DEVELOPMENT OF THE DUAL-SLOT RESONANCE LINAC*

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Abstract

We present the development of a novel electron accelerating structure with strong cell-to-cell coupling. The coupling is provided by a pair of resonant slots, separated by a non-resonant void region, located within the wall between adjacent cells. The 10+2/2 cell standing-wave structure, operating in a phase and amplitude stabilized π/2 mode, will provide an energy gain of 10 MeV.

INTRODUCTION

The dual slot resonance linac (DSRL) [1] is an adaptation of the patented slot resonance linac (SRL) [2] designed for use as an electron linac with β~1. An S-band prototype structure capable of providing 10 MeV energy gain is being designed and constructed for installation at the UCLA Pegasus laboratory The SRL design adjacent cavities are coupled using resonant slots as shown in Fig 1. The advantages of a DSRL structure include: 1) the losses associated with the resonant slots is smaller than for an equivalent side coupled linac case, 2) the slots do not increase the number of parts required to make the structure, and 3) the small radial size allows for greater flexibility in placing magnetic elements around the structure. This design creates a structure that provides around 30% coupling between cells. This large coupling allows for reduced manufacturing tolerance or the fabrication of a much longer structure.

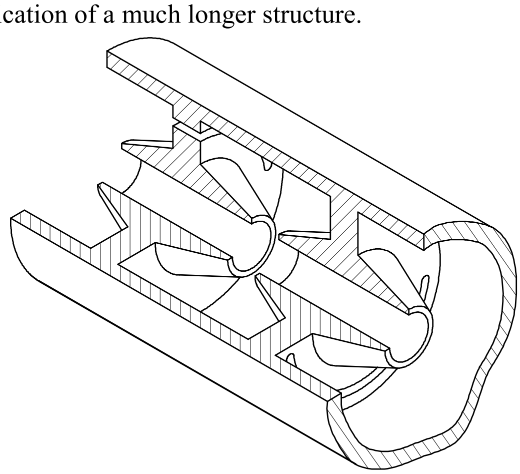

Figure 1: Slot resonance linac structure. Each slot extends nearly 180° in azimuth.

An important feature of the SRL design is a geometric sign change introduced in the coupling when compared to a side cell. In the resonant slot, the electric field is oriented along the height of the narrow slot and the magnetic field pattern wraps around the electric field in the middle of the slot. It has opposite direction at either end of the slot where it couples to the on-axis cavity. By comparison, a side coupled linac exposes each adjacent on-axis cell to coupled magnetic field vectors that point in the same direction. The result of this field reversal in the resonant slot is an accelerating field pattern where the electric field has 0° phase advance between adjacent on-axis cells when driven in an electric π/2 mode in which the slots are not energized. This feature makes the SRL an attractive accelerator for low velocity particles (0.2≤β≤0.4) but diminishes the efficiency of acceleration for faster particles.

DUAL SLOT RESONANCE LINAC

The DSRL overcomes the low velocity requirement resulting from the geometric sign change by replacing the single slot with a pair of strongly coupled slots. One slot couples the accelerating cavity to a small void and the second slot couples the other side of the void to the next accelerating cavity as shown in Fig 2. By choosing the correct collective mode of the coupled resonant slots an additional sign change is introduced that allows for an on-axis accelerating field that has 180° phase advance between adjacent on-axis cells when driven electrically as a π/2 mode in that the two slots are effectively unexcited. The use of small non-resonant voids results in a structure that is radially compact.

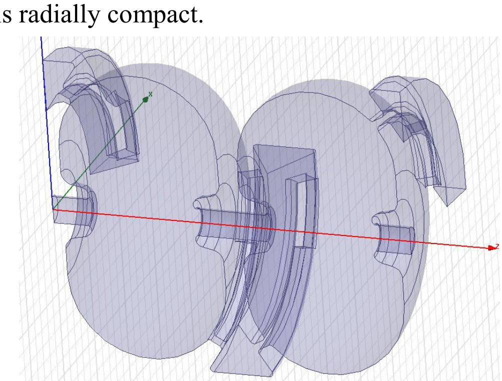

Figure 2: Dual slot resonance linac. Slots and void are not fully rounded in the HFSS model.

