# CRAB CAVITY AND CRYOMODULE PROTOTYPE DEVELOPMENT FOR THE ADVANCED PHOTON SOURCE*

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*Abstract*

Two single-cell, superconducting, squashed elliptical crab cavities with waveguides to damp Higher Order Modes (HOM) and Lower Order Mode (LOM) have been designed and prototyped for the Short Pulse X-ray (SPX) project at the Advanced Photon Source (APS). The Baseline cavity with LOM damper on the beam pipe has been vertically tested and exceeded its performance specification with over 0.5MV deflecting voltage.The Alternate cavity design which uses an "on-cell" waveguide damper is preferred due to its larger LOM impedance safety margin. Its prototype cavity has been fabricated by a Computer Numerical Controlled (CNC) machine and is subject to further testing. The conceptual design, layout and analysis for various cryomodule components are presented.

## INTRODUCTION

The SPX project at Argonne National Lab (ANL) will use superconducting radio frequency (SRF) crab cavities at 2.815GHz to produce short (~2ps) pulse x-rays for selected users without disrupting the regular x-ray pulse usage for other users around the APS. The current project status will be reported in [1]. The scope of the project requires 2MV deflecting voltage on each side of SPX production section in Sector 6 at the APS. Four cavities for each cryomodule will be utilized to attain the 0.5 MV with maximum surface magnetic field at 98mT on each cavity. Only single-cell cavity designs have been shown to satisfy the voltage performance, impedance budget and fabrication requirements. The design parameters of the most promising two candidates, Baseline and Alternate, have been summarized in [2].

The LOM and HOM damping become especially challenging for the crab cavity and cryomodule developments due to 200mA CW beam current and the small aperture due to the high cavity frequency. R&Ds and prototyping activities for the cavity have been carried out at Jefferson Lab [3] [4] in collaboration with ANL. To ensure the beam stability of machine operation, a larger impedance safety margin on the Alternate cavity design is preferred. In addition it produces less LOM and HOM power from the beam. It also features a dog bone shape iris on the cavity cell's open slot which can improve LOM/HOM damping with reduced magnetic field enhancement.

## CAVITY FABRICATION, PROCESS AND TEST RESULT

The first prototype on-cell damper cavity CCA1 was made by joining a saddle piece from a stamped cell to the waveguide adapter [4]. Unfortunately this trial article for Electron Beam Welding (EBW) parameter study had been used for the proof of principle in vertical tests [4]. The first baseline cavity CCB1's cell was stamped from

