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Recent Performance of Klystron Testing Modulators in the SLAC Klystron Test Lab*

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RECENT PERFORMANCE OF KLYSTRON TESTING MODULATORS IN THE SLAC KLYSTRON TEST LAB*

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Abstract

The mix of klystrons being designed and operated in the SLAC Klystron Test Lab continues to expand and now includes large klystrons, CW and pulsed, from UHF to X-band. To support these developments, a number of new pulse modulators and power supplies were designed from scratch, or upgraded from existing laboratory test systems. This paper presents recent experimental performance of these modulators and describes a quasi-line power supply that could efficiently support a high-power gridded klystron with a special isolated collector.

400 MW Peak Power Modulator (DESY)

A 400 MW peak power modulator was designed and constructed to power and test a 150 MW S-Band klystron for DESY. The basic approach, first described at PAC '93, is a straightforward SLAC modulator except that four parallel lines and two thyratrons are used to obtain the low line impedance and high discharge current. The voltage is obtained by using a pulse transformer with a turns ratio of 23 to 1. A simplified schematic of the modulator is shown in Fig. 1.

Specific attention was paid to minimizing inductance in the primary current path. This stray or wiring inductance and the pulse transformer leakage inductance are the limiting factors in the output voltage rise time. Therefore the connection from the PFN to the pulse transformer was made using 6-inch parallel-plate copper bus and kept as short as practical by directly connecting the pulse tank to the PFN cabinet. Connections from the PFN to the thyratrons are copper tubing. The four ten-section PFNs are packaged in a single rack with half of the coils on one side and half on the other producing a compact, symmetrical assembly. The thyratrons are located on either side of the PFN and the output to the pulse transformer is between the thyratrons.

Earlier this year the modulator was brought into operation and used to test and process a beam diode to 550 kV, 700 amps, 3.5 µs, and 60 Hz PRF. Figure 2 shows the beam voltage and current waveshapes obtained with this diode load. The peak beam voltage in this waveshape is 532 kV, and the current is 673 amps peak. The rise time of the beam voltage pulse is 0.8 µs from 10% to 90%. This measured rise time compares with the simulated 0.7 µs rise time for the pulse transformer and a primary estimated lead inductance of 0.5 µH. Figure 2 also shows the primary rise time of the PFN-thyratron combination to be very fast, less than 80 ns. Even with this fast rise time and a primary discharge of over 15 kiloamps, the ringing is minimized because of the close coupling of the modulator elements and the minimum-inductance, minimum-stray capacitance design.

200 MW Peak Power Simple Modulator

Another modulator, which we like to call "conventional", was constructed in the Klystron Test Lab this last year to power an X-band klystron that drives a resonant ring. This compact design is capable

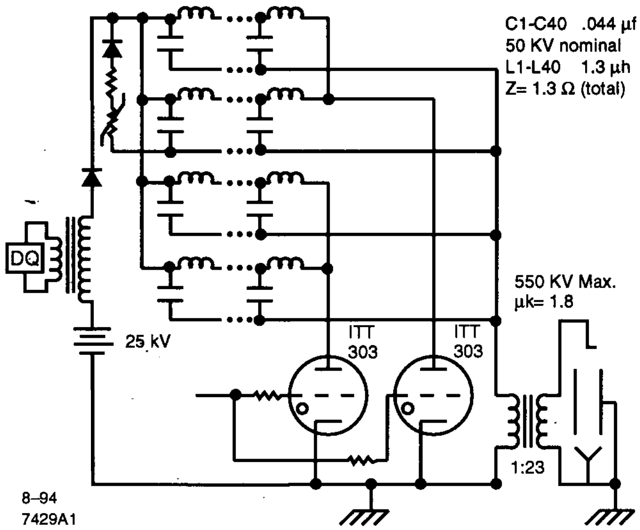

Fig. 1. Simplified schematic 550 kV modulator.

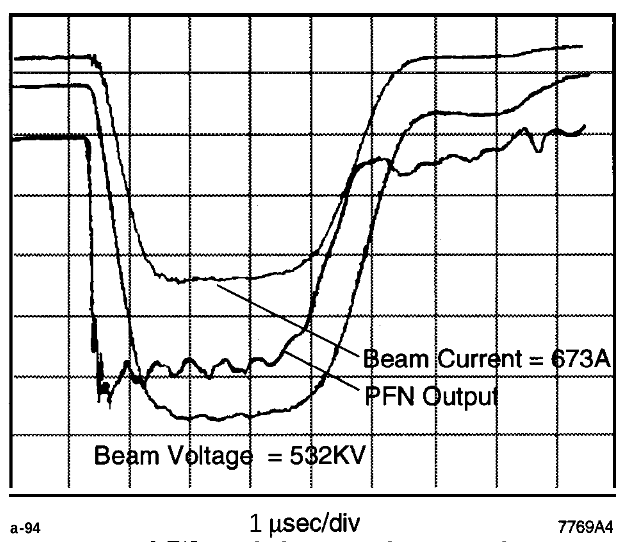

Fig. 2. 400 MW modulator voltage and current waveshapes.

