Bridge Coupler Design and Tuning Experience at Los Alamos*

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ABSTRACT

A bridge coupler is essentially a tuned rf power splitter which is an integral part of the accelerator structure, allowing an rf amplifier to drive more than one accelerator section while preserving the desirable properties of the $\pi/2$ mode for the combined structure. In its simplest form, a bridge coupler is an elongated accelerating cell of a biperiodic structure which is displaced off the beam axis to bridge over focusing magnets and beam diagnostic equipment.

This paper discusses the design of bridge couplers for the linear accelerator at Los Alamos and the modifications of the basic design required to retain the stability and power-flow phase shift characteristics of the $\pi/2$ mode. These modifications involve the addition of a resonant post coupler (or couplers, depending on the bridge-coupler length) similar to those used to stabilize the Alvarez structure.[1] An asymmetry in the post-coupler system allows one to adjust the relative amplitudes of the fields in the coupled accelerating structures.

I. INTRODUCTION

There are two somewhat conflicting requirements on the length of accelerator sections in waveguide linacs. Each section must be shorter than a phase oscillation wavelength to provide for placement of focusing and steering magnets and beam-diagnostic apparatus at appropriate intervals, but each section must be long enough to permit economical generation and use of rf power. At Los Alamos this means that each amplifier must drive two to four accelerator sections or tanks. Conventional power splitters have at least two major difficulties: 1) The tank phase would have to be controlled at high-power levels, and 2) the tanks would have to be electrically isolated from each other to prevent tuning interactions.

A simple solution[2] is to incorporate the power splitter into the accelerator structure by placing a main cell of axis and elongating it to bridge the gap (hence the name "bridge coupler") required for magnets and other apparatus. The advantage of this scheme is that it retains the inherent amplitude and phase stability of the $\pi/2$ mode while allowing an amplifier to drive more than one tank.

The bridge coupler is actually a more versatile device than its role as a power splitter would indicate. In a $\pi/2$-mode side-coupled structure, virtually any accelerating cell may be rotated off axis and elongated to break a structure into two or more sections of arbitrary length. Figure 1 illustrates how bridge couplers are used at LAMPF to make two or four tank modules.

This paper might more properly be entitled, "The Evolution of the Bridge Coupler." Like so many other things, the bridge coupler was not born fully grown, but rather evolved in a series of solutions to problems that were not evident until we attempted to build bridge couplers varying in length from 22-34 in. We discovered that the ability to tune long and short bridge couplers that worked did not necessarily imply the ability to tune middle-sized bridge couplers. However we are now confident, given our experience with the Los Alamos linac, that we can build and tune bridge couplers of arbitrary length.

II. THE BASIC BRIDGE COUPLER

The basic form of the bridge coupler is illustrated schematically in Fig. 2. There are three fundamental considerations in the design of the bridge coupler in its simplest form: 1) resonant frequency, 2) coupling to its coupling cells, and 3) length.

1) The bridge-coupler inner diameter must be chosen so that its TM_{010} mode resonates at the desired $\pi/2$-mode operating frequency. In practice, one choses a slightly higher initial frequency, taking into account the effects of the rf iris and coupling-cell slots. Then, adjustable capacitive end tuners are used to tune the bridge coupler to the correct frequency.

2) Stored energy in any nonaccelerating cavity reduces the overall shunt impedance of the structure. This effect is minimized by increasing the coupling at X with respect to the coupling at Y, leaving only enough stored energy in the bridge coupler to permit the desired degree of coupling to the waveguide. At LAMPF the reduction in shunt impedance from the bridge couplers is on the order of 1%.

3) In principle, there is only one constraint on the length of a bridge coupler other than the previously mentioned shunt impedance reduction. The gap bridged by bridge coupler must be an odd multiple of $\beta\lambda/2$ to maintain the correct phase relation between the coupled tanks. In LAMPF the gaps vary in length $9\beta\lambda/2$ to $5\beta\lambda/2$.