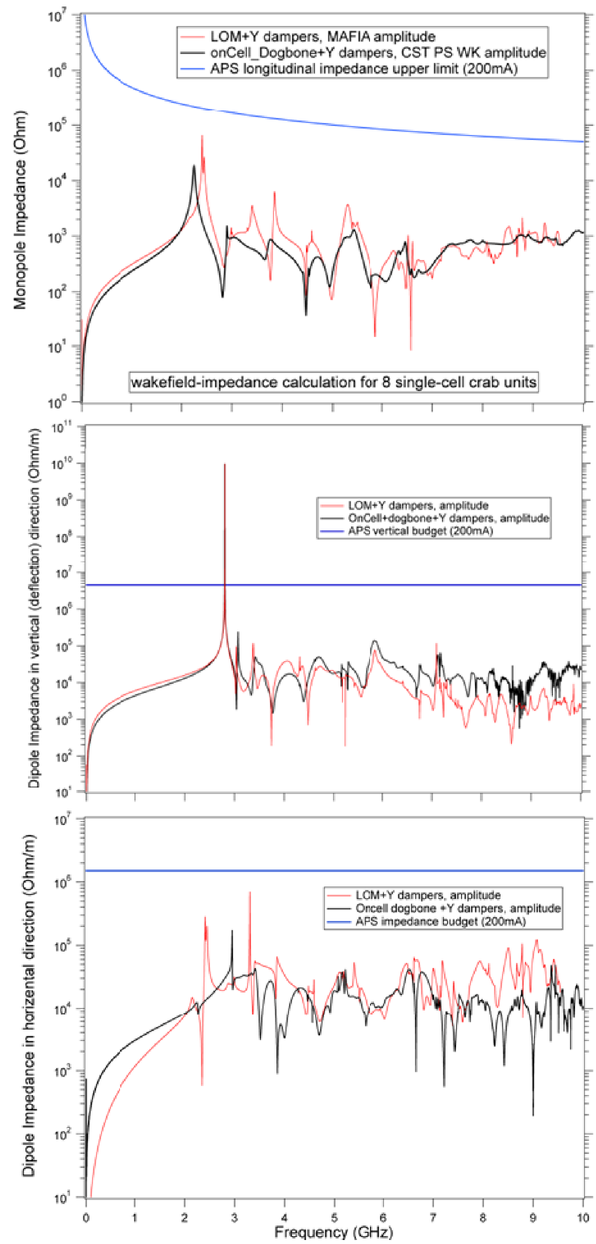


Figure 1: 8 Baseline (red) and Alternate (black) cavities' impedances againt to APS impedance budegt (blue).

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the same die, but the Y HOM waveguide was machined from bulk RRR>250 fine grain niobium by CNC machine [3].

### *Baseline cavity*

After grinding off a trench-like welding ripple on the cavity equator, the CCB1 cavity went through following processes:

- 90+10+80um Buffer Chemistry Polish (BCP) with ΔT <10°C, etching rate=1um/min to allow equal amounts of material removal from iris and equator. Inlet to outlet acid ΔT<1.5°C
- 600°C bake for 10hrs
- Final 5um BCP on bench
- Ultrasonic degreasing
- High Pressure Rinsed (HPR) in R&D system for ~1hr
- Dried in a class-10 clean area overnight
- Assembled with indium seals on RRR~ 80 Nb blank-off flanges in class-10 clean area
- Attached to test stand, leak checked and evacuated to <5e-8 mBar in class-100 room
- Set up variable coupling in vertical staging area

The cavity was in a vertical free hanging position with a variable coupling link for the probe coupler on the bottom. The input RF coupling can reproduce the setup at room temperature and be changed at 2K temperature.

The coupling antenna is a copper L shape electric probe. In the first power rise of test #2, the cavity reached 116mT maximum magnetic field on the iris which corresponds to a 0.59 MV deflecting voltage (in Figure 2). There was no sign of x-ray radiation or multipactoring (MP). The Lorentz Force Detuning (LFD) coefficient was measured as -14.9Hz/(MV/m)$^2$. The helium pressure sensitivity was measured also as -1.1kHz/Torr. The ANSYS simulations later confirmed these numbers quantitatively and found that they are critically dependent on the constraining conditions and detail feature regarding the EBW joint welds.

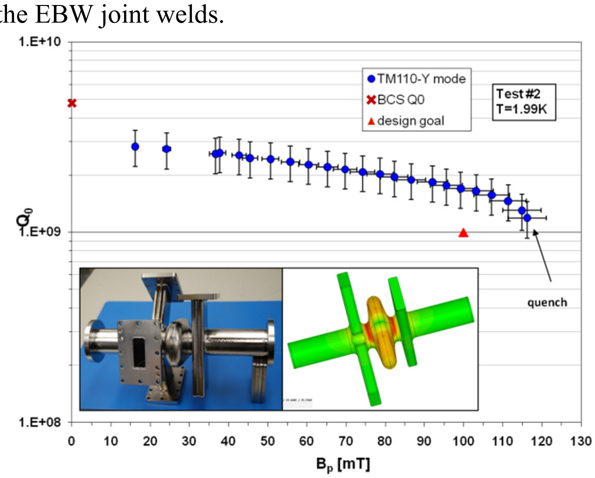


Figure 2: Baseline CCB1 cavity vertical #2 test result.

