SOLID-STATE TETRODE TEST STAND

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Abstract

In March 2009, Diversified Technologies, Inc. (DTI) delivered a 500 kW DC solid-state test stand for the evaluation and conditioning of high power tetrodes, commonly employed in a wide range of accelerator and radar systems. The test stand consists of both DTI-manufactured and commercially-sourced power supplies, a DTI high voltage opening switch, and DTI controls, all of which interface with the tetrode tube enclosure. High power gridded tubes are excellent candidates for opening switch protection because the wires used in the screen and control grids are even more delicate than the electrode surfaces in linear beam tubes.

This test stand was funded by the UK's Science and Technologies Facilities Council for the purpose of streamlining their testing of new tetrodes for the ISIS system at Rutherford Appleton Laboratories (RAL). This paper summarizes the design, construction, and performance of this high power test stand.

INTRODUCTION

The manufacturing and testing of RF amplifier tubes is complex. One of the key elements in this process is the initial tube operation (burn-in) and testing of the tube. During this initial period of operation, the test stand must be able to deliver a wide range of voltages, currents, and pulse parameters, in order to clean the tube of internal debris, projections, and out-gas. During this testing, it is critical that the test equipment can both withstand the repeated arcing that typically occurs in operating a new tube, and can protect the tube from damage during testing.

Diversified Technologies, Inc. (DTI) designed, built, and delivered a 500 kW DC solid-state test stand for this conditioning and testing process to Burle Industries in Lancaster, Pennsylvania (Figure 1). This system is primarily focused on testing of high power tetrodes, and can be used for other systems within the voltage and current envelope of the equipment. The test system consists of both DTI-manufactured and commercially-sourced power supplies, a DTI high voltage opening switch, and controls, all of which interface with the Burle-provided tetrode tube enclosure.

Figure 1: Tetrode Test Stand installed at Burle Industries.

A key element of this 500 kW test stand was the inclusion of a solid state, series opening switch for arc protection. This switch provides rapid removal of power from the tetrode's cathode in the event of any fault condition – including an arc – in approximately one microsecond.

SPECIFICATIONS

The tetrode test stand was designed to provide all of the electrical inputs required to operate a Burle 4648 High Power Tetrode, across the full range of voltage and current conditions. The basic electrical specifications are shown in Table 1.

The tetrode test stand specifications also require full control and coordination of each of these subsystems, with sequenced power-up and power-down / fault handling, to ensure the safety and reliability of the tetrode in the test stand.

SYSTEM DESIGN

The Tetrode Test Stand system is comprised of six primary sections, shown in Figure 2:

- Tube Enclosure – A Burle furnished EMI-tight screen room (ETS-Lindgren Series 71) that contains the 4648 High Power Tetrode and its associated water (coolant) and electrical (supply) lines.
- Control Rack - An open rack that houses the screen power supply, grid power supply, filament power supply control, system control box, and Kirk Key panel.

Table 1: Tetrode test stand electrical specifications

Designation	Description
Anode Output Power (Plate)	+25 kV adjustable, 20 Amps max; 20 kV, 20 A nominal average
Screen Output Power	+2 kV adjustable, 4 Amps max; 1400 V, 2 A nominal
Bias Supply (Control Grid) Power	-300 V adjustable, 2.5 Amps max; -200 V, 1 A nominal
AC Filament Supply	6 V adjustable, 2000 Amps max;4 V, 1650 A nominal

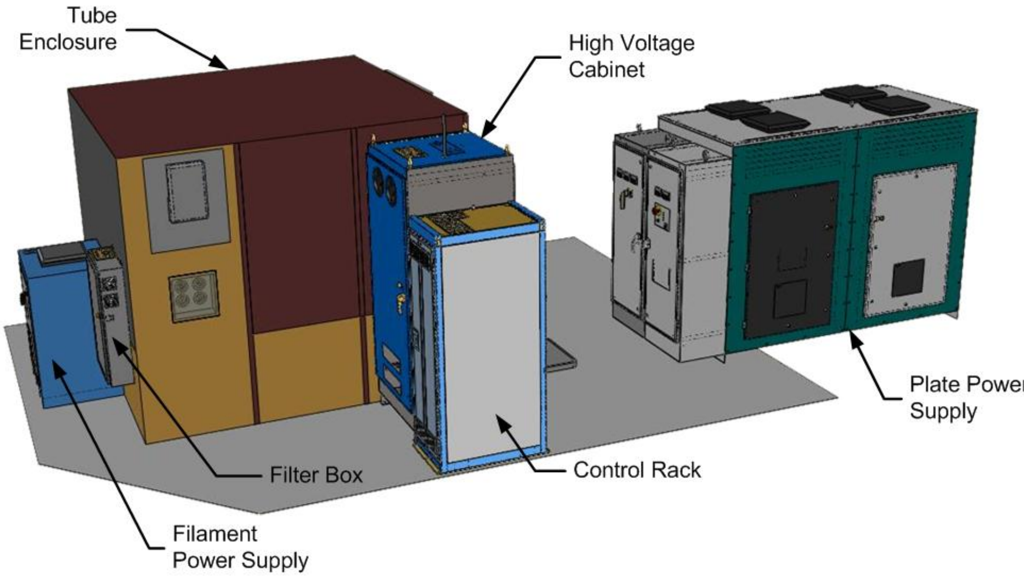

Figure 2: Tetrode test stand assembly.

