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TITLE ELECTRON-BEAM GENERATION, TRANSPORT, AND TRANSVERSE OSCILLATION EXPERIMENTS USING THE REX INJECTOR

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Electron-Beam Generation, Transport, and Transverse Oscillation Experiments Using the REX Injector

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Abstract

The REX machine at LANL is being used as a prototype to generate a 4-MV, 4.5-kA, 55-ns flat-top electron beam as a source for injection into a linear induction accelerator of the 16-MeV Dual-Axis Radiographic Hydrotest facility. The pulsed-power source drives a planar velvet cathode producing a beam that is accelerated through a foilless anode aperture and transported by an air core magnetic lens for injection into the first of 48 linear induction cells. Extensive measurements of the time-resolved (<1-ns) properties of the beam using a streak camera and high-speed electronic diagnostics have been made. These parameters include beam current, voltage, current density, emittance, and transverse beam motion. The effective cathode temperature is 117 eV, corresponding to a Lapostolle emittance of 0.96 mm-rad. Transverse oscillations of the transported beam have been observed via a differenced B-dot technique to be about ±100 μm at 245 MHz. This beam motion has been correlated via detailed rf measurements of asymmetric transverse cavity modes in the A-K gap.

I. INTRODUCTION

The Relativistic Electron-Beam Experiment (REX) machine at LANL has been selected as the type of injector for the Dual-Axis Radiographic Hydrotest facility (DARHT) 16-MeV induction accelerators. This decision is based upon the detailed measurements and results previously reported [1,2]. This paper presents recent results using a smaller cathode (63.5- vs 76.2-mm diam) with a finer-structure-cloth emitting material known as "velveteen." The pulsed power source [3] has recently been modified to produce a longer (85- vs 45-ns) FWHM and flatter (±1.5 percent) electron beam pulse as required by the DARHT accelerators. Beam matching hardware and transport measurements are described along with transverse beam-motion reductions observed at the entrance to the first DARHT induction cell. This beam motion can lead to the unwanted Beam Break-Up (BBU) instability in induction accelerators containing many gaps. The 2-D particle-in-cell code ISIS [4] has been used to closely model the experimental configuration. The experimental arrangement is discussed in Section II and the data and results are presented in Section III.

II. EXPERIMENTS

The output end of the REX injector is shown schematically in Fig. 1 wherein the 147-mm anode-cathode (A-K) gap region is housed in a vacuum vessel cryogenically pumped to a base pressure of 6×10^{-6} torr. The electron source consists of a 63.5-mm-diam, velveteen cloth cathode recessed about 1 mm into the surface of the cathode holder and field forming assembly. The field forming electrode is centered on a 1.83-m-diam x 254-mm-thick Lucite radial insulator with embedded aluminum grading rings separating the oil-filled output transmission line from the vacuum diode region. The magnetic field used for beam extraction is generated by an air-core, bifilar-wound, solenoid extraction magnet (161-mm i.d. x 216-mm o.d. x 485-mm long) whose center is located 505 mm from the cathode surface. The extraction magnet has two additional layers containing cosine-wound dipole trim coils [5] used to null the transverse fields. The magnetic field at the edge of the cathode is likewise nulled by a 1.7-m-i.d. bucking coil centered 141 mm behind the cathode surface.

The REX pulsed power consists of a Marx generator that charges a water pulse-forming line that is switched into a glycol- and then an oil-based transmission line terminating in a liquid radial resistor with a value of 175 Ω. This resistor provides a stiff voltage source to drive the diode. Voltages and currents associated both with the pulsed power and the electron

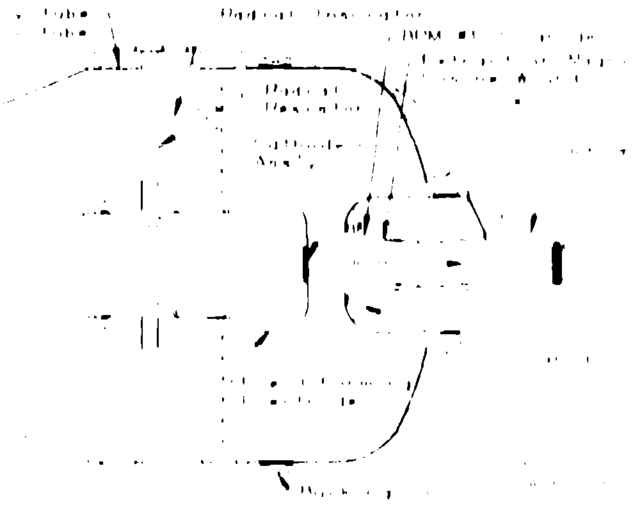

Figure 1. Schematic of REX Diode Region.

