A Chopper Driven 11.4-GHz Traveling-Wave RF Generator*

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Abstract

We have tested a high-power 11.4-GHz rf generator which consists of a 5.7-GHz chopping system and two 11.4-GHz traveling-wave output structures. The device was designed to generate about 500 MW of pulsed rf power at 11.4 GHz when driven by a 1-kA, 3-MeV induction beam. Problems with beam breakup in the output structures have limited the width of the rf output pulse for currents above 600 Amps. We have produced short rf pulses up to 420 MW. We are making modifications to decrease the growth of the beam-breakup fields in the output structures and will use the chopping section to study various extraction structures and to study reacceleration of a bunched beam by induction cells.

1. INTRODUCTION

We have used the injector at the Microwave Source Facility[1] at Livermore to study the choppertron, a high power rf generator built by Haimson Research Corporation. The design and construction of the choppertron has been described elsewhere[2]. The first section of the choppertron, shown in Figure 1, is a 5.7-GHz chopping system designed to produce a train of short beam pulses with a period corresponding to 11.4 GHz from the initial uniform beam. The chopper design has reduced sensitivity to beam-energy sweep of the induction beam. Emittance growth in the chopper is reduced by operation with an axial magnetic field matched to the beam emittance and the betatron resonance. The dc current through the device is reduced by about half at full drive, as shown in Figure 2 and 3.

The next section of the choppertron consists of two 11.4-GHz traveling-wave output structures[3]. The use of high-group-velocity structures with short interaction regions provides a broadband, phase and temperature insensitive circuit. The chopper is designed to generate about 500 MW of pulsed rf power at 11.4 GHz when driven by a 1-kA, 3-MeV induction beam.

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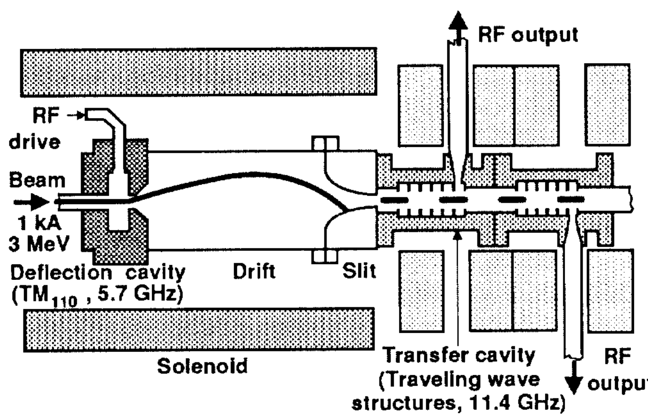

Figure 1. Schematic of the choppertron.

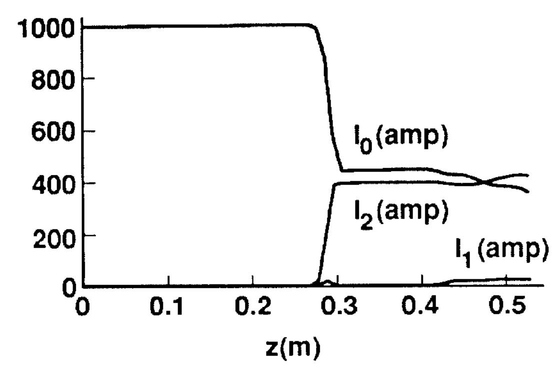

Figure 2. RF current as function of distance from the buncher cavity in the choppertron.

Table 1. Parameters for the rf output structures	
Frequency	11.424 GHz
Forward Traveling Wave Mode	TM_{01}
Phase shift per Cavity	120°
Electrical Length	720°
Output Shunt Impedance	46.5 MΩ/m
Maximum Surface E-field at 250 MW	135 MV/m
Avg. E-field at 250 MW	44 MV/m
RF current for 250 MW	420 A
Total Filling Time	1.02 ns
Diameter of beam apertures	14 mm
Structure Impedance with Sync. Beam	2850 Ω

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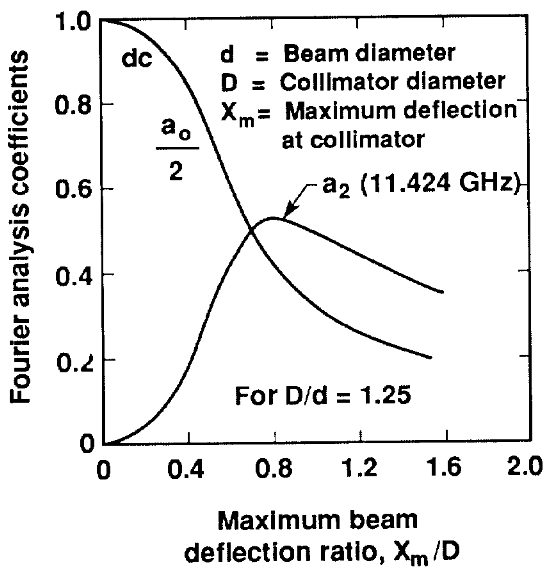

Figure 3. Fourier analysis coefficients versus normalized deflection.

