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FIRST TEST RESULTS OF SUPERCONDUCTING TWIN AXIS CAVITY FOR ERL APPLICATIONS *

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Abstract

RF superconducting (SRF) cavities with two beam pipes have been proposed in the past for energy recovery linac applications. The relatively complex geometry of those cavities presented a serious challenge for fabrication and surface processing. The main concerns have now been overcome with the fabrication and successful RF testing of a new elliptical twin-axis cavity proposed by Jefferson Lab (JLab) and optimized by the Center for Accelerator Science (CAS) at Old Dominion University (ODU) in the framework of a DoE accelerator stewardship program. The cavity design provides uniform accelerating or decelerating fields for both beams. This paper describes the cavity design, fabrication experience, and the first cold RF test results and explores potential applications especially for JLab's EIC (JLEIC).

INTRODUCTION

SRF accelerating structures with two beam pipes ('twin axis' cavity) intended for Energy Recovery Linacs (ERLs) applications were proposed a decade ago [1-3]. A seemingly complicated cavity was fabricated by KEK [1] but such a cavity has never been tested and therefore the feasibility has not been proved. ODU CAS designed the new geometry focusing on ease of fabrication and post-processing utilizing today's well-controlled procedures. The design was optimized to minimize the peak RF surface fields, to provide the same longitudinal electric field profile in both beam tubes, and eliminate multipacting [4]. The cavity design also provides a relatively strong cell-to-cell coupling so that several cells can be joined together for a multiple cell cavity design. The fabrication and post-processing followed typical methods used for conventional single beam pipe elliptical SRF cavities [5]. Room temperature measurements and a vertical cold test have been completed. The results prove the feasibility of the twin axis cavity that could be useful for applications such as in the JLEIC cooler ERL [6] or an asymmetric dual axis ERL [7].

DESIGN

The design went through a couple of evolutions to arrive at an optimized RF design, which provides good RF electromagnetic performance properties [4]. The final design is shown in Fig. 1 and its RF properties are summarized in Table 1 [4].

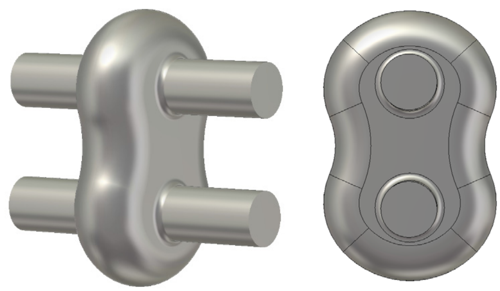

Figure 1: Elliptical-shaped twin axis cavity.

Table 1: Cavity Parameters and rf Properties of the 1497 MHz Single Cell Twin Axis Cavity as Fabricated

Parameter	Value as designed	Unit
Cavity height	202.5	mm
Cavity width	300.0	mm
Cavity length	100.13	mm
Cell length	81.13	mm
Iris curvature	8.0	mm
Beam aperture	60.0	mm
Beam axis separation	136.5	mm
E_p/E_{acc}*	2.68	-
B_p/E_{acc}*	5.5	mT/(MV/m)
$[R/Q]$	60.1	Ω
G	320.8	Ω
R_tR_s	1.93×10^4	Ω^2
LOM	1103	MHz
Nearest HOM	1806	MHz

The cavity uses the second TM110 mode as the operating mode. The transverse field components of the operating mode were minimized at the beam pipe centers, and the beam pipes are slightly shifted from the center to cancel the dipole effect [4].

FABRICATION

The fabrication process was comparable to that of typical single beam pipe elliptical cavities. The stamping die set consists of half-cell male and female dies, beam pipe opening punches, and a coining ring with one female

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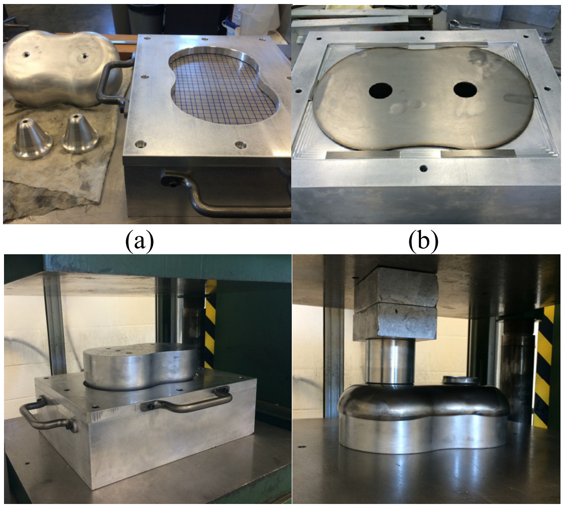
die used for all three stamping operations (i.e. forming of the main half-cell, forming of the beam pipe opening, and Coining of the beam pipe leading radius). The forming process was verified successfully with copper blanks, before stamping Nb sheets. The die set and the stamping operations are shown in Fig. 2.



