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MANUFACTURING AND FIRST TEST RESULTS OF EUCLID SRF CONICAL HALF-WAVE RESONATOR*

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Abstract

Euclid TechLabs has developed a superconducting conical Half-Wave Resonator (162.5 MHz β=v/c=0.11) for the high-intensity proton accelerator complex proposed at Fermi National Accelerator Laboratory. The main objective of this project is to provide a resonator design with high mechanical stability based on an idea of the balancing cavity frequency shifts caused by external loads. A unique cavity side-tuning option has been successfully implemented. Niowave, Inc. proposed a complete cavity production procedure including preparation of technical drawings, manufacturing, processing steps and resonator high-gradient tests. During manufacturing a series of cavity and helium vessel modifications to simplify their fabrication were proposed. Following standard buffered chemical polish surface treatment and high-pressure rinse, a vertical test was carried out at Niowave's facilities.

Here we present the status of the project and the first high-gradient results.

INTRODUCTION

The conical Half-Wave Resonator (cHWR) design was reported earlier elsewhere [1-4]. The cavity RF parameters are shown in Table 1. A photo of the niobium cavity prototype being leak checked is shown in Fig. 1.

The main objective of the project was the conceptual design of the cHWR with its liquid helium vessel, minimizing the sensitivity of the resonant frequency to fluctuations in helium pressure.

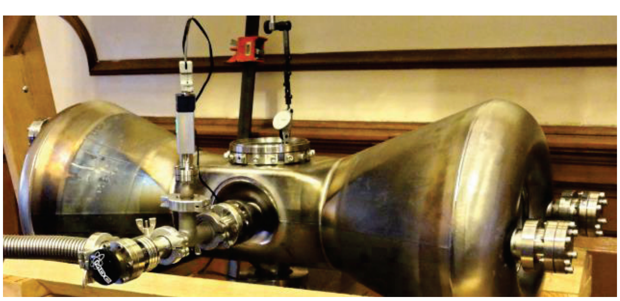

Figure 1: Modified cHWR with leak check setup.

Table 1: Conical HWR Parameters

frequency	MHz	162.5
$\beta = v/c$		0.11
R_aperture	mm	18
$\beta\lambda$	mm	202.94
R_cavity **)	mm	90
G	Ohm	36.36
R/Q	Ohm	119
E_{pk} / E_{acc} *)		5.1
B_{pk} / E_{acc} *)	mT/MV/m	7.1
B_{pk} / E_{pk}	mT/MV/m	1.39
tune	kHz/mm	-87
*) $L_{eff} = N_{gaps} * \beta\lambda/2$, where N_{gaps}=2 – number of gaps		
**) Cavity radius in center		

To use the outer conductor walls for cavity tuning deformations effectively, the central part of cHWR is made asymmetric with a planar surface on one side. This planar surface is used for tuning by deformation (Fig. 2).

The central resonator section optimization was made without compromising the cavity performance. The tuner ring is installed around the bellow (Fig. 2) connecting cavity and helium vessel tuning plates and provides compensation of the cavity tuning wall external pressure deformation (Fig. 3).

The side tuning procedure results in tune sensitivity up to 80 kHz/mm with acceptable stresses 350 MPa/mm and tuning pressure less than 1 kN/mm. There is nearly no dependence on the resonator frequency slow tuning.

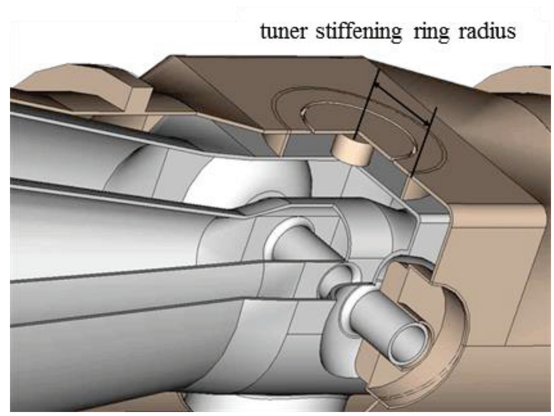

Figure 2: cHWR simulation model central part.

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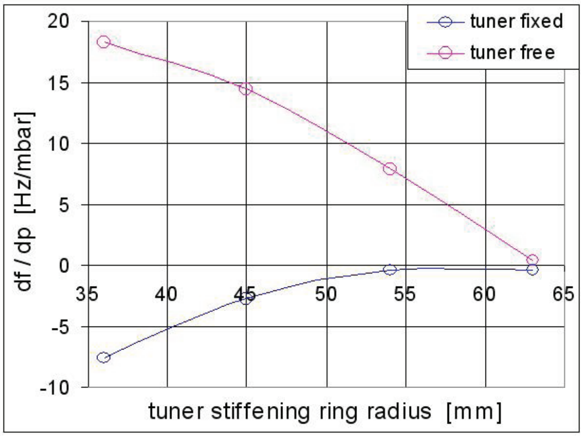

Figure 3: cHWR tuner ring position optimization.

