NOVEL CRAB CAVITY RF DESIGN*

M. Neubauer, A, Dudas, R. Sah, Muons, Inc., Batavia, IL.
B. Rimmer, H. Wang, JLAB, Newport News, VA.

Abstract

A 20-50 MV integrated transverse voltage is required for the Electron-Ion Collider. The most promising of the crab cavity designs that have been proposed in the last five years are the TEM type crab cavities because of the higher transverse impedance. The TEM design approach is extended here to a hybrid crab cavity that includes the input power coupler as an integral part of the design. A prototype was built with Phase I monies and tested at JLAB. The results reported on, and a system for achieving 20-50 MV is proposed,

BACKGROUND

Crab cavities like accelerating cavities have the same fundamental design issues: input coupler and windows, mechanical stability and alignment, phase stability, multipactor, higher-order modes and lower order modes, high surface fields, beam-loading, emittance growth, and etc [1]. In our novel crab cavity design, we believe that all of these design issues are easier to manage and less costly than has been proposed to date. As a result the novel crab cavity design in this proposal has a better chance of achieving the aggressive 20-50 MV integrated deflecting voltage required by the Electron-Ion Collider at a reasonable cost[2].

TECHNICAL APPROACH

The TEM mode structure first proposed by J. Delayen[3] is modified into a hybrid design as discussed below. A Phase I proposal was awarded Muons, Inc., and

The question of room temperature as opposed to SRF crab cavities rests in the issue of LLRF controls. The difference in Q_L between room temperature and SRF designs is a couple of orders of magnitude, and this directly impacts the feed-back loops required to maintain phase control through the crab cavity system. Phase control is a difficult issue to begin with at requirements of <0.1º phase stability. Lower Q_L of room temperature cavities just makes the difficult a little easier.

But to effectively make use of lower Q_L, the transverse impedance R_T/Q has to be larger than found in SRF systems. Typically R_T/Q for SRF cavities is on the order of 10^1 per cell, with $Q_L \sim 10^5$. Room temperature cavities have $Q_L \sim 10^3$ and with TEM type cavities $R_T/Q \sim 10^2$. To get the one more order of magnitude, the number of room temperature cells needs to increase by factors of 10^1. This is the basic approach to get to 20-50 MV integrated transverse voltage. Details of this crab cavity design follows.

*Work supported by SBIR monies under contract DE-SC00005444.

Design Goals

Many designs were explored during this Phase I project with several goals in mind:

- Minimize or eliminate lower order modes.
- Remove as many modes as possible through the input power coupler
- Design for an $R_T/Q \sim 10^2$ per cell
- Build a single cell prototype for bead pull measurements.

THE DESIGN

A design was settled on that had one resonant bar a half wavelength long in a pillbox cavity with an input power coupler opposite the resonant bar as shown in Fig. 1.

.

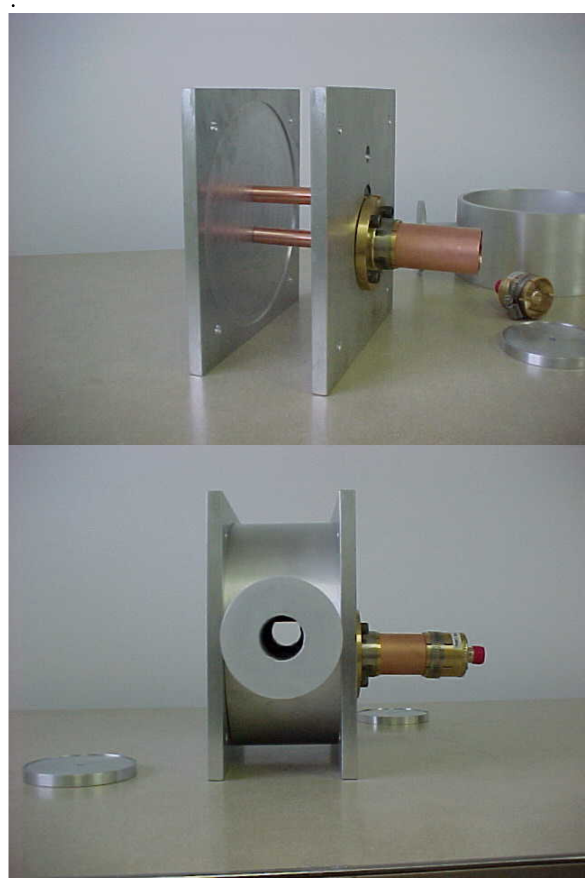

Figure 1: Pictures of the hybrid crab cavity prototype cold test components.

The cavity is designed for 1.5 GHz and the diameter of the cavity was chosen to eliminate the lowest order mode. The design curve is shown Fig. 2. The diameter is 8 inches, and the cavity height a half wavelength (3.932 inches). The input power coupler is 50Ω EIA 1-5/8 coax with a .664 OD inner conductor and 1.527 ID of the outer conductor.

