LCLS-II CAVITY HIGHER ORDER MODES COUPLER TUNING OPTIMIZATION AND CHALLENGES AT JEFFERSON LAB*

A. Solopova†, D. Forehand, A. Palczewski, Jefferson Lab, 23608, Newport News, VA, USA
T. Khabiboulline, FNAL, 60510, Batavia, IL, USA

ABSTRACT

The Thomas Jefferson National Accelerator Facility is currently engaged, along with several other Department of Energy (DOE) national laboratories, in the Linac Coherent Light Source II project (LCLS II) - a new XFEL linac based on 1.3GHz superconducting linear accelerator. Half of the LCLS-II cryomodules are being produced at Jefferson Lab, other half is made at Fermilab. Each cryomodule contains eight 9-cell cavities with two Higher Order Modes (HOM) loop couplers operating at 1.3 GHz. This paper summarizes the HOM filter tuning challenges at Jefferson Lab and describes optimization of the procedure for a 9-cell Tesla type cavity and its integration into a cryomodule production line.

INTRODUCTION

If HOMs are close to the operating mode frequency, they might be excited as well and can disturb the operating mode. HOMs excited in SRF structures by passing beam may deteriorate beam quality and affect beam stability. It is extremely important to properly tune HOM filters, i.e. to minimize RF transmission on the operating mode, to prevent beam breakup and excessive heating of the cavity end group. Capacitive tuning is first done on a single cavity before the vertical test, then checked and adjusted before the cavity string is inserted in the cryomodule vacuum vessel.

