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A PERSONAL HISTORY OF THE DEVELOPMENT OF THE LAMPF/LANSCE ACCELERATOR

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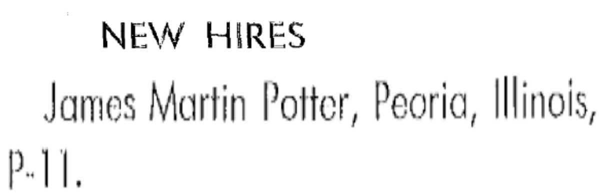
Abstract

The LAMPF/LANSCE accelerator has now been operational for 50 years. I arrived as a LASL employee in Group P11 in April 1964 at the beginning stages of its development. I participated in the development of the resonant coupling principle and went on to develop tuning procedures for the 805-MHz coupled cavity linac (CCL) structures and the post-stabilized drift tube linac (DTL). The resonant coupling principle is now well established as the basis for rf linear accelerators worldwide. I will discuss the development and building of the accelerator from my viewpoint as a member of a large, dedicated team of physicists, engineers, technicians, and support personnel.

DISCOVERY OF RESONANT COUPLING

Introduction

I came to Los Alamos in April 1964 with a brand-new BS in Physics from the University of Illinois to be the 19th member of Group P11 [1], which was in the beginning stages of designing a proton accelerator for meson physics research, Fig. 1.


NEW HIRES

James Martin Potter, Peoria, Illinois, P-11.

Figure 1: Entry in the June 1964 edition of The Atom.

The Cloverleaf Structure

My initial job was measuring the mode spectrum of a sheet metal model of an 805 MHz Cloverleaf accelerator. Figure 2 shows the basic Cloverleaf geometry [2]. Note that the lobes are rotated 45° between cells to create a p-mode accelerating structure.

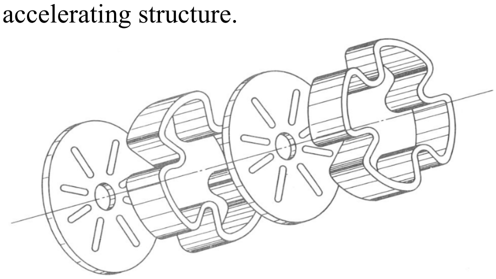


Figure 2: Basic 800 MHz Cloverleaf geometry.

Figure 3 is a photo of the 21-cell sheet metal Cloverleaf structure used for low power rf testing [2]. It was called a "cold" model because it was not intended for operation with high power rf.

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Figure 4 is a plot of the measured power flow phase shift along the 21-cell cold model when driven in cell 1 [2]. The solid curve is the theoretical phase shift based on a calculation of an effective coupling constant of 0.94 based on a fit to the mode spectrum at the p-mode.

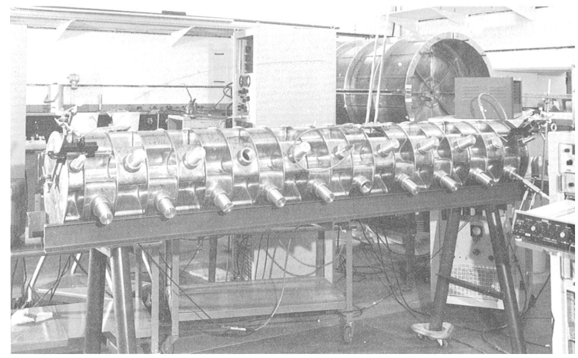

Figure 3: 21-cell Cloverleaf "cold" model.

The power phase shift is proportional to the square of the number of cells divide by the product of the coupling constant and the Q, based on the singly periodic coupled circuit theory.

