

## SLC Positron Source Flux Concentrator Modulator\*

J. de Lamare, A. Kulikov, R. Cassel, V. Nesterov  
Stanford Linear Accelerator Center, Stanford CA 94309

### Abstract

The modulator for the SLC  $e^+$  source flux concentrator provides 16 kA in a 5  $\mu$ s sinusoidal half wave current for a pure inductive load, at 120 Hz. The modulator incorporates 10 EEV CX1622 thyratrons in a switching network. It provides reliable operation with acceptable thyatron lifetime.

### I. DESIGN CONSIDERATIONS

Stanford Linear Collider (SLC) is an accelerator which collides electrons and positrons for particle physics research at SLAC. Such a collider requires a high yield positron source (See Reference 1 for details). The flux concentrator is a pulsed magnet that produces a focusing solenoidal magnetic field to effectively capture positrons emitted from an electron beam target (Figure 1). Positron production and capture are discussed in Reference 2. The production of a high magnetic field in the flux concentrator (up to 5.8 Tesla) requires a current pulse of 16 kA. The flux concentrator modulator provides 16 kA pulses at 120 Hz to the magnet.

Another design consideration is the system inductance. The inductance of the flux concentrator is approximately 1  $\mu$ H. A more detailed description of the flux concentrator is elsewhere in these proceedings (Ref. 3). The low inductance of the magnet requires a low inductance driver to meet the system's pulse requirements. The magnet's low impedance makes efficient energy transfer to the flux concentrator difficult.

### II. MODULATOR DESIGN

The flux concentrator modulator has four modules all of which charge by the same charging system composed of a high voltage power supply, a charging capacitor, and a charging inductor. Each module has two parallel charge and discharge paths. There are two forward thyratrons and one pulse cable per module. Also, two of the modules also have reverse thyratrons. There are four water cooled resistors, one per module. The four modules operate in parallel to supply the full current to the flux concentrator. The total modulator is approximately 1.5 m x 3 m x 1.5 m, and is in an interlocked high voltage room.

Because the flux concentrator modulator design requires a high current pulse into an inductive load, the system inductance was kept to a minimum. This was accomplished by building wide current paths while minimizing the current loops. Each module has a low impedance, 14  $\Omega$ , pulse cable. These cables are 15 meters long, and they are connected in parallel at the load. Creating several parallel paths reduces the system inductance and limits the average current requirements of many components; thus increasing the system reliability.

