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AUTHOR(S): P. J. Tallerico

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

A 150-kW, 450-MHz GYROCON RF GENERATOR*

P. J. Tallerico, AT-5, MS H827
Los Alamos National Laboratory, Los Alamos, NM 87545

Summary

The output-power and conversion efficiency of the Los Alamos gyrocon were increased by a factor of 150 in the past year. Major improvements in the phase- and amplitude-control system and in understanding the electron multipactor and surface-conditioning processes increased the output power. The highest measured efficiency on this gyrocon is 23%, which was obtained with several combinations of parameters. Both the output power and the efficiency are a factor of 3 below the design values, and several possibilities are being examined to remove the discrepancy between theory and experiment.

Introduction

The gyrocon deflection-modulated amplifier is a descendant of the Bermutron,¹ which was investigated in the 60s. Two gyrocons have been built by Budker's group² in the Soviet Union, and the dc-to-rf conversion efficiencies are reported to be over 75%. A computer simulation of the gyrocon interaction³ was written at Los Alamos. This simulation showed that very high electronic efficiencies (above 85%) are achievable in the gyrocon, and although the circuit efficiency is rather low by klystron standards (90%), overall efficiencies above 70% should be possible. Many cases were calculated in the UHF range that had an 80% overall efficiency. A gyrocon with a radial field output cavity and a conical bender solenoid (Fig. 1) was designed for operation at 450 MHz, a frequency used for proton accelerators. The electron beam enters the device at the top, from an electron gun, not shown in Fig. 1, and goes through a focus coil and a TM_{110} magnetic deflection cavity, into a drift space. The deflection cavity has a circularly polarized magnetic field that imparts a radial velocity to the beam, but the azimuthal direction of the velocity varies with time at 450 MHz. The circularly polarized radial velocity and the constant axial velocity produce a spiraling beam envelope, and the spiral increases in radius as the beam moves toward the bender solenoid. The beam goes around the bender solenoid and is deflected further, so that it moves almost radially through an output gap. The output cavity is a coaxial resonator excited in the TE_{11} mode. This mode also is circularly polarized, and the peak electric field rotates and remains synchronous with the electron beam. A pair of focus coils is located immediately at the entrance to the output cavity; the beam finally stops at the collector, which is outside the output cavity.

The Prototype Gyrocon

A prototype gyrocon was designed, using the simulation codes described in Ref. 3, to operate at 86 kV, the voltage of an existing large power supply. The calculated design parameters are listed in Table I. A detailed mechanical design was made. The gyrocon was thermally designed for long-pulse operation up to 1-ms pulses. The deflection cavity was made of copper with stainless steel backing and

Fig. 1. The prototype gyrocon. (1) Gun-focus coil, (2) output focus coils, (3) conical bender solenoid, (4) collector, (5) output cavity, (6) output coaxial transmission line, (7) electron beam, (8) deflection cavity.

TABLE I

DESIGN PARAMETERS OF THE PROTOTYPE GYROCON

Beam voltage	86 kV
Beam current	9.0 A
Operating frequency	450 MHz
Deflection angle	13.4°
Deflection-cavity length	8.0 cm
Deflection-cavity field	2.0 MV/m
Total deflection power	31.4 kW
First-focus coil ampere turns	-1540
Conical-bender ampere turns	14 000
Second-focus coil ampere turns	4000
Output cavity, i.r.	16.8 cm
Output cavity, o.r.	23.8 cm
Output-cavity field	1.80 MV/m
Electronic efficiency	93.0%
Radio-frequency gain	22.0
Overall efficiency	86.1%
Output power	691.9 kW

water-cooling of the two flat end walls. Two drive loops were put in the deflection cavity 90° apart, and two small sample loops were located opposite the drive loops. Eight bellows tuners were located near the maximum electric field radius along an end wall

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of the deflection cavity. Most of these tuners locate the two degenerate modes at right angles and center the modes about a coupling loop. The tuners opposite the drive loops adjust the two modes' frequencies.

