

INITIAL OPERATION OF THE MARYLAND COAXIAL GYROKLYSTRON EXPERIMENT

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Abstract

We describe results from the initial operation of our coaxial gyrokylystron experiment, which is being evaluated as a potential driver for future linear colliders. The interaction is designed to occur between a 500 kV, 500 - 700 A beam and a series of coaxial TE_{0n1} microwave cavities. Output powers in excess of 100 MW at 8.568 GHz are expected with an efficiency of about 40% [1]. We detail performance of our single anode magnetron injection gun in addition to the stability and amplification properties of our preliminary microwave circuit. We also discuss our designs of near-term future tubes which are expected to have comparable performance at 17.136 GHz.

1 INTRODUCTION

At the University of Maryland, we have been running a comprehensive program to study the suitability of gyrokylystrons as drivers for linear collider applications [1]. We have previously reported a variety of experimental results, all of which were achieved on a test bed which produced a small-orbit beam with a nominal voltage and current of 450 kV and 200 A, respectively. Published accounts of our effort include an amplified power level of 27 MW at 32% efficiency in a three-cavity first harmonic gyrokylystron near 10 GHz [2] and 32 MW at 29% efficiency in a two-cavity second harmonic gyrokylystron near 20 GHz [3].

In this paper we present the design details of two coaxial gyrokylystron tubes which are predicted to produce at least 100 MW of output power with an efficiency of nearly 40%. These tubes utilize a fundamental mode TE_{011}

input cavity which is driven by a 150 kW magnetron at 8.568 GHz. The first tube also has an 8.568 GHz TE_{011} output cavity, whereas the second tube has 17.136 GHz TE_{021} buncher and output cavities. We present details of all system aspects, including the test bed modifications required to produce the enhanced beam characteristics, simulated beam properties, and simulated circuit interactions. Cold and hot test results of the first experimental tube are discussed before the project status and a description of our future plans are summarized.

2 TEST BED MODIFICATIONS

We have just completed an upgrade of our facility which should enable us to produce amplified microwave powers in excess of 100 MW (see Fig. 1). Our modulator voltage and current have been increased to 500 kV and 800 A, respectively. We have designed, installed, and completed acceptance testing of a single-anode Magnetron Injection Gun (MIG) which is capable of producing a 480 - 720 A rotating electron beam at the nominal beam voltage with an axial velocity spread less than 7%. The simulated space-charge-limited perveance of $5.5 \mu P$ was in good agreement with the measured result. The maximum current produced in the acceptance test was limited by our modulator (due to an applied voltage which was lower than the nominal operating voltage) to 670 A.

The original water-cooled magnets have been used, but a larger power supply for the gun coil was required because of a decrease in the magnetic compression. We reduced our drive frequency from 10 GHz to exactly three times the current SLAC frequency, so a new coaxial magnetron and a modified input waveguide were required. The output waveguide (uptapers, beam dump,

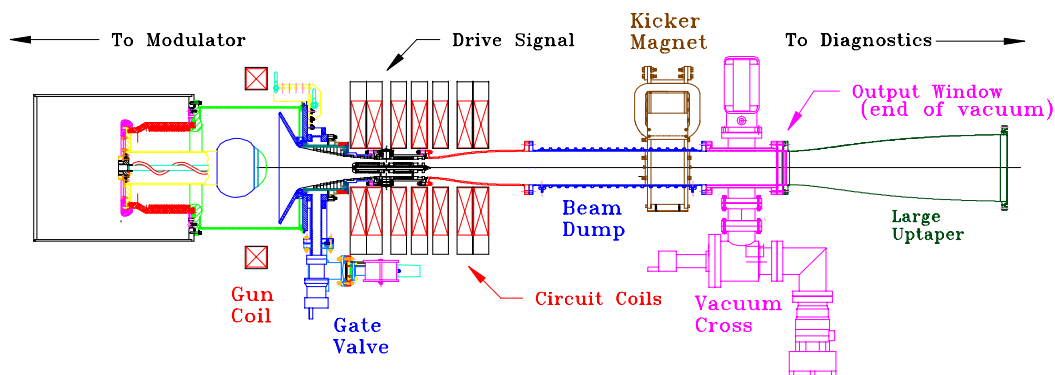


Fig. 1. The gyrokylystron test bed.

window, kicker magnet, pumping cross) was totally rebuilt to accommodate the expected larger peak powers. The anechoic chamber was modified to accommodate the new output waveguide and the directional coupler diagnostic was completely redesigned.

