DESIGN OF A FAST EXTRACTION KICKER FOR THE ALPHA PROJECT*

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Abstract

In this report, we present our design of a fast extraction kicker for the ALPHA project. Due to the fast rise time and high voltage requirement, we choose a traveling wave kicker. Both 2D Posisson and 3D Microwave Studio simulations are carried out. Uniformity of electric field, energy transmission through the stripline structure and time response of the kicker are studied carefully. A prototype kicker will be built and tested.

INTRODUCTION

The Advanced Electron-Photon Facility (ALPHA) [1] is an electron storage ring we are building at Indiana University Center for the Exploration of Energy and Matter (CEEM). The mission of this machine is to provide high power electron beams for radiation testing and high brightness X-Rays for the IU community.

One of the primary requirements for the radiation effects testing program is the intensity and uniformity of the electron radiation dose. During the accumulation operating mode, we will accumulate up to 1000 nC electron beam with a length of 50 ns and kick them to the extraction line in one turn. In this paper, we present our design of the fast extraction kicker. 2D Poisson [2] and 3D Microwave Studio simulations [3] are performed to design the structure and check the property.

SPECIFICATION OF THE KICKER

The circumference of the ALPHA ring is 20 m (66.7 ns). Thus the rise time of the kicker should be no more than 10 ns. The length of kicker is also limited by the available space in the ring, which is confined to 450 mm from flange to flange. The short length of the kicking field imposes a high voltage requirement on the kicker. Considering the fast rising time and high voltage, we choose a traveling wave kicker with a stripline structure. The kicker specification [4] is shown in Table 1.

The kicker gap is chosen to be the same as the inner diameter (ID) of the beam pipe to reduce the discontinuity and wakefield. The strip length is chosen to be 30 cm according the requirement of a high field region. The ID of kicker vacuum chamber is determined by available vacuum pipes and conical reducers from commercial suppliers.

Table 1: Kicker Specification

Beam Energy E_b	50 MeV
Kicker Gap h	47.6 mm
Kicker Vacuum Champer ID	73.0 mm
Field Rise Time	10 ns or less
Maximum/minimum Kick Angle θ	23/10 mrad
Duration of Kicker	100 ns
Flange to flange distance	45±0.2 cm
Length of High field region	30-35 cm

NUMERICAL SIMULATION

Simulations are done with 2D Possion and 3D Microwave Studio program. In the 2D Possion simulation, we study different geometries for the stripline and choose one that gives us a good uniform kicking field. This gives us a starting point for the 3D study. In the Microwave Studio simulation, we revise and trim the strip to match 50 Ω characteristic impedance. Energy transmission and time response are also investigated.

2D Possion Simulation

Using the 2D Possion simulation, we have studied the effects of geometry of electrode on the uniformity of electric field. Figure 1 shows an example of 2D electric field line and Fig. 2 shows the field uniformity in the transverse direction.

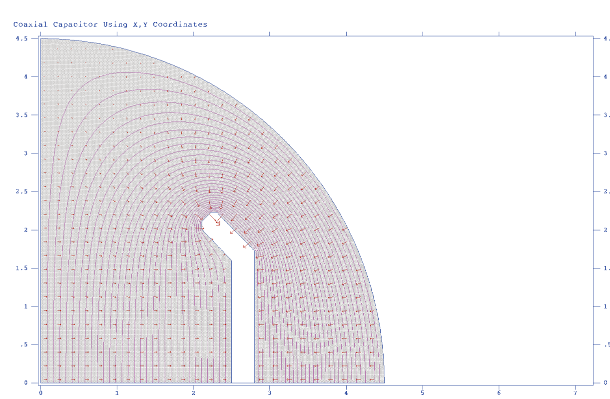

Figure 1: 2D electric field line in the kicker.

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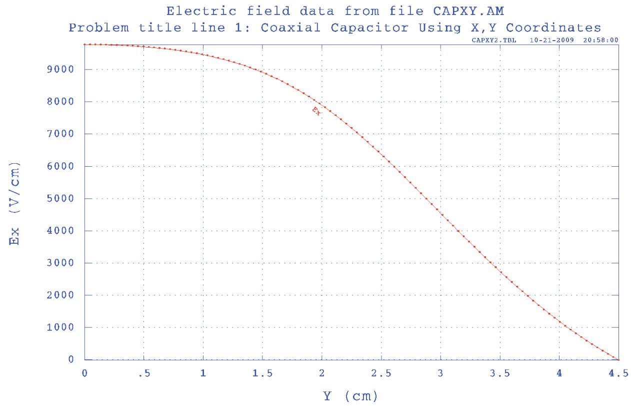

Figure 2: Kicking field along the central beam line.