The first tests of a basic bridge coupler on Model K in 1965 revealed a power flow phase shift across the bridge coupler - a sure sign of nonresonantly coupled behavior. Furthermore, there was one too many modes in the mode spectrum. The reason for this was found to be the presence of the TM_{011} mode, only 20 MHz higher in frequency than the TM_{010} mode. The elongated cell behaved qualitatively as though it were two nonresonantly coupled cells. A post was inserted perpendicular to the bridge-coupler axis in a horizontal plane to introduce a resonant-coupling mechanism to the bridge coupler in much the same way as the post couplers do in the stabilized Alvarez linac.[1]

Subsequent investigation showed that this post grossly perturbed the TE_{113} mode. Figure 3 illustrates schematically the effect of post penetration on three of the bridge-coupler modes. This behavior is much the same as for two resonantly coupled cells whose coupling cell is gradually reduced in frequency. The behavior of the TE_{113} mode frequency versus post penetration at frequencies much higher than the TM_{011} mode is actually more complicated than illustrated because of the presence of other modes in the bridge coupler.

III. POST-STABILIZED BRIDGE COUPLER

The post-stabilized bridge coupler had all of the properties envisioned in the original concept with the additional feature that an asymmetrical coupling post (in our case notched) could be rotated to vary the relative average fields in the coupled tanks as much as ±25%. Figure 4 shows the cross section of a typical post coupler. Figure 5 is a view of a post-stabilized bridge coupler.

When the 40-in.-long bridge couplers for the EPA linac were built it was discovered that one post no longer worked but that three uniformly spaced posts did. (At that time the coupling mode had not been identified because the equipment did not cover the frequency range above 1000 MHz.) Having made one short bridge coupler and three long ones work it was concluded that all lengths in between should work with either one or three posts. The bridge couplers were manufactured with provisions for installing three posts, if necessary.

IV. FIVE-POST BRIDGE COUPLERS

The first bridge couplers tuned on the Los Alamos linac required only one post and all seemed well. But, as progressively longer and longer bridge couplers were tuned, with gradually increasing difficulty, a critical length was reached where one post no longer worked. Unfortunately, neither did three. It was at this point that, by carefully identifying modes in the bridge coupler, it was learned that the coupling mode was the TE_{113}. The difficulty was traced to the fact that the TE_{113} mode, gradually becoming lower in frequency as the bridge-coupler length increased, had finally become so low that it was unusable as a coupling mode. The preceding bridge couplers were critical to tune because the small post penetration required to get zero-power-flow phase shift was equivalent to having a very small coupling to the resonant coupler. Study of mode charts (Fig. 6) revealed that the TE_{115} was a likely candidate for a coupling mode. A scrap bridge coupler was used to successfully test this theory.

Five posts were placed in a horizontal plane transverse to the bridge-coupler axis and alternating from one side to the next (Fig. 7) at the positions of the antinodes of the TE_{115} electric field. The bridge couplers that required five posts were modified, after installation, by drilling counter-bored holes at the appropriate places. The posts were installed from the inside by means of a stainless shaft and the vacuum was secured by means of a lead "O" ring and a concave stainless washer. Only the center post was rotatable and adjustable in length, the others were fixed in length. The length for the fixed posts was determined by substitution to the nearest 1/16 inch and the center post became the fine tuning control.

One benefit of using a five-post bridge coupler is the capability of varying the field distribution within the bridge coupler and hence change the VSWR for a driven bridge coupler by changing the relative length of the four fixed posts with respect to the center post. By increasing the length of the fixed posts 1/8 in. and decreasing the length of the center post to maintain the correct tuning ($\sim$ 1/2 in.), it is possible to increase the coupling to the waveguide as much as 30%. Similarly, by reducing the fixed posts in length and retuning with the center post, one can correspondingly decrease the coupling.

The only other side effect of five posts was that the effect of the rotatable notch on the relative field distribution was reduced a factor of four or five. This proved not to be a serious problem since an adjustment range of ±5% was still possible.

V. SEVEN-POST BRIDGE COUPLERS

The only remaining difficulty was discovered in certain of the longest bridge couplers used. The vertical TE_{113} mode (the TE_{11n} modes are doubly degenerate), affected only slightly by all the posts, was in the middle of the bridge-coupler passband. This problem was quickly eliminated by two fixed-length posts placed vertically from the top of the bridge coupler.

