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Scaled Accelerator Test For the DARHT-II Downstream Transport System*

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Abstract

The second axis of the Dual Axial radiography Hydrodynamic Test (DARHT-II) facility at LANL is currently in the commissioning phase[1]. The beam parameters for the DARHT-II machine will be nominally 18 MeV, 2 kA and 1.6 µs. this makes the DARHT-II downstream system the first system ever designed to transport a high current, high energy and long pulse beam [2]. We will test these physics issues of the downstream transport system on a scaled DARHT-II accelerator with a 7.8-MeV and 660-A beam at LANL before commissioning the machine at its full energy and current. The scaling laws for various physics concerns and the beam parameters selection is discussed in this paper.

I. INTRODUCTION

The DARHT-II downstream system, shown in Fig.1, consists of a diagnostic beam stop, a high-speed, high-precision kicker system [3] and the x-ray converter target assembly [2], [4]. The kicker is used to select 1-4 short pulses out of the long beam pulse provided by the accelerator and send them to the x-ray converter target. The beam line can be divided into two regions, i.e., the long pulse region and the short pulse region. Both these sections are mainly long drift sections. The nominal beam pulse length in the approximately 9-m transport line upstream of the quadrupole septum and in the main beam dump line is 1.6 µs. The selected short beam pulses will be delivered to an x-ray converter target through the target line, which is about also about 9 m.

There are several concerns, such as ion-hose instability, transverse resistive wall instability and background gas focusing regarding transporting a 1.6-µs and 2-kA beam pulse and a train of short 2-kA pulses over a 1.6-µs period in these two long drift sections. At the converter target region, maintaining the time integrated x-ray spot size in the presence of backstreaming ions is also an issue. Confining hydro-expansion of target material long enough for all four beam pulses to generate the required X-ray dose is another challenge. Finally, the x-ray spot sizes for all pulses need to meet radiography requirement even though the high energy intensity beam pulses would interact with the time-evolving target plasma. Many of these issues had been studied on the 5-MeV, 2-kA, 60-ns Experimental Test Accelerator II (ETA-II) [5], [6], [7], [8], [9]. However, ETA-II is a single pulse machine and cannot address long pulse and multiple pulse issues. Since the DARHT-II downstream system is the first system ever designed to transport a high current, high energy and long pulse beam, we will test these physics issues of the downstream transport system on a scaled DARHT-II accelerator with a 7.8-MeV and 660-A beam at LANL before commissioning the machine at its full energy and current.

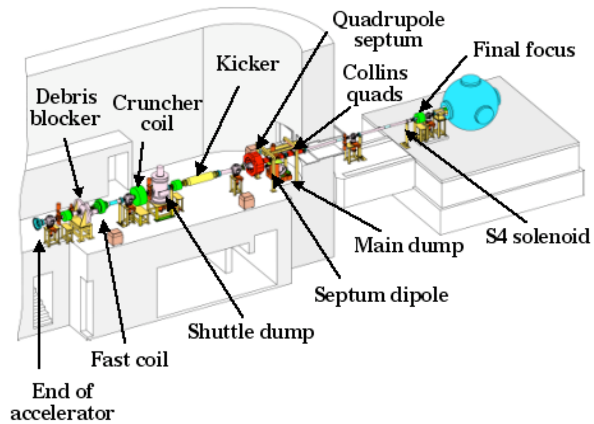

Figure 1. DARHT-II Downstream System

II. PHYSICS ISSUES

A. Background Gas

The beam electrons will ionize background gas as it propagates in the machine. The resulting ion population increases linearly with background pressure and with beam time until it reaches saturation level. In the envelope equation, the focusing term of these background ions at a given beam time τ is linearly proportional to $(I/I_o\gamma\beta)P\tau$, where I is the beam current, I_o is the Alfven current (17 kA), $\gamma\beta$ is the Lawrentz factor, and P is vacuum pressure.

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For a long pulse, high current beam, such as the DARHT-II beam, the head and tail of the beam would experience significant different background focusing forces if the system's background pressure is high. The average vacuum in the DARHT-II downstream system is designed to be less than 10^{-7} torr. Figure 2 shows the DARHT-II beam sizes in the x and y directions and beam ellipticity, defined as $2|x-y|/(x+y)$, on the x-ray converter target as functions of $P\tau$ (pressure times beam time). For a nominal 2-μs, 2-kA beam in the designed 10^{-7} torr vacuum, although small, there is noticeable spot size growth from the beam head to the beam tail, and the end of the beam is slightly elliptical. However, these head to tail variations are quite acceptable. A similar conclusion is given in Ref. [11].

