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Title: Determination of Kicker Vacuum Requirements

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Determination of Kicker Vacuum Requirements

Introduction

This note examines the effect of elevated vacuum pressures in the kicker region of the DARHT 2nd Axis which can lead to changes in the beam tune due to the long pulse length. The kicker uses Rexolite as an insulator supporting the electrodes. Rexolite is hygroscopic resulting is a large outgassing rate and prolonged pump down times after exposure to atmospheric conditions. LAMDA [1] is used to simulate the effect of ionization of the residual gas resulting in partial space charge neutralization and changes to the tune between the beginning and end of the pulse. The effect of the ion-hose instability is also examined. The purpose of this note is to establish/validate the required pressure in the downstream transport.

VACCALC Simulation

VACCALC [2] is used to calculate the pressure profile in the kicker region for different outgassing rates. These pressure profiles are used as input to LAMDA. The outgassing rate within the kicker was adjusted to achieve specific values of the pressure at the location of the ion gauge just after the kicker. Figure 1 shows the vacuum pressure in the Axis 2 downstream transport calculated with VACCALC for four values of the pressure at this ion gauge corresponding to 50, 100, 200 and 400 nTorr. These pressure profiles are used as input to a LAMDA simulation. As seen in Figure 1, the pressure in the kicker is a factor of about 3.4 larger that the pressure measured at the ion gauge.

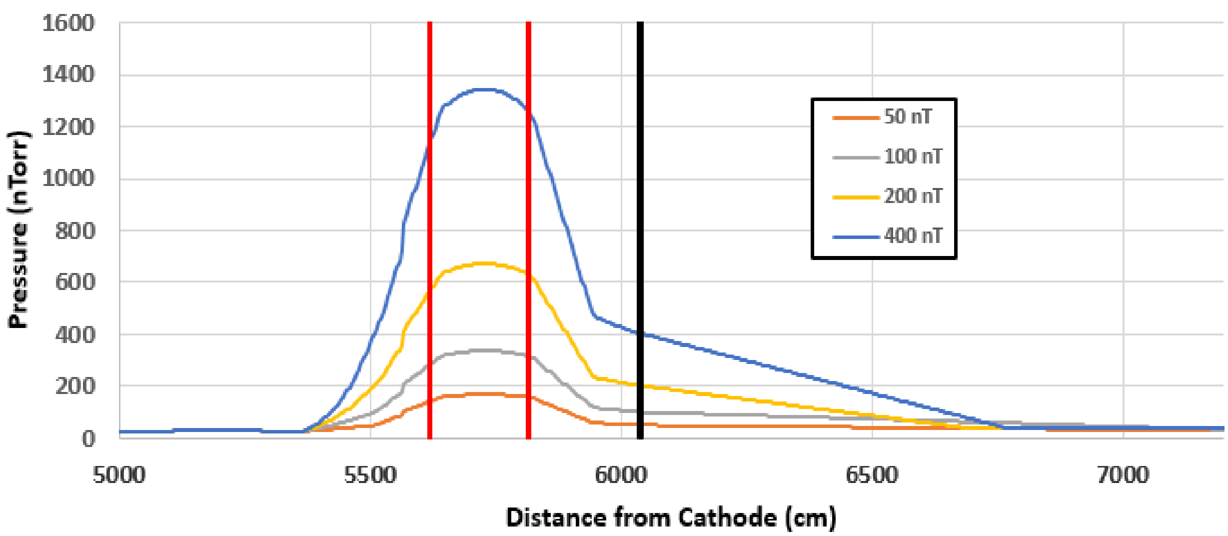

Figure 1: Vacuum pressure in the Axis 2 downstream transport as a function of different outgassing rated in the kicker corresponding to 50, 100, 200 and 400 nTorr. The vertical black line shows the location of the ion gauge. The two vertical red lines show the extent of the kicker vacuum chamber.

LAMDA Simulation

A long pulse (1800 ns) beam of constant energy (16.2 MeV) and current (1.65 kA) is generated in LAMDA at the beginning of the downstream transport (5030 cm). A normalized beam emittance of 1000 π(mm-mrad) was assumed with nominal beam size and convergence angle. The transport magnets were then adjusted to produce a round beam. The kicker and the bias dipole are adjusted to produce four pulses at times of 245, 750, 1250 and 1760 ns.

