SIMULATION RESULTS OF CORKSCREW MOTION IN DARHT-II

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Abstract

DARHT-II, the second axis of the Dual-Axis Radiographic Hydrodynamics Test Facility, is being commissioned. DARHT-II is a linear induction accelerator producing 2-microsecond electron beam pulses at 20 MeV and 2 kA. These 2-microsecond pulses will be chopped into four short pulses to produce time resolved x-ray images. Radiographic application requires the DARHT-II beam to have excellent beam quality, and it is important to study various beam effects that may cause quality degradation of a DARHT-II beam. One of the beam dynamic effects under study is "corkscrew" motion. For corkscrew motion, the beam centroid is deflected off axis due to misalignments of the solenoid magnets. The deflection depends on the beam energy variation, which is expected to vary by ±0.5% during the "flat-top" part of a beam pulse. Such chromatic aberration will result in broadening of beam spot size. In this paper, we will report simulation results of our study of corkscrew motion in DARHT-II. Sensitivities of beam spot size to various accelerator parameters and the strategy for minimizing corkscrew motion will be described. Measured magnet misalignment is used in the simulation.

INTRODUCTION

Recently, we have completed the Phase-I commissioning by successfully accelerating beam in DARHT-II [1]. We are proceeding to Phase-II commission (Long-Pulse Beam Optimization) when the minimization of the effective beam-spot size increase due to corkscrew motion is one of the major objectives.

A general analysis of corkscrew motion in induction linacs and their minimization was given in Ref. 2 and 3 by Chen. Such analysis was applied to DARHT-II and showed, using simulation, that corkscrew motions can be controlled using the "tuning-V" algorithm [4]. In this algorithm, transverse steering fields are added to cancel the effect of the error transverse field due to solenoid misalignments, leading to the minimization of the corkscrew motion.

Recently, we have performed more computer simulations in preparation of the Phase-II commissioning of DARHT-II. We have calculated the sensitivity of corkscrew motion to various beam parameters and improved the simulations by using the measured magnet misalignment data derived last year while testing the induction cell modules [5]. In addition, measured steerer fields were used in these simulations. The results of these simulations are described in this paper.

DETAILS OF SIMULATIONS

DARHT-II consists of an injector (between 0 and 100 cm, with the cathode at 0 cm) and a main accelerator (between 100 and 4860 cm). We have simulated the corkscrew motion in the main accelerator using the computer code LAMDA [6]. LAMDA represents the beam pulse with slices along the pulse. It calculates the development of beam size by solving the envelope equation and tracks the beam centroids of the slices under the influence of solenoids, steerers, and beam induced transverse fields. The code can be used to calculate magnet misalignment effects, the beam breakup instability, and the resistive-wall instability.

For the simulations, the injector beam entering the main accelerator has an energy of 2.5 MeV and a current of 1.24 kA. The energy spread of the injector beam is 0.5%, represented by one cycle of a sine wave with amplitude of 12.5 keV on top of the 2.5 MeV, over the pulse length of 200 ns. The magnets were randomly misaligned. The standard deviations in x and y offsets and in rotation and tilts of magnet misalignments are, respectively, 0.1 cm and 1 mrad. Such misalignment is slightly worse than the measured misalignment data of 0.05 cm and 1 mrad respectively. Ten sets of random magnet misalignments were generated to cover the actual misalignment after installation.

Beam centroid data were recorded at 1500-, 3000-, and 4860-cm locations. Figure 1 shows a typical output from LAMDA. It shows the beam centroid location in y direction along the length of the pulse. Data for the first 50-ns were not used because they would be part of the transient and were impacted by the beam breakup modes. Using data between 50 and 200 ns, we obtained y_{max} and y_{min} and calculated the average (y_0) and ranges of centroid offsets (dy) in y-direction.

$$y_0 \_ (y_{max} + y_{min})/2$$
$$dy \_ (y_{max} - y_{min})$$

Together with x_0 and dx similarly obtained for the x-direction, we calculated the average beam offset R and the equivalent corkscrew radius r:

$$R \_ sqrt(x_0 * x_0 + y_0 * y_0)$$
$$r \_ sqrt(dx * dy)$$

The quantity r is equivalent to the effective increase in beam radius.