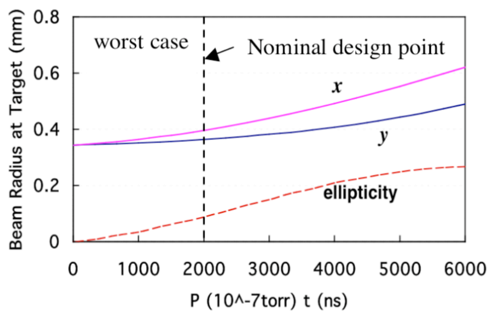

Figure 2. The horizontal and vertical beam sizes and beam ellipticity at the converter target as functions of gas pressure times beam time.

Since the DARHT-II accelerator will deliver a beam with a long beam head, the downstream transport line is designed to have a large beam acceptance. The beam head loss upstream of the kicker and beam loss at the septum during the kicker switching will deposit charge on the wall with the charge density on the order of nC/cm^2 and μC/cm^2 [10], respectively. In addition, electrons deposited on the dump will raise the dump's graphite temperature in approximately by 100ºC. These losses may lead to beam stimulated desorption. Subsequently, ions are born and provide unwanted time varying focusing on the beam. Furthermore, ions born in the dump may even backstream into the main beam. Our PIC simulations with background gas pressure raised locally in the dump line indicate that background gas may pinch the beam and increase heat load on the dump. Since there is no existing data on beam stimulated desorption for electrons in 10 – 20 MeV range, we need to test the system before the final commissioning at full energy. To observe the same background gas focusing effect on the beam envelope, $I/\gamma\beta$ should be kept constant.

The ion hose instability on a long pulse, high current beam in a long drift could be an issue potentially. However, the DARHT-II beam's large envelope variation shown in Figure 3 detunes the ion hose instability [2]. For the nominal design vacuum, our PIC simulations indicate that the peak of power spectrum at the instability's frequency only grows by a factor of 2 in the downstream system while other frequency components are damped. PIC simulations with raised pressure localized in the dump line give a modest growth of a factor of 66 in the peak of the power spectrum for 10^{-6} torr and a large growth of 54000 at 5×10^{-6} torr. The acceleration on the electron beam centroid provided by the ion channel is also proportional $(I/I_o\gamma\beta)P\tau$. Therefore, a similar ion channel effects on the beam centroid can be studied by keeping $I/\gamma\beta$ constant.

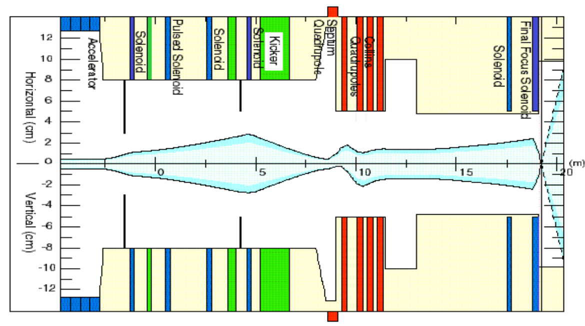

Figure 3. Beam envelope in the DARHT-II transport line from the accelerator exit to the target

B. Return Current and Image Charges

The return current in a resistive wall dissipates into the wall with time and lets a transversely displaced beam see a time varying dipole force. While this time varying dipole force is usually not a concern for a short pulse, it could potentially threaten the quality of the long pulse, high current beam in a long drift. The DARHT-II transport system with 70% of beam line made out of large radii aluminum pipes is designed to minimize the transverse resistive wall instability. This instability should not be a serious issue for DARHT-II. Estimated instability gain in both the long pulse region and the short multi-pulse region for various aluminum and stainless steel combinations are plotted in Figure 4. The estimated instability gain for both regions are about 1.5 – 1.6. The last beam steering caused by distribution of return current and image charges on the wall is the beam induced kicker steering. The nonuniform distribution of the return current along the kicker introduced by an offset beam excites the kicker cavity. The offset beam also excites the kicker cavity while it passes through the kicker gap at the downstream size of the kicker box. The backward propagating slow wave will then kick the beam. Theory and simulations indicate that the beam's displacement is amplified initially. However, these two kicking mechanisms eventually cancel out each other's steering effects on the beam after roughly 3 times of kicker transit time, and the beam displacement stays constant afterward. We have tested a scaled kicker box with the 60ns ETA-II beam to exam the beam induced steering and did not observe any run-away steering. Nevertheless, a test with a long pulse beam is needed to confirm predictions of the theory and simulations. The acceleration on the electron beam centroid provided by the image forces for both transverse resistive wall instability and beam induced kicker steering is proportional $I/I_o\gamma\beta$.

