FABRICATION TUNING OF FOUR 748.5 MHZ SINGLE CELL SRF BOOSTER CAVITIES FOR A 100 MA SRF FEL INJECTOR *

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Abstract

Advanced Energy Systems has recently completed the fabrication of four 748.5 MHz single cell superconducting cavities which are to be used in the JLAB FEL SRF Injector Test Stand. During the fabrication process a series of frequency measurements were made and compared to the frequency expected at that point in the fabrication process. Where possible, the cavity was modified either before or during, the next fabrication step to tune the cavity frequency toward the target frequency. The target frequency is calculated making a series of assumptions about the frequency effects of subsequent fabrication and processing steps.

INTRODUCTION

Advanced Energy Systems has recently completed the fabrication of four 748.5 MHz single cell superconducting cavities. Three of these four cavities are to be used in the JLAB FEL SRF Injector Test Stand that is currently under construction. The tuning was successfully completed and the cavities have been shipped to JLAB where testing has begun.

TARGET FREQUENCY CALCULATION

The first step in the cavity tuning was the calculation of the target frequency beginning with the desired operating frequency and working toward the lab frequency. The target frequency calculation accounts for tuner range, tuner offset, tuner preload, cooldown, chemical etching, and of the LHe pressure surrounding the cavity. The target frequency calculation is shown below in table 1.

Table 1: Frequency Effects

Source of Effect	dF (MHz)	F-dF (MHz)
Cold Target Frequency		748.500
Tuner Center of Range Offset	-0.393	748.893
LHe pressure	0.000	748.893
Warm to Cold (70F, 2K)	1.101	747.791
Chemical etch (210 microns total)	-0.819	748.610
Lab Tuning Target (70F,No Air)		748.610

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PRE EQUATOR WELD TUNING

Half cell frequency measurements

Following fabrication of the cavity half cells, the half cells (with all the end group components) were measured using a shorting plate. The shorting plate is designed to put a boundary wall at the correct symmetry plane. The results of these measurements are shown in table 2. The average frequency error is around 2.16 MHz, corresponding to an average required tuning cut of 152mils on each of the half cell equators. Each of the half cells was cut the same amount and most of the remaining error made up by the appropriate pairing of the half cells.

Table 2: Results of Half Cell Measurements

Cell #	Meas Freq (MHz, adjusted to 70F Vac)	Adjusted Target Freq (MHz, 70F Vac)	Error (MHz)
3	746.517	748.610	-2.093
2	746.563	748.610	-2.047
7	746.473	748.610	-2.137
6	746.366	748.610	-2.244
1	746.660	748.610	-1.950
5	746.435	748.610	-2.175
8	746.547	748.610	-2.063
4	746.383	748.610	-2.227

Cell Pairing and Half Cell Tuning

Cells were paired to offset the remaining frequency error based on a nominally uniform tuning cut. During machining a variety of circumstances led to some variation in the actual tuning cut amount. Some of this variation was a result of refinement of our fixturing and some of the variation was intentional, as we did not want to overcut.

Pre-weld Measurements

Prior to welding, and after the machining of weld preparations, the cell pairs were assembled into complete cavities. Frequency measurements were performed. The frequency error following welding was estimated based on the pre-weld frequency and estimated weld shrinkage. These results are shown in table 3 on the following page.

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Table 3: Pre-weld Frequency Measurements

Pair	Q_0 (lab)	Meas Freq (MHz, adjusted to 70F Vac)	Adjusted Target Freq (MHz, 70F Vac)	Error (MHz)	Error in dZ on Eq Plane (in, per side)	Expected Weld dZ (in, per side)	Welded dZ (in, per side)	Est Freq Error (MHz)
1&2	10534	748.575	748.610	-0.035	0.001	-0.007	-0.006	0.333
6&8	11145	748.458	748.610	-0.152	0.003	-0.007	-0.004	0.215
7&5	10501	748.806	748.610	0.196	-0.004	-0.007	-0.011	0.563
3&4	11147	748.650	748.610	0.040	-0.001	-0.007	-0.008	0.407

