# STATUS OF 3.9-GHz DEFLECTING-MODE (CRAB) CAVITY R&D

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*Abstract*

The superconducting 3.9GHz deflecting mode cavity design that has been under development [1] as a beam slice diagnostic is planned for use as the ILC crab cavity. We describe the applications and review the status of the R & D, giving both prototype test results and computational studies of the beam-cavity interaction.

## RECENT PROTOTYPE TEST RESULTS

In late 2005 and early 2006, a 3-cell prototype built in conjunction with Advanced Energy Systems of Medford NY (U.S.A.) was cold-tested. The cavity was processed only with buffered chemical polishing (BCP) using a 1:1:2 mix of nitric, fluoric, and phosphoric acids, and baked at 600° C for 10 to expel hydrogen. A high-pressure rinse of 18MΩ ultra-pure water for 3.5 hours removed particulate contamination. No couplers other than the main power coupler and a small pickup probe were installed.

At 3.9GHz and at the 1.8K test temperature, the intrinsic resistance from the BCS mechanism is, by extrapolation of DESY data, about 41nΩ. The magnetic field inside of our test Dewar has been measured at about 25mG, and using the rough rule

$$R_{SURF} \approx 0.3n\Omega \sqrt{f(GHz)}\; H_{EXT}(mG)$$

we expect a zero-temperature limit surface resistance ($R_0$) of roughly 15nΩ. Figure 1 shows that the low-temperature limit measurement of the surface resistance is a little higher than this expectation. It should be noted that the measured $R_0$ = 39.0 ± 6.9nΩ is higher than has been achieved with 3.9GHz $TM_{010}$ mode cavities in the same facility. Those cavities often go down to $R_0$ ~ 20nΩ, and values as low as 6 nΩ have been reported [2].

The field in these cavities is concentrated around the iris and the maximum electric field is about half the value typical to accelerating cavities for the same peak magnetic field. X-ray emission has never been observed in any 3.9GHz crab cavity except when it has been operated in $TM_{010}$ modes. The $Q$ vs. field strength curves are usually quite flat. Figure 2 shows the results as a function of peak magnetic field. This cavity has not gone above 90mT peak field to date; however 120mT has been obtained with similar cavities and this value is consistent

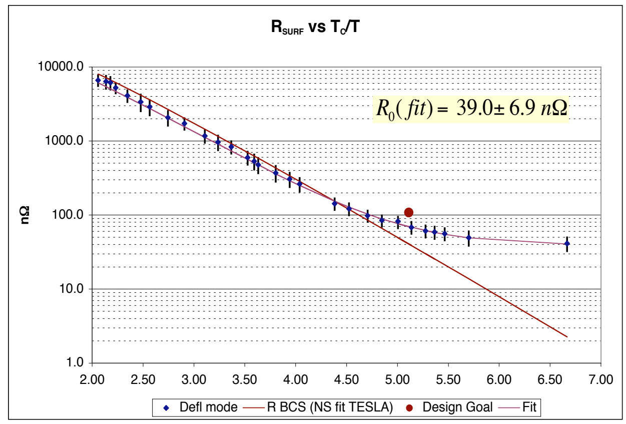


Figure 1: Surface resistance of the AES prototype cavity as a function of $T_C/T$.

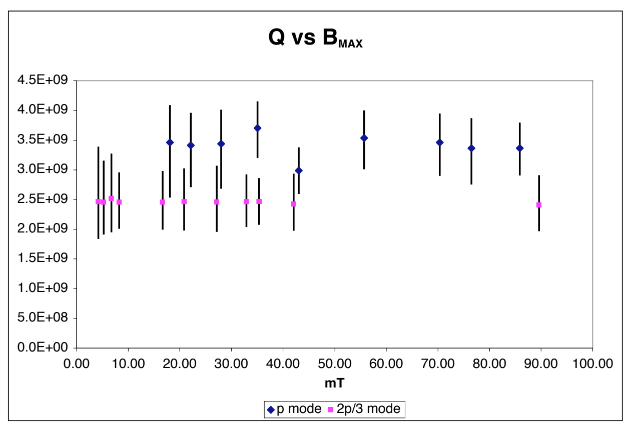


Figure 2: Q vs field strength at 1.8K, for 2 different modes of the 3-cell AES prototype cavity.

with the best results for BCP obtained by other laboratories.