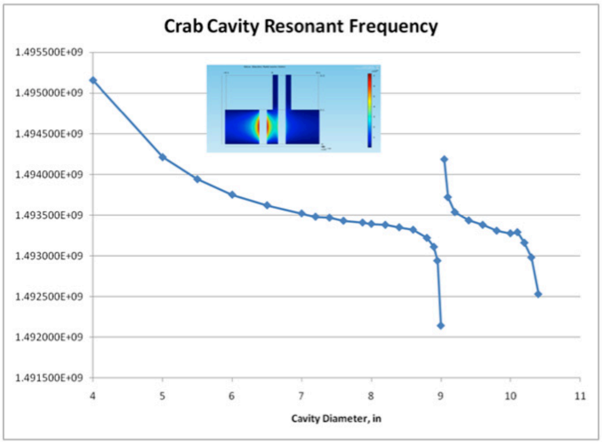

Figure 2: The resonant frequency of the half-wavelength bar as a function of cavity diameter.

Higher Order Modes

A Calculation of S11 into the cavity using Comsol is **shown** in Fig 3.

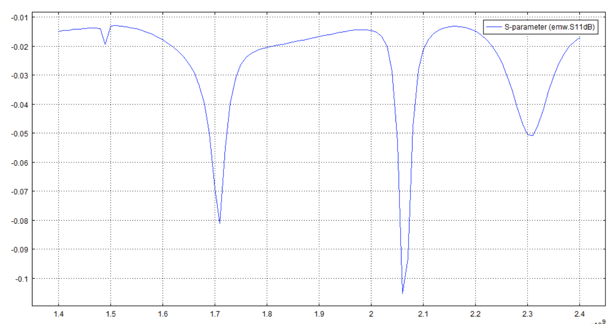

Figure 3: Calculations of S11 from 1.4 to 2.4 GHz.

All the reflections shown in the S11 plot are eigenmodes of the cavity over this frequency range (going from left to right):

- The first dip is the operating mode
- The second dip is the TE11 and it's rotation by 90º
- The third dip is the TE21 and it's rotation by 90º
- The fourth dip is a mixing of modes somewhat indistinguishably, but could certainly be removed by the input coupler.

The S11 plot shows the importance of the input power coupler being an integral part of the crab cavity.

TESTING THE PROTOTYPE

The prototype was built at Device Technologies in Yorktown, IL, and delivered to JLAB for testing. The measurement setup used is shown in Fig. 4.

Test results indicated a problem in coupling to the cavity that was not adequately explored or identified with Comsol calculations. The input power coupler in this cold test design was severely over coupling the cavity and loading it down. To address this problem during cold test an iris was designed that improved the situation but not entirely. Further work will be done to create an adequate coupling during the Phase II part of this program

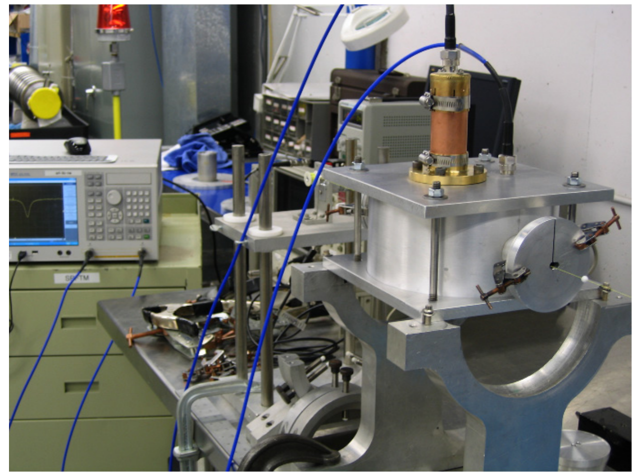

Figure 4: The cold test cavity is shown in the JLAB test lab for the bead pull measurement

Figure 5 shows the location of the iris at the inner surface of the cold test cavity, where the input coax enters. The test iris has an annular gap of 2 mm about the center conductor.

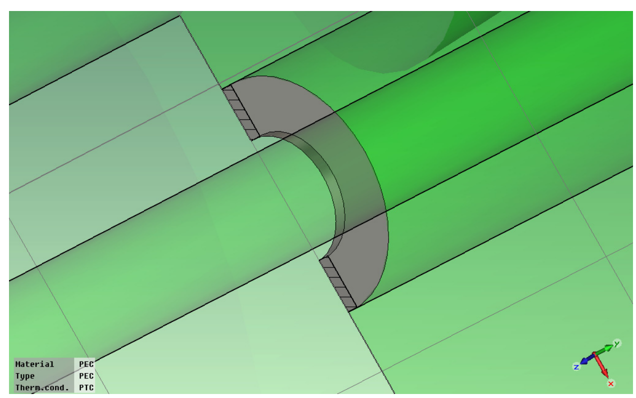

Figure 5: The coax iris used in the measurements

Measurement Results

With a Q_L=320 the R_T/Q at the beam axis was 47.1Ω, and measured 5 mm off the axis towards the resonant bar, it was 91Ω. There was an unsymmetrical field due to the loading of the cavity by the input power coupler.

The results and comparison to calculations in Microwave Studio (MWS) were in very good agreement as shown in Fig 6.