(a) (b)

(c) (d)

Figure 2: Half cell forming processes. Die set (a), niobium blank (b), first stamping for half cell body (c), and coining after second stamping of beam pipe opening (d).

After stamping, an uneven material thickness around the figure eight shaped equator was observed. It was predicted since the equator is not axisymmetric. The main challenge for this cavity was the electron-beam welding at the cavity equator. The equator seams were prepared for a butt weld. However, the half-cells exhibited a variation in the material thickness along the equator due to uneven spring-back effects. Therefore, the weld preparation machining did not provide a uniform thickness of the weld seam. This resulted in a less than optimal weld quality. Problems with the welding machine also created weld defects. In fact, two prototype cavities were built in the same period and both cavities had weld issues on the equator. One of the defect areas is shown in Fig. 3. For the second cavity, lessons learned were applied and a much better material thickness uniformity was achieved after additional CNC machining around the equators. This resulted in an improved weld joint with less defects.

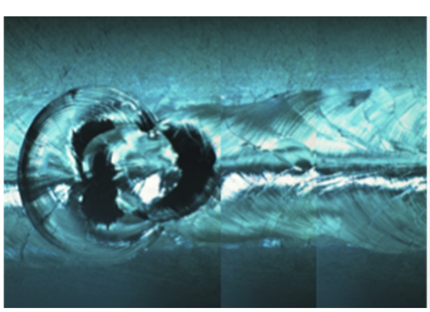


Figure 3: Inside view of equator weld defect.

POST FABRICATION PROCESSING

Standard bulk niobium cavity post-processing procedures were applied for the cavities after UHV cleaning.

- Heavy BCP: The damaged layer removal target was 200 microns. Thickness measurement before and after the process showed an actual removal of 180 micron on average.
- Heat treatment: High temperature heat treatment was performed at 800 deg. C for 3 hours. Residual gas in the furnace was monitored during the process. As temperature increases the hydrogen partial pressure peaked at 2×10^{-7} mbar and was less than 10^{-9} mbar after the heat cycle.
- Light BCP: An additional 25 microns was removed from the interior surface after the heat treatment.
- High pressure rinse: High pressure rinse was performed using JLab's automated system. The water wand went through 3 passes through the cavity cell (up and down) for each beam pipe.
- Clean room assembly: After overnight drying, the cavity was assembled with ancillary parts for testing including an input and pick-up coupler, a vacuum valve, and a safety burst disc. The cavity ready for the vertical test is shown in Fig. 4.
- Low temperature bake: The cavity was baked in the bake box at 120 deg. C for 12 hours for the second cavity (cavity #2) built. The first cavity built (cavity #1) was baked 24 hours at the same temperature.

Figure 4: Cavity ready for test.

Cavity #1 was treated with centrifugal barrel polishing to smooth out the more prevalent weld defects. This provided a mirror finish, but could not fully remove the weld defects.

TEST RESULTS

Cavity #2 was processed and tested first and cavity #1 followed after the centrifugal barrel polish.

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Room Temperature HOM Measurement

Figure 5 shows the room temperature HOM spectrum. The line is a S21 transmission measurement and the markers indicate the R/Q-value of each LOM and HOM. Due to the low spectral resolution, some HOMs were not detected.

