Reacceleration Experiment to Demonstrate the Concept of Efficiency Enhancement in a Relativistic Klystron Two-Beam Accelerator*

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Abstract

High conversion efficiency of electron beam energy to rf energy can be achieved in two-beam accelerators using reacceleration of the bunched drive beam. To study issues with these designs we are planning a demonstration in which a modulated beam's energy is boosted as it passes through induction accelerator cells. For this experiment we will use the front end of the Choppertron to modulate a 5 MeV electron beam at 11.4 GHz. We have now tested the 5-MeV Choppertron and are reporting on the results. For the reacceleration experiment we plan to use three stages of rf power extraction interspersed with two stages of reacceleration.

I. INTRODUCTION

We are designing an experiment based on the Choppertron to study the reacceleration of a modulated beam as a verification of the feasibility of building a relativistic klystron two-beam accelerator (RK-TBA). The motivation of our research program at the LLNL Microwave Source Facility is to develop microwave sources which could be suitable drivers for a future TeV linear e^+e^- collider. The Choppertron[1,2] is a microwave generator which used transverse modulation to generate x-band microwaves. It was originally designed for a 2.5-MV, 1-kA drive beam and configured with two traveling-wave structures (TWS). Although the Choppertron has demonstrated high-power pulses, >150 MW per output at 11.424 GHz with stable phase and amplitude and >400 MW total peak power, the conversion efficiency of beam energy to microwaves was only about 30%. To be a competitive rf source for a collider the conversion efficiency would have to be significantly increased. One means of improving the efficiency is by reaccelerating the beam and extracting additional power. The application of this concept to a linear collider is referred to as the RK-TBA.

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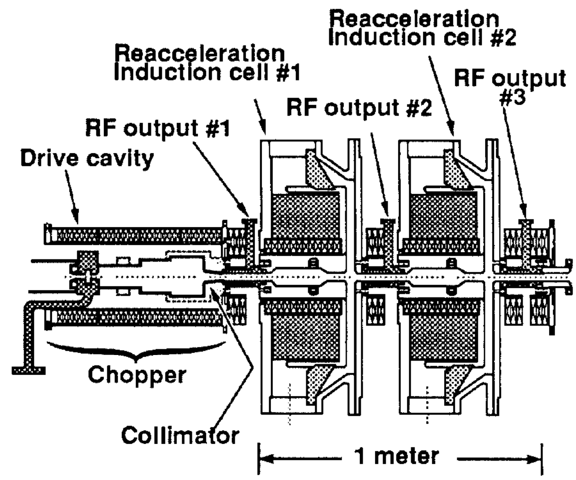

Figure 1. Schematic of the proposed reacceleration experiment.

II. THE 5-MEV MODULATOR EXPERIMENT

Initial computer simulations[3] for the reacceleration experiment with a 2.5 MeV electron beam showed a significant decrease in the available beam power for extraction due to debunching of the modulated beam by longitudinal space charge effects. Therefore, we added 10 induction cells to our beam line, which increases the beam energy to 5.0 MeV before it enters the Choppertron. We have now tested a modified version of the Choppertron designed for the 5-MeV induction accelerator beam. These modifications included aggressive suppression of higher order modes in the two output structures, and lengthening of the modulation section. Figure 1 shows a layout of the proposed reacceleration experiment. Our simulations indicate relatively consistent power extraction of 100-150 MW from each of the TWS and no beam breakup due to excitation of higher order modes (HOM).

Output rf power in the initial Choppertron was limited by the excitation of HOMs. The HOM damping in the the recent experiments proved effective at reducing this problem. However, operation with the damped structures did not increase

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the output power levels to the designed[1] 250 MW. We now believe that beam's emittance is a primary factor in limiting the obtainable output power in the present configuration of the Choppertron. In our experiments, the emittance of the beam determines the beam radius at various positions along the beam line. This is especially important in the modulator section where the betatron resonance and emittance are matched[1] to produce a desired betatron wavelength and beam radius.

A collimator, which consists of a 2-cm diameter 1-m long pipe surrounded by four solenoids, is located after the injector. It serves as an emittance selector allowing only the portion of the incident beam which can maintain a radius equal or smaller than the collimator's pipe radius to pass. By varying the magnetic field of the collimator, the amount of current transported through the pipe is adjusted from the 8 kA emitted from the cathode to the desired beam current. Measurements indicate that at 1 kA the electron beam has a normalized edge emittance of about 104 π-cm-mr, and at 0.5 kA a normalized edge emittance of 52 π-cm-mr.

When the Choppertron was initially being designed, the intention was to operate it on a different accelerator which had an normalized edge emittance of about 60 π-cm-mr. A number of simulations[3] were performed using the relativistic klystron code RKS2[4] to determine the best values of drive power, solenoidal fields, and incident current to maximize output power with no further modifications of the modulator. Figure 2 shows the variation of generated rf current with solenoidal field for about 1.2 MW of deflection cavity drive and at four different values of emittance/current. The emittance values used in these simulations agree with emittance measurements made on the injector at those currents. The rf current produced by the modulator has a broad maximum with magnetic field, drive power and beam current. The 320 amps of rf current shown in Figure 2 is expected to produce about 130 MW of rf power per output structure.

