DESIGN OF BEAM CLEANUP ZONE FOR DARHT-2

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Abstract

The DARHT-2 linear induction accelerator [1] is designed to produce a 2 kA, 20 MV, 2 μs flat-top electron beam. The injector is driven directly by a Marx bank, and may have a risetime as large as one microsecond. As a result, there will be a considerable amount of beam charge which is mismatched to the magnetic transport channel. Depositing some of this charge near accelerating gaps could potentially cause insulator flashover. Deposition near the thermionic cathode could lead to cathode poisoning by desorbed neutrals and ions. The approach that has been adopted is to transport the beam-head without loss through the first eight cells, and then eliminate most of the beam-head in a ”beam cleanup zone” (BCUZ). This consists of a 3m section of beam pipe, two apertures, and three static solenoids. We describe two different beam tunes through this region: an aggressive “head cleanup” tune which removes the low-energy beam-head at the expense of a large local envelope modulation in the beam-body, and a “smooth” tune, which transports the beam-body with minimal envelope modulation. Calculations of emittance growth, electron energy deposition, secondary electron emission, and surface neutral and ion desorption in the BCUZ for each tune will be presented. We will also show the effect on transport through the rest of the accelerator. The calculations make use of an envelope code (LAMDA), beam-slice code (SPROP), and particle-in-cell code (LSP).

1 INTRODUCTION

The risetime of the 2-kA, 3.2-MV injector for DARHT-2 [1] will be on the order of several hundred nanoseconds. As a result, there will be a considerable amount of beam charge which is mismatched to the magnetic transport channel. There is concern that losing some of this charge near accelerating gaps may cause insulator flashover or plasma arcs. The beam-head can probably be transported without loss through the accelerator with a suitably smooth magnetic lattice and a reduction in gap voltage to obtain an accelerating pulse long enough to accelerate the head as well as the beam-body. The disadvantages of this approach include larger beam-breakup growth and lower beam-body voltage. The option of allowing the beam-head to deposit on the wall downstream of the anode-cathode (AK) gap was discounted because of possible cathode poisoning by desorbed neutrals and ions.

The alternative approach described here is to transport the beam-head through the first eight-cell block, and then eliminate most of the head in a “beam cleanup zone” (BCUZ). Several options for removing the beam-head were considered, including a time-dependent dipole kicker, a dipole/quadrupole chicane, and static solenoidal fields [2]. Because of its relative simplicity, and because it appeared to adequately reduce the beam-head current, the static solenoidal-field option was selected for further study, and is the one described here. While the beam head is of primary concern because of the potential for a misfire, the beam tail also contains a large amount of unusable mismatched charge. The BCUZ reduces the amount of this charge reaching the downstream accelerator.

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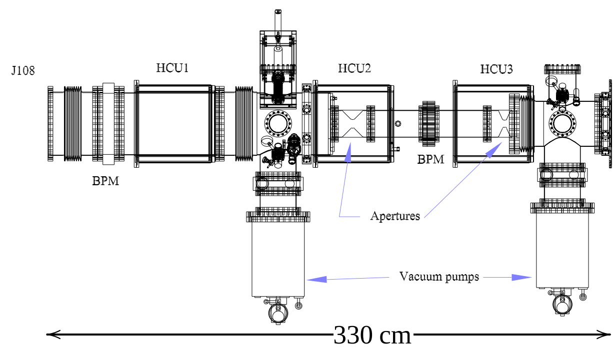

Figure 1: Elevation view of the beam cleanup zone. HCU1-3 are solenoids, J108 is the last solenoid in the injector block.

2 BEAM CLEANUP ZONE LAYOUT

The beam cleanup zone consists of a section of beam-pipe about 3 meters long, three solenoids (with dipole correction coils), and two apertures, as shown in Fig. 1. In addition, there are two vacuum pumps, two beam position monitors (BPM’s), and several diagnostics ports. Up to the first aperture, the beam-pipe radius is the same 17.8 cm (14” diameter) as the first eight cells. At the first aperture, the pipe radius drops to 7.6 cm (6” diameter), and after the second aperture, it increases again to the downstream pipe radius of 12.7 cm (10” diameter).

The lowest energy beam-head electrons deposit on the wall of the 14” section. Energies closer to the flat-top energy deposit on the flange between the 14” and 6” sections and on the first aperture. The function of the second aperture is to intercept off-energy transmission bands which get through the first aperture.

The BCUZ structure is made out of stainless steel to give a good safety margin with respect to melting if a mismatched beam strikes the apertures.

