OPERATION OF A 473MHZ PULSED KLYSTRODE POWER SOURCE

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Abstract

A 100kW peak rf power source was built using an Eimac 2KDW60LA klystrode at 473MHz. The klystrode has been operated at a peak power level of 104kW with 50μs pulses at a duty factor of 0.5%. The measured efficiency of the tube operating in this mode was 56%, with a gain of 23dB. This system is to be used as a power source for both a sparking cavity and a 500keV RFQ for H^- ions.

Introduction

The inductive output tube [1] or klystrode [2] (see Fig. 1) uses a combination of a cathode and grid to produce a density modulated electron beam which is accelerated with a high voltage and passed through an output cavity as in a klystron. Recently the klystrode has been revived as a compact and very efficient UHF power source for TV transmission [3].

In this paper, we describe a pulsed rf system using a TV klystrode, the Eimac 2KDW60LA, which was designed to provide a peak-of-synch output power of 60kW. The klystrode is to be used for two purposes: 1) to power a sparking cavity [4] for testing voltage breakdown of materials, and 2) to power a small RFQ [5] for accelerating H^- ions to 500keV. This klystrode has produced 5μs to 100μs pulses in excess of 100kW into a 50Ω load with a repetition rate of 100Hz.

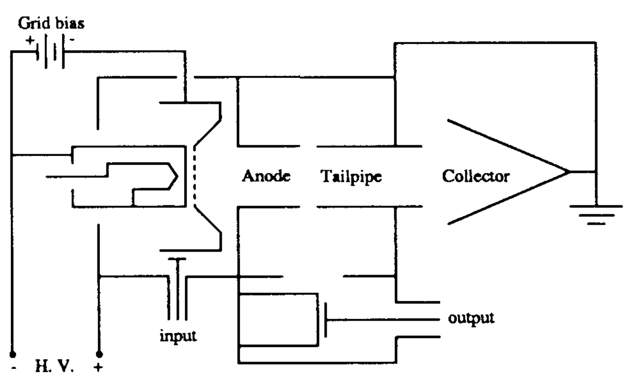

Fig. 1 Schematic of a klystrode with capacitive coupling for both input and output. The klystrode uses a grid to modulate the electron beam density but uses a cavity similarly to a klystron for the output.

Description of Apparatus

A pair of Eimac 3CX8007A planar triodes, operated in tuned cavities, are connected in series to drive the klystrode (see Fig. 2.) A small solid state amplifier (50dB, 10W) is used to amplify the signal from a Wavetek 2520 signal generator to a level sufficient to drive the triodes. The cw rf signal from the solid state amplifier is modulated in the triodes by pulsing the cathode to grid bias level between 35V and 4V. By pulsing the bias level, we are able to use a low current power supply for the anode to cathode voltage; a few milliamperes versus one to two amperes for cw operation. The second triode is capable of producing over 1400W in pulsed operation; however, only about 500W are required to drive the klystrode to a 100kW level. An isolator has been inserted before the klystrode to provide a constant load for the output of the second triode, since the input impedance of the klystrode varies with power level.

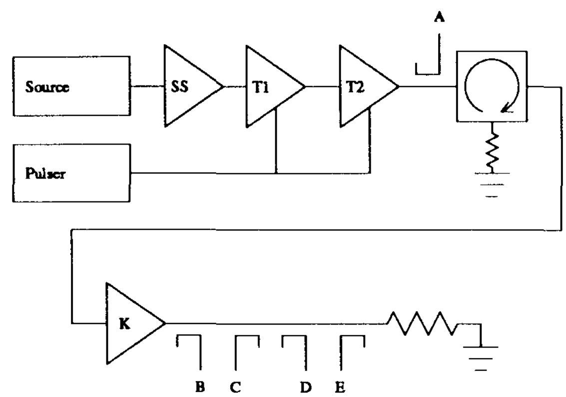

Fig. 2 A schematic of the amplifier chain. The symbols SS, T1, T2, and K respectively correspond to the solid state amplifier, the first triode, the second triode, and the klystrode. The modulation is done by pulsing the grid bias voltage of the triodes. The input to and output from the klystrode, as well as power reflected back to the klystrode, are monitored from the directional couplers labeled A through E. Here a 50Ω load is shown for the output device.