Work performed under the auspices of the U.S. Department of Energy beam are measured using E-dot and B-dot type monitors integrated with passive, 1 μs time-constant, 50-Ω integrators corrected for cable loss and integrator droop. The signals are transmitted to the screen room area via 50-ns-long, Andrews, 12.7-mm-diam, Superflex foam cable. Tektronix R7103 (1-GHz) oscilloscopes are used to record the data in digital format using their DCS01 Digitizing Camera System. The diode current (Ianode) that goes through the 133.6-mm-diam anode aperture is sensed by four symmetrically located B-dots contained within the anode Beam Position Monitor (BPM #1). The BPM also contains two pairs of diametrically opposed B-dots that are used to determine the x-y coordinates of the beam position; the limiting positional resolution is 0.25 mm. The A-K gap voltage (Vanode) is measured as the sum of four equally spaced E-dots mounted flush on the flat portion of the anode.

Figure 2 shows the matching and transport section between the output of the extraction magnet and the input to the first DARHT induction cell. The extraction magnet is set to form a beam waist at the end of the transport hardware, and the steering coils are used to center the beam in the drift pipe. The beam is injected along the axis of the DARHT accelerator by the adjacent dipole steering coils.

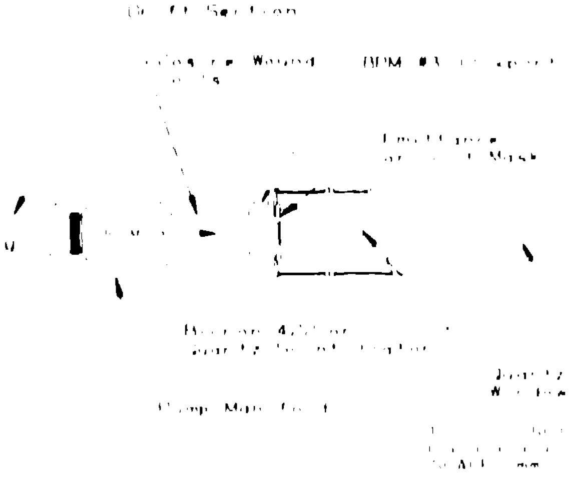

Figure 2. Rex Beam Matching Hardware

The emittance of the transported electron beam was measured by intercepting the beam with a brass mask [1,2] that was located 2.53 m from the cathode and is in the entrance plane of the first induction cell. The mask can be replaced by a 1.27-mm slit which yields the current density vs radius and time of the beam and, in particular, the modulation and energy variation of the beam. In both cases, the beam that was transmitted through the mask drifted 406 mm before striking either a 0.6-mm-thick strip of Bicron 422 or 1-mm-thick quartz plate scintillators. Light from the scintillator was imaged onto the photocathode of either an IMACON 500 or Thomson TSN-506 streak camera using a 90-mm-diam Questar telescope via two turning mirrors. Typical sweep speed for all of the measurements was 2 ns/mm.

The high-frequency transverse beam motion at the waist location was measured by using a differenced B-dot technique passively summing the opposite polarity B-dot loops of BPM #3. In an attempt to further understand the cause of this motion, a biconic transition cone from 50-Ω coax to the 53.3-Ω impedance of the REX output oil transmission line was installed. A Hewlett Packard 8753B network analyzer was used to drive this cone while either reflections or transmissions to the diode region were monitored with various shielded electric and magnetic field probes that could be rotated about the axis of the A-K gap.

III. MEASUREMENTS AND ANALYSIS

Typical diode voltage and current waveforms are shown in Fig. 3. The time delay (~ 7 ns) before the velveteen surface begins field emission corresponds to a field of 9.5 kV/mm. The current for a given voltage across the A-K gap is about 15% higher than that predicted by the ISIS code and is presently thought to be due to an even greater edge enhancement of emitted current than that calculated [1].

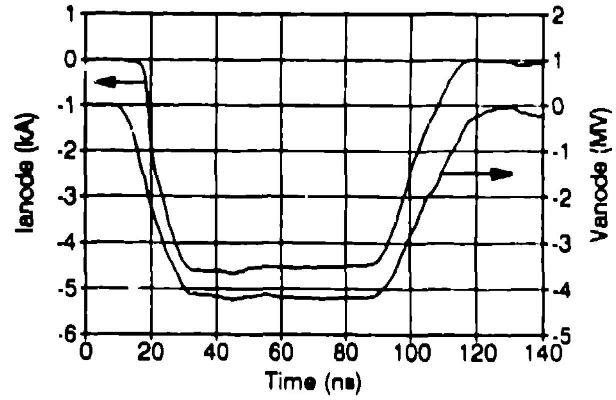

Figure 3. REX A-K Gap Voltage and Diode Current.

Streak camera slit measurements of the beam at BPM #3 with the extraction magnet set to 778G were made for comparison of the beam waist size and energy spread with the calculations as well as with the A-K gap voltage and current data of Fig. 3. Figure 4 is a slit record indicating an energy spread of ±2.5% over 55 ns as compared to the ±1.5% of Fig. 3. The cause of the increased beam diameter at ~20 ns is still being examined. The beam edge diameter from Fig. 4 is about 62.5 mm, which is very close to the 60-mm diam calculated by ISIS.