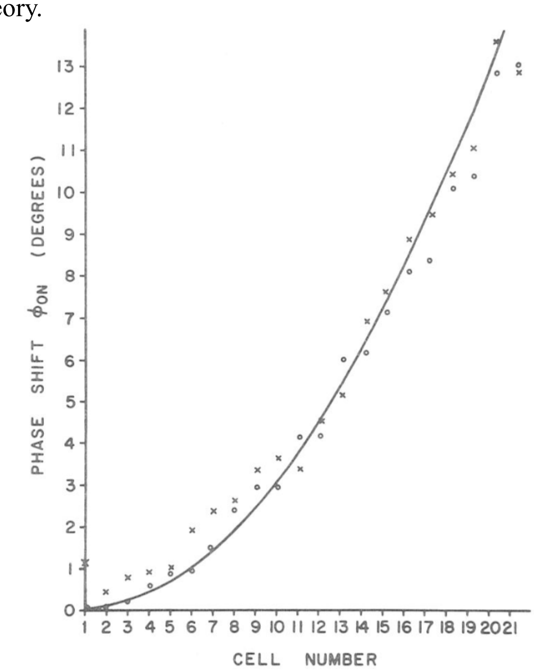

Figure 4: Measured and theoretical power flow phase shift in the 21-cell cold model.

The mode spectrum of the 21-cell cold model is plotted in Fig. 5 [2]. The stopband and upper passband are due to the resonant frequency of the slots. The slot frequency is close enough to the p-mode to affect the properties of the structure. Despite the large effective coupling constant, the passband is still quadratic near the p-mode resulting in high sensitivity to cell frequency errors. The tuning of the

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21-cell cold model to an acceptable field flatness took over a month of tuning time.

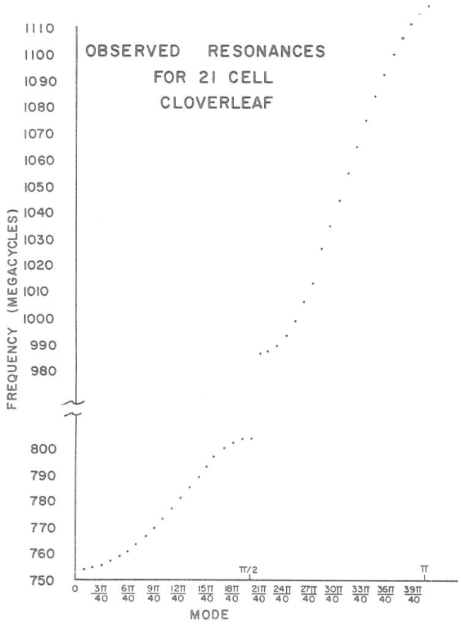

Figure 5: Measured mode spectrum of the 21-cell cold model.

Resonant Coupling

The difficulty of interpreting the tuning data in terms of the singly coupled periodic resonator model led to the modification of the model to include biperiodic structures [3].

We soon discovered based on the biperiodic coupled circuit analysis that the sensitivity of the accelerating field amplitude to tuning errors went to zero when the stopband was closed.

This led to the calculation of perturbations in second order. We discovered that the amplitude errors were proportional to the product of two tuning errors. We then realized that accelerators with resonant coupling were much easier to build with a good field distribution. The stability of the field distribution is attested to by the fact that the LAMPF/LANSCE accelerator reached its 50th year of operation in 2022.

We studied several variations of biperiodic accelerator structures and settled on what we called the side coupled structure. There are two papers that describe the biperiodic coupled circuit theory in detail, Nagle et al (1967) [4] and Knapp et al (1968) [5], both published in 1968. We were leery of the on-axis coupled structure because we didn't have the ability to understand whether the beam would interact with the coupling cells. However, it is now in common use for high current electron linacs, where the reduction in shunt impedance isn't a major consideration, because it is simpler to manufacture, and greater coupling can be obtained between the accelerating and coupling cells compared to the side coupled structure.