In addition to the klystrode, Varian/Eimac supplied the input fixture, output cavity, focusing magnet, Vacion pump, grid bias supply, and arc detection circuitry. The input fixture consists of four tuning stubs feeding a capacitively coupled resonant cavity with tuned connections for the grid and cathode. The output cavity is really a pair of tunable cavities coupled through a tunable iris. One section of cavity surrounds the ceramic output window of the tube, and the other section is capacitively coupled to an EIA $4\frac{1}{16}$" coaxial transmission line. The solenoid magnet of 250 to 300G is placed around the top of the klystrode, above the output cavity, to focus the beam into the collector.

The grid bias and heater power supplies for the klystrode are placed in a high voltage coffin and powered through an isolation transformer. The beam voltage is supplied to the cathode of the klystrode by a 4kW dc power supply with a maximum current of 65mA at 0 to 60kV. The peak current required for the beam is several amperes, so a high voltage 0.7μF capacitor was connected in parallel with the supply to provide energy storage. At the 60kW level the klystrode may be operated with a beam voltage of only 32kV. For operation up to 100kW the voltage must be increased to 38kV.

For protection, an arc sense transformer couples the cathode current to a crowbar control circuit which can fire a spark gap in case of a fault. The crowbar can be fired also by a high vacuum reading in the klystrode or a high light level in the output cavity. The vacuum level is measured by a Vacion pump controller, and the light level is sensed by a photo resistor.

A small water pump and heat exchanger cool the collector, anode, and tailpipe. Additional cooling and ion clearing is provided by fans blowing air through both the input and output cavities of the klystrode. The entire rf power source including the klystrode and all required support equipment is housed in a movable 3-bay rack assembly measuring 32"×82"×80".

The output transmission line was stepped down to EIA $1\frac{5}{8}$" line and four directional coupling loops (two forward and two reverse) were installed for measurements and diagnostics. After passing through the top of the rack enclosure a connection is made to either a water cooled 20kW Bird load or to a flexible $1\frac{5}{8}$" coaxial line (Andrews Heliax 50Ω with air dielectric). The flexible line is then connected to the output device to be tested.

Measurements

Average power levels are measured with a Hewlett Packard HP438A power meter connected to one of the directional couplers, and pulsed measurements are analysed with a Tektronix DSA602 digitising signal analyser. The frequency generator, power meter, and signal analyser are connected to a Hewlett Packard 200 series computer with an IEEE-488 bus. The output power level is controlled mainly by varying the signal level from the frequency generator. Additional control is possible by varying the cathode to anode voltage of the triodes. When operating the triodes way below saturation, they are susceptible to an overshoot of the bias voltage at the beginning of a pulse. This causes a power spike at the beginning of the pulse. By lowering the triode anode voltage, the triodes will run closer to saturation, and the output pulse is much flatter. Typical settings are between 2kV and 3kV.

Figure 3 shows the klystrode output power vs the input power, measured from directional coupler A of Figure 2, with a beam voltage of 38kV. The gain versus output power is shown in Figure 4. The efficiency (see Figure 5) was calulated for 50μs long pulses with a duty factor of 0.5% by dividing the average output power by the dc power provided by the beam power supply during the rf pulse. A typical 50μs pulse is shown in Figure 6.

The x-ray radiation from the klystrode near the anode at 32kV was measured to be less than 0.1mR/hr. At 38kV the level increased to about 6mR/hr. With the cabinet doors closed the radiation is less than 0.1mR/hr.

