QUARTER-WAVE-STUB RESONANT COUPLER

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Abstract

Most small proton and other ion linacs involve two different linac structures, namely an RFQ linac section and some other, more efficient, linac structure, such as the Drift Tube Linac (DTL), the interdigital (Wideröe) linac, or the Rf Focused Interdigital (RFI) linac. Such linacs can benefit a lot by being resonantly coupled into a single resonant unit. The resonantly coupled structures can be driven by a single rf power system, through single rf drive loop, at a single rf frequency. The relative phase and relative amplitude of the fields in the two structures are locked by the resonant coupler. Such systems require no control of phase of the rf power. By designing the rf power system to track the resonant frequency of the combined structures, the control of the resonant frequencies of the two structures is greatly simplified. A simple, compact, resonant coupler, based on a quarter-wave-stub, will be described. Models of this resonant couple have been tuned and adjusted, and are scheduled to be tested at operating powers in the fourth quarter of 2008.

BACKGROUND

Resonantly coupled linac structures have been around for 50 years. In the mid-60s, the Side Coupled Linac (SCL) structure was developed at Los Alamos for use in the Los Alamos Meson Physics Facility (LAMPF), and subsequently in thousands of today's electron linacs. Later in that decade, the post coupled Drift Tube Linac (DTL) was developed, which stabilized the amplitude and phase of the fields in these structures. Resonant coupling and operation in the $\pi/2$ mode are essential to modern linac technology.

The same technology that stabilizes linac structures can be used to couple any two resonant structures that operate at the same frequency. The bridge couplers of LAMPF are prime examples. They are not resonant couplers themselves, but rather resonant structures that are resonantly coupled to adjacent linac structures. The first 8 modules of LAMPF are built as 4 SCL linac tanks and 3 bridge couplers. The last 36 modules of LAMPF are built as two SCL linac tanks and one bridge coupler. In all cases, the SCL tanks are resonantly coupled to the bridge coupler by a minor modification of the side coupling cell. The "bridge coupler" name comes from the fact that these devices bridge the resonant properties of the structure around the required beam focusing quadrupoles.

For proton and ion linac applications, where the relative amplitude and phase of the fields are so important, the resonant coupling of the resonant units in a linac system is very important. The resonant couplers operate in the $\pi/2$ mode. They are nominally unexcited while the units that they couple are excited. The $\pi/2$ mode is unique in that it is the only mode in the mode spectrum where no changes are required in the amplitude or phase of the excited cells to accommodate changes in power flow through the structure. The resonant couplers lock the relative amplitude and phase of the fields in the excited cell of the structures. They stand by to support power flow in whichever direction is required to keep the fields in the excited structure at their design value.

For the theory of resonant coupling go to the Nagle, Knapp, and Knapp[1] or the Knapp, Knapp, and Potter[2] papers of the late 60's.

INTRODUCTION

Particle accelerators employ electromagnetic resonators to produce high electric fields that can be used to accelerate charged particles to higher energies. Particle accelerators involving a single resonator have a requirement that the amplitude and distribution of the fields in the resonator be appropriate for the acceleration process. Particle accelerators involving two or more resonators have an additional requirement that the relative phase of the fields in adjacent resonators be controlled. Control of the relative phase of the fields requires that the frequency of the electromagnetic excitations in the all resonators be the same or harmonically related.

The conventional solution to these requirements is to control the resonant frequency of all resonators to the required accuracy, to control the amplitude of the fields in all resonators to the required accuracy, and to control the phase of rf fields in all cavities to some phase reference to the required accuracy.

The use of a resonant coupler greatly simplifies the controls problem for two-resonator particle accelerators. The resonant coupler provides a single frequency at which the pair of resonators can be excited, even when the resonant frequencies of the individual resonators are slightly different. The resonant coupler locks the relative amplitudes and relative phases of the field in the two resonators. Consequently, the resonant coupler reduces the controls problem for two-resonator accelerators to that of controlling the frequency of the drive power to the single frequency offered by the resonant coupler and controlling the amplitude of either resonator to the required accuracy.

