Precision fast kickers for kiloampere electron beams[1]

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Abstract

These kickers will be used to make fast dipoles and quadrupoles which are driven by sharp risetime pulsers to provide precision beam manipulation for high current kA electron beams. This technology will be used on the 2nd axis of the DARHT linac at LANL. It will be used to provide 4 micropulses of pulse width up to 120 nsec. selected from a 2 µsec., 2kA, 20MeV macropulse. The fast pulsers will have amplitude modulation capability [1][2] to compensate for beam-induced steering effects [3] and other slow beam centroid motion to within the bandwidth of the kicker system [4]. Scaling laws derived from theory will be presented along with extensive experimental data obtained on the test bed ETA-II [5].

1 INTRODUCTION

The kicker system is the principal element of the beam transport section of DARHT-II. It is similar in design to stripline beam position monitors. There are four equal size electrodes enclosed within a vacuum housing that has a DC bias magnetic dipole wound over the enclosure as shown in fig. 1. An opposite pair of electrodes is driven by fast amplifiers through transit time isolated cables to provide beam deflection. The other two electrodes are terminated at their matched impedance. A drift space between the kicker and a DC septum magnet provides additional separation between the switch positions. The bias dipole is turned on at all times to deflect the beam into a dump. When an x-ray pulse is desired the pulsers activate and overcome the bias dipole force allowing the beam to steer straight ahead through the rest of the transport section and on to the converter target (see fig. 2).

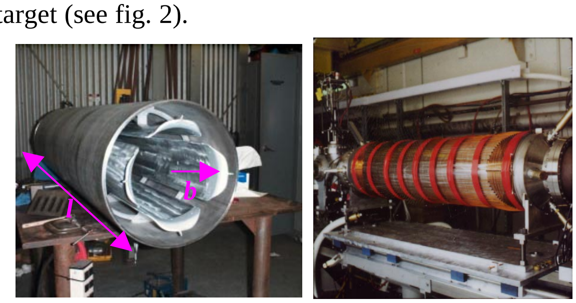

Figure 1: Cross-sectional view of kicker and completed assembly on beam line. The red tape holds the bias dipole windings.

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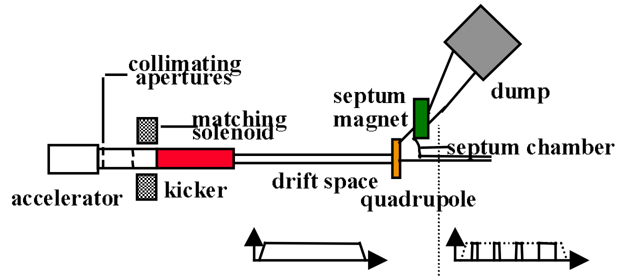


Fig. 2 Kicker system beam line layout

2 SCALING LAWS

The following is a list of scaling laws that relate performance of the system to the kicker geometry, pulser performance, and beam parameters.

2.1 Applied "kick"

The complete treatment of dipole steering through the kicker has no analytic closed form solution. However, a numerical particle code treatment can be found in [6]. If we assume negligible beam-induced steering effects, we have a solution to the differential-integral equation of the kicker as a function of time [4].

$$x(z=l,t)=\frac{c^2}{4V_0 l}\int_{t-2l/c}^{t} V_p(t')(t-t')dt' \qquad (1)$$

where $V_p(t)$ is the applied voltage and c is the speed of light in free space. This equation yields for an ideal square pulse

$$x(z=l)=\frac{V_p}{2V_0}l$$

where V_p is a square output from the pulsers. The characteristic voltage V_0 is a parameter used in determining the amount of kick. It is given by

$$V_0=\frac{1}{32}\frac{b}{l}\frac{\gamma\beta^2 I_0 Z_0}{\sin^2 45°}$$

where I_0=17kA and Z_0=377Ω. The following proportionalities relate the amount of output displacement and angle to the dimensions of the kicker.

$$x \propto \frac{l^2}{b}$$

$$\angle \propto \frac{l}{b}$$

2.2 Rise time of beam

Assume that the pulsers have a linear rising edge with a rise time (from 0 to maximum) of τ_{pulser}. Using eqn. (1), the rise time of the beam as it switches from one position to another is

$$\tau_{beam} = \tau_{pulser} + 2l/c \tag{2}$$

2.3 Beam-induced steering effects

The critical current, I_c, as derived in [3], is a parameter used to measure the amount of beam-induced steering the kicker adds to the beam. One generally would like to design it such that $I_b << I_c$ to minimize this effect where I_b is the beam current. Assuming that this is true, the following laws can be used.

$$I_c \propto \frac{b^2}{l^2 Z_k}$$

$$\text{amplification in input } x \propto 1 + \frac{I_b}{I_c}$$

$$\text{amplification in input } \angle \propto 1 + \frac{I_b}{3I_c}$$

$$\text{amplification in } k_\perp \propto 1 + \frac{I_b}{6I_c}$$

where Z_k is the dipole impedance of the kicker and determined by the radius of the striplines and outer vacuum chamber.