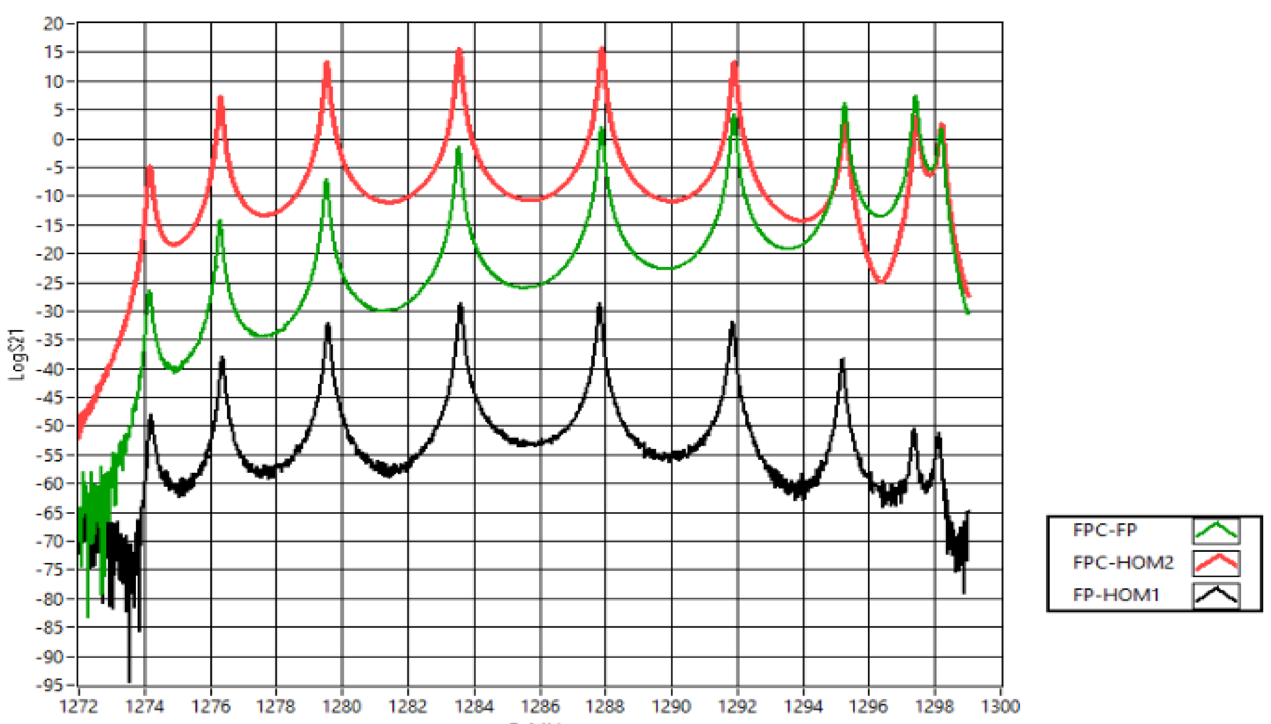

Figure 1: Fundamental mode spectrum of an LCLS-II cavity

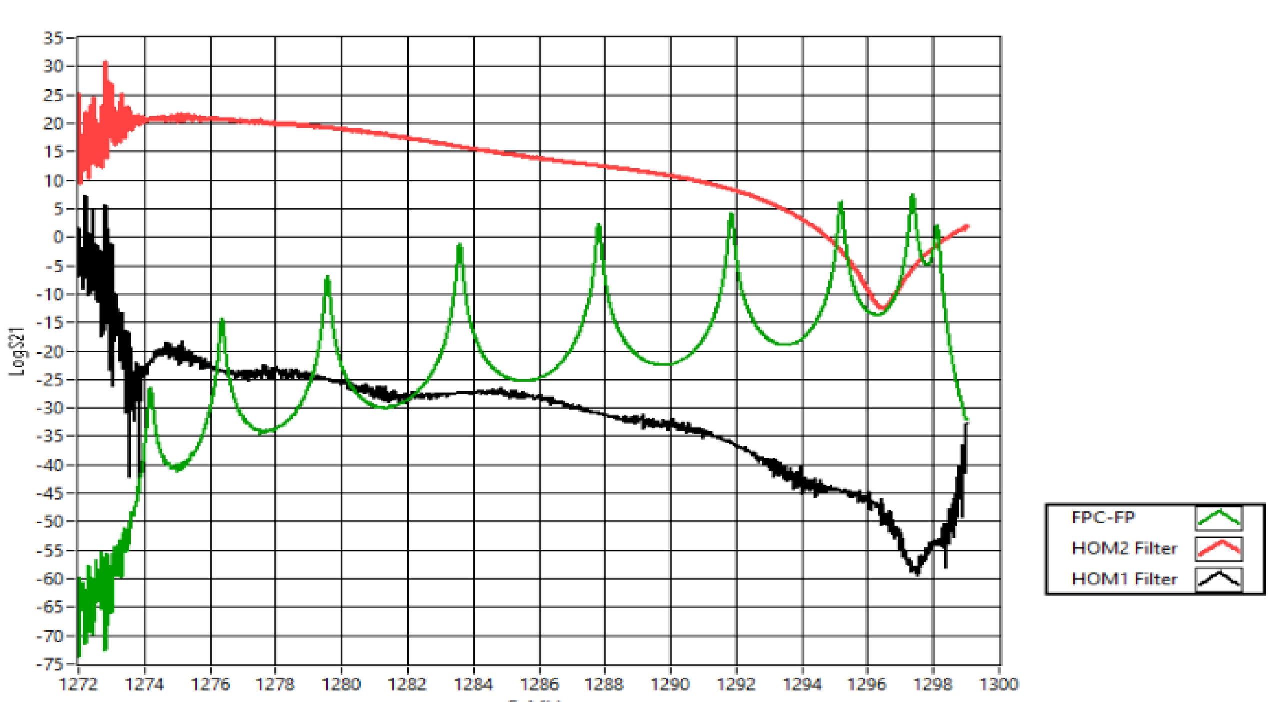

Figure 2: Notch filter view of an LCLS-II cavity spectrum

PROCEDURE OPTIMIZATION

Iterative tuning to the specific notch frequency is a time-consuming procedure: each cryomodule required about 16 hours or work. As a result, iterative tuning was moved to the cavity incoming inspection stage, when all received cavities fundamental modes are measured and recorded. Required tuning time was now reduced by a couple of hours. Different tuning techniques were studied on individual cavities tested at the Vertical Test Area to develop a procedure most consistent with the process at the partner laboratory. As we acquired more data, a pattern became obvious: cavities tuned such that $\frac{7\pi}{9}$, $\frac{8\pi}{9}$ and π modes amplitudes were within 2dB from each other and 12-15dB lower than $\frac{5\pi}{9}$ mode and there is a local minimum between $\frac{7\pi}{9}$ and $\frac{8\pi}{9}$ modes, show the lowest measured power out of the HOM coupler, Figure 7. This visual method is consistent with the previously set target notch frequency, provides good HOM power damping and reduces time required for tuning. In addition to these improvements, a new LabVIEW software package was developed to help automate data taking and analysis.

