NLC KLYSTRON PULSE MODULATOR R&D AT SLAC*

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Abstract

The basic elements of a klystron pulse modulator are: a charging supply, a PFN with energy storage capacitors, a thyratron switch tube, and a pulse transformer. The design group mentioned above is working on the system requirments of an NLC modulator, is carrying out tests on components, and building a prototype NLC modulator of conventional, but optimized design. A PFN using Russian K15-10 type high energy density glass capacitors has been constructed and tested into a conventional pulse transformer and klystron load. Rise time is less than 400 nsec. Developmental work with thyratron manufacturers is being started. Similarly, R&D pulse transformers developed in cooperation with industry are being tested.

1 KLYSTRON PULSE MODULATOR REQUIREMENTS OF NLC

An X-band 75 MW PPM klystron has been developed and operated successfully at SLAC. The present technical specifications for a two klystron pulse modulator assembly are listed below. These specifications change as the klystron design is optimized, so the NLC modulator design must be adaptable to these changes.

Parameters	Operating value
Beam voltage	500 kV
Beam current (2 kly)	530 amps
Pulse width (flat top)	1.5 μsec
Pulse rep rate (PRF)	120 PRF
Rise time (10 - 90%)	less than 400 nsec
Pulse Top Ripple	2%
Droop	2%
Primary charge voltage	up to 80 kV
Pulse transformer ratio	14/1

On the civil side of NLC planning, space is at a premium partly due to construction cost, so the pulse modulator and support electronics must be designed to fit in a modest size area, be compatible with the RF delivery waveguide layouts, be energy efficient, and allow for effective servicing during operation. We categorize these requirements in three general classifications:

- Ergonomic design
- Reliability & Maintainability
- Power Efficiency

1.1 Ergonomic design

In the NLC system design, the klystron modulator is recognized as just one component of the general RF delivery system which must mate smoothly with other parts of the complex. Fig. 1 shows an initial configuration of a two klystron-modulator assembly in which all pulsed high voltage components are housed in a cylindrical oil tank which also mounts the two klystrons. Except for the thyratron and its carrier which can be changed in place, all other servicing including klystron and modulator component replacement is done at a depot after the whole two tube assembly is removed from the housing location. The term "ergonomic design" refers to the need in the design phase to consider what components will fail, how accessible are these components for replacement, and what diagnostics will be put in place to detect and identify fault conditions preferably before they do collateral damage.

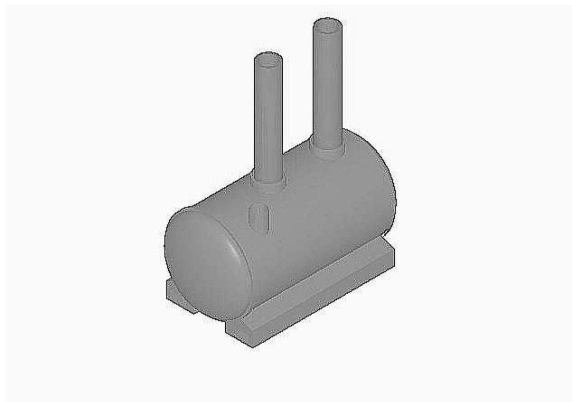


Fig 1. Klystron & Modulator Assembly

1.2 Reliability & Maintainability

The NLC design contains over 2,000 pulse modulators. While some M of K redundancy will be used in the system design of the RF power sources, individual RF power sources including the modulators will have to have very high MTBF ratings, well over 12,000 hours. Similarly, failed units must be capable of being changed out and the station put back on line quickly, ideally in less than 4 hours (MTTR - Mean Time to Repair). Quick changing of whole klystron-tank assemblies and depot repair help to keep MTTR low. Even in the depot, though, the hours to diagnose, disassemble, repair, and retest the klystron-modulator assembly must be kept low to minimize the size of the sustaining maintenance organization.

1.3 Power Efficiency

Electricity is a major operating cost of the NLC. The overall power efficiency from 480 volt input to usable klystron electron beam must be maximized to minimize operating cost. Keeping the charging power supply and modulator systems simple can produce high efficiency designs. Some areas, cathodes, have inherent inefficiencies. A klystron load is not a true resistance, but a perveance (non-linear) which cannot be matched during rise and fall times of the drive pulse. Beam current during rise time is not usable for producing RF, and thus represents an energy loss which can be minimized with faster rise time. The whole pulsed high voltage system has stray capacity which must be charged and discharged each pulse. All these are energy loss mechanisms which must be taken into account in the modulator design.