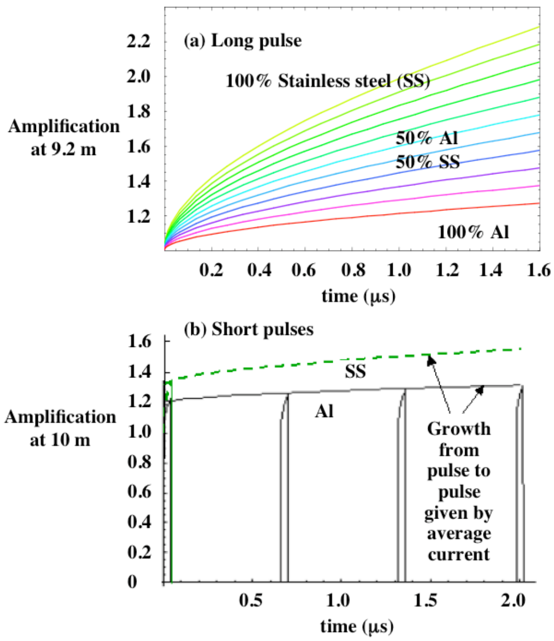

Figure 4. Amplifications of an initial beam offset caused by the transverse resistive wall instability for (a) the 1.6-μs beam transporting from the accelerator exit to the quadrupole septum and (b) the 4 short pulses travelling from the septum exit to the x-ray converter.

C. X-ray Converter Target

The strong electric field of the high current and high intensity electron beam may pull ions upstream from the desorbed gas at the target surface or from a pre-existing target plasma plume created by preceding pulses. To minimize the time varying focusing effects of those backstreaming ions on the beam spot size on the target, a foil is used as a barrier [12] to confine the ion channel within the disruption length, given as

$$L_D \approx a\sqrt{\pi\gamma\beta^2 I_o / f_i I} \quad , \qquad (1)$$

which is the length of the ion channel needed to make the beam over pinched and rebound back to its original beam size. Success of the foil-barrier scheme depends on the foil's ability to sustain impact of 1-4 high current pulses over 1.6 μs and its inability to become a new backstreaming ion source at its upstream side. To ensure survivability of the foil, the foil material and the beam spot size on the foil must be chosen carefully, and other mitigation methods need to be used to prevent ions from backstreaming from the foil front surface.

In order to minimize the target hydro-expansion over 1.6 μs, the deposited energy density in the x-ray converter material is reduced by distributing the target over a distance [13]. Using the radiation hydrodynamics code, LASNEX, our modeling indicates that there is enough material to generate four X-ray pulses over 1.6 μs with the required doses. The foil-barrier scheme with other mitigations and the target hydro confinement of distributed targets have been demonstrated successfully on the ETA-II/SNOWTRON double pulse facility, However, due to complexity of the target physics and the ETA-II beam being shorter than some of the DARHT-II short pulses, how well the DARHT-II target scheme will work on the multi-pulse DARHT-II is still uncertain.

III. SCALED ACCELERATOR

Many of the issues discussed earlier have been studied on the 5-MeV, 2-kA, 60-ns (with 40-ns flattop for $\delta\gamma/\gamma = \pm 1\%$) Experimental Test Accelerator II (ETA-II) [5], [6], [7], [8], [9] as shown by the check marks in Table 1. However, ETA-II is a single short pulse machine and cannot address issues specially concerning long pulse and multiple pulses. Since the DARHT-II downstream system is the first system ever designed to transport a high current, high energy and long pulse beam, the remaining issues need to be studied on DARHT-II. Instead of waiting to learn about these physics concerns after completion of all the accelerator cells, we will test them on a scaled DARHT-II accelerator with a lower energy and current since most of these physics issues scale with $I/\gamma\beta$. The DARHT-II transport hardware has recently been tested on ETA-II [9]. To take the advantage of the tuning experience gained from the ETA-II's DARHT-II transport experiment, the scaled DARHT-II accelerator's beam parameters, 7.8-MeV and 660-A, are chosen to be close to the ETA-II DARHT-II transport experiment's parameters while $I/\gamma\beta$ is kept about the same value as that for the full energy machine.

