

STATUS OF THE LOS ALAMOS GYROCON*

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Summary

The gyrocon is a deflection-modulated RF amplifier that can achieve very high peak-and-average-output power, as well as excellent direct-current-to-radio-frequency conversion efficiency. The electron dynamics of the gyrocon are analyzed with a large-signal computer code that is used to design a prototype gyrocon. This gyrocon is now built and it has been operated at low duty cycle. The design goals, construction details, and initial operating results of the prototype gyrocon are discussed.

Introduction

Deflection-modulated microwave generators have been the subject of research for about 40 years,¹⁻³ but generally have met with limited success. Budker and his colleagues have made several innovations^{4,5} in the past decade that have resulted in operable gyrocons. The gyrocon (Fig. 1a) is operated with TM₁₁₀ deflection of an electron beam, followed by an electrostatic bending and magnetic bending system. Finally, the beam enters a resonant ring of waveguide, where the electron energy is extracted. This type of gyrocon is called an axial gyrocon, because the output-cavity electric field is axial. The first gyrocon produced 600 kW of pulsed power in 1971, and achieved 90% electronic efficiency. The next pulsed gyrocon (Fig. 1b) built by the Budker group has produced 40-MW pulses of 6- μ s duration at 0.5 Hz. The operating efficiency is over 60% and the frequency is 430 MHz. The radial-type gyrocon has been designed for 5-MW CW output power at 181 MHz. The Budker group has achieved 1 MW of beam power and 600 kW of output power from this device. Reference 6 gives a comprehensive review of the Soviet work.

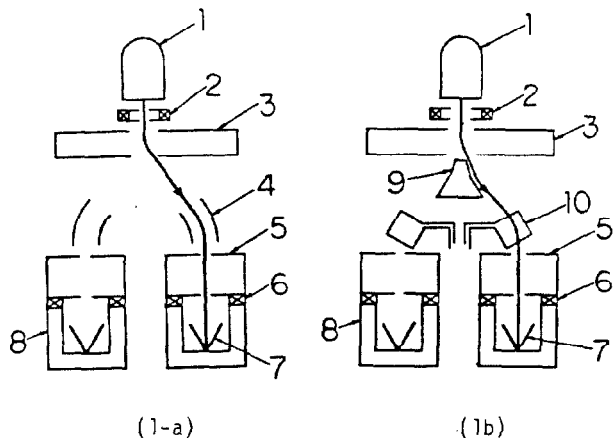


Fig. 1. Soviet axial-style gyrocons. 1-a) The first gyrocon, 1-b) the present Soviet axial gyrocon. (1) Electron gun; (2) gun focus coil; (3) deflection cavity; (4) electrostatic bender; (5) output cavity; (6) compensation coil; (7) collector; (8) compensation-field pole piece; (9) conical bender coil; (10) first order bender coil.

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A project to investigate the gyrocon theory and to build a prototype has been underway at Los Alamos for several years. A particle-tracing computer code has been written to calculate the overall conversion efficiency of the radial gyrocon. We have used this code (GYRO1) to examine the behavior of the gyrocon as a function of beam power, frequency, and beam voltage. The conclusion of this theoretical study is that high efficiency can be obtained only at high power, and that the optimum frequency range for the radial gyrocon is between 300 and 1500 MHz. Details of the theory and the calculated results are presented in Refs. 7 and 8.

A radial-type gyrocon was designed with GYRO1 to operate at 86 kV, 8 A, and 450 MHz. The output power is over 500 kW, and the dc-to-rf conversion efficiency (which includes the RF drive power) was calculated to be over 80%. A gyrocon has been built according to this design. Some aspects of the mechanical and electrical design, as well as the initial operation of this gyrocon are discussed below.

Design of the Los Alamos Gyrocon

The klystrons at the Los Alamos Meson Physics Facility (LAMPF) operate at 86 kV, and are pulsed by a floating-deck modulator.⁹ A large power supply at this voltage was available for experimental purposes. Thus, an electron gun from a LAMPF klystron was a logical choice for the prototype gyrocon. Because this electron gun has a modulating anode, the beam current may be varied with minimal change in the beam optics. Computer simulation of the gun indicated that the electron beam is well collimated at currents over 3 A (Fig. 2a); but at lower currents, a crossover is formed (Fig. 2b). Electron trajectory data from the gun-analysis codes were used as input data for the gyrocon design.

A TM₁₁₀ deflection cavity is designed to produce a rotating magnetic deflection field. Two RF inputs are required, and the input loops are displaced by 90° in azimuth. The input signals also must be displaced by 90° in time, and a phase controller is built to maintain the 90° phase difference between the two drive signals. Our calculations indicate that a TE deflection cavity of the type proposed by Wessel-Berg¹⁰ would reduce the RF drive power requirement by 50%. The TE cavity has more beam loading than the TM cavity; thus, one must include beam loading, as well as ohmic losses, when comparing the two types of cavities.