Table 4: Post-weld Frequency Measurements

Cavity	Pair	Q_0 (lab)	Meas Freq (MHz, adjusted to 70F Vac)	Pre-weld Freq (MHz, adjusted to 70F Vac)	DF from Weld (MHz)	Weld dZ (in, total)	Adjusted Target Freq (MHz, 70F Vac)	Error (MHz)
1	1&2	11211	751.515	748.575	2.939	-0.056	748.610	2.905
2	3&4	11303	750.004	748.650	1.354	-0.026	748.610	1.394
3	6&8	11299	749.704	748.458	1.246	-0.024	748.610	1.094
4	7&5	11231	750.054	748.806	1.248	-0.024	748.610	1.444

Post-weld Measurements

The measurement results of the complete welded cavities are shown in table 4. The frequency error was larger than anticipated. Based on the observed frequency change after the weld, the weld shrinkage was estimated and is shown. We planned on a total weld shrinkage of 14 mils per weld. Based on the frequency measurements and calculations we estimate that we had weld shrinkage of more than that. We attribute this additional weld shrinkage to additional weld passes that were made to improve the characteristics of the weld bead especially in cavity 1. Clearly a good quality weld is more important providing that the cavity is within the tunable range.

POST EQUATOR WELD TUNING

Post-weld tuning of the cavities was accomplished by adjusting the cavity length by deformation. In all cases the cavity frequency was to be reduced, so the cavity needed to be shortened. The cavities were tuned by deforming them under compression using a hydraulic press.

Table 5 summarizes the results for this tuning operation showing the target frequency, initial (untuned) frequency, and the frequency at the completion of the tuning operation. The frequency was then measured again after the cavities sat for about 18 hours. This is also shown in table 5 along with the overall frequency change from the tuning, the springback after 18 hours, and the final overall frequency error. The final frequency error is very good for cavities 2-4 and acceptable for cavity 1. Note that the springback varies with the total tuning dF applied.

Table 5, Results of Post Equator Weld Tuning

All Freq in MHz at 70F Vac	Cavity 1	Cavity 2	Cavity 3	Cavity 4
Target Frequency	748.610	748.610	748.610	748.610
Initial Frequency	751.468	750.014	749.701	750.080
Finished Frequency	748.647	748.598	748.618	748.612
Final Frequency after ~18 Hours	748.662	748.600	748.618	748.615
dF from Tuning	-2.806	-1.414	-1.083	-1.465
18 hour springback	0.016	0.002	0.000	0.002
Final Freq Error	0.052	-0.010	0.008	0.005

Figure 1 on the following page shows the cavity frequency and load for each tune step for all four cavities. We see that for load under ~ 3000 lbs most of the frequency shift is elastics, it goes away as the load is removed. Loads in the range of 4000 to 5000 lbs were required to effectively tune the cavity by yielding it. During the tuning of cavities 3 and 4 we went right up to 4000 lbs before removing the load and checking for yield.

