SIMULATION AND MEASUREMENT OF THE ELECTROSTATIC BEAM KICKER IN THE LOW-ENERGY UNDULATOR TEST LINE*

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Abstract

An electrostatic kicker has been constructed for use in the Low-Energy Undulator Test Line (LEUTL) at the Advanced Photon Source (APS). The function of the kicker is to limit the amount of beam current to be accelerated by the APS linac. Two electrodes within the kicker create an electric field that adjusts the trajectory of the beam. This paper will explore the static fields that are set up between the offset electrode plates and determine the reaction of the beam to this field. The kicker was numerically simulated using the electromagnetic solver package MAFIA [1].

1 INTRODUCTION

The kicker is positioned just downstream of a 2.856-GHz high-brightness thermionic-cathode rf gun. The rf gun produces peak beam energies of up to 4.5 MeV and peak macropulse current of up to 1.3 A at a repetition rate of 10 Hz. This greatly surpasses the operational limit of the thermionic gun currently in use by the APS. The APS linac then accelerates this beam to energies of approximately 650 MeV before being transported to the LEUTL beamlines. However, this output exceeds the radiation safety restrictions on the linac vault [2,3].

The kicker was designed to dump much of the beam before it reaches the linac and to retain only a fraction of the total beam produced by the rf gun. To achieve this, the kicker is physically surrounded by a constant magnetic field. The field envelopes the kicker, thus deflecting the beam into a dump positioned just past the kicker. The kicker is pulsed by a 150-ns generator, which raises the potential of the electrode plates to 25 kV. When this potential exists, it is sufficient to nullify the effects of the magnetic field, thereby enabling the bunch to pass the kicker and continue along the LEUTL beamline.

Since the bunch length is on the order of picoseconds while the electrodes are pulsed for nanoseconds, the field is considered static. The uniformity of this field, as well as effects due to fringing are discussed in this paper.

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2 DESCRIPTION

As shown in Figure 1, the kicker consists of dielectric standoffs, two electrodes, and a feedthrough. The stainless steel electrodes are 10 cm long and separated by 1 cm. They are electropolished with rounded edges in order to improve their reliability under high voltage. An electron beam passing through the kicker can be deflected by nearly 4 mm due to the constant magnetic field. In order to prevent beam scraping, the electrodes are offset from the beamline axis by roughly 2 mm in the direction of the magnetic force. This asymmetry creates a potential perturbation in the electric field that may result in irregularities in the electric field pattern between the electrodes.

The dielectric standoffs serve a dual purpose. They function as a mechanical support for the electrodes and as an alignment device to ensure that the electrodes are positioned within 0.1 mm of specifications. The 35-kV vacuum rated, angled feedthrough supplies the 25-kV potential from the constant current supply through coaxial cables [2].

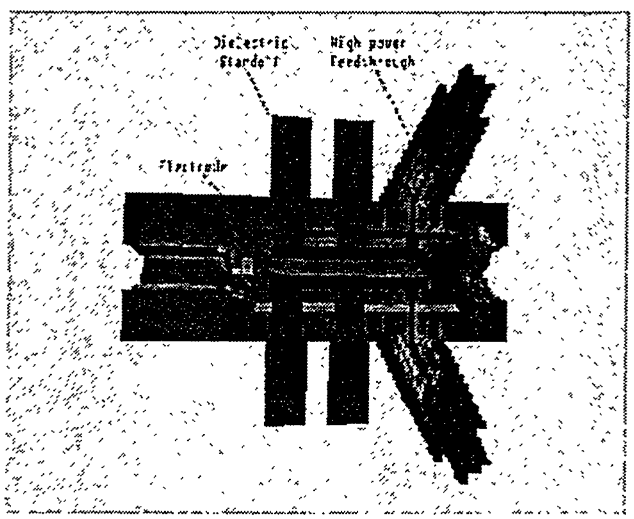

Figure 1: MAFIA rendition of kicker.

3 NUMERICAL SIMULATION

Simulations were done with MAFIA 4.01 ECAD software. Two questions were primarily investigated during the simulations. The first question concerns the possible effects of shifting the electrodes off-axis. The second question arises from the actual design criteria, that is, how does the beam behave as is traverses the enclosure. In order to evaluate these issues, the structure

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was first modeled as accurately as possible within the capabilities of MAFIA. The simulated structure faithfully modeled the important electrical and physical properties of the kicker. The offset electrodes consisted of rounded edges as did the corners of the interior chamber walls to prevent radiating sources from potentially corrupting the computational domain. The angle of the feedthrough was also considered in order to allow for any slight variation in the field that this produced. The simulation model can be seen in Figure 1.