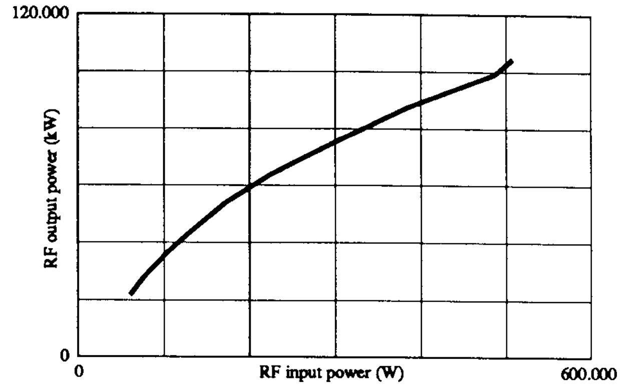

Fig. 3 The output rf power vs input rf power for the klystrode with an anode to cathode voltage of 38kV.

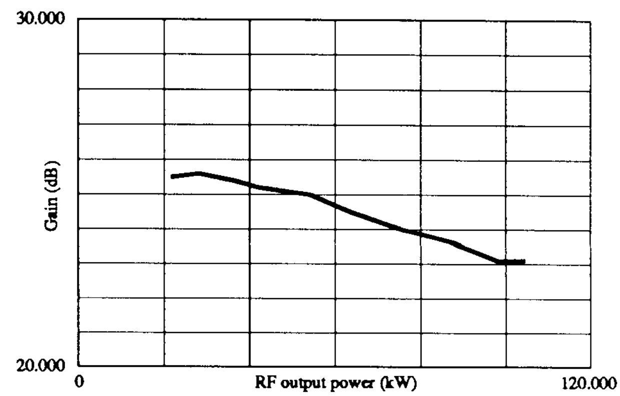

Fig. 4 The gain vs output rf power for the klystrode with an anode to cathode voltage of 38kV.

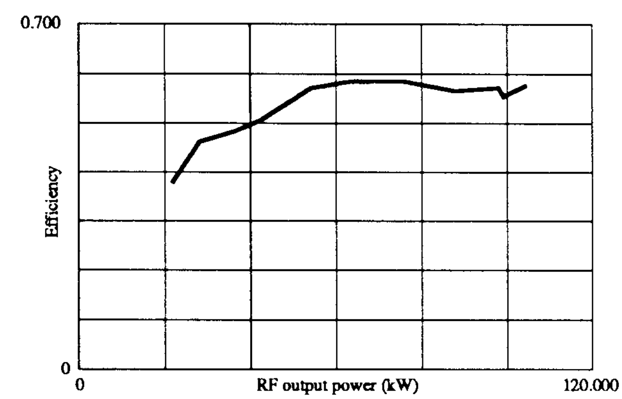

Fig. 5 The efficiency vs input rf power for the klystrode with an anode to cathode voltage of 38kV.

Future Modifications

A feedback circuit is being designed to sense the output power level and adjust the input to the solid state amplifier so that the output power remains constant. The signal from one of the forward directional couplers (B in Figure 2) will be converted to a dc voltage with a crystal detector. This voltage will be filtered and compared with a reference voltage to produce a difference voltage which will adjust a voltage-controlled attenuator placed in front of the solid state amplifier.

Additional instrumentation will be added to measure the tube's performance parameters. The feedback control, high voltage supplies, and instrumentation will be connected to a supervisory control computer for automated operation.

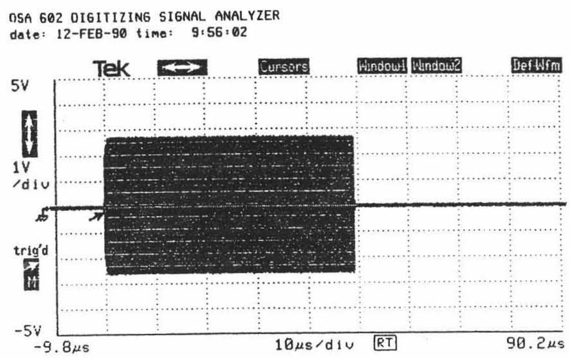

Fig. 6 A typical 50μs long rf pulse at 100kW level.

Conclusion

The klystrode is an excellent compact source of pulsed rf power for use in small accelerator systems operating in the UHF band. It is compact, and does not require a pulsed high voltage supply for the anode. Varian/Eimac has developed [6] a prototype 0.5MW tube at 425MHz which is physically only a little larger than the 2KDW60LA.

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References

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