STRAIGHTENING OF APS LINAC ACCELERATING STRUCTURES UTILIZING A PORTABLE ARTICULATING ARM CMM

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Abstract

The Advanced Photon Source (APS) linear accelerator system (LINAC) utilizes 3-meter long SLAC-type 2856 MHz accelerating structures. Surveys of the APS LINAC indicated deformation in the straightness of the accelerating structures over time, with 7 mm of sag detected in the worst case. A long-term project to straighten the accelerating structures, swapping them out one-by-one and straightening those removed, was implemented. The straightening is intended to improve charge transportation efficiency and minimize wakefield effects in the structures. The first straightened structure was installed in January 2016, and the swaps will continue until all 13 APS LINAC accelerating structures have been straightened. A portable 3-D articulating arm CMM (PCMM) is utilized accomplish the straightening of the structures to a tolerance of +/- 200 μm over the length of the accelerating structure. Techniques used at the APS to straighten the LINAC accelerating structures and the results achieved are presented.

BACKGROUND

A survey of the APS LINAC performed in June 2013 revealed deformation in the straightness of the accelerating structures. In the worst case a vertical sag of up to 7 mm was detected, as indicated in the Figure 1 graph. The discovery of accelerating structure deformation prompted an initiative to straighten the devices in an effort to improve overall performance of the APS LINAC in anticipation of the APS upgrade.

Similar work was undertaken in 2013 at the SLAC National Accelerator Laboratory (SLAC) in an effort to improve performance of the Linac Coherent Light Source (LCLS). [1] The process and hardware developed at SLAC were adopted for straightening the nearly identical APS accelerating structures. Measurement of straightness at SLAC was accomplished using a large bench coordinate measurement machine (CMM); however, this type of CMM is not available at APS. Instead, a PCMM arm was selected. The PCMM has 2 sigma accuracy of 25 μm, sufficiently accurate to achieve the specified tolerance for straightness of +/- 200 μm over the length of the accelerating structure. The SLAC design of the strong-back support and halo adjustment system were adapted to fit the APS structures.

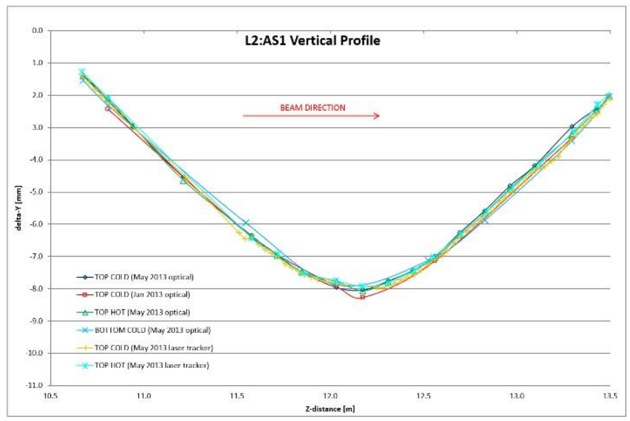

Figure 1: Accelerating structure L2-AS1; worst-case vertical profile measured in June 2013

PROJECT

In 2015 a long-term project to straighten the APS LINAC accelerating structures, swapping them out one-by-one and straightening those removed, was implemented.[2] The project is expected to take approximately 4 years, at a rate of about 3 structures per year. The straightening is intended to increase LINAC performance in anticipation of the coming APS Upgrade. Additionally, in order to take full advantage of the high quality beam produced by the new APS photocathode RF gun, the LINAC structures must be aligned to +/- 200 μm. Improvements to alignment should diminish transverse wakefield effects, reducing emittance enlargement of the beam during acceleration to ~400 MeV. The first structure to undergo straightening was not installed due to degradation of tuning. The second straightened structure was installed in the APS LINAC in January 2016. The Third straightened structure, installed in May 2016, failed due to arcing as a result of field emission effects that are not believed to be related to the straightening process or retuning, and was replaced in August 2016 with the fourth structure to undergo the process.

PROCESS

The process adopted at the APS to straighten the LINAC structures utilizes hardware developed at SLAC, and a measurement procedure developed at APS.

Setup

Prior to measurement and straightening, an accelerating structure is mounted to a strong-back support that is rigidly secured to a steel work table. The upstream end of the accelerating structure is fastened to a fixed, rigid support, while the downstream end is fastened to an adjustable, flexible support to allow for expansion in the Z direction. The ends of the accelerating structure are nominally levelled to a gravity reference using a precision optical level. Baseline measurement is performed prior to installation of flexible intermediate supports.

Figure 2: PCMM arm set up to measure an accelerating structure

Baseline Measurement

A baseline measurement set is recorded to establish the magnitude and direction of deformation in the straightness of the accelerating structure. Measurement is performed using a PCMM arm in conjunction with 3-D industrial coordinate measurement software. Figure 2 is a photograph of the PCMM arm set up to measure an accelerating structure. The baseline measurement procedure is described as follows:

- A nominal gravity plane, established on the work bench using a precision optical level, is recorded.
- Projection planes, normal to the Z-axis (beam centreline), are established through the centre each individual cell.
- Circular fit measurements are recorded using the PCMM for all 84 cells, with 8 individual points measured around each cell. Circles are projected on to the previously established projection planes at the centre of each cell. A complete measurement set requires 2 instrument stations to accomplish.
- A best-fit line is established though the measured cell centres, and a query between the centre points and line is computed. An example of a baseline measurement set is shown in figure 3.