THE 20-50 MV DESIGN APPROACH

Assuming the coupling problems are fixed during the work in Phase II, the way to get to 20-50 MV integrated voltage in the electron-ion collider is as follows:

The limiting design variable is the surface electric field in a room temperature cavity. If that number is 50 MV/m which is reasonable for standing wave structures such as this, then the ratio of surface field, E_s, to transverse field, E_T, indicates how much power we can put into the cavity.

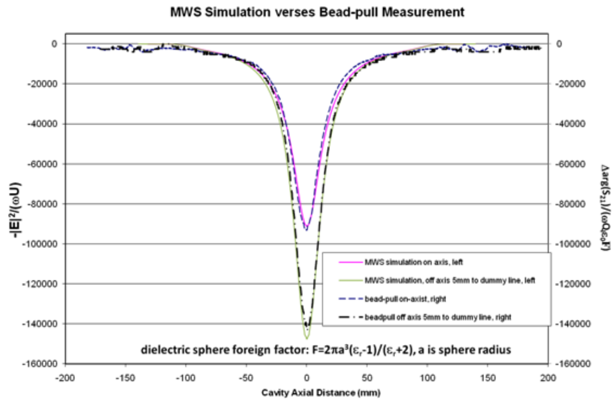

Figure 6: Test results of the bead pull measurement compared to MWS calculations

The ratio E_s/E_T=2.07 yielded by the Comsol calculations is a fairly conservative number. This means to play it safe, the max peak field, E_T, should be less than 25 MV/m.

Two-cell Cavity

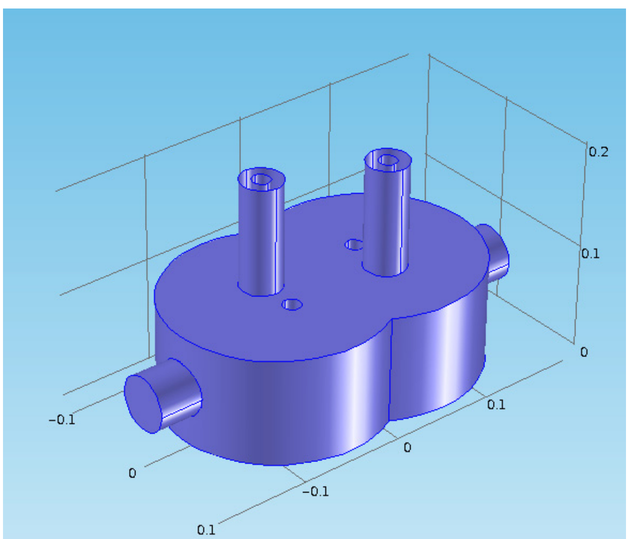

Figure 7: A two cell hybrid crab cavity with offset input power couplers

The two cell cavity shown in Fig 7, was calculated in Comsol, to have an R_T/Q =614Ω with a Q_L=6288. With 100 kW into the input power couplers and phased properly, the peak voltage was calculated to be 8.2 MV/m, for an on crest integrated voltage of .77 MV. The peak surface field was 17 MV/m. And if the RF duty is .1%, then 154 watts are dissipated in the cavity.

To get to 20-50 MV, thirty of these cavities would produce 23 MV total integrated voltage for 15 MW of peak power at 1.5 GHz in an electron-ion collider. If the number of cavities needed to be reduced, then there is a margin in the peak surface field, and/or the number of cells per cavity can be increased.

The other advantage of using an even number of cells per cavity is the fact that an integrated voltage will be symmetrical about the beam centreline as long as the coupling from the input couplers is adjusted to maintain "anti-symmetrical fields."

CONCLUSIONS

The prototype crab cavity designed and built in this Phase I project is the proof-of-principle of a TEM mode cavity with a built in input power coupler. It is significantly easier to build than SRF crab cavity designs. If the integrated voltage can be produced by a number of these cavities, then this is the way the electron-ion collider crabbing system should be built.

There are a number of issues that still need to be resolved, and that is the purpose of the Phase II work. Muons, Inc. is proposing the following for Phase II activities

Cavity RF Design

- Adjust the coupling and flatten $E_x(x)$.
- Determine the mode damping requirements, if any.
- Design a means for tuning the cavity.
- Optimize the shape of the cavity.
- Determine if a multiple module cavity is more efficient and reliable.
- Calculate multi-pactor bands.

Cavity Mechanical Design

- Window design and placement.
- Cooling design.
- Assembly structure for the cavity to maintain beam alignment.

REFERENCES

[1] D. Li "Workshop Group Charges," Sept 1, 2010, 2nd ICFA Beam Dynamics Mini-Workshop on Deflecting/Crabbing Cavity Applications in Accelerators at the Cockcroft Institute

[2] M. Neubauer, et. al., "Novel Crab Cavity RF Design," IPAC10

[3] J. R. Delayen and H. Wang, "New Compact TEMtype Deflecting and Crabbing RF Structure", Physical Review Special Topics – Accelerators and Beams, 12, 2009"

[4] G. Krafft, "Electron-Ion Collider at Jefferson Lab," Electron-Ion Collider Workshop, Rutgers University, March 14, 2010,