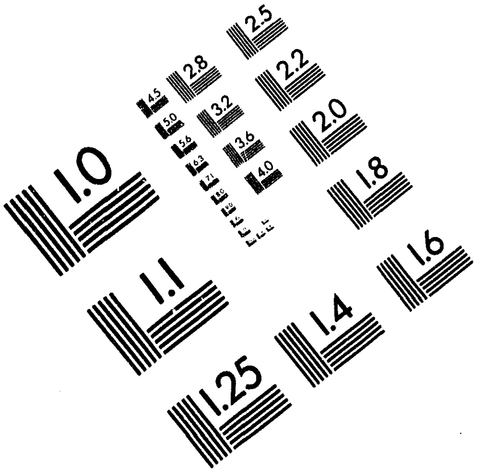

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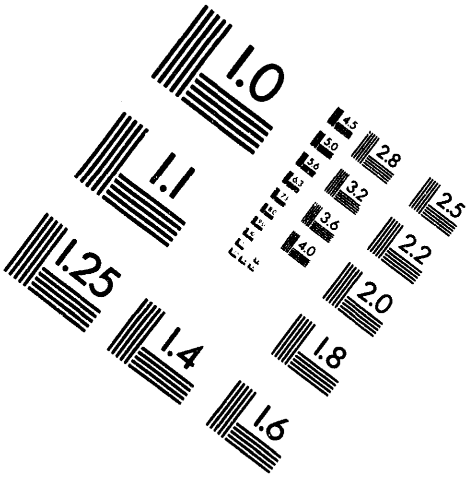

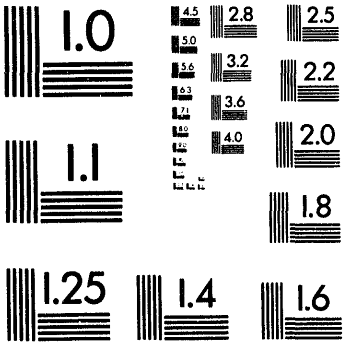

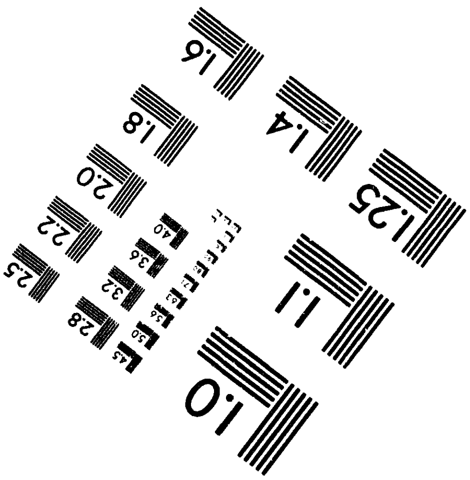

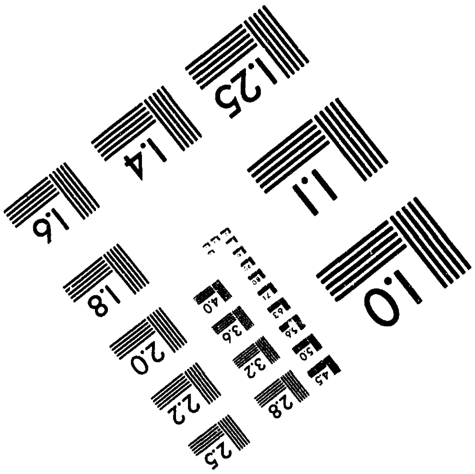

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Results of the Reacceleration Experiment: Experimental Study of the Relativistic Klystron Two-Beam Accelerator Concept

G. Westenskow And T. Houck

Lawrence Livermore National Laboratory, University of California
P.O. Box 5508, L-440, Livermore California 94550, USA

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Lawrence Livermore National Laboratory

Results of the Reacceleration Experiment: Experimental Study of the Relativistic Klystron Two-Beam Accelerator Concept*

Glen Westenskow and Tim Houck
Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94550

Abstract

We recently demonstrated the reacceleration of a bunched beam through an induction accelerator cell in support of the two-beam accelerator concept. We present the results of this experiment including amplitude and phase measurements of the extracted microwave power at 11.424 GHz. We also describe progress in achieving a two-beam accelerator microwave source design that is efficient and cost effective for linear collider applications.

Relativistic klystrons are being developed as an rf power source for high gradient accelerators applications that include compact accelerators, large linear electron-positron colliders, and FEL sources. In a relativistic klystron two-beam accelerator (RK-TBA), the drive beam passes through a large number of rf output structures. High conversion efficiency of electron beam energy to rf energy can be achieved in the relativistic klystron by using reacceleration of the bunched drive beam.

