatment was preformed at FermiLab.

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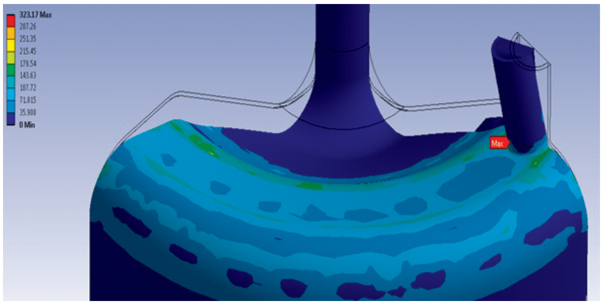

Figure 2: von-Mises stress on the end cap under 1 atm external vacuum load.

Before each test at Jefferson Lab, high pressure rinsing was performed. The cavity geometry made it difficult to reach certain surfaces through only the beam ports. Also, the size of the cavity made it impossible to simply offset the cavity in the HPR cabinet in order to rinse through the cleaning ports. For this reason, a manual rinse was performed through the cleaning ports prior to a 3-pass HPR though the beam ports in the HPR cabinet at JLab. The cavity was then dried and assembled in JLab's class 10 cleanroom before being moved to the Vertical Staging Area (VSA) where it could be heated to 120 °C for 48 hours before being loaded into the dewar for cryogenic testing.

HIGH POWER TESTING

The cryogenic testing 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 cavity 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 were taken in order to determine the residual resistance. Finally, the 2 K tests were carried out.

Gradient Measurements

A fixed-length input coupler installed in one of the cleaning ports was used for all the tests. The input coupler was calibrated to have a Q_{ext} of $6{\times}10^9$ for the first set of tests and $1{\times}10^{10}$ for the second. In both cases, the pickup probe was calibrated to 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 [10]). Below 2.5 MV/m, strong multipacting was predicted from simulations and confirmed to exist. Figure 3 shows the simulated multipacting overlayed with the gradient measurements. These barriers were eliminated after several minutes of processing and did not reoccur.

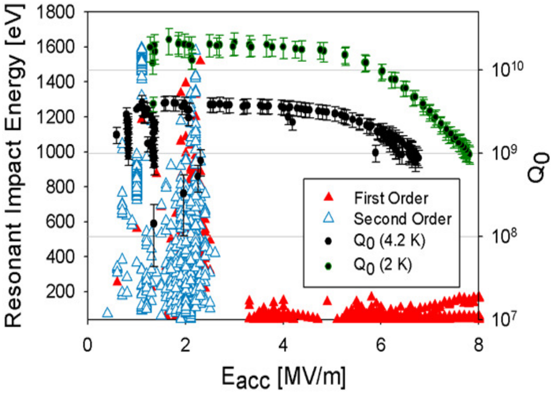

Figure 3: 325 MHz single-spoke cavity initial test results showing simulated multipacting events.

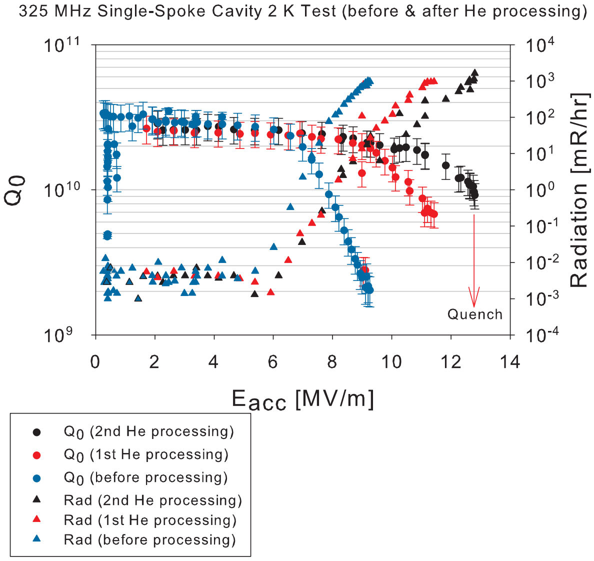

Figure 4: 325 MHz single-spoke cavity test results before and after helium processing.

The cavity suffered from abundant field emission during these initial tests. This 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 used to slightly improve the performance, however, there were traces of white residue in the cavity which could not be removed through high pressure rinsing. Therefore, the cavity was reprocessed at Niowave where it received an additional light BCP. The same HPR, assembly, and heat treatment were performed prior to the second round of testing. Figure 4 shows the results for the second round of helium processing and testing.

It is clear that the achievable gradient improved significantly through helium processing. Table 2 summarizes the cavity performance.

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}

Table 2: 325 MHz, β_0 = 0.82 single-spoke cavity performance

Parameter	4.2 K Value	2 K Value
V_{acc} [MV]	9.1	9.7
E_{acc} [MV/m]	12	12.8
E_p [MV/m]	43.2	46
B_p [mT]	72	77
Q_0	5.6×10^9	2.5×10^{10}

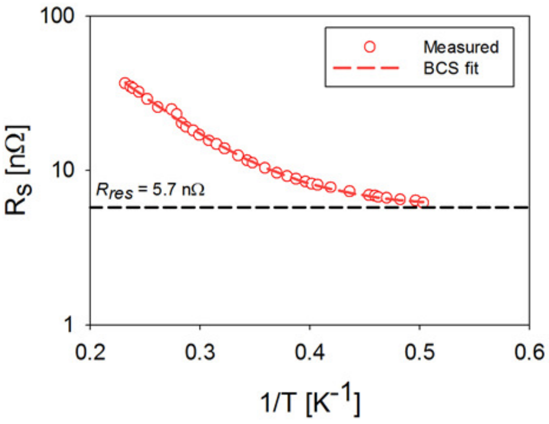

Figure 5: Surface resistance measurement.

depends on the quality of the surface. At 325 MHz, the R_{BCS} is estimated to be 33 nΩ at 4.2 K and less than 1 nΩ at 2 K.

To calculate the residual resistance (R_s), we measured the intrinsic quality factor Q_0 while the cavity was being cooled from 4.2 K to 2 K. Using the relationship between the geometry factor, quality factor, and effective surface resistance, we can calculate $R_s = G/Q_0$. With this, we can extrapolate R_{res} by fitting the data to

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

where a and b are constants to be determined.

The surface resistance vs. $1/T$ is shown in Fig. 5. The residual resistance of the 325 MHz single-spoke cavity was found to be 5.7 nΩ.

CONCLUSION

The 325 MHz, β_0 = 0.82 single-spoke cavity reached a high Q_0 with a low residual resistance. Multipacting was encountered at levels predicted by simulation, but was easily processed. After helium processing, the achievable gradient and surface fields were significantly higher.

A high-β_0 spoke cavity which has been optimized to reduce the peak surface fields while maintaining a high shunt impedance results in dimensions which are typically greater than those of previously fabricated spoke cavities. The transverse dimensions, however, remain 20%-30% lower than a TM cavity operating at the same frequency. The size does present some unique challenges for fabrication and processing. Chemical etching and high pressure rinsing can be particularly challenging without the proper tools and fixtures.

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