AN RF-DRIVEN LASERTRON*

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Abstract

An rf-driven lasertron has been built and is being tested. It is designed to produce over 1 MW of power at 1.3 GHz, with over 60% conversion efficiency between the beam's kinetic energy and microwaves. The design and experiment are discussed, and calculations are presented that show lasertrons can operate at frequencies up to 20 GHz.

Introduction

The purpose of the lasertron family of rf generators is to convert dc power into microwaves and to accomplish this task with high efficiency. Designing and building a complete lasertron is a fairly expensive, several-year effort. Because there is a photoinjector program[1] at Los Alamos and a 1300-MHz high-power klystron, an rf-driven lasertron could be built there to generate over 1 MW of output power in less than a year and at moderate cost. Thus, it was decided to design and build an rf-driven lasertron as the first step towards producing a complete lasertron. Figure 1 is a schematic diagram of the experiment. An rf modulated laser beam strikes a photocathode situated inside an rf cavity. The photoelectrons are rapidly accelerated to 0.5-1.0 MeV in this cavity, next they traverse a short drift space, and then they enter the output cavity, where a large fraction of their kinetic energy is converted to microwave energy. Although the overall efficiency between the electric power source and the lasertron output power is low with this arrangement, one can concentrate on the electronic efficiency and beam dynamics and gather much information on lasertron design, simulation, and operation.

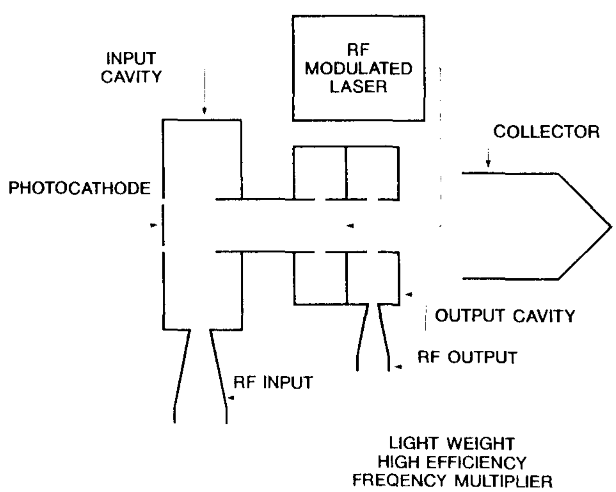

Fig. 1. Schematic drawing of the rf-driven lasertron experiment.

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Simulation Method and Calculation Results

The particle tracking code, PARMELA was used to follow electrons from the photocathode through an acceleration cavity, a drift space, an output cavity, and then a final drift space, all in the presence of an external magnetic field. The cavities were designed with SUPERFISH, and the output code SF07 wrote files of the cavity fields that were inputs to PARMELA. The static magnetic fields were designed with POISSON, but simple coils were used in PARMELA to produce the same axial magnetic field. The graphical output program PARGRAF was modified to calculate the beam kinetic energy after each element, and the output ohmic losses were calculated manually. The phase and magnitude of the output cavity fields were optimized to extract the most energy from the beam. In addition to the cavity variables, the laser-light pulse length, the average current, and the magnetic-field profile must be specified for the simulation. Thus, there are ~20 parameters to optimize even for the simple system of Fig. 1. The calculations were performed with 10- and 20-ps light pulses, but the results were almost independent of the optical micropulse length in this range.

Calculations were made at 1-, 3-, and 5-A average over the micropulse and with a constant driver-cavity field that accelerated the beam to about 900 kV. The optimized results for the three currents are shown in Fig. 2 as curves of output power versus output cavity voltage.

