PULSE-POWER-INDUCED OSCILLATIONS OF THE REX ELECTRON BEAM*

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Abstract

The Relativistic Electron-Beam Experiment pulse power generator is used to produce a 4-MeV, 5-kA, 50-ns electron beam. The beam is produced by a planar velvet cathode. Multiple current rise times are used to examine pulse-power-induced beam oscillations. Diagnostics include a streak camera and high-speed electronic probes for monitoring current and voltage. Correlation between beam oscillations and TE/TM cylindrical cavity modes in the anode-cathode gap is examined.

1. Introduction

The Relativistic Electron-Beam Experiment (REX) machine at Los Alamos National Laboratory is used to generate a 4-MeV, 5-kA, 50-ns electron beam. Initially, time-resolved investigations of the electron beam emittance indicated the presence of asymmetric oscillations. These oscillations dramatically affect the beam quality. This is most evident when the beam is magnetically focused to a minimum diameter spot. In Sec. 2, the experimental arrangement for these observations is briefly discussed. Section 3 describes observation of the beam oscillations. The solution for removing the oscillations and further experiments are presented in Sec. 4.

2. Experimental Arrangement

The electron source and beam diagnostics for the experiment are described in detail in Ref. 1. The experimental arrangement is shown in Fig. 1. In addition to the emittance measurement (Ref. 1), a measurement of the beam current-density distribution as a function of time is made by replacing the emittance mask with a plate containing a slit instead of an array of holes. The beam transmitted through the slit strikes a 0.75-mm-thick quartz glass plate and generates Cherenkov light, which is recorded by the streak camera. The quartz plate is located 500 mm from the center of the extraction magnet. The peak axial solenoidal field required to focus the beam to a minimum diameter spot is 1.108 kG.

3. Problem Identification

Initially, streak photographs produced with an emittance mask indicated significant transverse beam motion (Fig. 2a). Transverse displacement is in phase across the beam indicating that the beam is oscillating rigidly from side-to-side. The oscillations are even more noticeable when a streak is taken near the beam focus (Fig. 2b), where the transverse excursions exceed the beam radius. This effect causes an increased time-integrated beam diameter. The oscillations suggested that there is an asymmetric electromagnetic field near the cathode surface and that the beam was swept as a function of time. Voltage waveforms (Fig. 3a) from the integrated capacitive monitor (V-diode) taken simultaneously with the streak photographs show high-frequency modulations with a magnitude of ~ 25% of pulse height. This indicates evidence of electromagnetic energy being transferred back and forth between

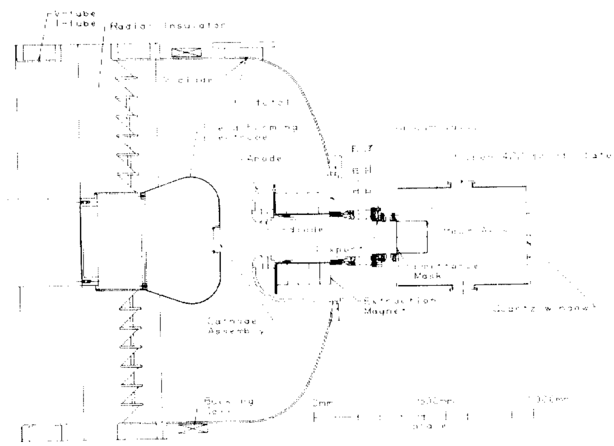

Fig. 1. REX Experimental Arrangement.

the vacuum vessel and the pulse power drive. Since the beam motion is asymmetric, any driving field must be asymmetric; there must be an asymmetry in the pulse power drive or the anode-cathode (A-K) assembly.