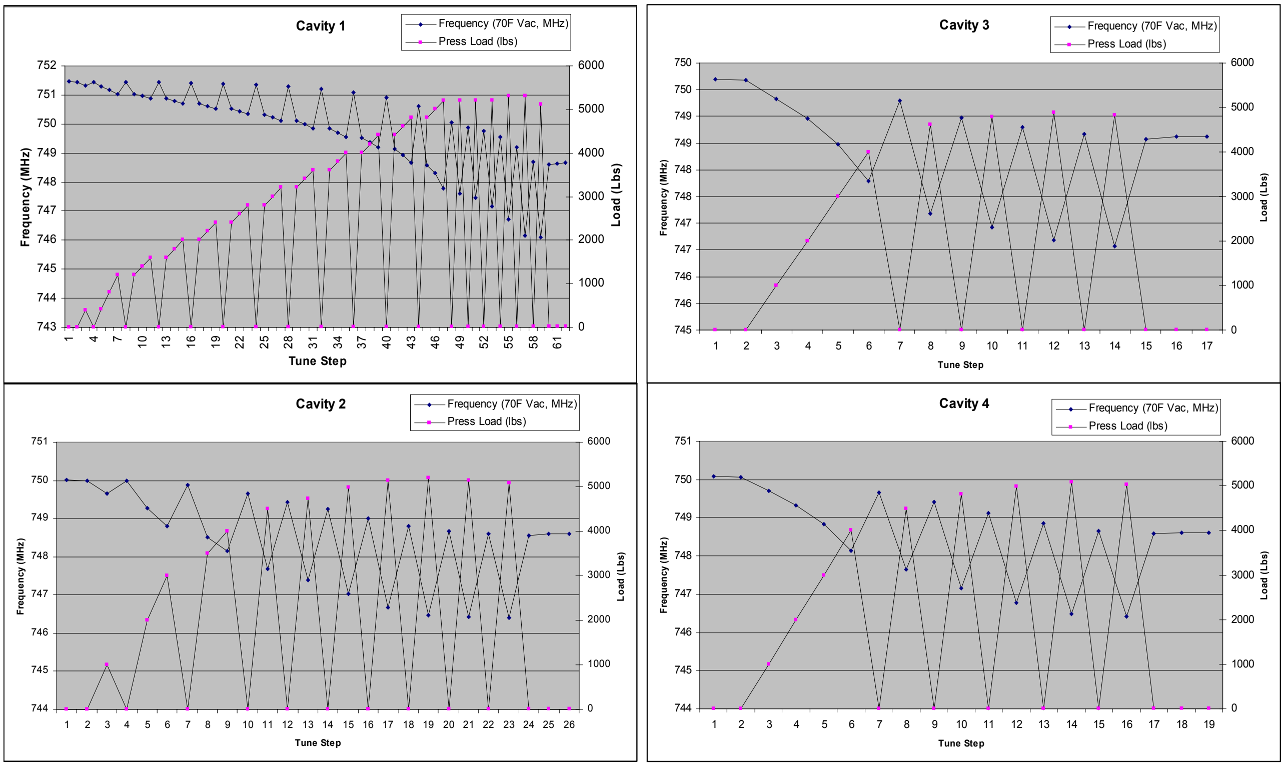

Figure 1, Cavity frequency and load during tuning

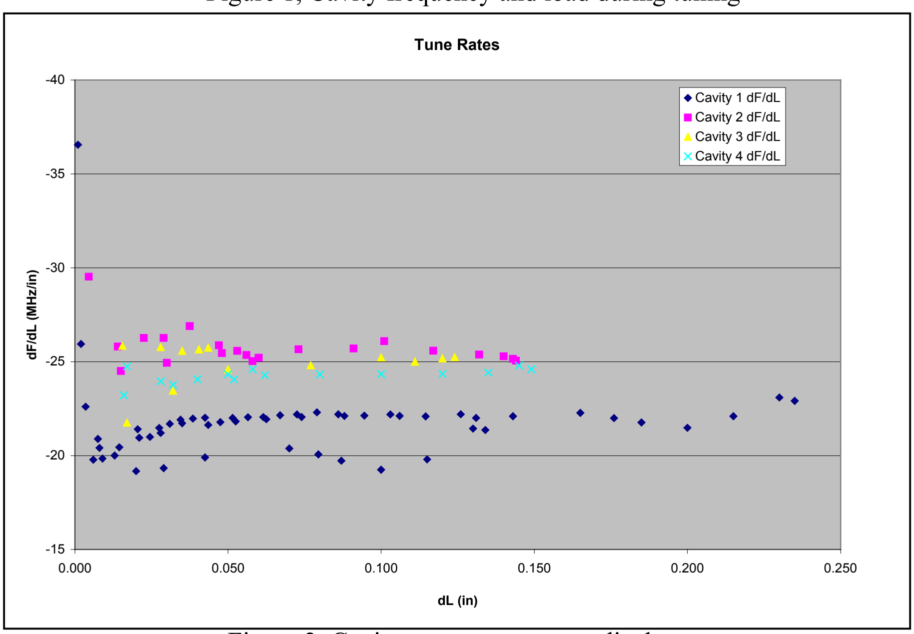

Figure 2, Cavity tune rates vs tune displacement

Figure 2 shows a plot of the tune rates (total dF/total dL) measured for each cavity during each tune step of the tuning operation. These values are plotted as a function of the total dL at each tune step. Results for cavities 2 thru 4 were very similar, while cavity 1 behaved a little differently. This difference in behavior may be due to the additional equator weld passes and the resulting additional weld shrinkage in cavity 1.

CONCLUSION

We have completed the fabrication tuning of four single cell SRF cavities. Tuning was accomplished by machining during the fabrication process and by deformation following the final welds. Three of the cavities were tuned to within 10 kHz of the target frequency while one was 52 kHz off. Loads in excess of 4000 Lbs were required to permanently tune the cavities effectively.