THIRTY MEGA-WATT KLYSTRON MODULATOR DEVELOPMENT AT THE DUKE UNIVERSITY FREE-ELECTRON LASER LABORATORY*

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Abstract

The Duke FEL Lab requires no less than ten additional 30 mega-watt S-Band RF modulators to satisfy requirements for the storage ring and future linac projects. Ideas focusing on economy of cost and space utilization will be presented along with their current status. These ideas range from rebuilding old *SLAC* klystrons with commercially available dispenser cathodes, using inexpensive industrial PLC technology for modulator instrumentation and control, to a proposed modulator driving twin klystrons. This last item is especially applicable to reducing cost and space requirements.

1 KLYSTRON REFURBISHMENT

Roughly half the cost of an RF modulator system is the output klystron. A number of old *SLAC* klystrons with oxide cathodes are at Duke. The cathodes in these tubes suffer from reduced electron emission due to their more than thirty years of age. By using the services of our in-house vacuum shop and technicians, along with a dispenser cathode package designed by HeatWave Technologies, we will attempt to give our old *SLAC* klystron tubes a second useful life.

1.1 Cathode Replacement

Removal of the old cathode necessitates opening the klystron at the weldment above the ceramic high-voltage bushing. This allows the bottom of the tube containing the cathode and heater filament to be removed from the upper vacuum shell containing the anode and collector body. Following careful inspection and photographic documentation of the disassembled components, the cathode, focus electrode, heater filament and ceramic bushing were reassembled and sent to HeatWave for evaluation.

HeatWave will design, produce and mount a cathode package with the following attributes:

- Dispenser style cathode with integral heater filament
- Molybdenum heat shield and mounting canister
- Attachment of focus electrode to the perifery of the cathode
- Provision for mounting the package in the ceramic bushing that allows for easy swap and replacement

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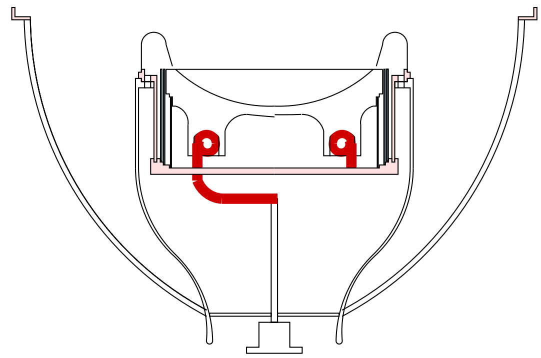

Figure 1: Cut-away section of dispenser cathode assembly in high voltage ceramic bushing

1.2 Cathode Filament Power

Dispenser cathodes require a higher operating temperature than oxide cathodes, see Reference[1]. This translates to an increase in the electrical power delivered to the heater filament. AC filament power is delivered to the cathode via the bifilar secondary windings of the high-voltage pulse transformer. The filament is connected to a coaxial terminal at the base of the high-voltage bushing. The cathode is also connected to the outer conductor of the coaxial terminal. To keep the filament current manageable through the windings of the pulse transformer, an auto-transformer is used to step-up the current after passing through the pulse transformer windings. The auto-transformer floats electrically with the klystron cathode voltage which is pulsed to 260kV.

The pulse transformer, filament auto-transformer and other associated hardware for driving the klystrons were designed for the old dispenser cathode requirements. The power required for the dispenser cathodes is approximately 300W. The filament auto-transformer was tested into a dummy load and was found to be limited to 360W. This is the lower limit of power required for the dispenser cathode being provided by HeatWave. Prior to commissioning the refurbished klystron, the cathode surface has to be *formed* by heating the dispenser matrix to above typical operating temperature. This causes the barium emitter material to melt and migrate up through the sintered tungsten matrix of the cathode bed, providing a uniform emitter surface. Due to the power limitation of our filament transformer, we will attempt to form the cathode at the end of the vacuum bakeout.

1.3 Klystron Vacuum Bakeout

Once the klystron has been reassembled with its new cathode, it will have to go through a vacuum bakeout. We have done this previously using heater tapes and bakeout blankets, see Reference[2]. For future bakeouts a dedicated oven has been built. It was fabricated in-house and is about the size of a telephone booth. This will allow a quicker, easier and more uniform bakeout of the klystron.

Toward the end of the vacuum bakeout, when the oven temperature has come down to ambient, the cathode will be formed using a suitable power source.