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of driving any klystron from 350 kV to 430 kV at a perveance from 1.2 to 1.9 μperv. The pulse width can be adjusted from 1 μs to 4 μs by selecting the number of PFN segments in the network. The pulse capacitors are 0.044 μfd, 50 kV each, and the tunable inductors are 2 μH each. A standard ITT 241 thyratron is used for the switch element or the corresponding EEV, or Litton thyratrons may also be used.

One and 3 MW CW Test Stands (*B* Factory)

CW low-frequency klystrons are being produced and tested in the Klystron Test Laboratory for use on the *B* Factory. At present, there is one 500 kW, 476 MHz klystron in place on the one megawatt test stand that is used for component testing. The power supply in this test stand operates at 67 kV, 15 amps. A second, higher voltage and power test stand is under construction that will deliver 97 kV, 30 amps to a new design 1.1 MW CW 476 MHz klystron. The power supply is designed to provide three intermediate stages of voltage that can be used to bias a depressed collector for energy recovery. The test stand is instrumented to operate a depressed collector klystron, although a depressed collector klystron is still in the preliminary design stage. The 3-MW test stand uses a programmable logic controller (PLC) for the interlock system. The test stand will be in operation in December 1994.

Quasi-line Power Supply for Gridded Klystron with Isolated Collector

Because of the very large rf power demand of all proposed NLC systems, it is most important to maximize the efficiency of rf delivery systems. Energy is dissipated when large amounts of charge are moved into and out of the system stray capacities. In addition, the klystron electron beam dissipates energy during the rise and fall times of the beam pulse when no rf energy is produced. As klystron voltages go higher, and pulse widths grow shorter, there is pressure to build faster and faster rise- and fall-time pulse modulators to minimize these losses. The fast rise and fall times, however, do not change the energy lost in charging stray capacity, or left over in stray inductance. This energy is lost independent of the pulsed power rise and fall times.

It has been recognized for some time that the cathode of a klystron need not be moved in voltage if there were some other way to control the current emitted from the cathode. Some klystrons at low power have been built using either full or partial voltage-swing modulating anodes. These designs limit the amount of stray capacity that must be moved to produce pulses, but the voltage swing necessary to switch on current is high, and the cathode voltage must come from a DC supply that contains much stored energy. The gun area of the klystron must be designed to withstand this DC voltage without arcing, and arc protection in the form of a high power crowbar must be incorporated in the design to discharge the high stored energy of the DC supply. Until now, conventional wisdom has dictated that high power, short pulse klystrons be built with diode guns driven by pulse modulators, usually line type with step-up pulse transformers.

It is time to revisit the idea of high-voltage gridded guns for klystrons. New cathode technology that allows emission at a lower temperature makes possible the use of a conventional intercepting grid in front of a klystron cathode that can have a transconductance approaching 50,000 μmhos. This will allow the klystron beam to be switched by a fast grid pulser of only about 5,000 volts. Such pulsers are available in solid-state components with rise times of less than 5 ns. The beam optics of such a klystron gun is difficult, but not impossible. A serious problem, however, is the DC voltage holdoff, and the minimum stored energy required in the DC supply to deliver the klystron beam current without excessive cathode voltage droop.

To make a high-voltage, fast-grid pulsed klystron feasible, a limited energy storage, high voltage pulse line can be used with a specially designed klystron incorporating an isolated collector. Figure 3 shows a block diagram of a unique quasi-line power supply-klystron system that is almost circuit loss free. For this example, a klystron of low perveance (0.6 μperv), high voltage (500 kV) is switched with a 5 ns rise- and fall-time grid drive pulse (1.5 μs pulse duration). The klystron cathode is connected to one terminal of a high-voltage lumped element PFN, which in this example has a characteristic impedance of 500 ohms. The unique part of this design is that the other end of the PFN is connected to the isolated collector of the klystron. Note that this configuration allows the klystron cathode to be held at a fixed 500 kV potential by a low current sustaining power supply which can also be used to maintain intermediate voltages on the multi-element DC klystron gun In operation, this sustainer supply delivers only the klystron cathode current that is lost to the klystron body.

The uniqueness of this design is the voltage swing on the klystron collector. Assume that the PFN has been resonantly charged to 600 kV from an unregulated, multiphase 500 kV power supply with no capacitor energy storage. There is 500 kV across the cathode-body gap, and this voltage is held fixed by the sustainer power supply. With no beam in the klystron, the voltage that is present across the

