Fast ion beam chopping system for neutron generators

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Fast deuterium (D^+) and tritium (T^+) ion beam pulses are needed in some neutron-based imaging systems. A compact, integrated fast ion beam extraction and chopping system has been developed and tested at the Lawrence Berkeley National Laboratory for these applications, and beam pulses with 15 ns full width at half maximum have been achieved. Computer simulations together with experimental tests indicate that even faster pulses are achievable by shortening the chopper voltage rise time. This chopper arrangement will be implemented in a coaxial neutron generator, in which a small point-like neutron source is created by multiple 120 keV D^+ ion beams hitting a titanium target at the center of the source. © *2005 American Institute of Physics.* [DOI: 10.1063/1.1852871]

I. INTRODUCTION

The use of short neutron pulses is being considered as a way to scan cargo containers and luggage in harbors and airports around the world.[1] As the few nanosecond neutron pulse hits the target container, the elements in the target materials will emit characteristic secondary gamma rays with which the elemental composition of the target can be identified. The fast pulsing of the neutrons enables three-dimensional spatial resolution of the target materials. A compact, coaxial neutron generator with a point-like neutron source in the middle of the source has been developed at the Lawrence Berkeley National Laboratory (LBNL). The viability of the fast pulsing of the ion beam for this source was studied with a separate axial ion source in a single ion beam configuration. The goal was to integrate the beam extraction and chopping systems into a single, compact unit. No separate parallel plate or other type beam chopper was needed to pulse the beam.

II. SIMULATIONS

The ion beam optics of the system was simulated by using the PBGUNS[2] ion optical simulation code. The electrode sweeping the ion beam across the collimator electrode was part of the einzel lens used to focus the beam through the collimator aperture. This can be achieved by splitting the final electrode of the einzel lens into two sections. Similar extraction structure has been used in the past to chop H^- ion beams.[3] The extraction geometry was optimized so that a 1 mA ion beam extracted from a 2 mm diameter extraction aperture can pass through a 2 mm diameter collimator aperture placed 35 mm from the split einzel electrode. A PBGUNS simulation of the extraction geometry is shown in Fig. 1. Beam chopping with the beam focusing einzel lens was a three-dimensional problem, which was simulated with SIMION ion beam transport code.[4] The results of a 20 keV, 1 mA D^+ ion beam chopper are presented in Fig. 2. The beam displacement is proportional to the voltage applied between the two halves of the split electrode. As the voltage difference between the halves approaches zero and continues sweeping to reverse polarity, the beam is swept across the 2 mm diameter collimator aperture and a fast ion beam pulse is formed. The length of the beam pulse depends on the speed with which the voltage of the split electrodes is varying and the size of the beam spot at the collimator plate. Results of computer simulations indicated that a 2 mm diameter, 20 keV, 1 mA D^+ ion beam could be swept with 1500 V split electrode voltage difference about 15 mm at the collimator. This would create an ion pulse with duration of approximately one quarter of the chopper voltage rise time.

III. EXPERIMENTAL SETUP

A schematic of the ion source and extraction system used in the fast pulsing tests is presented in Fig. 3. The ion source was a 5 cm diameter quartz cylinder with an external, water-cooled radio frequency (rf) antenna coiled around it. The source plasma was formed with a 13.56 MHz rf generator with the accompanying inductive matching network. The extraction system consisted of a plasma electrode with a 2 mm diameter aperture, a three-electrode einzel lens with 3 mm aperture in the first electrode ($E1$) and 4 mm apertures in the final two electrodes ($E2$ and $E3$). The final, 10 mm deep einzel electrode ($E3$) was split into two halves, $E3A$ and $E3B$, for deflection of the ion beam. Placed 35 mm from $E3$ was a collimator electrode (CE) with a 2 mm diameter aperture to collimate and define the fast ion beam pulse from the sweeping ion beam. A 50 Ω impedance matched Faraday cup (FC) was used to measure the fast ion beam pulse. The FC was located 22 cm from the CE.

