ELECTROMAGNETIC COLD-TEST CHARACTERIZATION OF THE QUAD-DRIVEN STRIPLINE KICKER

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Abstract

The first kicker concept design [1] for beam deflection was constructed to allow stripline plates to be driven; thus directing, or *kicking*, the electron beam into two subsequent beam lines. This quad-driven stripline kicker is an eight port electromagnetic network and consists of two actively driven plates and two terminated plates. Electromagnetic measurements performed on the bi-kicker [2] and quad-kicker were designed to determine: (1) the quality of the fabrication of the kicker, including component alignments; (2) quantification of the input feed transition regions from the input coax to the driven kicker plates; (3) identification of properties of the kicker itself without involving the effects of the electron beam; (4) coupling between a line current source and the plates of the kicker; and (5) the effects on the driven current to simulate an electron beam through the body of the kicker. Included in this are the angular variations inside the kicker to examine modal distributions. The goal of the simulated beam was to allow curved path and changing radius studies to be performed electromagnetically. The cold test results produced were then incorporated into beam models [3].

1 INTRODUCTION

The original kicker design was conceived to allow for the diversion of the electron beam dynamically during a long pulse; thus acting like a beam splitter. Experiments performed on the kicker [4] detail the operating parameters of the system. This paper outlines the electromagnetic cold-test measurements performed on the kicker as part of the analysis and concepts for the kicker pulser requirements.

Figure 1. The quad-kicker in the Experimental Test Accelerator (ETA-II) beamline as part of the verification experiments [4]. Note the four ports on each end of the quad-kicker. These ports connect directly to the deflection plates. Two of the white pulser cables are visible in the foreground.

Due to beamline usage and the motivations for the cold-test measurements, the kicker was tested in the LLNL Electromagnetics Laboratory using a variety of vector network analyzers (to sweep the frequency band) and time domain impulse generators and scopes.

Figure 2. The quad-kicker was tested using frequency- and time-domain scopes to cover the band for the swept frequency tests and instantaneous impulse tests.

2 KICKER PORT TESTING

Each of the eight input ports of the kicker were tested over a frequency band from 45 MHz to 500 MHz. Two ports connected to the input and output of each of the four plates through a tapered transition region through a coaxial connector. The pin on the plate connected directly to the center pin of the coax. The results of the measurements (shown in Figure 3) indicate a broadband match with the exception of resonances caused by the feed regions. The comparison in Figure 4 illustrates the feed region effects based on experience learned from the bi-kicker and quad-kicker development activities.

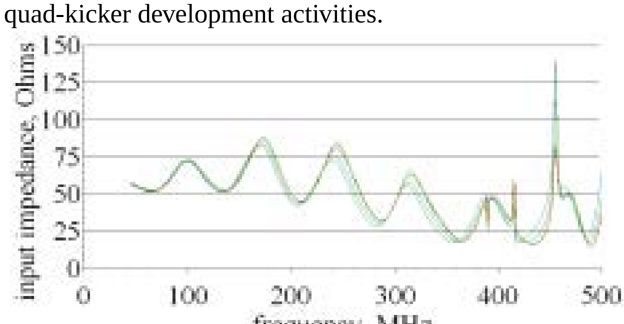
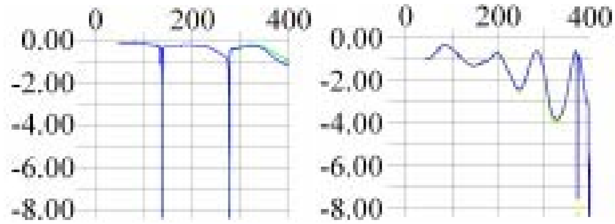


Figure 3. The input impedance of each of the ports is shown vs. frequency (margin of error is +/- 0.3 ohms). The spikes at 388.75, 414.0, 460 MHz are higher order mode resonances and correspond to Q's of 310 (quadrupole mode), 61 (dipole mode), and 29 (dipole mode) respectively.



bi-kicker quad-kicker

Figure 4. The input reflection coefficient (in dB) vs. frequency (in MHz) of the bi-kicker was much more uniform due to the more gradual transition region after the coaxial feeds. The quad-kicker had a more abrupt transition after the coax and has a larger input reflection coefficient. The spikes in the bi-kicker response curve are due to the grounded plate resonances and were eliminated in the quad-kicker.