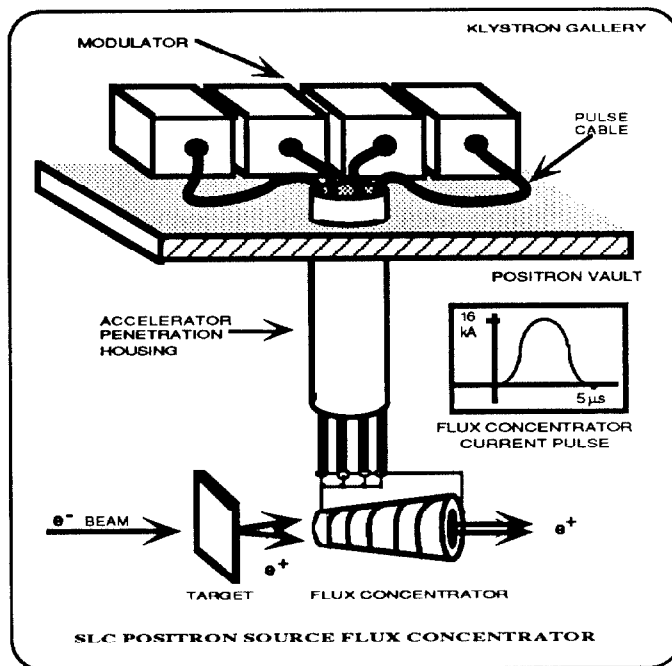


FIGURE 1: Positron Source

### III. MODULATOR OPERATION

The basic modulator design is shown in Fig. 2. A 5 kV, 15 kW power supply charges the charging capacitor. This capacitor resonantly charges the parallel modulator capacitors through the charging inductor. There are eight parallel charging paths in the modulator through eight parallel charging diodes. The charging path continues through the modulator capacitors to ground via the pulse cables and the load. Each modulator capacitor has a switch to ground. These switches are EEV CX1622 thyratrons, called forward thyratrons. The forward thyatron grids are pulsed simultaneously by a grid driver. This output pulse drives a pulse transformer with eight secondaries, one per forward thyatron. Nanosecond switch jitter is ignored since the modulator current pulse is several microseconds in duration. When the forward thyratrons are switched, the positive high voltage side of the modulator capacitors are brought to ground potential, thus the parallel side of these capacitors becomes negative high voltage, and a current path is created from the modulator capacitor through the thyatron, and the load, then back to the modulator capacitor.

Before the voltage on the parallel side of the modulator capacitors swings positive, another thyatron is triggered. This tube is the reverse thyatron. Its purpose is to act as a diode such that when the voltage on the parallel side of the modulator capacitors swings positive, some of the returning energy will be dissipated through the water cooled resistor.

\* Work supported by US Department of Energy contract DE-AC03-76SF00515

Oscillographs of the thyatron currents are shown in Data 1. It is necessary to dissipate some of the returning energy, because after the forward thyratrons recover they are reverse biased by the modulator capacitor. EEV recommends that these thyratrons are not reverse biased above 10 kV for the first 25 microseconds after the anode pulse, because this can cause reverse conduction in the thyatron and thereby damage the tube.

After the discharge cycle is completed, the charging cycle begins again. The energy remaining in the modulator capacitors together with the energy transferred from the charging capacitor combine to swing the modulator capacitor voltage from negative to positive as seen in Data 2. The oscillograph shows the current and voltage of the charging inductor at the anode of the charging diodes. The net modulator voltage is the inverse of the recovered voltage plus twice the power supply voltage. Because the modulator recirculates some of its energy, the make-up power required from the supply is reasonable.

In series with the forward thyatron is a saturable inductor with an unsaturated inductance of  $10.5\mu\text{H}$ . Because of the mismatch between the impedance of the load and the pulse cables, reflections occur up and down the cables adding an oscillation on top of the load current. The oscillations are seen on the flux concentrator current pulse at 12 kA in Data 3. The saturable inductors help to minimize these oscillations by initially slowing the rate of rise of voltage across the load.

#### IV. MODULATOR PERFORMANCE

The modulator has been in service since October 1989 and has 7400 hours of operating time. Thyatron lifetime has proven to be longer than expected. To this point the average thyatron lifetime in the system has been 3700 hours and  $1.6 \times 10^9$  shots. These thyratrons have been operated at levels well below the manufacturer's specifications (See Table 1). The thyratrons show signs of aging by failing to recover after

firing (latching). For the modulator to recover from a latching thyatron, the power supply is inhibited for one second when a latching current is detected. This gives time for the thyatron to recover. Then, the power supply is enabled, and the modulator returns to its normal operating levels. This recovery method is automatic, because latching may occur several times per day when the thyratrons are near their end of life. Generally, all thyratrons are replaced simultaneously so they age together.

#### V. INTERLOCKS

The whole positron system is comprised of several interlocks, many of which are attributed to the modulator. Besides the personnel safety interlocks, there are also interlocks for equipment protection. These include: a water flow interlock for the water cooled resistors, an over-current interlock that monitors the input current of the power supply, a frequency interlock to protect the flux concentrator from being pulsed at its mechanical resonance, and a crowbar interlock to protect the modulator from excessive charging current and charging voltage.

#### VI. CONCLUSIONS

A modulator for the SLC positron source flux concentrator is presently in operation at SLAC. This modulator has thus far operated at 12 kA for 7400 hours at 120 Hz and can operate at currents up to 16 kA. The modulator's switches, EEV CX1622 thyratrons, have given an average lifetime of 3700 hours and  $1.6 \times 10^9$  shots.