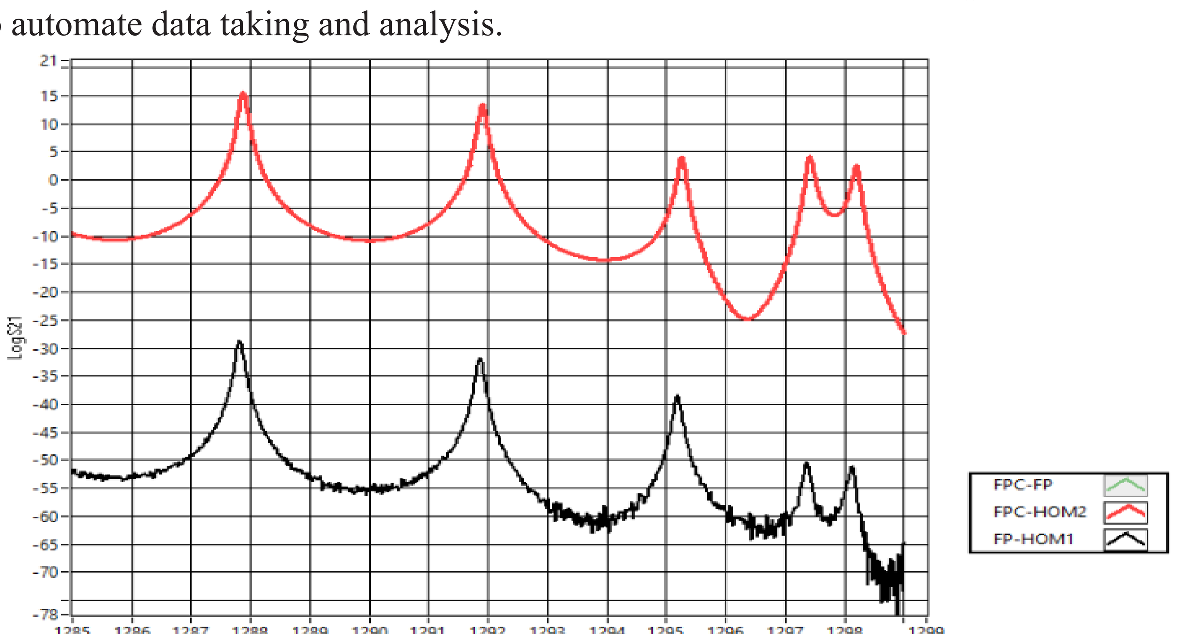

Figure 7: Examples of HOM spectrum: top – properly tuned; bottom – not tuned.

CHALLENGES EXPERIENCED

The first production cryomodule (CM02) HOM filters were tuned using the procedure for Jefferson Lab C100 style cryomodules [1]. CM02 was at the Cryomodule Test Facility in July 2017.

Over a half of the HOM had a measured quality factor below specification. A plan was developed to asses CM02 and CM03 HOM tuning and HOM heat station connections. 14 out of 16 HOMs accessible through the tuner ports on the CM03 were tuned to the partner laboratory standard notch frequency for a cavity under vacuum, 1297.0 MHz [2].

We independently rediscovered that tuning is extremely sensitive to any external manipulation: tightening cables, assembling magnetic shield covers, tightening of the heat stations. Notch position was measured multiple times during the process and under several different vacuum conditions, including: cavity under vacuum - insulating vacuum at atmosphere; both cavity and insulating vacuum established.