BASELINE CALCULATIONS

As a baseline for later comparison, we used the beam parameters listed in the last section to calculate R and r for the ten magnet-misalignment sets. The beam was

injected into the accelerator on axis. At the exit of the accelerator (4850 cm), we obtained:

$$R = 0.61 \pm 0.32 \text{ cm}, \quad r = 0.058 \pm 0.028 \text{ cm}$$

The effective increase of beam radius, r, is slightly higher than the DARHT-II requirement of 0.05 cm (10% of beam size). Our results are similar to previous calculation reported [7].
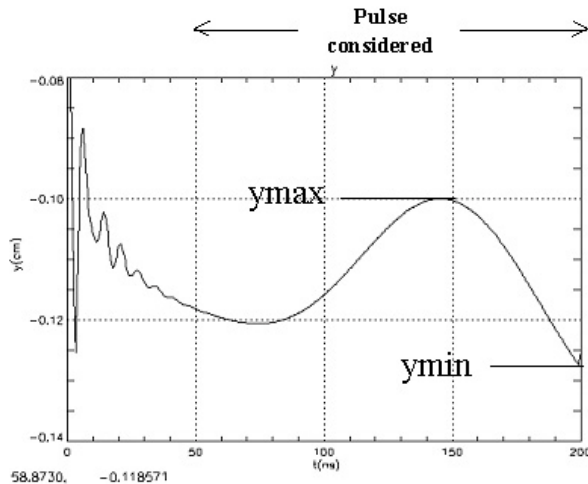

Figure1: Typical LAMDA data showing the beam centroid position along the pulse

SENSITIVITY CALCULATIONS

To understand the effects of different beam parameters on the effective increase in beam radius, we calculated r for beam conditions modified from the baseline calculations. The results are summarized in Table 1.

Table 1: Increase of effective beam radius with modified beam parameters compared to baseline calculations

Beam Condition	Effective radius increase (cm)
Baseline calculation	0.058
0.3 cm input beam offset	0.065
3 mrad input beam tilt	0.121
37.5 keV beam energy spread (3x baseline)	0.177
0.3 cm magnet offset (3x baseline)	0.160
3 mrad magnet rotation and tilt (3x baseline)	0.076

TUNING-V ALGORITHM

LAMDA simulations were used to obtain experience for applying the "tuning-V" algorithm to minimize corkscrew motions. In order to see the changes in beam radius more clearly, the simulations in this section were performed with an energy spread of 37.5 keV, which is three times larger than the baseline beam energy spread. The same set of magnet misalignments was used in all the simulations in this section and the centroid motions were recorded at the end of the accelerator. We systematically applied steering fields using each of the steerers installed

on the cell blocks along the accelerator. These steerers have a current carrying capability of at least 8 amperes. Figure 2 shows an ideal V-shaped "tuning curve" with a minimum r of 0.02 cm achieved with a steerer in cell-block 1 (CB1) at the beginning of the accelerator operating at a current of 2.5 A.
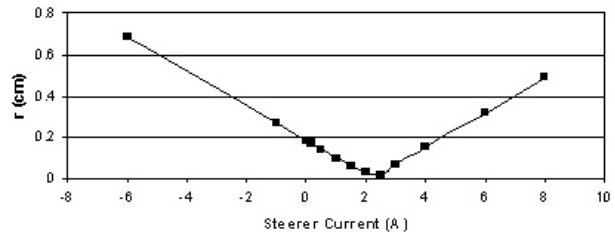

Figure 2; An ideal V-shaped tuning curve

Figure 3 shows the R and r at three locations in the accelerator as a function of steerer current using the same steerer as used in Figure 2. Figure 4 shows the dx and dy that were used to calculate r at location 1500 cm. Figure 5 is a tuning curve using a steerer at 3657 cm and observed at the end of the accelerator. Data in Figures 3 to 5 show:

1. Although most the tuning curves show the typical V-shape, there are deviations from this shape, particularly at steerer currents far from the minimum of r.

2. Because of the V-shape, which is different from a parabola, using a parabola fit to a few data points on the tuning curve can only locate the minimum r location approximately.

3. The effectiveness of a steerer to change r decreases towards the high-energy end of the accelerator. The minimization of r is most effectively done with steerers at the low-energy end of the accelerator.

4. While the value r is being minimized, the average centroid of the beam R also changes along the accelerator.

5. The minima of dx, dy, and r do not necessarily fall on the same values of steerer currents.

PROPOSED PROCEDURE TO MINIMIZE COCKSCREW MOTION

We propose the following procedure for minimizing corkscrew motion in the DARHT-II accelerator. Beam positions in x and y directions, equivalent to centroid data shown in Figure 1, will be measured using BPM's (Beam Position Monitor) installed along the accelerator. We will begin tuning for minimum r starting with steerers at the beginning of the accelerator.

1. We will obtain three points on the tuning curve with steerer currents –6, 0 and 6 A. A parabola will be fitted to these three points to estimate the steerer current for minimum r.

2. Around this initial estimate, we will look for minimum in r by measuring r in steerer-current steps of 0.5 A. This search usually takes not more than 4 current steps.