Collective Slot Modes

The dual resonant slots coupled by the void acts as a system of two strongly coupled oscillators. These degenerate oscillators will split into two eigenmodes. An HFSS [3] simulation result for the lower frequency (symmetric) mode is shown in Fig 3a. The higher frequency (anti-symmetric) slot mode is shown in Fig 3b.

The symmetric mode suffers some undesirable features. As can be seen on Fig 3a, it has electric field overlap with the cavity mode which would result in additional RF losses. In this mode, the magnetic field couples directly between the two slots making them behave like the single

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slot in the SRL design with respect to the magnetic field coupling. This means that there would only be a single geometric sign reversal and the associated coupling would result in an accelerating field pattern where the electric field has 0° phase advance between adjacent on-axis cells, analogous with the SRL. The anti-symmetric mode introduces an additional sign change between the fields in the two slots. This additional sign change, combined with the geometric sign change associated with the use of the resonant slots results in the desired accelerating field in the on-axis cavities that resembles a standard π-mode. Thus, the higher frequency, anti-symmetric, collective slot mode is desired. The ratio of the slot anti-symmetric frequency to the symmetric frequency is almost 2:1. Therefore, the symmetric mode should not interfere with any nearby cavities which are tuned to the same frequency as the anti-symmetric mode.

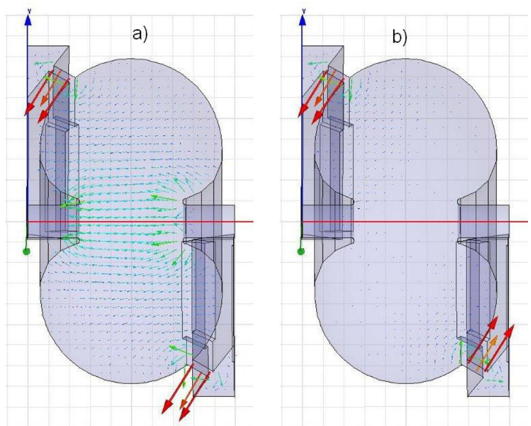

Figure 3: Slot modes of the DSRL with a) showing the lower frequency, symmetric mode and b) showing the higher frequency anti-symmetric mode.

In understanding the mode structure of the accelerator as a whole, the dual slots with their non-resonant coupling void can be considered as a single oscillator, hereafter simply referred to as "the slots", which may have many other modes in addition to the operating mode. This conventions makes for easier understanding where this coupled resonant slot system serves the same purpose as the side cavity in a side coupled linac.

Cell Design

Fig 2 shows the half model geometry for 2 full cells with the parting line at the mid-plane of a void. The slots extend 180° azimuthally with the ends wider to increase the coupling. The two slot faces are parallel and are oriented at 30° from the beam axis. The void region extends further in the azimuthal direction to allow for machining access and to improve coupling between the slots. The orientation of each successive slots/void set are rotated 180° around the beam axis to minimize the effect of the magnetic field perturbations caused by the coupling to the slots. This orientation of the slots will also reduce the impact of the next nearest neighbor coupling of the slots on each side of the cavity.

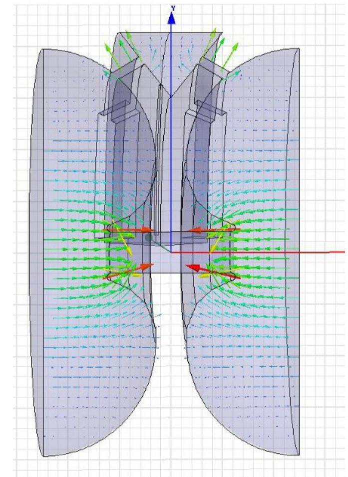

Figure 4: Accelerating mode of the DSRL. The electric field in the slot region is the parasitic coupling to the symmetric slot mode and results in RF losses. The anti-symmetric mode is unexcited.

