Experiments Investigating the Effects of the Accelerating Gap Voltage Pulse on the Ion Focused (IFR) High Current Electron Recirculators*

M. G. Mazarakis, D. L. Smith, J. W. Poukey, J. S. Wagner, L. F. Bennett,
W. R. Olson, B. N. Turman, K. R. Prestwich
Sandia National Laboratories
P. O. Box 5800
Albuquerque, NM 87185

J. Wells
Science Applications International Co.
2340 Alamo, SE
Albuquerque, NM 87106

Abstract

The lifetime of the Ion Focusing Regime (IFR) channel following the pulsing of the post-accelerating gaps is critical for an open-ended, spiral recirculating electron linear accelerator. It dictates the number of allowable beam recirculations through the gap. In the case of a racetrack configuration, it is significant but not as critical, since the presence of the electron beam focuses the ions and lengthens the lifetime of the ion channel.

It was established that pulsing the accelerating gap perturbs the IFR channel. However, for the parameters studied, the lifetime is long enough to allow at least four beam recirculations in a spiral device. In addition, cusp fields positioned upstream and downstream from the gap prevent it from perturbing the IFR channel.

INTRODUCTION

Figure 1 is a schematic diagram of our low energy Recirculating Linear Accelerator (RLA) in a closed geometry racetrack configuration. For these experiments we used the first straight section of the low-energy RLA beam line. The injector was removed, and the beam line was extended downstream from the ET-2 post accelerating cavity. It has a 1.3-MV electron injector and a single post-accelerating (ET-2) cavity with the accelerating gap located inside the IFR channel. In our RLA devices, we use a low-energy, 300-V electron beam (LEEB) to ionize a 0.1 to 0.4 mTorr argon gas. The low-energy electron beam is focused and guided along the beam line by a 200-G solenoid wrapped around the outside walls of the vacuum pipe. When the main high-energy electron beam enters the channel, the low-energy plasma electrons are expelled, leaving behind an ion channel (IFR) which electrostatically focuses and guides the beam. In the experiments reported here we energize only the post accelerating cavity. A ~ 1.2-MV voltage pulse is applied at the post accelerating gap, and the response of the preformed IFR channel is studied and analyzed.

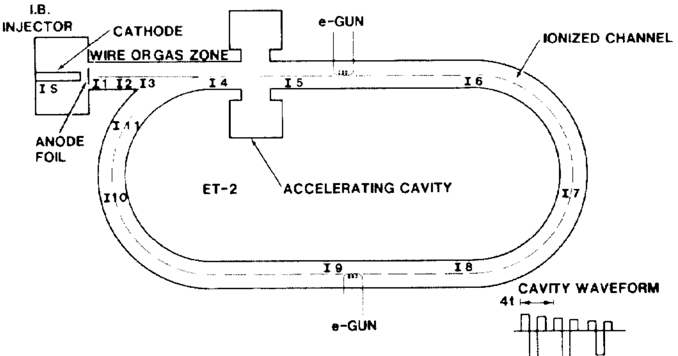


Figure 1: Schematic diagram of the low energy RLA.

EXPERIMENTAL SETUP

Figure 2 is a sketch of the actual experimental setup. Only the post-accelerating gap (ET-2) is included in the system. The IFR

---

*Supported by Navy SPAWAR under Space Task No. 145-SNL-1-8-1, by US DOE Contract DE-AC04-76DP00789, and DARPA Order No. 7877.

0-7803-0135-8/91$01.00 ©IEEE

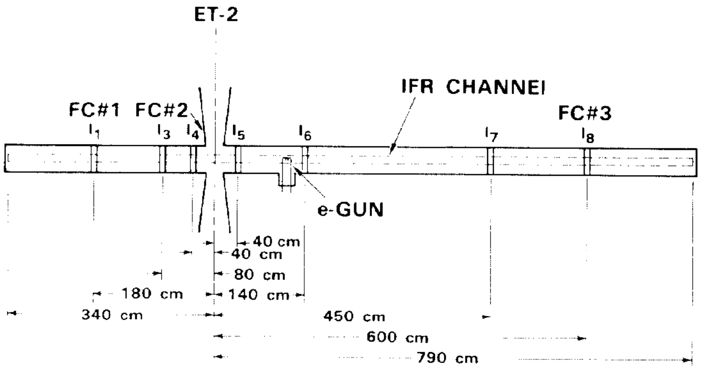


Figure 2: Experimental setup.