3 THEORETICAL CIRCUIT PERFORMANCE

A detailed design analysis has been carried out on a number of coaxial, two- and three-cavity gyrokystron systems with the aid of our partially self-consistent nonlinear code. The input cavity in all tubes is in resonance with the signal frequency at 8.568 GHz and the output cavity is resonant with either the first (8.568 GHz) or the second harmonic (17.136 GHz) frequency. In a three-cavity system, an additional buncher cavity is introduced which is resonant at either the first or second harmonic frequency. In the following sections, we describe only the first harmonic tube which has been hot-tested and the second harmonic tube which is scheduled to undergo hot testing in the near future.

3.1 Two-Cavity First Harmonic Tube

The first harmonic tube consists of an input cavity and an output cavity separated by a drift section. The input cavity is defined by a decrease in the inner conductor radius only and the quality factor is brought down to $Q \approx 70$ by loading the cavity with a thin ring of carbonized aluminum-silicate placed at one end of the cavity. The inner radius is 1.05 cm and the length is 2.29 cm. Power is injected through two radial coupling ports which are separated by 180° and excited in phase. Our start-oscillation code predicts that the input cavity is completely stable up to a current of 800 A.

The drift section has inner and outer radii of 1.825 cm and 3.325 cm, respectively. The inner conductor is required so that the drift tube is cutoff to the operating mode. The regions adjacent to each cavity are made of copper, but lossy ceramics line the majority of the drift tube to eliminate spurious modes. The total length of the drift region is 9.1 cm. Lossy ceramics are also used in the downtaper between the gun and the input cavity.

The output cavity is defined by changes in both radii and has a length of 1.70 cm. Power is extracted axially into the output waveguide via a coupling aperture. The aperture has the same radii as the drift tube and has a length of 0.9 cm. The diffractive quality factor is about 122. The start-oscillation code also predicts the output cavity to be stable at the nominal current, which is given in the middle column of Table 1 along with the other operating parameters. The efficiency is nearly 40% and the output power is about 95 MW. The dependence of tube efficiency on axial velocity spread is plotted in Fig. 2 with the solid line. The simulated velocity spread of the electron gun is 6.4 % at the nominal current. The curve shows a slow but steady decrease in efficiency with increasing spread and indicates that an efficiency of 37%

is still possible if the spread is as high as 10%. A simplified schematic of the tube dimensions along with the optimal axial magnetic field profile is indicated in Fig. 3.

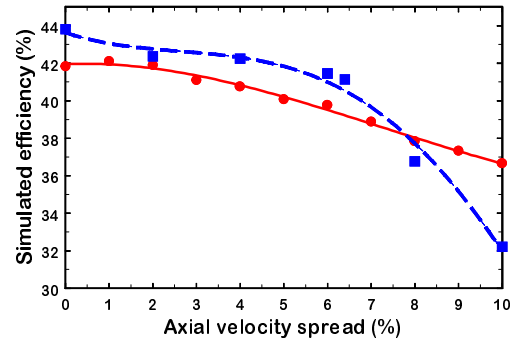


Fig. 2. Efficiency of the first (solid line) and second harmonic (dashed line) tubes vs. velocity spread.

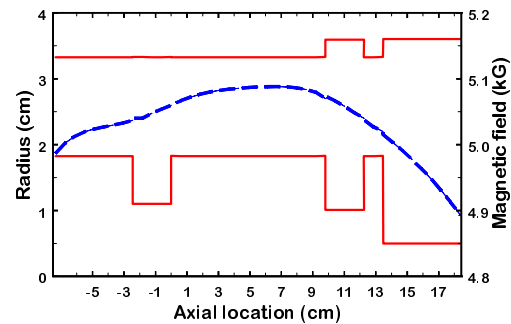


Fig. 3. The first-harmonic two-cavity tube and the optimal magnetic field profile.

3.2 Three-Cavity Second Harmonic Tube

The second harmonic design which we intend to test is a three-cavity system. The buncher cavity operates at the second harmonic and is formed with non-adiabatic radial wall transitions. Mode conversion from the TE_{02} mode to the TE_{01} is estimated to be about -40 dB. Dielectric loading of the cavity is used in order to obtain a Q of 389 and is achieved by reducing the thickness of the copper sections that separate the cavity from the drift tube dielectrics. The linear start oscillation code indicates that the buncher cavity is stable to beam currents below about 1000 A at the design value of the magnetic field ($B_0 = 4.81$ kG). The output cavity is also designed with non-adiabatic radial wall transitions. The scattering matrix code estimates the purity of the TE_{02} operation in the output cavity to be 97%. The ratio of the power flowing

into the drift tube to the power flowing into the output waveguide is better than -24 dB. Furthermore, the lossy dielectric loading in the drift tube, which will have a minimum effect on the Q-value of the operating mode, will suppress the excitation of the spurious modes and reduce the cross-talk.