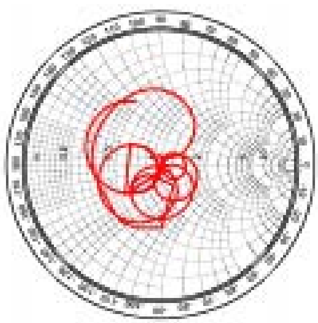


Figure 5. The complex input impedance of the kicker is shown for one of the ports (the variance between the ports is +/- 7 ohms due to fabrication differences). The three straight lines in the curve represent under sampling.

3 CROSS COUPLING TERMS

The cross-plate coupling terms of the kicker corresponded to the coupling between adjacent and opposite ends of the various plates to each other. These coupling terms represent energy that couples from the kicker pulser driven plate to those plates that are terminated, thus inducing fields onto plates that are not directly driven. These cross coupling terms are appreciable (8% and 20%) even at the lower frequencies.

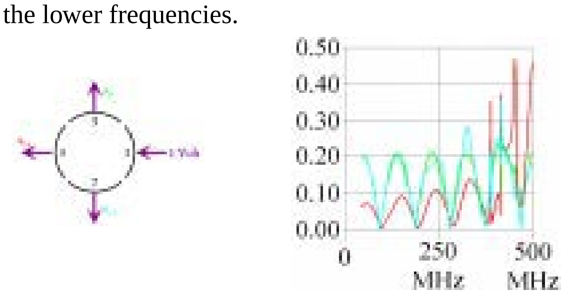


Figure 6. The magnitude of the coupling between adjacent plates vs. frequency shows significant cross coupling at multiples of 80 MHz. The adjacent plate coupling is 20% and the cross plate coupling is 8%.

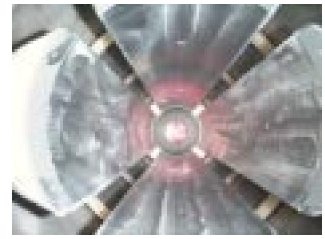


Figure 7. The quad-kicker plates are identical and each is connected to a 50-ohm coaxial port. For the experiments [4] using the existing kicker pulsers, two of the plates were driven and the other two plates were terminated in matched loads. Each plate is 78 ^{o} wide (12.87 cm radius) and is supported by rexolite.

4 FORWARD COUPLING TERMS

The kicker pulsers drive one end of the plates and the other end is mated to reduce reflections on the plate structure. The loss along the plates is less than 1 dB and the transfer function from one end of the plate to the other is shown in Figure 8.

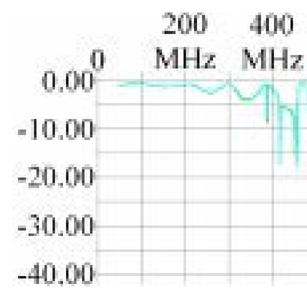


Figure 8. The transfer function (in **dB**) vs. frequency from one end of the plates to the other end. In the low frequency part of the spectrum, the curves for the various plates overlap to within 0.025 dB.

5 KICKER RESPONSE

For identification of the transient properties of the kicker and the association between a simulated beam and the kicker ports, a ramp pulse (0.95V per 300ns) was used to excite the wire-current. The resulting waveform that was induced on the downstream output port is shown in Figure 9.

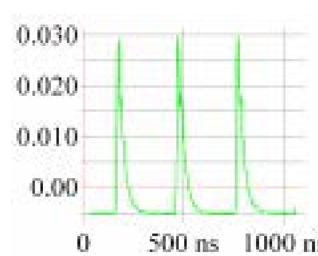
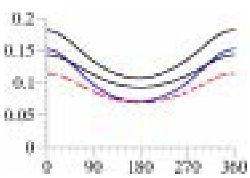


Figure 9. The effect of the 300 ns ramp pulse coupling from the wire-current to one of the kicker plates being monitored at a downstream port. Notice that after about 70 ns, the coupling stabilizes to -0.005 Volts (corresponds to -0.53%). The spikes occur at the transition of each 300 ns excitation ramp waveform.

When the central wire representing an electron beam was excited through the main body of the kicker, the "pump-up" time of the kicker was observed as an equivalent time constant of 70 ns. This corresponds to the cavity fill time between the simulated beam pulse and the ports.