channel is formed using our usual technique of low-energy electron-beam ionization of a 2.5 x 10^{-4} Torr argon gas atmosphere which fills the beam transport vacuum pipes. The average channel radius is ~ 1 cm and the plasma ion density (n_i) of the order of 7 x 10^{10} ions/cm^3. The entire length of the channel is 11 m: 8 m downstream and 3 m upstream from the accelerating gap. Rogowski coils and radial Faraday cups[1] are used as diagnostics.

EXPERIMENTAL RESULTS AND ANALYSIS

Figure 3 gives samples of the current waveforms at various locations in the beam line and of the voltage pulse produced by the ET-2 cavity. Timing fiducials provide the absolute time differences of the arrival of the front of the waveform at different locations. Pulsing the gap causes the propagation of two distinct types of "disturbances," one downstream and the other upstream from the gap. The one downstream has the characteristics of an electron-beam pulse propagating with the expected maximum velocity of 2.7 x 10^{10} cm/sec (800 kV is the ET-2 first pulse) in the direction of the accelerating electric field. The other disturbance, although appearing in the Rogowski monitors as an electron-beam pulse, propagates with smaller velocities, 0.7 x 10^{10} cm/sec, and is apparently due to the upstream propagation of the sheath separating the deneutralized from the neutralized part of the IFR channel. The axial electric field created by the ion channel accelerates the channel electrons at the sheath and moves the sheath away from the accelerating gap.

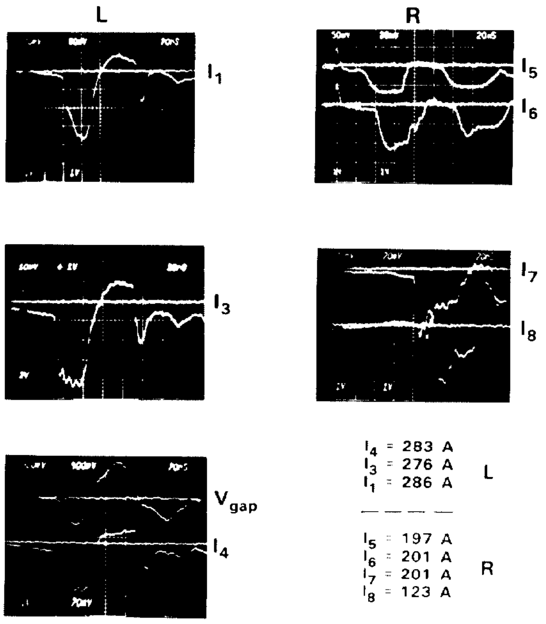


Figure 3: Samples of the current wave forms at various locations.

MAGIC[2] simulations of the beam line (Fig. 4) reproduce quite well the observed ~ 300 amps beam currents that are accelerated by the gap, the electron current accelerated by the ion column, and the propagation velocities in both directions (Table 1). Richard Hubbard arrived to the same results using his FRIEZR code.[3]

Table 1

t ns	FC#2 mA	FC#3 mA	I_3 A	I_4 A	I_7 A
6	50	0	30	222	0
12	70	0	289	282	0
18	10	0	274	274	0
24	0	0	255	268	0
30	10	0	247	259	0
36	10	0	273	262	37
CHANGE POLARITY E OF GAP					
42	0	0	94	-76	149
48	0	0	-85	-114	133
54	0	0	-117	-114	178
60	0	0	-106	-115	132
66	0	2	-89	-105	97
72	0	4	-90	-90	71
78	0	0	-104	-94	104
84	0	0	-105	+13	116

It takes 36 ns for the deneutralizing front to reach Rogowski #7 located 3.88 m from ET-2 gap.