3.1 Static Solver

The uniformity of the electric field between the electrode plates is of great importance to the reliability and predictability of the kicker. A 25-kV potential was created across the plates be means of the MAFIA static solver module. Using the cgxyz solver, the field strength throughout the volume of the kicker was evaluated. Although the electrodes were offset 20% from the axis, the uniformity of the field strength was verified. An arrowplot showing the constant E-field as well as a visual representation of the fringing fields can be seen in Figure 2. Note that the electrodes are variously colored in order to allow different potentials to exist on each surface.

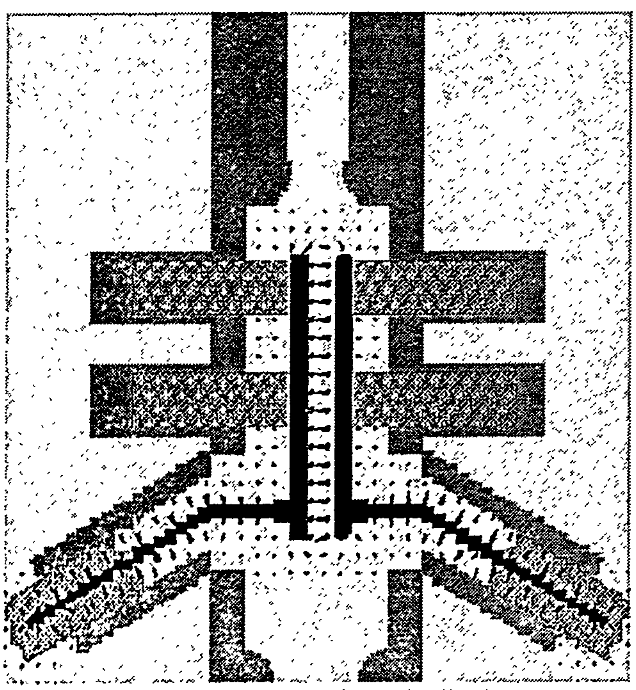

Figure 2: Electric field distribution.

Of primary concern is the uniformity of the field along the beam axis, since this is the potential imposed on an intruding beam. Ideally, there exists no field outside the electrodes, while a strong transverse field serving to deflect the beam upward would exist between the plates. The actual field strength along the beam axis is plotted in Figure 3. Since the gap between the electrodes in 1 cm, the maximum electric field between the plates is 2.5 MV/m. In the plot, the electrodes begin at approximately 3.9 cm and extend to 13.9 cm. The virtually constant field strength may be viewed along the entire surface of the electrodes in Figure 4.

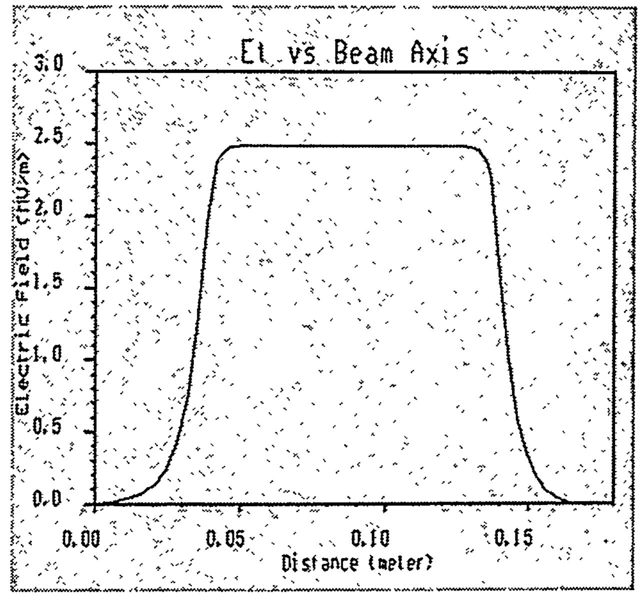

Figure 3: Transverse electric field vs. distance.

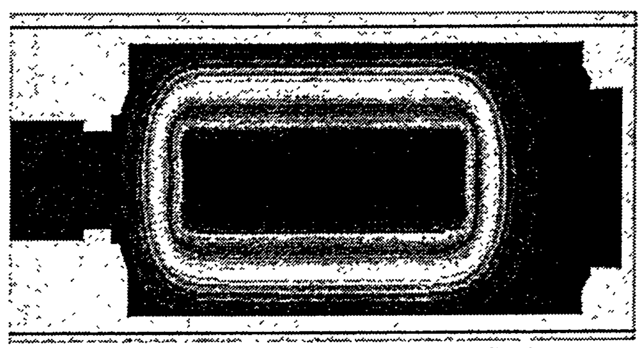

Figure 4: Contour plot of electric field.

