ACHIEVING HIGH ACCURACY IN CORNELL'S ERL CAVITY PRODUCTION

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Abstract

The phase 1 R&D program launched in preparation to building a 5 GeV Energy Recovery Linac (ERL) at Cornell, a full main linac cryomodule is currently built, housing six 7-cell cavities. In order to control the beam break-up limit, the shape of the cavity was highly optimized and stringent tolerances on the cavity production were targeted. We will report on the details of the cavity production, the accuracy of the cups forming the individual cells, the trimming procedure for the dumbbells, the cavity tuning and final accuracy of the cavity concerning field flatness, resonant frequency and overall length within this small series production.

INTRODUCTION

Six Cornell ERL 7-cell cavities will be connected in each cryomodule in the full LINAC. Between each cavity there are bellows and HOM absorbers. Therefore a tight tolerance of +/- 0.5mm must be applied to the length of each cavity (see Table 1). Unfortunately, due to space restrictions in Cornell's electron-beam welder, the beam tubes must be welded to the cavity before the final equator weld, which does not allow the cavity to be trimmed to its final length. Therefore, the cavity length must be controlled through other means.

Table 1: Length and Frequency Tolerances

Length (mm)	1160	+/- 1
Frequency (MHz)	1298.985	+/- 0.100

The first series production of three unstiffened ERL cavities at Cornell was completed some time ago. Each of the cavities did not meet the length or frequency tolerance. The results of the production can be seen in (Table 2). Each cavity was long, as well as low in frequency. Adjusting the frequency through the use of tuning served only to lengthen the cavities even further. In an effort to avoid a situation such as this in the second production series of three stiffened cavities, the previous production steps were analysed and a new strategy was formed.

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Table 2: Length and Frequency of Production Cavities

Pre-Tuning

	Length (mm)	Frequency (MHz)
ERL7-002	1161	1298.46
ERL7-003	1161.5	1298.459
ERL7-004	1160.7	1298.498

Post-Tuning

	Length (mm)	Frequency (MHz)
ERL7-002	1165.9	1297.462
ERL7-003	1163.9	1297.504
ERL7-004	1162.1	1297.541

RF AND MECHANICAL TOLERANCES AND GRADIENTS

The half-cell contour was designed using FEM to calculate the correct resonant frequency at 1.8 K under vacuum. The room temperature frequency at STP is then extrapolated from this calculation.

The half-cell contour, when combined with the end-groups, drives the overall cavity length. However, several manufacturing and processing steps can have an effect on either length, frequency, or both. For example, etching the cavity will drive the frequency of the cavity down, but has no consequence on the overall length. However, field flatness tuning can be used to adjust the frequency of the cavity while simultaneously changing the overall length of the cavity.

It is important to know how each process will affect both the frequency and length of a cavity. To do so, each process' "gradient" must be known. For example, the tuning gradient is 430 kHz/mm. This means tuning the cavity will change its frequency by 430 kHz for every on millimetre. Other gradients are shown in Table 3.

The trimming gradient is, perhaps, the most salient variable during production. This gradient was calculated

Table 3: Various Manufacturing Gradients

Dumbbell Trimming	5	kHz/µm
Etching	10	kHz/µm
Tuning	430	kHz/mm

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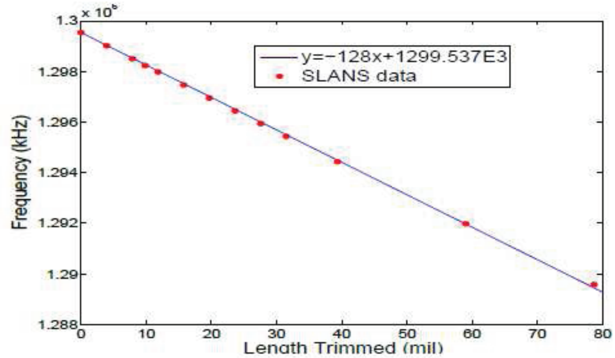

Figure 1: Calculated trimming gradient using the SLANS Code.