In order to sweep the ion beam at the CE, two DEI PVX-4140 pulse generators with the accompanying high voltage power supplies were connected to the two halves of $E3$. The pulse generators were connected in a push-pull

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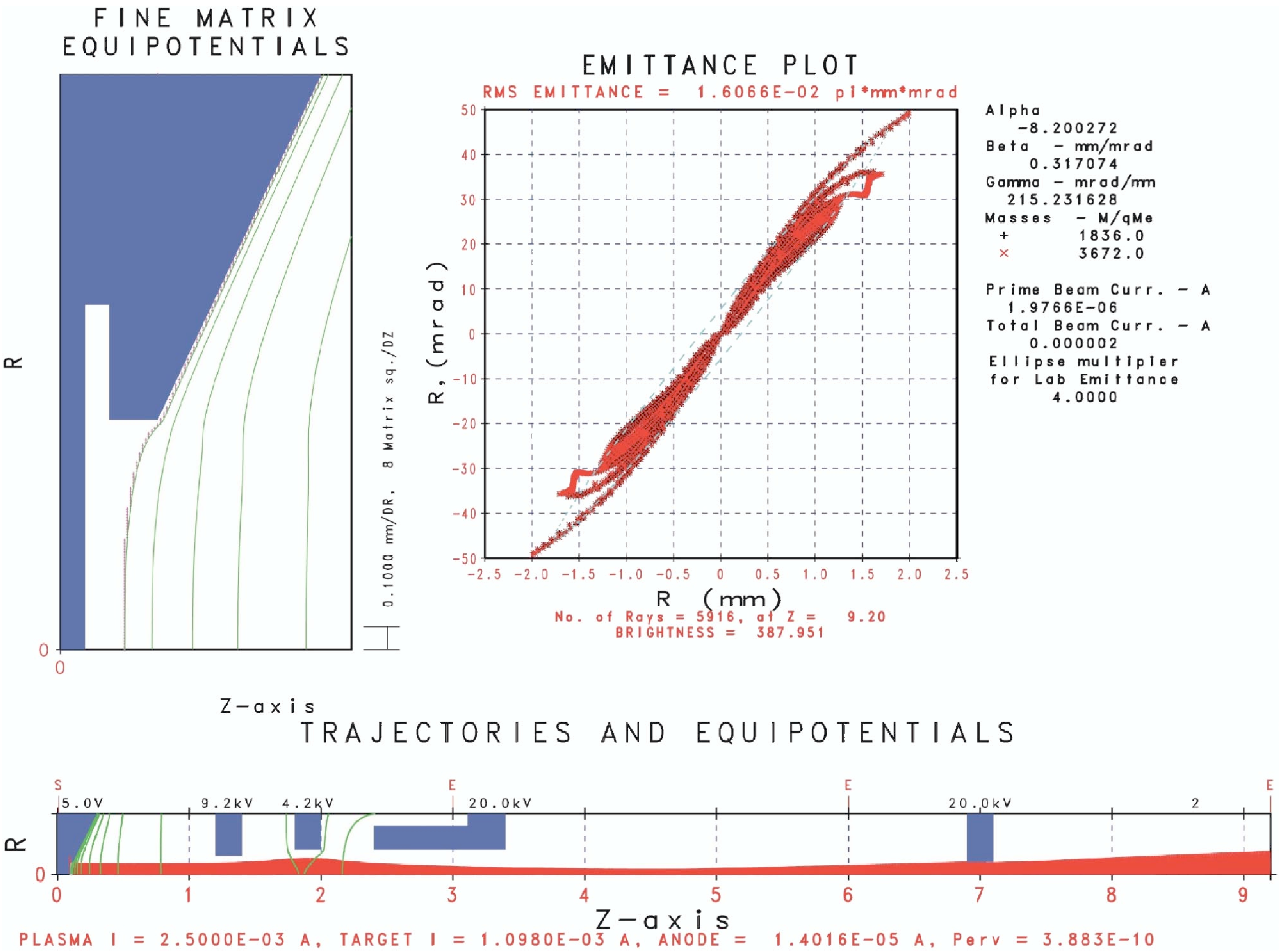


FIG. 1. (Color online) PBGUNS simulation of the axial extraction/pulsing geometry for 1 mA, 20 keV D^+ ion beam.

setup, were the voltages of the $E3$ halves could be swept from $-V$ to $+V$ and from $+V$ to $-V$ for $E3A$ and $E3B$, respectively. Since the maximum amplitude for the voltage V of this setup was V=800 V, a total voltage difference ΔV of 1600 V was achievable for the beam chopper.

