TRANSVERSE CAVITY TUNING AT THE ADVANCED PHOTON SOURCE

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Abstract

A 15-cell transverse deflecting cavity based on a SLAC design was fabricated at the Advanced Photon Source and is being prepared for installation into the linac. A beadpull method for tuning was selected in lieu of the nodal position method to minimize the possibility of contamination and surface damage to the irises. The process has been successfully documented for accelerating mode structures, but there has been limited application to dipole mode cavities. In this paper, we will discuss the methodology for tuning the 2.856 GHz backward-traveling-wave deflecting cavity.

INTRODUCTION

In December 2014, a low-emittance photocathode gun [1] was installed in the front end of the APS linac. It was commissioned to 12 MW full power with a 2.5 µsec pulse length at 30 Hz. An additional effort has been undertaken to remove a gravity-induced sag in the original accelerating structures in the linac to maintain the beam quality as it is transported through the linac. To assist in the evaluation of the final beam characteristics, a transverse-deflecting, T-cavity, shown in Fig. 1, will be installed downstream of the accelerating cavities in May, 2016. The beam will be transversely deflected by the driven dipole mode where beam parameters will be evaluated including the bunch length, normalized beam emittance, average energy, as well as the time-dependence of the energy spread of the beam.

BEADPULL TUNING

Non-resonant beadpull tuning was proposed at Desy [2] as an alternate method to the more invasive nodal shift technique [3]. It is based upon a non-resonant perturbation algorithm where the complex-valued electric field is measured at intervals along the structure [4]. Beadpull algorithms are commonly available for traveling wave structures for accelerating cavities [5]. However, accommodations must be made for a deflecting cavity [6] due to the differences in the field distribution of the dipole mode. As a result of the magnetic coupling between cells, additional consideration must be made for the backward traveling wave nature of the T-cavity.

The electric field, Ez, is calculated in each cell using the non-resonant method described by Steele [4]:

$$E_z^2 = k * (S11_p - S11_u) \tag{1}$$

where k is dependent upon the frequency, power input, and geometry of the bead. $S11_u$ is the baseline return loss with no bead in the cavity, and $S11_p$ is the perturbed return loss with a bead located inside the cavity. Measurements of the relative electric field level from eqn. (1), without knowledge of the factor k, are sufficient for using the beadpull method.

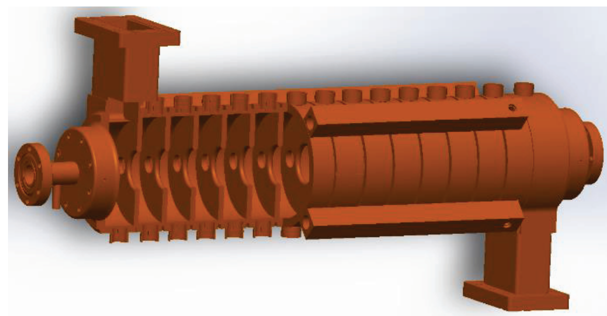

Figure 1: Backward-traveling-wave deflecting T-cavity with two tuning pins for each cell.

The calculation of the phase advance between cells requires the complex-valued electric field in the current cell and in each neighboring cell [7]:

$$\varphi_{measured} = \text{acos}\left(\frac{E_{z+p}+E_{z-p}}{2*E_z}\right) \tag{2}$$

where E_z is the electric field at location z, and p is the periodic distance to the neighboring cells.

Once the electric field values are measured, the associated local reflection coefficients (LRCs) are calculated and used to determine the extent of the mistuning of each cell due to manufacturing tolerances. To the first order, only the imaginary part of the LRC is necessary to tune any geometric imperfections and is used to guide the tuning process by quantifying the magnitude and direction.

The formula for the LRC, shown in eqn. (3), accounts for the backward traveling wave nature of the T-cavity. It is valid for the interior cells, only, since the formulation requires the electric field values in the prior and following cells. The LRC at a single cell can then be related back to a physically measureable global reflection coefficient acquired by a network analyzer at the input to the power coupler. The equation for the global coefficient in eqn. (4) accounts for the two-way ohmic transit losses of the locally reflected signal:

$$\Gamma_{n(local)}^{int} = \frac{E_{z-p} - 2\,E_z\cos(\varphi) + E_{z+p}}{E_z e^{j\varphi} - E_{z-p}} \tag{3}$$

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$$\Gamma^{int}_{n(global)} = \Gamma^{int}_{n(local)}\, e^{-2\alpha_d l} \qquad (4)$$

where $\boldsymbol{\varphi}$ is the desired phase advance, n = 2 … N-1 are the interior cells of an N-cell cavity, l is the distance from the current cell through the output coupler cell, and α_d is the attenuation constant representing the ohmic losses.