The emittance of the beam (defocussed to 120-mm diam) at this same location was determined by fitting gaussian distributions to the beamlets of the post-processed streak camera records. These distributions were averaged over 45 ns of the flat-top portion of the pulse using 1-ns beam slices of the computer processed image. The angular spread of the center beamlet yields an effective cathode temperature of 117 eV. The Lapostolle emittance of the beam is obtained by calculating the weighted phase space area of the x-x' plot

Since a 117-eV temperature corresponds to an emittance of 0.96 mm-rad at the cathode, the measured emittance of 1.0 mm-rad demonstrates negligible emittance growth after 2.53 m of transport.

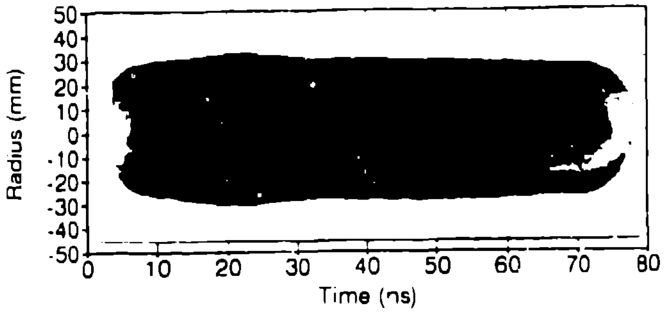

Figure 4. Slit Record of Beam Waist at 2.53 m

The transported and emitted beam current are shown overlaid on the same scales in Fig. 5 for a beam energy of 4.2 MV; the fraction transported is 90 percent. The loss of current is most likely due to high-emittance electrons that get through BPM #1 but are not transported to BPM #3. The calculated maximum size of the beam at the pole of the extraction magnet is ≈120-mm diam compared to the 161-mm diam of the magnet bore and the 148-mm diam of the propagation pipe. Figure 5 also shows that the low energy electrons associated with the rise and fall of the current pulse are over focused into the pipe walls and are not transported to the beam waist region; the beam pulse is effectively sharpened.

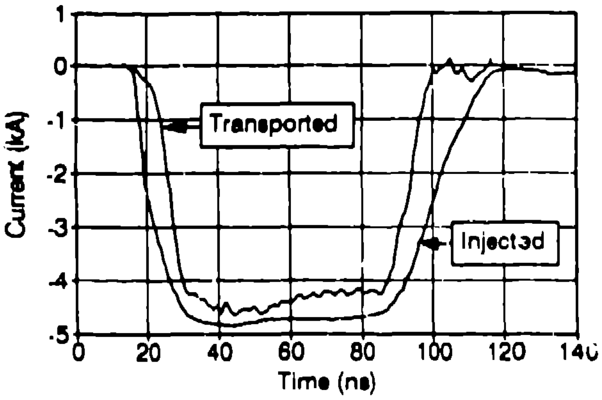

Figure 5. Emitted and Transported Beam Current

Although transverse beam motion beyond the extraction magnet has been measured on REX previously [6], the recent pulsed power modifications have reduced the motion to below the streak camera's resolution limit of ≈100 μm. Figure 6 is a typical differenced B-dot signal recorded from BPM #3 at the nominal operating conditions of 4 MV and 4.5 kA. A predominant frequency of ≈245 MHz is present and corresponds to a beam motion of ±100 μm. Since this frequency is not present in the derivatives of the pulsed power diagnostics, the code URMEL-T [7] was used to investigate the possibility of cavity modes associated with the A-K cavity region that could produce transverse fields to deflect the beam in time.

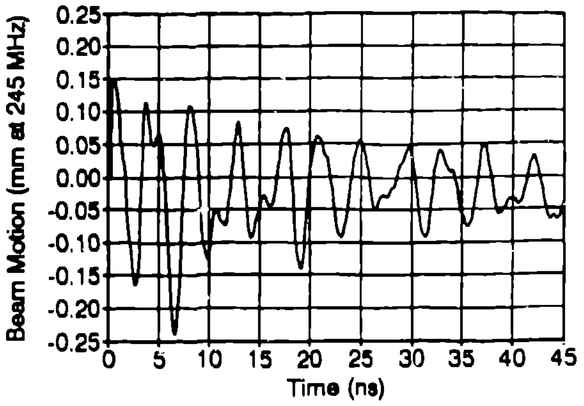

Figure 6. Differenced B-dots for Transverse Beam Motion

Accelerating (m=0) modes under 500 MHz were found at 64(67), 149(143), 310(294), 360(364), 385, and 458 MHz with URMEL-T predictions in parenthesis. Deflecting (m=1) modes were found at 254(249), 263, 335(320), 340, 380, and 437(421) MHz indicating some asymmetry either in the transmission line or in the cavity. The deflecting 254 (249)-MHz (m=1) mode was dominant and is in good agreement with the ≈245 MHz measured by the differenced B-dots. Varying the alignment of the cathode field forming electrode or of the transmission line conductor reduced the excitation only a few db. It may be that several small misalignments are causing the nominally TEM transmission-wave to have components that excite the TM$_{1n0}$ modes of the cavity. Since this motion is where BBU gain is very low, far from the DARHT induction cell resonances, the required beam centroid stability of REX as an injector has been demonstrated.

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