- High Voltage Cabinet - A closed cabinet that contains the DTI high voltage opening switch (Figure and Figure), filter capacitors, and the associated circuitry required to energize monitor, and protect the plate of the tetrode. The capacitor bank consists of two Maxwell 12.5 uF, 25 kVDC capacitors. Series resistors limit the current through the capacitors in the event of a short circuit. A 5 megohm bleed resistor bank is included to discharge the cap bank in the event of a drop-bar failure. The RC time constant is approximately two minutes.
- Plate Power Supply - A closed cabinet from Marelco that generates 0 - 25 kVDC at 0-20 ADC output through a 480 V transformer / rectifier and SCR controller. It connects to the high voltage cabinet for filtering and monitoring.
- Filament Power Supply - A commercially provided, closed cabinet that generates 0 - 6 VAC at 0 – 2000 A. This supply directly connects to the tetrode to drive the filament.
- Filter Box - A cabinet that contains monitoring equipment, safety relays, and reverse current bleed resistors for the screen and grid power supplies.

The system provides knowledgeable users, such as Burle, with the free use of several parameters, allowing conditioning of the tetrodes by varying each power supply voltage independently. The control interface is centrally located to aid in adjustments during testing. The control system enforces proper power supply sequencing, and monitors system conditions to detect and respond to faults. Finally, all high voltage sections are completely enclosed for safety, and a Kirk key system prevents opening of any cabinet containing high voltage equipment when the system is powered. Design of the user interface was developed with close involvement of system operators to ensure functionality and ergonomics.

TEST STAND OPERATION

The test stand offers several advantages in the tube test environment, including reduced arc energy dissipation, increased system availability via the elimination of disruptive crowbars, improved reliability from the reduction of electromechanical stresses on test stand components, and increased tube processing throughput by rapid return to operation after an arc. The operator is not constrained by lengthy recycle times or crowbar lifetime issues common in many older test sets, because the system can remain at full voltage during arc fault handling.

To minimize the arc energy deposition inside the tetrode, DTI employs a solid-state opening switch consisting of a series stack of commercially available IGBTs incorporated into switch plates. The high voltage switch assembly consists of ten commercial DTI solid state switchplates, each of which is capable of withstanding 3.3 kV, yielding a total standoff of 33 kV. A turn-on snubber circuit limits the current through the switch stack to protect the switches and the tube in the event of an arc. The inductor size allows the current to reach approximately 400 amps before the high voltage switch opens. Current sensors on the output of the supply recognize the presence of an arc when the current in the switch exceeds a preset fault threshold value, causing the switch to open in ~ 1 μs and disconnecting the high voltage from the load. After the arc extinguishes, the switch can resume operation in as little as a few milliseconds, instead of shutting down the system as is the case with a crowbar. This tube protection circuitry is tested through an automated system that introduces a short circuit through a length of 40 AWG wire. Sensors verify that energy limiting does not cause the wire to break.

By limiting both peak fault current and follow-on-current, the total energy in an arc event is greatly

Figure 3: The control rack and high voltage cabinet of the tetrode test stand.

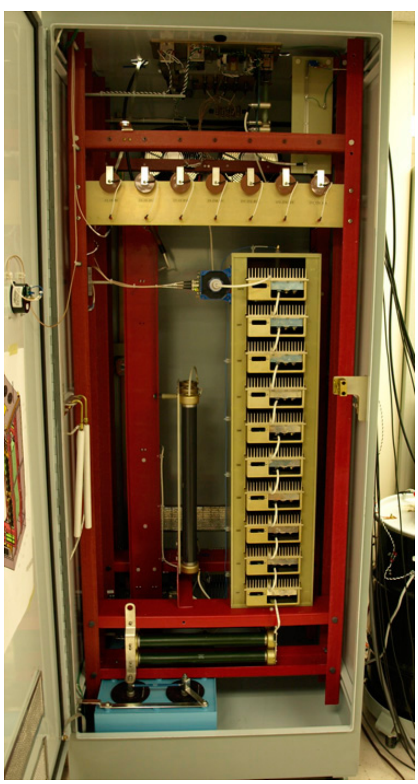

Figure 4: High voltage cabinet interior, showing the solid state switch (R), consisting of ten 3.3 kV switch modules connected in series.

minimized, reducing damage inside the tube. If greater energy (or action) is required for initial tube processing, additional load capacitance downstream of the switch is included and can be added into the circuit for "spot knocking" purposes. Less than 4 joules of energy are delivered to the tube during an arc. Since this system sometimes operates to condition the tubes, an adjustable capacitor bank at the output is included to allow extra energy to flow into the tubes during an arc. BNC plugs allow the user to add up to seven pairs of high voltage film capacitors to the output, for a total energy of 10 Joules at 20 kV.

Combining an opening switch and fast responding power supplies allows the hi-potting and high power burn in to be somewhat (if not entirely) combined. Faulty tubes, which would not operate in a crowbar equipped test stand, and could not be processed to health on a high potter, can be revived with this fast opening switch circuitry.

SUMMARY

The Tetrode Test Stand is currently in operation at Burle Industries. It has met or exceeded all of its initial specifications and goals, and simplifies testing for Burle's high power tetrodes.

This test stand design is flexible enough to support a range of CW and pulsed tube designs, and could be readily modified in terms of voltage, current, and average power to support a broader range of tubes. This design could also be used, with minimal modification, as an operational transmitter in an accelerator, radar, or other high power RF system.

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