ION EFFECTS IN THE DARHT-II DOWNSTREAM TRANSPORT

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Abstract

The DARHT-II accelerator produces an 18-MeV, 2-kA, 2-μs electron beam pulse. After the accelerator, the pulse is delivered to the final focus on an x-ray producing target via a beam transport section called the Downstream Transport. Ions produced due to beam ionization of residual gases in the Downstream Transport can affect the beam dynamics. Ions generated by the head of the pulse will cause modification of space-charge forces at the tail of the pulse so that the beam head and tail will have different beam envelopes. They may also induce ion-hose instability at the tail of the pulse. If these effects are significant, the focusing requirements of beam head and tail at the final focus will become very different. The focusing of the complete beam pulse will be time dependent and difficult to achieve, leading to less efficient x-ray production. In this paper, we will describe the results of our calculations of these ion effects at different residual-gas pressure levels. Our goal is to determine the maximum residual-gas pressure allowable in DARHT-II Downstream Transport such that the required final beam focus is achievable over the entire beam pulse under these deleterious ion effects.

INTRODUCTION

DARHT-II is an 18-MeV, 2-kA induction linear accelerator. After acceleration, the 2-μs beam pulse is delivered to the final focus at the X-ray target via a beam transport section called the Downstream Transport.

The 2-μs beam pulse, during acceleration and transport, will produce ions by ionizing the residual gas. The fractional neutralization, *f*, due to these ions at the end of the pulse, can be estimated as:

$$f \approx 1.0\times10^{3} \bullet P(torr)\,\tau(\mu s)$$

where P is the residual gas pressure and τ is the beam pulse length. For a pressure of 2×10^{-7} torr and a pulse length of 2 μs typical for DARHT-II, we expect the fractional neutralization to increase from zero at the head of the pulse to ~ 4×10^{-4} at the tail of the pulse.

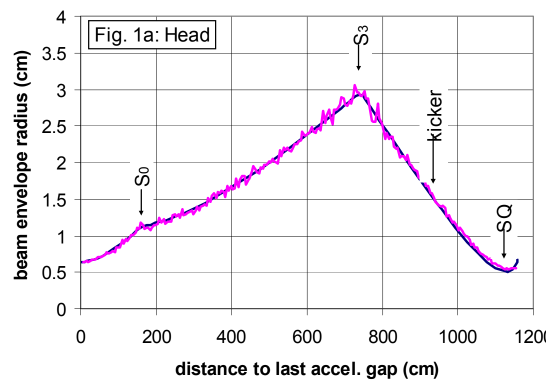
These ions might affect the beam dynamics in two ways. First, the ions will decrease the space-charge force. With different focusing forces for the head and tail of the pulse, head-tail envelope differences might result. Second, the interaction between the ion channel and the beam might result in ion-hose instability.

Recently, we have investigated head-tail beam envelope variance and ion-hose instability in the Downstream Transport with computer simulations, and the results are being summarized in this paper. The gas used in the simulations is H_2O. Related work can be found in References 1-4.

DOWNSTREAM TRANSPORT

The Downstream Transport, in addition to delivering the beam to the target, has the function of forming four short pulses spaced in time over the 2 μs. This function is performed with a kicker and a group of quadrupole magnets. The beam will be 2-μs long only up to the first quadrupole magnet, called the septum quad. After the septum quad, the pulse length will be on the order of 50 ns. With a shorter pulse length, the ion effects after the septum quad will be small and therefore will not be taken into account in our simulations.

Figure 1 shows the beam envelope between the accelerator and the septum quad. After leaving the last accelerating gap and entering the Downstream Transport, the beam pulse is focused by two solenoids (S_o and S_3) to a waist at the septum quad (SQ). After the quadrupoles, the beam is transported with a solenoid and focused on the target with a final focus solenoid. The target is located ~ 10 m from the septum quad.



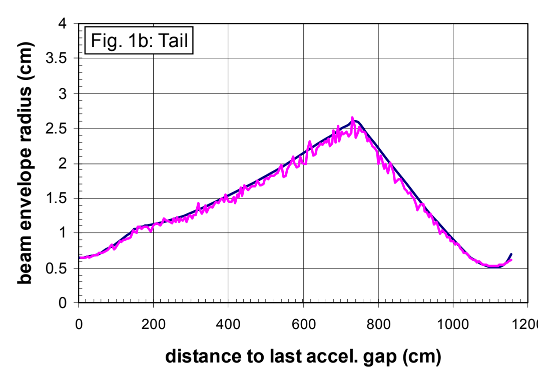


Figure 1: Comparison of beam envelopes calculated using LAMDA (blue) and LSP (red) at 2×10^{-7} torr for the head (a) and the tail (b) of the pulse. Locations of the magnetic transport elements S_o, S_3, kicker, and septum quad (SQ) are also marked in Fig. 1a.