3.2 Particle-in-Cell Solver

The module TS3 was executed in order to evaluate the overall impact of the kicker with an actual electron bunch passing through the static field. The Gaussian beam used in the simulation had a bunch length of 20 ps with an energy of 3.5 MeV and a charge of 350 pC. Given these parameters, a beam deflection of 3.57 mm was calculated analytically. Numerical simulations that account for the effects of fringing fields found the deflection to be approximately 10% greater as the beam traveled the entire length of the kicker chamber.

A plot of the beam can be seen in Figure 5. In this plot, the path of the beam is traced to show the aggregate deflection resulting from the electrodes.

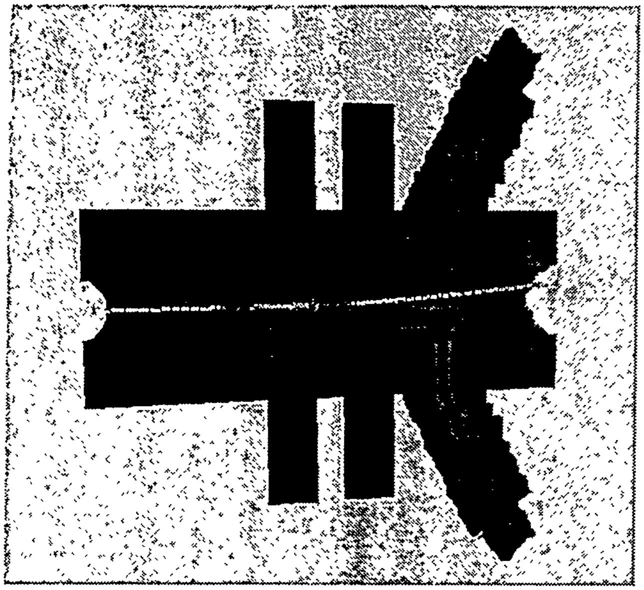

Figure 5: Beam trajectory.

4 MEASUREMENT

Preliminary measurement of the relative field distribution in the kicker was made using the HP8753C vector network analyzer. Initially a two-port through calibration was made with a thin plastic line positioned between the electrodes. A small metallic disk, 0.125 inches long with a 0.125-inch diameter, was attached to the line and pulled along the beam axis between the electrode plates. The presence of the disk modified the capacitance of the electrodes. Since the capacitance due to the disk is dependent upon the magnitude of the electric field, the field strength was derived from the power transfer through the plates. This transfer characteristic was then recorded by the network analyzer. The limited distortion of the electric field due to the disk was ignored.

Assuming that the structure is much smaller than a wavelength of the excitation signal, approximate field distributions can be derived. As expected, lower signal frequencies gave noisy results since the coupling was small, whereas higher frequencies gave a distorted field distribution due to transmission line effects. It was found that for 10-cm-long electrodes, a few MHz to tens of MHz gave results considered dependable. Figure 6 shows the measured field strength along the beam axis for a 10-MHz signal. The relative electric field distribution can be approximated from this data as:

$$U = \sqrt{|S_{21}|^2 - 1}.$$

The above rf technique was used to approximate the static electric field strength. However, reports exist on the measurement of these fields using a truly static approach [4,5]. At this time, techniques for such measurements are not as well developed as those for magnetic fields.

5 DISCUSSION

The numerical simulation demonstrates the effectiveness of the kicker as a beam chopper. In spite of the offset electrodes, the uniformity of the field was analyzed and found to be satisfactory. The numerical simulation as well as the attempted measurement of the electric field strengths provided results close to those calculated. However, the method used for static field measurements will need to be refined in order to provide more dependable results.

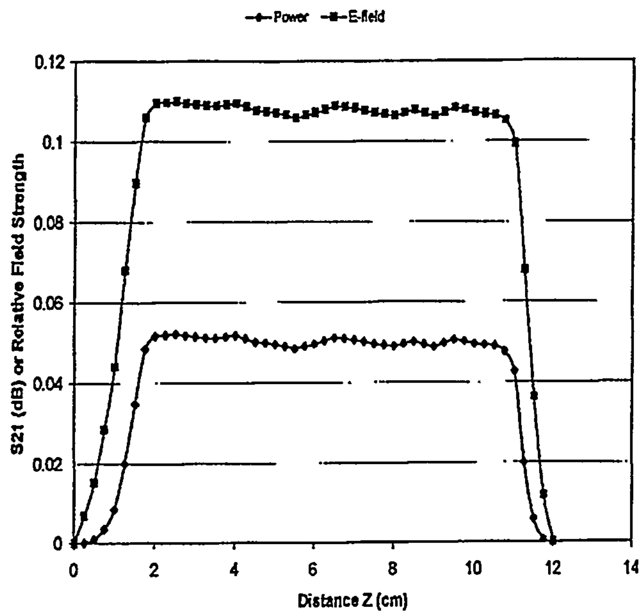

Figure 6: Measured electric field uniformity.

6 ACKNOWLEDGEMENT

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7 REFERENCES

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