A 500 KV POWER SYSTEM FOR A GRIDDED SHEET-BEAM KLYSTRON

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Abstract

This paper describes DTI's progress in the design of the power electronics supporting the sheet beam klystron development at SLAC. The power electronics include a 500 kV multiplier power supply, a 10 kV grid modulator, a multi-concentric high voltage cable and an advanced, re-entrant interface between the cable and the klystron (Figure 1). The design allows the klystron to be located adjacent to the beamline, and separated from the power electronics. The system is potentially very low cost, very high efficiency, and highly reliable and maintainable.

INTRODUCTION

The Next Generation Linear Collider (NLC) will require a large number of klystrons as RF drivers. These klystrons typically require 500 kV 265A pulses of 1.6 µs duration, and a complex microwave delay line to achieve 400 ns RF pulses. The scope of this power system is such that small changes in power efficiency can enable 10-year operating cost savings comparable to the capital equipment cost of the power systems themselves.

For several years, this has inspired a number of efforts to develop solid-state switching technology to the point where improvements in operating cost, reliability, and performance clearly supplant conventional thyratron/PFN approaches, and make the NLC significantly more affordable to build and operate.

SLAC, in collaboration with Calabasas Creek Research (CCR) is currently developing an advanced gridded sheet-beam klystron. Dramatic efficiency gains are enabled because this klystron does not require cathode pulsing to 500 kV.

DESIGN OVERVIEW

The key advantage of the sheet-beam gridded klystron is that the cathode is held at its operating voltage continuously. No capacitive charging and discharging of the cathode and cable occurs during each pulse. The beam is gated by a low voltage (6 kV) grid, normally held at a few kV back-bias. Arc protection is provided, in part, by using a tube design with an intermediate anode (IA) biased to quench arcs in the gun region, and, in part, by limited stored energy availability.

The beam energy is delivered via a long, multi-concentric coaxial cable, which also serves as a pulse forming delay line. During the pulse, the cable (which is not impedance matched to the gun) depletes by about 10% in voltage, thus is physically slightly longer than the round-trip delay-length of the pulse. This long cable thus serves to isolate the high-radiation zone of the klystron from the HV source electronics.

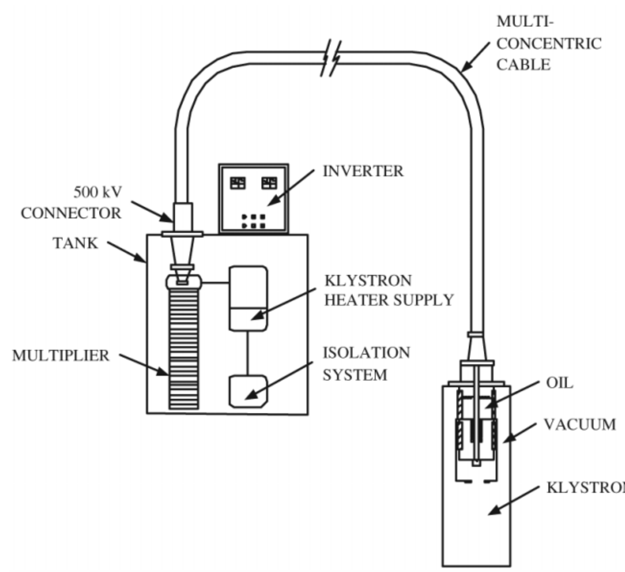

Figure 1: HV system layout with inverted sheet beam klystron. The upper tank holds the multiplier, grid pulser, filament supply, and terminations. The other termination is an oil-filled well which is integral with the tube envelope.

The fast risetime of the grid-pulsed tube also enables the klystron to deliver 400 ns pulses, eliminating the network of microwave delay lines used with the cathode pulsed, 1.6 µs klystrons. This short pulse decreases the required cable to manageable lengths.

The gridded sheet beam klystron design is an aggressive one. Significant component developments are required for most elements – RF structure, gun, cable and feedthrough, and grid pulser. DTI is currently working on all of the electronics support systems, as well as the cable and feedthrough (in collaboration with Dielectric Sciences, Inc. (DSI)).

MULTI-CONDUCTOR CABLE

The cable must provide HV energy storage, IA bias, filament power, and grid pulse transmission (Figure 2). The grid pulse itself must be transmitted with very low dispersion, to maintain the fast risetime required.

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After a number of design iterations, DTI, DSI, and SLAC have settled on a low-loss polypropylene paper laminate with oil impregnation for the two high voltage dielectric sections of the cable. This material is capable of 1500 V/mil, yielding a compact and flexible net assembly. Semiconducting wraps are used to separate the electrical and mechanical breaks at the HV boundaries.

On hard HV arcs (where IA suppression fails), the modeling shows that the dielectric gaps can experience transients fields 60% in excess of the DC fields. As a result, the design dimensions were chosen to accommodate these higher fields within the dielectric strength of the material.