After finding the minimum r, we will leave that steerer at that current and repeat the process with the next steerer downstream. This procedure have been tried using

LAMDA simulations and was found to be able to obtain a r satisfying the requirement of 0.05 cm using less than three steerers. While minimizing the corkscrew motion in the accelerator, we have to monitor the average beam offset R along the accelerator, to insure that beam is not too far off axis. A limit on beam centroid displacement should be set administratively.

After the corkscrew motion has been minimized, we will use steerers near the end of the accelerator to steer the beam centroid back on axis in the beam line following the accelerator. Experiment showed that this would take less than five shots.

With our proposed procedure, we will take 26 shots to have a beam on axis with minimum corkscrew motion. The number of shots actually needed will depend on other practical consideration and 26 shots should be considered an optimistic estimate.
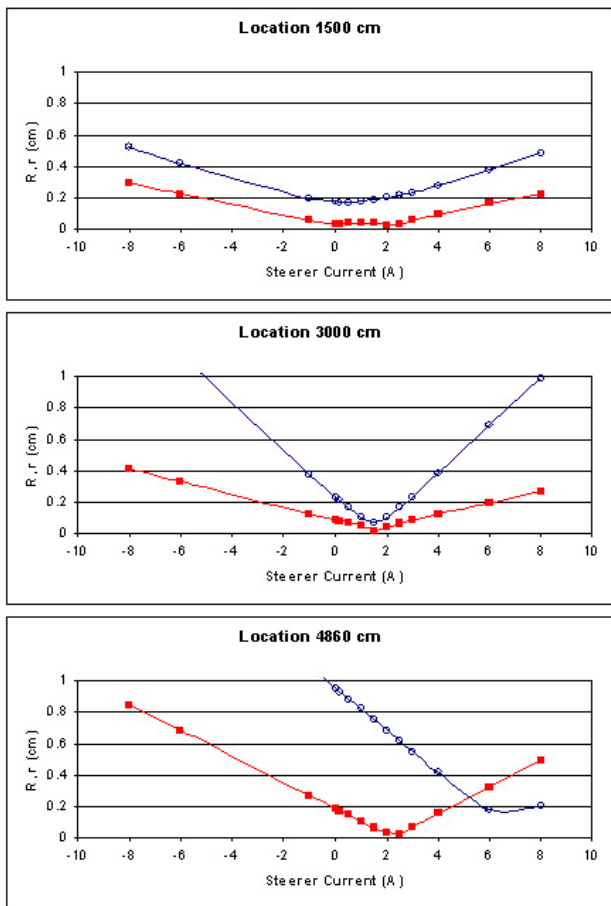
were calculated. A procedure that might need only 26 shots to accomplish has been proposed.
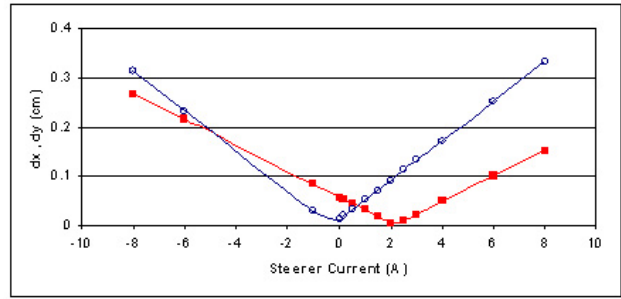

Figure 4: dx (open) and dy (solid) at location 1500-cm as a function of steerer current of a steerer in cell block 1
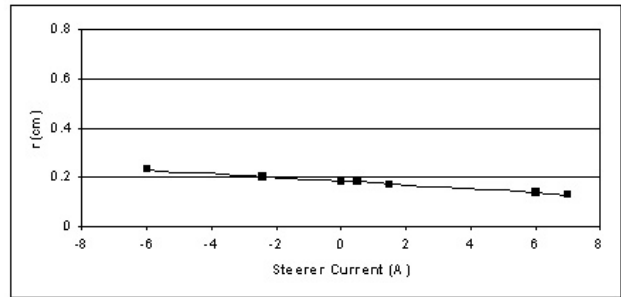

Figure 5: Tuning curve using a steerer at the high-energy end of the accelerator (2287 cm)

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Figure 3: R (open) and r (solid) at three locations as a function of steerer current of a steerer in cell block 1

CONCLUSION

Increase of beam spot size in DARHT-II due to corkscrew motion has been studied using computer simulations. Using baseline accelerator parameters, the increase in beam spot size is only slightly larger than allowed by DARHT-II requirements. The sensitivities of the beam spot size to different accelerator parameters

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