Refurbished Cryomodules (C50):
Cavity Frequency Recipe

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Summary: A critical part of refurbishing cavities in support of the C50 cryomodule program is setting the warm frequency of the cavities in order to obtain the proper cold frequency. To achieve the proper frequency, the following effects must be considered:

- Warm tuning to obtain required field flatness,
- Chemistry to obtain desired surface characteristics,
- Pressure loads due to beamline and cryostat vacuum,
- Frequency shift due to cooldown,
- Cold tuning to attain the desired accelerating frequency, and
- Minimizing backlash throughout the active tuning range.

All contributions from these effects must result in a cold cavity ready for operation within a desired tuning range (see Table 1).

In addition, there are points between manufacturing steps where the cavity frequency is checked or verified. It is important to know the target frequencies and allowable variations at these intermediate points.

This note details the various frequency contributions to the recipe, references the methods for obtaining these contributions and documents the permissible frequency variations before and after key manufacturing steps.

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Expected ΔF (MHz)</th>
<th>Mfg. Step</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1497.000</td>
<td>-0.300</td>
<td>At Accelerating Frequency</td>
<td>1497.100</td>
<td>1496.300</td>
</tr>
<tr>
<td>1497.300</td>
<td>0.070</td>
<td>CM at 2K</td>
<td>1497.400</td>
<td>1497.200</td>
</tr>
<tr>
<td></td>
<td>2.400</td>
<td>Pumdown</td>
<td>1497.400</td>
<td>1497.200</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>Warm-Cold Shift</td>
<td>1497.400</td>
<td>1497.200</td>
</tr>
<tr>
<td>1494.830</td>
<td>-0.050</td>
<td>HV Welding</td>
<td>1494.930</td>
<td>1494.730</td>
</tr>
<tr>
<td>1494.880</td>
<td></td>
<td>CP Assy, After Tuner Installation</td>
<td>1494.980</td>
<td>1494.880</td>
</tr>
<tr>
<td>1494.480</td>
<td>0.400</td>
<td>Tuner Preload</td>
<td>1494.580</td>
<td>1494.380</td>
</tr>
<tr>
<td>1494.800</td>
<td>-0.120</td>
<td>Establish Vacuum</td>
<td>1494.675</td>
<td>1494.525</td>
</tr>
</tbody>
</table>

Table 1. C50 Cavity Tuning Recipe

1 of 3
Frequency at Various Manufacturing Steps

The manufacturing and processing steps begin with a cavity tuned to some frequency that is predetermined by knowing how the cavity responds to a variety of processing steps. The frequency shifts due to cooldown, evacuation, chemistry, tuning and assembly have been measured on several cavities in order to arrive at the final recipe. The assumptions and boundary conditions for each process step are described below. It should be noted that the minimum and maximum values for the frequency at each step are nominally chosen to allow for some variation in cavity frequency due to manufacturing and processing variations, and also some measurement error. A detailed analysis would yield different allowed variations for each processing step. This mostly applies to variations in warm frequency measurements taken with a network analyzer.

The frequency shifts caused by orientation, chemistry, vacuum loading, cooldown and tuner installation have been measured on some cavities. The results of these measurements are shown in the appendices. The effects on frequency of chemistry, orientation, vacuum loading and cooldown in the VTA were measured on cavities INT-077 and INT-078 (App. A). The effects of vacuum loading and tuner installation were measured on cavity INT-016 (App. B). The effects of cooldown in the VTA and vacuum loading were measured on IA-082 (App. C). The effect of orientation was measured on cavity INT-016 (App. D).

Tuned and Ready for Cavity Pair (CP) Assembly
- The cavities receive up to 200 microns of bulk chemistry.
- After coarse tuning, the field flatness is set to less than 3% routinely, compared with a specification of less than 10%.
- Finally the cavity is ready for final chemistry and high-pressure rinsing.

Ready for Cryo-Unit (CU) Assembly
- The cavities receive approximately 20 microns of chemistry.
- Assuming an etch rate of 6 kHz per micron, the cavity frequency decreases by 120 kHz.
- The etch rate is an average value verified with coupons in the acid bath. Etch rates can be higher with a new batch of acid.
- After chemistry and other processing, the cavity is assembled into a CP, where the beamline vacuum is established. This results in a 400 kHz frequency increase. This shift was measured on the first CP delivered to the CU Assembly Area, with and without the tuner installed.
- After successful leak-checking, the CP is ready for CU assembly.