2 TEST BED CIRCUIT AND COMPONENT DEVELOPMENTS AND RESULTS

A high voltage modulator tank and test position in the Test Lab at SLAC has been modified into a Test Bed for NLC components. Figure 2 is a picture of the oil tank showing the thyratron, PFN and pulse transformer being tested. Figure 3 is a simplified schematic of the test circuit.

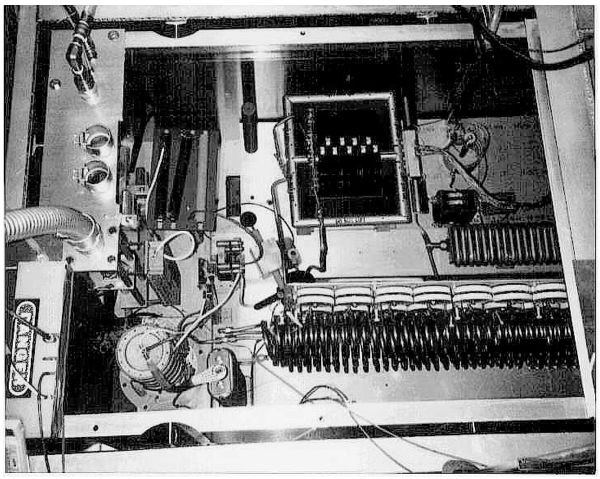


Fig 2. Test Bed for NLCModulator

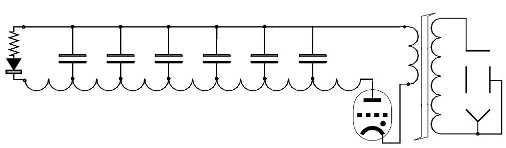


Fig 3. Test Circuit Schematic

The components to be studied for development and optimization for an NLC modulator are the PFN with its associated capacitors, the pulse transformer and the high voltage switch, which is still envisioned as a thyratron. The initial purpose of this development is to physically realize a simple, reliable modulator design which will meet the basic requirements of the NLC. The NLC modulator requirements are still evolving as an interdependent part of Klystron development, pulse compression and the high power RF ransmission system and the overall Linac tunnel construction.

2.1 High Energy Density Pulse Capacitors

The PFN under test is comprised of high energy density glass capacitors which are manufactured in St. Petersburg, Russia. These capacitors are made from a crystaline glass with a dielectric constant of 1000 and have a standard value of 10nF @ 40kV. A single capacitor, approximately 4î in diameter and æî thick including end connections, is shown in Figure 4. Two capacitors are placed in series to get to 80kV. The PFN has to store approximately 500 joules to deliver a pulse for two 75MW klystrons. The PFN will be made up of 40

Fig 4. Russian K15-10 Glass Capacitor

capacitor sections of 5nF each. The first testing of this configuration will be four parallel lines. Each line will have ten sections and an impedance of approximately 19.3 ohms, for a total PFN impedance of 4.8 ohms. The PFN coils are designed with mutual inductance to help flatten the pulse top. See Fig 5.

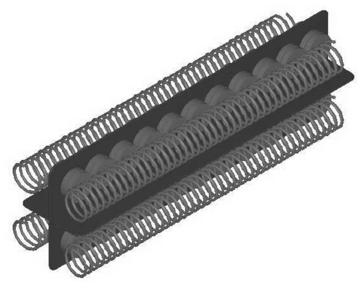
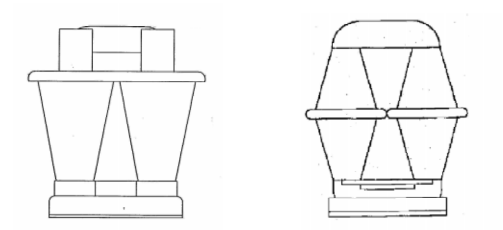


Fig 5. Four Parallel PFN Configuration

It is anticipated that a tuning method at low voltage will be studied to eliminate the need for high voltage hot tuning of the modulator. This also means that klystron variations will be minimized and klystrons will be installed in matched pairs.

