PRELIMINARY MEASUREMENT OF ENERGY-SPREAD CHANGE RESULTING FROM THE RESISTIVE-WALL INSTABILITY*

H. Suk†, J.G. Wang, Y. Zou, S. Bernal, and M. Reiser
Institute for Plasma Research, University of Maryland, College Park, MD 20742, USA

Abstract

Experiments on the resistive-wall instability have been conducted. Electron beams with energies of 2.5 to 8.5 keV and currents of 30 to 135 mA are transported through a resistive glass tube for this experiment. The resistive tube is one-meter long and the resistance is 5.4 kΩ. The electron beams in the resistive tube are uniformly focused by a long solenoid. Localized space-charge waves are generated in the beams to investigate any energy spread change as a result of the resistive-wall instability. A longitudinal energy spread of the space-charge waves is measured at the entrance and the exit of the resistive channel for comparison. The preliminary experimental results are presented.

1 INTRODUCTION

The resistive-wall instability[1-3] is potentially dangerous for some accelerators with special experimental parameters. Especially it plays an important role in high current accelerators with space-charge-dominated beams[4]. According to the theory and simulation, the resistive-wall instability leads to amplitude growth of slow space-charge waves and damping of fast space-charge waves[5-7]. In addition to amplitude change, the instability may lead to an emittance growth and a longitudinal energy-spread increase. To answer these questions, small scale experiments with space-charge-dominated electron beams and a resistive glass tube have been conducted at the University of Maryland[8]. In this paper, preliminary experimental results on the energy-spread measurement are presented.

2 EXPERIMENTS

2.1 Experimental Setup

The experimental setup for energy spread measurement is shown in Fig. 1. The experimental system consists of an electron gun, solenoid matching lenses, a resistive tube, diagnostic tools, etc. Space-charge dominated electron beams with an energy of 2.5 to 8.5 keV and a current of 30 to 135 mA are generated from the gridded electron gun with a variable perveance. A single localized space-charge wave, i.e., a fast wave or a slow wave, is produced in the electron beam pulse to investigate the properties of the wave in a resistive environment. The electron beams are matched and injected into the resistive glass tube with the aid of three solenoid lenses. The resistive tube has a resistance of 5.4 kΩ, a length of 0.96 cm and a diameter of 3.8 cm. The resistive glass tube is located inside a long solenoid for uniform magnetic focusing. The magnetic field of the long solenoid is adjusted to confine the beams within the resistive tube. If the space-charge wave is a fast wave, its amplitude decreases as it propagates in the beam, while if the wave is a slow wave, its amplitude grows. The amplitudes of the space-charge waves are measured with two current monitors at the entrance and the exit of the resistive tube for comparison. To measure the energy of space-charge waves resulting from the resistive-wall instability, two retarding-field energy analyzers are placed at the entrance and the exit of the resistive transport channel, as shown in Fig. 1. The retarding-field energy analyzer[9,10] consists of two parallel conducting plates and a Faraday cup. Each plate has a hole with a diameter of 4.8 mm and both holes are covered with a fine stainless-steel mesh with a transmittance of 80 %. One plate is grounded and the other is charged with a negative high voltage, so that a uniform retarding electric field is produced between the two plates. With these energy analyzers, the energy spread is measured at both locations alternatively, and the results are compared.

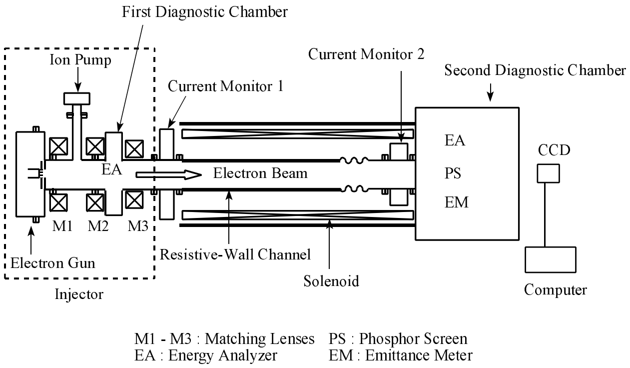

Figure 1: Experimental setup to measure an energy spread.

2.2 Energy Spread Measurements

Figure 2 shows a typical beam pulse with a localized fast wave. This beam pulse is measured with the Faraday cup of the first energy analyzer when the retarding high voltage is zero. In this case, the beams pass through the two plates without any retardation and arrive at the Faraday cup which is located just behind the two plates. As a result, the energy analyzer can measure the beam profile with space-charge waves.

The signal in Fig. 2 changes as the retarding voltage is increased. Figure 3 shows a fast wave on the beam for dif-

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† Present address: Department of Physics and Astronomy, UCLA, Los Angeles, CA 90095, USA.