Table 1: Notch frequency shift for HOM1

HOM 1 notch atm-vac, MHz	HOM 1 notch vac-vac, MHz	Frequency shift, MHz
1296.7	1297.2	0.5
1297.4	1298.3	0.9
1297.3	1298.0	0.7
1297.3	1298.1	0.8
1297.2	1298.5	1.3
1296.8	1297.4	0.6
1297.4	1297.9	0.5
1296.8	1297.8	1.0

Table 2: Notch frequency shift for HOM 2

HOM 2 notch atm-vac, MHz	HOM 2 notch vac-vac, MHz	Frequency shift, MHz
1296.7	1297.1	0.4
1296.8	1297.8	1.0
1297.0	1298.1	1.1
1297.0	1298.1	1.1
1298.6	1300.4	1.8
1297.8	1298.8	1.0
1297.3	1297.9	0.6
1297.1	1297.7	0.6

Table 3: Notch frequency vs Qext

Cavity	HOM 1 notch, MHz	HOM 1 Qext	HOM2 notch, MHz	HOM 2 Qext
CM03-1	1296.6	4.12E+12	1296.5	3.21E+11
CM03-2	1297.2	4.80E+10	1296.8	9.74E+10
CM03-3	1298.9	4.50E+11	1297.0	4.04E+11
CM03-4	1297.2	9.10E+10	1296.9	8.54E+10
CM03-5	1297.0	4.20E+10	1298.7	1.70E+10
CM03-6	1296.5	4.00E+12	1297.8	1.56E+11
CM03-7	1296.9	7.70E+10	1296.9	3.50E+11
CM03-8	1296.6	3.70E+10	1296.9	1.80E+11

Notch filter position was expected to shift by +0.4MHz [2], observed frequency shift at Jefferson Lab was 0.8MHz for HOM 2, 1MHz for HOM 1, Tables 1 and 2. Target notch frequency was lowered to 1296.6MHz for HOM 1 and to 1296.3MHz for HOM 2. Test results showed inconsistency between tuned notch frequency and measured cold external quality factor. Cavities with close notch frequency showed a big difference in Qext and vice versa, Table 3.

After examining the process used at DESY and consulting with experts at DESY and Fermilab, we implemented an iterative tuning procedure to improve the stability of tuning by reduction of the local stresses and hardening of the material of HOM coupler, Figure 5, and improved our notch calculation technique [2, 3, 4]. We think this iterative tuning become even more important after CM02 because the cavity's recipe changed from the baseline 800°C annealing to a 900/950/975°C annealing, which in turn soften the HOM can material even further [6].

