EXPERIMENT ON THE COLD TEST MODEL OF A 2-CELL SUPERCONDUCTING DEFLECTING CAVITY FOR ALS AT LBNL

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Abstract

Deflecting cavities are proposed for ALS at LBNL to generate sub-pico-second X-ray pulses. A 2-cell structure has been simulated to achieve required deflecting voltage and damping waveguide is attached on beam pipe to get low impedance. To demonstrate the simulation, we made an aluminum cold test model. Detailed configuration of the experiments measuring the field distribution and Qs with/without waveguide loaded are presented. Calculated (R/Q)s and waveguide damping are compared with simulation.

INTRODUCTION

Zholents et al. proposed a scheme to generate short x-ray pulses [1]. The scheme requires a correlation to be generated between longitudinal and transverse phase space within an electron bunch. Preliminary studies indicate up to 2-MV deflecting voltage at 1.5 GHz is required for 1.9-GeV electron beam at the ALS of LBNL [2]. Three to four cells superconducuting RF structures may be required to achieve 2-MV deflecting voltage at 1.5 GHz [3, **?**].

A 2-cell azimuthal symmetric structure with damping waveguide has been simulated to achieve the design requirements. The cavity geometry is optimized in CST MICROWAVE STUDIO$^{\rm TM}$. To damp the LOM and HOM, we add a waveguide on the beam pipe and simulated the external Q of each mode.[4]

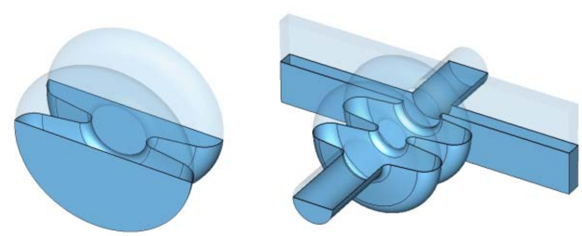
An aluminum cavity has been made for experimental check. The model can be assembled in different ways. The smallest unit is the “two half cell”, as we first simulates, gives the frequency of the TM$_{110}$, the coupling between the adjacent cells and R/Q of the cavity. Also can be set up is the 2-full-cell structure with or without damping waveguide, on which we can measure unloaded Q and loaded Q to check the damping.

In this paper, we describe the simulated design and the experimental setup of the structure. Field distribution using “bead-pull” method and the R/Q calculation of TM$_{110}$ is discussed in the 2-half cell structure. Detailed procedure of the Qs measurements is introduced.

THE 2-CELL STRUCTURE

As the smallest unit as a period of a cell-chain, the model of two half cell coupling through beam iris is created and eigen-mode solver in CST MICROWAVE STUDIO$^{\rm TM}$ is run to get frequency and field distribution of each mode. If we set periodic boundaries with different phase advanced at z-direction, the solution is a traveling wave and we can simulate the dispersion curve to find the coupling between adjacent cells. (R/Q)s are calculated from the field of each modes. Peak magnetic field on surface is obtained as a criteria for the maximum field strength. Depends on these characteristics, we make geometry parametric simulation to optimize the radii of the arcs that make up the cross section.

2-cell structure is generated based on the geometry and damping the LOM and HOM of the cavity is discussed. First the R/Qs of LOMs and HOMs are calculated in the postprocess of the eigen-mode solver. Then after adding waveguide, Qs of each mode is computed from the energy decay rate in transient solver. The geometry of the waveguide is carefully chosen to damp the unwanted modes and keep the working mode a high Q.



(a) (b)

Figure 1: Simulated design (a): 2-half-cell (b): 2 cell cavity with damping waveguide

Table 1: Brief summary of the preliminary design

Number of cells	2	
Operating frequency	1.500	GHz
Cell length	100	mm
Beam pipe radius	40	mm
Iris radius	30	mm
$B_{\rm peak}$ @ 2MV	~ 90	mT
$E_{\rm peak}$ @ 2MV	~ 15	MV/m
Transverse $(R/Q)_\perp$	110	Ω
Damping waveguide	170×30	$\rm mm \times mm$

Based on the simulation design, we made an aluminum model. The model can be assembled as the 2-halfcell (Figure 2) or 2-cell (Figure 4) structure easily and disassembled. The cavity is connected not by brazing but by pushing the flange on the 2-ends.

