EFFECT OF STIMULATED AND THERMAL DESORPTION IN DARHT-2

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Abstract

The DARHT-2 accelerator generates a 2 kA, 18 MeV, 2 μsec flat-top electron beam. The beam risetime is about 700 ns, and a "beam cleanup zone" (BCUZ) has been designed to scrape off these mismatched electrons. Experiments on DARHT-1 (which has a 60 ns flat-top) have provided excellent quantitative data on stimulated and thermal desorption of neutral monolayers on various metal surfaces by multi-MeV electrons. We have used these data in the particle-in-cell code LSP to model the production of ions from the walls of the DARHT-2 BCUZ. The effect of these ions on the transport of the main beam pulse is discussed.

INTRODUCTION

The DARHT-2 linear induction accelerator [1] is designed to produce a 2 kA, 18 MV, 2 μs flat-top electron beam. The injector is driven directly by a Marx bank, and has a long voltage risetime: 1–99% in 700 ns. As a result, there is a considerable amount of beam charge which is mismatched to the solenoid transport channel. The design of a "beam cleanup zone" (BCUZ) to filter out this charge was previously described [2]. In this paper, we present a computational estimate of the ion charge produced by beam electrons striking the walls of the BCUZ. The computational model uses data from experiments carried out on DARHT-1 [3], a companion accelerator with a 60 ns beam pulse [1].

COMPUTATIONAL MODEL

Beam Generation

The DARHT-2 injector geometry is shown in Fig. 1. A 10 m sections of beam pipe is modeled in $2\frac{1}{2}$-D using the electromagnetic particle-in-cell (PIC) simulation code LSP[4]. The transmission line attached to the radial boundary at T_{AK} in Fig. 1 produces the voltage pulse shown in Fig. 2 [5]. The cathode is treated as a zero-work-function, space-charge-limited emitter. Emitted electrons are given a transverse temperature corresponding to the surface temperature ($\approx 1000°$ C). The beam electrons pass through the accelerating gaps and solenoidal fields of the first eight accelerating cells. As in the physical accelerator, each gap in the simulation is powered by a separate transmission line attached at the boundary (T_1–T_8 in Fig. 1). The accelerating voltage, also shown in Fig. 2, is based on the experimentally-measured voltage trace [5]. The magnetic tune, shown in Fig. 3 was chosen to avoid any beam-loss

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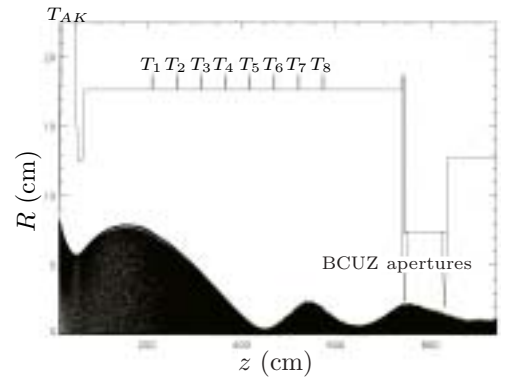

Figure 1: Geometry of desorption calculation, showing injector, 8 accelerating gaps, and BCUZ. The beam is shown at the flat-top energy and current.

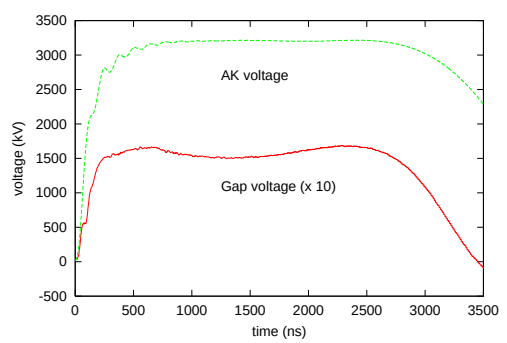

Figure 2: Voltage pulse applied to AK gap (green) and to accelelerating gaps (red). The latter has been multiplied by 10 for scaling purposes.