We built a somewhat crude cold model welded together from sections of copper pipe with cylindrical coupling cells welded onto the side. Figure 6 shows the first resonantly coupled cold model [2]. It was nicknamed "Mickey Mouse" because its coupling cells resembled mouse ears. Figure 7 is a drawing of a section view of the structure on the horizontal mid plane [2].

We were astounded by the performance of Mickey Mouse. The coupling constant was only 2.5%. The field distribution within 5% as built Yet no amount of adjusting the tuners changed the field distribution. In addition, there was no measurable power flow phase shift observed.

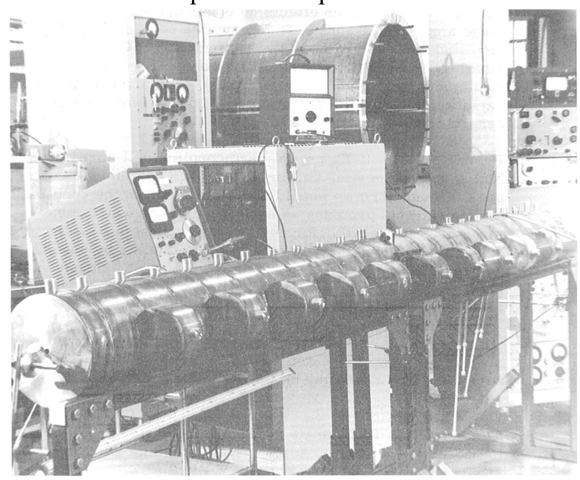

Figure 6: First resonantly coupled accelerator cold model, called "Mickey Mouse".

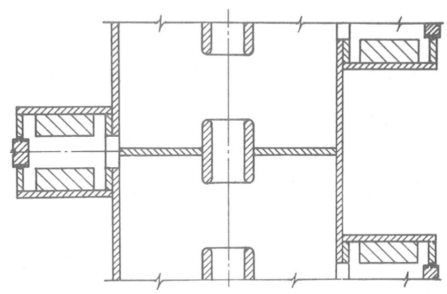

Figure 7: Horizontal mid-plane section view of Mickey Mouse.

The development of the resonantly coupled structure for LAMPF/LANSCE was aided by the increase development time available due to budget problems. There was a long period where we were unable to get funding to build the accelerator, but Louis Rosen managed to get enough funding to keep the team together.

Ultimately, we settled on the design shown in Fig. 8 [5].

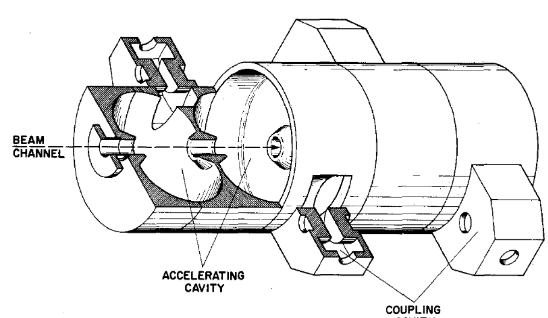

Figure 8: Side coupled design used for the LAMPF/ LANSCE accelerator.

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The off-axis coupling cells separates the optimization of cavity Q and gap capacitance, The Q is enhanced by radiusing the outer walls of the cells and the gap capacitance is reduced by tapering the nose surrounding the beam aperture, resulting in a higher shunt impedance than previous coupled cavity linear accelerators.

Post Couplers

During the R&D period, 1964-1968, we also developed a method for applying resonant coupling to the Drift Tube Linac (DTL) structure. Figure 9 is a photo of the upgraded SSC DTL, modified by JPAW for International Isotopes, Inc. in 1999-2000 [6]. The post couplers, sometimes called

