STATUS OF THE CHOPPERTRON EXPERIMENTS*

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Abstract

The Choppertron is a high-power, 11.4-GHz microwave generator driven by a linear induction accelerator (LIA). Earlier work with the Chopperton using a 2.5-MV, 1-kA beam demonstrated both high power and quality (phase and amplitude stability) microwave pulses. Significant effort was expended on suppressing pulse shortening caused by excitation of higher order modes. A new series of experiments are coming on-line using a 5-MV, 1-kA LIA beam to drive an upgraded Choppertron. In this paper we review the performance of the Choppertron at 2.5 MV including observed pulse shortening and describe the current status of the experiments. We discuss proposed experiments including reacceleration, active phase stabilization, and high-power microwave extraction.

Introduction

The purpose of this paper is to summarize the results of experiments performed on the Choppertron and present the planned experimental program at the LLNL Microwave Source Facility. The design and operating principles of the Choppertron have been described in detail elsewhere.[1,2] The current modulating section consists of a 5.7 GHz rf deflecting cavity, a drift section, and a collimator. The deflection of the beam across the collimator results in a modulated current at twice the deflecting cavity frequency and approximately half the initial dc current. The output section was designed to allow the testing of different structures. We have tested four different configuration of traveling-wave structures (TWS). The rf pulses produced have demonstrated good phase and amplitude stability, but we have found it necessary to incorporate aggressive damping of higher order modes (HOM) in the output structures to avoid pulse shortening.

Recently additional induction accelerator cells have been added to the beam line to increase the initial beam voltage to 5 MV. The increased energy will allow for an experiment in reacceleration of a modulated beam and the testing of a 400-MW TWS output.

Experimental Results

The experiments can be divided into four phases corresponding to the different output configurations.

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Table 1 lists the parameters of the three traveling-wave structures used in the experiment. The output configurations consisted of either a single or two TWS's in series.

TABLE 1
Parameters for the RF Output Structures

Design Parameter	TW1 & TW2	TW3
Resonant Frequency	11.424 GHz	11.424 GHz
Forward Traveling Mode	TM_{010}	TM_{010}
# of Active Cavities	6	4
Phase Shift per Cavity	120°	120°
Aperture Diameter	14 mm	13 mm
Harmonic Group Velocity	0.167 c	0.13 c
Phase/Temp Sensitivity	0.09 deg/°C	0.11 deg/°C
Output Power (achieved)	250 MW	120 MW
Maximum Surface E-Field at 250 MW	130 MV/m	120 MV/m

Phase 1: TW1 - TW2

The original output section of the Choppertron consisted of two identical TWS's of six cells each. It was designed to produce approximately 250 MW rf pulses from each output structure when driven by a 1-kA, 3 MV incident electron beam (~ 420 A modulated current). High rf output powers (combined rf output power > 400 MW) were achieved, but with narrow pulse widths. At lower modulated current levels, reduced power (≈ 200 MW) full-width pulses could be generated. The narrow rf pulses corresponded to shortening of the current pulse exiting the Choppertron indicating beam-wall intercept, or beam breakup (BBU) in the experiment. See Fig. 4 for an example of BBU. Also associated with the shorten rf pulse was an exponential increase in power in the 13.2-14.7 GHz frequency band. Computer simulations[3,4] support the concept that this pulse shortening phenomena was due to excitation of higher order modes in the TWS's.

Phase 2: TW1

To determine the severity of the transverse instability leading to BBU, the second TWS was removed and the experiment repeated with a single output structure. In this configuration, input currents up to the design maximum of 1 kA and transmitted currents of 650 A, exhibited no pulse shortening. Full width rf pulses of > 150 MW were easily attained. Phase and amplitude measurements of an rf output pulse for this configuration are shown in Fig. 1 and 2. The 200-MHz oscillation in the phase variation is assumed to be noise and was present in the absence of the rf pulse. As illustrated in the figures, both phase and amplitude variations were small.