TABLE 1. Comparison of the 1st and 2nd harmonic designs.

Parameters	1 st harmonic	2 nd harmonic
Voltage	500 kV	500 kV
Current	480 A	770 A
Velocity ratio	1.508	1.508
Input Cavity Q	50	50
Buncher Cavity Q	-	389
Output Cavity Q	122	320
Gain	21 dB	49 dB
Efficiency	39.4%	41.1 %
Output Power	94.6 MW	158.2 MW

The simulated results at the nominal operating point are indicated in the final column of Table 1. The optimal current according to the simulations is 770 A and the estimated peak output power is over 150 MW. The corresponding gain and efficiency are 49 dB and 41%, respectively. The dependence of efficiency on velocity spread is shown as the dashed line in Fig. 2. Note that the efficiency begins to drop off fairly rapidly for spreads above 7%. However, these simulations are not re-optimized with respect to magnetic field profile, etc., at each point, and additional investigations indicate that higher efficiencies can be achieved if the velocity spread is higher than expected.

4 COLD AND HOT TEST RESULTS

The construction, cold testing, and hot testing of the first experimental tube has been completed. Cold-testing yielded the final dimensions of the input cavity required to achieve the frequency of 8.568 GHz and a quality factor of 70. They are quite near the theoretical estimates given in the previous section. Cold-test drift tube attenuation measurements have indicated adequate isolation. The results for the output cavity were also quite close to the predicted values.

The performance of the microwave amplification experiment was limited by an input power coupling problem that developed after the tube was installed on the test bed. The net result was that we were only able to inject about 5 kW of power into the input cavity. The two cavity system had a predicted gain slightly above 20 dB, so the tube was severely gain limited. The best amplification results yielded a peak power of about 600 kW with a pulse width of over 1.5 μ s at a beam voltage of 270 kV and a current of 290 A. The performance at this reduced operating point was consistent with our simulations. While some instabilities were observed in the output waveguide, performance of the tube at these beam parameters was not limited by spurious modes.

5 PROJECT STATUS AND FUTURE PLANS

We have nearly completed a rebuild of the first harmonic tube which incorporates two major changes. First we have added a third port on the vacuum jacket at the input cavity so that we can use transmission measurements to characterize the input cavity parameters in situ. Second we have lengthened the overall system in order to add a buncher cavity so that the tube should not be gain limited. The buncher cavity is nearly identical in shape to the drive cavity and has the same resonant frequency and Q. We expect this tube to go on-line early in June 1997.

We continue to work on improving our simulation capabilities. Time-dependent capability has been added to our nonlinear (single-mode) code by researchers from the Naval Research Laboratory and initial results have confirmed the steady-state code predictions. We hope in the future to add multi-mode capability to our time dependent code.

We are also looking at advanced cavity concepts for future tubes. For the input cavity, we are using the High Frequency Structure Simulator code HFSS to simulate a single waveguide injection scheme which couples to the input cavity via an outer coaxial cavity. Furthermore, we are investigating an output cavity which couples through the inner radial wall to a circular waveguide, thereby decoupling the microwaves and the beam beyond the output cavity and enabling the use of additional tube stabilization schemes. Preliminary HFSS simulations of this output cavity scheme have been successful. Both concepts promise to improve performance of the gyrokystron tubes beyond the current predictions.

Finally, we are beginning to look at the application of gyrokystron circuits to Ka-band and beyond.

6 ACKNOWLEDGEMENTS

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REFERENCES

- [1] Granatstein, V. L. and W. Lawson, "Gyro-Amplifiers as Candidate RF Drivers for TeV Linear Colliders," *IEEE Trans. Plasma Sci.* **24**, 648 - 665 (1996).
- [2] Tantawi, S., W. Main, P. E. Latham, G. Nusinovich, W. Lawson, C. D. Striffler, and V. L. Granatstein, "High Power X-Band Amplification from an Overmoded Three-Cavity Gyrokystron with a Tunable Penultimate Cavity," *IEEE Trans. Plasma Sci.* **20**, 205 - 215 (1992).
- [3] Matthews, H. W., W. Lawson, J. P. Calame, M. K. E. Flaherty, B. Hogan, J. Cheng, and P. E. Latham, "Experimental Studies of Stability and Amplification in a Two-Cavity Second Harmonic Gyrokystron," *IEEE Trans. Plasma Sci.* **22**, 825 - 833 (1994).