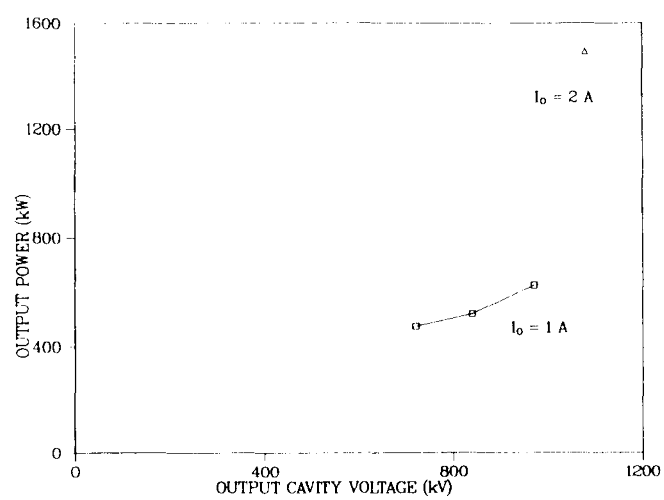

Fig. 2. Calculated output power versus output cavity voltage for the system of Fig. 1, with average beam current as the parameter.

A similar set of calculations was made to determine the lasertron's performance at 6.5 GHz, the fifth harmonic of the drive frequency In Fig. 3 these results are shown for several values of cathode current and with a 10-ps optical pulse. Note that the beam to rf efficiency reaches to 50% even at this relatively high frequency. The 10-ps optical pulse is the pulse length in the present laser system, and this may be reduced by a factor of 3 if the lasertron

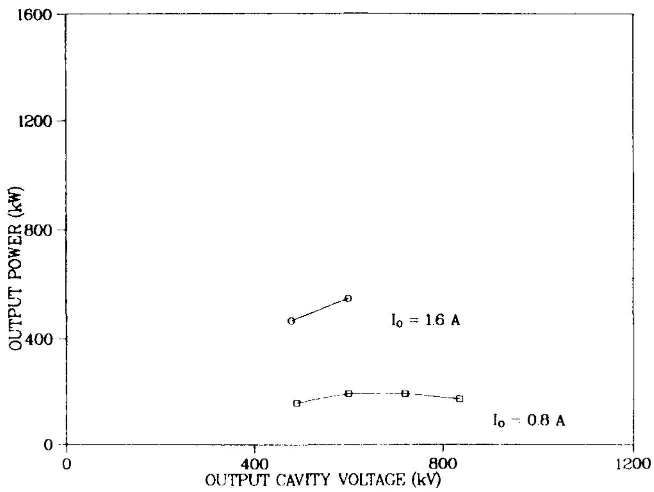

Fig. 3. Calculated output power versus output cavity voltage for the five times lasertron frequency multiplier, with average beam current as the parameter.

requires it. Thus, lasertrons can be developed at even higher frequencies, to about 20 GHz. For still higher frequencies, one must resort to the gigatron traveling-wave-lasertron concept of McIntyre.[2]

The Experiment

The rf system is limited by the klystron modulator to 10-μs pulses, and the repetition rate may be varied from 1 to 10 Hz. The average beam current during these 10 μs is up to 5 A, and the peak current is perhaps 100 times this value. A first cavity gradient was chosen so that the beam was accelerated to 900 keV, and an optical pulse width of 20 ps was used in the simulations. The best overall efficiency occurs when the electron bunch is injected during the rising portion of the rf field in the first cavity. In this mode, the front of the bunch is accelerated less than the back by the rf fields, and the bunch remains compact for a longer time, even in the presence of space charge.

Sheffield's[1] alkali metal photocathodes and laser system are used; the only modification was to temporally multiplex the light pulses by a factor of 12 so that the laser light micropulses would repeat at 1.3 GHz, rather than 108.33 MHz. The laser system is shown in Figure 4. A 10-W, cw, Nd:YAG laser is the primary oscillator. An electroacoustic modulator that operates at 108.33 MHz is placed inside the laser cavity to provide a train of 100-ps micropulses at 1.06 μm. The light next goes through a dispersive line pulse shortener[3] that compresses the pulse to 3 ps. The repetition rate is increased to 324 MHz with a times three temporal multiplexer. A Pockels cell gates this pulse train into 10-μs macropulses. The light then goes through a two-pass amplifier and a single-pass three multiplexer, then passes through a second optical amplifier. The optical frequency is doubled by a KTP crystal, and finally the light passes through a times four multiplexer. The resulting 0.53-μm light then has a microrepetition rate of 1.3 GHz, and it is directed to the lasertron cathode. The amplifiers increase the micropulse full width at half maximum to 15-20 ps, as measured by a streak camera. The rf cavity configuration is shown in Fig. 5. The cavities were fabricated of OHFC copper, and the operating pressure of the system after bakeout is usually on the 10^{-10} torr scale. A system of inserts were made to vary the electrical size of the iris during the experiments. Wedges on the waveguide broad walls increased the coupling to the load, and straight blocks along the narrow walls reduced the coupling to the load. These blocks or wedges were inserted in the output waveguide, close to the coupling iris on the cavity. Although the vacuum system must be opened to change the cavity loading, this method is more convenient than reforming the iris, which requires machining on the output cavity. Mechanisms were also provided to change the cavity resonant frequency by small deformations of the cavities.

