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TEST RESULTS OF A COMPACT CONVENTIONAL MODULATOR FOR TWO-KLYSTRON OPERATION

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Abstract
Modulator technology has not advanced greatly over the last 30 years. Today, with the advent of the High Voltage, High Power IGBT there are several approaches for a solid state ON/OFF switched modulator. Klystron and accelerator technology is forcing voltages and peak powers higher such as the demand for 500 kV and 500 amperes peak to power two X-Band klystrons. Conventional technology (line-type modulators) were never overly concerned about rise time and efficiency. A few years ago, the klystron department at Stanford Linear Accelerator Center (SLAC) undertook an investigation into what could be done in a conventional modulator at 500 kV. We have reported on test bed measurements and shown both conceptual and hardware pictures during design and construction. We have now completed the modulator tank

1. INTRODUCTION

The Two-Pack conventional modulator was originally conceived of to power the klystrons in the main linac of the Next Linear Collider (NLC). The objective was to design a conventional modulator with maximum possible efficiency, small size and reliable. The first obstacle to high efficiency in a narrow pulse width, very high voltage modulator is waveshape, usable flat top energy to total pulse energy. Coupling between the Pulse-Forming-Network (PFN), the thyratron switch and the pulse transformer primary as well as the pulse transformer itself have a major impact on this waveshape and overall efficiency.

The NLC is being designed using a Solid-State Induction Modulator. The klystron department decided to complete the Two-Pack design on a low priority to use as a test position for klystron development or life testing.

2. DESIGN FEATURES

2.1 Electrical

Early analysis centered on PFN charging voltage and pulse transformer ratio. It was believed that the charge voltage should be less than 100kV and to obtain a reasonable primary leakage inductance a maximum transformer ratio of 1:14 should be used. Therefore, a power supply of 80kV was chosen. This also fit into a reasonable three gap thyratron design. There would be two parallel 10-section PFN's, each with a mutually coupled inductor. Careful attention was given to isolate grounds and control the current paths to reduce noise. The primary discharge path between the thyratron, PFN and the pulse transformer would be made closely coupled with low inductance. Additional pulse isolation would come from making the connection between the cathode of the thyratron and tank ground inductive. Thyratron heater and reservoir leads and the core bias would all be common mode inductor filtered and capacitively bypassed to ground. A double pulse scheme was chosen to trigger the thyratron, instead of using a DC keep-alive circuit and the trigger leads would be filtered for common mode rejection.

The pulse transformer secondary circuit ground return would be isolated, and tied into the tank at a single point with a short return to the klystrons. The two sets of klystron heater leads would be individually bypassed and common mode filtered to keep all pulse noise inside the tank. Voltage and current monitoring signals would also require common mode filters.

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2.2 Mechanical

The design approach was for a single oil tank, which would house the thyratron, PFN's and the pulse transformer as well as room to install the klystrons. A horizontal, round tank configuration was chosen because of its inherent strength to support the klystrons and their lead shielding and ability to withstand evacuation before backfilling with oil. The challenge is always cost and ease of assembly and maintainability. The components were designed on a platform that would roll into the end loaded tank. The pulse transformer was mounted on a plate, which is electrically and mechanically isolated (shock mounts) from the main platform to control current paths and reduce noise from transformer vibration. Wiring was kept to a minimum and the low inductance coupling is short and made using aluminum sheet metal. The thyratron was designed to be removable from the top of the tank through a large port also used for expansion. This design shielded the thyratron, made the path somewhat coaxial and is completely plug-in including the anode connection.

3. FINAL TANK ASSEMBLY

The pictures of Figures 1 and 2 depict the final assembly of the Two-pack tank. In Figure 1, picture 1 at the upper left is the tank shell with a 5045 klystron mounted on the tank. There is a socket for second klystron on the right. The slide-in chassis can be seen inside the tank. On the right side of the tank is one of the feed thru bulkheads for the auxiliary supplies and viewing cables.