The beam-induced ionization model in LAMDA provides a means for simulating the effect of electron beam ionization of a neutral gas and the subsequent space charge neutralization. It is assumed that the ions are not moving and are uniform over the size of the electron beam. Ions are created through collisions between the beam and the background gas. The ion fraction, f_{ion}, in LAMDA is given by Eq. (1):

$$f_{ion} = f_0 + \frac{p(Torr)t(ns)}{\alpha} \quad (1)$$

where α is the ionization constant. We use a value for α of 1.1 ns-Torr corresponding to air [3]. Here, f_o, is the preexisting ion fraction which is set to zero in our simulation.

Figures 2-5 show the beam envelopes calculated using LAMDA for pulse 1 and pulse 4 for the four different pressure profiles shown in Figure 1 corresponding to the ion gauge pressures of 50, 100, 200, and 400 nTorr respectively. The elevated pressure in the kicker results in residual gas ionization that is sufficiently large enough to cause space charge neutralization as indicated by the smaller beam size at around a distance of 5780 cm. Figure 6 shows the vertical beam envelope for pulse 4 for the four pressures.

The simulations for ion gauge pressures of 50 (Figure 2) and 100 nTorr (Figure 3) show very little difference in the beam envelopes between the pulses 1 and 4. There is only a very small variation in the beam envelopes between pulses 1 ad 4 for a measured gas pressure of 200 nTorr as shown in Figure 4. Figure 5 shows substantial variation between pulses 1 and 4 for a measured pressure of 400 nTorr. This implies that at measured pressures below 200 nTorr, the beam envelopes are not significantly altered by ionization of the residual gas in the kicker.

Analyses with different beam emittance and magnetic tunes also show similar results indicating that a measured pressure of 200 nTorr is a good upper limit on the vacuum pressure. The downstream transport vacuum is interlocked to prevent beam operation when the pressure in this ion gauge exceeds 200 nTorr. Typically, the measured pressure is less than 50 nTorr after an extended exposure to ambient pressure followed by a few weeks of pumping.

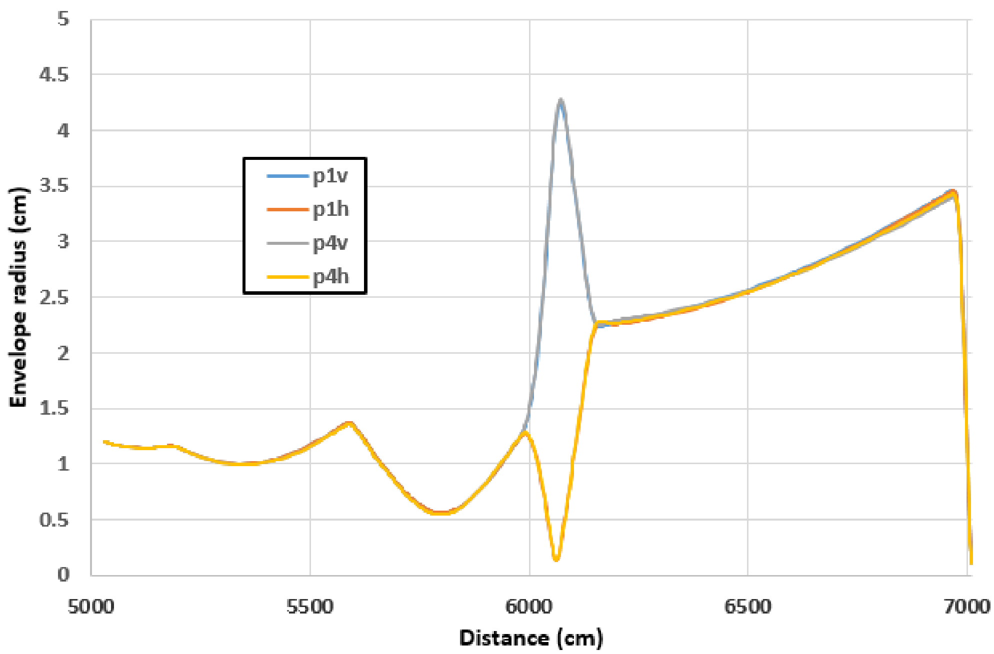

Figure 2: Beam envelopes from LAMDA in the downstream transport for the first and fourth pulse for a kicker pressure profile corresponding to an ion gauge pressure of 50 nTorr.

