EXPERIMENTAL PROGRESS TOWARD A 1 GW, 1 μS PULSE LENGTH, HIGH CURRENT RELATIVISTIC KLYSTRON*

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Abstract

A 1 μs pulse-length, high-current relativistic klystron is being developed with a desired peak output power of 1 GW at 1.3 GHz. The tube consists of an input cavity, a single idler cavity, and an output cavity. Power levels as high as 475 MW have been experimentally observed. Current experimental results are presented. Physics and engineering issues affecting klystron performance are discussed.

I. INTRODUCTION

Los Alamos is developing an L-band high current relativistic klystron amplifier (RKA). Although the present experiments are single pulse, the long term goal is to achieve 1 kJ/pulse with repetitive pulse capability at a PRF of 5 Hz, with a longer term goal of 100 Hz. The RKA has an input cavity, a single idler cavity, and an output cavity. The buncher section, which consists of the input and idler cavities, has been experimentally tested and is performing as designed. The design was done with the help of particle-in-cell (PIC) code calculations using the Los Alamos code ISIS. PIC code modeling has proven to be very important for a successful design because of the highly nonlinear nature of the RKA caused by the intense space charge effects.[1] The most recent efforts involve improving the performance of the output cavity and optimizing the output power and pulse length to reach the design goal of 1 kJ/pulse. A number of expected problems have been encountered with the output cavity that are being systematically addressed. These problems include rf breakdown in the cavity and matching the beam impedance to the cavity gap shunt impedance for the most efficient coupling of modulated beam to microwaves. This paper summarizes the the current experimental results. The electron gun and the modulation section consisting of the input and idler cavities have been discussed elsewhere. [2-4]

II. EXPERIMENTAL WORK

The RKA configuration is shown schematically in Fig. 1. The electron beam is formed from a 6.2 cm-diameter annular field-emission cathode and is slightly compressed by a converging 0.5 T axial magnetic field to a nominal 5.9 cm diameter beam with a 5 mm thickness. The typical beam voltage is 620 kV with the current increasing from 3 to 6 kA during the pulse. This increase is caused by the drop in electron gun impedance due to plasma closure of the anode-cathode gap during the pulse. The input cavity is driven by a 500 kW L-band magnetron. The idler cavity has an annular tuning ring which gives flexibility in inductively tuning the cavity. The output cavity is a noseless pillbox design with several annular coupling slots near the outer diameter which couples power into a low impedance coaxial transmission line. The coax tapers out into standard 6-inch-diameter, 50 Ω line where power is measured by a directional coupler with 25 dB directivity and then dissipated in a dummy load.

The complete klystron tube has been assembled and is undergoing testing. The beam modulation section consisting of the input cavity and idler cavity is performing as designed, and is providing a modulated electron beam with a harmonic curent $I_1 = 0.6\ I_0$ where I_1 is the fundamental harmonic at 1.3 GHz, and I_0 is the dc beam current. The extracted rf power has been increased from about 10 MW to 475 MW. Currently about 475 MW of peak power is being extracted from the output cavity in a pulse of 1 μs duration. The energy residing in the pulse is about 140 J.

A graph showing the output power overlaid with the beam voltage and current is shown in Fig. 2. The rf output power pulse shape approximately follows the beam current shape until the rf output terminates at the peak value of 375 MW. At this time the total rf pulse energy is about 160 J. The rf pulse terminates before the beam voltage and current reach their maximum values. It is not yet certain why the rf pulse is terminating prematurely. The most reasonable explanation is that the output cavity gap field is high enough to reflect electrons back up the beam-line and/or start some oscillation phenomenon such as a virtual cathode. At the time the rf pulse terminates, a highly rf modulated electron beam pulse propagates upstream and is detected by B-dot loops located in the idler cavity and input cavity, and by the directional coupler between the drive magnetron and the input cavity. All of these signals have a spike at the time the rf output power goes away. These signals are bandpass filtered with a bandwidth of several hundred MHz around 1.3 GHz, so the spike appears to be the result of an rf modulation on the beam traveling back up the beam toward the cathode. The interpretation of the observation could be complicated by the fact that the output gap could be breaking down at this time as well. In Fig. 3 is the trace representing the magnetron's reflected power (or power flowing from the input cavity toward the magnetron). The spike at 2.3 μs is the result of the electron reflection back upstream. The electron reflection is a manifestation of the intense beam's space charge effects resulting in the severe potential depression of the beam as it is decelerated in the output gap.

