The HOM measurement of a TESLA cavity (Z84) for HOM-BPM and cavity alignment

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abstract:

Measurements of HOMs for the HOM BPM and the cavity miss-alignment was made with TESLA cavity (Z84) at KEK in this summer. The measured passbands were TE111, TM110 and TM011.

When HOM in multi-cell cavity is used as cavity BPM and cavity miss-alignment, the following are important:

(1) The polarization angle of used dipole mode at each cell has same angle. X and Y polarizations are separated.

(2) How much is difference in the electrical mode center and the mechanical center at each cell?

We tried to measure them by using bead-pull method and antenna scan.

In addition, my group of KEK is developing the STF shape cavity (S.Noguchi, E.Kako et al) for ILC. We have made a comparison of the HOM performance of STF cavity and TESLA cavity. This presentation will be report the result of HOM measurement at KEK.
(1) Introduction and Purpose

(2) Measurement list
   2-1. Checked accelerating mode: frequency and field flatness
   2-2. Main HOMs passband: comparison in STF cavity
   2-3. Qext value of HOMs: comparison in STF cavity
   2-4. Polarization direction measurement
   2-5. Difference in electrical center and mechanical center of dipole modes

(3) Conclusion
1. Introduction and purpose

At FLASH, HOM study group is doing the HOM BPM study and HOM based on cavity alignment study.

When HOM in multi-cell cavity is used as cavity BPM and cavity miss-alignment measurement,

the following are important:

(1) The polarization angle of used dipole mode at each cell has same angle.
    X and Y polarizations are separated.

(2) How much is difference in the electrical mode center and the mechanical center at each cell?
    We tried to measure them by using bead-pull method and antenna scan by used TESLA cavity (Z84) for HOM BPM and HOM base cavity alignment !!!

And my group of KEK is developing STF TESLA shape cavity (S.Noguchi, E.Kako, H.Hayano et al) for ILC. We have made a comparison in the HOM performance of STF cavity and TESLA cavity.
2. Measurement list

(1) Checked the accelerating mode: frequency and field flatness (important !!!)

(2) Measured HOM passband: TE111, TM110, TM011, etc…

(3) Measured HOM Qext value: comparison in STF cavity

(4) Measured the Polarize direction of Main dipole modes: bead-pull method
   (TE111 and TM110 passband, distribution of each cell and each mode)

(5) Difference in Electrical mode center and Mechanical center: antenna scan method
2-1. TM010 passband

Good frequency tuning for accelerating mode

<table>
<thead>
<tr>
<th>TM010 pass band</th>
<th>[MHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM010–1</td>
<td>1271.350</td>
</tr>
<tr>
<td>TM010–2</td>
<td>1273.675</td>
</tr>
<tr>
<td>TM010–3</td>
<td>1277.175</td>
</tr>
<tr>
<td>TM010–4</td>
<td>1281.475</td>
</tr>
<tr>
<td>TM010–5</td>
<td>1286.050</td>
</tr>
<tr>
<td>TM010–6</td>
<td>1290.425</td>
</tr>
<tr>
<td>TM010–7</td>
<td>1294.125</td>
</tr>
<tr>
<td>TM010–8</td>
<td>1296.500</td>
</tr>
<tr>
<td>TM010–9</td>
<td>1297.375</td>
</tr>
</tbody>
</table>
2-1. TM010 field pattern

Field flatness was about 90%.

Amplitude of End cells were lowering in comparison with a center cells.