3D Microwave Studio Simulation

Impedance Matching After determining a rough geometry from the Possion simulation, we revise the strip electrode in Microwave Studio to obtain a 50 Ω characteristic impedance for the odd TEM mode (kicking mode). 50 Ω is a standard output impedance of RF devices. By this matching scheme, we can minimize the reflected energy on the power supply, which is important for a high power pulse. Figure 3 shows the odd TEM mode.

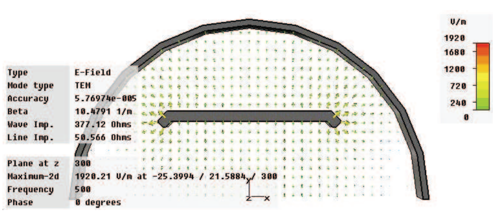

Figure 3: Odd TEM mode along stripline. The characteristic impedance is 50.6 Ω.

There is also an even TEM mode, which applies the same voltage on both electrodes. This corresponds to the beam induced voltage. When the odd mode has 50 Ω characteristic impedance, the even mode usually doesn't. However, beam induced voltage is much smaller than the applied kicking voltage so we can ignore this part. Figure 4 shows the even TEM mode.

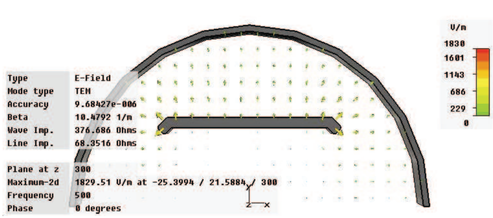

Figure 4: Even TEM mode along stripline. The characteristic impedance is 68.4 Ω.

Energy Transmission To calculate the energy transmission from a downstream port linked with a power supply to an upstream port linked to a dummy load, we build a 3D model in Microwave Studio. The ports are approximated by coaxial cylinder with 50 Ω characteristic impedance. Ceramic standoffs are added to support and align the stripline electrode. We also consider the tapering on each ends and the tube linked to a vacuum pump.

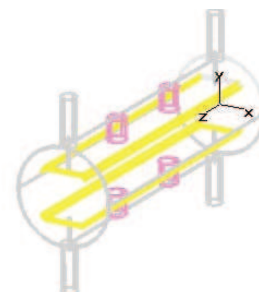

Figure 5: Perspective view of kicker. Here the tapering and the vacuum pump tube are not shown.

Figure 6 shows the pattern of our kicking pulse, and Fig. 7 shows its discrete fourier transform (DFT). We can see its frequency range is no higher than 200 MHz.

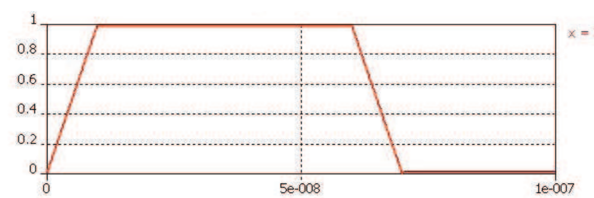

Figure 6: Pulse signal pattern: A square wave with 10 ns rise time, 10 ns fall time and 50 ns flat top.

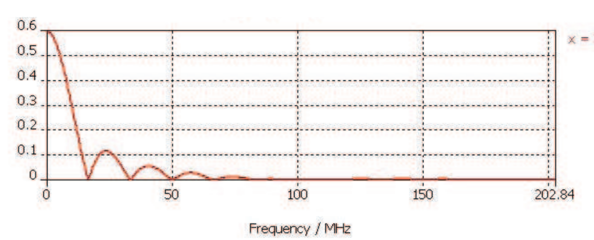

Figure 7: The DFT of pulse signal.

The scattering parameters from the pulse port to the dummy load port is shown in Fig. 8. Under 200 MHz, S_{11} is all below 20 dB, which means little power reflection.

Electric Kicking Field From Microwave Studio, we can calculate the kicking field along both transverse and longitudinal axes of the kicker. The results are shown in Fig. 9 and 10. The uniformity of the kicking field meets the design requirement.