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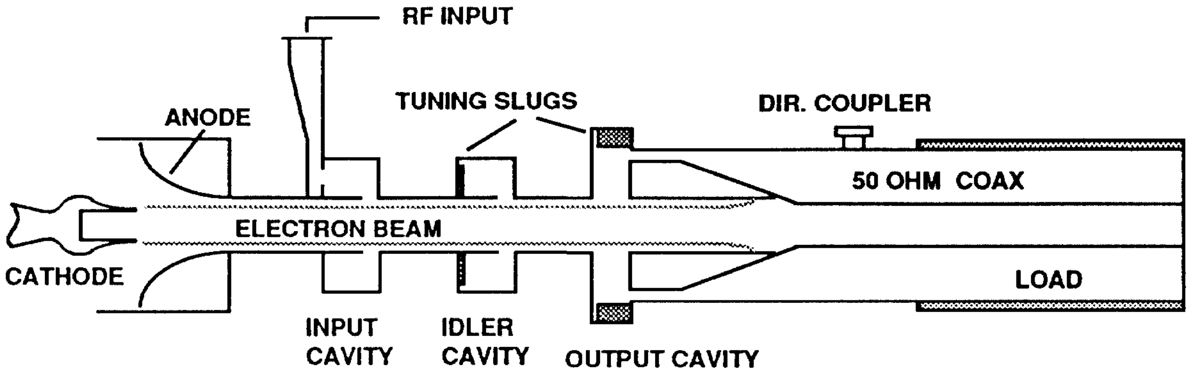

Fig. 1. Schematic diagram of the RKA.

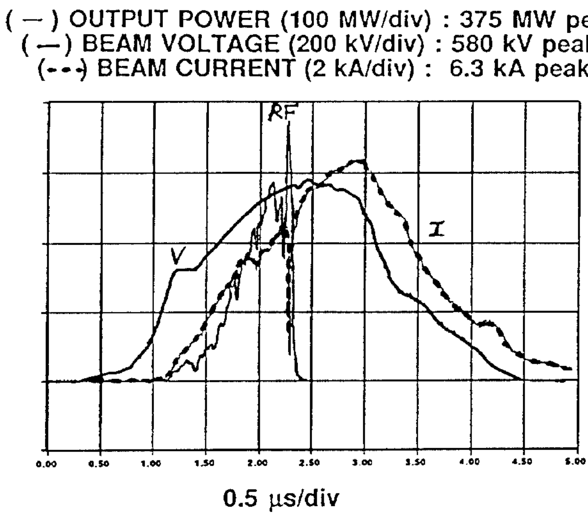

Fig. 2. Rf output power overlaid with the beam voltage and current.

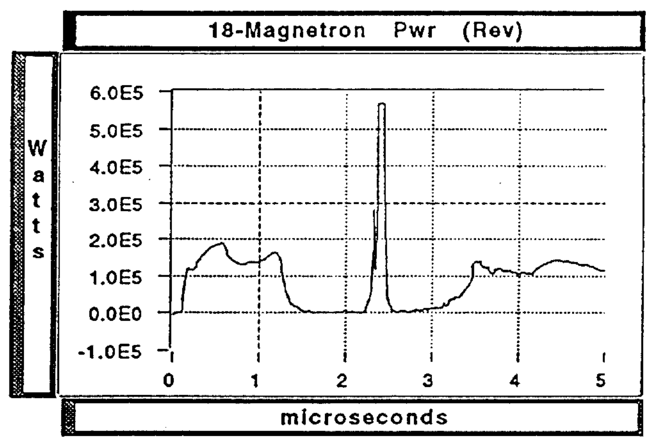

Fig. 3. Magnetron's reflected power signal (power flowing from the input cavity toward the magnetron). The spike at 2.3 µs is the result of the electron reflection in the upstream direction from the output cavity.

III. DESIGN MODIFICATIONS

The power extracted can be expressed as

$$P_{ext} = \frac{1}{2} I_1 V_{beam}$$

where I_1 is the beam's average fundamental harmonic current in the output cavity and V_{beam} is the available voltage that can be extracted from the beam before the space-charge limiting current is reached. To efficiently couple the rf energy from the modulated beam, the output cavity must have a low enough shunt impedance that the gap voltage induced by I_1 does not exceed V_{beam}. A very low cavity shunt impedance is necessary to efficiently couple to the low impedance beam.

The loaded Q (without beam) of the output cavity in these most recent experiments was about 10. This is obviously not low enough. We have started an overall redesign of the output cavity using a three dimensional rf structures simulator program (HFSS-High Frequency Structures Simulator) to confirm that the new cavity will have the desired gap geometry, and a significantly lower shunt impedance and loaded Q. This will lower the output gap voltage, thereby eliminating electron reflection and rf breakdown across the gap. Once the electromagnetic cavity simulations are complete, the new cavity geometry will be compared to the old geometry with the particle-in-cell code ISIS to model the electron beam in the gap to determine if the problems have been sufficiently addressed.

The new pillbox-shaped cavity has a considerably smaller outside diameter which will make the cavity less likely to induce virtual cathode formation caused by the large space-charge bunches passing through the gap. The design Q is about 4. The decreased Q will help prevent the cavity fields from reaching the point where electrons are reflected. The coupling slots have been increased in both height and angular width.

IV. SUMMARY

A three cavity high-current relativistic klystron is operating at 1.3 GHz with a peak power of 475 MW and an energy per pulse of about 150 J. The rf pulse length is 1 μs. The limit to performance is the output cavity which has a shunt impedance high enough to produce electron reflection, and possibly virtual cathode oscillations, leading to beam disruption and rf termination. An effort is underway to build a new output cavity with a much lower shunt impedance in order to reach the goal of 1 GW peak power and an energy of 1 kJ in a 1 μs pulse.

V. REFERENCES

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