Figure 8 is a picture of the inside of a seven-post bridge coupler looking to the left through the waveguide coupling iris with a wide-angle lens. The two posts at left center are two of the fixed-length coupling posts. The notched adjustable coupling post is on the right of the figure. Hanging from the top of the bridge coupler is one of the posts used to remove the vertical TE_{113} mode from the vicinity of the $\pi/2$. The end tuners are not visible in the picture but one of them is hidden from view by the leftmost coupling post. One of the bridge-coupler coupling slots is visible beneath that coupling post.

Figure 9 is an exterior view of the same bridge coupler. The maze of plumbing on top is to provide cooling for the coupling posts.

V. TUNING PROCEDURE

Eventually the bridge-coupler tuning became very straightforward. Each of the two tanks coupled by the bridge coupler was individually tuned.[6] Then they were joined by the previously shorted bridge coupler. The end tuners on the bridge coupler were adjusted so that the resulting $\pi/2$-mode frequency was nominally the same as the average of the two tanks. The post couplers and the bridge-coupler coupling cells were adjusted for zero-power-flow phase shift and for symmetry if the bridge coupler was to be driven. Finally, the center post was rotated to match the average field of the two tanks. Occasionally, if large adjustments had to be made, several iterations were necessary to complete the tuning. Perturbation experiments have been made to verify the $\pi/2$-mode behavior of systems with post-coupled bridge couplers.

VI. SOME CONJECTURES

Experience with the behavior of long post-coupled bridge couplers leads to some conjectures about resonantly coupled Alvarez linacs. The stem-coupled linac at Brookhaven[3] is apparently coupled by the vertical TE_{11n} family of modes, originally much lowered in frequency by the presence of the drift tube and its support, but then raised in frequency by additional stems. The post-stabilized linac, on the other hand, uses the horizontal TE_{11n} family of modes, lowered in frequency by horizontal tuning posts. The possibility exists that fewer than n posts could be used in this structure so long as the modes in use were sufficiently higher than the operating frequency. This possibility has been considered by Swenson[4] of LASL and Bomko et al.[5] of the U.S.S.R.

VII. CONCLUSION

Having successfully tuned 68 bridge couplers varying in length from 22-34 inches using one to seven posts, we are confident that we have a qualitative understanding of their operation and tuning.

ACKNOWLEDGMENTS

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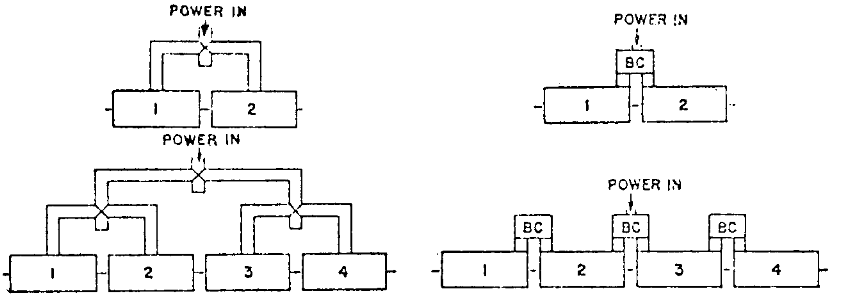


(a) feed by power splitters

(b) feed using bridge couplers (BC)

Fig.1. Method of using bridge couplers to join 2 or 4 accelerator sections.

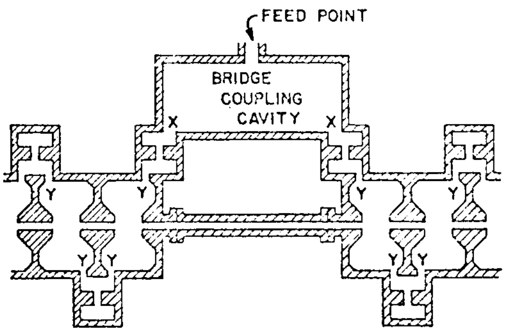


Fig.2. Sketch of the basic form of a bridge coupler.