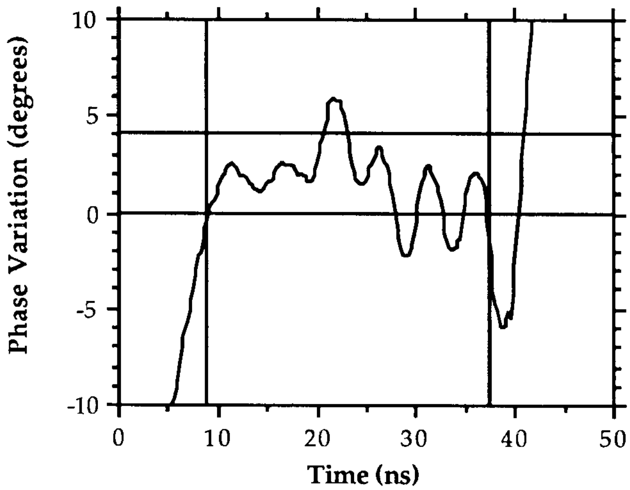

Figure 1. Phase variation of the rf output pulse.

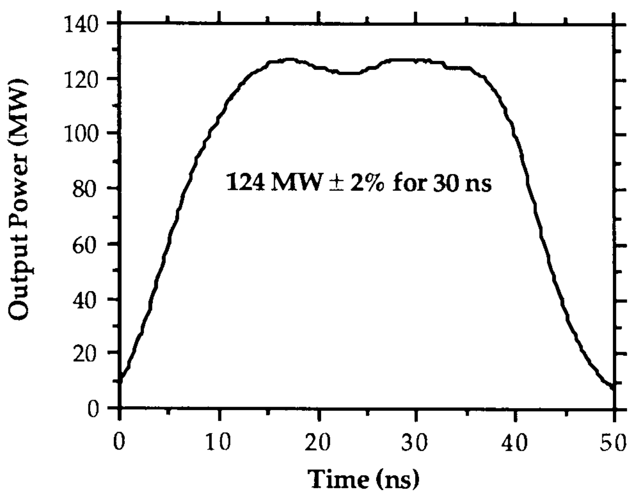

Figure 2. RF output pulse corresponding to Fig. 1.

During this and later phases of the experiment, the spectral content of the rf pulses and beam was measured. Table 2 list the resonances associated with transverse modes which were measured. The HEM_{11} modes[5] (see Fig. 3) are associated with the traveling-wave structures. The drift tube resonance modes are associated with resonances in the interconnecting beam line sections, "trapped" by an impedance mismatch at the ends of these sections.

Phase 3: TW3

A third traveling-wave output structure was constructed by the Haimson Research Corporation with a HOM de-Q-ing circuit for broadband damping built into the first two cells of the six cell device.[3] This structure when inserted into the experiment in place of TW1 produced extremely stable, full-width rf pulses. However, the maximum power level was only about 120 MW. The reduced power level could possibly be attributed to the aggressive de-Q-ing and/or increased difficulty of beam transport through the smaller aperture. The effectiveness of the HOM damping was obvious by contrasting the spectrum of TW3 with TW1:

a. For TW3 only multiples of the drive frequency were detected in the beam induced fields in the drift section after the output structures. For TW1 all the resonances were present in these induced fields,

b. Without modulator drive only one frequency was detected in the rf spectrum from the main output waveguide of TW3 while all the transverse resonances were noted with TW1.

TABLE 2
Measured Resonances in Choppertron Experiments

Resonant Mode	TW1 GHz	TW3 GHz	TW3 - TW2 GHz
HEM_{11} Upper Branch	17.91	16.43 16.14	17.92 17.39 17.25 16.95 16.81 16.32
Drift Tube	14.01	13.78	14.30 14.26 14.14 13.99 13.74
HEM_{11} Lower Branch	13.85 13.67 13.53 13.33	13.46 13.26	13.86 13.66 13.59 13.48 13.26 13.15

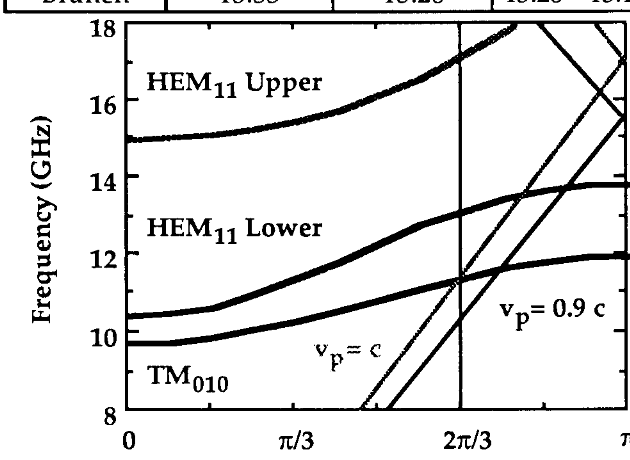

Figure 3. Dispersion graph for "extended" TW1.