IV. MEASUREMENTS

The measurement of few nanosecond current pulses is a demanding task which requires carefully impedance matched connections and minimized stray capacitances for the electrodes and cables. For this reason in the initial tests a KEPCO bipolar voltage supply was connected to $E3A$ to provide beam chopping in longer time scale with which the source and extraction could be tuned with less sensitive diagnostics. This power supply could deliver a sawtooth voltage pulse at 2 kHz frequency and sweep the voltage between

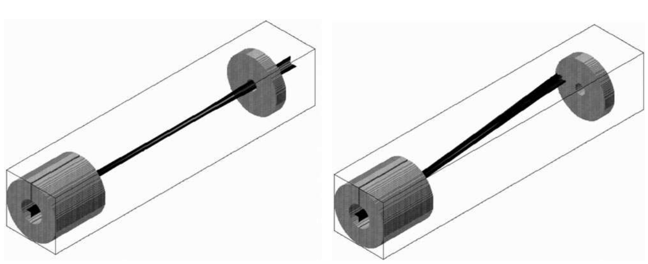


FIG. 2. (Color online) SIMION simulation of the ion beam sweeping for the 1 mA, 20 keV D^+ ion beam of the PBGUNS simulation of Fig. 1, when no voltage was applied between the split electodes (left) and 800 V voltage difference applied (right).

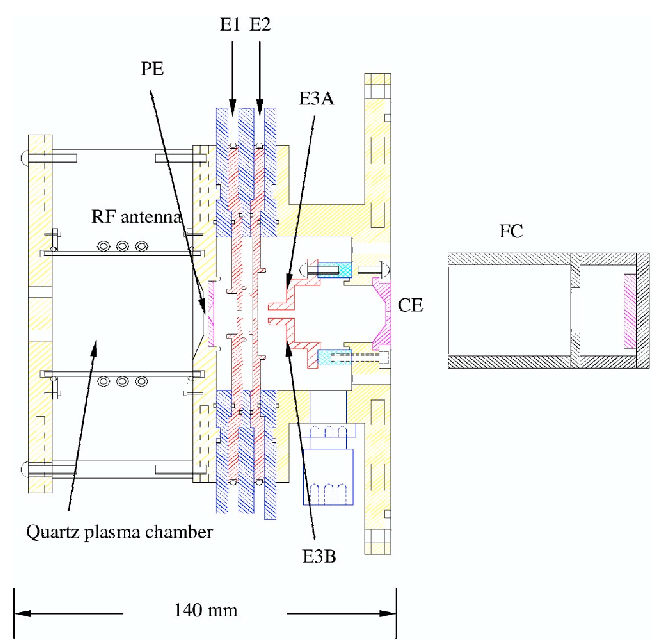


FIG. 3. (Color online) Schematic of the constructed ion source and extraction/pulsing geometry.

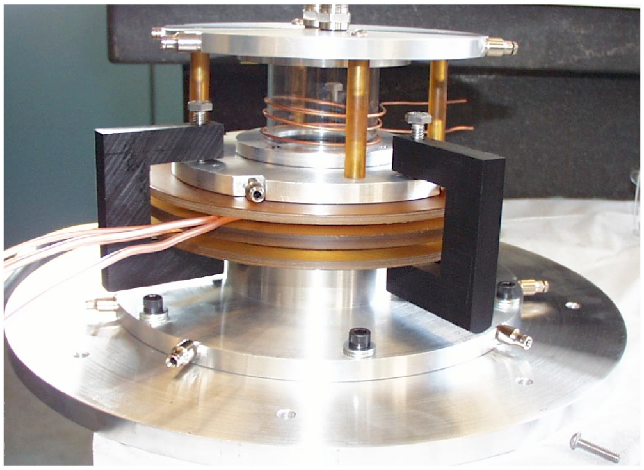


FIG. 4. (Color online) Assembled axial test source.