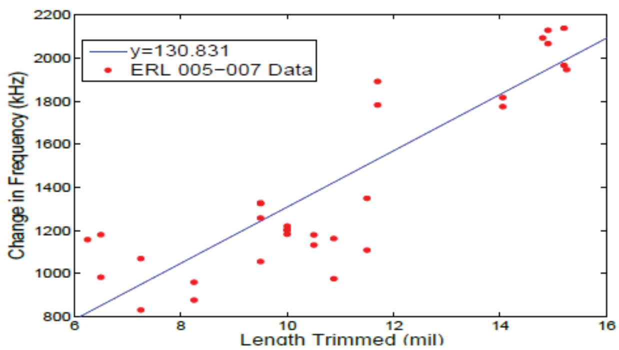

Figure 2: Measured trimming gradient using the newly designed dumbbell apparatus.

using SLANS and was found to be very linear (Fig. 1). Experimental trims of various dumbbells at various lengths confirmed this value (Fig. 2). The experimental trimming gradient is approximately 5.2 kHz/µm. This is within 1.5% of the theoretical value, giving good agreement between theory and experiment. The good agreement is partially due to the improved design for the RF measurement of the dumbbells which now ensures that the dumbbell does not deform under the load (see below).

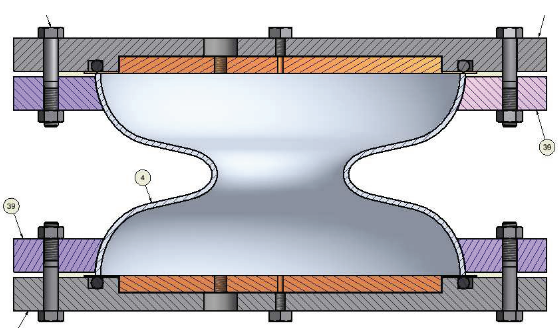

Figure 3: Improved dumbbell apparatus.

ROOT CAUSE OF FREQUENCY AND LENGTH DISCREPANCY

Before attempting to develop a protocol for frequency and length control during production, an effort to find the root cause of the discrepancy between the target cavity frequency and the manufactured cavity frequency was made. After many tests, it was determined that the fixture used to measure the resonant frequency of dumbbells reported an incorrect result. The original fixture, based on the JLab design [1,2], ensures adequate RF contact by pressing the dumbbell between two copper plates using a power screw. The middle of the dumbbell is unsupported. This can lead to a deformation of the dumbbell and subsequent shift in resonant frequency. To combat this problem, a new fixture was designed and constructed.

The revamped RF measurement fixture design was based off of the DESY design used for tesla cavities [3]. Figure 3 shows the new apparatus as built. Two aluminium plates are placed on the ends of the dumbbell. Inside these plates are copper RF contact plates. Aluminium plates are placed on the outer contour of the half-cells of each dumbbell. These plates are bolted to the equator plates for a good RF contact.

The middle plates in this fixture serve to brace the half-cells of the dumbbell so that adequate force may be applied to obtain a sufficient quality factor for measurement, while avoiding deformation of the half-cells.

LENGTH AND FREQUENCY CONTROL DURING THE SECOND SERIES PRODUCTION

During the second series of stiffened cavity production, the following quality control steps were applied:

- Coordinate measurement (CMM) of all half-cells in both untrimmed and trimmed states.
- CMM of untrimmed welded dumbbells.
- Frequency measurement of all dumbbells in the untrimmed state.
- CMM and RF measurement of all dumbbells after trimming.

Steps 1 & 2 were performed to verify all half-cell contours were within acceptable limits. Steps 3 & 4 were used to derive the cavities length and frequency.

To insure the cavity being produced would fall within both the frequency and length tolerances, the following algorithm was used:

$$\Delta L = d_{Trim} + d_{Tune} \ ,$$

$$\Delta F = d_{Trim} \times \Delta_{Trim} + d_{Tune} \times \Delta_{Tune} \ ,$$

where, d_{Trim} and d_{Tune} are the change in length due to trimming the dumbbells and tune the cavity, respectively. Δ_{Trim} and Δ_{Tune} are the trimming gradient and tuning gradient, respectively. Using these two equations, it is possible to find a solution that will yield the correct cavity length after frequency and length after trimming and tuning.