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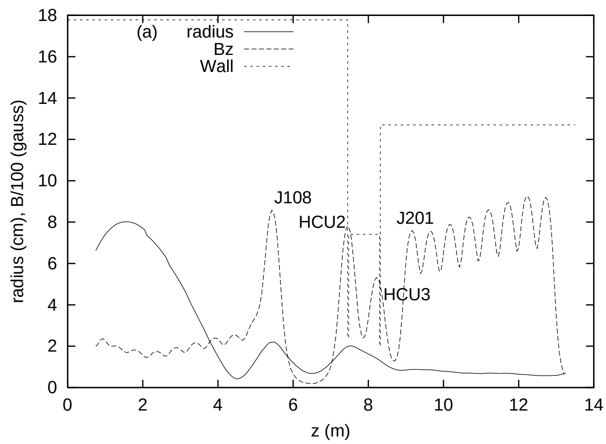

Figure 2: Beam-body tune vs. z for the "head-cleanup" tune. Edge radius, axial magnetic field, and wall radius are shown.

3 BEAM TRANSPORT THROUGH THE BCUZ

We have used three different numerical tools to model beam transport: a beam envelope code LAMDA, a particle-in-cell (PIC) beam-slice code SPROP, and a 2D/3D PIC code LSP [3]. The main constraints we impose on the BCUZ tunes are (a) no current loss through the first 8-cells and (b) minimal modification of the LBNL downstream tune [4]. To meet these criteria, we used LAMDA to scope out different BCUZ tunes. To obtain the time-varying beam properties coming out of the injector, we did a series of LSP diode simulations at different voltages, obtaining the beam current (I), radius (a), slope (a'), and normalized Lapostolle emittance (ϵ_L) as functions of voltage (V) at $z = 75$ cm (62 cm from the cathode surface) in Fig.2. We fit these results with splines to get $I(V)$, $a(V)$, $a'(V)$ and $\epsilon_L(V)$. Now one just needs to specify $V(t)$ to get all the beam waveforms required for LAMDA. A half-sine function with risetime $T_{\rm inj} = 350$ ns gives a reasonable fit to the circuit code simulation result for $V(t)$ obtained by J. Fockler [5]. (More recent experimental data indicates that the risetime may be a factor of 2 or more larger. Generally, this just requires our results to be scaled proportionally.) The emittance is dominated by the AK gap optics: the only intrinsic emittance imposed on the beam at the cathode surface is that due to the $\sim$ 1000 K surface temperature. Surface roughness or nonuniform emission may produce a larger emittance than used here.

For the gap voltages, we assume a waveform like the injector, but with half the risetime, $T_{\rm gap} = T_{\rm inj}/2$, and no applied voltage for $t < T_{\rm inj}/2$. Thus, the first half of the beam-head is not accelerated in the first cell-block.

Eliminating the beam-head requires a strongly dispersive magnetic field tune in the BCUZ. The beam-body transport for a "head-cleanup" tune is shown in Fig. 2. In this tune, magnet HCU1 in Fig. 1 is turned off. Most of the beam-

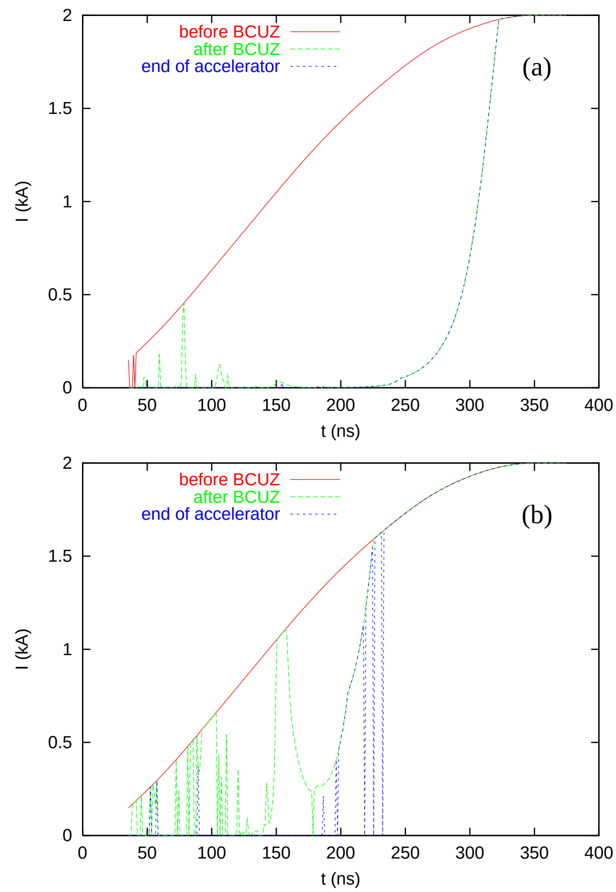

Figure 3: Current waveforms before the BCUZ, after the BCUZ and at the end of the accelerator for (a) cleanup tune and (b) smooth tune.

head has been removed, as shown in Fig 3(a).

By turning on magnet HCU1 in Fig. 1, we can obtain a much smoother beam-body envelope through the BCUZ, shown in Fig. 4. This may be a useful alternate tune during commissioning of the injector and BCUZ, to avoid bringing the beam to a small focus and transporting it through apertures (the two apertures have been removed in Fig. 4). The lower dispersion of this tune means that it is considerably less effective for removing beam-head as shown in Fig 3(b).