#### VII. ACKNOWLEDGEMENTS

We would like to thank Scott Hewitt for his dedicated efforts in support of this project, as well as John Krzaszczak and the AMSS crew for their assistance in the maintenance of the modulator.

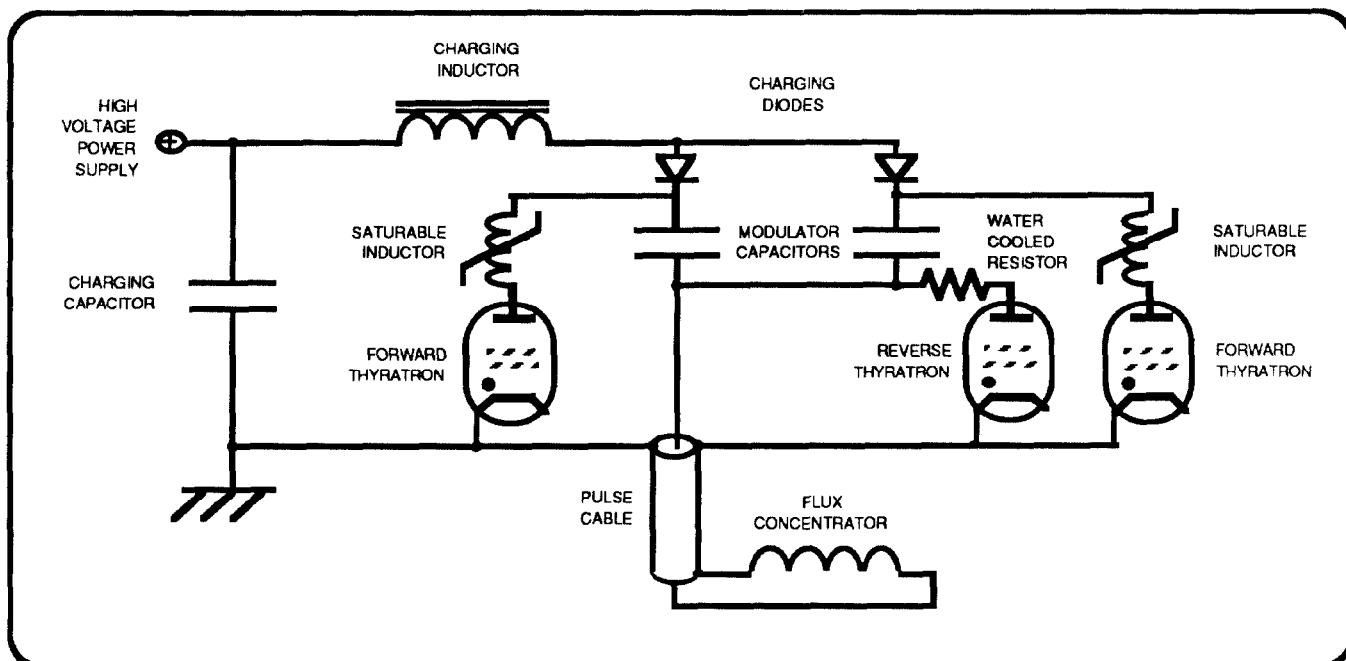


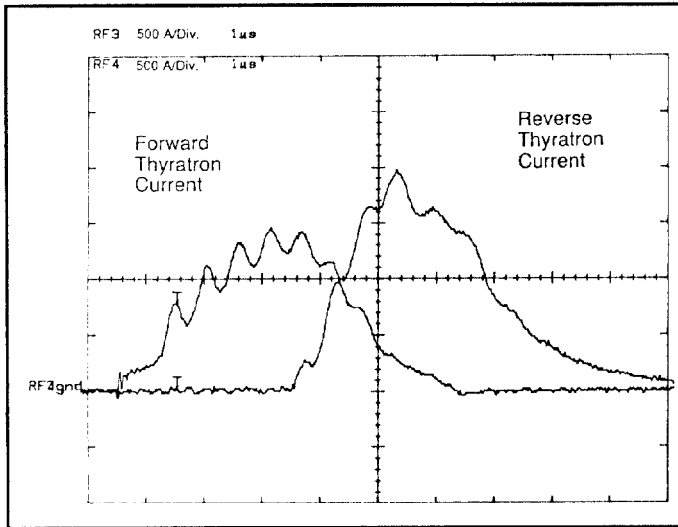
FIGURE 2 : Simplified 1/4 Modulator Schematic

