SUBJECT: RF Cavity Lab.

NAME

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Purpose

a) Measure mode spectrum of an RF cavity

b) Measure cavity coupling, loaded and unloaded Q of a cavity

c) Measure electric field profile and R/Q of a cavity with a bead pull.

Equipment

Network Analyzer

3.5 calibration kit.

Single cell cavity with an E field and B field couplers.

Bead Pull Setup

Graph Paper

Calculator

Background Info

The cavities used in this experiment are aluminum mockups of the Fermilab Linac Upgrade. They resonate at about 810 MHz.

FERMILAB ENGINEERING NOTE

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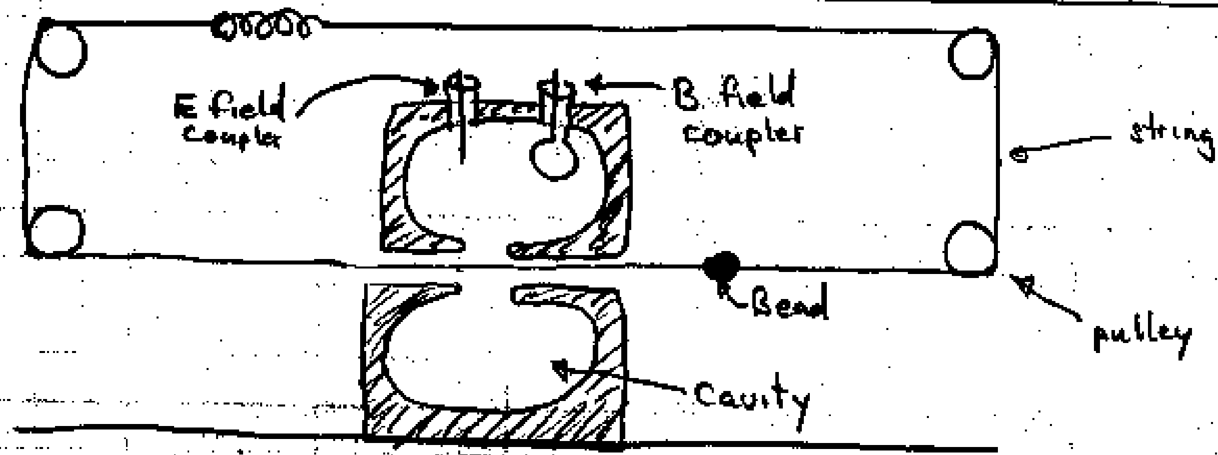

The cavity has two couplers. One is a quasi-B field coupler in which the angle of the coupling loop with respect to the magnetic field can be changed in order to change the coupling. The other coupler is a E field coupler that is weakly coupled to the cavity.

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Procedure

1) Connect port ① of the NWA to the B field probe. Connect port ② to the E field probe. Reflection measurements will be done by measuring S_{11}. Transmission measurements will be done by measuring S_{21}.
2) In the transmission mode, find the resonant frequencies of the first 5 modes. Because the modes couple differently to the B field probe, rotate the probe 360° to make sure you can couple to all the modes.
3) Zoom in the NWA on the first mode. (It should be around 815 MHz). Calibrate. Port ① for reflection measurements.
4) Adjust the B field coupling loop for a coupling of 1.
   a) Set the display format to Smith Chart
   b) Center the trace (it should be a circle)

4b(cont.)) around the Γ real axis as shown in the notes. by putting a phase offset into the NWA. One can also center the trace looking at the Imaginary display format and centering the trace using a phase offset.

c) Rotate the B field coupling loop until the coupling of 1 is achieved.

5) Measure the <u>unloaded</u> Q of the cavity by finding the frequencies in which the real part of the impedance $= \pm$ the imaginary part of the impedance.

6) Knowing the coupling of the cavity, calculate the <u>loaded</u> Q of the cavity.

7) Sketch the log magnitude of the reflection coefficient vs frequency. What is the value of S_{11} at $\omega = \omega_0 \pm \frac{\omega_0}{Q_{loaded}}$ and $\omega = \omega_0 \pm \frac{\omega_0}{Q_{unloaded}}$?

8) Connect Port ① to the E field probe and Port ② to the B field probe. Measure the coupling of the E field probe.

9) Connect Port ① to the B field probe and Port ② to the E field probe. Using S_{21} on the NWA, measure the Loaded Q of the mode. Does it agree with Step 6 ?

10) Change the B field probe coupling to 3. Be sure to re-center the cavity trace on the Smith Chart by adjusting the phase offset on the NWA.

11) Measure

a) The coupling

b) The resonant frequency

c) The unloaded Q

d) The loaded Q with S_{11}

e) The loaded Q with S_{21}

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12) Set the coupling to 1/3 with the B field probe. Repeat <u>Step 11.</u> How does the resonant frequency change with coupling and why?

13) Set the coupling of the B field probe to 1 @ the fundamental mode (815 MHz). With the B field probe fixed, Repeat <u>step 11</u> for the next 4 higher order cavity modes.

14) Set the NWA up for a S_{21} measurement for the fundamental mode. (The B field probe coupling should still be set at 1) With the bead outside the cavity, set the phase of S_{21} at the resonant frequency equal to zero by adjusting the phase offset of the NWA. The resonant frequency with the bead outside the cavity will be called the "unperturbed" resonant freq.

15) Pull the bead slowly thru the cavity and measure the "perturbed" resonant frequency and the phase of S_{21} at the "unperturbed" resonant frequency as a function of bead position.

16) Repeat Steps 14 & 15 for the next 4 higher order modes.

Bead Pull Analysis

The shunt impedance of the cavity is given as

$$R = \frac{1}{\mathcal{F}} \frac{1}{2\omega_0} \left[\int_{gap} \left(Q \frac{\Delta\omega_0}{\omega_0}(x,y,z) \right)^{1/2} dz \right]^2$$

where $\mathcal{F} = \pi a^3 \varepsilon_0$ for a metal bead.

The electric field profile along the gap is:

$$\frac{E(x,y,z)}{V_{gap}} = \sqrt{\frac{1}{\mathcal{F}} \frac{1}{2\omega_0} \frac{1}{R}} \sqrt{Q \frac{\Delta\omega_0(x,y,z)}{\omega_0}}$$

However, if the bead is very small or the electric field in the cavity is small, the shift in resonant frequency ($\Delta\omega$) might be very hard to measure. A more sensitive measurement would be to measure the phase shift of S_{21} at the "un-perturbed" resonant frequency as the bead is pulled thru the cavity.

The impedance of the cavity is:

$$Z = Re^{j\phi}\cos\phi$$

where

$$\tan\phi = Q\left(\frac{\omega_0}{\omega} - \frac{\omega}{\omega_0}\right)$$

if

$$\omega = \omega_0\left(1 + \frac{\Delta\omega}{\omega_0}\right)$$

where $\frac{\Delta\omega}{\omega_0} \ll 1$

then

$$Q\frac{\Delta\omega}{\omega_0} \approx \frac{1}{2}\tan\phi.$$

For the measurements made in Steps 15 & 16 Calculate the R/Q of each mode and plot $\frac{E}{V_{gap}}$ for each mode.