## WAKEFIELDS FOR 13 CELLS

A detailed study of wakefields for the case of a 13-cell cavity, as is contemplated for the beam emittance application, has been completed. The techniques used, have also been applied to the 9-cell cavity envisioned for the ILC crab cavity application [3,4]. The study contains (1) a frequency domain evaluation of long-range wakes; (2) a 3D time-domain analysis with a rather coarse 1mm cubic mesh to verify the frequency domain analysis; (3) a 2.5D finely meshed (75µm) time domain analysis to evaluate short-range wakes; an analytic short-range wake evaluation to serve as a cross-check to the fine-meshed computation and to facilitate extrapolation down to the extremely short bunch lengths envisioned for these applications. However, only the ideal geometry has been modeled. The MAFIA package was used throughout. A detailed writeup is available [5].

The largest contributions from the wakefields are from the fundamental monopole mode and the vertical polarization of the dipole π mode.

For the ILC, the transverse deflection due to the dipole modes and the energy change due to the wakefields are at least 3 times lower than tolerances

## DIPOLE BEAM LOADING

For a cavity operating in a crabbing dipole mode, if the beam traverses the cavity off-axis it will experience a longitudinal electric field that either accelerates or decelerates the bunch. This will cause the bunch to either add energy to the operating mode or take energy out, depending on the position of the bunch. In order to keep the energy in the cavity stable, the power from the driving rf source will have to be adjusted accordingly. The power required from the RF source is given by,

$$P_f = \frac{P_c}{4\beta}\left(1+\beta+{\alpha x}/{P_c}\right)^2$$

where $(q_{\mathrm{BUNCH}})(f_{\mathrm{BUNCH}})(204kV/mm)(x) = \alpha x$.

A plot of power required against external $Q$, in Figure 3, shows that the high Q factor of 1.5 x$10^7$ earlier chosen for the DMC is insufficient for the transverse offsets of 1.8mm expected in the ILC crab cavity, due to the high level of beam loading.

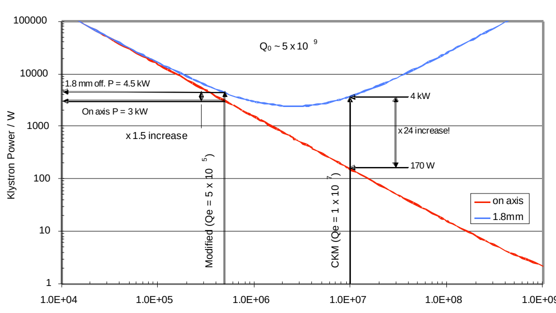


Figure 3: Dipole beam loading in the ILC.

It is proposed that the ILC crab cavity should have an external Q factor of 5 x$10^5$ which will require a driving power of 5kW. The coupler currently proposed for the 3.9GHz 3rd harmonic cavity should be able to handle this power at a 5-10% duty factor. Further work is planned to increase the power handling of this coupler to permit CW operation.

The operating mode of the cavity is not the fundamental mode of the cavity. This means that the cavity has a lower order mode that must be damped with a special coupler. A hook coupler has been simulated for use as the LOM coupler.

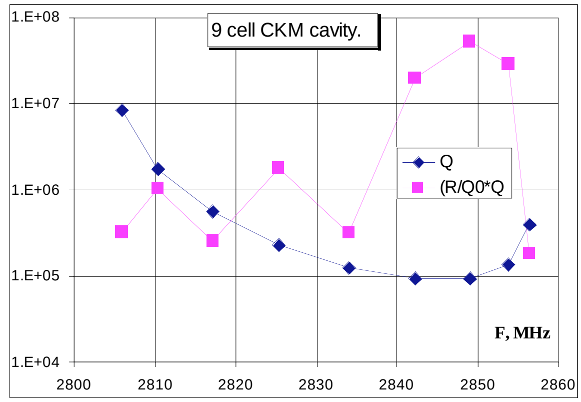


Figure 4: 9-cell lower order modes frequencies vs. external Q.