REX was originally designed to include a concentric array of metal pins in the center conductor of the pulse line ahead of the vacuum diode. The function of these pins was to sharpen the rise time and reduce

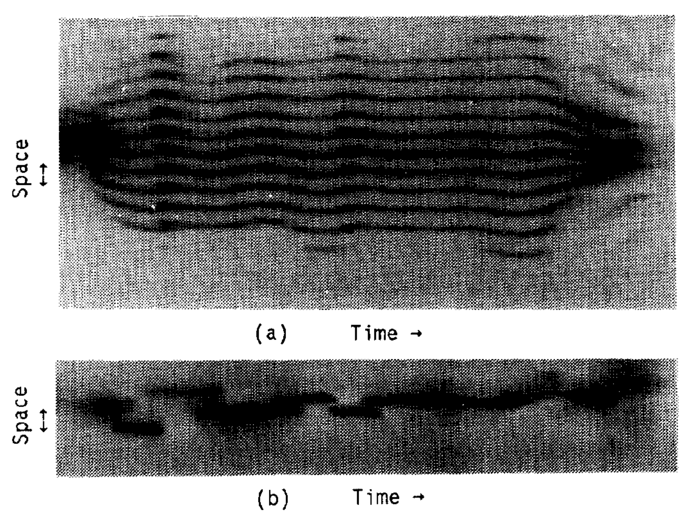

Fig. 2. Streak Camera Record of the (a) Emittance Mask and (b) Minimum Focus at 50 cm. First Observed in REX Experiment.

the prepulse voltage on the cathode for an application using a high current field emission diode. The present REX experiments utilize a low-current, large A-K gap diode geometry that does not require a short rise time and low prepulse levels. Beam motion was examined with the prepulse pins closed (Fig. 4a); when the prepulse pins were opened (Fig. 4b), transverse beam motion increased in magnitude. Amplitudes of the modes driving the electron beam could be increased by

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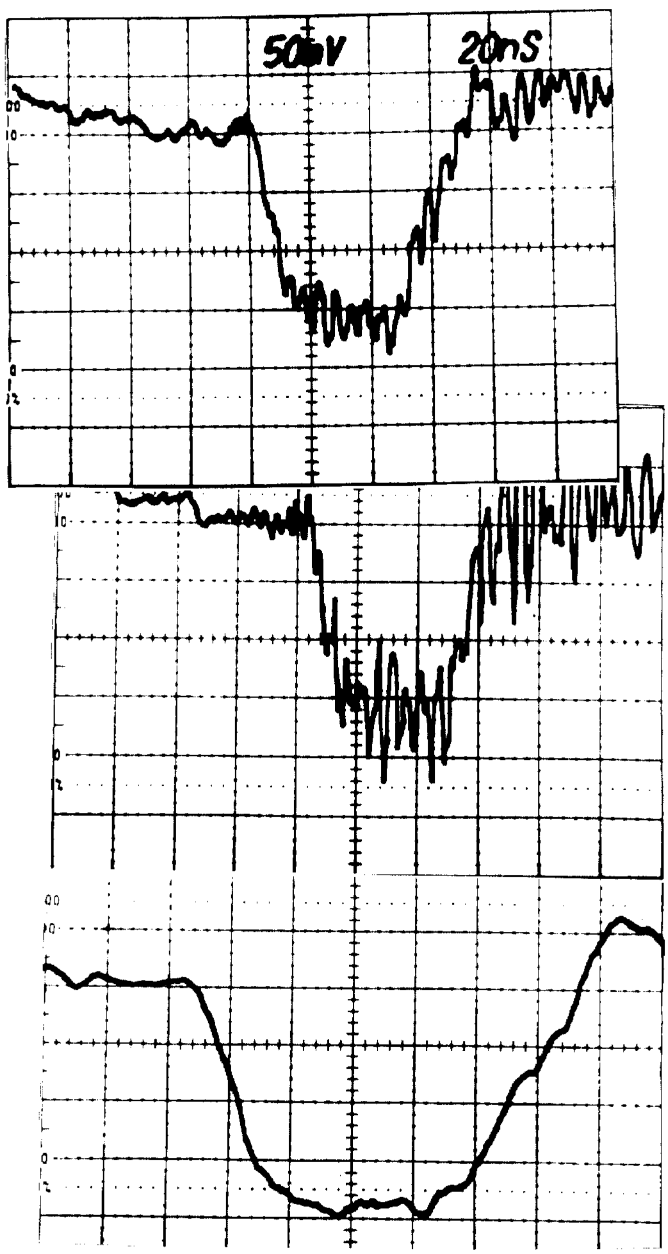