Table 1. List of physics concerns for the DARHT-II downstream systems and their scaling

Issues	**ETA-II test**	Remaining issues	**Scaling**
<u>*Transport and kicker*</u>			
Kicker operation and control	√	4 pulses 1.6μs	none
Gas desorption	√	4 pulses 1.6μs	$In_p\tau_{sw}$
Beam induced kicker steering	√	1.6μs	$I/\gamma\beta$
Background gas focusing		1.6μs	$I/\gamma\beta$
Ion hose instability		1.6μs	$IP/\gamma\beta$
Resistive wall instability		1.6μs	$I/\gamma\beta$
Spot dilution due to kicker switching	√	none	none
<u>*Target*</u>			
Backstreaming ions	√	4 pulses 1.6μs	$I/\gamma\beta$
Foil-barrier survivability	√	4 pulses 1.6μs	$I\tau_{total}/a^2$
Target confinement	√	1.6μs	$I\tau_{total}/a^2$

To achieve the same amount of beam simulated gas desorption on the scaled DARHT-II accelerator, we will compensate for having a lower current hitting the septum wall either by slowing down the kicker switch time or by increasing the number of times that the beam being kicked. To observe similar background gas focusing effects in the dump line, we will raise the background pressure in the dump to compensate for having the lower current dumped in the dump. We will keep the beam envelope, shown in Figure 9, on the scaled accelerator similar to that on the 18-MeV machine, shown in Figure 3, to exam the envelope variation's detuning effects on the ion hose instability.

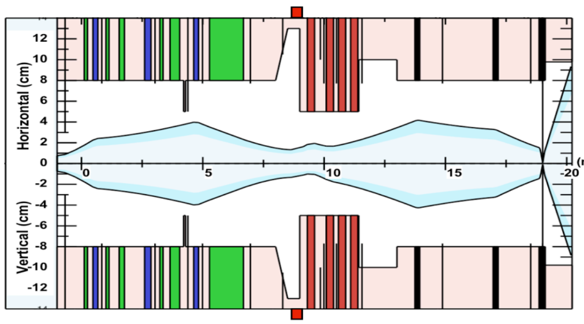

Figure 9. Beam envelope in the DARHT-II downstream transport line on the scaled accelerator

As discussed earlier, keeping $I/\gamma\beta$ and the beam envelope in the target area constant makes the length of the backstreaming ion channel or the target plasma channel needed to disrupt the beam spot size the same. Since the backstreaming ions are born on the target surface and pulled of from the target surface by the beam current's space charge forces, their backstreaming velocities are proportional to $I^{1/2}$. Therefore, ions will take a longer time to form such channel on the scaled accelerator. If the beam envelope is the same, to simulate how backstreaming ions change the DARHT-II beam spot size, the short beam pulse lengths on the scale experiment should increase with $I^{-1/2}$. The total energies deposited by electrons on the foil-barrier and x-ray converter target determine their survivability and confinement. Assuming that the beam envelopes for all pulses will stay the same over their durations via some spot control mitigation techniques, we will extend all the short pulses by a factor of $1/I$ to deposit the same amounts of energy on the foil and the x-ray converter.

IV. SUMMARY

The DARHT-II downstream system will be the first system to transport a long pulse, high energy and high current electron beam, and the first system to deliver four selected 10-100 ns beam pulses to a novel, static x-ray converter target to produce high quality x-ray pulses for flash radiography. The physics concerns regarding the long pulse and multiple-pulse issues need to be tested on using a long pulse machine. We will test these physics issues of the downstream transport system on a scaled DARHT-II accelerator with a 7.8-MeV and 660-A beam at LANL before commissioning the machine at its full energy and current.

V. REFERENCES

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