In the #3 test setup, the LOM waveguide blank-off flange was changed from Niobium to Stainless Steel (SST) material. Process procedure followed above steps after HPR. The measurement showed that the low power $Q_0$ at 2K dropped to $8\times10^8$ which indicated an error of the LOM waveguide alignment relative to the long axis of racetrack crab cell. The loss due to the beam pipe blank-off flanges using SST was calculated by MWS to be ~3e9 in unloaded Q.

### *Alternate cavity*

The CCA1 cavity has been tested for number of times with the highest $B_p$ field of 95mT [3] but with the signs of low $Q_0$, soft MP barrier, early quench and weak coupling. A high resolution optical inspection revealed an interior weld crack (with chemical residual around it) on the saddle joint which could be caused by a non-penetration EBW and opened up by later grinding and chemistry. This find could explain the low Q and the contaminated surface which emitters the MPs.

The fabrication of CCA2 cavity was decided then all parts except beam pipes are to be machined from the RRR>250 bulk, large grain niobium ingot directly to avoid the electrical centre (EC) alignment error and the difficulty of forming the dog bone iris by sheet metal. The final geometry of CCB2 and CCB3 cavities followed the frequency recipe previous developed have been finalized.

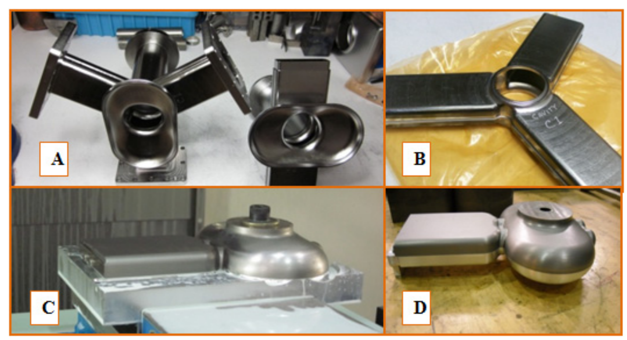


Figure 3: Bare crab cavity prototypes. A: two half CCB1 cavity groups before the final equator EBW; B: Y HOM waveguide group made by CNC machining for CCB1 cavity with RRR>250 Nb; C: CCA2 cavity fabricated on CNC machine; D: Finished Nb and Al prototype cavity.

## CRYOMODULE COMPONENTS DEVELOPMENT

The cryomodule components of cavity tuner, LOM/HOM loads, RF windows, bellows and alignment device are all critical to the schedule and success of the SPX project. The R&Ds and conceptual designs of loads, RF windows have been presented in Ref. [2]

### *Alignment*

Due to the tight tolerance of individual cavity assembly in the cryomodule string [6], a wire-stretching technique based on the S21 of RF signal has been proposed [5] for the clean room assembly on the rails. The tuning sensitivity on the vertical offset is about 20dB/0.5mm. Special fixtures to do this mock-up experiment have been developed. A beam based feedback alignment scheme using the crab cavity as the beam position monitor (BPM) has been proposed. The accuracy of EC using cold (2K) actuators' adjustment is estimated to be ±0.1mm.

### *Cavity tuner*

The scaled JLab C100 type scissor jack tuner is going to be used [Figure 4]. The tuning sensitivity has been measured and simulated on CCB1 cavity being 4.64kHz/lbf and 8.84kHz/µm for the 3mm Nb wall thickness. For the ±200kHz tuning range, the sub-micrometer resolution is needed. The piezo tuner device and the 4mm thickness are preferred at this point to compromise the tuning sensitivity.

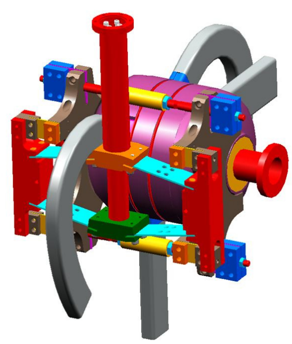

Figure 4: Baseline crab cavity with helium vessel and scissor jack tuner conceptual designs.