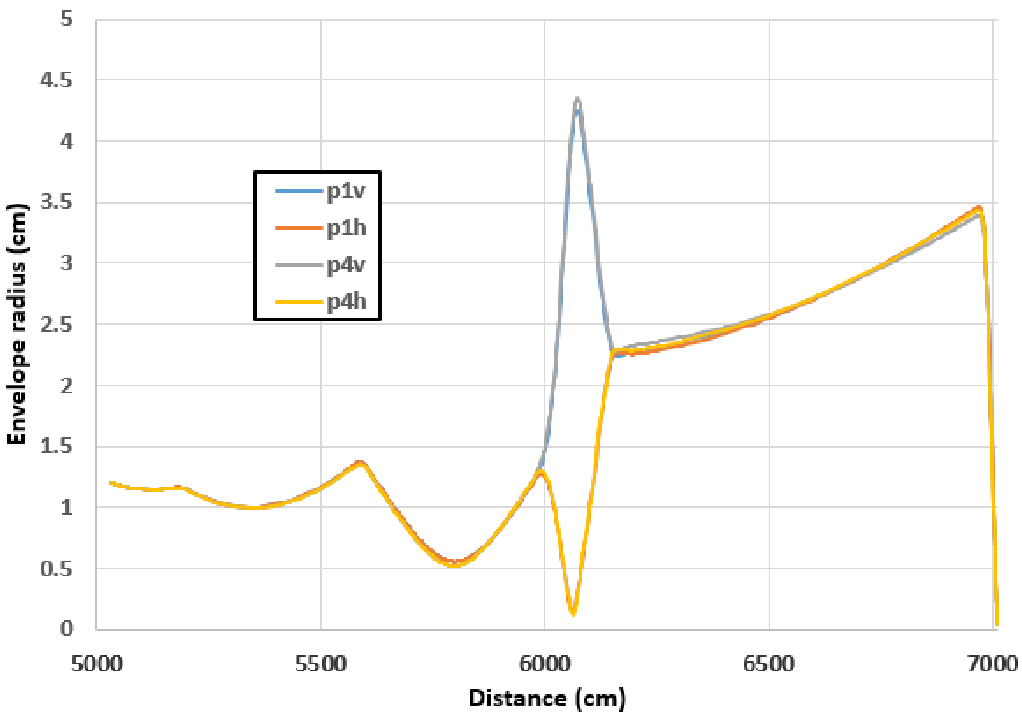

Figure 3: Beam envelopes from LAMDA in the downstream transport for the first and fourth pulse for a kicker pressure profile corresponding to an ion gauge pressure of 100 nTorr.