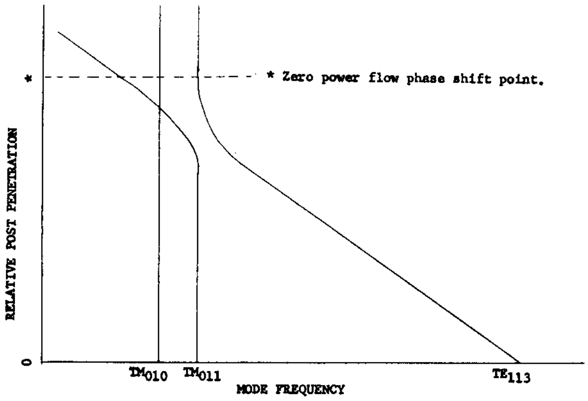


Fig. 3. Effect of post penetration on three bridge-coupler modes.

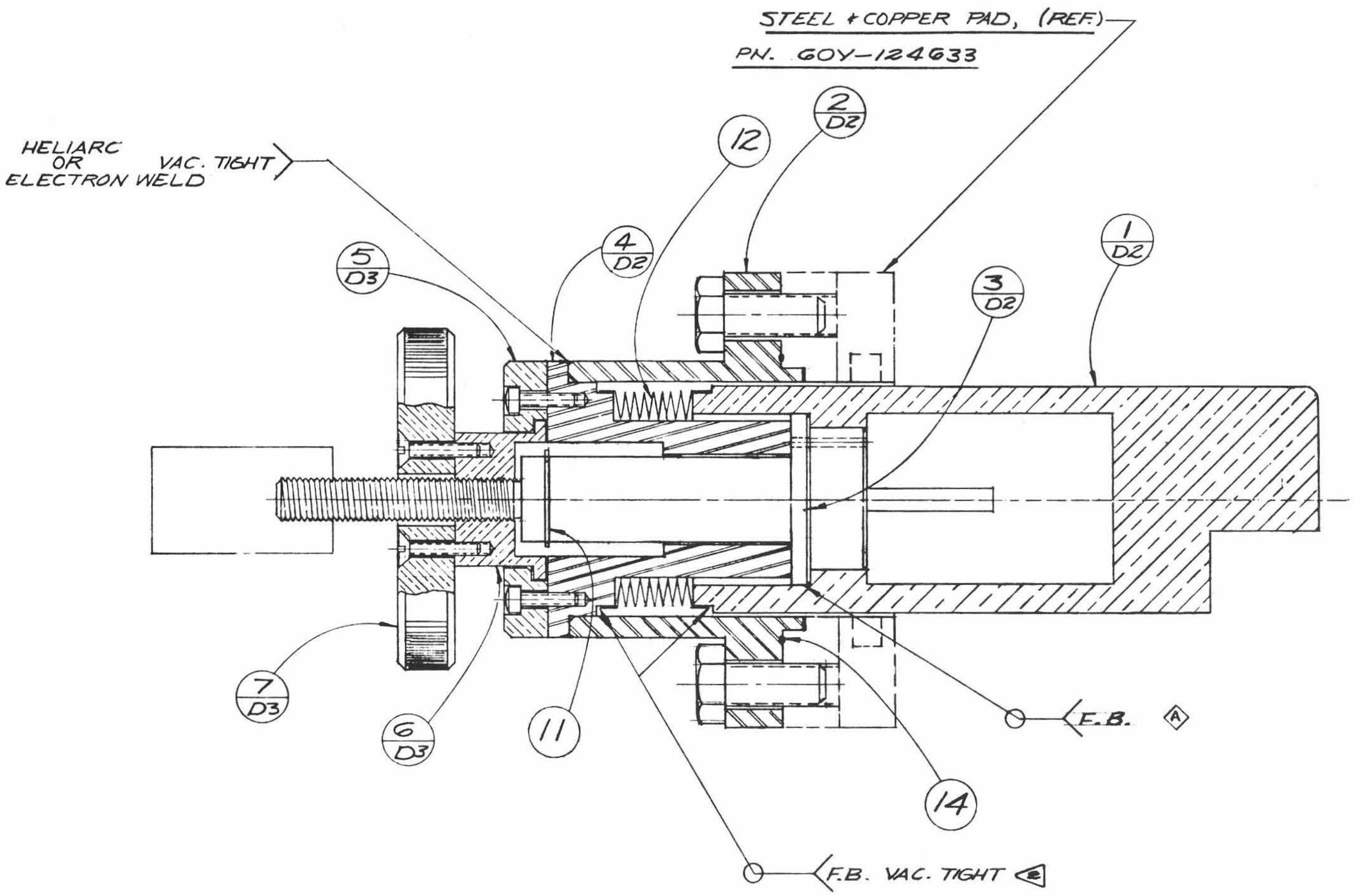