Figure 1. Left: Modulator Tank w/ 5045 klystron, Right: Multi-lam pins for ground

When the chassis is in place in the tank, a set of multi-lam sockets mounted on the inner chassis for grounding of the transformer secondary mates with the pins shown in the picture on the upper right. The pins are made floating to ensure that they properly mate with the sockets. The final ground is made by the short braid connections.

When the main chassis is extended from the cabinet the inside configuration can be seen. The picture on the left in Figure 2 looks at the inter-connect between the PFN, the pulse transformer and the thyratron. The bottom mounting plate of each of the PFN's is connected together and to the pulse transformer primary with a wide strip of sheet aluminium. The low side of the pulse transformer primary connects directly to the cathode of the thyratron with another wide strip of aluminium. The high voltage power supply connection is shown mounted on standoffs above the low side of the pulse transformer. The picture on the right, in Figure 2, is of the thyratron chassis and anode housing. The anode connection from the can is on standoffs from the thyratron chassis cathode plate. The PFN coils directly connect to this anode ring. The legs supporting the cathode plate are sitting in ferrite toroids as a method of pulse isolation. The thyratron cathode has a DC connection to ground. An inverse diode is mounted across the thyratron.

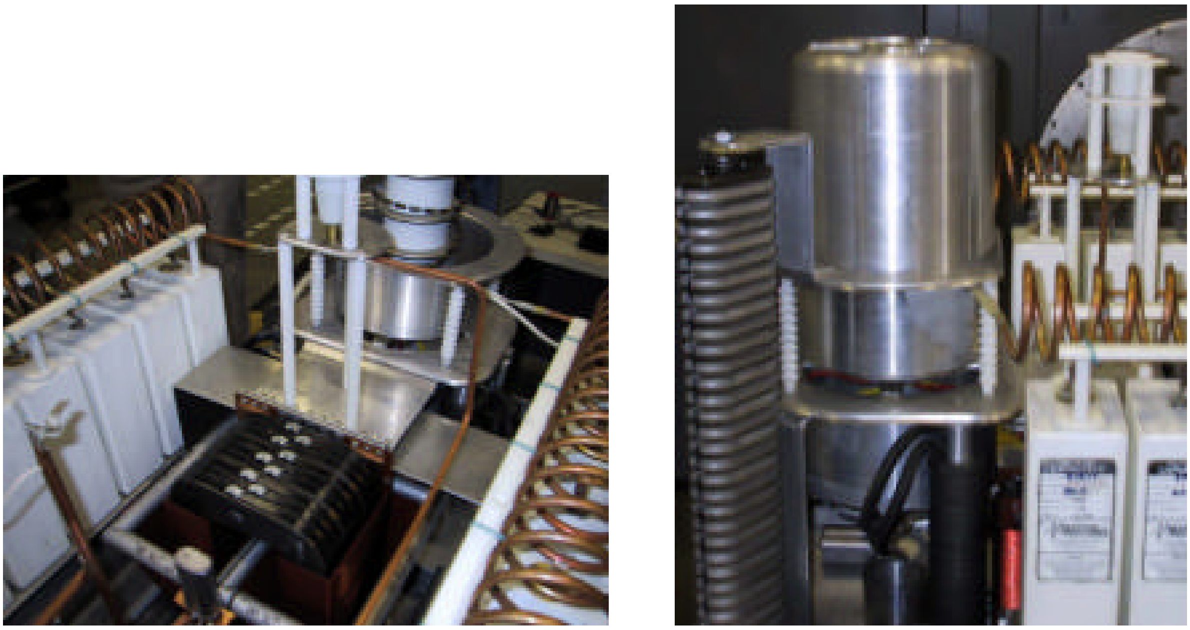

Figure 2. Left: Primary Discharge coupling; Right: Thyratron deck and anode housing

The tank can be used with either a direct charging power supply of up to 80 kV or a resonant charging supply. The charging diode is located inside of the tank. We are connected to a resonant charging supply in Test Stand 03 for testing and operation.