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HEAD-TAIL ENVELOPE DIFFERENCE

We have studied the head-tail envelope difference of a DARHT-II beam while transported from the accelerator to the target with computer simulations. Our results have been obtained using an envelope-code, LAMDA [5], and a particle-in-cell code, LSP [6]. Figure 1 shows the excellent agreement between these two codes.

We simulated the beam envelope between the accelerator and the septum quad at residual gas pressures of 5×10^{-8}, 2×10^{-7} and 1×10^{-6} torr. For Downstream Transport, the design pressure is 2×10^{-7} and the pressure estimated is ~ 5×10^{-8} torr. LAMDA results (Figure 2) show a smaller beam radius for the beam tail because of smaller space-charge force and the beam waist at the septum quad for the beam tail is moved toward the accelerator. This head-tail envelope difference increases when the pressure level increases.

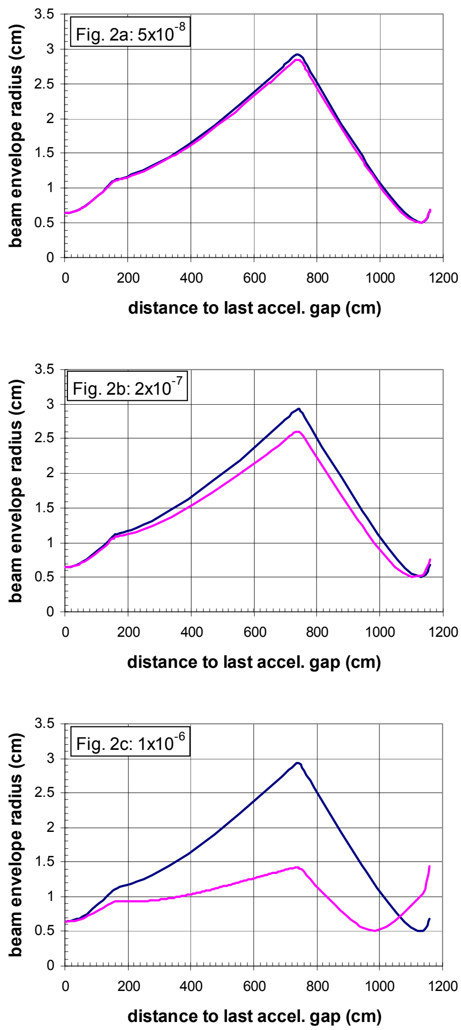


Figure 2: Beam envelopes for the head (blue) and for the tail (red) between the last accelerator gap and the septum quad at different pressure.

The beam pulse was transported further from the septum quad to the target (the final focus) in the simulations to determine the effect of the ions on the target beam size. Because of the short pulse length, we did not include the ion effect on this part of the beam transport. Figure 3 shows the horizontal and vertical radii of the target beam spot versus time during the pulse. It shows that the ion effect has caused the radii to be changing between head and tail of the pulse and the change over the pulse length is also different for the horizontal and vertical radii because of the different actions of the set of quadruples for the horizontal and vertical directions. One can conclude that, with the ion effect, we cannot produce a perfectly round spot over the span of the pulse, but can come very close at low pressure levels. At a pressure level of 2×10^{-7} torr, one can maintain a round beam with radius variation less than 10% as required at the target.

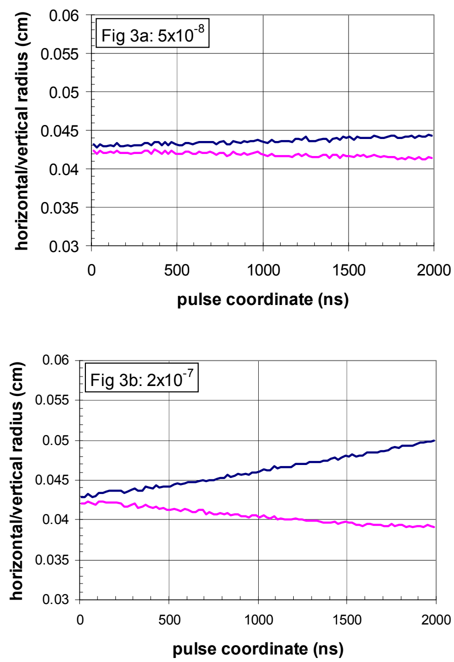


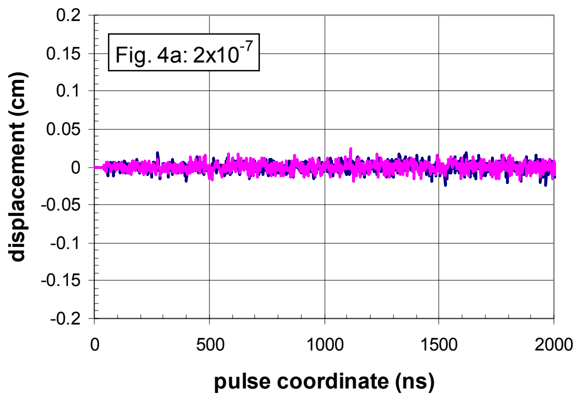
Figure 3: Horizontal (red) and vertical (blue) beam radii during the beam pulse at the final focus for pressure levels (a) 5×10^{-8} and (b) 2×10^{-7} torr.

