A 40-KILOVOLT, 125-AMPERE HARD TUBE MODULATOR FOR ACCELERATOR SERVICE*

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Summary

A hard tube modulator designed to generate a 40-kilovolt pulse at 125 amperes for 2 milliseconds at 6% duty factor has been constructed. The rise and fall times will be controlled and the flat top regulated to program requirements. The Machlett ML-LPT 14 was used for the switch tube in this application utilizing magnetic focusing with a coarse grid structure and multiple cathode beams to achieve low grid drive with high plate efficiencies. Low grid drive allows simplification of the drive to one tube driven directly from the rectified rf control signal. The rf control signal at 4.8 Mc is coupled across the high voltage interface through a ferrite core transformer.

Modulator Function

A plate modulator was required for the 805 Mc power amplifier for the following reasons:

1. To obtain 1-1/4 megawatts power output during the pulse the plate voltages must be pulsed to higher values than can be tolerated on the Coaxitron anode continuously.

2. For the Coaxitron to operate stably at 805 Mc/s the plate voltage pulse must be terminated before the grid drive pulse is terminated.

3. The flattop portion on the anode pulse must be regulated during the pulse to allow for beam loading and other perturbations.

4. It must be possible to terminate the anode pulse in event of a fault without crobarring the capacitor bank.

Design Specifications

The initial design specifications were 40 kilovolts at 125 amperes output for 2 milliseconds at 6% duty factor. This allowed for maximum variation for both plate voltage and plate current for the A15191 Coaxitron then under development.

Circuit Considerations

The design requirements and specifications eliminate the use of either line or magnetic modulators. Hard tube modulators were not attractive because all existing switch tubes had one or more of the following shortcomings:

1. Excessive grid drive requirements.

2. Positive grid current flow during portions of the grid voltage swing resulting in instability or loss of grid control of the plate current.

The grid drive requirements for a switch tube can be minimized either by electrostatic or electromagnetic focusing of the electron beam to reduce the portion of the cathode current captured by the grid structure.

Electrostatic focusing has been successfully employed in the RCA 15034 and the Machlett ML-6544 series tube.

A magnetically focused, sixty megawatt switch tube was reported by Machlett Laboratories[1] at the Symposium on Hydrogen Thratrons and Modulators in May of 1964. H. D. Doolittle, C. Kirka and J. A. Randmer expressed an interest at that time of developing a scaled version for use in the LAMPF test facility.

Positive grid current can be reduced by focusing to minimize grid heating, using large grid wires to dissipate what heating does occur, keeping any material which might cause secondary emission out of the grid or its support system, and keeping positive grid voltage required to a minimum.

The initial cost of the modulator system could then be reduced perhaps by a factor of 5 with a suitable switch tube. This would allow elimination of switch tube bias supply shorting tubes, grid resistor shorting thyratrons at the end of the pulse, and simplification of driver components on the high voltage deck.

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Switch Tube

Machlett proposed at type LPT-14/ML-8618 with typical operation:

DC Plate Voltage	50	kV
Pulsed Output Voltage	47	kV
DC Grid Voltage	-4500	v
Pulse Positive Grid Voltage	1300	v
Pulse Plate Current	125	a
Pulse Grid Current	1.8	a
Pulse Driving Power	10.5	kw
Pulse Output Power	5.9	Mw
Duty Factor	.06	

Pulse Drive Power

The pulse driving power as indicated on tube data sheets is often misleading because it is calculated as

$$P_{drive} = (E_{g1\,max} - E_{g1\,co})\, I_{g1\,max}$$

where $E_{g1\,max}$ = Pulse positive grid voltage
$E_{g1\,co}$ = DC grid voltage for cutoff
$I_{g1\,max}$ = Pulse grid current

For the LPT-14 this is indicated above as 10.5 kw. For a rectangular pulse the actual pulse driving power required is

$$P_{drive} = (E_{g1\,max})(I_{g1\,max}) + (E_{g1\,max} - E_{g1\,co})^2/R_{g1}$$

where R_{g1} is the effective grid to cathode dc resistance during the pulse.

For the limiting case where the value of R_{g1} is infinite the total driving power would be

$$P_{drive} = (1300)(1.8) = 2.34 \text{ kw}$$

For a practical case where the value of R_{g1} = 10k

$$P_{drive} = 2.34 + (1300 + 4500)^2/10000 = 5.70 \text{ kw}$$

For other than a rectangular pulse a graphical integration of the tube characteristics would be required.

The limits of R_{g1} are set on the low end of the power consumed from the driver, and on the high end by the required decay time on the end of the pulse. Instability may become a problem with large values of R_{g1} if the total capacitance of the switch tube grid to ground is allowed to become too large. The driver deck "floats" at the switch tube grid potential and may total 1000 mmfd.

Circuit Stability

Large power systems are prone to oscillate in the 0.5 to 2 mc region when pulse modulated because the reactive components of current to voltage during switching can be several times greater than the steady state in phase components. The switch tube grid voltage can approach 90 degrees phase difference from the cathode voltage so that very little additional phase shift is required from reactive components either in the cathode or in the driver to cause oscillations on the rise and fall of the output pulse.

Effect of Magnetic Focusing

The characteristics of the LPT-14 with no magnetic field applied are comparable to tubes of conventional design.[2] Machlett supplied the following tabulation with and without the field for a common operating point of 100 amperes plate current with tube drop and positive grid drive voltage being identical for both test conditions.