A coaxial bender magnet is used to increase the deflection angle of the electrons, so they can enter the output cavity radially. The coils are external to the gyrocon vacuum system, and are surrounded by water for cooling. The surface of the cone that faces the water is grooved like a klystron collector, so that ~100 W/cm² may be dissipated on the cone surface, without damage by the electron beam during tune up. The output cavity is a resonant ring of rectangular waveguide, having rather large slits (8 cm) through which the beam enters and emerges. The output cavity is constructed of copper-plated stainless steel for strength, and is water cooled to dissipate the ohmic losses. The edges of the slots in the output cavity, which may be hit by the electron beam, are solid copper and well cooled.

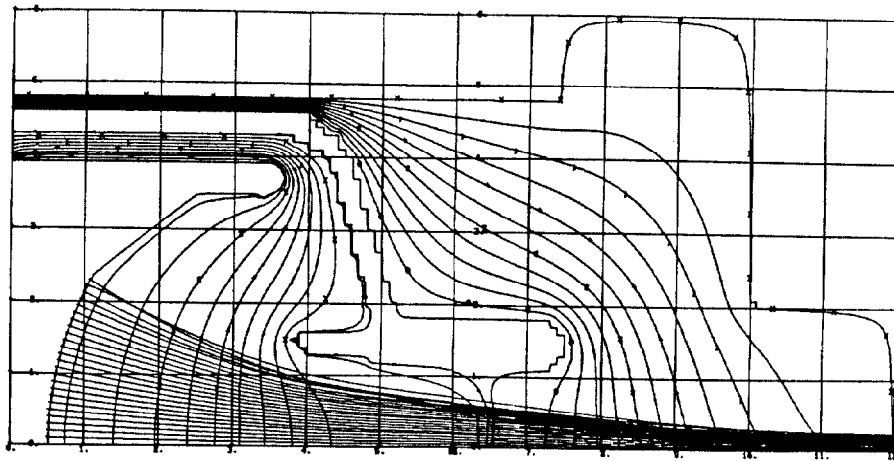


Fig. 2-a.

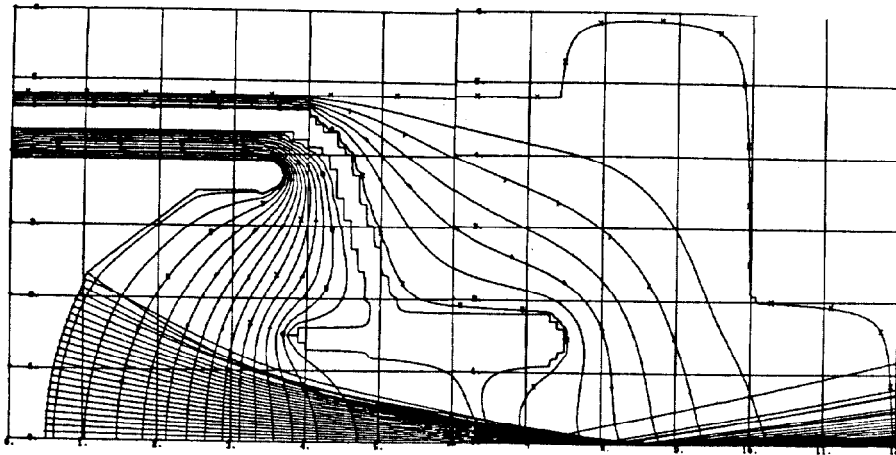


Fig. 2-b.

Fig. 2. Equipotentials and trajectories in the prototype gyrocon gun with no magnetic fields. 2-a) 7.2-A beam current. 2-b) 2.4-A beam current.

The output power is sent out of the cavity by two loops that are displaced 90° in azimuth. The loops are adjustable in penetration, and are connected to coaxial transmission lines that terminate in coax-to-waveguide transition similar to that used on the PEP klystron at Stanford. The collector is isolated from ground with ceramic standoffs. A vacuum valve is located between the electron gun and the deflection cavity, allowing the RF cavities to be reworked without injury to the oxide cathode. A scale drawing of the device is shown in Fig. 3.

Control System

The control system comprises seven power supplies for the magnets, two ion-pump power supplies, filament and oil-pump controllers, an interlock chain, and the driver chain. The drive system is a stable frequency synthesizer, followed by several amplifier stages. The final amplifiers are large tetrodes that can deliver over 30 kW of peak forward power to the two gyrocon inputs. The drive system also includes phase and amplitude controllers that keep these quantities constant in the deflection cavity despite variations of beam current.