The field strengths for magnets J108 and HCU1–3 in Figs. 2 and 4 are all within the capabilities of standard first-cell-block solenoids. The BCUZ is flexible enough to allow many variations in the beam envelope tune, so that trade-offs can be made if necessary, e.g., in head-cleanup effectiveness versus mismatch sensitivity of the beam-body.

Using LAMDA, we propagated the beam to the end of the accelerator for both the head-cleanup and smooth tunes. The current waveforms before and after the BCUZ, and at the end of the accelerator are overplotted in Fig. 3. For the cleanup tune, the small amount of current in "passband" pulses which get through the BCUZ is lost in the first cell-

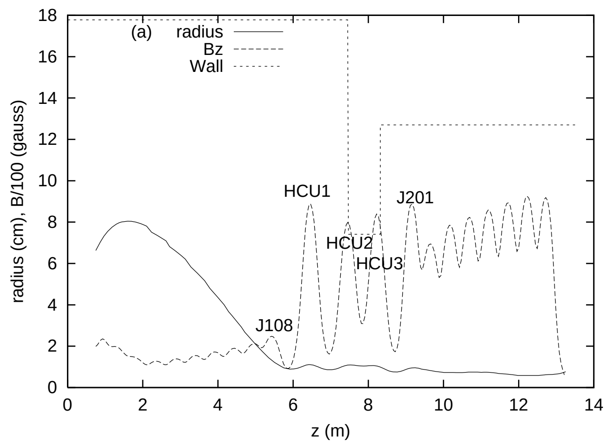

Figure 4: Beam-body tune vs. z for the "smooth" tune. Edge radius, axial magnetic field, and wall radius are shown.

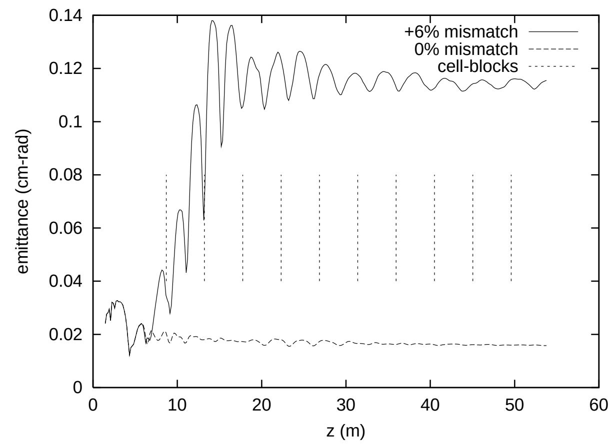

Figure 5: Comparison of emittance for matched and mismatched (+6% change in J108) transport.

block after the BCUZ. For the smooth tune, most of the passband current is lost in the first cell-block, but some pulses are transported to the end of the machine.

4 EMITTANCE PRESERVATION THROUGH THE ACCELERATOR

To compute the emittance variation in the beam-body through the machine, we used the slice-code SPROP. The LSP code was used to generate a beam-body slice at $z = 145$ cm, which we used to initialize SPROP. Over the region from 145 cm to 940 cm where the LSP and SPROP simulations overlap, the beam-body radius and emittance are in close agreement. Using the standard LBNL tune [4], the beam-body slice was transported through all 88 gaps of the accelerator. The result in Fig. 5 shows that the emittance remains low to the end of the accelerator for a well-tuned magnetic field.

The sensitivity of the beam emittance at the end of the accelerator to mismatch in the two main BCUZ magnets, J108 and HCU2, is shown in Fig. 6. The emittance growth results from large envelope oscillations, which drive the formation of a beam halo. The halo particles move in a strongly anharmonic potential, and so phase-space mixing occurs, which manifests itself as emittance growth. In Fig. 5, we compare the beam envelope and emittance for matched and mismatched cases. We see that the emittance saturates by about the third cell-block and is reasonably constant thereafter. Since the beam radius is sensitive to mismatch-generated emittance growth, this means that beam-profile measurements for $z > 17$ m (past the third cell-block) could be used for fine-tuning the BCUZ magnets.

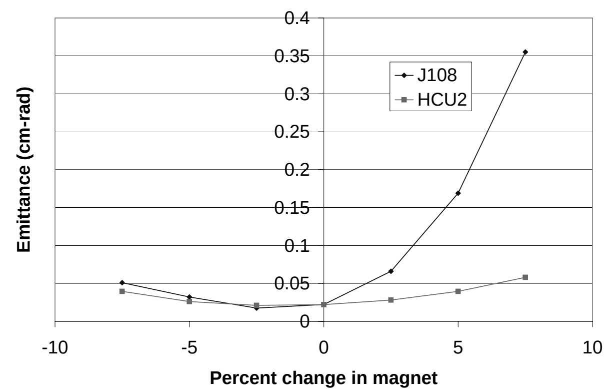

Figure 6: Emittance at the end of DARHT-2 as a function of the change in magnets J108 and HCU2 for the cleanup tune.

5 ACKNOWLEDGMENTS

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