Baseline measurements after removal from the LINAC showed a slight improvement compared to the 2013 survey data.

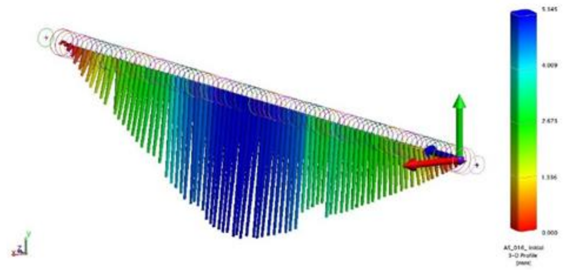

Figure 3: 3-D profile of accelerating structure baseline measurement set recorded prior to straightening

Straightening

Intermediate flexible supports with the adjustment halos and copper saddles are located and installed according to the baseline measurement results, accounting for space constraints due to quadrupole magnet locations. The saddles are carefully tightened to avoid detuning of the structure. Figure 4 shows an image of a halo adjuster with a load collar. Coarse adjustment is accomplished using threaded rods located where the base of the support attaches to the strong-back. Fine straightening is accomplished by iteratively adjusting the halo push screws, utilizing feedback from the PCMM, until +/- 200 μm straightness tolerance is achieved. Straightening measurements are focussed on adjustment points and mid-points along structure. It is not necessary to monitor the position of every cell during the straightening process. Numerous adjustment and measurement iterations, as many as 10, are necessary to achieve the desired straightness tolerance. Large, initial moves are relatively easy; however fine-adjustment becomes increasingly difficult. Straightening of a structure takes 2 to 3 days of effort to accomplish.

Figure 4: Halo adjuster and saddle used to straighten APS accelerating structures

Reporting

Once an accelerating structure has been straightened within the required tolerance, a complete measurement report including all 84 cells is recorded. The report data also serves as fiducial information for subsequent alignment in the APS LINAC. An example of an accelerating structure post-straightening profile plot is depicted in Figure 5.

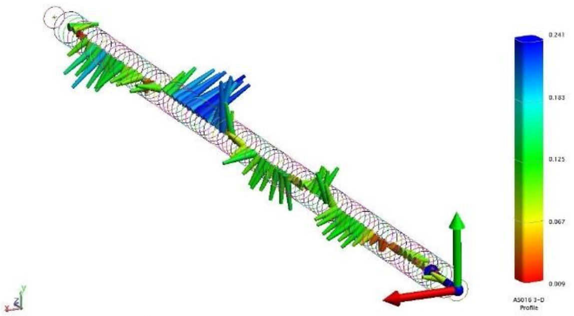

Figure 5: 3-D profile of accelerating structure post-straightening.

Installation and Alignment

After an accelerating structure has been straightened it is scheduled to be swapped out with a deformed LINAC structure during the next maintenance period. A deformed structure is removed from the LINAC, and a modified mounting pattern is laid out and drilled in the support table. The straightened structure is then installed, and utilizing information recorded in the straightening report the best-fit centreline of the structure is aligned collinear with the LINAC beam axis. Figure 6 is a photograph of the first straightened APS accelerating structure to be reinstalled in the LINAC.

Figure 6: First straightened accelerating structure reinstalled in the APS LINAC

RESULTS

As of this writing 4 of the 13 accelerating structures have undergone the straightening process, and two have been successfully installed and are in operation. Initial results are promising and indicate that the specified tolerance can be met. An example of the results achieved using the straightening process is shown in Table 1.

Table 1: Example of measured results after straightening

Statistic	dX [mm]	dY [mm]	Mag [mm]
Min	-0.194	-0.164	0.011
Max	0.124	0.129	0.195
Average	0.000	-0.001	0.094
RMS	0.077	0.070	0.104

Structure 1 was not installed due to degradation of tuning. Structure 2 is in operation. Structure 3 failed due to arcing as a result of field emission effects not related to the straightening process or retuning. Structure 4 is in operation, but the tolerance was exceeded as a result of vacuum bake out. A before and after comparison of the structures straightened thus far is shown in Table 2.

Table 2: Before and after comparison

Structure	Straightness Before	Straightness After
1	+/- .98 mm	+/- 0.14 mm
2	+/- 1.2 mm	+/- 0.17 mm
3	+/- 2.7 mm	+/- 0.18 mm
4	+/- 1.9 mm	+/- 0.36 mm*

*0.26mm after straightening, 0.36mm after vacuum bake

CONCLUSION

Four APS accelerating structures have been successfully straightened utilizing the process described herein. We are confident the mechanical and metrology methods are sound, and look forward to completing the project over the next 3 to 4 years. Although it is too soon to report, the work described here should produce measurable improvements to electron beam quality in the APS LINAC.

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