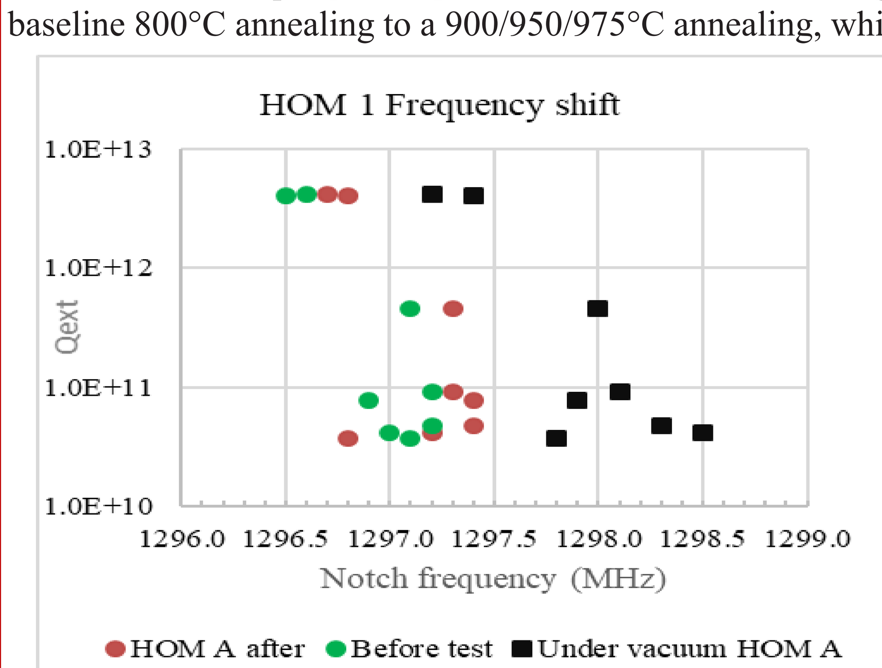

Figure 3: HOM 1 new notch frequency target 1296.5MHz

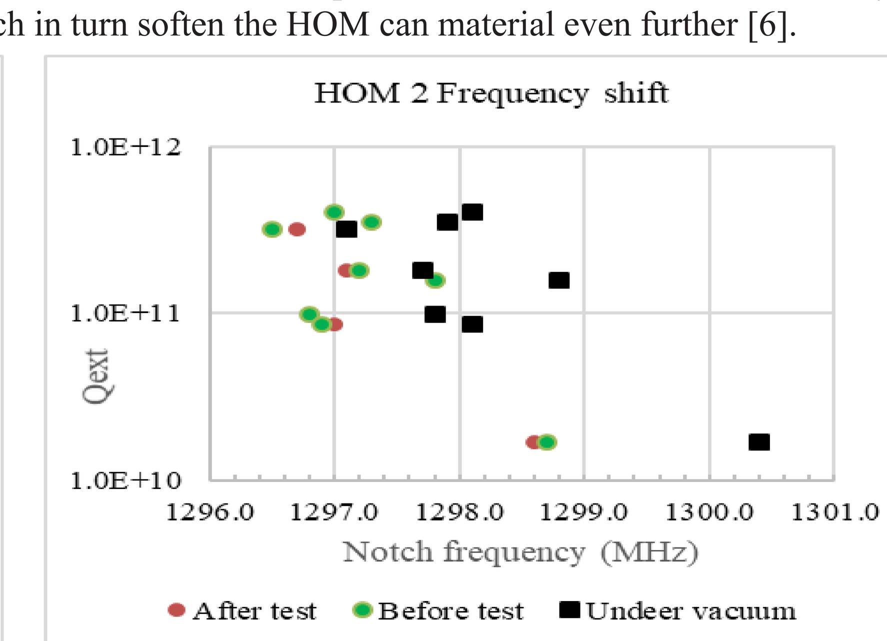

Figure 4: HOM 2 new notch frequency target 1296.3MHz

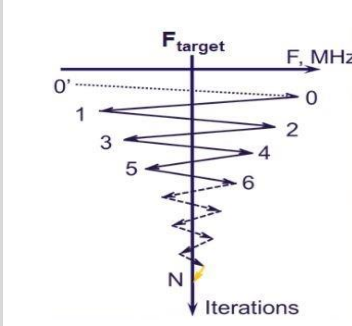

Figure 5: Iterative tuning pattern

After the second cold test, CM03 results were better, but still inconsistent: notch frequency measured at 2K showed a random shift, more so on the coupler side HOM can, Table 4. Discrepancy led us to believe that some external forces were changing the tune during the cool down. After a meticulous investigation we have found a mechanical interference between magnetic shields of the HOM can and a helium vessel, Figure 6

For the next cryomodules magnetic shielding was modified and mechanical interference was removed, which proved to be effective, Table 5.

Table 4: CM03 notch position and Qext measured at 2K after the final tune

Cavity	HOM 1 notch, MHz	HOM 2 notch, MHz	Notch 1 shift, MHz	Notch 2 shift, MHz	HOM 1 Qext	HOM 2 Qext
CM03-1	1299.5	1300.5	2.7	4.2	4.90E+12	3.50E+11
CM03-2	1304.8	1300.8	8.3	4.4	7.50E+10	4.70E+11
CM03-3	1300.9	1300.2	4.4	4	1.70E+12	5.30E+12
CM03-4	1303.3	1301.3	6.9	5.1	1.90E+11	1.50E+11
CM03-5	1304.8	1300.9	8.4	4.8	1.50E+11	4.70E+11
CM03-6	1300.0	1300.4	3.2	4.0	8.00E+12	1.50 E+12
CM03-7	1300.9	1300.6	4.5	4.3	1.30E+11	1.84E+11
CM03-8	1300.9	1300.9	4.2	4.5	1.70E+11	5.10E+11