After EP, STF cavity also has a same tendency.
2-2. Main HOM passband

Frequency distribution of main HOMs

R/Q comparison in TESLA and STF

<table>
<thead>
<tr>
<th>Mode</th>
<th>TESLA R/Q [Ω/cm²]</th>
<th>STF R/Q [Ω/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE111-1 (π/9)</td>
<td>0.01</td>
<td>22.4</td>
</tr>
<tr>
<td>-2</td>
<td>0.14</td>
<td>23.6</td>
</tr>
<tr>
<td>-3</td>
<td>0.03</td>
<td>43</td>
</tr>
<tr>
<td>-4</td>
<td>0.75</td>
<td>58.7</td>
</tr>
<tr>
<td>-5</td>
<td>0.04</td>
<td>46.1</td>
</tr>
<tr>
<td>-6</td>
<td>10</td>
<td>549</td>
</tr>
<tr>
<td>-7</td>
<td>15.4</td>
<td>2100</td>
</tr>
<tr>
<td>-8</td>
<td>2.23</td>
<td>793</td>
</tr>
<tr>
<td>TE111-9</td>
<td>1.4</td>
<td>43.2</td>
</tr>
<tr>
<td>TM110-1</td>
<td>0.71</td>
<td>119</td>
</tr>
<tr>
<td>-2</td>
<td>0.45</td>
<td>89.1</td>
</tr>
<tr>
<td>-3</td>
<td>0.33</td>
<td>52</td>
</tr>
<tr>
<td>-4</td>
<td>6.47</td>
<td>864</td>
</tr>
<tr>
<td>-5</td>
<td>8.75</td>
<td>1270</td>
</tr>
<tr>
<td>-6</td>
<td>1.83</td>
<td>394</td>
</tr>
<tr>
<td>-7</td>
<td>0.1</td>
<td>0.28</td>
</tr>
<tr>
<td>-8</td>
<td>0.18</td>
<td>20</td>
</tr>
<tr>
<td>TM110-9 (π/9)</td>
<td>0.01</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode</th>
<th>TESLA R/Q [Ω]</th>
<th>STF R/Q [Ω/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM011-1</td>
<td>0</td>
<td>0.33</td>
</tr>
<tr>
<td>-2</td>
<td>0.17</td>
<td>0.11</td>
</tr>
<tr>
<td>-3</td>
<td>0.65</td>
<td>3.31</td>
</tr>
<tr>
<td>-4</td>
<td>0.65</td>
<td>0.84</td>
</tr>
<tr>
<td>-5</td>
<td>2.05</td>
<td>8.65</td>
</tr>
<tr>
<td>-6</td>
<td>2.93</td>
<td>6.26</td>
</tr>
<tr>
<td>-7</td>
<td>6.93</td>
<td>37.8</td>
</tr>
<tr>
<td>-8</td>
<td>67.0</td>
<td>188</td>
</tr>
<tr>
<td>-9 (π/9)</td>
<td>79.5</td>
<td>96.8</td>
</tr>
</tbody>
</table>

Note: dipole mode unit is different.

Few MHz change due to EP and many pre-tuning.

Calculated by Anton (DESY) and E.Kako (KEK)
2-3. Q\textsubscript{ext} value of HOMs

TM011 damping is weak in STF cavity.

More improvement as like a TESLA (rotation angle etc…)

TE111 and TM110 is all most same.

Probe conditions:

- **TESLA Z84**: probe 12 mm, gap 0.3 mm
- **STF #3**: probe 12 mm, gap 2 mm

STF cavity has a broad gap.

Both cavity were measured by room temperature.
2-4. Polarization direction measurement

Important point: for HOM BPM etc…

1) The polarization angle of used dipole mode at each cell has same angle.
(linear polarize)

2) X and Y polarizations are separated for used dipole mode. 90 deg?
(HOM BPM case: TE111-6)

To check them, try to measure by using bead-pull method (off center scan).

Of course, we were known that TE111-6 mode can be used as HOM BPM.
(good V-curve and phase response). But, to search the field distribution in
inside cavity is important, and is useful to estimate the reasonable of the this
mode.

Note: this measurement was one cavity only and room temperature.