2.2 Pulse Transformer Designs

The pulse transformer is one of the more critical elements of the modulator. The transformer leakage inductance and distributed capacitance are often the limiting factor in pulse rise time. Much of these characteristics are controlled by the physical geometry of the transformer. The geometry is dictated by voltage standoff and cross sectional core area required. Stangenes industries designed a 14:1 pulse transformer of standard configuration. This transformer is designed with higher voltage gradients and is therefore smaller than previous models. The outline of this transformer is shown in Fig 6a. Northstar Research has designed a double basket transformer depicted in Fig 6b.



a) Conventional b) Double Basket

Fig 6. Pulse Transformer Outlines

Preliminary tests using the Stangenes Industries conventional pulse transformer and a standard 5045, 15:1 ratio, pulse transformer are compared in Fig 7. As seen both the rise time and fall time of the output pulse are greatly improved and approach the base NLC requirement.

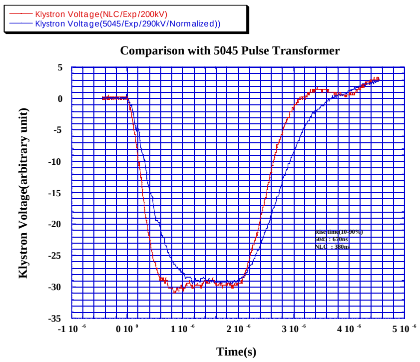


Fig 7 Transformer Beam Pulse Comparison

We are planning test and analyze the Northstar Research double basket transformer configuration in the same circuit and make a direct comparison of the two design approaches. Prior to these tests, the test bed layout will be reconfigured to minimize loop inductances and control noise. Future pulse transformer development plans include investigating other core materials and stripline transmission line transformers.

2.3 Thyratron Developments

The thyratron remains as the most stable choice for the high voltage switch at this time. Thyratrons already exist which meet the voltage and current handling characteristics required, namely 80kV and 10kA. There are three major thyratron manufacturers in the western world and all three are aware our basic requirement. Long history with the SLC at Stanford Linear Accelerator Center has shown the thyratron be one of the more frequent failures for the modulator assembly. The reliability of the NLC is an integral part of the design and therefore even in the first cut early stages components and assemblies are being assigned values for MTBF. The required thyratron MTBF is 50,000 hours. This is a factor of five+ over the existing SLC thyratron. We plan to continue to work with the manufacturers in their development of a low cost, more reliable thyratron. Another factor in operating the large number of modulators and thyratrons is to eliminate the need for thyratron ranging (adjusting of the reservoir voltage during thyratron lifetime). EEV proposes a scheme, which they have used successfully, to pre-pulse grid 1 instead of using DC to initiate a plasma at the cathode. We plan to set up this pre-pulsing arrangement in the Test Lab with thyratrons from different manufacturers to test and optimize the effects. Future advances in stacked solid state switches with regard to power handling, di/dt and reliability may in time make them the choice to replace the thyratron.

2.4 High Efficiency, Capacitor Charging Supplies

Physical size of the high voltage charging supply will also have a large impact on the NLC design. The power supply system needs to charge the PFN to approximately 80kV at a repetition rate of 120 Hz. The PFN capacitance is 200 nF. It is desirable that the entire charging system fit into a 19” rack cabinet and be as small as practical. There are existing capacitor charging power supplies commercially available at lower voltage and power levels. This technology needs to be expanded to the NLC requirement. There are also multiple schemes for pulse charging of the PFN which require further investigation. The power supply community is being encouraged to develop supplies that will meet our requirements

3. DEVELOPMENT PROGRAM PROJECTIONS

We are currently projecting NLC modulator development work for the next eighteen months. We have two operational test areas, one in the Klystron Test Lab, and a second in the fourth modulator position of the NLCTA (End Station B - SLAC).

3.1 NLCTA Prototype Operation

The prototype klystron & modulator assembly shown in Fig. 1 will be completed in design and assembled in the Klystron Test Lab. After the usual testing, characterization, and shakedown, it will be installed in NLCTA and begin operational running to collect lifetime data for both the modulator, power supply, and klystrons.

3.2 Component Development with Industry

In the Klystron Test Lab, the more open test bed as shown in Fig. 2 will continue to be used to test various capacitor and PFN configurations, optimized pulse transformer designs, and when they become available from manufacturers, prototype long life thyratrons. The secondary systems associated with modulator and klystron operation will be developed and optimized for low cost production Participation of industry will be most important as in all of these areas, the quality, longevity, and cost of the components and sub-systems available will determine the configuration of the final modulator design. Even though we have adopted a very simple, conventional design for the prototype NLC modulator, there is still time to consider other ideas that could lead to a lower cost, higher efficiency, and more reliable design. We will work with interested parties on any promising developments.

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