The core of the cable was chosen to have a characteristic impedance of 90 Ω. The high impedance lessens the load on the grid pulsing circuit, thus improving risetime. For low dispersion, center conductor dimensions somewhat larger than RG/8 equivalent were chosen, with higher aspect ratio to give higher impedance. The core is manufactured from extruded polyethylene, and can withstand the 10 kV repetitive grid pulsing at under 200 V/mil stress (non-corona), and survive short transient arcs to IA voltage (150 kV) at under 1000 V/mil.

CABLE TERMINATION

Figure 3 shows the cable terminations. The source tank (multiplier, grid pulser, filament supply) end of the cable will be terminated with a conventional stack of spread dielectrics, corona rings, and tapered conductors. The grid and heater connections will be jointly housed in an integrated tip assembly, which maintains matched impedance coaxial fittings on the grid signal.

The klystron end of the cable will be terminated in a much more aggressive reentrant design, under study at

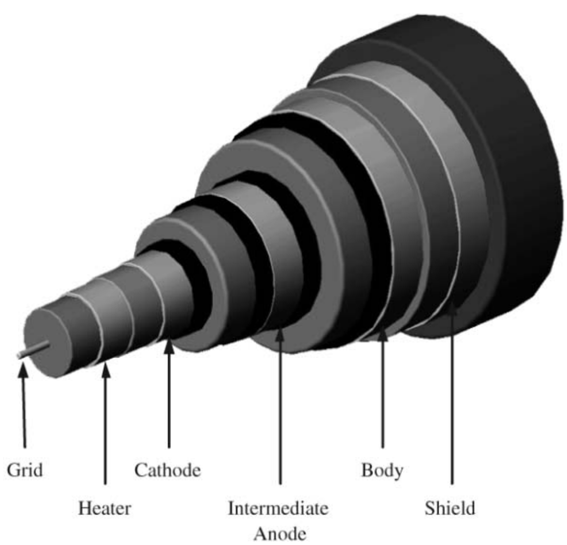

Figure 2: The key elements of the multi-concentric 500 kV cable are two high voltage laminated dielectric gaps (body-IA and IA-cathode), a low dispersion high impedance grid pulse core, and 40A heater-cathode conductors. The entire cable is approximately 3” diameter.

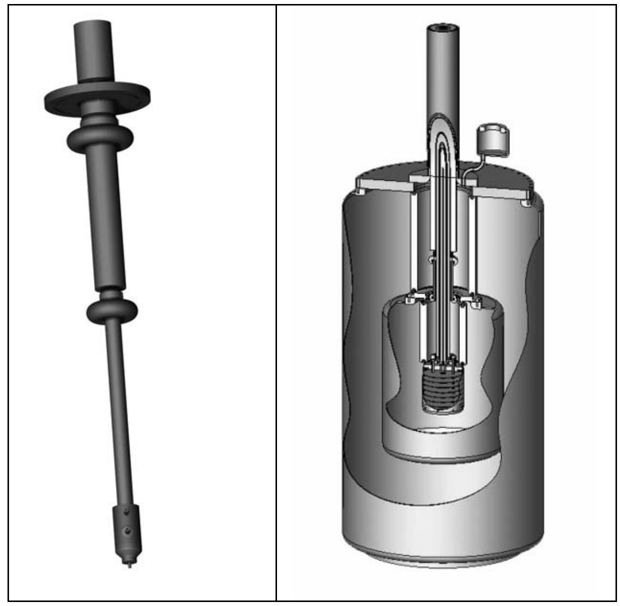

Figure 3: (left) Conventional corona shield and tapered dielectric expansion construction is used to terminate the cable at the HV source tank. (right) A novel re-entrant socket is built into the klystron gun, making an inverted direct compact interconnect between cable and klystron.

DTI in a separate DOE SBIR contract. If successful, this design will eliminate some very expensive ceramic elements of the klystron gun assembly, and will reduce complexity and size of the hardware which must reside in the accelerator tunnel. The terminated cable will insert into an inverted oil-filled socket which comprises the gun and vacuum standoff assembly.

There are several difficulties to be overcome in this design, including the pre-compression of ceramic joints that would otherwise be under tension, heat removal from the filament, and placement of the arc-quenching series resistor relative to the IA terminal. Preliminary solutions to all of these issues have been identified, and initial design studies are anticipated to begin this year.

GRID PULSER

The klystron grid requires a high fidelity pulse on the order of 10 kV (~ 6 kV from a back-bias) with risetime of 10-20 ns. Although the grid intercepts little or no current (the amount of beam intercept is still being debated in the gun design), the load of the pulser must be thought of as the characteristic impedance of the cable core.

For this purpose, we have assembled a solid-state switch (Figure 4) made up of series integrated gate bipolar transistors (IGBTs). To achieve the fastest risetimes, we use low voltage (1200V) IGBTs. The switch inductance is minimized by an extremely compact series/parallel topology, fat and short board interconnects, and an image/ground plane closely coupled underneath the switch assembly. Figure 5 shows a 26 ns (10%-90%) risetime of 6.2 kV into a 100 Ω load. Further work has obtained slightly faster results using additional parallel discrete IGBTs.