6 AZIMUTHAL VARIATIONS

During the course of the measurements, the azimuthal variation caused by the offset-rotations of the current-wire was measured and compared against the theoretical solution for an offset wire in an ideal kicker. A comparison between this theoretical solution (dashed line) for an electrostatic coupling case and that for the experimental cases at the peak coupling points of 68.4, 139.2, and 209.4 MHz is shown in the above plot. The angular frequency spectrum of the above plots was taken to determine the relationships between the various modes (**D**ipole, **Q**uadrupole, and **S**extupole) in the kicker and those modal ratios are shown in the table below and are



	static	**68.4**	**139.2**	**209.4**	**eq (1)**
$\mathbf{V_Q/V_D}$	0.136	0.134	0.140	0.169	0.174
$\mathbf{V_S/V_D}$	0.0252	0.0315	0.0327	0.0351	0.0203

in a similar range to that determined by integrating the simple analytic representation [5] along the plate boundaries shown in Equation 1,

$$\frac{V_S}{V_D} = \frac{4q\frac{a^3}{b^4}\int_{-\phi}^{\phi}\cos 3\theta\, d\theta}{4q\frac{a}{b^2}\int_{-\phi}^{\phi}\cos\theta\, d\theta} = \frac{1}{3}\frac{a^2}{b^2}\frac{\sin 3\phi}{\sin\phi} \qquad \frac{V_Q}{V_D} = \frac{1}{2}\frac{a}{b}\frac{\sin 2\phi}{\sin\phi}, \quad (\mathbf{1})$$

where ϕ is the plate half-angle (39^o) but 45^o was used to be consistent with the theory since Eq(1) assumes no gaps, b is the plate radius (12.87 cm), and a is the radius to the wire position (3.175 cm). Differences can be attributed to gap effects between plates, end effects near the feeds, and simplifications of the analytic representation.

The equivalent circuit model for the kicker is composed of a series of transmission line sections and cross-coupling terms representing the plate-to-plate effects.

7 CONCLUSIONS

Although the frequency range of interest for kicker applications is in the low hundreds of megahertz range and is based on the bandwidth of the kicker pulser, there were initial concerns about beam induced effects. For this frequency range: the cross coupling between adjacent ports is less than 14 dB; the input impedance for each port is between 50 and 90 ohms; transmission along the plates experiences less than 1 dB of loss; and cavity measurements show a cavity pump-up time, and a dI/dt coupling between the current-wire and the cavity.

The input reflection coefficient for some higher frequencies can approach 30%; but these frequencies are expected to be outside of the normal operating range of the kicker. However, in making the modifications from the bi-kicker design to the quad-kicker design, the frequency band where these effects make a pronounced difference was lowered and is closer to the operating band. Thus, subsequent changes in the kicker design would need to be leery of this limit. It should be emphasized however that the elimination of the shorted plates from the bi-kicker design substantially improved the operation of the quad-kicker [4].

8 ACKNOWLEDGMENTS

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9 REFERENCES

[1] G.J. Caporaso, Y.J. Chen, B.R. Poole, "Transmission Line Analysis of Beam Deflection in a BPM Stripline Kicker," 1997 Particle Accelerator Conference, Vancouver, B. C. Canada, May 12-16, 1997, LLNL UCRL-JC-126073.

[2] S. D. Nelson, "Electromagnetic (Cold Test) Characterization of the bi-Driven Kicker," Lawrence Livermore National Laboratory, UCRL-ID-129997, January 1998, http://www-dsed.llnl.gov/documents/em/sdnkick98/

[3] B.R. Poole, G.J. Caporaso, Y. J. Chen, "Analysis and Modeling of a Stripline Beam Kicker and Septum," LLNL, 1998 Linear Induction Accelerator Conference (Linac98), Chicago, Ill. USA, August 24-28, 1998.

[4] Y.J. Chen, G.J. Caporaso, J. Weir, "Experimental Results of the Active Deflection of a Beam from a Kicker System," LLNL, 1998 Linear Induction Accelerator Conference (Linac98), Chicago, Ill. USA, August 24-28, 1998.

[5] A. W. Chao, "Physics of Collective Beam instabilities in High Energy Physics," John Wiley & Sons, Inc., pg 6, 1993, ISBN 0-471-55184-8.