Two-resonator accelerators are common in low energy range of ion accelerators, where the first resonator is a radio frequency quadrupole (RFQ) linac structure, with its superb very low energy capabilities, followed by some other low energy linac structure with better acceleration properties. This resonant coupler offers significant advantages to this important class of low energy ion accelerator.

A block diagram of two generic resonators that are resonantly coupled by a generic coupling resonator is shown in Fig. 1.

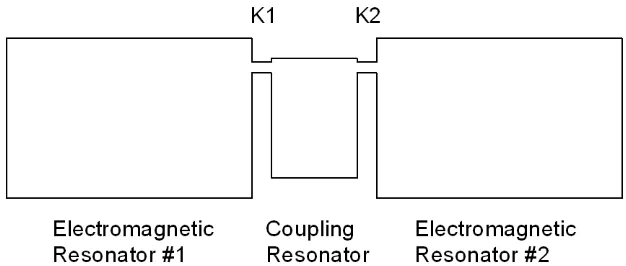

Figure 1: Diagram of resonantly coupled resonators.

The coupling between resonators can be either between the magnetic fields of the resonators or the between the electric fields of the resonators as shown in Fig. 2. Here the dots represent magnetic fields coming out of the paper, the pluses represent magnetic fields going into the paper, and the arrows represent electric fields in the plane of the paper.

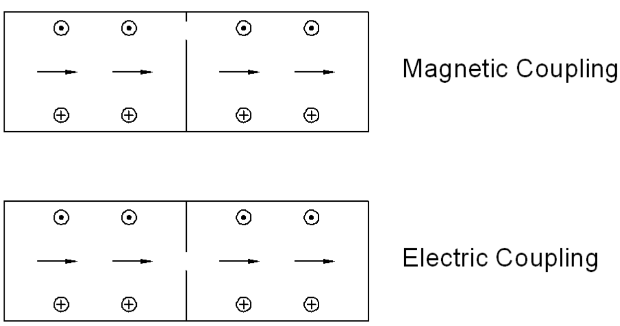

Figure 2: Examples of magnetic and electrical coupling.

The properties of the three basic electromagnetic modes of a three resonator configuration are shown in Fig. 3, where in the "0" mode, the electric fields in adjacent resonators are "in phase" (same direction), where in the "π" mode, the electric fields in adjacent resonators are π radians (180°) "out of phase" (opposite directions), and where in the "π/2" mode, the first and last resonators are excited "out of phase" and the coupling resonator is nominally unexcited;

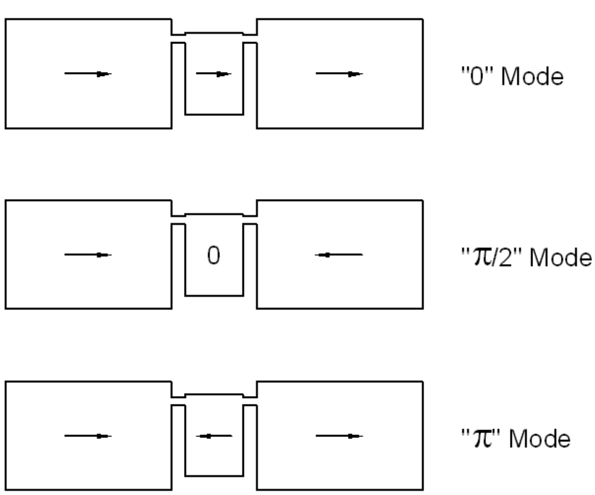

Figure 3: Basic modes of three coupled resonators.

The generic quarter-wave-stub resonator is shown in Fig. 4. It comprises a cylindrical outer conductor with a concentric quarter wave length cylindrical post along the axis. The magnetic fields are primarily at one end and the electric field are primarily at the other end.