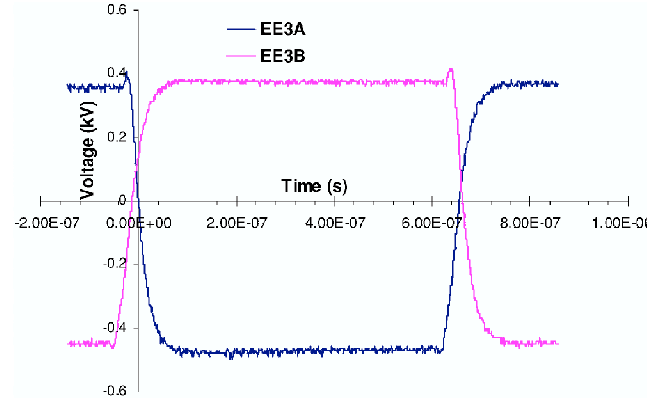


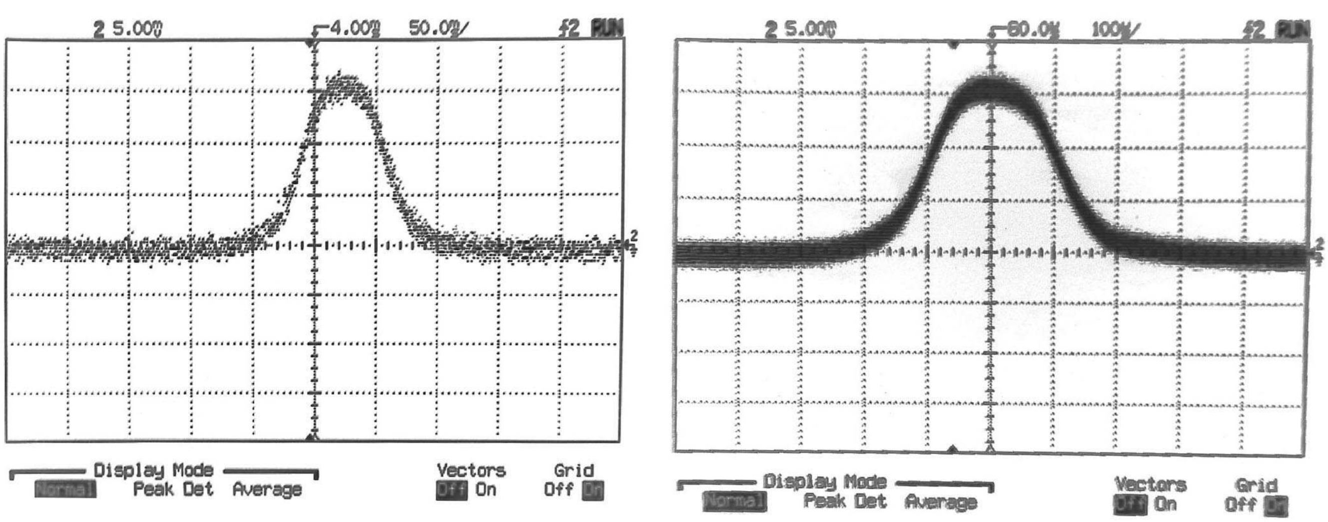
FIG. 6. (Color online) Typical voltage sweep of *EE3A* and *EE3B*, $\Delta V = 800$ V, $t_r = 110$ ns.

-1000 and $+1000$ V with rise time t_r in the range of 250 μs$<t_r<$500 ms. If the voltage of both *E3A* and *E3B* would be modulated, this would correspond to voltage range of -500–$+500$ V for *E3A* and *E3B*. According to the PBGUNS and SIMION simulations, this voltage will form a current pulse of about one third of the duration of the voltage sweep at 15 keV beam energy. Figure 4 shows the measured ion beam pulse with 0.3 mA beam current and 15 keV beam energy when *E3A* voltage was swept from -1000 to $+1000$ V with frequency $f=1$ Hz and $t_r=500$ ms for Fig. 4(a) and $f=350$ Hz and $t_r=1.4$ ms for Fig. 4(b). The current pulse lengths t_p are 150 and 0.4 ms in Figs. 5(a) and 5(b), respectively. The simulated and measured pulse lengths matched well in the initial measurements.

After the measurements, the fast switches were connected to the test stand. According to the manufacturers data sheet the PVX-4140 pulse generators are capable of about 60 ns voltage risetime when connected to a 50 pF load. The capacitance of the pulsing electrode setup was measured to be 130 pF. This means that the optimal actual voltage rise times would be longer in the pulsing experiment than the optimum values described by the manufacturer.