Fig. 3. Oscilloscope Trace of Integrated Capacitive Monitor in the Vacuum (V-diode) (a) with the Pulse Sharpening Switch Closed, (b) with the Pulse Sharpening Switch Open, and (c) with the Pulse Sharpening Switch Removed.

sharpening the initial rate of rise of the current pulse. The magnitude of the oscillations increased considerably as shown in Fig. 3b. The emittance streak camera record also gave evidence of an increase in transverse oscillations.

4. Solution

Several modifications were made in an effort to dampen the beam motion. The vacuum ports were covered with wire mesh and the vacuum valve was removed from the system to eliminate asymmetries. Also, the A-K gap was reduced from 25- to 15-cm to increase the accelerating electric field; however, the beam oscillations remained. The magnetic alignment was dismissed as a cause of the beam motion because oscillations existed at reduced amplitude with no magnetic field.

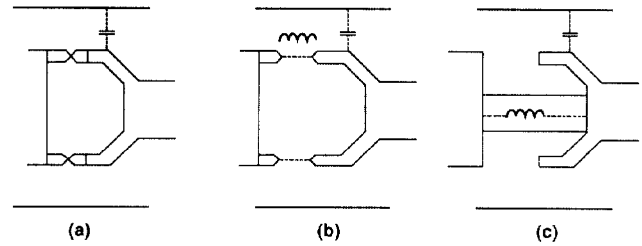

Fig. 4. Pulse Sharpening Configurations (a) Pins Closed, (b) Pins Open, and (c) Pins Removed and L-C Filter Installed.

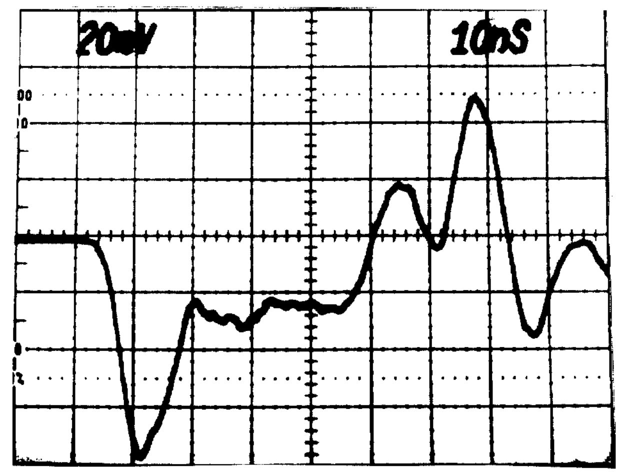

Fig. 5. Oscilloscope Trace of the Total Vacuum Current (I-total).

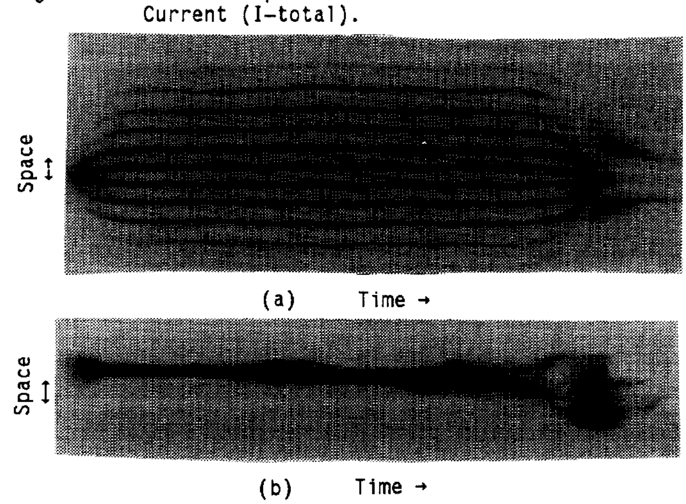

Fig. 6.* Streak Camera Record of the (a) Emittance Mask and (b) Minimum Focus at 50 cm with Pulse Sharpening Switch Removed.

