TUNING OF THE APS LINAC ACCELERATING CAVITIES AFTER STRUCTURAL RE-ALIGNMENT*

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Abstract

A new S-band LCLS type Photo-cathode (PC) gun was recently installed in the APS linac. As a consequence, it was recognized that many of the linac accelerating structures were out of their 1 mm straightness tolerance. In order to reduce the effects of wakefield on the beam and increase the quality of the beam transport, several of the misaligned structures were straightened. This paper discusses the bead-pull RF measurements, the effect of the straightening efforts on the rf performance and the cell-to-cell retuning efforts that were performed.

INTRODUCTION

To take full advantage of the improved beam quality produced by the new photocathode gun recently installed in the linac, an effort has been initiated to straighten the accelerating structures. Due to physical connections made to the structures in the APS tunnel, they were found to have been deformed by up to ~6 mm. Two of the thirteen structures in the linac and two spares have been straightened, at this time, with a worst-case of 5.4 mm total deformation [1] before straightening.

Initial mechanical straightening of the structures to within the ±200 µm specification resulted in significant impact on the rf properties of the structures. The most apparent impact was found on the input match which changed from –30 dB to –12 dB on the first structure. This effect was also closely related to the degradation of the cell-to-cell phase advance. The source of the degradation of the rf performance as well as the methodology used to measure and recover the structure for optimal operation will be discussed.

BEAD-PULL RF TUNING METHOD

A bead-pull method using a non-resonant perturbation algorithm [2] was used on the linac structures. With this approach, the complex electric field values were measured thereby accommodating field amplitude and phase advance calculations. Assuming a small perturbation (copper cylinder = 2 mm diameter x 5 mm length), the change in input reflection at the position of the bead is proportional to the sum of the square of the magnitude of the electromagnetic field components. Bead-pull algorithms such as this are commonly available for traveling wave accelerating cavities [3] as well as for deflecting cavities [4,5]. This method is capable of making amplitude and cell-to-cell phase measurements in real time for fast and accurate tuning of an APS linac accelerating structures shown in Fig. 1.

* Work supported by U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357.

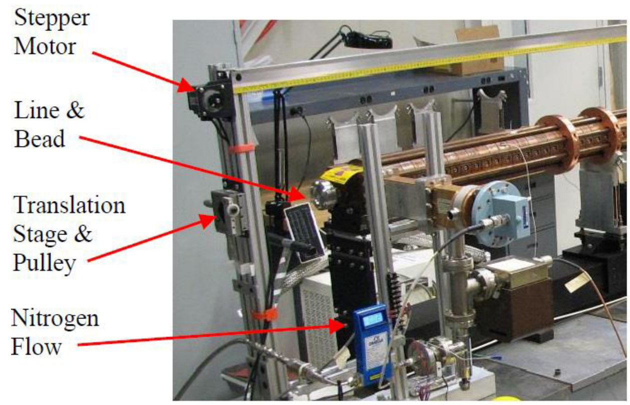

Figure 1: Linac structure with bead-pull setup.

The perturbing bead is supported on a 90 µm diameter nylon fish line and pulled through the structure using a servo motor which is controlled by a LabVIEW program. The bead is pulled at a constant speed with continuous data acquisition to quickly and efficiently measure each structure. Phase advance measurements were made using the electric field values at the same relative locations in each of the interior cells. These locations were determined by searching for the peak electric field value within a cell and performing a least squares fit to compensate for noisy data [4]. The phase advance of a given cell was calculated using the electric field in the current cell and in both neighboring cells.

The local reflection coefficients (LRCs) are derived from the electric field in each cell and are used to create a quantitative measure of the amount of tuning required in an individual cell to compensate for any deviation of the cell from the desired cell-to-cell phase advance. In effect, the LRC guides the extent of the deformation which needs to be applied to the tuning apparatus of each cell. Conveniently, the LRC is defined at each cell and can be referenced back to the global reflection coefficient measured by a network analyzer. The tuning of an individual cell can be performed by appropriately interpreting the global reflection coefficient and tuning only a moderate percentage (~40%) of the reflection at each cell. Tuning of the interior cells typically requires several passes over the entire structure to get it within specifications of 120° ±1°.

STRUCTURE STRAIGHTENING AND BEAD-PULL RF MEASUREMENTS

Before any tuning, the structure is mounted onto the strong back along with supports and saddles. The mechanical straightening process is performed by applying pressure on the structure at the four different support locations as shown in Fig. 2. The saddle's width is

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approximately the width of a single cavity cell and it is clamped to the structure at the top of the support. It straddles a cavity iris and, as a result, each one comes into contact with two cells. Given four supports, a total of eight cells are being affected during the process of straightening as transverse forces are applied to the saddles.