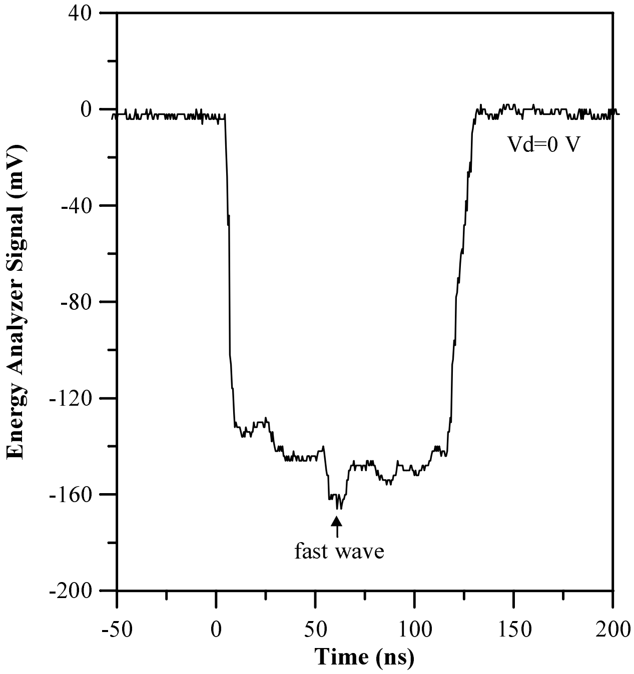

Figure 2: Typical electron beam pulse measured with a Faraday cup of the first energy analyzer at the entrance. The square-shaped localized wave in the central region of the pulse is a single fast space-charge wave.

ferent retarding voltages. The figure indicates that the flat part of the beam profile disappears when the retarding voltage V_d is 3,280 V, while two peaks are shown at t=5 ns and t=64 ns, respectively. Hence, the electrons at the two peaks have higher energies than those in the flat part of the beam pulse. Analysis in time scale indicates that the small peak at t=5 ns corresponds to the front edge of the beam pulse, where the electrons have a higher velocity, as a result of a strong nonlinear space-charge force in forward direction. The other peak at t=64 ns is the fast space-charge wave. The fast wave signal decreases as the retarding voltage V_d is increased gradually, and it disappears completely when V_d is 3,305 V. Therefore, the full energy width of the fast wave is 25 eV at the entrance of the resistive transport channel.

Similarly, a slow wave can be generated by adjusting electron gun conditions, and its energy spread can be measured. The wave is indentified as a fast wave or a slow wave by current monitor signals which are not shown here. Figure 4 shows a typical measurement result for a slow wave. The flat part of the beam pulse disappears at V_d=2,575 V and the slow wave disappears completely at V_d= 2,602 V. The full energy width of the slow wave is measured as 27 eV. The result implies that the electrons in the slow wave have higher energies than those in the flat part of the beam pulse. Hence, both fast and slow waves have higher energies, which is consistent with the previous measurement[11].

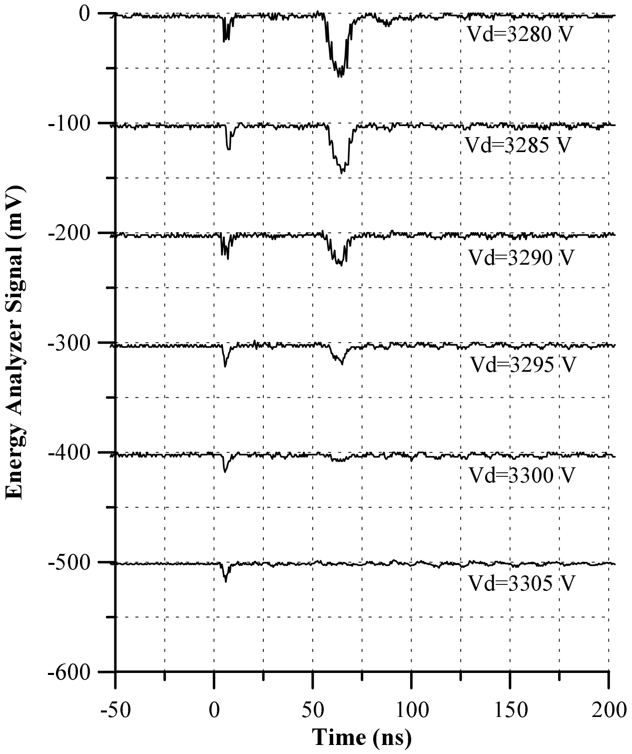

Figure 3: Fast wave signals from the Faraday cup of the first energy analyzer at different retarding voltages. The bump at t=64 ns is a localized fast wave and its amplitude decreases as the retarding voltage V_d increases.