II. Experimental Results

The beam voltage for the experiments described in this paper is about 2.5 MeV. The injector with its present electrode package produces about 8 kA of current at this voltage. A 1-m long, 2-cm diameter collimator immersed in a 600 Gauss field is used to select about 1 kA of current for the choppertron. Variations in the position of the beam's centroid at the front of the choppertron were less than 1 mm during the pulse.

High rf output powers have been achieved from the choppertron, but with narrow widths. The maximum total power is about 420 MW as shown in Figure 4. This was with 980 A of input current and 0.9 MW of drive power. The current pulse out of the choppertron was also narrow. For input current below 600 A the choppertron behavior is well modeled by computer codes. Figure 5 shows a scan where the beam transport before the collimator was changed to vary the input current to the choppertron. Figure 6 shows the transmitted current for this case (without drive power). For input currents above 600 A the output current pulses generally had a sharp notch after ~20 nsec (see 1000 A curve in Figure 6). With drive power the trailing current pulse would decrease, and the pulse would narrow. Below ~600 A the rf output power would increase proportionally to the square of the input current. The higher peak powers, like that shown in Figure 4, were obtained with a different beam transport tune than was used to generate curves in Figures 5 and 6. We believe that the front end of the choppertron is working as expected, with some additional loading than what was predicted (probably from low energy particles at the front of the pulse, or from low energy electrons reflected off the slit).

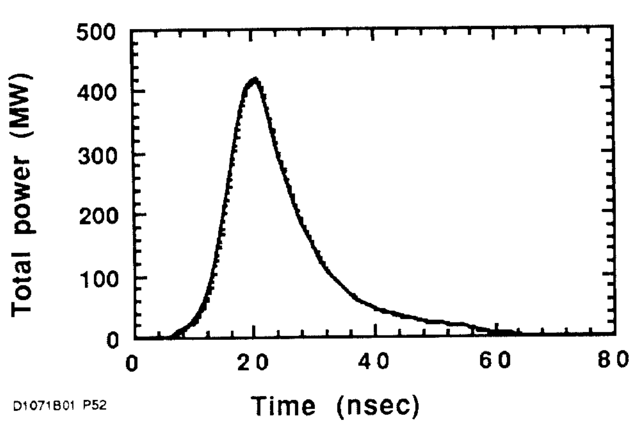

Figure 4. Output of choppertron at high current.

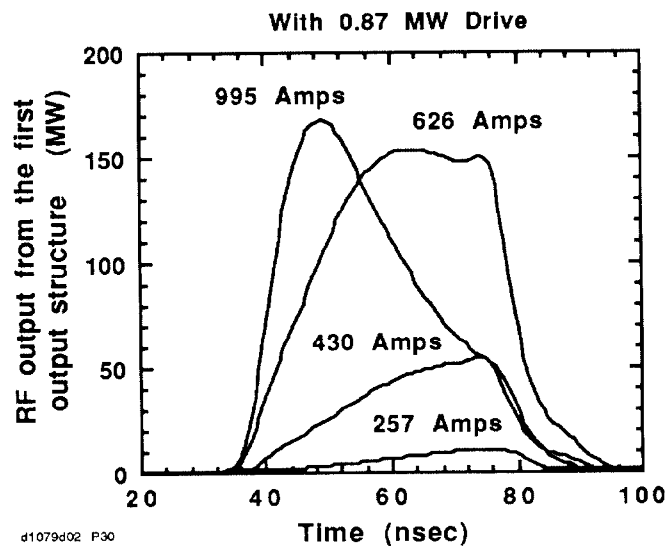

Figure 5. RF output from the choppertron for different input currents.

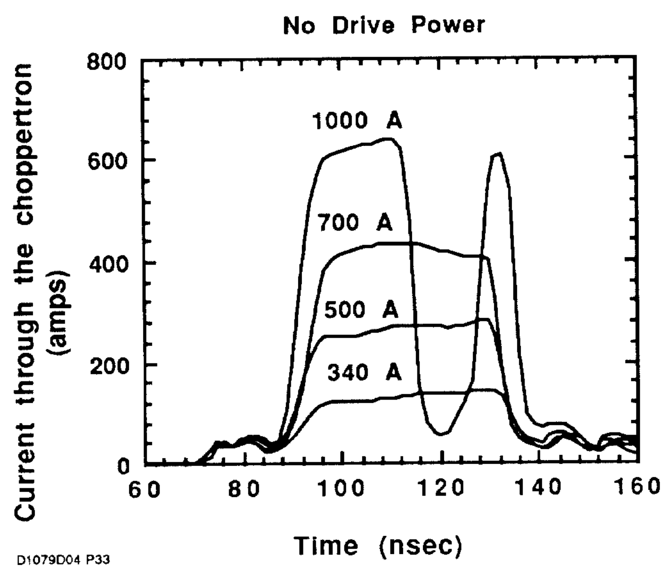

Figure 6. Current pulses transmitted through the choppertron for different input currents.