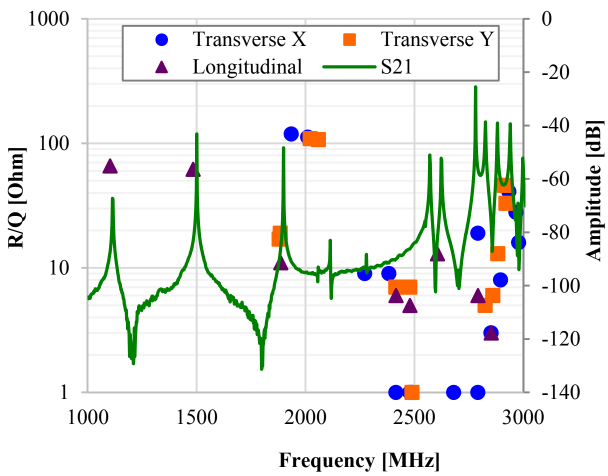

Figure 5: HOM measurement and simulated R/Q.

Cold Test

The main results of the vertical RF tests are plotted in Fig. 6 for both cavities. Cavity #2 reached an accelerating/decelerating field of 23 MV/m with a maximum quality factor of 1.2×10^{10} in the low field regime. As predicted by simulations using Track3P as part of SLAC's ACE3P suite of codes [4], multipacting was not observed.

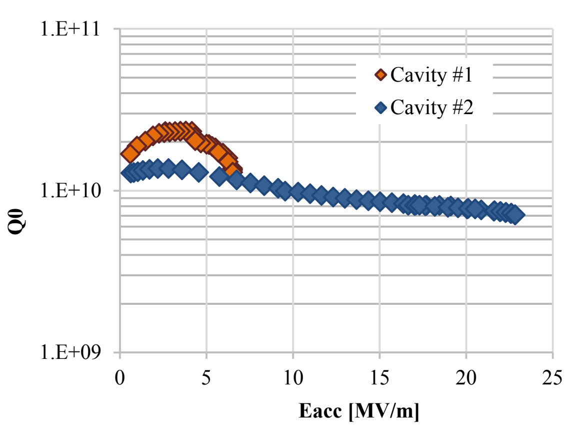

Figure 6: Cold test Q curve.

Four Cernox sensors were mounted on the cavities and the temperatures were monitored during the cold RF test. For both cavities, sensor #1 was installed at the peak magnetic field area, which is located between the beam pipes. All other sensors were placed on the equator weld defect area. The temperature profile of cavity #2 (Fig. 7) shows that the weld quality on the equators did not limit the cavity performance for cavity #2.

Cavity #1 quenched at around 7 MV/m. The test indicates however that the main weld defect could be responsible for the quench. We observed a fast rise of the temperature at the weld defect spot (Fig. 8). This resulted in a strong roll-off of the Q curve at the time of quench. A second-sound quench detection system also pointed to the weld defect as the origin of the quench.

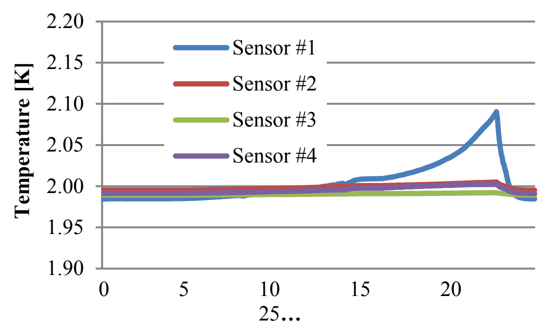

Figure 7: Temperature profile of cavity #2 during rf test.

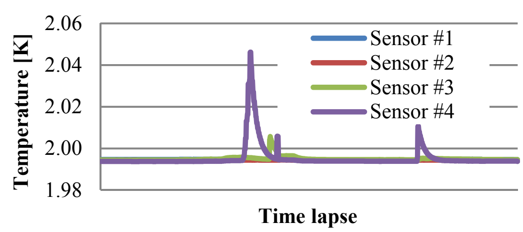

Figure 8: Temperature profile of cavity #1 during rf test.

CONCLUSION

Two proof-of-principle twin axis elliptical cavities were designed, built, and tested. The combined test results of both cavities prove they can be used in ERL applications. The experience shows that the performance can be improved when the processes are custom-fitted to this design, specifically to provide better electron beam welds at the equators. Even though cavity #1 showed a premature quench, the quality factor is very respectable for a BCP'd cavity, although this cavity had a mirror-finish after CBP. The cause of the early quench of cavity #1 is well understood (weld defect) and corrective actions are available. Concerns related to the cavity post-processing due to the relatively complex design are now resolved through this successful test. More studies, for instance HOM damping and implementation, are encouraged to further develop such cavities for actual applications.

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