The Klynac: An Integrated Klystron and Linear Accelerator

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Klynac Concept

- The Klynac concept integrates:
 - an electron gun,
 - a radio frequency (RF) power source,
 - a coupled-cavity linear accelerator
- into a single resonant system.

Klynac Overview

- Gun—Established technology
- Klystron (RF Source)—Established technology
- RF Linac—Established technology
- **Innovative Coupler: Linac and RF source are an integrated system**

Klynac Coupler

- The Klynac uses:
 - a unique cavity structure to resonantly couple the klystron output cavity to the accelerator cavities,
 - locking the two in amplitude and phase,
 - and eliminating the normal transmission line between klystron and accelerator.

Klynac Coupler Concept

The coupler is a TEM (coaxial) cavity tuned to transmit RF power and resonantly couple the klystron output cavity to the accelerator input cavity

Resonant Coupling

- The resonant coupling concept was developed at Los Alamos in the early days of the LANSCE (LAMPF) accelerator design
- The LAMPF design had a coupling resonator that was off axis. It was called a “side-coupled” structure.
- The on-axis coupled accelerator structure was conceived at the same time

On-Axis Coupled Linac Cell

On-axis coupled accelerator structure

Coupled Circuit Model

Coupled Circuit Analysis

- In the perfectly tuned case, the $\pi/2$ mode frequency is the frequency for which $I_2 = 0$.
- This requires that $\omega_1 = \frac{1}{\sqrt{L_1 C_1}}$, $\omega_2 = \frac{1}{\sqrt{L_2 C_2}}$ and $\omega_1 = \omega_2$
- Then the $\pi/2$ mode frequency is ω_1 .
- The coupling factors are $k_{12} = \frac{M_{12}}{\sqrt{L_1 L_2}}$ and $k_{34} = \frac{M_{34}}{\sqrt{L_3 L_4}}$.
- The currents I_1 and I_4 have the opposite sense and $k_{34} I_4 = -k_{12} I_1$.

Transmission Line Added

- Transmission line
- Arbitrary two-port network

Chain Matrix Representation

$$M = \begin{vmatrix} A & B \\ C & D \end{vmatrix} = \begin{vmatrix} \cos(\mathcal{G}) & jZ_0 \sin(\mathcal{G}) \\ \frac{j}{Z_0} \sin(\mathcal{G}) & \cos(\mathcal{G}) \end{vmatrix}$$

- Chain matrix representation of coaxial transmission line
- $\mathcal{G}$ is the electrical length of the line
- ℓ is the physical length of the line
- Z_0 is the characteristic impedance of the line $\mathcal{G} = \frac{\omega \ell}{c}$

If Line Electrical Length is a Multiple of π

$$M = \begin{vmatrix} (-1)^N & 0 \\ 0 & (-1)^N \end{vmatrix}$$

- $\mathcal{G} = N\pi$
- The amplitude relation is now $k_{34}I_4 = -(-1)^N k_{12}I_1$

More General Case

- C2 and C3 have been removed

- For $I_2 = I_3 = 0$ we get $M = \begin{vmatrix} 1 & -j\omega_1(L_2 + L_3) \\ 0 & 0 \end{vmatrix}$

Form of the Matrix M

- The matrix M must contain a series impedance that resonates with the coupling slot self inductances at frequency ω_1 .
- This could be the equivalent of the circuit of Slide 10, with series capacitances and a transmission line of electrical length $\mathcal{G} = N\pi$.
- Or, it could be a more complex circuit.

Coupler Network Properties

- The network has to have the property that the currents $I_2 = I_3 = 0$ in the accelerating $\pi/2$ mode, $\omega_{\pi/2} = \omega_1$ and the currents $I_1 = I_4 = 0$ in the coupling $\pi/2$ mode, $\omega'_{\pi/2} = \omega_1$.
- The accelerating mode is calculated with short circuit boundaries as illustrated in Slide 13.
- The coupling mode is calculated with open circuit boundaries.

Circuit Model with Open Circuit Boundaries

For a periodic structure the resonant frequency is the mode with stored energy in the coupling mode and no stored energy in the accelerating mode

HFSS Model of a Coupler

- The rings on the outer conductor labeled transmission mode tuners capacitively load the coaxial line so that the short circuit mode resonates at the operating frequency
- The rings on the inner conductor labeled coupling mode tuners capacitively load the coaxial line so that the open circuit mode resonates at the operating frequency

Tilt Sensitivity Method 1

- The tuning of the accelerating mode can be done by direct measurement
- The coupling mode is tuned by an indirect measurement
- The relative amplitudes of the resonators on each side of the coupler is measured with the resonators detuned

Tilt Sensitivity Measurement 2

- One measurement is made with one end tuned high and the other end tuned low keeping the frequency constant
- Then the tuning errors are reversed
- The change in the amplitude ratio is plotted against the frequency of the coupling mode
- When reversing the error produces no change in the field ratio the coupler is tuned

Coupling Mode Frequency

The coupling mode frequency can be calculated with HFSS as a function of tuner radius.

Tilt Sensitivity versus Coupler Frequency

Tilt Sensitivity Technique

- For several values of the coupler frequency the tilt sensitivity is measured for several tuning errors
- For moderately small tuning errors the tilt sensitivity is linear in the tuning error
- It is also linear in the error in the coupler frequency
- The tilt sensitivity vanishes when the coupler is tuned

E-Fields in Operating Mode

- Logarithmic field plot
- Quadrant with symmetry planes
- Half cells at ends
- Short circuit end boundaries
- Equal amplitudes in end cells
- Voltage across slots equal at each end
- Open circuit transmission line mode

E-Fields in Coupling Mode

- Logarithmic field plot
- Open circuit boundaries
- Transmission line terminated by slot self inductance
- Mode must be at same frequency as main mode for resonant coupling
- Resonant coupling
 - Reduces sensitivity of field distribution to tuning errors

What Next?

- We have demonstrated that we can make a suitable resonant power coupler of whatever length is required
- We need to do beam dynamics calculations to show that we can get some fraction of the klystron beam to the accelerator at the right phase
- Then we build a cold model to perfect tuning techniques
- Next we would build a full prototype to demonstrate performance