In the recent 5-MeV experiments a combined peak power for the two structures of 260 MW was measured (110 MW in the first TWS and 150 MW in the second TWS). However these high peak power pulses were very narrow, due to electrical breakdown. Wide pulse up to 100 MW could be produced in both output structures (Figure 3). Additional rf conditioning may be required to achieve higher output power. We plan to install other components to the experiment before spending additional conditioning time. We will also

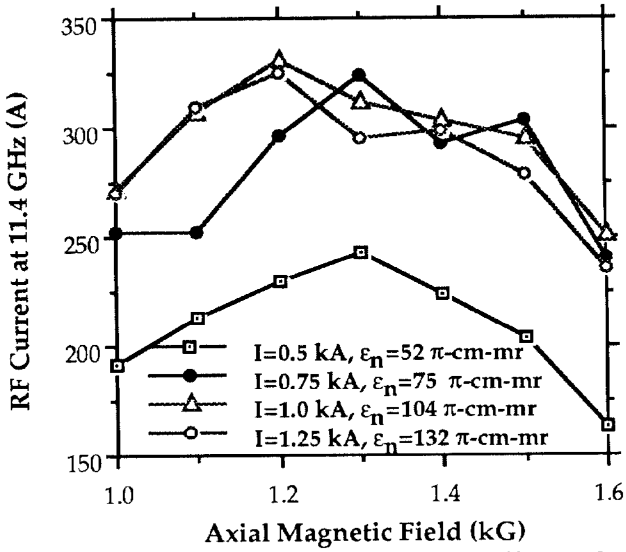

Figure 2. Predicted rf current for different beam emittances and dc currents, drive level = 1.2 MW.

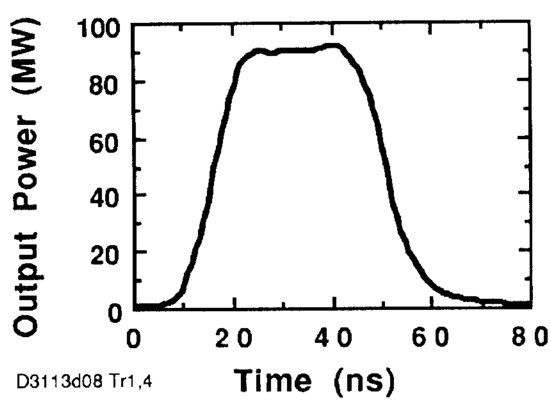

Figure 3. RF power produced in recent experiments.

investigate other possible sources of the electrical breakdown such as the rectangular waveguide flanges and the rf loads used in the experiment.

During the recent experiment we studied the rf power which is reflected off the loads used to absorb the high power rf generated in the output structures. The loads only have a low VSWR close to the 11.424 GHz operating frequency. The leading edge of the rf output pulse has frequency components which are reflected off the loads. This reflected power results in higher electrical fields in the TWS during the leading edge of the pulse and can lead to breakdown. A VSWR of 1.35 for the load experimentally decreased the sustainable output power by ~60%. Similar problems will occur when the output structures are connected to the high energy accelerator structures in a two beam accelerator. A slower ramp in the front edge of the rf pulse may be desirable to alleviate this problem.

Operation of the Choppertron at low input beam currents (500 amps) has been useful in understanding the operation of the device. At these lower currents the beam has a lower emittance which results in good current transmission through the output structures. Also there are lower electrical field stresses on the surfaces.

III. MODELING FOR THE REACCELERATION EXPERIMENT

Computer simulations[3] has been performed to study the reacceleration of a modulated beam. Our simulations indicate that approximately 250 MW/m can be achieved (assuming a 1 kA drive beam with normalize emittance of 104 π-cm-mr). The two induction cells used for reacceleration should not adversely effect the electron beam dynamics. However, a completely redesigned induction cell which takes advantage of the small bore of the beam line and has significantly reduced impedance characteristics is needed for larger reacceleration experiments. Similarly, the growth of transverse instabilities caused by the traveling-wave structures should not be significant for this experiment, but will require further study[5] as the number of output structures is increased. We intend to use data from a currently operating experiment to improve the modeling for the reacceleration experiment.

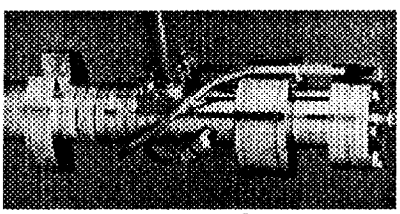

Figure 4 . The12-cell TWS to be tested next.

IV. NEXT EXPERIMENT

In our next experiment we plan on replacing the two TWSs with one 12-cell TWS designed and constructed by the Haimson Research Corporation (see Figure 4). The structure was designed so that when it is driven with 420 amperes of rf current it will produce 400 MW of rf output in fundamental waveguide. With the 320 amperes of rf current we believe we are now producing with the 5-MeV Choppertron it should produce about 230 MW. This structure has mode suppression similar to the de-Q-ing circuits used in the present Choppertron output structures plus suppression of higher order modes propagating down stream of the structure. We also hope to test a feed forward phase and amplitude stabilization system with this TWS.

V. CONCLUSION

Initial experiments using the Choppertron with a 5-MeV drive beam have been completed. Beam breakup due to the excitation of higher order modes in the traveling-wave output structures was successfully suppressed. We have identified the beam's emittance as being a constraint on maximum achievable rf output power. Additional running time will be needed for conditioning the rf surfaces in these output structures to obtain output power greater than 100 MW. We have shown that the front end of the Choppertron can serve as the modulator for the reacceleration experiments which will start later this summer.

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