Table 5: Cryomodule 4 test results

Cavity	HOM 1 notch, MHz	HOM 1 Qext	HOM2 notch, MHz	HOM 2 Qext
CM04-1	1296.4	3.6E+13	1296.2	1.5E+13
CM04-2	1296.6	6.8E+12	1296.3	3.5E+13
CM04-3	1296.8	3.0E+16	1296.4	4.0E+13
CM04-4	1296.6	1.7E+14	1297.4	3.8E+11
CM04-5	1296.6	4.2E+13	1296.6	1.1E+13
CM04-6	1296.6	1.5E+14	1296.4	1.6E+12
CM04-7	1296.6	3.2E+13	1296.3	7.7E+12
CM04-8	1297.1	3.2E+12	1296.3	4.1E+12

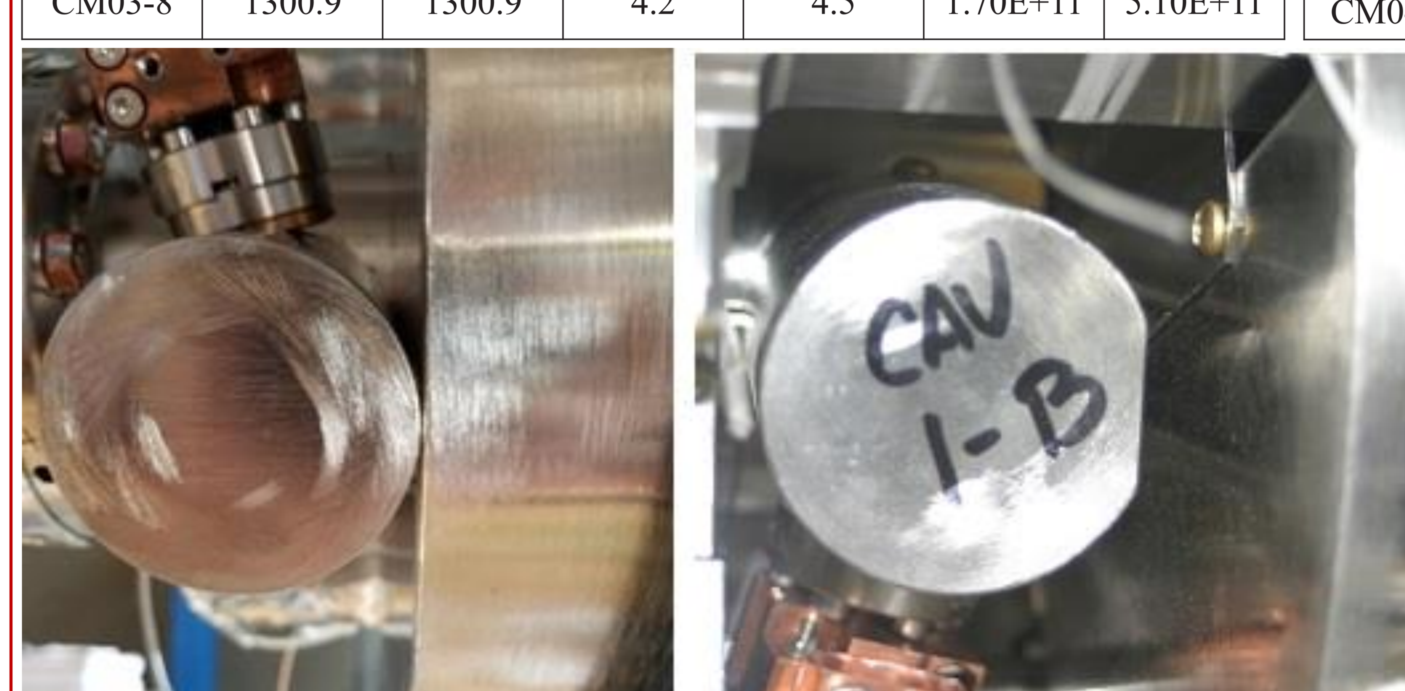

Figure 6: HOM magnetic shield mechanical interference (left) and correction (right)

SUMMARY

The HOM notch frequency adjustment must be converging iteratively to remove mechanical stress in the end plate. Tuning procedure should be done after all other adjustments and checks have been completed. Small difference in dimensions of the helium vessel and HOM can magnetic shields caused mechanical interference at 2K, modified HOM covers corrected the issue. Optimized tuning procedure and updated software allowed to cut tuning time in half while still providing results well within specification.

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† shabalin@jlab.org