This coupler achieves an external Q factor of 9.3x$10^4$ at the LOM with the highest loss factor, the monopole 7π/9 mode at 2.85GHz, as shown in Figure 4..

## ILC PHASE TOLERANCES

As a crab cavity is a displacement cavity operated with a 90° shift on the beam timing, any error in this timing will displace the centre of the bunch. A cavity timing error $\Delta t$ (i.e. a phase error) causes a transverse displacement of the bunch centre

$$\Delta x_{ip} = R_{12} x_c'(\Delta t) = c\,\theta_r \frac{\sin(\omega \Delta t)}{\omega} \approx c\,\theta_r\, \Delta t$$

A horizontal displacement of an electron bunch with respect to a positron bunch will lead to luminosity loss. The luminosity budget for crab cavity timing errors set by the GDE is currently at 2%. If at the IP the positron bunch has a horizontal displacement of $0.5\Delta x$ and the electron bunch has a displacement of $-0.5\Delta x$ and both bunches have Gaussian profiles then luminosity reduction factor is therefore given as

$$S = \exp\left(-\frac{\Delta x^2}{4\sigma_x^2}\right)$$

Using a horizontal beam size at the ip of $\sigma_x = 554\,nm$, then a luminosity reduction of 2% (S = 0.98) for 20 mrad crossing gives an rms timing tolerance of 0.053 ps, corresponding to an rms phase tolerance of 0.075° at 3.9 GHz with the ILC 1TeV nominal parameters. A Monte Carlo study by Church [6] supports the results of this simple geometric model, leading to a 0.043 ps timing tolerance spec.

## TEST MODEL CAVITY

In order to verify the simulation work a modular aluminum model of the DMC was constructed. The modular design allows up to 13 cells to be tested and for couplers to be switched in and out. Bead-pull perturbation tests have been conducted and initial results have been in good agreement with the simulations. Figure 5 shows the frequencies measured for the LOM compared to MAFIA simulations.

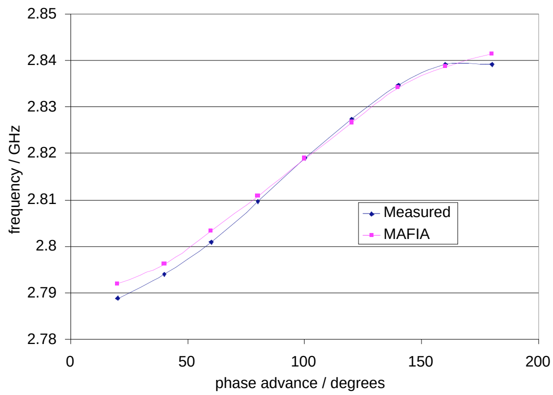


Figure 5: LOM frequencies for a 9 cell cavity compared to MAFIA calculations.

The test model can be used to verify the external Q factors of the electromagnetic designs for the cavity couplers.

## PLANS AND STATUS

The HOM and LOM couplers are designs based heavily on the HOM coupler design for the 3.9GHz 3rd harmonic cavity, which is scaled from the DESY HOM coupler. Our next step is solidly reliable examples of these couplers; with that in hand, a cavity will be constructed for use as a beamslice diagnostic in a beamline at FNAL.

A 9-cell version of the cavity will be produced at the Cockcroft Institute as a prototype of the ILC crab cavity. For the ILC crab cavity, a suitable power coupler must be designed and tested. Initial work will look at the 3rd harmonic coupler to assess if it is a possible design choice. A LLRF phase control system is a major priority for the ILC crab cavity, due to the tight phase tolerances.

## ACKNOWLEDGEMENTS

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