The bender cone has a water-cooled copper nose, but the cone itself is stainless steel, water-cooled on the coil side. The simulation code predicted that the bender solenoid should have constant ampere turns per unit length. These coils are built to fit snugly within the bender cone, and the entire inside of the cone is water-cooled. The output cavity is made of copper-plated stainless steel, with axial water channels for cooling. Solid copper is used for the gap edges where the likelihood of electron interception is high. Six bellows tuners are located along the axial end of the output cavity. Two output loops are located 90° apart, and the loops and coaxial output lines are terminated in an open-circuit transformation to WR-1A00 waveguide. Two separate output waveguides are used to permit each loop to be individually matched. The collector is solid copper and fabricated by brazing two disks together to form two water-cooled washers. The washers are then bent into a conical shape and welded together. The collector is insulated from ground by ceramic standoffs.

The electron gun is mounted in a standard "LAMPF modulator" and a viton-sealed gate valve is used to isolate the gun from the deflection cavity. The electron gun is at the lowest end of the gyrocon; the bender cone, output loops, and even one end of the entire output cavity may be removed after the oxide cathode is activated. This feature substantially increases the mechanical complexity of the device, but it has been used several times to greatly improve the gyrocon performance.

Initial Experimental Tests

The deflection cavity initially supported multipactor discharges and would not properly deflect the beam. This was remedied by titanium coating the deflection cavity. The deflection system was tested separately by removing the bender cone and installing a view screen and pepper-pot aperture plate there. After replacement of a partially poisoned gun, and reassembly of the device, 500 W per output channel could be produced with almost any adjustments of the experimental parameters. The output cavity evidently was experiencing such severe multipactor discharge that the discharge, rather than the output cavity tuning and the beam voltage and current, was establishing the rf field loads in the output cavity. Further details of the gyrocon's construction and initial operation have been presented.⁵

The 1982 Experimental Results

A spectrum analyzer was used to examine the power spectrum of the 1-kW output power. The first discovery was that the collector water lines were radiating microwaves that were disturbing the spectrum analyzer and oscilloscope. After several experiments with capacitor by-pass schemes, the collector had to be grounded solidly to eliminate this rf interference.

The output-power spectrum was examined, and strong outputs were found at each integer multiple of 446 MHz, the drive frequency. After some attempts to calibrate the waveguide couplers at the harmonics and the observation that the output frequency tuners had no effect on the output power, it was realized that the output power was the untuned response of an impulse-excited circuit. The multipactor was destroying the cavity resonance. If this hypothesis were correct, the multipactor discharge in the output

cavity had to be stopped before any real progress could be made. The output cavity was driven by the 1-kW amplifier that usually drives the final stage of the deflection amplifier system. The multipactor discharge in the output cavity began at 80 W. By conditioning the cavity for a few days, the multipactor level would increase to 500 W. The output-cavity mode was deliberately rotated to maximize transmission from loop-to-loop, and transmission loss was measured at 4.2 dB. The output-cavity Q was 2200 in each orientation, with the collector insulators open or shorted.

The RCA 8501 tetrode final stage of the deflection system can produce slightly over 15 kW per channel, and one of these was next connected to the output cavity. The vacuum, which had been below 1×10^{-7}