When 2K, the coupling beta of modes are changing. (so possible to change
a polarization?), But, 2K measurement is difficult. (beam?)
Set up (bead-pull measurement)

encoder

Bead line

Input coupler: blind flange

HOM1

HOM2

0 mm

1300 mm

Step motor

S11 or S22

monitor

Network analyzer 8363B

Motor controller

GP-IB

PC

Bead line can move X,Y plane, Z-axis scan.
Define of polarize direction

Scan position:
- off-center 30mm (+ - 0.4 mm, 1deg error)
- angle 90 to –90 deg, step 30 deg
  (temperature: + - 0.2 degC / scan)
Total 7 scans per one mode.
Bead : ceramics ball , diameter 6 mm
  (only detect E-field for polarize measurement)
Measurement error : about < + - 7 deg.
Sample: measurement data : TM110-1 (pi-mode)

Field pattern of each measurement angle

Center of cell

Plotted the polar coordinate
TE11 and TM11 mode case:

$E_{\phi}$ in the R=R ?, when Z (beam axis) and R (off center) are decided, finally

$E_{\phi} \propto \cos(n \phi)$ or $-\sin(n \phi)$

From the relation of $E \propto (\delta f / f_0)^{1/2}$

Become fitting function as

$\delta f \propto A \cos^2(\phi + \xi)$

Where A is delta f, $\xi$ is polarize angle.
Z84 TE111-6 low (1) by using HOM BPM

Center scan (metal ball diameter 6 mm)

Off center scan
(ceramics ball diameter 6 mm)
Iris part changes delta f.
Z84 TE111-6 low (2)

Iris part
Polarize directions: Z84 TE111-6 low

Polarize angle is 55 deg
Z84 TE111-6 high (1) by using HOM BPM

Center scan (metal ball diameter 6 mm)

Off center scan
(ceramics ball diameter 6 mm)
Z84 TE111-6 high (2)

Iris part
Polarize directions: Z84 TE111-6 high

Polarize angle is -35 deg
Polarize direction in Z84 TE111-6: each cell distribution

Same polarize angle at each cell. (Linear polarize)

And separated X and Y polarization. (90deg)

STF cavity also was same tendency.
## Summary table of polarize angle in each mode

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>TE111: ave. (error), max, min [deg.]</th>
<th>TM110: ave. error, max, min [deg.]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>1</td>
<td>Ave. 19 (1.5)</td>
<td>Ave. -68 (0.8)</td>
</tr>
<tr>
<td></td>
<td>Max:23, Min:13</td>
<td>Max:-66, Min:-72</td>
</tr>
<tr>
<td>2</td>
<td>Ave. 23 (0.3)</td>
<td>Ave. -67 (0.6)</td>
</tr>
<tr>
<td></td>
<td>Max:24, Min:22</td>
<td>Max:-65, Min:-69</td>
</tr>
<tr>
<td>3</td>
<td>Ave. 18 (1.5)</td>
<td>Ave. -76 (0.8)</td>
</tr>
<tr>
<td></td>
<td>Max:28, Min:14</td>
<td>Max:-74, Min:-82</td>
</tr>
<tr>
<td>4</td>
<td>Ave. 17 (0.6)</td>
<td>Ave. -74 (0.4)</td>
</tr>
<tr>
<td></td>
<td>Max:21, Min:16</td>
<td>Max:-73, Min:-76</td>
</tr>
<tr>
<td>5</td>
<td>Ave. 49 (0.5)</td>
<td>Ave. -45 (0.6)</td>
</tr>
<tr>
<td></td>
<td>Max:52, Min:46</td>
<td>Max:-43, Min:-48</td>
</tr>
<tr>
<td>6</td>
<td>Ave. 55 (1.0)</td>
<td>Ave. -35 (1.0)</td>
</tr>
<tr>
<td></td>
<td>Max:60, Min:51</td>
<td>Max:-31, Min:-39</td>
</tr>
<tr>
<td>7</td>
<td>Ave. 52 (0.9)</td>
<td>Ave. -38 (0.5)</td>
</tr>
<tr>
<td></td>
<td>Max:56, Min:49</td>
<td>Max:-36, Min:-40</td>
</tr>
<tr>
<td>8</td>
<td>Ave. 43 (0.5)</td>
<td>Ave. -46 (0.5)</td>
</tr>
<tr>
<td></td>
<td>Max:45, Min:41</td>
<td>Max:-43, Min:-49</td>
</tr>
<tr>
<td>9</td>
<td>Ave. 37 (0.6)</td>
<td>Ave. -49 (0.6)</td>
</tr>
<tr>
<td></td>
<td>Max:40, Min:35</td>
<td>Max:-46, Min:-51</td>
</tr>
</tbody>
</table>

TE111-1,2,3,4 were same, and TE111-5,6,7,8,9 were same.