The Reacceleration Experiment was designed to study the RK-TBA concept. Figure 1 is a photograph of the beamline and Figure 2 is a schematic of the experiment. A 5-MeV, 1-kA induction beam is modulated by a transverse deflection technique (Chopper) to generate several hundred amperes at 11.4 GHz. The extraction section is comprised of three traveling-wave output structures and two induction cells located between the outputs. The output structures operate at 11.424 GHz in the TM_{01} mode with a $2\pi/3$ phase advance per cell and phase temperature sensitivity of about 0.1 °/°C. Additional parameters are listed in Table 1. The induction cells used for reacceleration of the modulated current are each pulsed at 250 kV. The design of the modulator and the experiment has been described in detail elsewhere. Here, we report on the results.

Table 1. Parameters for the output structures.

Design Parameter	#1	#2	#3
# of Cavities (Undamped)	4	5	6
# of Cavities (Damped)	2	2	0
Aperture (mm)	13	14	14
Fill Time (ns)	1.35	1.22	1.05
Group Velocity	0.13 c	0.167 c	0.167 c

Figure 3 shows the maximum power achieved, with no pulse shortening, from each output. The "flat top portion" of the pulse lasts about 25 ns. This time is the length of the current pulse minus both the transient time of the drive cavity in the modulator and the fill time of the output structures. Linear collider applications place severe constraints on amplitude and phase variation. The anticipated requirements are for phase to be within ±1°, and for amplitude to be within ±1% over the power pulse.

Output power was limited by the vacuum pressure and hydrocarbon contaminants in the vacuum system. The induction cells use neoprene o-ring seals and insulating oil. These cells represent the major source of the contaminants. The operating pressure was in the mid 10^{-7} torr range at the vacion pumps in the output waveguide. The highest rf output power levels obtained were about 20% greater than those shown in Figure 3. However, these higher power pulses exhibited pulse shortening. Table 2 lists power levels and maximum sustainable surface electric fields. Figure 4 shows a combined, coincident power pulse for the three outputs.

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*The work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract W-7405-ENG-48.