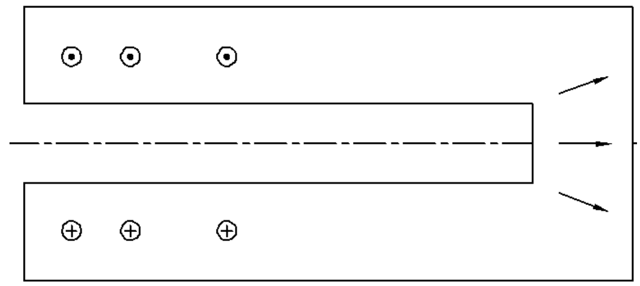

Figure 4: Generic quarter-wave stub resonator.

Most linac structures have their strongest electric fields on the axis of the linac structure for particle acceleration, and their strongest magnetic fields off the axis near the outer extremities of the linac structure. A favourable configuration for coupling two resonators with a quarter-wave resonator is shown in Fig. 5, which employs magnetic coupling between the two resonators and the resonant coupler. As there is a 180° shift in the direction of the magnetic fields across the resonant coupler, the field directions shown here are correct for the π/2 mode. The resonant coupler is nominally un-excited.

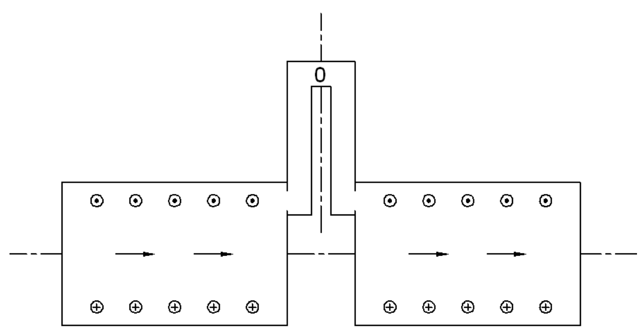

Figure 5: Quarter-wave-stub resonant coupler.

The common linac structures include the RFQ linac, the drift tube linac (DTL), the coupled cavity linac (CCL), the side coupled linac (SCL), the disk and washer (DAW) linac, the rf focused interdigital (RFI) linac[3], the alternating phase focused interdigital (APF-IH) linac. The DTL, CCL, SCL, and DAW linac structures employ transverse magnetic (TM) electromagnetic modes, which have strong transverse magnetic fields near the ends and outer extremities of the structure. The RFQ, RFI, and APF-IH linac structures have primarily longitudinal magnetic fields for most of the structure, which turn around at the ends of the structure, resulting in a transverse components of the magnetic fields. In the RFQ, there are four azimuthal locations at each end of the structure that suitable for magnetic coupling to a resonant coupler. In the RFI, there is one azimuthal location at the each end of the structure that is suitable for magnetic coupling to a resonant coupler. In the APF-IH, the best coupling to a resonant coupler may be through electric coupling to the off-axis electric fields near the ends of the structure.

EXAMPLE

A 1.1-MeV RFQ linac structure resonantly coupled to a 3.5 MeV RFI linac structure is shown in Fig. 6. The resonante coupler is the horizontal projection at the interface between the two structures.

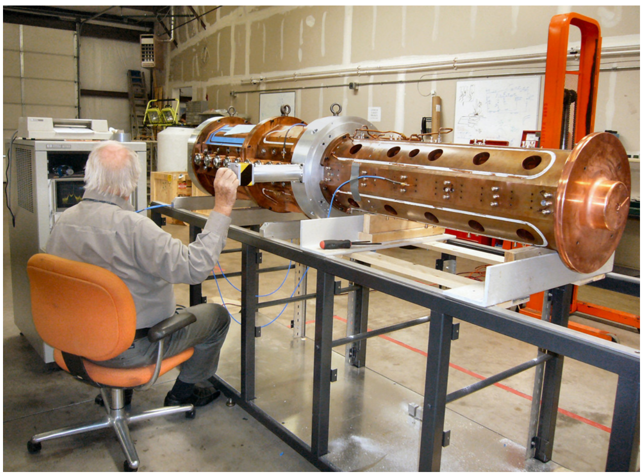

Figure 6: A 1.1-MeV RFQ linac resonantly coupled to a 3.5-MeV RFI linac with a quarter-wave-stub resonant coupler.