Since the global reflection coefficient is only an estimate of the total tuning and is also weakly dependent upon the tuning of nearby cells, the current cell is tuned such that the change in the measured reflection coefficient, before and after tuning, is some percentage of the global coefficient. As a result, complete tuning of the interior cells of the cavity is done using multiple passes over the structure.

After the interior cells are tuned, any remaining reflections spanning the length of the cavity are, in theory, due entirely to the output structure of the cavity. These reflections are evident as field variations in the magnitude of the electric field measurements from cell-to-cell. To compensate for the mismatch in both the output coupler cell and the matching iris to the power coupler, two cells at the output end of the cavity are typically tuned in tandem. In this case, reflection coefficients for the end cells are calculated with the objective of cancelling reflections, not to tune the cells for phase advance but to achieve field flatness.

A general description of the methodology for tuning the output cells is found in reference [6]. However, to accommodate a backward-traveling-wave deflecting cavity, the local reflection coefficient for the output cells, N-1 and N, is shown as follows:

$$\Gamma^{out}_{N-1(local)} = -\frac{\alpha}{\tan(2\varphi)} - \beta \qquad (5)$$

$$\Gamma^{out}_{N(local)} = \frac{\alpha}{\sin(2\varphi)} \qquad (6)$$

where $\Gamma^{int}_{N-1(local)} = \alpha + j\beta$. Note that the N-1[st] cell is defined twice, once as an interior cell and again as an ensemble with the output coupler cell. This cell is tuned the second time based on the local reflection coefficient defined in eqn. (5) where an adjustment must be made for ohmic losses similar to eqn. (4). As a final step, the input coupler cell is simply tuned to minimize the overall return loss of the cavity.

To accelerate the tuning process, a bead was pulled through the cavity using various algorithms. A servo motor was controlled by a labview program to pull the bead on a 2# nylon fish line. The most accurate measurements consisted of lengthy runs where the bead traversed the cavity in small, discrete steps. Identical, relative positions were found in each of the interior cells by determining the peak electric field value after performing a least squares fit of the data. More rapid data collection was employed while the cells were actively being tuned by either running the bead at a constant speed with continuous data acquisition or by taking a minimal number of samples at large discrete steps at each of the peak field values from one cell to the next.

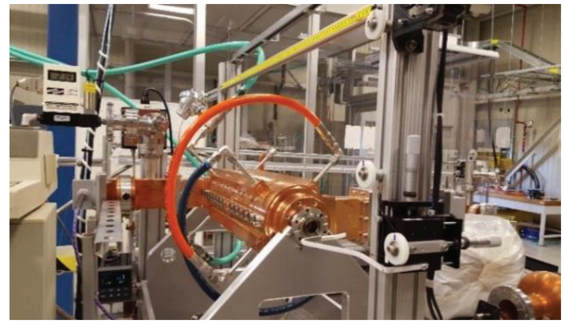

Figure 2: T-cavity tuning setup.

TUNING RESULTS

The tuning setup for the T-cavity is shown in Fig. 2. The cavity was maintained at a fixed temperature with constant purging of dry Nitrogen while tests were performed. A labview program controlled the rate of data acquisition and provided regular feedback of the tuning parameters. Frequency compensation for the temperature and non-vacuum environment was adjusted using the formulas presented in [8].

It was found that minimal response, on or off-axis, was acquired with a 2 mm O.D. x 5 mm long copper bead that was customarily used for accelerating mode cavities. Due to the modal difference in tuning a deflecting cavity, a high permittivity, high density 8.5 mm O.D. x 7.3 mm long alumina ceramic disk from Ortech Ceramics was used as an alternative and produced repeatable results.