v_{front} = 3.88 m/36 x 10^{-9} sec = c/3

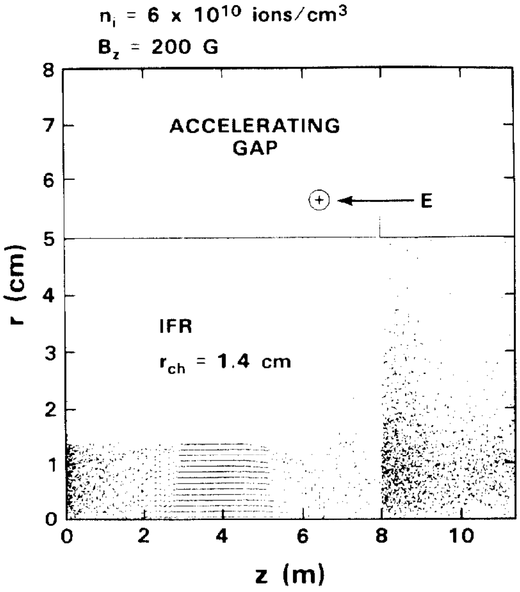
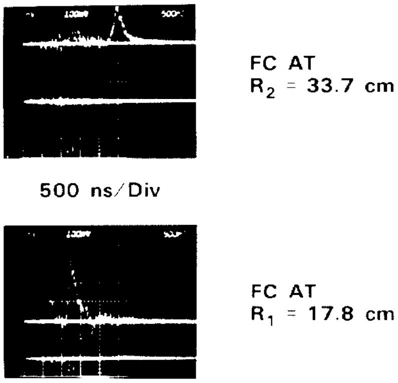


Figure 4: Electron map 24 ns following the pulsing of the ET-2 cavity.



$\Delta R = R_2 - R_1 = 15.9$ cm

$\Delta t = 2.6$ Div x 500 ns = 1.3 μs

$v_i = 15.9$ cm/1.3 x 10^{-6} sec = 1.22 x 10^7 cm/sec

$E_i = 3$ kV

Time for an ion to hit the wall,
$T_w \gtrsim 5$ cm/1.2 10^7 cm sec^{-1} = 400 ns

Figure 5: Time of flight measurements utilizing two Faraday cups located at different radial distances from the beam pipe axis.

Time-of-flight measurements of the ions into two Faraday cups located at different radial distances from the IFR axis (Fig. 5) gave an ion escape velocity of ~ 1.2 x 10^7 cm/sec. This velocity suggests a 400-ns escape time for the argon ions to reach the walls of the 5-cm-radius beam pipe. Numerical simulations with BUCKSHOT[4] accurately reproduced the arrival times, amplitude, and time evolution of the collected ions by the Faraday cups. Richard Hubbard with FRIEZR got the same results. For the heavier Xe ions to be used in the final device, the escape times should be ~ 600 ns.

These experimental results are encouraging, particularly for the spiral IFR version of the proposed recirculating accelerator. A Xe IFR channel could provide beam focusing for at least four recirculations (600 ns) through the post-accelerating gap. Experiments with cusp fields or transparent grids upstream and downstream from the ET-2 cap demonstrated that IFR channel can be decoupled from the gap. Electron beams or sheaths were not observed when cusp magnetic fields were utilized. It should be pointed out again that no high-energy beam was injected into the IFR channel during the experiments reported here.

CONCLUSIONS

We have established experimentally that pulsing the accelerating gap of the ET-2 cavity puts the electrons and ions of the IFR plasma channel into motion. As a result of the electron motion, two types of "disturbances" propagate axially into opposite direction: (1) electrons move to the left of the gap, and (2) a sheath moves to the right (direction of gap electric field). Both "disturbances" cause the Rogowski coils to register a 200 to 300-A current in the same direction. The argon ions of the IFR channel escape radially with velocities equal to 1.2 x 10^7 cm/sec and take 400 ns to hit the 5-cm-radius pipe. Cusp magnetic fields or possibly transparent grids upstream and downstream from the accelerating gap can decouple it from the IFR channel. The experimental observations are in very good agreement with numerical simulations.

REFERENCES

[1] K. W. Struve, et al., Mission Research Corporation, Private Communication.

[2] B. Goplen, et al., Mission Research Corp. Report MRC/WDC-R-068, 1983.

[3] R. F. Hubbard, et al., Bull. Am. Phys. Soc. 35, No. 4, p. 932 (1990).

[4] J. S. Wagner, Sandia National Laboratory Report, SAND87-2019 (1987).