The time-resolved A-K vacuum (I-total) current measurement is shown in Fig. 5. This trace contains two components—the displacement current, which charges the vacuum capacitance, and the beam current. A substantial amount of current is required to charge the vacuum capacitance. Therefore, a slight asymmetry could produce significant fields in the cavity. Since eliminating physical asymmetries in the pulse power and A-K gap did not solve the problem, the current rise time was decreased to inhibit simulation of the cavity modes.

The voltage pulse rise time was decreased by removing the pulse sharpening switch and inserting a small diameter pipe in its place (Fig. 4c). This produced a diode voltage trace shown in Fig. 3c. Figures 6a and 6b are corresponding emittance and 50-cm focus streak records. The transverse oscillations have been minimized by decreasing the coupling of the pulse power drive into the vacuum cavity, slowing the current rise time. The inductance of the inserted transmission line and the capacitance of the remaining section of the pulse sharpening assembly act as a filter for the high frequency part of the pulse.

Computer studies of asymmetric cavity modes using the code ANDY (Ref. 2) have been made using simple cavity boundaries (Fig. 7). The resulting electromagnetic modes are shown in the spectrum in Fig. 8. The

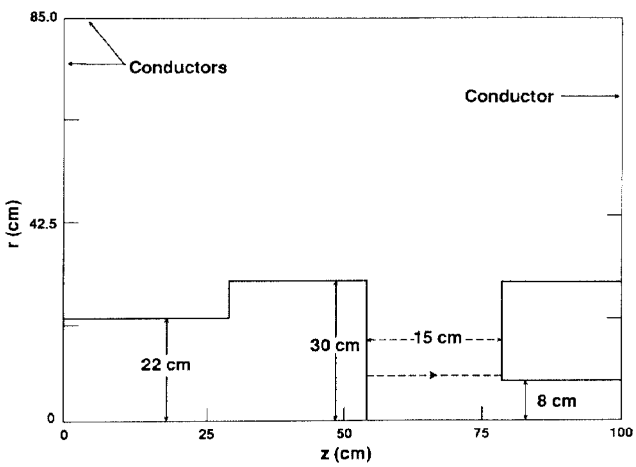

Fig. 7. Simple Cavity Model Used to Study Asymmetric Cavity Modes Using the Computer Code ANDY.

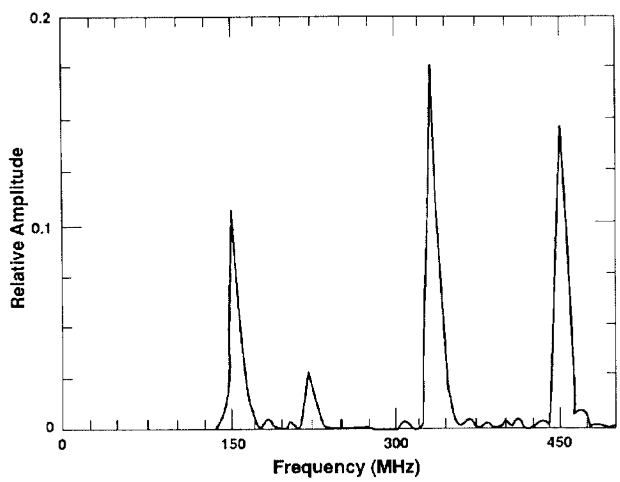

Fig. 8. Spectrum of Cavity Modes Obtained Using ANDY.

lowest resonance appears at 153 MHz. Resonances at 150 MHz and 330 MHz have been found experimentally by exciting the cavity with dipole loops; this agrees closely with the frequencies obtained from the ANDY calculations with a 15-cm A-K gap. In an experiment with a 15-cm A-K gap, the transverse oscillation of the beam was measured by analyzing the center beamlet of the emittance mask. The centroid of the beamlets as a function of time obtained from the analysis of the streak record is shown in Fig. 9a for a current pulse with a fast rise time. Figure 9b is the same analysis with a longer rise time. A large reduction of transverse oscillation is evident in comparing Figs. 9a and 9b. A sinusoidal fit of the streak record of Fig. 9a yields a frequency of 153 MHz. This agrees with the ANDY calculation as well as with the measurement of the cavity modes.