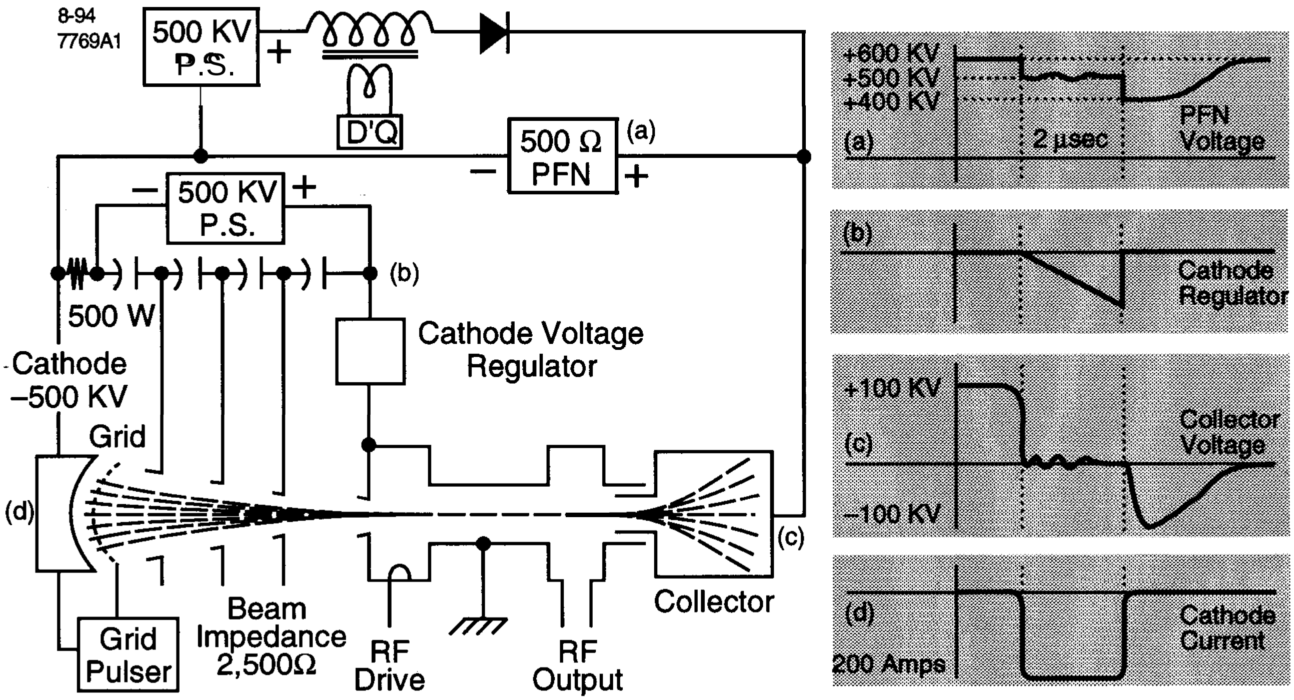

Fig. 3. Quasi-line klystron and power supply system.

klystron collector-body gap is +100 kV. The grid pulser now turns on the klystron cathode to 200 amps. The PFN sees a real beam load of 2,500 ohms between the klystron cathode and collector. This 2,500 beam load on the PFN reduces the PFN voltage to 500 kV where it stays for one-discharge period of the PFN. The voltage on the klystron collector goes to zero with respect. to the klystron body. At the end of one discharge period of the PFN, the grid drive is turned off, the beam current stops, and the voltage on the PFN drops to 400 kV. This applies a -100 kV voltage to the klystron collector. The resonant recharge returns the PFN to 600 kV over the interpulse recharge period, and the klystron is ready to pulse again.

This system design allows a DC-grid pulsed gun to be mated to a mismatched high-voltage PFN of limited energy storage without the gun having to withstand the overvoltage of a charged PFN. The over and under voltage swing has been transferred to the collector of the klystron. During the actual klystron beam pulse, the voltage on the collector is zero, or close to zero. The "close to zero" statement is important as the PFN network ripple and capacitive charge and discharge voltage appear here during the klystron beam pulse rather than on the klystron cathode. Within limits, these voltage variations at the collector do not affect the beam efficiency of the klystron. The resonant charging of the PFN. is self regulating during normal operation, but on initial startup some dQing of the charging choke is necessary to limit the initial inrush current from overvoltaging the network.

The block diagram shows a capacitor stack, and an active makeup voltage regulator in the sustainer power supply circuit. Since the klystron body current can be as much as 1% (2 amps) during the beam pulse, the capacitor stack is necessary to deliver this current. Low value capacitors are used in this capacitor stack to minimize energy storage, and an active regulator is used in the bottom of the stack to maintain and regulate the cathode voltage during the klystron beam pulse. Intermediate gun electrodes are also fed from this stack, and the high impedance nature of the sustainer stack provides a measure of arc protection for the gun. An arc between any two electrodes causes the voltage between these electrodes to collapse with the lost voltage being distributed among the other gaps. The arc extinguishes, and no energy from the main PFN is dissipated in the arc.

This scheme of klystron power system development requires primary R&D work in several areas. A few are listed below.

1. Low temperature klystron cathodes mated with high transconductance grid structures.

2. High voltage, compact, low lead inductance PFN's operating in a common oil tank.

3. High vacuum, low perveance, high voltage multielement electron guns with good beam optics.

4. Medium voltage holdoff isolated collectors with low impedance rf choke joints.

5. Periodic, permanent magnet focused klystrons.

With much R&D and component development, this type of high power rf delivery system has the possibility of realizing the high efficiency needed for a future NLC accelerator.