SPECIFICATIONS	MFG.	FRWD. THYR.	RVRS. THYR.
Peak frwd. anode voltage	35 kV	20 kV	--
Peak rvrs. anode voltage	10 kV	12 kV	--
Peak anode current	5.0 kA	2.0 kA	3.0 kA
Average anode current	1.25 A	0.76 A	1.15 A

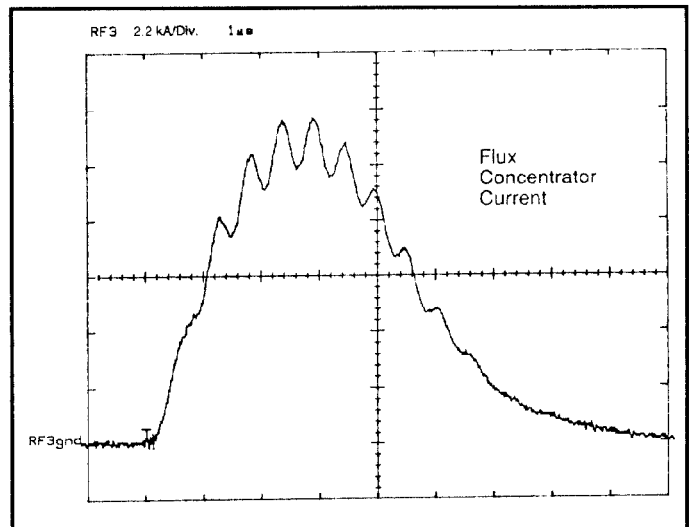
Table 1: Thyatron specifications with operation levels.

## VIII. REFERENCES

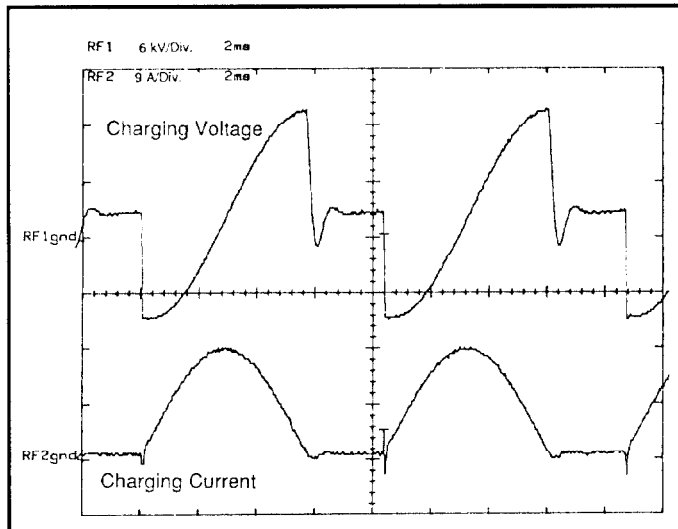
1. F. Bulos, H. De Saebler, S. Ecklund, R. Helm, H. Hoag, H. Le Boutlet, H.L. Lynch, R. Miller, K.C. Moffeit, "Design of a High Yield Positron Source," IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, Oct. 1985, pp. 1832-1834.
2. S. Ecklund, "Positrons for Linear Colliders," SLAC-Pub-4484, November 1987
3. A.V. Kulikov, "SLC Positron Source Flux Concentrator," These Proceedings



Data 1: Thyatron Current



Data 3: Magnet Current



Data 2: Charging Waveforms