CONSTRUCTION AND TESTING OF THE DUAL SLOT RESONANCE LINAC∗

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Abstract

The dual slot resonance (DSR) linac is a novel method of providing enhanced coupling to a coupled cavity linac system, resulting in very strong coupling. For the 11-cell, 2856 MHz structure described here, the acceleration mode bandwidth is about 650 MHz, which is an order of magnitude greater than many traditional side-coupled and axis-coupled linacs. The strong coupling promotes phase and amplitude stabilization, and offers decreased sensitivity to fabrication errors. We describe the construction, tuning, and RF conditioning of the prototype structure.

INTRODUCTION

The basic concept of the DSR linac was reported in [1], and that article contains a more in-depth explanation of this linac type. FAR-TECH was granted a patent for this technology [2]. The geometry of a pair of linac cells is shown in Figure 1, which shows a half-geometry of the vacuum region inside the linac structure. A group of two resonant slots connect two adjacent linac cells through an intervening swept triangular volume which we refer to as a “void”. The void region serves to provide RF coupling between the two slots. Each group of two slots has two collective resonant modes: a mode at around 1 GHz, and the working mode at the target operating frequency of 2.856 GHz. The mode split between these collective modes is so large that the pair of slots can effectively be considered a single oscillator at 2.856 GHz. The two slots serve the same purpose as a coupling cell in a side coupled linac. The advantages of the DSR linac include: a very large coupling with about 22% bandwidth, a compact geometry, no additional radial space required for the coupling cells, and shunt impedance competitive with a side-coupled linac. Simulations with HFSS [3] and with Omega3P [4] predict a shunt impedance $ZT^2$ of 85 $\text{M}\Omega/m$. This is competitive with other linac designs featuring large coupling such as the PWT design [5], and is slightly less efficient than an equivalent side-coupled linac, which might have about 8-10% higher $ZT^2$ with the same basic cavity and nose cone shape. The linac is designed for the UCLA Pegasus laboratory to aid in ultra-short electron bunch experiments [6] by boosting the beam energy by a design 10 MeV. The linac can also be operated in bunching phase, which will further shorten the bunch length and enable better resolution for experiments such as electron diffraction studies. It is hoped that the DSR linac design will also find uses in industrial and medical applications.

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dependent studies simulating the RF fill transient, as well as steady-state field balance sensitivity studies, reveal that a larger stop band, beyond 10 MHz, does indeed start to affect performance.

Construction

The copper components for a half cell were made with a combination of lathe and 5-axis milling processes, which is more complicated than what is required for other linac types. We estimate that components for this linac type are 50-100% more expensive to machine than for conventional linac types, but this added cost is only a small fraction of the overall cost of producing the structure, and is offset by the simplified tuning method discussed below. Figure 3 shows a finished half-cavity part. The full linac was brazed with Au/Cu alloy in a dry hydrogen atmosphere using three braze steps.

TUNING AND BEAD PULL

The purpose of bead pull and structure tuning is to close the dispersion curve, achieve the correct operating frequency, and properly balance the field gradient in each cell. Tuning steps were interspersed with bead pull measurements and data fitting to a matrix model. A matrix description used one oscillator for each linac cell and one oscillator representing the collective mode of a pair of slots. The full eigenvalue equation has the form:

\[ \mathbf{M} \mathbf{V} = \frac{1}{f^2} \mathbf{V} \]

with \( \mathbf{V} \) describing the voltage in each oscillator, and \( \mathbf{M} \) for an example five-oscillator system is given by:

\[
\mathbf{M} = \begin{bmatrix}
\frac{1}{f_1^2} & k_{ac} & k_{aa} & \frac{1}{f_2^2} & 0 \\
\frac{k_{ac}}{f_1^2} & \frac{1}{f_2^2} & 0 & \frac{k_{ac}}{f_3^2} & 0 \\
k_{aa} & 0 & \frac{1}{f_3^2} & 0 & \frac{k_{aa}}{f_4^2} \\
\frac{k_{ac}}{f_1^2} & \frac{k_{ac}}{f_2^2} & 0 & \frac{k_{ac}}{f_3^2} & 0 \\
\frac{1}{f_2^2} & \frac{1}{f_3^2} & 0 & \frac{1}{f_4^2} & \frac{1}{f_5^2}
\end{bmatrix}
\]

where the matrix for the full 21-oscillator system follows the same pattern, \( f_i \) is the natural frequency of the \( i^{th} \) oscillator, \( k_{ac} \) is the coupling coefficient from the cell to the coupling slots, and the remaining coupling terms are the next nearest neighbor coupling terms from one accelerating cell to another \( (k_{aa}) \) and from one set of coupling slots to another \( (k_{cc}) \).

The tuning procedure is significantly different for the DSR structure than for a conventional side-coupled structure. Adjustments made to a single slot in a two slot system are capable of adjusting the field balance of the structure, and these adjustments can be performed after the final braze. The effect of such tuning is shown in Figure 4, which shows the slope of the before and after plots to be mostly consistent, except between cells 7 and 8 where the adjustment was made. Adjustments to both slots also have an effect on the resonant frequency of the surrounding cells, and can be used to tune the structure frequency as a whole, as long as the dispersion curve tolerance is adhered to. Although the structure was built with dimple tuners in each cell and deformable wall push-pull tuners at the end cells, these did not have to be used to arrive at the final tune, and all tuning was performed entirely by slot adjustments. The tuning method consisted of tightening a two-piece aluminum collar around the linac while monitoring the mode frequencies. In the final field balance measurement, all cells were within ±1.9% of the average. The dispersion curve was closed to within 400 kHz, much better than the initial goal.

We believe this tuning method, together with relaxed tolerances afforded by the large bandwidth, can simplify the production of a DSR linac structure. RF measurements of the as-machined half cell components were consistent enough that we believe it may be possible to machine the components to their net final shape in one machining pass with no additional tuning cuts. It may also be possible to eliminate any stack-up and bead pull tests performed ahead of the brazing operation. In this scenario, the only difficult stage would be the final tuning, which can be guided by a computer model.

POWER DISTRIBUTION

For the installation at the Pegasus laboratory, we have acquired or built the major waveguide components to distribute the power to the linac, including a high-power phase shifter, directional coupler, power divider, and several adapters between different flange types. The power divider, shown in Figure 5, was designed and built by F AR-TECH following the idea of the variable tap-off (VTO) device developed for ILC [7]. The device has four waveguide ports including an input port, an isolated port, and two output ports. In order to change the power split, the fastening bolts must be loosened and the central cartridge rotated to the new position. The device was designed for infrequent changes to the power ration, as the adjustment also de-pressurizes the SF\(_6\)-filled waveguide. A challenge for the power divider RF design was to optimize the RF
CONCLUSIONS

We have conceptually developed, built, and tested a linac structure based on dual slot resonance coupling. The linac was installed at the Pegasus laboratory at UCLA, where it is used to boost the beam energy and perform velocity bunching to achieve < 100 fs bunch length for ultrafast electron diffraction microscopy applications. The new linac design is more compact than a side-coupled structure and the large bandwidth, combined with the unique properties of the structure, results in simplified manufacturing.

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REFERENCES