FIELD DISTRIBUTION AND (R/Q)

2-Half-cell Structure

If the boundaries at z-direction is set as electric, we can get standing wave solution as the 0-mode and π-mode. So in experiment, the two end plane is aluminum.

Probes are inserted into the cavity to excite the modes. Table.2 gives the frequencies of the mode in 2-half-cell structure, the frequency difference between simulation and measurement is less than 1MHz. For TM_{110}, the working mode, the π mode is lower than 0 mode since it is magnetic coupled.

Table 2: frequencies in the 2-half-cell structure

mode	f_{sim}(GHz)	f_{meas}(GHz)
$TM_{010}, 0$	1.03065	1.0300
TM_{010}, π	1.03749	1.0370
TM_{110}, π	1.50065	1.4995
$TM_{110}, 0$	1.52719	1.5262
$TM_{210}, 0$	2.03292	2.0314
TM_{210}, π	2.03557	2.0345

Bead-pull Method

Field distribution can be measured by "bead-pull" method. The bead gives a perturbation of the field and frequency shift. For measuring R/Q of some dipole modes, it is important to separate the longitudinal electric field E_z from other field components.

$$\frac{\Delta f}{f_0} = \frac{1}{W}\Big(k_1\varepsilon_0 E_{\parallel}^2 + k_2\varepsilon_0 E_{\perp}^2 - k_3\mu_0 H_{\parallel}^2 - k_4\mu_0 H_{\perp}^2\Big), \quad (1)$$

where Δf is the frequency shift, and W is the stored energy in the cavity.

A bundle of metallic needles is used as the "bead" with much larger longitudinal effect than transverse $k_1 >> k_2, k_3, k_4$. FIG.3 shows the field distribution of the cavity by plotting frequency shift with respect to z.

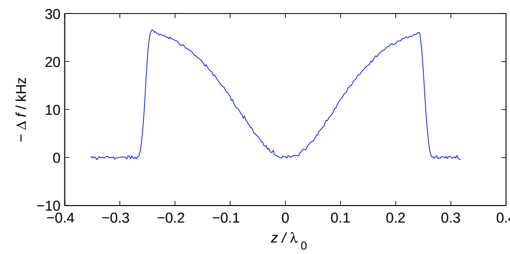
R/Q Calculation

The transverse R/Q can be calculated by integral of the longitudinal electric field off axis[5]:

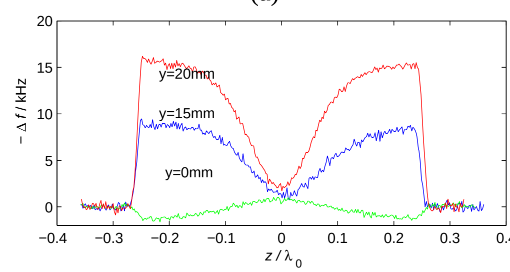
$$\left(\frac{R}{Q}\right)^{\perp} = \frac{(\int E_z(r=r_0)e^{-j\kappa z}\mathrm{d}z)^2}{\omega U(\kappa r_0)^2}. \quad (2)$$

From the frequency perturbation, we can calculate R/Qs. However, in equation(1), we need to know the k factors.

Figure 2: Picture of the 2-half-cell assembly and bead-pull system



(a)



(b)

Figure 3: Measured field distribution(frequency perturbation) of the 2-half-cell model, (a):field on axis of TM_{010};(b):field of TM_{110} at different position

The field of TM_{110} on axis shows the "bead" has a smaller effect of magnetic field and transverse electric field than the effect of longitudinal electric field. If we calculate using the approximation

$$\frac{\Delta f}{f_0} = \frac{1}{W}\left(k_1\varepsilon_0 E_{\parallel}^2\right),$$

there may be an error of $\pm 10\%$. The longitudinal effect k_1 can be calculated by Δf of TM_{010} on axis.