CAVITY FABRICATION

Niowave, Inc. worked out a series of cavity and helium vessel modifications to simplify their manufacturing without affecting the main resonator mechanical stability parameters [3]. The modified cold mass design calculations (cavity and helium vessel) confirmed that the total effect of external pressure on all cavity and liquid helium vessel walls results in nearly complete compensation of the frequency shifts caused by cavity and vessel wall deformations (df/dp is close to zero).

Niowave, Inc. performed the cavity fabrication and installation into the stainless steel helium vessel. The niobium walls of inner and outer conductors are formed of 2.8 mm thick niobium sheets. Significant efforts were made for precise manufacturing of the beam ports and the central part of the cavity (Fig. 4).

Figure 4: Cavity tuner section.

The central electrode was formed in halves and seam welded together. The outer conductor conical walls also have been manufactured from two halves and longitudinally welded. All niobium-niobium joints in the cavity body were joined by electron-beam (EB) welding.

After the final EB closure welds and leak checks, a bead pull measurement was performed, indicated field flatness between the two accelerating cells less than 2%. The tuner deflection during cavity leak test was around 0.44µm/mbar.

The cavity helium vessel was manufactured from 3 mm thick stainless steel. A special technology has been used to join the cavity niobium port pipes with their stainless steel flanges using brazing via a copper layer. All cavity vacuum ports are sealed with Conflat flanges. The final modified geometry of the cavity with helium vessel is presented on Fig. 5.

Figure 5: Helium vessel leak check setup.

During the leak check of the helium vessel (Fig. 5-6), measurements of the tuner displacement were made and the sensitivity of the cavity frequency with pressure was estimated at ~2 Hz/mbar with the tuner loose (maximum measured displacement of ~0.01 mm).

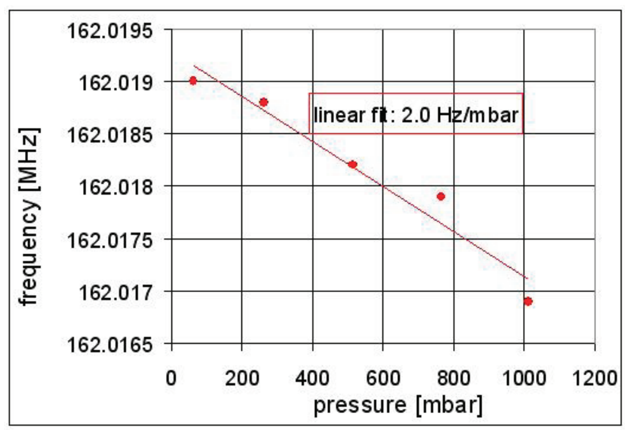

Figure 6: Frequency shift during helium vessel leak test.

The cavity BCP was made with the resonator oriented in vertical position through vacuum ports with acid entering from the bottom and leaving through the top ports. The procedure was repeated twice rotating the cavity by 180 deg. A high-pressure rinse with ultra-pure water has also performed with the cavity in a vertical position using vacuum ports and beam pipes with the cavity flipped top to bottom during the rinse. A long wand with a nozzle at the end can reach the middle of the cavity using top-bottom vacuum ports. This allows spray on all interior cavity surfaces, including ports and beam pipes.

FIRST HIGH-FIELD RESULTS

Two high-field cryotests of the cavity have been performed at Niowave in a vertical test dewar. Because of the limited project budget every test lasted not longer than

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one day. The cavity was cooled down to the superconducting transition temperature in a little over two hours, with special care taken to cool more quickly in the temperature range of 50-150 K. The frequency of the cavity was 162.35 MHz at 4 K (shift of 220 kHz from the warm frequency, Fig. 7).