TM110 modes had a various angle.

Error: standard error,
Delta: High – Low [deg]
Delta $f$ [Hz] vs delta angle [deg] in doublet of dipole mode

When the delta $f$ [Hz] of doublet is small less than about 100 kHz, its delta angle is not 90 deg. due to the overlap each other of doublet.
To used HOM as cavity alignment, agreement of electrical mode and mechanical center is important.

We tried to be measurement it by using antenna scan method.

How does it see a result ?, Is this method possible ?

In addition, we tried to be cross-check the polarize direction by measured bead-pull method.

Measured polarize direction by bead pull method and the orthogonal axis of it scanned.
Picture of antenna scan system (HOM stand at STF)

- Wire (diameter = 70 um)
- Dummy flange: Alignment target
- Reference plane (plate)
- Coaxial antenna
- Rotate reference: Input coupler
- Jig for alignment
Detail setup

Alignment target (antenna center and cavity center [beam pipe center]): <100 um

Up view

Jig for antenna alignment

Dummy flange: Alignment target

Tungsten wire

Reference plane

Side view

Weight: 510 g

Wire tension

Reference plate

X-Y stage and roller for cavity alignment

X-Y-Z stage and coaxial antenna for antenna scan

Reference plane
Coaxial antenna for antenna scan

Concentricity target: 100 um

Machinable ceramics
condition-1

Microwave absorber
To stabilize a RF signal.

Insert length of antenna: 30mm

NWA  E8363B

RF amp 15dB
RF amp : mini circuit , ZX60-6013E-S+

RF amp 15dB
RF amp : mini circuit , ZX60-6013E-S+

Measured S21(transmission) max search vs antenna position
Spectrum of condition-1 (HOM2 S22 and S21)

Single peak (TE111-4)

Twin peak (TE111-6)

Spectrum pattern (S22) dependent on the polarize direction

Try measurement with both case
Single peak (mode: TE111-4 high peak)

-76 deg

High peak: polarize direction = -76 deg

Measured by bead-pull method

This mode could be observed V-curve, this signal was very good. And orthogonal axis of YY scanned, XX-axis was no response to amplitude and phase.

Measured polarize angle by bead-pull method, and antenna scan result was same polarize angle. Could be cross-check to both method result.
Twin peak (mode : TE111-6 high peak)

High peak: -35 deg
Low peak: polarize direction = +55 deg

High peak and Low peak is orthogonal.

This mode had the response (amplitude and phase), but could not be observed V-curve at the mover area. However, in scanning the orthogonal axis of YY, had the phase response. Maybe signal had a possibility mode mix.
### Result of condition-1

<table>
<thead>
<tr>
<th>mode</th>
<th>HOM2 (reflection) condition-1</th>
<th>Polarize direction (bead)</th>
<th>Off-center [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE111-1</td>
<td>Single peak : High</td>
<td>L: 19deg, H: -68 deg</td>
<td>- 2.6 mm</td>
</tr>
<tr>
<td>TE111-2</td>
<td>Single peak : High</td>
<td>L: 23deg, H: -67 deg</td>
<td>- 2.4 mm</td>
</tr>
<tr>
<td>TE111-3</td>
<td>Single peak : High</td>
<td>L: 18deg, H: -76 deg</td>
<td>- 1.5 mm</td>
</tr>
<tr>
<td>TE111-4</td>
<td>Single peak : High</td>
<td>L: 17deg, H: -74 deg</td>
<td>- 2.0 mm</td>
</tr>
<tr>
<td>TM110-4</td>
<td>Single peak : Low</td>
<td>L: 77deg, H: 5 deg</td>
<td>- 0.5 mm</td>
</tr>
<tr>
<td>TM110-5</td>
<td>Single peak : High</td>
<td>L: 27deg, H: 87 deg</td>
<td>- 1.5 mm</td>
</tr>
<tr>
<td>TM110-6</td>
<td>Single peak : Low</td>
<td>L: 93deg, H: 9 deg</td>
<td>- 1.0 mm</td>
</tr>
<tr>
<td>TM110-8</td>
<td>Single peak : Low</td>
<td>L: 81deg, H: -4 deg</td>
<td>+ 0.8 mm</td>
</tr>
<tr>
<td>TM110-9</td>
<td>Single peak : Low</td>
<td>L: 98deg, H: 13 deg</td>
<td>- 0.4 mm</td>
</tr>
</tbody>
</table>

Could be measured a single peak coupling mode only. Other modes were twin peak at HOM2 reflection.