Multipactoring in the deflection cavity has been a constant problem. The deflection cavity was titanium coated, but this did not change the multipactoring characteristics; thus, we conclude that the multipactoring discharge is located in the

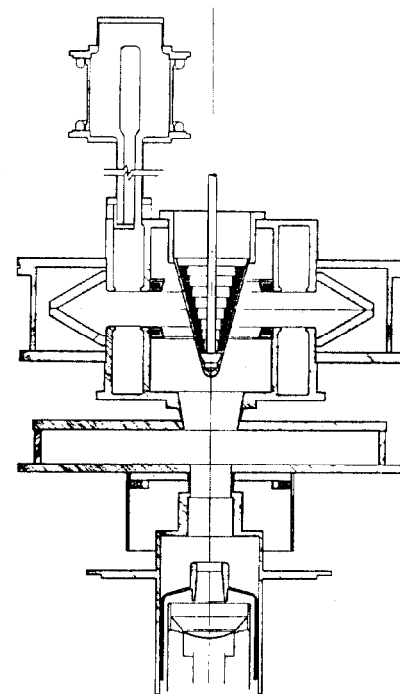


Fig. 3. Scale drawing of the prototype gyrocon. The inside diameter of the deflection cavity is 83 cm.

drive loops, which are not easily accessible for coating. The deflection cavity may be conditioned for RF by operating the drive system for ~ 24 hours with the beam off. Some multipactoring problems are avoided by turning on the RF drive before the high voltage, which implies that the beam has a halo, or at least has some stray electrons that can easily start a multipactoring discharge in the deflection cavity.

Operating Results

The prototype gyrocon was assembled in October 1980. The device was too large to be baked in the oven that is used to repair the LAMPF klystrons; thus, it was given a low-temperature (~80°C) bake with heating tapes while it was on the modulator. The various metal surfaces remain impregnated with gas and we have been able to operate at only 1 Hz to keep the vacuum pressure in the low 10^{-6} torr region. A 75% beam transmission from the cathode to the collector has been measured; but upon applying a bias to the collector, the current varied by ~ 10% with 100 V of bias. This indicates that a substantial fraction of the collector current is low-energy, scattered, electrons presumably from the bender cone.

The peak output power measured to date has been only ~10 W per output, and this power is independent of the output-cavity tuners. The primary beam diagnostic built into the device is water-temperature monitors in several of the cooling passages. These indicators are essentially useless at the low duty factor at which the gyrocon is operated for good vacuum. After several weeks of conditioning, it became clear that the RF power output could not be increased by tuning the magnet or RF variables. The electron beam was suspected of being grossly different from the calculations of Fig. 2. Accordingly, a 7.5-cm-diam pepper-pot aperture plate and phosphor screen were built to replace the bender cone. This aperture plate could be moved from slightly beyond the deflection cavity to the midplane of the output cavity. The screen is almost always illuminated across its entire surface, even without any RF fields in the deflection cavity. The electron beam appears to fill the entire physical aperture and its emittance is very large. When RF is applied, the beam rotates in a very small (~1-cm-diam) circle. The RF beam loading is much higher than calculated, because of the very large beams at the deflection cavity. The axial electric fields vary almost linearly from the zero at the cavity center, and the beam loading is a quadratic function of the beam diameter. The reason for the large beam size is not understood. There are two possibilities: (1) the electrons are not originating from the cathode as they should, or (2) the electrons are experiencing a magnetic or electric field that is not considered. This electron gun failed to emit properly on initial tests and had to be flashed repetitively to obtain 5 to 8 A of current. Because the filament is operated at ~ 10% higher voltage than is normal for this gun, focus-electrode emission could be causing the beam to be so large. The cathode is poisoned quickly, and the full space-charge limited current is rarely achieved; it is clear that there is something seriously wrong with the gun. The second possibility could be caused by having some magnetized iron in the valve mechanism. This can be checked when the electron gun is removed for recoating.

Conclusions

Although the prototype gyrocon has a serious problem with its beam, the author remains convinced that the gyrocon concept can be used to generate high power microwaves at high efficiency. Nothing in the theory indicates that the concept is invalid, and the Soviet gyrocons have been at least partially successful in achieving their design goals.

The electron gun on the prototype device will be changed and the experimental program will be continued for the remainder of the year. The fundamental difficulty of the gyrocon is the beam transport, which cannot be helped by magnetic fields. Smaller beams, operated at higher voltage and lower current, should help this problem. Recent work on electric deflection¹² and on planar¹³ and spherical¹⁴ versions of the device, should result in better gain and more compact designs.

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