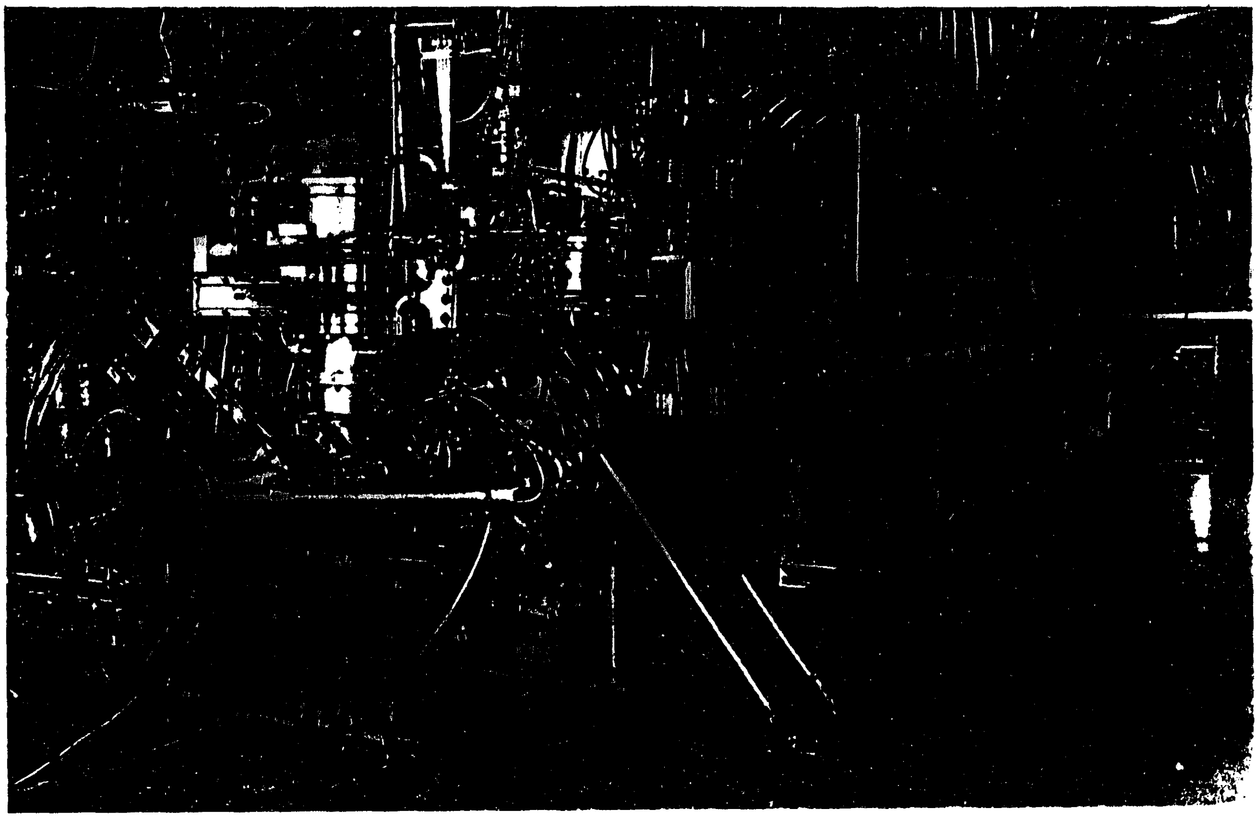

Figure 1. Photograph of the Reacceleration Experiment Beamline. The injector is located in the background to the left of the raised platform. The large cylindrical cables extending from the ceiling deliver the pulsed power to the induction cells of the injector/accelerator. The rectangular boxes attached to the cables contain compensation resistors and bus bars. The induction cells used for reaccelerating the beam are located just left of center in the photograph.

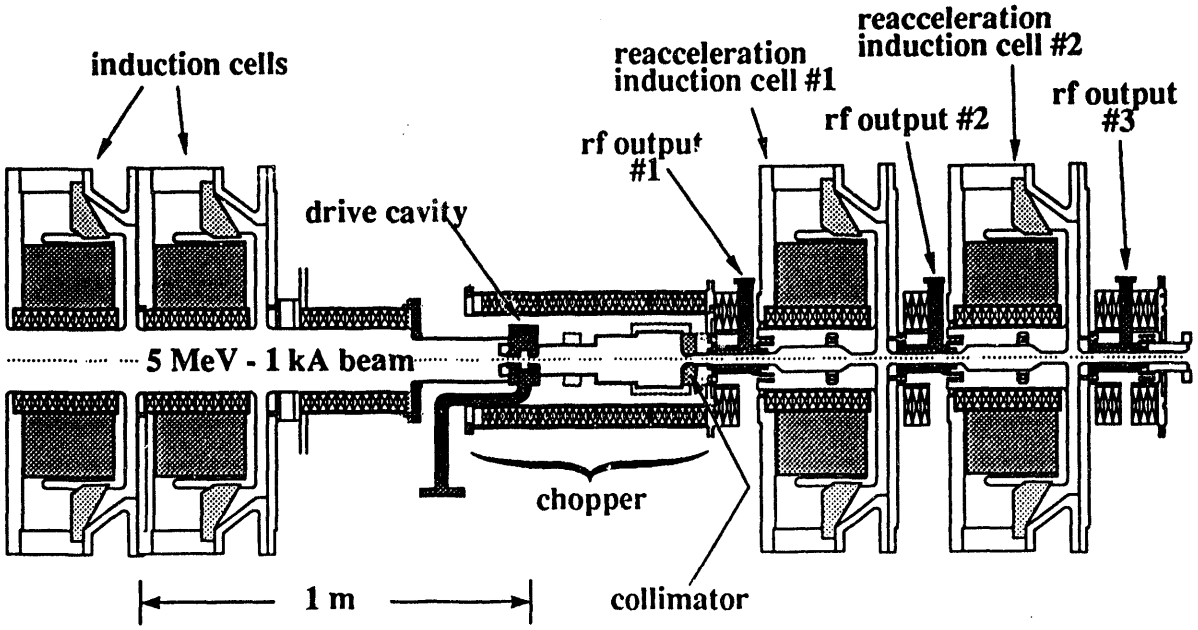

Figure 2. Schematic of the Reacceleration Experiment.

Table 2. Maximum rf output powers achieved for each structure.

Output	"Flat top" Power (MW)	Surface E-Field (MV/m)	Peak Power (MW)
TWS#1	64.5±4%	60	86
TWS#2	88.5±3%	75	101
TWS#3	50.0±3%	60	59

Figure 5 shows the phase of the power from the first output structure with respect to the modulator reference. The phase is measured by mixing the output power pulse of the first structure with the frequency doubled modulator drive pulse in a double balanced four-diode ring mixer. The variation shown in Figure 5 is primarily due to beam loading of the drive cavity in the modulator. The contribution due to energy (velocity) variation of the beam is negligible for two reasons: the short drift distance from the point the beam is modulated to the output structure and the high beam energy.