### *Deflecting mode coupler*

The 10kW power coupler with double windows will use the WR284 (or WR340) waveguide step as the fixed coupling. The step position will be outside of helium tank inside of space frame. Waveguide port is downward to the cryomodule bottom.

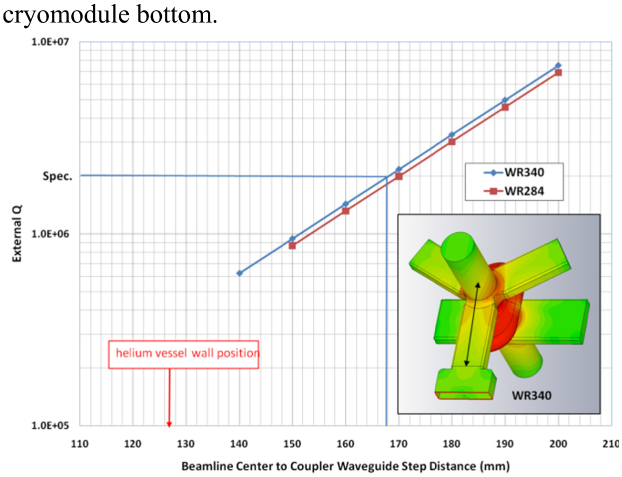


Figure 5: Power coupler design uses one branch of Y waveguide. The external Q is calculated by MWS.

### *Cavity-to-cavity spacing (CCS)*

This space is dominated by the straight section of Sector 5 and 7 at the APS. Within a 2.8m of flange-to-flange confined space, the minimum CCS for 8 cavities can have a <-80dB deflecting mode isolation, but the hardware volume could drop the cavity number from 6 to 4. Figure 6 shows the MWS calculated result with a periodic boundary condition (BC) on the cavity equator planes which also represents the both resonance condition of the neighbour cavities. Figure 7 lays out the four-cavity string in the APS cryomodule which leaves plenty rooms for the component development. The schemes of 5 to 8 cavities have been also planned in the design stage.

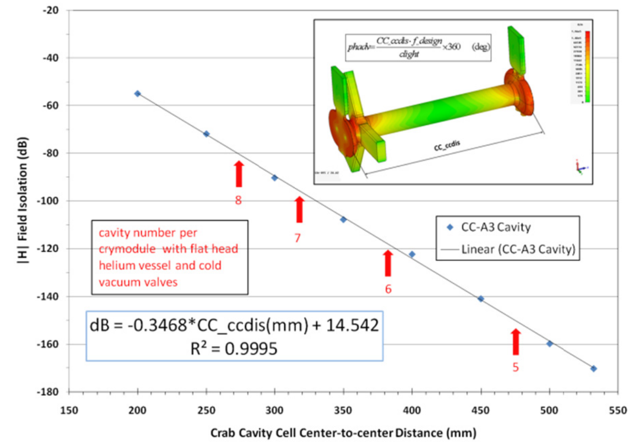


Figure 6: RF isolation calculation for Alternate CCA3 cavity for minimum cavity spacing.

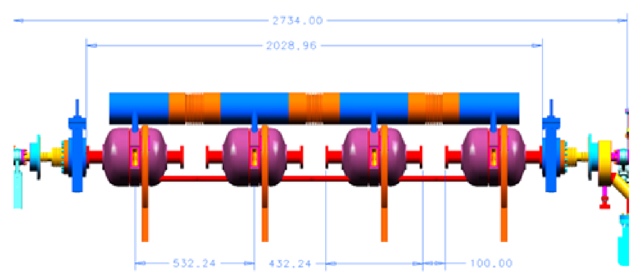


Figure 7: Four-cavity string's cryomodule layout within 2.734m of the APS straight section. Shield bellows are to be placed between in 100mm space.

## ACKNOWLEDGEMENT

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