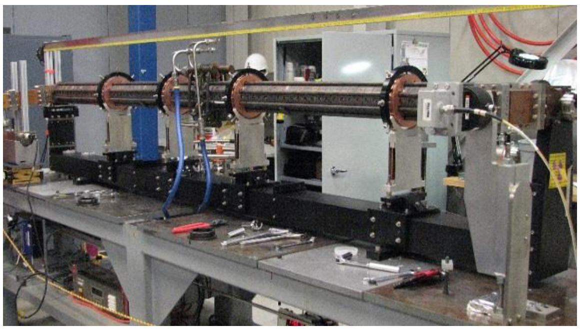

Figure 2: Linac structure with four support locations.

While bead-pull measurements are performed, the accelerating structures are held to a fixed temperature (115.5º F) with constant purging of dry nitrogen at a cavity frequency that was compensated for temperature and non-vacuum conditions. The field distribution including phase and amplitude is then measured before and after straightening. Figure 3 shows the results of the bead-pull measurements for structure SN 018. The phase advance is measured for all the interior cells of the 86 cell structure. The input and output coupler cells are handled separately.

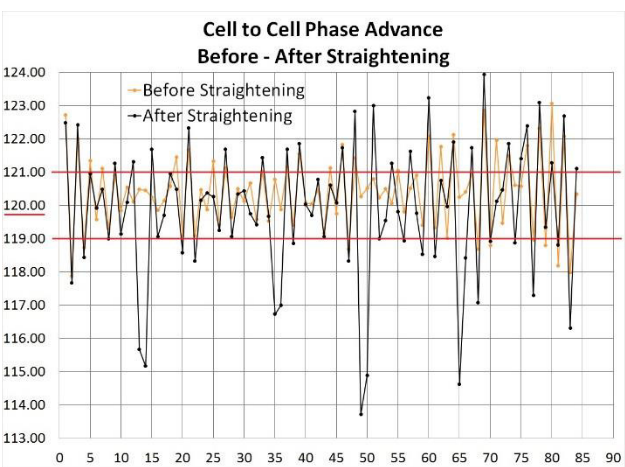

Figure 3: Phase advance before/after straightening.

It is clear from Fig. 3 that the cells in contact with the support saddles were strongly affected by the straightening process. From the figure, it is evident that cells 13, 14, 35, 36, 49, 50, 65, 66 were driven out of tune by the applied pressure required to bring the structure within the ±200 µm tolerance. The amount of change in phase, in some cases, is several times greater than the dynamic tuning adjustment range of the cell. The overall match of the structure also degraded after the straightening process from –25.2 dB to –14.8 dB.

TUNING RESULTS

After straightening, the phase advance was tuned for each of the interior cells using multiple iterations. Upon completion of the interior cells, the "output coupler" cell along with the last interior cell (prior to the output coupler cell) was not adjusted for phase advance but rather for the best E-field flatness. As a final step, the "input coupler" was adjusted to minimize the global return loss of the entire accelerating structure. Figure 4 shows the results of the phase advance before and after a full tuning of the structure was completed.

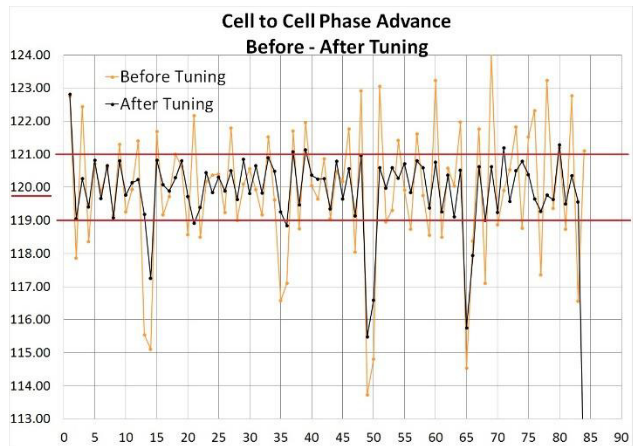

Figure 4: Phase advance before / after retuning.

Note that five of the eight cells that were affected directly by the straightening process at the supporting saddles exceeded the maximum tuning range of the cell and could not be brought to within specifications.

The E-field flatness in Figs. 5 and 6 is plotted before and after the tuning process for a typical structure. The more uniform fields are due to an overall improvement of the tune in the structure and in the final adjustment of the output coupler cells to macroscopically negate any remnant reflections. The tuning of the field flatness concluded once the maximum tuning range of the cells was reached.