2 MODULATOR CONTROLS

The modulators that provides the high-voltage pulse to drive the klystrons are relatively simple devices compared to other technologies in common use today. They consist of a high-voltage dc power supply, storage capacitors configured with inductors as a Pulse Forming Network, a high current switch(hydrogen thyratron or SCR stacks) to switched the stored charge from the pfn to the klystron pulse transformer, instrumentation, controls, interlocks and support electronics.

2.1 PLCs

Programmable Logic Controls are a mature technology that provide the following features to an automation application:

- Easily configurable Input/Output points
- State-Machine style management of event responses
- Consolidated operator interface
- Remote communications port
- Logging of event responses
- Proven reliability in harsh industrial environments
- Highly cost effective

These features have greatly simplified the task of automating and monitoring modulator operation. The consolidation of local front panel indicators and controls into a single interface module costing no more than a single analog panel meter, has resulted in significant cost reduction. This also translates to simpler wiring and panel layout.

2.2 Surge and Fault Protection

Power transformers and thyratron filaments require protection from in-rush currents at turn-on. Typically this has been done with current-limiting resistors that are shunted at some predetermined time following turn-on by a time-delay relay. In the case of thyratron filaments, variacs are typically used to ramp the power to the filament by an operator. In both of these cases Negative Temperature Coeffiecient Thermistors can be used.

NTC thermistors have a relatively high resistance at room temperature. As they heat up their resistance drops. This provides automatic surge protection during turn-on of reactive devices (e.g. power transformers) or cold filaments. They have been used reliably for years in motor start circuits. They are available in a wide range of sizes and ampacities.

During a klystron arc the modulator must be protected from the voltage reversal due to the sudden load mismatch caused by the arc. A common method for doing this is by using an end-of-line clipper wired across the end of the pfn. The clipper consists of a diode stack, a matched load and a voltage triggered switch (e.g. a calibrated spark gap). During normal operation the diodes are reverse biased. When a voltage reversal occurs across the pfn, that exceeds the breakover voltage of the spark gap, the diodes become forward biased and the energy reflected back from the load during a fault is dumped in the matched load in series with the diodes and spark gap. Such spark gaps cost several hundred dollars depending on their size. A cost effective alternative to the calibrated spark gap switch is a Metal Oxide Varistor. Below it's transition voltage, the MOV behaves like a large resistor (hundreds of mega-ohms). As it's transition voltage is reached, it's resistance drops acting like a lossy switch. MOVs come in a wide range of sizes and packaging styles. For modulator pfns insulated with transformer oil, an unpackaged MOV of the style used in electrical utility transformers for lightning fault protection are ideal and inexpensive (more than an order of magnitude less expensive than calibrated spark gaps).

3 DUAL KLYSTRON MODULATOR

Developed lab and service spaces never seem to be large enough. This may become obvious soon after occupancy if planning was casual and hasty or it may not occur until later in the evolution of a successful lab that has been blessed with careful and studied planning. Most labs likely fall in between these extremes. Service buildings that house power, controls and support equipment always seem to be the first to become filled to over flowing. It will be attempted to prevent this situation from occurring by optimizing the space requirements for the modulators in our service buildings.

One way to do this that seems straight-forward and realizable is to use one modulator to drive two klystrons. Due to the low repetition rate (5 pulses/sec) and short pulse width (2 microseconds), the only significant item that requires changing are the pfn capacitors and inductors. The F-243 hydrogen thyratrons switches are being operated more than an order of magnitude below their maximum specifications. The modulator cabinet has the additional room needed for the larger pfn. This is because the cabinets were originally built to house a resonant charging high-voltage supply. Such supplies require substantial reactive components. The space required for these components is no longer required with the use of modern, switching, capacitor charging supplies from Maxwell Labs and other vendors.

4 ACKNOWLEDGEMENTS

We would like to recognize the patient expertise of Kim Gunther at HeatWave for his patient cooperation in trying to address the many constraints involved with finalizing a dispenser cathode specification.

5 REFERENCES

[1] 'Microwave Tubes', by A. S. Gilmour, Jr., published by Artech House, 1986.

[2] 'In-House Repair of a 30 Megawatt, S Band Klystron', R. Sachtschale, P.G. O'Shea, M. Ponds, G. Swift, proceedings of the 1995 Particle Accelerator Conference, published by the American Physical Society, 1996.