Two views of the resonant coupler are shown in Fig. 7, one looking downstream (upper) showing the RFQ coupling slot, and one looking upstream (lower) showing the RFI coupling slot. In the downstream view, the resonant couple cavity has been sectioned to show the quarter wave stub. In the upstream view, you can see a rectangular slot cover plate held in place with four screws. Initially, this cover plate was flush on the left (no cut back), which resulted in a very small coupling to the RFI structure. In the course of the adjustment of the ratio of cavity powers in the two accelerating structures, this cover plate was machined to the shape show here, which resulted in a significant coupling to the RFI structure.

The mode spectrum of the three modes (0, $\pi/2$ and π) of this three cavity system are shown in Fig. 8, with a total width of 2.3-MHz. The knob at the end of the Resonant Coupler moves a tuning slug in and out to adjust the resonant frequency of the resonant coupler. Using this knob, it is possible to achieve the symmetrical distribution of mode frequencies, which is important for proper operation.

ACKNOWLEDGEMENTS

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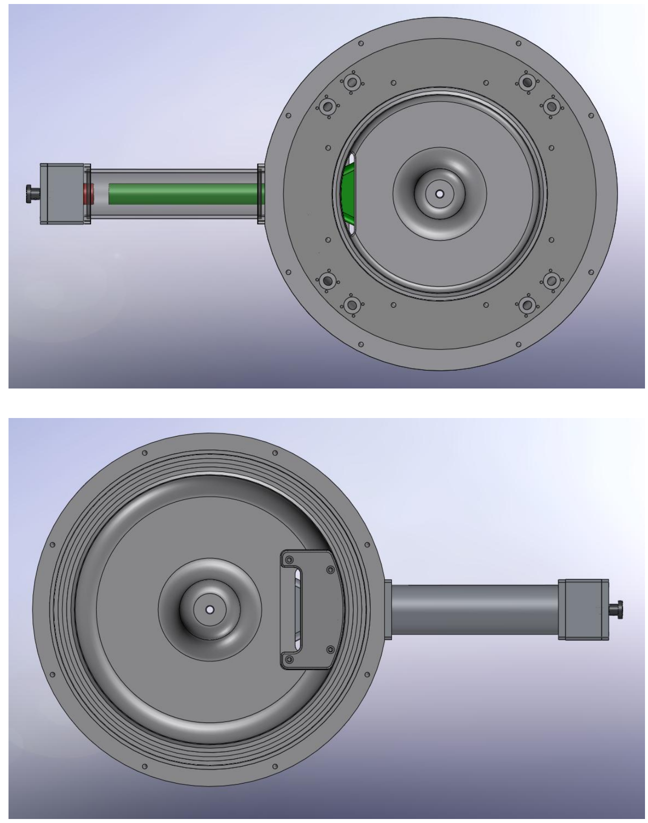

Figure 7: Two views of the resonant coupler.

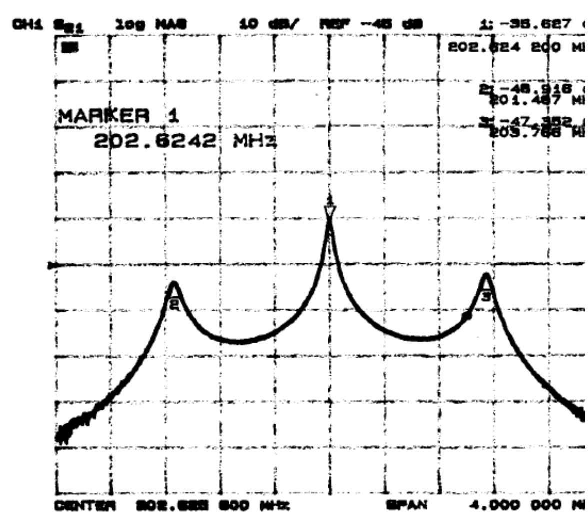

Figure 8: Mode spectra for resonantly coupled structures shown in Fig 6.

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[2] E. Knapp, B. Knapp, and J. Potter, 1968, Rev. Sci. Instr. 39, 979.

[3] D.A. Swenson and W.J. Starling, CAARI 2002 Conference, Denton, TX.