Fig. 4. Cross section of a typical adjustable post coupler.

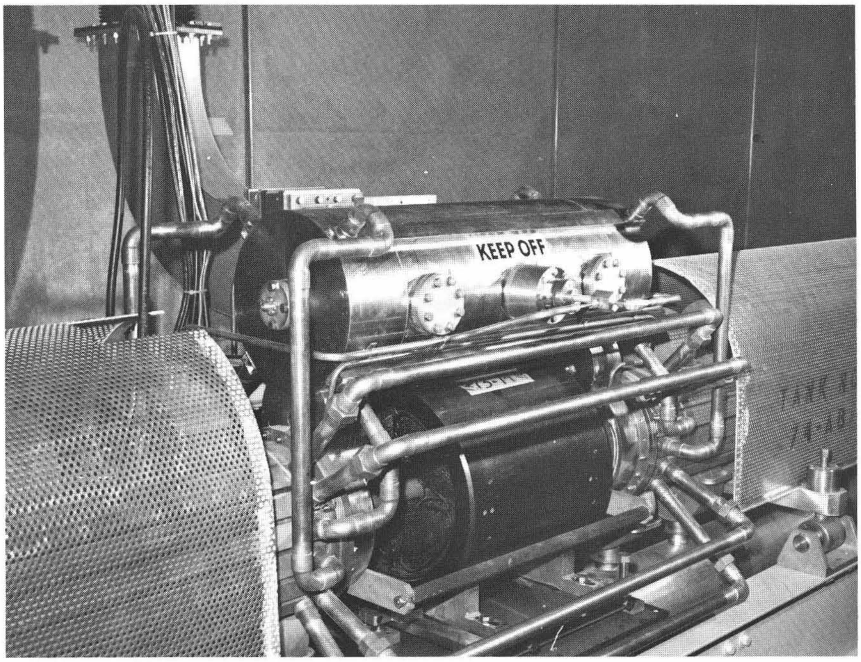


Fig. 5. View of a post stabilized bridge coupler.