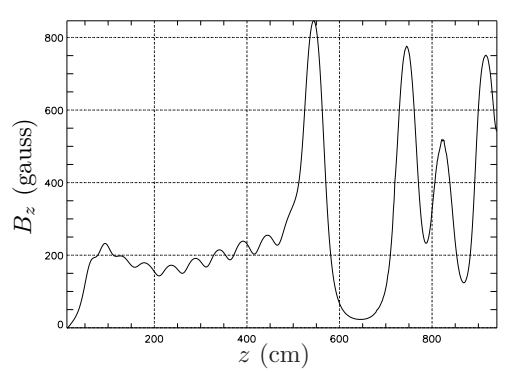

Figure 3: Axial magnetic field tune used in Fig. 1.

in the accelerating cells, and to scrape off the beam-head in the BCUZ[2]. In the simulation, we see no beam loss until the start of the BCUZ, about 6 meters from the cathode.

Ion Generation Model

When energetic electrons strike a solid surface, they can generate neutral molecules and ions. There are two mechanisms for generating neutrals: stimulated desorption (ESD) and thermal desorption. Ions can be generated directly by ESD and by a two-step process of neutral desorption followed by ionization. In LSP, these processes are modeled by the following equations:

$$\frac{dN_d^n}{dt} = \frac{j_e}{e}\sigma_d^n N_a + N_a \nu \exp\left(-\frac{Q_b}{T}\right) \quad (1)$$

$$\frac{dN_d^+}{dt} = \frac{j_e}{e}\sigma_d^+ N_a \quad (2)$$

$$\frac{d(N_d^n + N_d^+)}{dt} = -\frac{dN_a}{dt} \quad (3)$$

$$\frac{dN_i}{dt} = \frac{j_e}{e}\sigma_i N_d \quad (4)$$

where N_d^n is the area density of desorbed neutral particles, N_a is the area density of adsorbed particles, N_d^+ is the area density of desorbed ions, N_i is the area density of ions due to gas-phase ionization, σ_d^n, σ_d^+ and σ_i are the cross-sections for stimulated desorption of neutral species, stimulated desorption of ionized species, and gas-phase ionization of the neutral species, respectively, j_e is the electron current density striking the wall, ν is a thermal-desorption rate-constant (typically 10^{13} s^{-1}), Q_b is the binding energy of the adsorbed material in eV, and T is the surface temperature in eV.

In the calculation, we initialize the surfaces with one monolayer (10^{15} cm^{-2}) of neutral water. In the DARHT-1 experiments [3], the stimulated neutral desorption yield, $N_a\sigma_d^n$, was measured to be in the range 0.1–0.2, and the adsorbed inventory was estimated to be about 1 monolayer, mainly consisting of water. Thermal desorption became significant when the surface temperature increased by 300–400° C. Roughly, a desorption rate of one monolayer/ns occurs when the surface temperature reaches $Q_b/9$ eV, which corresponds to about 630 K ($\approx 330°$ C above room temperature) for $Q_b = 0.5$ eV, a typical value for water vapor [6]. At room temperature (300 K) the desorption rate is a factor of 2×10^4 smaller.

Neutrals produced by either stimulated or thermal desorption can be ionized by subsequent beam electrons. We use the gas-phase cross-section for water molecule ionization by relativistic electrons: $\sigma_i = 0.9 \times 10^{-18}$ cm^2 [7]. Water is known to "crack" under electron impact, producing significant fractions of OH^+ and H^+, in addition to H_2O^+ [8]. We have not included these species in the calculation.

Direct stimulated production of ions was not measured in the DARHT-1 experiments. Typically, the cross-section for producing ions is much less than that for neutrals [9].

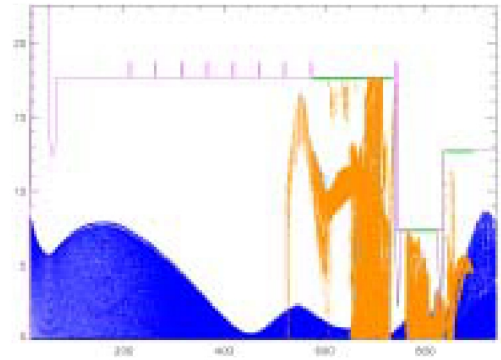

Figure 4: Beam (blue) and H_2O^+ (orange) distributions at $t = 1000$ ns; cf. Fig. 1.