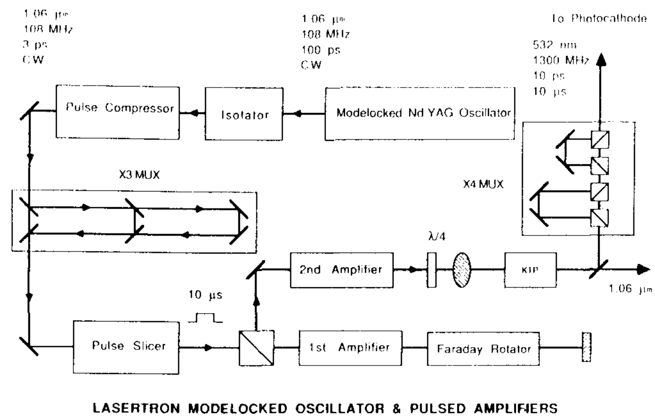

Fig. 4. Block diagram of the mode-locked laser system.

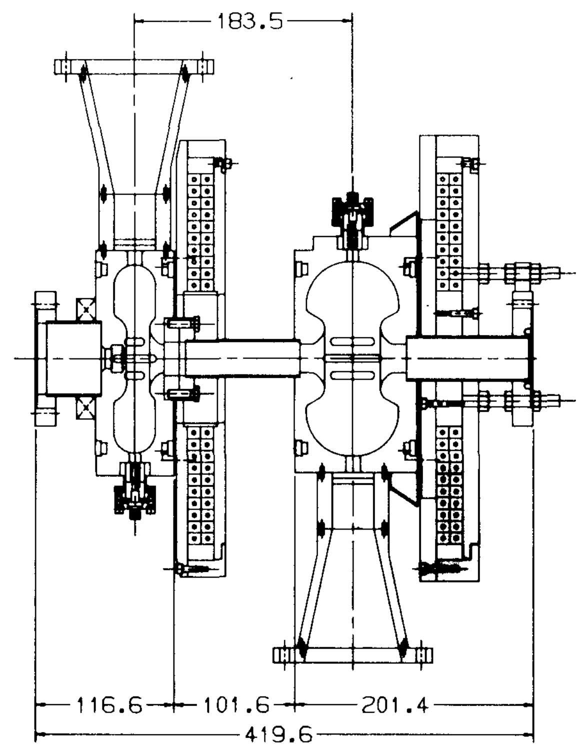

Fig. 5. Scale drawing of the rf-driven lasertron (dimensions in millimeters).

Experimental Results

The rf-driven lasertron was assembled and is now being tested by driving the laser and input cavity at several levels and by optimizing the phases and magnet currents for maximum rf output, which was measured with a directional coupler and calibrated diode. The best results achieved to date show that the basic design is sound and that the expected power and efficiency will be realized in the near future.

Conclusions

The rf-driven lasertron has been shown to be an efficient convertor of beam energy to microwave radiation at frequencies below 2 GHz. Calculations indicate that the device will remain efficient as a multiplier up to 10 or 20 GHz. The experiments are still under way, and the next experiments will show the multiplier's advantages at 6.5 GHz. We remain confident that these devices can be perfected for applications at frequencies below 20 GHz.

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