Real Time Response of Input Pulse By the transient mode of Microwave Studio, we can calculate the output

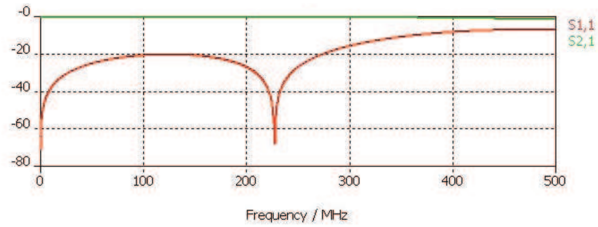

Figure 8: The scattering parameters between pulse port and dummy load port.

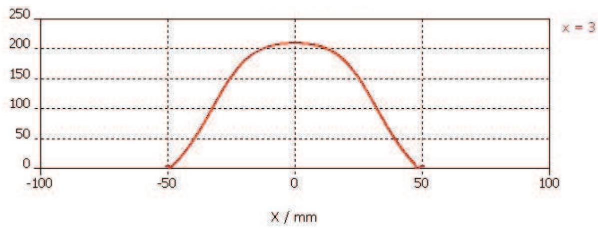

Figure 9: Electric field along the transverse center of kicker.

signal and the reflected signal in the time domain. The result is shown in Fig. 11. Due to the kicker length, the output signal is about 2 ns behind the input signal. This means the rising time of power supply should be limited within 8 ns, to limit the total rise time of the kicker within 10 ns.

REQUIREMENT OF POWER SUPPLY

The kicker voltage $V_\perp$ is:

$$V_\perp = \frac{h \cdot E_b(\mathrm{eV})}{2gl} \times \theta$$

For our current design, the length of the kicker l is 30 cm, the kicker gap h is 4.76 cm and the width of the stripline W is 5.08 cm. The coverage factor g is:

$$g = \tanh\left(\frac{\pi \times W}{2 \times h}\right) = 0.93$$

For a 50 MeV beam, the minimum kick angle θ_{min} of 10 mrad requires voltage:

$$V_\perp = \frac{4.74 \times 50 \times 10^6}{2 \times 0.93 \times 30} \times 10 \times 10^{-3} = 42.5\mathrm{kV}$$

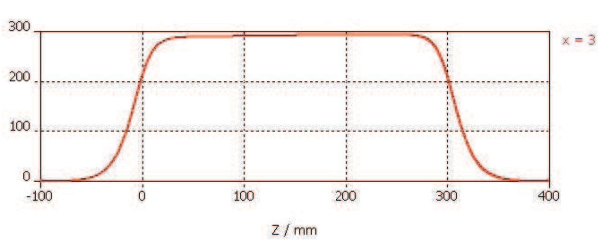

Figure 10: Electric field along the beam line center of kicker.

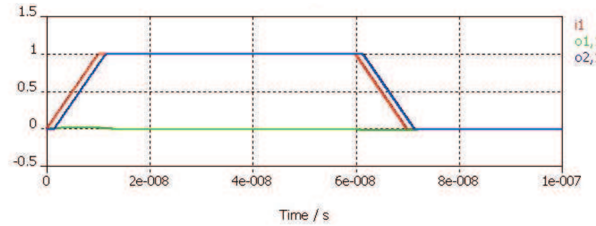

Figure 11: Input signal (red) at pulse port, output signal (blue) at dummy load port and reflected signal (green) at pulse port.

We can also calculate the voltage requirement of the maximum kick angle θ_{max} of 23 mrad, which is 97.7 kV. The voltage on each electrode is half of the kicking voltage but with opposite polarity. It is a challenge to find a feed through and power supply that can provide such a high voltage, UHV sealing and a fast rise time of 10 ns.

The shunt impedance of the kicker

$$R_s(\omega) = 2Z_c\left(\frac{2cg}{\omega h}\right)^2 \sin^2\left(\frac{\omega l}{c}\right)$$

For our signal, the frequency is very low compared to the length of kicker, so $\sin\left(\frac{\omega l}{c}\right) \approx \frac{\omega l}{c}$. Then

$$R_s(\omega) \approx 2Z_c\left(\frac{2gl}{h}\right)^2 = 1.37 \times 10^4\Omega$$

With the shunt impedance, we can calculate the peak power on each electrode $P_k = V_p^2/R_s$, where $V_p = V_\perp/2$, and the average power with certain repetition rate [5].

CONCLUSION

For the ALPHA facility, we designed a traveling wave kicker to extract accumulated electron beam in one turn. The characteristic impedance of the stripline structure is 50 Ω. We also consider the effect of ceramic standoff, tapering ends and vacuum pump connection in the kicker. The power reflection and kicking field uniformity are within the requirements. The parameters of power supply have also been calculated. A prototype will be built and tested in near future.

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