2.4 Quadrupole shaping

The kicker can act like a quadrupole lens, shaping the beam with a dynamically controlled quadrupole electric field. Two pulsers connected on opposite plates similar to the dipole configuration excite the plates with the same polarity voltage signals. The strength which is defined to be the field gradient multiplied by the length of the lens can also be applied here.

$$\frac{dE}{dx} l \propto \frac{l}{b^2}$$

2.5 Emittance

If we assumed a small perturbation from the particle trajectory due to sextupole fields that exist in an activated kicker, we can deduce a simple scaling law for emittance growth through the kicker structure.

$$\Delta\varepsilon \propto \left(\frac{l}{b^3}\right)^2 R_0^{\ 6}$$

R_0 is the beam radius assumed to be constant through the kicker (no space charge effect included). One can see that the distance of the strip lines from the center and the beam size dominate the emittance growth through the kicker.

3 NEW EXPERIMENTAL DATA

A review of the landmark data [1] acquired during testing of the kicker structure is presented alongside new data on emittance and the control system. Septum data is not included due to lack of space.

3.1 Kicker dipole measurements

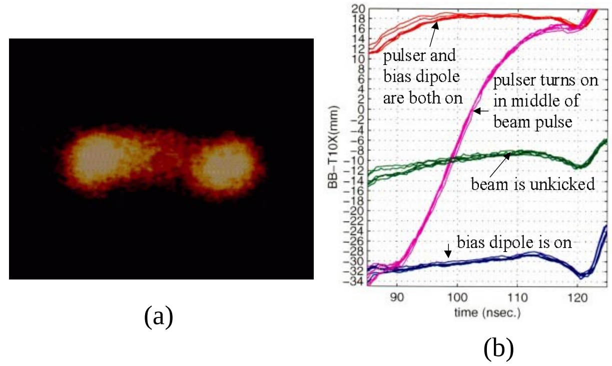


Fig. 3 (a) Photo of beam switching from one position to another. I_b=1200A, V_p=±9kV, camera gated over entire beam pulse, and Δx=4cm. (b) Further downstream sat a resistive wall monitor (a.k.a. beam bug) to measure beam centroid motion. One can see that the risetime of the switched beam is about 20nsec. which matches eqn. (2).

3.2 Kicker quadrupole measurement

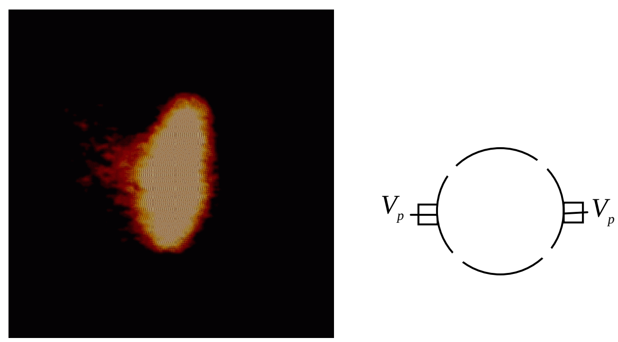


Fig. 4 When the polarity of the pulser signals are the same, a quadrupole instead of a dipole field is formed. The photo is for a beam current of 1200A, V_p=-10kV and the ratio of major to minor axes is 2:1.

3.3 Kicker emittance measurements

Emittance measurements use a pepper pot method [7] whereby the beam impinges on a grid of holes (the pepper pot mask) and the beamlets which survive are allowed to drift a distance. The amount the beamlets expand is used to calculate beam emittance.