We got a result of TM_{110}, $(R/Q)^{\perp} = 66.3\Omega$ at $y =$ 20mm, while $(R/Q)^{\perp} = 61.4\Omega$ at $y = 15$mm, comparing 64.3Ω from simulation.

DAMPING RESULT OF THE WAVEGUIDE

A 2cell model with damping waveguide is setup for bench mark with simulation. The damping waveguide is made by stainless steel, and use ferrite as absorbing material. Probes is attached on the holes of the cavity wall. Each cavity has four probes at every 90° for different polarization. Two of them are loops for magnetic coupling, the others are antennas. Peak in S_{21} curve from the network analyzer shows the frequency and Qs can be read directly from 3-dB width.

Figure 4: Picture of the cold model with damping waveguide

Calibrating the Coupling of Probes

When exciting the cavity and picking up signal by two probes, the measured Q is actually:

$$\frac{1}{Q_{\mathrm{meas}}} = \frac{1}{Q_{\mathrm{eA}}} + \frac{1}{Q_{\mathrm{eB}}} + \frac{1}{Q_0}, \tag{3}$$

where Q_{eA}, Q_{eB} is the external Q of the 2 probes, Q_0 is the instinct quality factor which depends on the surface and the cavity shape. The external quality factor describes how strong the coupling is between the probe and the cavity.

To estimate the Q_{ext} of a specified probe, for example, probe "C", we use another two probes("A, B") and measure Q_{load} from s_{21} with probe "C" loaded(Eq.4) and shorted(Eq.3).

$$\frac{1}{Q_{\mathrm{meas}}} = \frac{1}{Q_{\mathrm{eA}}} + \frac{1}{Q_{\mathrm{eB}}} + \frac{1}{Q_0} + \frac{1}{Q_{\mathrm{eC}}}, \tag{4}$$

After Q_{ext} of each probe is measured. The Q_0 of the cavity or Q_{load} after damping can be easily calculated from the measured Q.

Q_{ext} of the Damping Waveguide

The cavity is disassembled and reassembled several times to check whether the result can be repeated. Fig.5 shows the Q_0s of the modes in different assembly. Since the surface is a little rough and oxidized, they are much lower than the simulation result with $\sigma = 3.9 \times 10^{-7}$S/m as the conductivity (only 40%).

Q_0 and Q_{load} is measured on the cavity without/with damping waveguide, from which we can calculate Q_{ext} to compare with the simulation result from the energy decay rate in transient solver of CST MICROWAVE STUDIO™ . Table 3 shows the comparison between measured and simulated Q_{ext}. The Q_{ext} from cold model is a little smaller than simulation. The frequency, especially the frequency difference between x and y-direction agrees well.

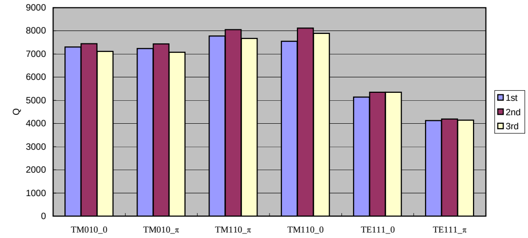


Figure 5: Q_0 of the modes, repeating the assembling

Table 3: Preliminary experimental result of waveguide damper compared with simulation

mode	Cold Test		CST MWS T	
	f (GHz)	Q_{ext}	f (GHz)	Q_{ext}
TM_{010}	1.0400	1707	1.0400	2013
	1.0434	1387	1.0438	1542
TM_{110},x	1.4962	486	1.4917	639
	1.5062	618	1.5025	836
y	1.4928	–	1.4894	–
	1.5037	–	1.5013	–
TE_{111}, x	1.8529	141	1.8465	202
	1.9260	257	1.9243	341
y	1.8587	111	1.8539	181
	1.9293	179	1.9278	257

CONCLUSION

Preliminary design of a 2-cell superconducting deflecting structure with couplers for damping LOMs and HOMs is presented. We discussed the detailed progress of the experiment on an aluminium model, showing that the simulation agrees very well for frequencies and field distributions.

Damping the LOMs and HOMs by waveguide attached on beampipe is a promising idea. More study on the damping waveguide would be carried out.

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