Figure 6 shows the phase of the power from the third output structure with respect to the first. The phase variation can be explained by the beam energy variation during the pulse. For this case, the energy variation is about ±2.5% and the phase variation is ±3°, in agreement with the standard equation

$$\Delta\varphi = -\frac{L\omega}{c}\left\{(\gamma - 1)(\gamma + 1)^3\right\}^{-1/2}\frac{\Delta V}{V},$$

where L=0.95 cm is the distance between the two outputs, $V \approx 4.6$ MeV is the beam energy, and the modulation frequency is 11.424 GHz.

Current transport below 500 amperes was not an issue in the experiment. Figure 7 shows a comparison of current entering the modulator and exiting the last output structure without modulator drive. The two curves agree to within the uncertainty of the diagnostics indicating no measurable current was lost. Measurements taken at two intermediate positions also confirm full current transport.

Beam breakup was observed for dc current levels above 550 amperes and with a beam energy of 4.6 MeV. A typical current pulse exhibiting BBU is contrasted with a full width pulse in Figure 8. The 550 amperes is a substantially greater dc current than when the beam is modulated (≈ 380 amperes) and agrees with computer simulation. Beam break-up due to the excitation of higher order modes in the

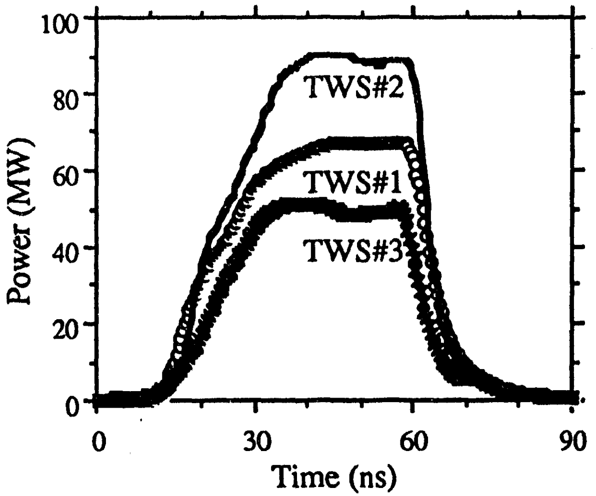

Figure 3. Maximum "flat top" power levels.

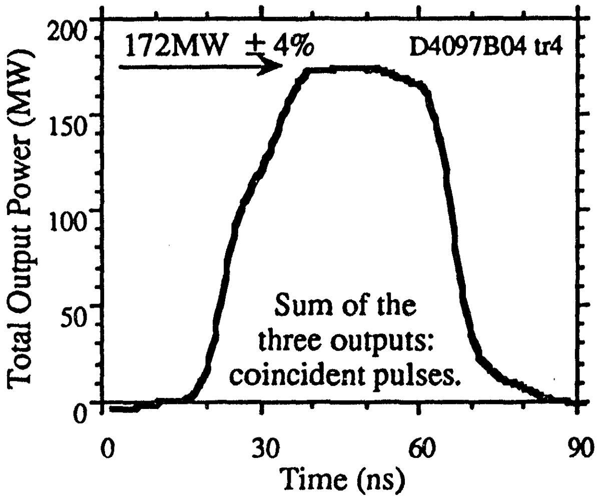

Figure 4. Maximum combined power level.

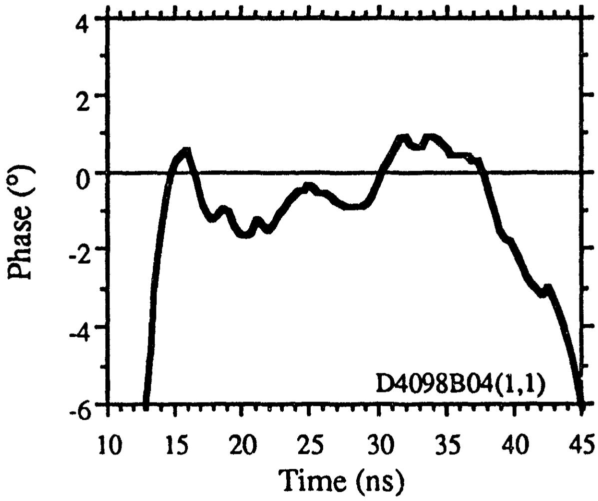

Figure 5. Phase of the first output with respect to the modulation reference.

acceleration gaps and the output struc-tures is a serious issue for long RK's. The OMICE Code,[4] formerly called the BBU Code, was developed at LLNL to study transverse instabilities in RK's and has been benchmarked against our experiments.