torr, was driven into the 10^{-6} torr range when the multipactor began. Two weeks of conditioning was required before the output cavity could withstand several kilowatts per output loop. When the gyrocon was operated, it produced the same few kilowatts per loop, but then the output cavity would multipactor and no additional power could be produced. The encouraging point was that the power spectrum now was essentially pure, and the traveling wave in the output was being excited by the beam. After 2 days of conditioning, the output power increased to 30 kW, and after 4 more days of operation, 53.3 kW was reached. The rf pulse lengths were kept to 50 μ s and the repetition rate was 1 or 2 Hz. Each rf pulse produced a gas burst that was visible on the ion pump. The fields in the deflection cavity would sometimes multipactor and remain at a low level. A logic circuit was made that compares the two deflection cavity fields with a reference; if both fields are large enough, the circuit sends the beam-on pulse to drive the modulator. The power output remained at 53 kW for several weeks. The phase- and amplitude-control system on the deflection cavity was improved, but this did no good. When the deflection fields were rotated in the other direction by changing the phase of one drive by 180°, the output power jumped to 87 kW, which grew to 100 kW in 2 weeks of 8-h/day operation. The beam current was 5.3 A in these experiments, and the modulator was modified to produce 8 A of beam current. This brought the power up to 150 kW and an overall efficiency of 23%. After 2 weeks of operation, the output power remained at 150 kW. Tuners were placed in the output waveguide to vary loaded Q, and more, or less, voltage was produced in the output cavity, but the output power was reduced. The gyrocon was operated for several days with high output-cavity fields by reducing the coupling to the load, but when the coupling was adjusted back to normal, 150 kW was all that could be produced. Two months were spent in this coupling experiment, and the best loaded Q is half the unloaded Q. The electronic efficiency may well be twice the overall efficiency. The gyrocon output cavity was opened, and the output cavity and the output coaxial lines were coated with titanium. The gyrocon has been reassembled, and it will be retested in the future, as funding permits. Thus, the peak output power remains at 150 kW, and the best overall efficiency is 23%.

Conclusions

The experiments so far have definitely proved the feasibility of the gyrocon's operating principle. The output power is quite sensitive to the phase of the two drive signals, the output-cavity tuning, and the magnets' settings. The direction of the beam's spiral is also important, as has been predicted by the analysis code. The reasons for the difference between the actual performance and the

predictions of the analysis code remain unknown. The most likely cause is the fringe field that extends through the output-cavity gap. The output-cavity gap is 8 cm wide in a cavity that also is 8 cm wide. The fringe fields extend rather far, both into the bender region and into the collector region, whereas the code assumes that the cavity fields end abruptly at the inner and outer radii of the output cavity. The author suspects that the true transit time of the electrons in the output fields may be substantially larger than the time used in the code, and that this may be the reason for the major discrepancy between the theory and experiment. Some analysis of the fringing problem has been done, but this has not yet been incorporated into the design code. A method of attaching grids to the apertures on the output cavity has been designed, and a grid between the output cavity and the collector may be tried in the future.

At the 150-kW output level, the output pulses have some high-frequency noise, which may be an indication of electron multipactor. A coating of titanium has been applied to the output cavity, and tests at low power indicate that the cavity is more resistant to multipactor than before. A power test with the new coating will be the next step in the experimental program.

In summary, the gyrocon has produced significant output power from the first prototype device, and most of the theoretical predictions have been experimentally confirmed. Thus the gyrocon should be considered for high-power, high-efficiency microwave generation for frequencies between 200 and 2000 MHz.

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References

1. I. Kaufman and G. Oltman, "Harmonic Generation by Electron Beam Pattern Motion - The Bermutron," IEEE Trans. Electron Devices, Vol. 12, p. 31 (January 1965).
2. G. I. Budker, M. M. Karliner, I. G. Makarov, S. N. Morosov, O. A. Nezhevenko, G. N. Ostreiko, and I. A. Schekhtman, "The Gyrocon--An Efficient Relativistic High Power VHF Generator," Particle Accelerators, Vol. 10, p. 41 (1979).
3. P. J. Tallerico and J. E. Rankin, "The Gyrocon: A High-Efficiency, High-Power Microwave Amplifier," IEEE Trans. Electron Devices, Vol. 26, No. 10, p. 1559 (October 1979).
4. P. J. Tallerico, R. L. Cady, and J. D. Doss, "Design and Performance of the LAMPF 1-1/4 MW Klystron Modulator," IEEE Conf. Record, 11th Modulator Symposium, p. 56 (September 1973).
5. P. J. Tallerico, "Progress on the Gyrocon Deflection - Modulated Amplifier," IEEE 1982 IEDM Technical Digest, p. 199 (1982).