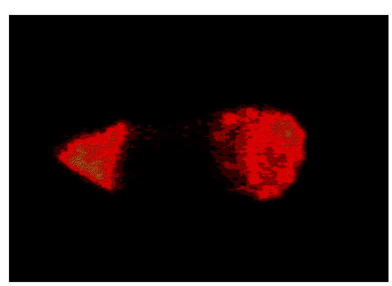
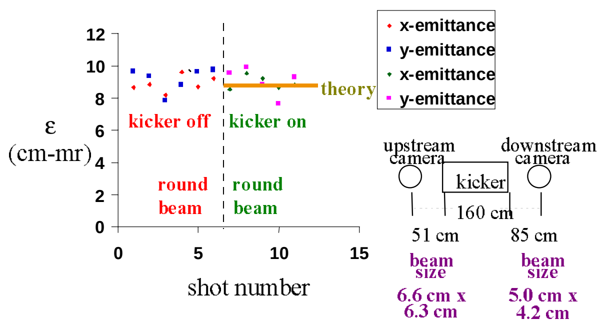
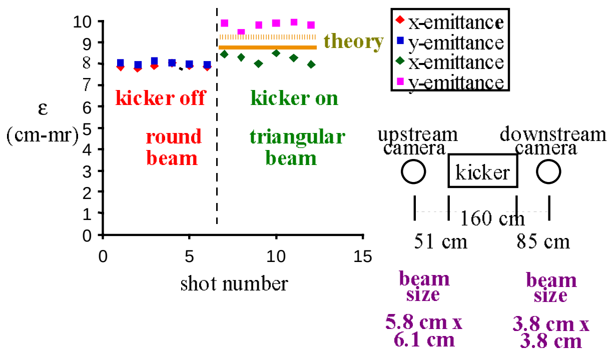


Fig. 5 A large beam being switched from one position to another has a triangular shape due to the sextupole moment in the powered kicker. Sextupole fields, due to their nonlinearity, contribute to emittance growth.



(a)



(b)

Fig. 6 Emittance measured downstream of the kicker with and without an applied voltage. (a) A round beam at the output yielded no emittance growth. (b) A larger beam yielded some emittance growth. The *y*-emittance is slightly larger than in *x* which is predicted by theory.

3.4 Kicker control system

A kicker control system that attempts to regulate beam motion with the dynamics of the kicker has been designed and tested on ETA-II. As shown in Fig. 7, the outer loop takes beam position data and calculates a desired pulser voltage waveform. The inner loop then attempts to match actual output of the pulser to the desired waveform.

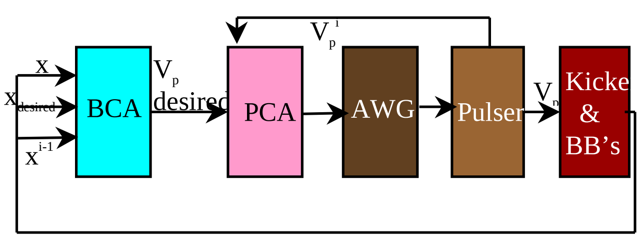


Fig. 7 The beam control algorithm (BCA) takes measured beam location to find the desired voltage needed for the next correction. It then feeds into the pulser control algorithm (PCA) which trys to produce the desired waveform at the output of the pulsers via the arbitrary waveform generators (AWG). The pulses are then sent to the kicker and beam position data is acquired from beam bugs (BB). Each pulser is controlled independently.

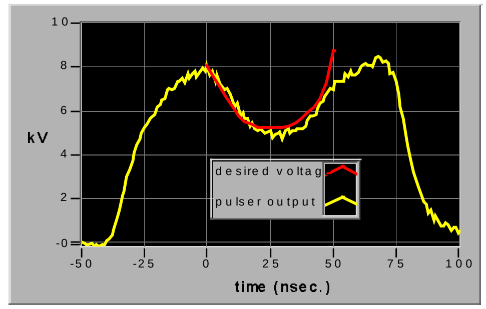


Fig. 8 The desired voltage is achieved at the output of the positive pulser (similar for the negative pulser) to within 2%. Notice the tail end of the waveform has a steep slope that the pulser cannot physically meet.

3.5 The septum magnet and split beam pipe

A septum magnet which is capable of generating two opposing dipole field regions was designed and built [6]. A split beam line and the transport section for two diverging beamlines, one straight-ahead and one at 15° were designed and tested in conjunction with the septum. Results of the experiment have lead us to believe that the aperture of the magnet is too restrictive for a low repetition rate machine such as DARHT. Hence, it is decided that a quad septum will be used in it's place (see fig. 2).

4 CONCLUSION

Development of a complete kicker system is well underway. The kicker structure itself and the septum magnet have been designed and tested on ETA-II. The two components are well-characterized. The kicker structure itself has shown success in beam switching and little emittance growth. The control system has been implemented and is undergoing further refinements. A new generation of solid state pulsers is being pursued. Long pulse precision beam position monitors for beam steering throughout the kicker system have been developed and scheduled to be tested on ETA-II later this year [9].

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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