The sweeper voltage differential was limited to $\Delta V = 800$ V in the fast pulsing tests due to the fact that metal sputtered from the CE had partially coated the insulator stand which supports *E3A* and *E3B* causing occasional voltage breakdowns. Figure 6 shows the measured voltages for *E3A* and *E3B*. Voltage rise time was 110 ns when swept from -400 to 400 V.

Figure 7 shows the FC signal corresponding to the voltage sweep of Fig. 6 with 0.4 mA beam current, 250 W of rf power, 10 mT source pressure, and 15 keV beam energy. The three different hydrogen peaks H^+, H_2^+, and H_3^+ and some residual peaks from air can be seen in the signal. The different masses could be separated due to the characteristic time-of-flight from the CE to the FC of each ion species. The hydrogen peaks have full width at half maximum of 15 and 40 ns base width. The t_r/t_p ratio in the measurements was about 2.75, which is in reasonably good agreement with the simulations. The measurements show that that the simulations give a quite reliable picture of how the beam behaves and indicate that even shorter beam pulses can be achieved



(a) (b)

FIG. 5. (Color online) (a) $t_r=500$ ms, $t_p=150$ ms, (b) $t_r=1.4$ ms, $t_p=0.4$ ms.

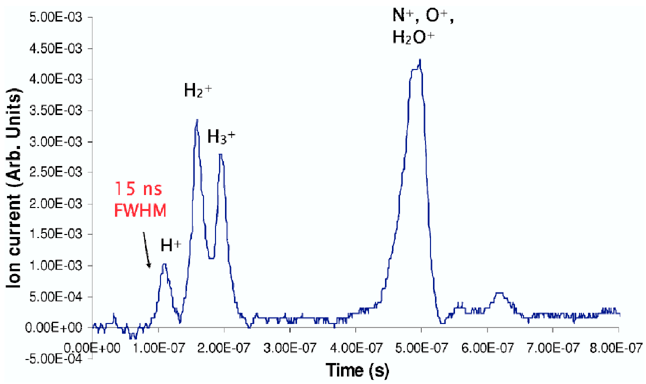


FIG. 7. (Color online) Measured current pulses with $\Delta V = 800$ V, $t_r = 110$ ns.

by minimizing the stray capacitances in the extraction and measurement setup and by shortening the voltage sweep time.

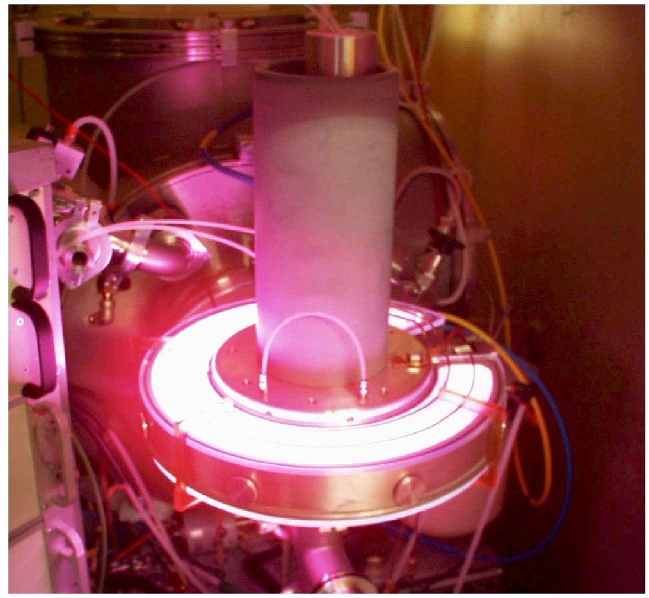


FIG. 8. (Color online) Coaxial neutron generator.

V. COAXIAL NEUTRON GENERATOR

Figure 8 shows the coaxial neutron generator developed at the LBNL. The rf plasma is formed at the outer rim of the generator and extracted to the target which is in the middle of the source. Multiple beams are extracted and transported using slits, which will allow larger beam currents without changing the extraction/pulsing geometry too much.