Phase 4: TW3 - TW2

For this phase, the experiment was configured with two output structures, TW3 followed by TW2. It was felt that the most efficient use of the damped TW3 was to use it first in the beam line to avoid initial transverse beam displacements rather than attempting to control beam motion caused by the undamped TW2.

This configuration allowed the doubling of the threshold current (≈ 800 A) at which BBU was observed compared to Phase 1. Fig. 4 shows two pulses of a series where the current was approximately at the threshold for pulse shortening. Minor shot-to-shot variations would occasionally lead to conditions of

BBU as shown. This series permitted the definitive measurement of the resonance associated with the pulse shortening phenomena. The frequency spectra corresponding to the current pulses in Fig. 4 exhibited a resonance at 14.3 GHz, which was identified with the drift tube resonances, for both wide and narrow pulses. This resonance was reduced during shortened pulses, presumably due to lower current. An additional resonance at 13.6 GHz was present only when the current pulse was narrow. The 13.6 GHz resonance was identified with the HEM_{11} lower branch of the dispersion curve for TW2 and is near the phase velocity equal to speed of light crossing (see Fig. 3).

The combined power output for this configuration was lower than expected. Wide rf pulses up to about 170 MW and narrow pulses up to 230 MW were attained. The narrow rf pulses were not correlated with current pulse shortening and appeared to be caused by electrical arcing in the second TWS. Inspection of this TWS indicated minor damage from beam intercept which probably occurred during the high current experiments exploring the BBU threshold. The output section also exhibited discoloration typical of operation at higher than normal vacuum levels. A current upgrade to the beam line includes improvements to the vacuum system.

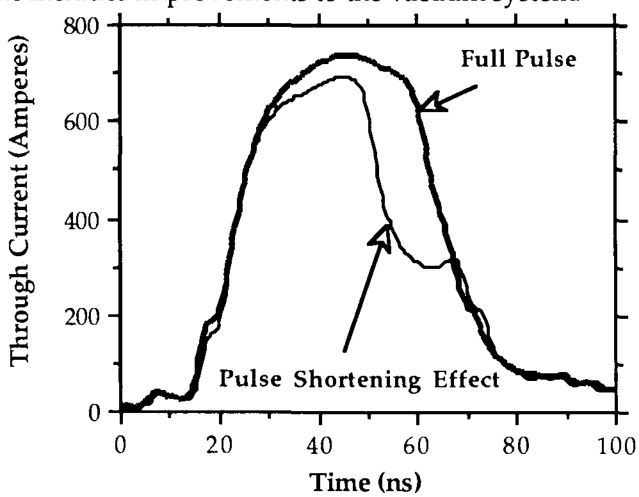

Figure 4. Normal overlaid with shortened pulses.

Future Choppertron Experiments

Currently the accelerator at the Microwave Source Facility is being upgraded to 5 MV with current levels adjustable up to 8 kA. The modulator section of the Choppertron has been modified for operation at the higher beam energies and is ready for installation in the beam line. The upgrade and beam characterization is expected to be completed during September 1992 and a new series of experiments based around the Choppertron started. Planned experiments include:

a. A two output, 5-MV Choppertron. The first output will be TW3 while the second is a modified TW1 with a de-Q-ing circuit built into the first of 7 cells. Goals are to produce > 400 MW, full-width, high quality rf pulses and characterize the performance of the Choppertron for future experiments,

b. The application of a phase control system to correct repeatable phase variations in the rf output of the Choppertron,

c. The reacceleration of a modulated beam. Traveling-wave output structures will be alternated with induction accelerator cells to test the klystron-two beam accelerator concept, and

d. Testing of a new 12 cell traveling-wave output structure designed to produce 400 MW when driven by 420 amperes of modulated current.

Summary

We have completed testing the Choppertron microwave generator with 2.5-MV, 1-kA beams. We have produced high power (> 400 MW), but narrow pulses due to pulse shortening. At lower power levels (~150 MW) we have produced phase and amplitude stable pulses. Attempts to suppress HOM induced pulse shortening have been successful, doubling the earlier current threshold for BBU and encouraging additional experimentation with more/longer output structures.

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