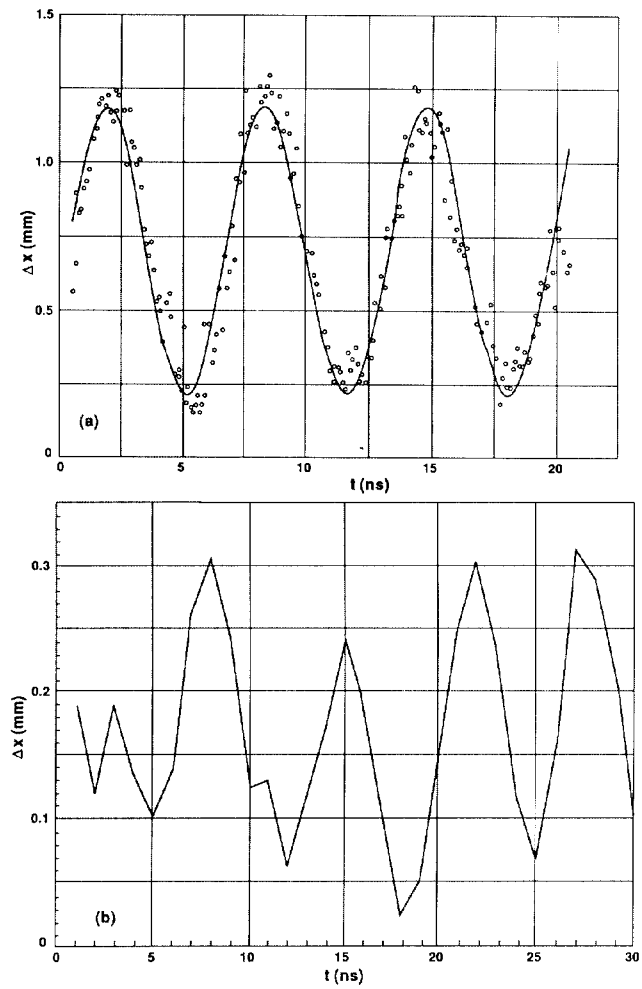

Fig. 9. Transverse Oscillation of the Center Beamlet of the Emittance Mask with (a) Fast and (b) Slow Current Pulse.

As modification of the hardware to remove asymmetries had no observable effect on beam oscillations, all recent efforts to improve beam dynamics have been to reduce the current rise time. Experiments are in progress to optimize the current pulse waveform to drive the REX diode section. This is being accomplished by further refining the L-C filter section located in the former pulse sharpening switch region.

5. Conclusion

Electromagnetic excitation of the cylindrical A-K gap in the REX experiments produced unacceptable levels of beam motion as a function of time. Correction of hardware asymmetries did not eliminate the problem. The problem was solved by tailoring the current rise time of the pulse power to minimize the coupling of the pulse power drive to the cavity.

References

[1] R. L. Carlson, L. A. Builta, T. J. Kauppila, D. C. Moir, R. N. Ridlon, and T. P. Hughes, "A 4-Megavolt, 5-Kiloampere Pulsed Power High-Brightness Electron Beam Source," presented at the IEEE Conference on Accelerator Engineering, Chicago, IL, March 20-23, 1989.

[2] T. P. Hughes, R. M. Clark, R. L. Carlson, L. A. Builta, T. J. Kauppila, D. C. Moir, and R. N. Ridlon, "Beam Generation and Transport on REX: Theory and Experiment," MRC Report No. MRC/ABQ-R-1133, February 1989.