Figure 9 shows a PBGUNS simulation of the slit extraction/ pulsing in the coaxial geometry for one beamlet. The 50 mA/cm^2 D^+ beam will be swept similarly to the axial test configuration by sweeping the voltage of the different sections of the third extraction einzel electrode $E3$. The goal is to produce 2 ns neutron pulses.

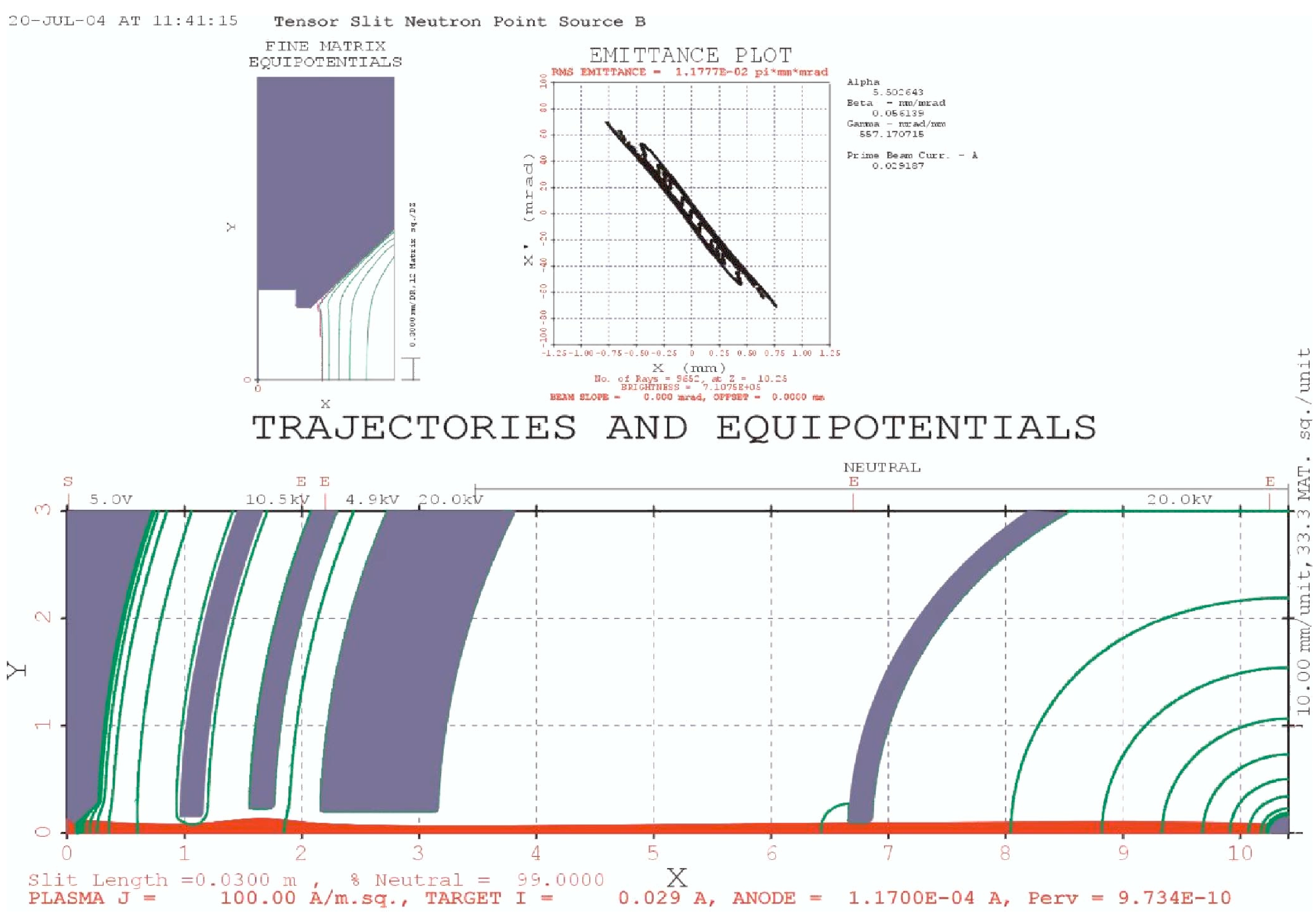


FIG. 9. (Color online) PBGUNS simulation of the coaxial extraction geometry with slit beam.

ACKNOWLEDGMENTS

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