NOVEL CRAB CAVITY RF DESIGN

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Abstract

The design and construction of electron-ion colliders will be facilitated by the development of an SRF "crab crossing" cavity with 0.5 to 1.5 GHz frequency range and 20 to 50 MV integrated voltage. These RF cavities provide a transverse kick to the particle beam. Current state of the art crab cavities provide 2-5 MV of integrated voltage, and most of the existing designs require complex schemes to damp unwanted RF modes. We propose a novel system for implementing TEM-like two-bar structures. Two phase-locked sources 180º out of phase each drive a half-wavelength coax antenna inside of a cavity designed for the fewest possible unwanted modes. The cavity design will required a high-Q system composed of coax windows designed for maximizing the shunt impedance of the structure. A series of cavities can be installed in a beam line, and individual phase adjustment for each module will accommodate their longitudinal spacing and will provide the required integrated voltage.

INTRODUCTION

The design and construction of electron-ion colliders will be facilitated by the development of a Superconducting RF (SRF) "crab crossing" cavity with 0.5 to 1.5 GHz frequency range and 20 to 50 MV integrated voltage. The development of RF cavities that provide a transverse kick to the particle beam will include RF design, computer modeling, and hardware development. Current state-of-the-art crab cavities provide only 2-5 MV of integrated voltage, and most of the existing designs require complex schemes to damp unwanted RF modes.

Achieving 20 to 50 MV of integrated voltage will require a series of cavities operating in tandem. The relative RF phases of these cavities must be accurately controlled for maximum beam deflection and for beam stability. ILC experiments at Daresbury by Peter McIntosh using two single-cell 3.9 GHz dipole mode cavities showed that the cavities could be easily phase locked to 0.14º rms., this accuracy being primarily limited by the RF noise injected into the system by the RF source [8].

Multipacting in complex cavities with various RF input designs is a problem. In general the simulations confirm the rule-of-thumb design criterion: the reduction of peak magnetic fields at waveguide surfaces is done by rounding corners and for coax lines, one should minimize the diameter transitions and impedance steps.

Damping unwanted modes is a problem in most crab cavity designs. The design and construction of a number of mode dampers add significantly to the complexity and cost.

TECHNICAL APPROACH

We propose a novel system for implementing TEM-like two-bar structures. Two phase-locked sources each drive a half-wavelength coax antenna inside of a cavity designed for the fewest unwanted modes. A series of cavities will be installed in a beam line, and individual phase adjustment for each module will accommodate their longitudinal spacing and will provide the required integrated voltage.

Freq, MHz	3900	2800	400	508	400	400	3900
$R_\perp/Q$, Ω	350	37.8	774	48.9	47	260	235
Deflecting Voltage, MV	1.346	1	3	1.4	1.5	.375	2.05
Bsp mT/MV	80	160	45	59.8	89	35	120
Type of Cavity	7-cell	ellipse	2-rods in "z"	ellipse	λ/2	2-rods in "y"	9-cell
RF Coupling	Undef.	WG	Undef.	Coax	Coax	Undef.	Coax
Mode Damping	Undef.	WG	Undef.	Beamline ferrites	WG and Coax	Undef.	Coax
Reference	[1]	[2]	[3]	[4]	[5]	[6]	[7]

Table I: Summary of selected SRF crab cavity designs.

As shown in Table I, the lowest peak surface magnetic field per MV of deflecting voltage (Bsp mT/MV in the table) occurs in the Delayen TEM-mode type cavity [Reference 6] and in the CEBAF-type deflecting cavity with two rods [Reference 3]. We propose a novel implementation of a two-bar structure that is conceptually similar to these cavity designs, and yet is quite different in detail. As shown in Figure 1, the bars are part of the RF input – they are grounded antennas at the end of the coax lines. The grounded coax center conductor also permits the design of cooling systems which will provide cooling precisely where needed

Deflecting Voltage

The integration of Ez off the centerline (Figure 2b) and normalizing to the stored energy and wavenumber is the standard method used for computing $R_\perp/Q$. As shown in Table I, the highest value for $R_\perp/Q$ is for the two rods in "z", and the CEBAF deflecting cavity type arrangement. In the concept presented here, the value of $R_\perp/Q$ is also around 800Ω:

The deflecting voltage per module is not yet optimized with regards to the geometry shown (Figure 2a shows an example of the deflecting gradient, Ex). The spacing between bars, the diameter of the bars and the impedance steps in the coax line all need to be adjusted to maximize the deflecting voltage per module. What is known is that

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the peak magnetic field on the surface will be similar to the bar systems described in Table I, allowing for high input power and high operating gradients. Figure 3 shows the operating mode of the crab cavity when fed by 180º out of phase coax lines.