ION-HOSE INSTABILITY

The ion-hose instability has been studied using both a spread-mass code [7] and the LSP code [3]. The spread-mass code was used because it takes very little computer time as compared to a particle-in-cell code, therefore can be used efficiently to explore the parameter space. A benchmarking between the spread-mass code used and the LSP code can be found in refs. [3] and [4].

Results from the spread-mass code and LSP show negligible ion-hose instability growth between the accelerator and the septum quad at a design pressure of 2×10^{-7} torr or below. Ion-hose instability does not grow significantly until the pressure reaches a level above 10^{-6} torr. Figure 4 shows some typical LSP results at pressure levels of 2×10^{-7} and 1×10^{-6} torr.

The ion-hose instability growth between the accelerator and the septum quad is small, even without the strong solenoidal magnetic field as in the accelerator, because the average beam radius is large. Figure 5 shows results of a set of spread-mass simulations demonstrating the decrease of instability growth with increasing beam radius. In this set of calculations, uniform beam radii were used with axial position.



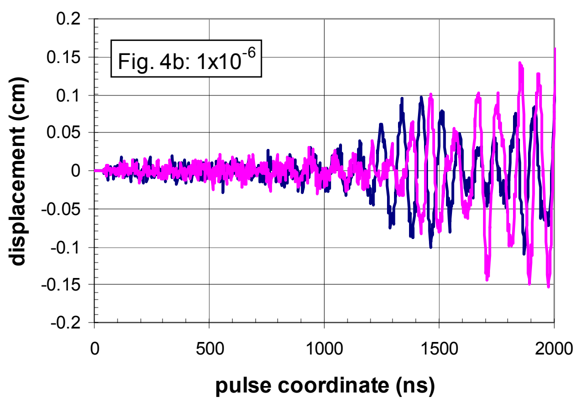


Figure 4: LSP results of horizontal (red) and vertical (blue) beam displacement, observed at the septum quad, due to ion-hose effect at pressure levels of (a) 2×10^{-7} and (b) 1×10^{-6} torr.

A second set of spread-mass simulations was also done to study the effect of changing radius with axial position on ion-hose instability growth. These simulations were done using rms radii with the same average of 0.89 cm but having different linear increase with axial position. Results show that ion-hose instability growth reduces for larger linear increase in radius.

Table 1 summarizes results of the two sets of simulations by listing the average beam displacement amplitudes over the last quarter of the 2-µs beam pulse at the end of a 12.5-m transport channel.

Table 1: Average beam displacement amplitudes with uniform radius and linearly increasing radius

Uniform beam radius		Linear increase in beam radius	
Radius (rms, cm)	Average Amplitude (cm)	Radius change (rms, cm/m)	Average Amplitude (cm)
0.445	0.125	0.0	0.031
0.668	0.061	0.036	0.025
0.890	0.031	0.071	0.020

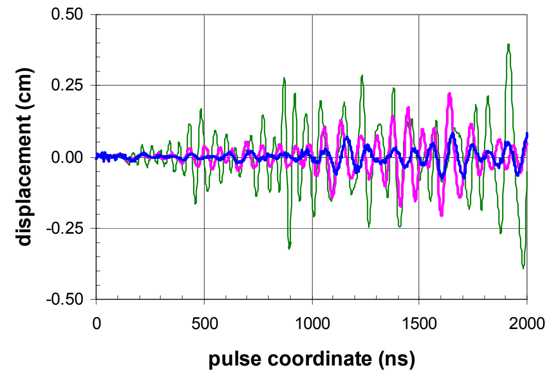


Figure 5: Horizontal beam displacement along the pulse when uniform radii of 0.445, 0.668, and 0.890 cm (green, red, and blue) are used over the transport channel.

CONCLUSION

Ion effects produced by beam ionization of residual gases have been studied for DARHT-II Downstream Transport section. Simulation results show that the head-tail envelope variation and ion-hose instability are acceptable if the residual gas pressure level is kept under 2×10^{-7} torr.

ACKNOWLEDEMENT

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3. T. C. Genoni and T. P. Hughes, "Ion-hose instability in a long pulse linear induction accelerator," PRST-AB, **6**, 2003.
4. K. C. Dominic Chan, et al, "Simulations of the ion-hose instability for DARHT-II long-pulse experiments," presented at the 2004 LINAC Conference, Lübeck, Germany, August 16-20, 2004.
5. LAMDA is an envelope code. It was developed for LANL by ATK-MR (www.mrcabq.com).
6. LSP is a particle-in-cell code. It is a software product of ATK-MR (www.mrcabq.com).
7. A code for studying ion-hose instability. The code originates from ATK-MR and has been modified by one of the author (KCDC kcchan@lanl.gov).
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