The $\pi/2$ phase advance accelerating mode has a maximum steepness in the dispersion curve, allowing greater separation between the operating mode and the next nearest structure eigenmodes. This allows a single RF input port to drive a longer structure. Additionally, in this mode, alternate oscillators (the slots) are unexcited resulting in lower structure losses and greater shunt impedance. In order to achieve this maximum steepness, the transmission band of the slot system must merge with the transmission band of the on-axis cavity system. In practice, the cavity frequency and the anti-symmetric slot frequency were tuned to the same value using HFSS and cross checked using Omega3P [4]. The frequency of the slots is dependent upon both the natural frequency of each resonant slot and the strength of the coupling between them. The slot frequency is most sensitive to the height of the slot in the narrow region but has significant dependence on all of the slot and void dimensions. Despite this sensitivity, the requirement of having a slot height that could be manufactured was important. Based on simulation results for the S-band structure, the shunt impedance (ZTT) is approximately 85 MΩ/m.

End Cell Design

In the nominal cells, the perturbations to the magnetic field were balanced by rotating the azimuthal orientation of the slots on each end wall of the full cavity cell. The entrance and exit of the linac structure will contain half-cells and will not have benefit of this field balancing. A balanced magnetic field was created by offsetting the axis of symmetry that defines the outer wall of the cavity relative to the beam axis that defines the nose cone and slot/void symmetries as is shown in Fig 5. The required the offset of the outer wall axis to be toward the center of the slot. The slot frequency tuning was maintained by adjusting the radius of curvature of the outer cavity corner to account for the change in the depth of the slot that would occur had the radius not changed. Additional cavity tuning required a counter bore coaxial with the offset outer wall.

Figure 5: Solid model drawing of the cavity side of the end cell. The wall rounding was offset from the center axis compensate the perturbation in the magnetic field caused by the asymmetric slot geometry at the ends of the linac.

STRUCTURE MANUFACTURE

A DSRL structure with 10 full cells and 2 half cells at the ends operating in S-band, shown in Fig 6, was designed and is being manufactured for the UCLA Pegasus laboratory. This structure will provide 10 MeV energy gain to the electron beam. The separation between the operating mode and the next nearest mode in this structure is approximately 40 MHz. The number of cells was chosen based on the desired energy gain and available RF power budget while maintaining a conservative peak surface field. The number of cells results in an asymmetric coupling scheme meaning that the RF power coupler can directly excite all of the coupled modes of the structure. This choice was made to trade off a conservative peak surface field while maximizing the mode separation. It is not expected to affect the performance of the linac.

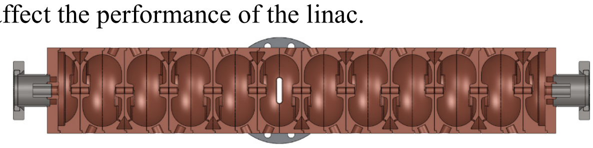

Figure 6: Sectional view of the DSRL 10+2/2 cell solid model drawing.

Precision turning and high-speed 5-axis milling were used to construct the oxygen free copper half cells. Sharp corners where the slot couples to the cavity and void could have severe impact on RF losses and possibly result in breakdown. The primary concern in the machining process was the complicated rounding and blending of the surfaces where the angled slots sweep through the rounded outer wall of the cavity. In essence, these edges represent the intersection of a cone and a sphere, and required full use of the 5-axis milling capabilities for the 3D geometry. The blending of the slot with the cavity wall can be seen in Fig 7. The rounding and blending where the slot meets the void surface, as shown in Fig 8, is somewhat less critical because the magnitude of the fields nearer the voids are smaller by design and this surface is easier to machine; however, 5axis milling was still required. In addition to the interfaces with the cavity and the void, the internal corners of the slots were also rounded. Several half cells are in the manufacturing process and the structure will be brazed in a hydrogen atmosphere once the machining and cold testing is complete. Once completed, the DSRL will be installed and tested in the UCLA Pegasus laboratory.

Figure 7: Cavity side of a machined DSRL half-cell.

Figure 8: Void side of a machined DSRL half-cell.

CONCLUSION

The slot resonance coupling concept has been fully extended to the DSRL case. A prototype S-Band structure capable of providing 10 MeV energy gain has been designed and is undergoing fabrication for installation and testing at the UCLA Pegasus laboratory. The DSRL scheme has many advantages including simpler fabrication, reduced radial size, and competitive shunt impedance.

REFERENCES

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