Tuner Installation (and Operation)
- During CU assembly, the tuner is installed.
- The cavity is in compression over the entire tuning range. This minimizes backlash in the cold mechanism and avoids hysteresis in the tuning mechanism, as can be observed in CEBAF CM tuners when cavities change from compressive to tensile loading or vice versa.
- Adding a small pre-load ensures linear operation of the tuner over its entire tuning range. Pre-loading increases the compressive load which then decreases the cavity frequency.
The tuning sensitivity is 300 kHz per mm, the stroke is 2 mm and the resulting tuning range is 600 kHz. Some measurements have shown the tuning sensitivity may be as high as 400 kHz per mm. The lower value is a conservative working number.

There is no shift in frequency due to helium vessel welding. The bellows on the ends of the cavity pair provides strain relief during this operation. In addition, the tuners are installed and restrain the cavities.

After assembly is completed, the CU is ready for integration into a CEBAF CM.

Cold at 2K

The largest frequency shift is due to thermal contractions experienced during cooldown.

The value shown in the table (an increase of 2.4 MHz) does not include the effect of establishing cavity vacuum, since nearly all cavities are tested with the interior space evacuated already.

An additional shift is measured when pumping down from 760 torr to 23 torr. This minor increase of 70 kHz is included in the total frequency shift.

Tuned to Accelerating Frequency

The tuner is used to compress the cavity, increasing its frequency by approximately half of the tuner range, 300 kHz.
Final Re Meas (when)

* Chemistry

1494.552
1494.432
1494.832

* Vac. Shift

0.480
0.050

1494.882

* VRT change

1497.225

VTR Test Data

* Warm Cold Shift

2.343

Horiz on Rail (as founded)

1494.779
0.050

1494.829

* Vert shift

1497.225
1494.779
2.448
0.050
2.398

* Should match

\( \Delta = 0.053 \)

Actual Warm/Cold Shift

* Vert Shift

\( \Delta = 0.055 \)

* = Assumed FREQ Shift
Final Fr. Mfrs (warm) | 1444.526
---|---
* Chemistry | -0.120
| 1444.406

* VAC. SHIFTS | 0.400
| 1444.806

* VERT. CHANGED | 0.050
| 1594.856

VTA TEST DATA | 1497.240

* WARM/COLD SHIFT | \( \sqrt{2.384} \)

Vert. On Rail (As Rec'd) | 1494.730
* VERIFY VERT SHIFT | + 0.050
| 1494.780

Actual Warm/Cold Shift | -1497.240
* VERT SHIFT | \( -2.504 \)
| -0.050
| 2.454

\( \Delta = 0.070 \)

* = **Assumed** Frer Shift
Cavity ID: 1NT-016

Status: Tuner Installed
- Cavity & Atmos. (Air)
- No Cond on Tuner

\[ f_0 = 1994.342 \text{ MHz} \]
* Cavity Evacuated

\[ f_1 = 1994.712 \text{ MHz} \rightarrow \Delta = 0.370 \text{ MHz} \]
* Cavity Heated (Air)

\[ f_0 = 1994.340 \text{ MHz} \rightarrow \Delta = 0.372 \text{ MHz} \]
* Tuner Unfolded

\[ f_0 = 1994.239 \text{ MHz} \rightarrow \Delta = 0.101 \text{ MHz} \]
* Cavity Evacuated

\[ f_0 = 1994.628 \text{ MHz} \rightarrow \Delta = 0.389 \text{ MHz} \]
APPENDIX C
Warm/Cold Frequency Shift

Cavity ID: 1A-082

Cavity handling in Dewar

* Dewar Pressure = 860 Torr
  $f_s = 1494.728 \text{ MHz}$

* Dewar Pressure = 23 Torr
  $f_s = 1494.798 \text{ MHz}$
  $\Delta f = 0.070 \text{ MHz}$

* Test Data @ 2K
  $f_s = 1497.146 \text{ MHz}$
  $\Delta f = 2.348 \text{ MHz}$

* Dewar Pressure = Atmos. (777 Torr)
  $f_s = 1494.723 \text{ MHz}$
APPENDIX D

VERTICAL

HORIZONTAL

FREED SHIFT

Cavity ID = INT-016
Position in Pair = Top

FRED in Mil

<table>
<thead>
<tr>
<th>Horiz.</th>
<th>Vert.</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>494.335</td>
<td>494.385</td>
<td>0.050</td>
</tr>
</tbody>
</table>

Cavity ID = INT-010
Position in Pair = Bottom

<table>
<thead>
<tr>
<th>Horiz.</th>
<th>Vert.</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>494.310</td>
<td>494.343</td>
<td>0.033</td>
</tr>
</tbody>
</table>

Cavities are both in an evacuated state at time of test.