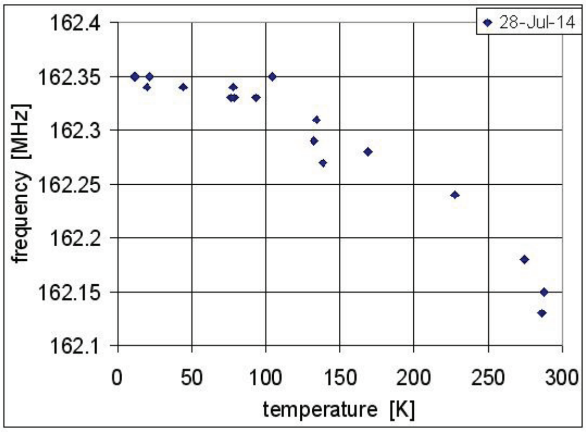

Figure 7: Frequency change during cavity cool-down.

A first initial cryotest was performed with a cw 100 W amplifier. Several multipacting barriers were observed at low field levels, with some conditioning of these barriers accomplished. The measured Q was consistent with the expected low-field unloaded Q near 1.6×10^9. Further conditioning would be required to reach the design field levels.

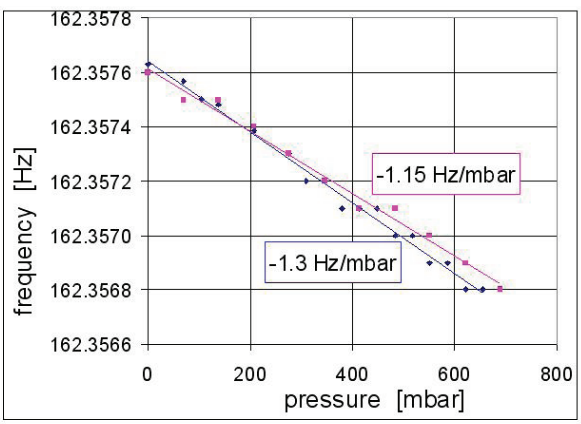

Figure 8: df/dp measurements at 4K.

The helium vessel was pressurized to test df/dp under cryogenic conditions. These df/dp measurements confirm the numerical simulations and are consistent with previous room temperature df/dp measurements (Figs. 6 and 8).

A second cryogenic test with a higher power amplifier and circulator up to 500 W, was performed to further condition the cavity. The multipacting barriers that had been problematic in previous tests were almost nonexistent. What barriers which could still be found were easily conditioned away with the higher available RF power. The disappearance of multipacting is possibly associated with reduced levels of adsorbates on the niobium surfaces as a result of the cavity being under vacuum continuously for several months. A high-field Q slope consistent with field emission in the cavity was observed. X-ray emission at high fields was also detected. A controlled leak of clean helium gas was used to lower the breakdown field level for erosion of field-emitter tips on the cavity walls. The result of this helium processing with high levels of RF power was a ~25% increase in the operating fields, as shown in (Fig. 9). Further high-field operation of the cavity is expected to continue conditioning the cavity toward higher accelerating field levels. More helium processing will increase the speed of this conditioning process, but may or may not be required to reach the design fields for the structure.

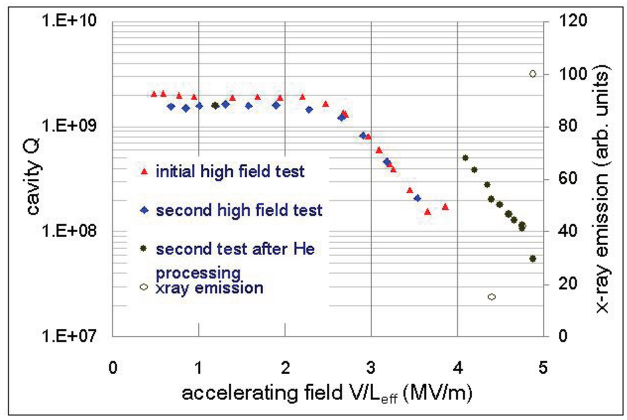

Figure 9: Q measurements at 4K.

CONCLUSIONS

1. An engineering design of the conical Half-Wave Resonator in the helium vessel with side tuning possibility was completely realized. The main project goal of the cavity and helium vessel structure designed to minimize microphonics caused by an external pressure has been confirmed by the structure cold test at 4K. The side option of the cavity tuner was effectively implemented providing the self-compensated frequency shift design and low tuning pressure.
2. The cavity with helium vessel has been fabricated at Niowave Inc. with supervision and quality control from Euclid Techlabs.
3. During cryotests resonator has demonstrated high cavity Q, low df/dp, and over half of its design field level (design E_{acc} is 8 MV/m) in only two short tests. The longer tests should secure improvements in the field emission and result in higher field gradients.
4. Better vacuum (time under ion pump) and more RF power (500 W) were critical to demonstrated progress in recent test.
5. Multipacting not problematic with enough power.
6. X-rays at high field behave as field emission – no quenching and no hard barriers.

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