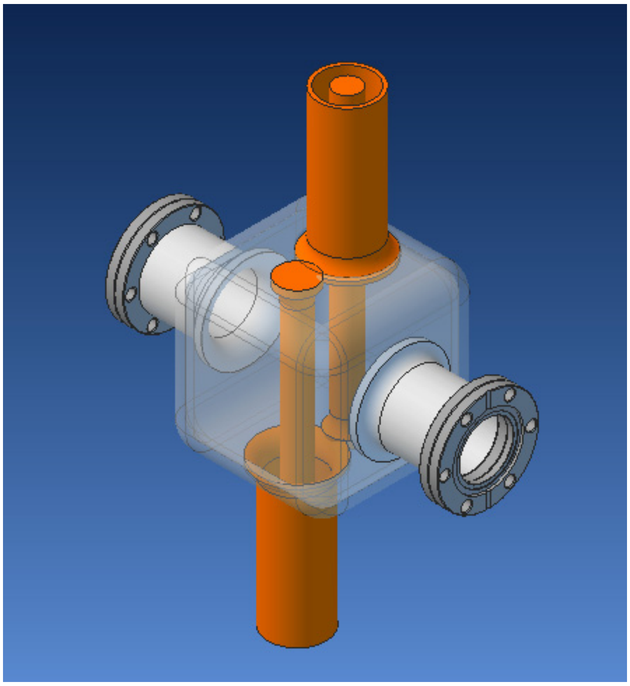
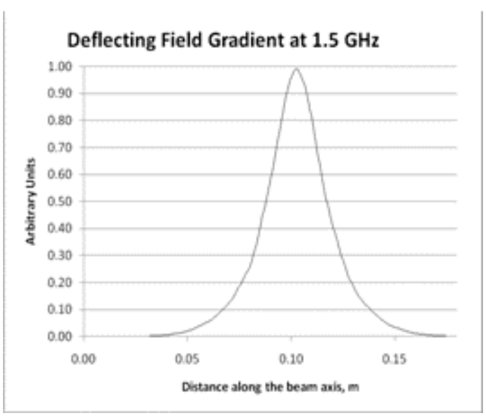
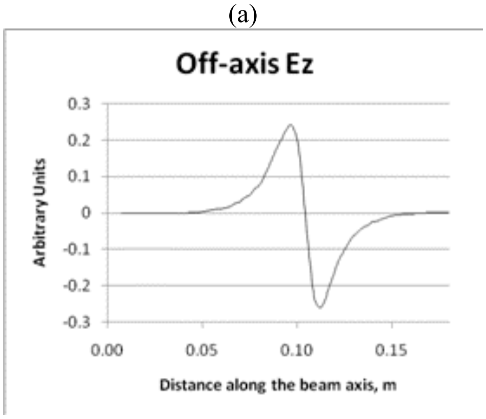


Figure 1: Conceptual view of two-bar structure with coaxial RF input



(a)



(b)

Figure 2: Examples of the operating mode field patterns in the two bar structure: (a) deflecting gradient Ex, (b) off-axis Ez used to calculate deflecting voltage.

Half wavelength windows

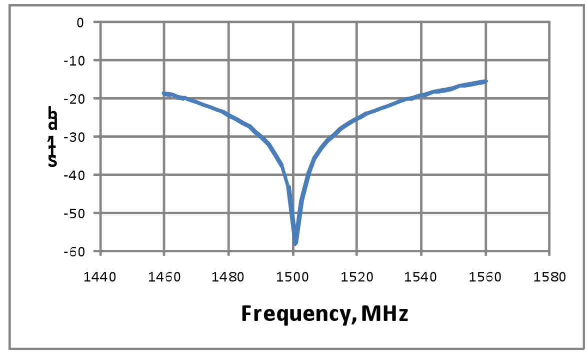


Figure 3: S11 for a half wave alumina window, 32.75 mm long, in coax.

Half wavelength windows in the coax line offer the opportunity to increase the Q of what would normally be a low Q cavity if just two coax lines were terminated. The bandwidth of the window is a function of the tanδ of the ceramic. In Figure 3, the ceramic is alumina and tanδ = .0001 at room temperature.

Modes

The competition among lower-order modes, same-order modes, and higher-order modes is to a large measure the main technical and engineering issue encountered in crab cavities. The mode problems occur mainly because attempting to make the deflecting dipole mode dominant requires (1) suppressing all the normal accelerating modes of a cylindrically symmetrical cavity, or (2) forcing the dipole mode to be in the correct orientation by designing elliptical cavities. Two-bar structures tend to have fewer modes than other designs, depending of course on the shape of the cavity that surrounds the two bars.