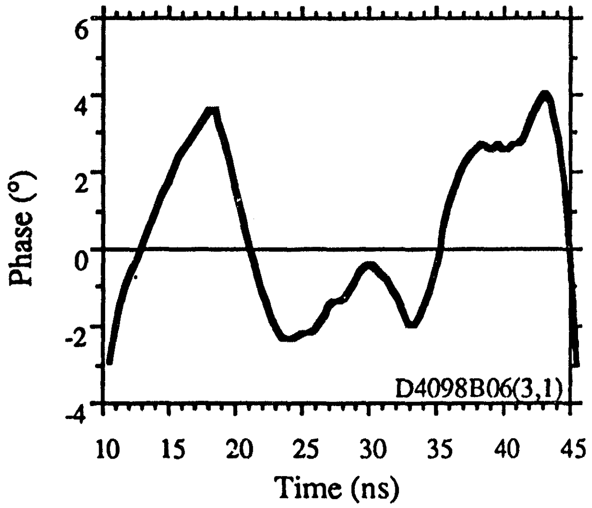

Figure 6. Phase of the third output with respect to the first output.

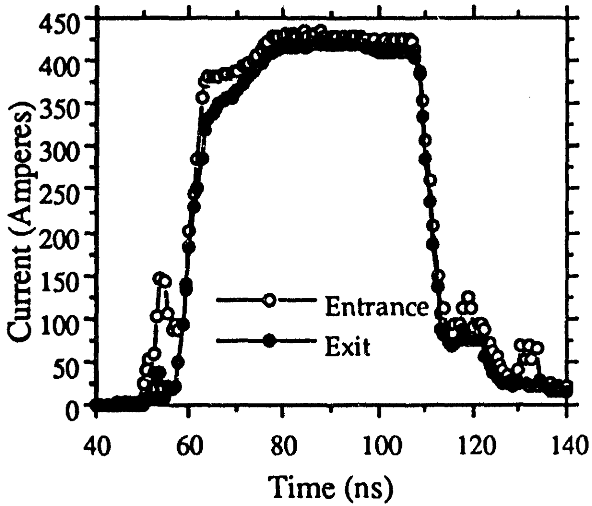

Figure 7. Current pulses entering and leaving the experiment show low losses.

Our experience gained from the RK experiments has enabled us to design an efficient and cost effective RK-TBA microwave source. The modulator for this design is similar to that used in the Reacceleration Experiment. The transverse modulation technique is phase stable and compact. Its efficiency is enhanced by partially modulating the beam with the chopper and then further compressing the phase space with idler cavities. Also, the transverse modulation is performed at an intermediate energy. The beam is accelerated to full energy during the compression stage. The induction modules are constructed of metglass with each core driven at 20 kV for 200 ns of "flat top." Five cores are sleeved to produced 100 kV across an accelerating gap. This technique eliminates the need for an external high voltage step-up transformer. We intend to conduct experiments to study issues related to this new design.

Acknowledgments

We thank J. Haimson and B. Mecklenburg for the design and construction of the modulator and output structures used in the experiment; A. Meyers and S. Petz provided technical support for the experiment. S.S. Yu led the design effort for the proposed RK-TBA Power Source. A.M. Sessler furnished theoretical support and program guidance.

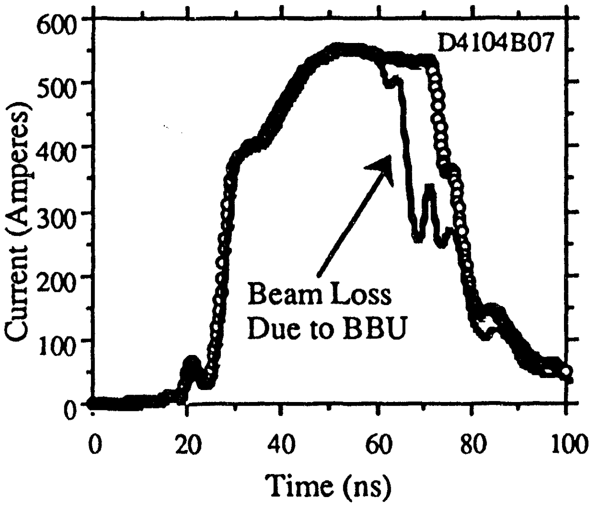

Figure 8. Evidence of beam breakup.

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