Table 4: Dumbbell Length and Frequency (untrimmed, upper table and trimmed, lower table)

Dumbbell	A	B	Frequency (MHz) A	Frequency (MHz) B	fpi (mean) (MHz)	Length (mm)
CC	79	83	1296.815	1296.782	1296.800	115.443
CC	86	98	1296.686	1296.864	1296.777	115.900
CC	78	81	1296.661	1296.706	1296.685	115.938
CC	97	101	1296.763	1296.852	1296.809	115.900
CC	104	108	1296.647	1296.924	1296.788	115.653
CC	111	113	1296.818	1296.738	1296.780	115.741

Dumbbell	A	B	Frequency (MHz) A	Frequency (MHz) B	fpi (mean) (MHz)	Length (mm)
CC	79	83	1298.635	1298.635	1298.635	115.443
CC	86	98	1298.635	1298.635	1298.635	115.900
CC	78	81	1298.635	1298.635	1298.635	115.938
CC	97	101	1298.635	1298.635	1298.635	115.900
CC	104	108	1298.635	1298.635	1298.635	115.653
CC	111	113	1298.635	1298.635	1298.635	115.741

SECOND SERIES PRODUCTION OF STIFFENED CAVITIES

Six dumbbells were selected for a prototype fabrication in the second series of cavity production (ERL7-005). These dumbbells are listed, along with their pre- and post-trimmed lengths in Table 4. (Note: weld shrinkage has been accounted for in the overall length calculation.) At the target frequency of 1298.985 MHz, each these dumbbells would be shorter than the target dumbbells length, adding up to a cavity that was too short, but at the right frequency. Figure 4 shows the variance in both frequency and length of the six selected dumbbells before and after trimming. The pre-trim dumbbells have some variance in both length and frequency, but this is to be expected, as no frequency control protocols have been applied yet. The post-trim dumbbells, however, are very close in frequency relative to one another, while varying in length by approximately 0.5 mm.

The dumbbells' target frequency was changed to 1298.635 MHz in an effort to correct the lack of length at

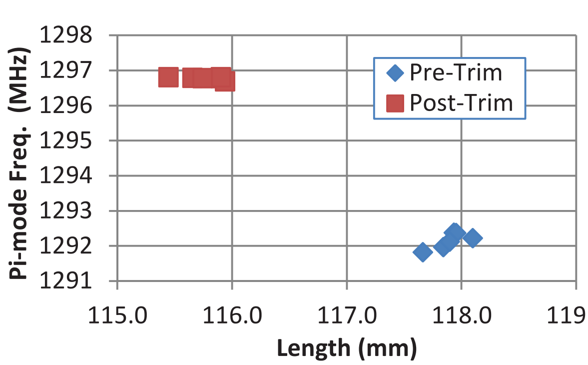

Figure 4: Variance of dumbbell frequency before and after trimming.

the correct frequency. By leaving an extra 0.7 mm per half-cell on each dumbbell after trimming, the resonant frequency of the cavity would be too low by 350 kHz, but the length would only be -+1.1 mm. It is assumed that, tuning the cavity by 350 kHz to the correct pi-mode frequency would lengthen the cavity by approximately 0.8mm, bring the finished cavity to the tolerable length, and correct frequency. (Note: The target length has been changed from 1160 mm to 1159 mm for this production series.)

CONCLUSION

Cavity ERL7-005 has just recently come off of the production line. ERL7-005's length is 1157.1mm and its' pi-mode frequency is 1298.259 MHz with 79% field flatness. This results differs from the predicted above. ERL7-005 is approximately 1.1mm too short in length (1157.1mm overall) and 400 kHz (1298.259 MHz) too low in frequency. The cause of this is still under investigation.

REFERENCES

[1] F. Marhauser, JLab SRF Cavity fabrication errors, consequences and lessons learned. JLab-TN-10-021, August 2010

[2] V. Shemelin, "Frequency Control in the Cornell-ERL Main-LINAC Cavity Production", Proc. of the 2013 Int. Conf. on Part. Acc., Shanghai, China (2013).

[3] G. Kreps, et. al. "Half-Cell and Dumb-Bell Frequency Testing for the Correction of the TESLA Cavity Length", Proc. of the 1999 Workshop on SRF, Santa Fee, USA (1999).

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