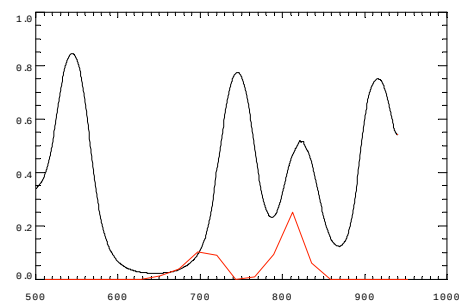

Figure 5: Ratio of ion (H_2O^+) charge to beam charge vs. z at $t = 1000$ ns, within a radius of 1.5 cm (red line). The axial solenoidal magnetic field in kilogauss is overplotted (black). Horizontal scale is in cm.

We have used a value $\sigma_d^+ = 0.01\sigma_d^n = 2 \times 10^{-18}$ cm^2 in the calculation.

EFFECT ON THE ELECTRON BEAM

Ions resulting from stimulated desorption or from ionization of desorbed neutrals can affect the tune and stability of the electron beam. A snapshot of the particle distribution at $t = 1000$ ns is shown in Fig. 4. By this time, about 1000 μC of beam electron charge has struck the wall, yielding about 2 μC of stimulated ion charge. Taking the line-ratio of stimulated ion charge to beam charge within a radius of 1.5 cm from the axis, we get the results shown by the red line in Fig. 5. The dominant contribution to the ion line-density is from stimulated ions. The number of ions generated from desorbed neutrals is much less: the surface temperature rises by at most 50° C, as shown in Fig.6. From Fig. 7 is clear that the ions have a large effect on the beam exiting the BCUZ. We can convert the line-charge ratio f to an equivalent magnetic field through the relation

$$B_{eff} \approx 3.4\sqrt{2\nu\gamma f}/r_b \qquad \text{kG} \quad (5)$$

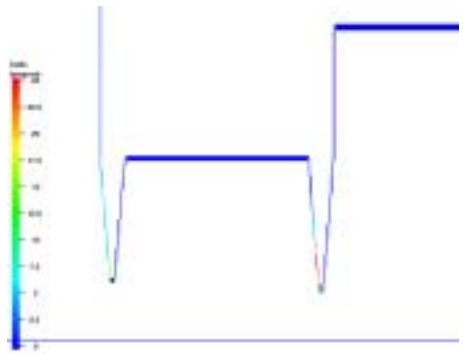

Figure 6: Surface temperature rise (K), in the BCUZ region at the end of the beam risetime.

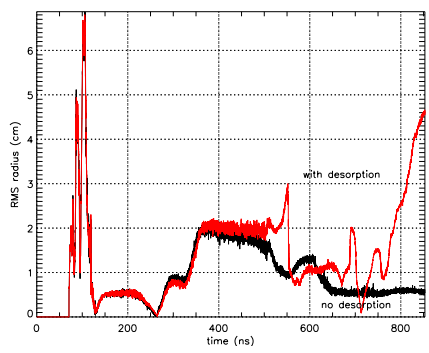

Figure 7: RMS beam radius at $z = 938$ cm with (red line) and without (black line) the effect of desorbed ions.

where ν is Budker's parameter for the beam current and r_b is the beam radius in cm. Thus, the first peak in f in Fig. 5 is roughly equivalent to a 1 kG field extending over 30-40 cm, comparable to the actual focusing solenoids in Fig. 5.

CONCLUSIONS

Beam deposition on the walls of the DARHT-2 beam cleanup zone generates ions through direct stimulated desorption and through neutral desorption followed by impact ionization. For lack of data, the stimulated ion yield used in the calculation is a free parameter. For a sample value equal to 1% of the measured neutral yield, there is a large disruption of the beam. Experimental data on the stimulated ion yield is needed to make a prediction for how large the effect will be in the actual machine.

ACKNOWLEDGMENTS

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