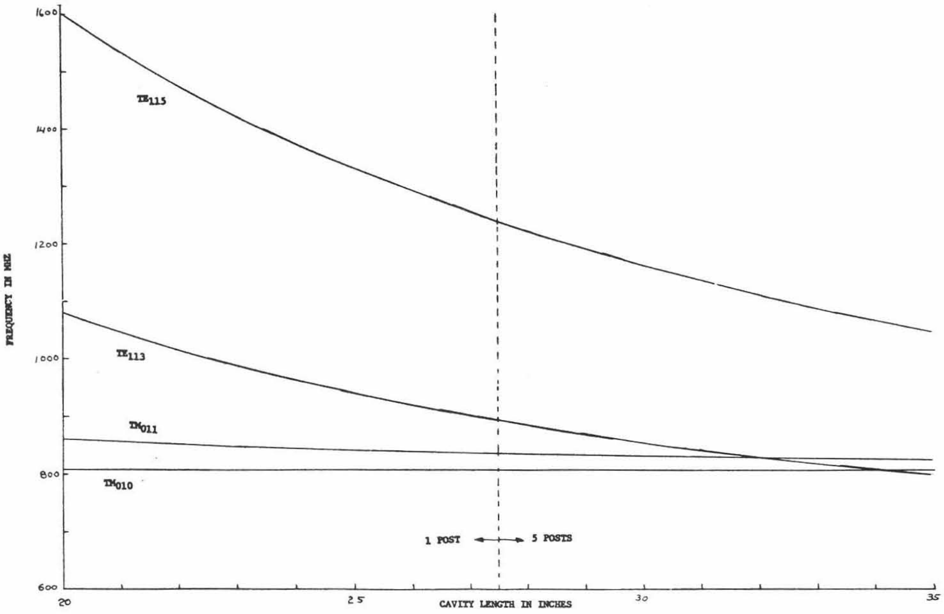


Fig. 6. Mode frequency versus bridge coupler length for the LAMPF bridge couplers.

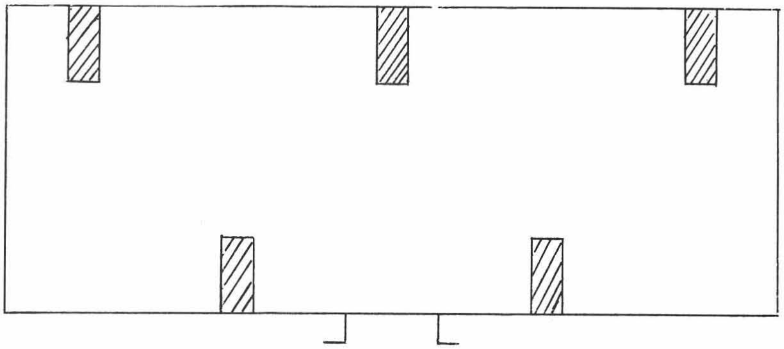
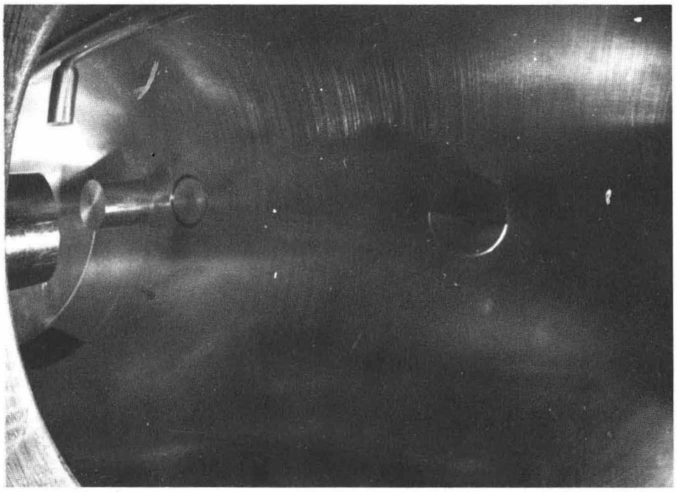


Fig. 7. Sketch of location of coupling posts in the 5 post bridge coupler.



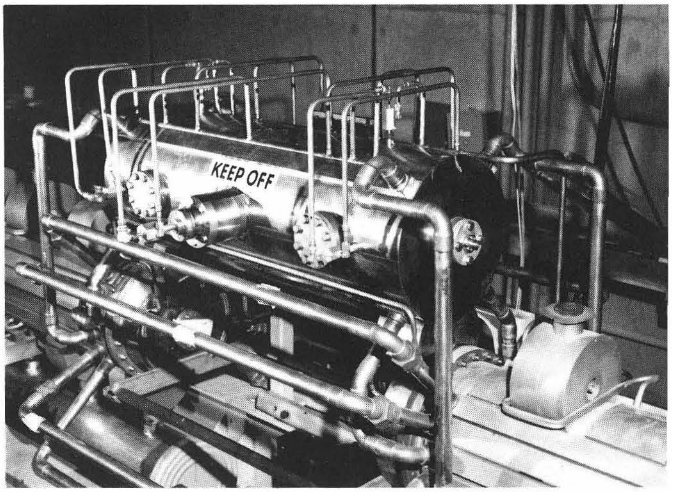


Fig. 8. Interior view of a 7-post bridge coupler.

Fig. 9. Exterior view of a 7-post bridge coupler.