In the cavity concept for this Phase I grant proposal, one of the critical elements is the feeding of the RF input from the two coax lines 180º out of phase. This eliminates the occurrence of the nearest mode in the Delayen TEM-type resonant RF structure described in reference [6]. In fact, there are two modes in our Phase I concept between the fundamental and second harmonic using a square, solid-surface cavity. For a cavity designed for 1.5 GHz, the nearest two trapped modes are 2.134 GHz and 2.679 GHz as shown in Figure 3.

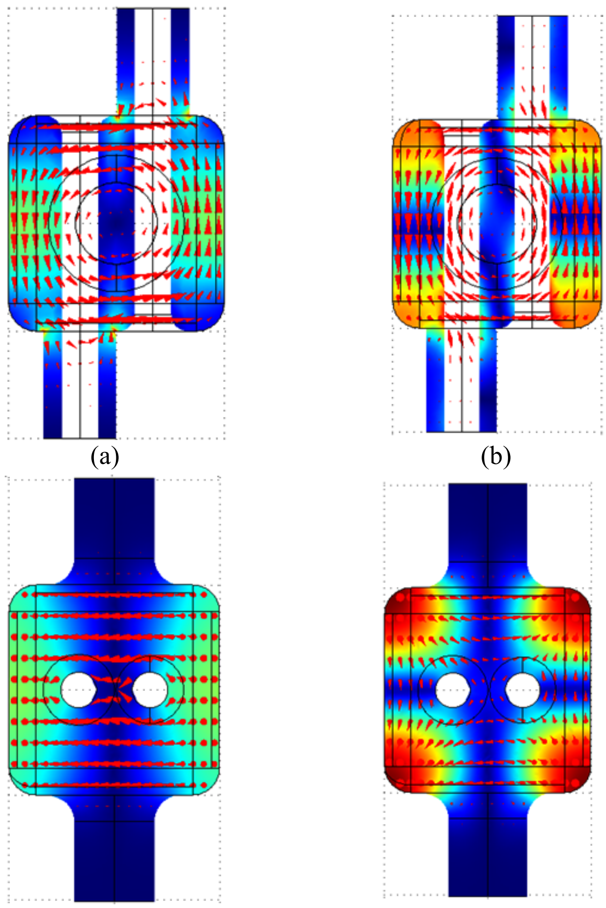

(a) (b) (c) (d)

Figure 3: The nearest trapped modes in the 1.5 GHz square cavity: (a) x-y plane at 2.134 GHz, (b)x-y plane at 2.679 GHz, (c) x-z plane at 2.134 GHz, (d)x-z plane at 2.679 GHz

Coupling Modules Together

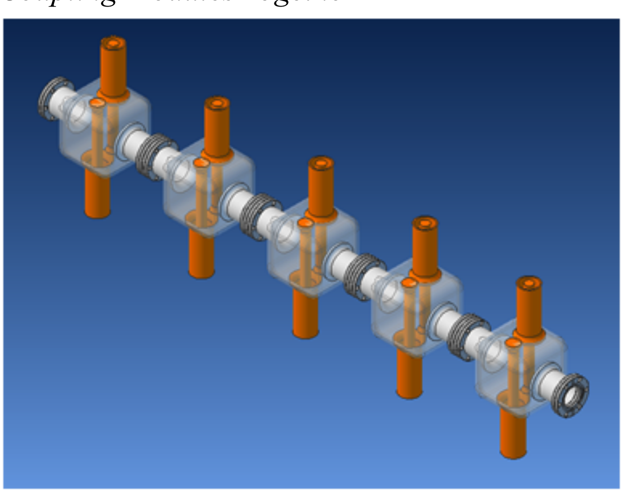


Figure 4: Five modules assembled together using up about 50 cm of beamline at 1.5 GHz

To achieve the final integrated gradient of 20 to 50MV, cavity modules will be operated in tandem, and the RF into each cavity will be phase matched and adjusted based upon the beam parameters. As was discussed in reference [8], the phase locking of cavities does not appear to be a problem, with phase noise variation mostly dependent upon the source noise. With the size of cavity modules shown here for 1.5GHz, fifty modules would fit within the footprint of a main linac ILC cryomodule

CONCLUSIONS

We have presented a means for implementing the transverse field mode first described by John Delayen, who has a patent on the idea. We propose implementing this concept with some concepts of our own, namely: two coax lines terminating in the cavity fed by RF 180° out of phase to minimize the occurrence of other modes. In addition, the system Q will be increased by using half wavelength windows positioned within the coax lines.

REFERENCES

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