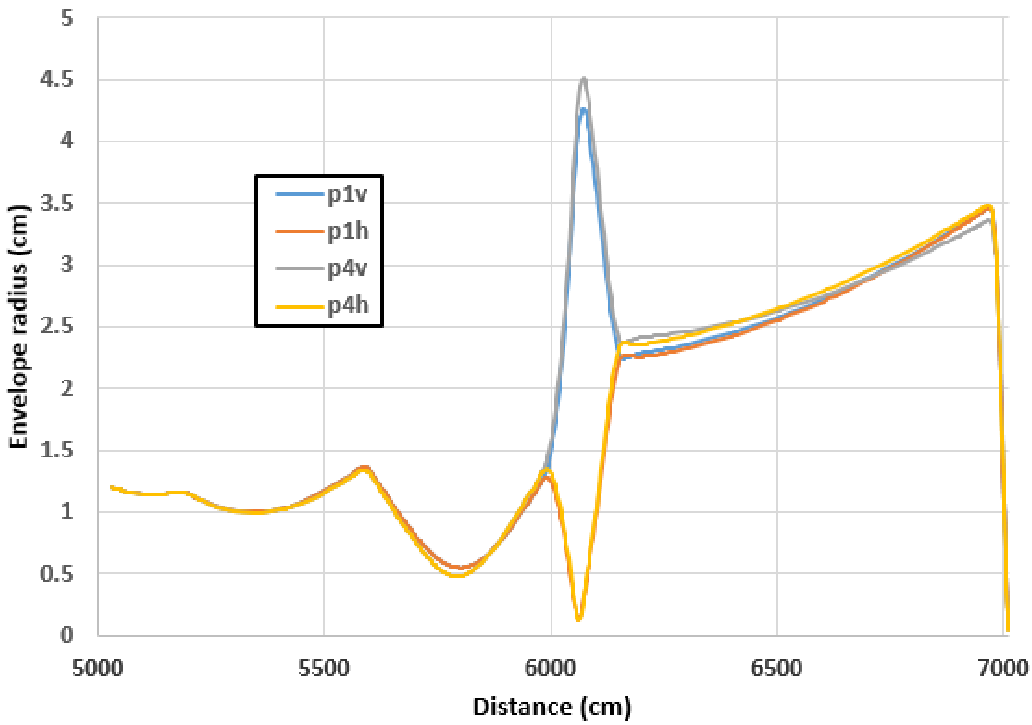

Figure 4: Beam envelopes from LAMDA in the downstream transport for the first and fourth pulse for a kicker pressure profile corresponding to an ion gauge pressure of 200 nTorr.

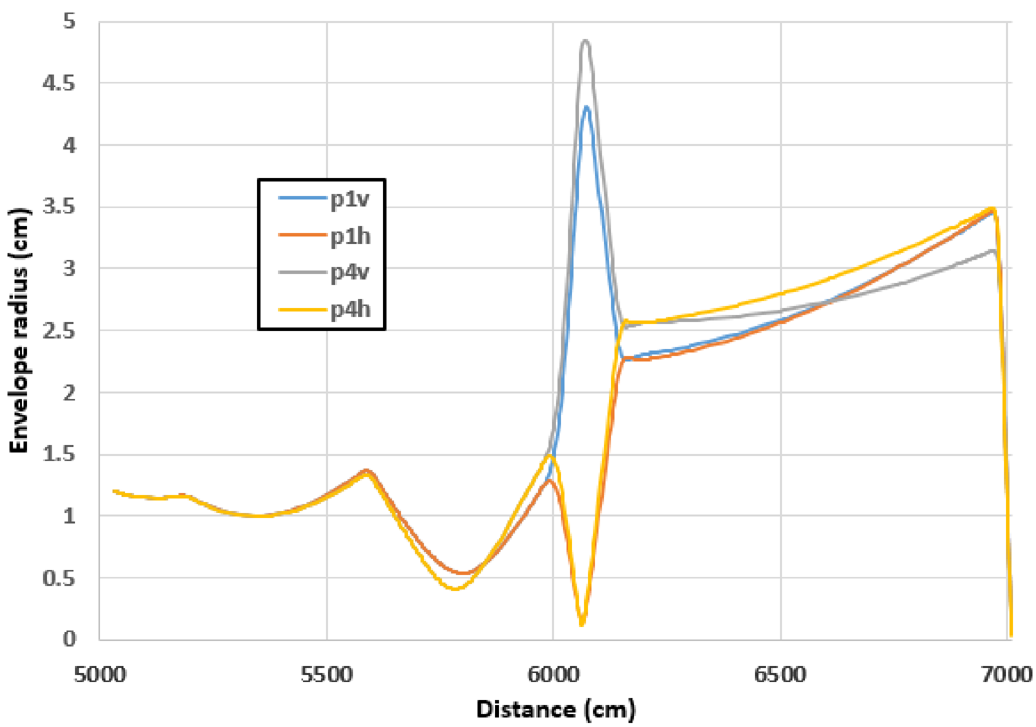

Figure 5: Beam envelopes from LAMDA in the downstream transport for the first and fourth pulse for a kicker pressure profile corresponding to an ion gauge pressure of 400 nTorr.