4. TEST RESULTS AND OBSERVATIONS

Unfortunately our test results are still incomplete. Priorities and manpower constraints have continually delayed the program. We have done enough work and testing to make certain observations about the design, both good and bad. The unit assembly went together without many problems. The assemblies mounted on the main chassis are easy to get to with the chassis extended outside of the tank. The wiring for auxiliary circuits terminates on a plate with oil tight feedthru's on either side of the tank. The plate seals to the tank from the inside and remains with the main chassis. The main chassis slides into the tank, the secondary ground is made up by multi-lam pins at the rear of the tank. The high voltage cable is plugged in from the top of the tank. The cathode and heater connections to the klystron are made through the side access/ viewing port, and then the port is sealed. The tank can be evacuated and filled with oil. It is a relatively simple process unless it has to be done too often during de-bugging stages.

The original plan was to fine tune the waveform at low voltage outside of the tank and relate waveforms from low voltage to high voltage. We have not had time to do this and therefore did our checking of the waveform at about 3 to 4 kV, 50 kV on the klystron in air but inside the tank. We therefore had to disconnect all of the cables and the klystron, to pull the main chassis, every time we wanted to make a change. In fact, the line is hard to fine tune as built. We can short turns, squeeze or lengthen coil spacing, or move turns between capacitors. Each step has been tedious. Furthermore, when we felt we had a good waveshape at this lower voltage, we sealed the tank to backfill it with oil. The capacitance added by the oil was enough to change the waveshape significantly. We still need to understand the relationship between the low voltage, air pulse and the high voltage oil pulse and the physical set-up is not conducive to easily making changes.

It appears that the primary discharge path is very low inductance and not a limiting factor in achieving a fast rise time. The limiting factors will be the pulse transformer leakage inductance and the transformer and load capacitance. Preliminary results show the klystron pulse rise time to be in the order of 300 nanoseconds from 10 to 90%. Tuning the line for overshoot and flatness is more difficult. A sample waveshape at about 350 kV is shown in Figure 3. The waveform has overshoot and the pulse is not as flat as desired. If we suppose that the waveshape could be flattened with almost no overshoot then the rise time would be as stated above. The DC power supply was delivering 14.8 kilowatts into the modulator. Using the same supposed waveshape as for the rise time the pulse with would be about 1.32 microseconds and the efficiency would be 67% plus the efficiency of the power supply. This agrees with our predicted overall efficiency of 63 to 65%.

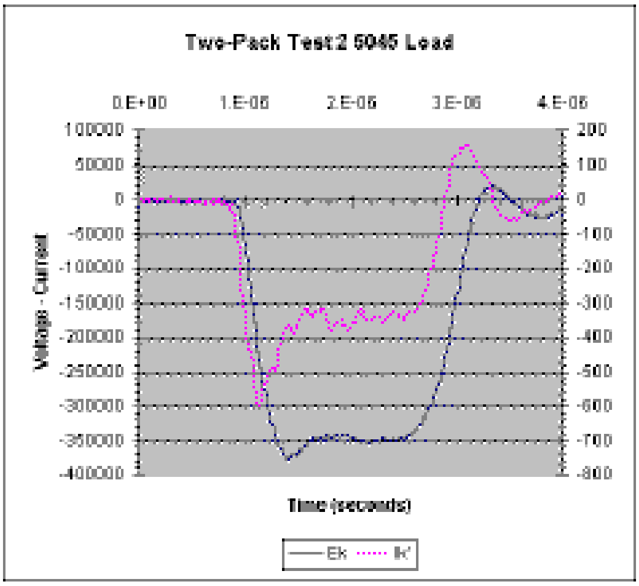

Figure 3. Initial Test Waveform

5. CONCLUSION

The Line-Type modulator still has a place in pulsing high peak power klystrons. For single tube pulsing it may still be the most economical modulator. Proper care in design and construction will enable the modulator to be more efficient. The inherent current limiting protection of this type modulator has successfully allowed tubes to survive gun arcs.

'Direct Switch' modulators have the advantage of the ability to dial in a pulse width and they are not dependent upon impedance matching although the pulse fall time is still dependent on the impedance of the load. As these type modulators continue to develop and be used with high peak power devices, such as klystrons, we will be better able to compare design merits.

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