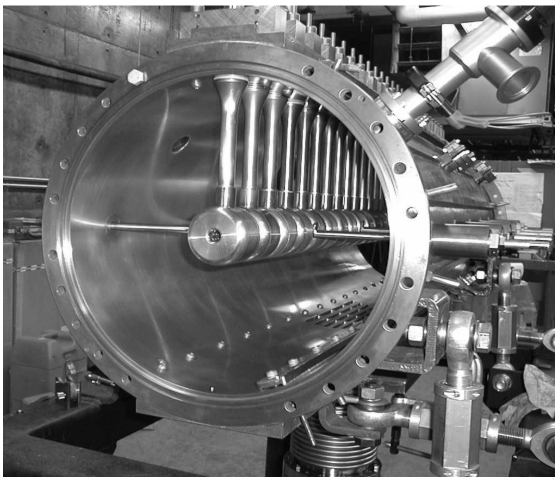

Figure 9: Drift Tube Linac with post couplers.

post stabilizers, are approximately quarter wave posts resonated by the capacitance from the end to the drift. These posts are a series resonator that, when tuned, forces the zero voltage point on the drift tube to be aligned with the post. The metal flag on the end allows the effective center point on the post to be moved longitudinally this changing the voltages at each end of the drift to change relative to one another. Tuning the post couplers adjusts the field distribution and stabilizes it. This is despite the large cell-to-cell coupling inherent in a DTL.

Bridge Couplers

One of the developments during the R&D period was the concept of a bridge coupler to carry rf power past the required focusing quadrupoles. This allowed us to make structures with two or four sections (tanks) powered by one klystron rf amplifier. Figure 10 is a drawing of an early bridge coupler design. The bridge coupler is a TM_{010} mode cylindrical resonator. In developing this we discovered that there was a power flow phase shift across the bridge coupler. The power flow phase shift is due to the mixing of the TM_{011} mode which gets closer to the TM_{010} mode frequency as the bridge coupler cell is lengthened.

The post in the middle of the bridge coupler derived from the ides that maybe you didn't need a drift tube to resonate a post coupler. That was a good guess. Eventually we learned that there was a TE_{113} mode that was the coupling mechanism which stabilized the bridge coupler and removed the power flow phase shift. Then we learned that as the bridge couplers grew in length to match the increasing beam velocity the TE_{113} mode came down to the operating frequency (805 MHz) and the post length went to zero eliminating the coupling to the TE_{113} mode. The fix was to add auxiliary posts to bring the TE_{115} mode down in frequency with sufficient post length to create a resonant coupling mechanism. We also discovered that a large notch in the center post shifted the symmetry of the coupling so that imbalances between the average fields of adjacent tanks could be tuned out.

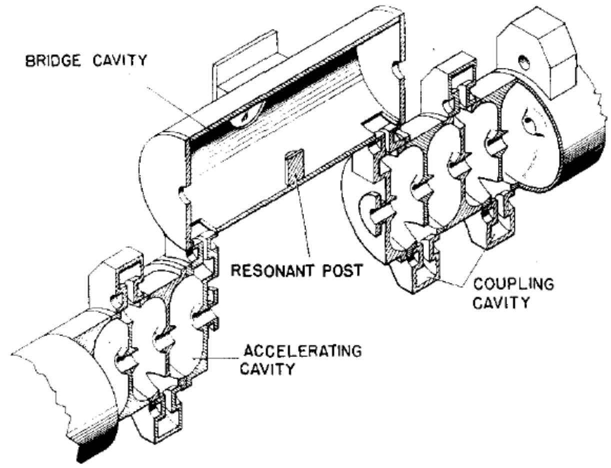

Figure 10: Initial bridge coupler concept.

CONCLUSION

The period 1964-1972, culminating in the first operation of the LAMPF/LANSCE accelerator, was an exciting period of development of new ideas in rf linear accelerator technology. I remember, when attending the MURA Accelerator Conference in Madison, WI in 1964, there was an undercurrent of, "Who are these guys from Los Alamos who think they can build an accelerator? They've never built an accelerator before".

From my perspective the development of resonant coupling shows that a bunch of smart guys who don't know what can't be done can sometimes make an improvement over existing technology.

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