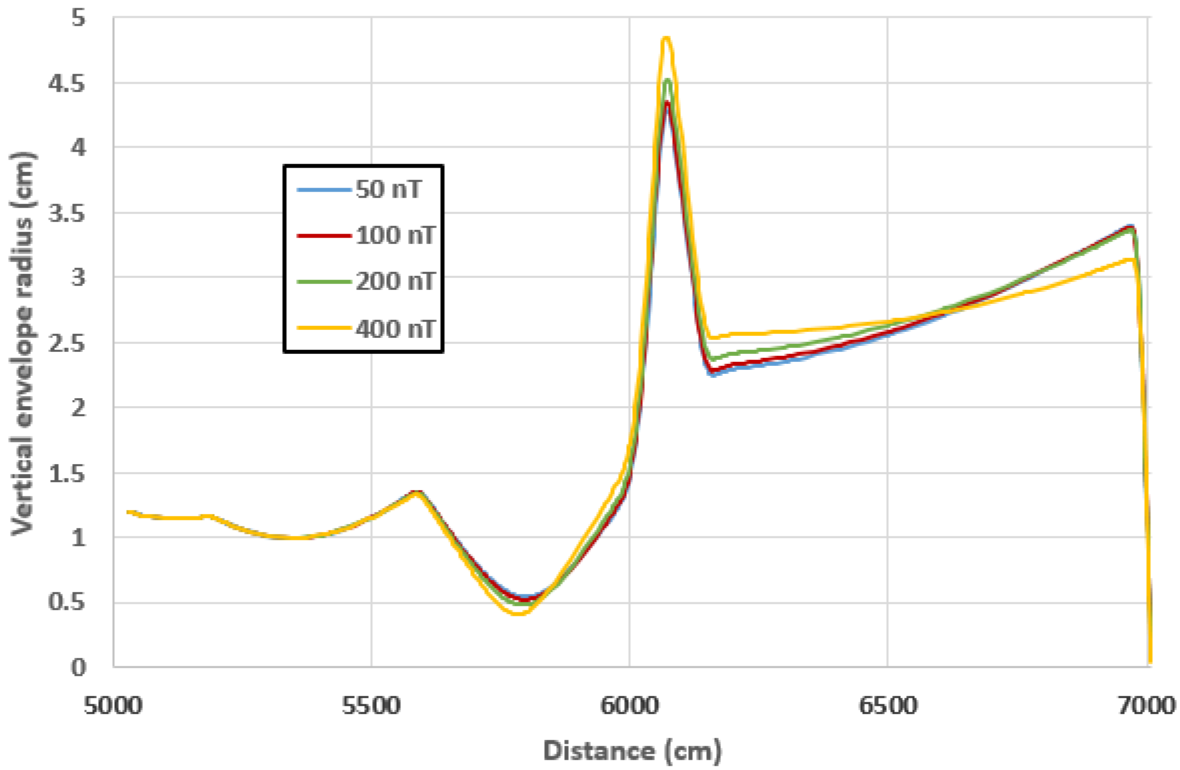

Figure 6: Vertical beam envelopes from LAMDA in the downstream transport for the fourth pulse for different kicker pressure profiles.

Ion-Hose Instability

The ion-hose instability also limits the maximum pressure in a long-pulse intense relativistic electron beam. In this case, the ion channel created by ionization of the residual gas couples to the transverse motion of the electron beam. Extensive studies on the DARHT-II accelerator [4] have been performed to determine the vacuum pressure threshold at which the ion-hose instability begins to impact the size of the beam. The results provide a threshold for the product of the pressure, p, and distance, d, below which this instability can be ignored as given by Eq. (2) [5].

$$pd < 10^{-3}\ (cm - Torr) \tag{2}$$

All of the pressure profiles considered in Figure 1 are below this threshold. This implies that the ion-hose instability is not the primary concern associated with elevated pressures in the kicker region.

Conclusions

The effect of elevated pressures in the DARHT-II downstream transport has been investigated. Elevated pressures are most important in the long pulse region of the DARHT-II downstream transport from the end of the accelerator to the region just downstream of the kicker. The kicker is the major concern for elevated pressures due to significant outgassing of the insulators. Ionization of the residual gas results in an ion channel that can alter the beam tune through neutralization of the space charge of the beam. Pressure profiles calculated for different amounts of outgassing consistent with measured vacuum pressures are used to estimate the space charge neutralization. The results indicate that pressures measured at the ion gauge downstream of the kicker must be below 200 nTorr. Another concern associated with elevated pressures, the ion-hose instability, is found to be much less important in the downstream transport.

References

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