Twin peak case, could be seem response of dependence antenna position, but could not observe a V-curve.

The off-center had the shifting HOM coupler side, about few millimeters.

Note, this measurement has the strong effect of the end cell, not all cells.
Condition-2

Changed cavity position!!
Excited from HOM2 side, pick-up from HOM1 port.
Result of condition-2

Could not observe the V-curve.

Due to input coupler port? (break a symmetrical geometry of beam pipe? Or more big off centers?)

Try to change the antenna position (more depth to insert length, measured mode etc...), but could not observe the good V-curve.
3. Conclusion

Measurements of HOMs for the HOM BPM and the cavity miss-alignment was made with TESLA cavity (Z84) at KEK in this summer.

1) Accelerating mode frequency was very good for 2K operation. Field flatness was about 90%.

2) TE111 and TM110 passband was all most same, but TM011 was different about -50 MHz lower than TESLA.

3) TE111 and TM110 Qext was all most same, but TM011 was weak in STF cavity, more improvement to obtain the strong damping as like the TESLA.

4) All dipole mode polarize direction at each cell were the linear polarize. Not circular polarize. Made a table all TE111 and TM110 passband of polarize directions.

When the doublet delta f [Hz] is small less than 100 kHz, its delta angle is not 90 deg. Due to the overlap each other of doublet.

5) Measured polarize angle by bead-pull method, and antenna scan result was same polarize angle. Could be cross-check from both method result.

Could observe the V-curve at single peak coupling modes, in this case, off-center had the shifting HOM coupler side, about few millimeters. However, this measurement has the strong effect of the end cell.

The twin peak mode and HOM2 side exited case could not measure these.
Thank you for your kind attention !!
Passband TM010(2)

Field pattern

TM010-4: 1281.475 MHz

E-field TM010-4

Bead position (mm)

TM010-3: 1277.175 MHz

E-field TM010-3

Bead position (mm)

TM010-2: 1273.675 MHz

E-field TM010-2

Bead position (mm)

TM010-1: 1271.350 MHz

E-field TM010-1

Bead position (mm)

Metal ball, diameter = 6 mm, center scan
Passband TM011(1)

Metal ball, diameter = 6mm, center scan
Passband TM011(2)

Metal ball, diameter =6mm, center scan
Passband TM011(3)

Field pattern
TM011-7: 2431.47 MHz
E-field TM011-7

Field pattern
TM011-8: 2440.72 MHz
E-field TM011-8

Asymmetry field pattern
Metal ball, diameter = 6 mm, center scan
Passband TE111(1)

Passband TE111(1)

Metal ball, diameter =6mm, center scan

Passband TE111(1)
Passband TE111(2)

Metal ball, diameter =6mm, center scan
Passband TE111(3)

Metal ball, diameter =6mm, center scan
Passband TM110(1)

Metal ball, diameter = 6mm, center scan
Passband TM110(2)

Metal ball, diameter =6mm, center scan
Passband TM110(3)

**Graphs:**
- **TM110-7**
- **TM110-8**
- **TM110-9**

Each graph shows a plot of `delta f [Hz]` against `bead position (mm)`.

- **TM110-7**
  - Delta f (Hz) values range from 0 to 3 x 10^4 Hz.
  - Bead position ranges from -5000 to 15000 mm.

- **TM110-8**
  - Delta f (Hz) values range from 0 to 3 x 10^4 Hz.
  - Bead position ranges from -5000 to 15000 mm.

- **TM110-9**
  - Delta f (Hz) values range from 0 to 2.5 x 10^4 Hz.
  - Bead position ranges from -5000 to 15000 mm.