The ceramic disk created maximum perturbation at the irises due to the strong transverse electric field of the dipole mode. As a result, electric field values used in calculating the tuning parameters were measured at the irises, rather than the center of the cells. Therefore, the calculated parameters were a compilation of the properties of the two neighboring cells which shared the iris. Due to this, an error in the tuning of each cell may be introduced from offsetting effects of the measured value of the LRC from neighboring cells. For example, the LRC may be zero at a shared iris if neighboring cells are equally, but oppositely mistuned, which does not preclude the possibility that the cells are significantly out-of-tune. In other words, minimizing the LRC is necessary, but not sufficient for tuning a dipole mode cavity.

Preliminarily, the LRC measured at a given iris in the T-cavity was divided between neighboring cells and both cells were tuned equally until the desired reduction in LRC was achieved. Tuning progressed to the next iris where neighboring cells were tuned, again using half the

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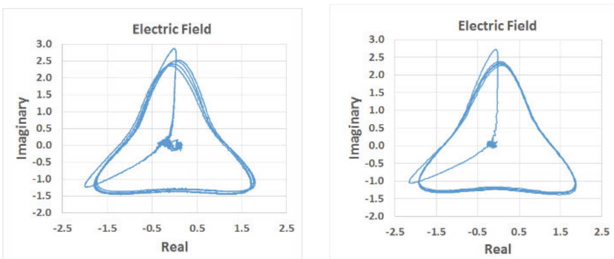
value of the LRC. Since neighboring irises shared a common cell, the LRC at the previously tuned iris may be de-tuned due to tuning of the current iris. However, this was not compensated until a future iteration. Tuning continued until all interior cells were completed. The process is repeated until specifications have been met to reduce errors from manufacturing tolerances and to reverse the effect of detuning the cells.



(a) (b)

Figure 3: Plots of the complex-valued electric field: (a) cavity tuned such that LRC is reduced to specifications and (b) cavity fine-tuned to compensate for unequal tuning of neighboring cells.

At the completion of the tuning process, it is possible that the cells may still be out-of-tune. As stated earlier, the neighboring cells of an iris may have offsetting effects. Figure 3(a) shows a subtle, but clear deviation of the electric field from the ideal which may or may not exceed specifications. Any shift in the clover from a perfect overlay is due either to phase errors between cells or lack of field flatness. On a simplistic level, field flatness is evident primarily as radial variations of the clover, while phase errors were prone to exhibit more azimuthal variations. Fine tuning was achieved in Fig. 3(b) by noting the irises which deviated most significantly from clover overlay. The neighboring cells were slightly retuned to determine which was most responsible for any deviations.

The final results of the tuning are shown in Figs. 3(b) and Fig. 4. The return loss improved from -13.6 dB to -18.3 dB after final tuning with a phase advance that spanned within ± 0.5°. The field flatness, on the other hand, did not achieve optimal magnitude as shown in Fig. 4(b). Only two tuning pins were available and had reached their perceived maximum extents. In the interest of preventing a possible mechanical failure and since the cavity was not operating at high gradients, further output cell tuning for field flatness was not pursued.

CONCLUSION

A deflecting T-cavity will be installed in the APS linac in May 2016 to characterize the beam parameters from the recently installed PC gun. It has been tuned for field flatness and 120° phase advance with ± 0.5° variation. A non-resonant beadpull method was used to perform the tuning using an automated labview software setup. Since the cavity operates in the dipole mode, existing algorithms were modified to account for the deflecting mode and to accommodate the backward-traveling-wave properties of the cavity.

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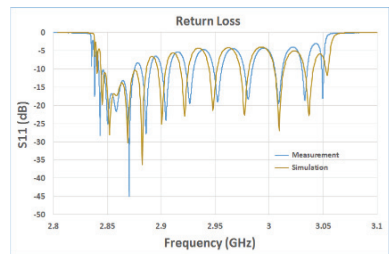
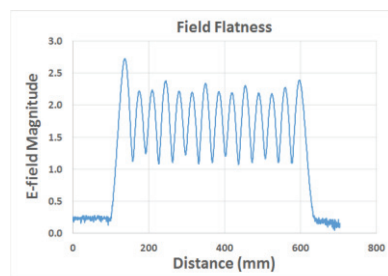


(a)



(b)

Figure 4: Final tuning results: (a) measured and simulated return loss and (b) field flatness.

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