It should be noted that the above energy-width measurements of the space-charge waves are relative to the flat part of the beam pulse. In other words, the electrons in the flat beam pulse have a certain energy width and the space-charge waves have additional energy width above it. In this measurement, the additional energy width of the wave is measured. To verify this, the amplitude of a voltage perturbation which is added to the beam pulse for generation of the localized wave in the gun is measured. It turns out that the voltage perturbation is measured to be 27.2 V, and this is very close to the measured full energy width of 25 eV and 27 eV in Fig. 3 and Fig. 4, respectively. This fact implies that the above method employed to measure the net energy width of the localized space-charge wave is correct.

The same method is used to measure the energy spread of the space-charge waves at the exit of the resistive transport channel for comparison. Figure 5 shows the measurement result of the slow wave at the exit. In the figure, the flat part of the beam pulse disappears at V_d=2,565 V and the slow wave disappears completely when V_d is 2,607 V. Therefore, the energy width of the slow wave at the exit is 42 eV, which is 56 % larger than at the entrance of the resistive transport channel. This experimental result clearly demonstrates that the resistive wall instability leads to an increase in energy width of a slow space-charge wave. A similar measurement for a fast wave at the exit is in progress and will be reported in the near future.

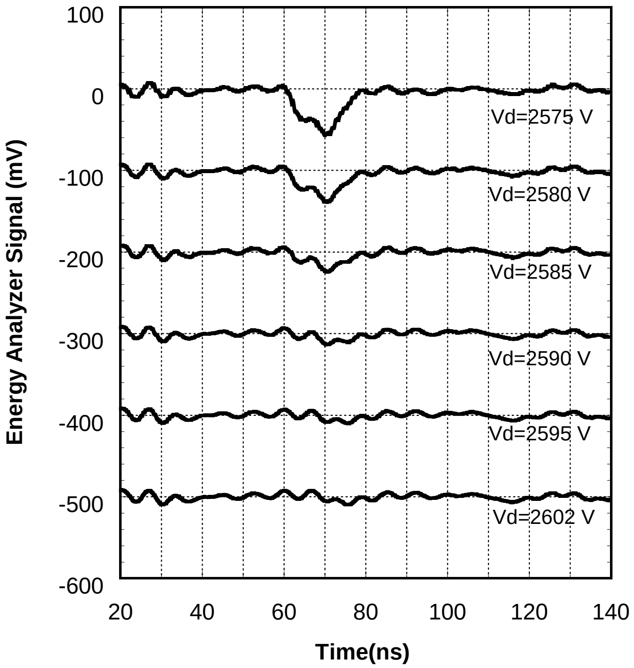

Figure 4: Slow wave signals from the Faraday cup of the first energy analyzer for different retarding voltages. In this figure, the full energy spread of the slow wave at the entrance of the resistive transport channel is measured as 27 eV.

3 SUMMARY

Experiments have been conducted to investigate the energy spread change by the resistive-wall instability. The energy spread of a localized space-charge wave has been measured at the entrance and exit of the resistive transport channel for comparison. It was observed that a slow space-charge wave leads to an evident energy-width increase as a result of the resistive-wall instability. Experiments with a fast are underway.

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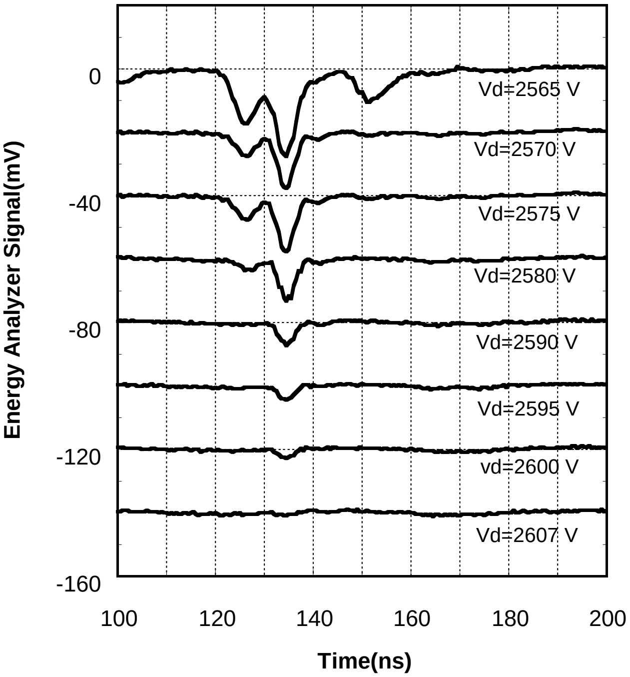

Figure 5: Slow wave signals from the Faraday cup of the second energy analyzer for different retarding voltages. The wave is shown to disappear completely at $V_d = 2,607$ V, so the full energy spread of the slow wave at the exit of the resistive transport is measured as 42 eV.

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