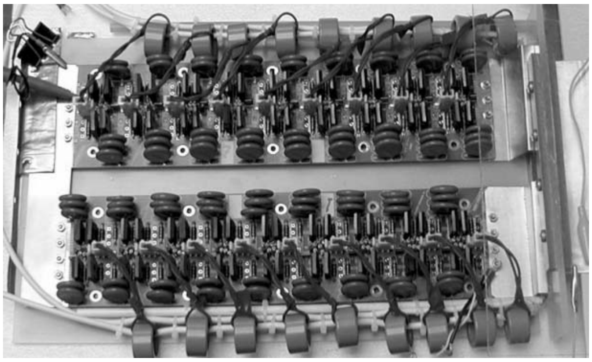

Figure 4: A series/parallel array of 1200 V IGBTs in discrete TO-247 packages makes for a very fast hard switch. This assembly is capable of 11 kV operation, with about 25 ns risetime into a 100 Ω load.

The grid pulser circuit (Figure 6) must operate as a half-bridge, effectively using two full switches to actively pull the grid terminal of the cable to "on" or "off" potential. It is required that the back-bias leg of this circuit have a series termination resistor to match the impedance of the cable, otherwise grid pulse reflections will result in spurious transient beam emission in the interpulse period.

MULTIPLIER POWER SUPPLY

Prime power for the klystron discharge will be provided by a 500 kV DC multiplier supply, requiring about 50 kW average power.

Many schemes exist for multi-leg multipliers to minimize ripple but these are unnecessary here, because the supply is essentially a current source used for capacitor recharge. Regulation is not important, but accuracy in the end point is.

Multipliers are often thought of as inefficient devices, due to their high source impedance, but this is not the case, because the internal impedance is reactive in nature. Our multiplier design is chosen for very high power efficiency.

The efficiency of a multiplier is critically dependent on the design of the inverter and transformer which drive the first stage. We will use 12-14 sections, with ~ 50 kV of drive, and a high-efficiency inverter with phase-controlled PWM regulation.

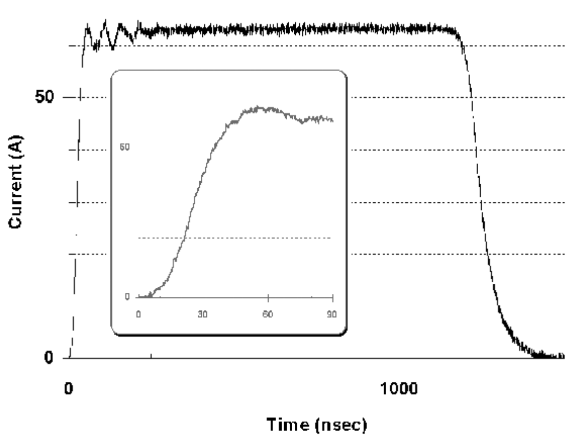

Figure 5: A 10%-90% risetime of 26 ns is achieved with a 6.2 kV pulse into a 100 Ω load with the grid pulser circuit.

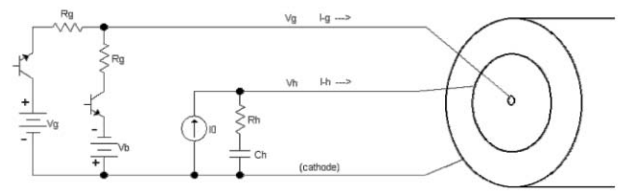

Figure 6: The circuit at the source end of the grid/ heater/ cathode hot deck must have forward and back bias supplies for the grid, plus two fast switches.

AUXILIARY SYSTEMS

The grid pulser and heater current supply must "live" on a hot deck at 500 kV DC. This will be installed in a moderately sized oil tank at the source end of the cable. Included in this assembly (Figure 1) are the isolation power system (to power the hot deck), fiber optic communication to the hot deck, the cable socket, and termination resistors and diodes for transient snubbing of the HV cable conductors.

The key challenge here is to maintain a compact and practical design which remains free from arc-over events with continuous presence of 500 kV DC. The extreme effects of electro-convection and polarization of suspended oil impurities will necessitate the use of well-shaped intermediate guard rings and shields.

SUMMARY

A coordinated effort is underway to develop all components necessary for a grid-pulsed sheet beam klystron suitable for NLC application. Such a system would exhibit very low costs and very high efficiencies – far in excess of other, more conservative, designs presently in development. This system would enable elimination of the complex microwave delay lines now used to overcome the long risetime of cathode pulsed devices, and would not require expensive and complicated cathode switches for arc protection.

The klystron development is underway at SLAC and CCR. DTI is actively working on all aspects of the driving electronics, and in collaboration with DSI, on the multi-conductor cable. In the next 18 months, we anticipate completion and demonstration of all major subsystems, and delivery of a fully functioning test stand to SLAC for evaluation by the end of 2005.