	Magnetic Field	No Field
Peak Plate Current	100 a	100 a
Tube Voltage Drop	3 kV	3 kV
Positive Grid Voltage	1050 v	1050 v
Grid Current	1.2 a	35 a
Total Cathode Current	101.2 a	135 a

The LPT-14 is shown with its associated anode magnet and water jacket in Fig. 1. The completed assembly is shown in Fig. 2.

Driver

The modulator circuit is shown in Fig. 3. A single 4CX50000A3 is driven by the rectified 4.8 Mc/s pulse. The 4.8 Mc pulse is carried through the high voltage interface with a ferrite core transformer.

The interface transformer core is an Allen-Bradley R-02 ferrite toroid 3" I.D., 4-3/32" O.D., 2" long. The primary and secondary are each a single turn of stripped RG-8U. No significant loss was observed at 200 watts through the transformer for 2 milliseconds.

The rectifiers were Fairchild FD-200. The rectified pulse was 200 volts across 24 k in the grid circuit of the 4CX5000.

Total power gain of the modulator is 3.55×10^6.

All modulator parts for the switch tube, ferrite core, and FD200 diodes were salvaged from the White Sands Nike-Zeus installation.

Experimental Results

The modulator performed as prescribed on first turn-on and was run to 37.5 kV plate voltage with a 32 kV output pulse at 120 amperes with a 200 microsecond pulse length at 30 cps. Lack of an adequate dummy load limited total duty factor that could be tested.

The modulator was run on the Coaxitron at 21 kV output at 94 amperes with a 1 millisecond pulse length at 30 cps for a 3% duty factor.

The fundamental principle of magnetic beam focusing has proven sound for switching 3.73 megawatts with only 10 kw grid drive. The tube is undergoing further development to eliminate internal problems associated with the tube fabrication.

Acknowledgements

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References

[1]H. D. Doolittle, H. Langer, J. A. Randmer and B. Singer, "A Sixty Megawatt High Vacuum Pulse Modulator Tube", Eighth Symposium on Hydrogen Thyratrons and Modulators, May 1964.

[2]Private Communication, C. Kirka, Machlett Laboratories, January 18, 1965.

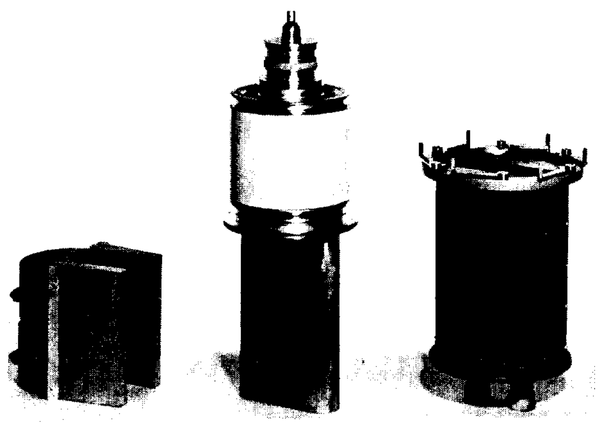

Figure 1.

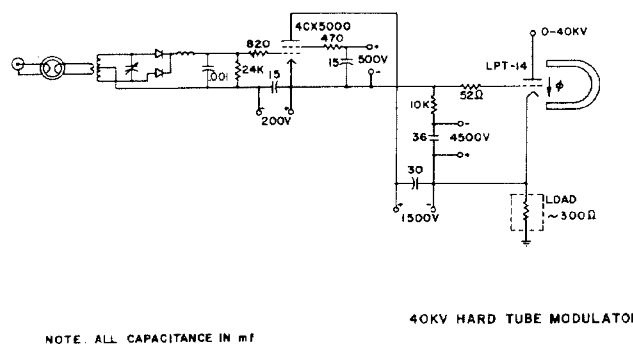

Figure 3.

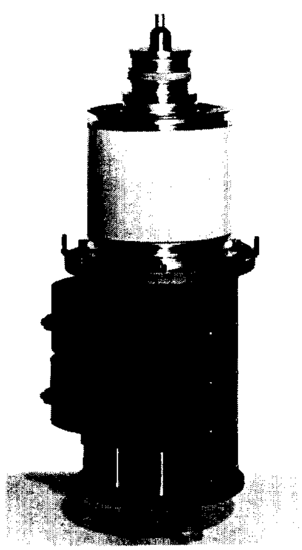

Figure 2.

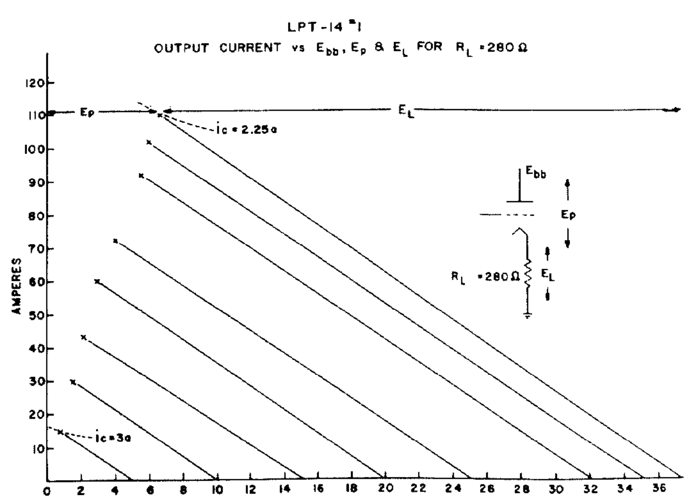

Figure 4.