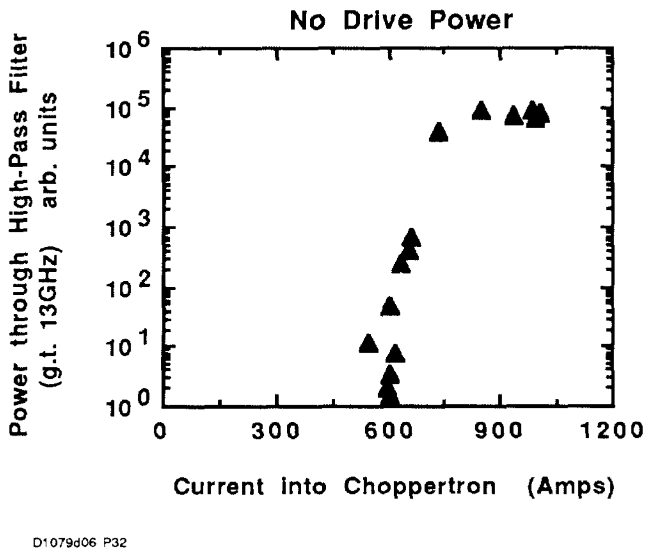

Figure 7. RF power in the 13-15 GHz band from the first output structure of the choppertron.

The narrowing behavior of the output current pulse, and the rf power output pulse, is believed to be caused by the growth of transverse electrical fields in the output structures. These fields can grow to a level such that the beam is swept into the walls of the output structures. The dispersion curves for the output structures show that the lower branch of the HEM_{11} mode has a phase velocity of c at approximately 13.8 GHz. Power generated by this mode in the second output structure can propagate to the first output structure, resulting in regenerative beam breakup. By placing a high pass filter (a section of waveguide with a 13.2 GHz cutoff) in the rf output line we were able to detect power in this range from the output structures. Measurements with another filter, with a 14.7 GHz cutoff, showed that the power was in the 13.2 - 14.7 GHz band. The power in this band had a sharp rise for current above ~600 amps as shown in Figure 7. The saturation in power was believed to result when electrons are driven into the walls. The short fill time of the structure might explain the recovery of the beam current in the second part of the current pulse shown in the 1000A case in Figure 6. The current threshold for generating power in this band was higher when rf drive power was applied to the chopper cavity. Applying drive power will decrease the dc current through the output structures, and decrease the spectrum noise near 13.8 GHz at the front of the pulse.

A frequency spectrum of the rf pulse from the choppertron was measured. A lower input current was used to produce a wide flat rf pulse (about 45 ns). The measured spectrum agreed well with the power spectrum generated from an FFT of the rf pulse envelope. The spectrum was dominated by the pulse width of the rf output from the choppertron. The action of the chopper section will create rf current at the third harmonic of the drive frequency (17.1 GHz). The modulation of the rf current above 15 GHz was observed to increase with drive power.

Computer modeling of the choppertron has been done with two groups of codes. Much of the original design was done using codes developed by Haimson Research Corporation[2]. Computer models have been developed at Livermore to study the traveling wave output structures[4].

III. FUTURE WORK

We plan to remove one of the traveling-wave output structures from the choppertron and retest the device. This should raise the current threshold for the bream breakup phenomenon. This configuration should provide about 250 MW of rf power in a single output line. This rf power could be used to test high-gradient structures, or to test high-power rf pulse compression schemes. We will also use a spectrometer to measure the energy spread caused by extracting rf power in the traveling-wave structure.

By separating the two output structures about 10 cm, and using a short section to decrease the 13.8 GHz power generated in the second structure from reaching the first structure, we will be able to increase the current threshold for beam breakup in the dual output choppertron. We would also like to rebuild the output structures with additional internal damping for the HEM_{11} mode.

The front end of the choppertron can also be used to generate high-energy 11.4-GHz rf current for other experiments. We plan to study key physics issues involved with reacceleration of a bunched beam by induction cells using this arrangement. These tests will support the study of key physics issues involved with two-beam accelerators. We also wish to build a multiple output section to follow the chopper which utilizes inductively detuned output cavities to increase the efficiency. The modulated current could also be used to study additional types of output structures from other users.

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