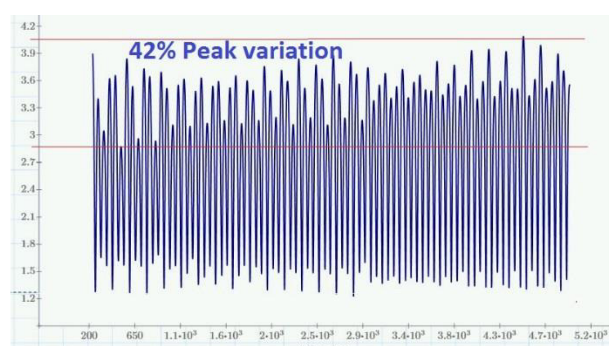

Figure 5: E-field flatness after straightening.

During the tuning process the E-field flatness was improved from ~42% peak variation to ~20%. The match improved from –14.8 dB in Fig. 7 to –27.8 dB in Fig. 8.

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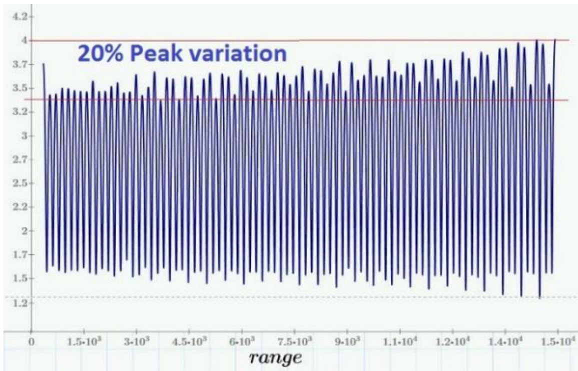

Figure 6: E-field flatness after retuning.

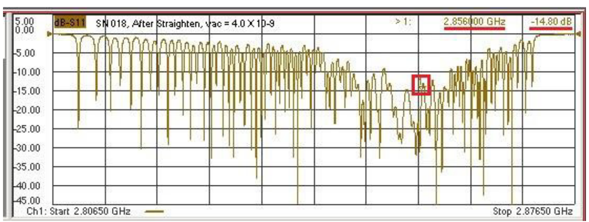

Figure 7: Return loss after straightening, –14.8 dB.

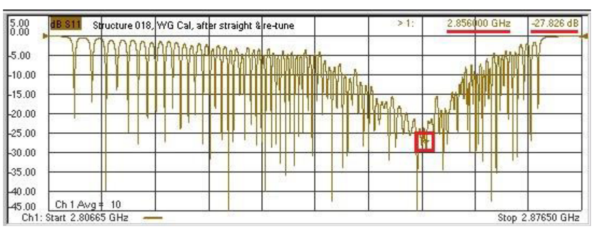

Figure 8: Return loss after retuning, –27.8 dB.

Clover Plot of Electric Field

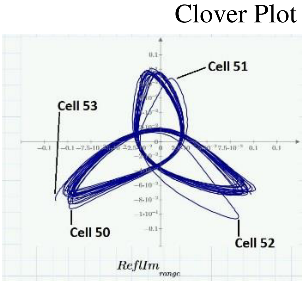

Figure 9: Cells 1 to 53.

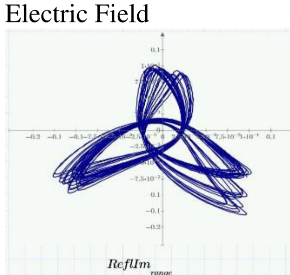

Figure 10: Cells 1 to 84.

Figure 9 shows the mistuning at cells 49/50 (start of degradation in the energy spread) and Fig. 10 shows the net result from all interior cells.

PLANS FOR IMPROVEMENT

To eliminate the detuning effects produced by the support saddles during the straightening process, new saddle designs are being manufactured to distribute the force of straightening the structure over a larger area. The new saddles are approximately two and four times the width of the current saddle shown in Fig. 11.

Intermediate bead-pull runs are now being planned to inspect the state of detuning of each cell near the saddles during the straightening process. If it is found that detuning is nearing the limits of a given cell, the support will be moved to a new location where the straightening process will continue. In this way, the wider supports as well as the relocation of supports will serve to redistribute the effects of straightening across multiple cells.

Figure 11: Original supporting saddle.

SUMMARY

The non-resonant bead-pull perturbation method has proven to be effective in retuning the accelerating structures after straightening to the 120° ±1° specification. However, it was found that the mechanical force required to straighten the structures to within ±200 µm has significantly detuned cells at each of the four supports. In some cases, the detuning is in excess of 5 times the tuning specification and exceeds the dynamic range of the adjustment for an individual cell. Two structures have been straightened, high power RF conditioned and are now being used in the APS Linac Operations. New saddles are being fabricated to reduce the detuning effects during the straightening process which will insure the structure remains within the specified retuning range.

ACKNOWLEDGMENTS

The authors would like to thank Roy Agner and Tim Jonasson for performing many bead-pulls and the development of new tools needed for structure tuning.

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