HIGH VOLTAGE SWITCH PERFORMANCE OF THE EIMAC X-2159 TETRODE

by

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ABSTRACT

High Power Tetrodes designed as RF power amplifiers often times have excellent characteristics that enhance their performance when used as switch tubes. This paper reports on the test and evaluation of one such high power tetrode, the EIMAC X-2159. This tube has a design anode dissipation rating of 1.25 megawatts average power and the cathode grid and screen have very substantial ratings. The objective of the test was to determine the maximum achievable pulsed power with this tube. One main data point of interest was a pulsed current of 1000 amperes - 10-20 microseconds and 50 KV hold-off. This point has been achieved. Further testing is planned to fully evolve the limits.

Problems encountered included secondary emission causing the load pulse to increase in length as if it were a function of primary emission from grid. Other features of the tube to be discussed will be the ability to interrupt a faulted load current pulse and its overall operating stability.

Introduction

Purpose of this program is to determine the maximum power handling ability of the EIMAC X-2159 Tetrode. The maximum reliable anode voltages and current are to be determined over a number of pulse lengths and repetition frequencies. Of particular interest is pulsewidth up to 1 (one) millisec at duty factor up to 0.01. Mode of operation is to seek the maximum pulse current for the minimum anode voltages by varying the load resistance, grid voltage, screen voltages and filament voltage. No attempt is being made to exercise the tube as a regulator or be modulated with any waveform other than a rectangular pulse. Because of some of the problem areas identified with secondary electron emission, these types of operation must be considered in greater detail.

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High Power Tetrodes designed as RF power amplifiers often times have excellent characteristics that enhance their performance when used as switch tubes. This paper reports on the test and evaluation of one such high power tetrode, the EIMAC X-2159. This tube has a design anode dissipation rating of 1.25 megawatts average power and the cathode grid and screen have very substantial ratings. The objective of the test was to determine the maximum achievable pulsed power with this tube. One main data , point of interest was a pulsed current of 1000 amperes - 10-20 microseconds and 50 KV hold-off. This point has been achieved. Further testing is planned to fully evolve the limits.

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Considerable data has been taken to date but unfortunately a mechanical failure in the regulator for the high voltage supply has caused a delay in achieving the maximum levels the tube is conceptually able to handle. Enough data has been taken to highlight some particular problem areas to be considered in using the tube. These will be covered in detail.

Grid Circuit

The basic pulser scheme shown in Figure 1 utilizes a 4CW100000E Tetrode driven by a Cober Electronics Mod 604 Pulser. It would seem that it is a bit "overkill" to use a tube which has an average anode dissipation rating of 100 kilowatts to drive a tube which has a anode rating of 1.25 megawatts. Although a smaller tube should be able to provide adequate drive, a 4CW100000E was used because of uncertainty of the maximum drive current required to keep a net positive grid current flow during the pulse. The driver tube is run as a cathode follower with its bias supply and screen voltage supply floating at some voltage above ground but referenced to its' cathode. Isolation for the Cober pulse driver is provided within the unit itself which has internal floating circuitry of bias supply current for isolation of either output level to 2500 VDC. Figure 2 is a photograph of the tube in the test set.

Grid Circuit Regulation

Realizing that it was essential to maintain a low grid input impedance in order to maintain stability under any drive condition, the driver stage for this test was initially loaded with 50 ohms of low inductance type resistance. Operation appeared to be satisfactory until screen voltage of about 1500 volts and grid voltage 200-300 were reached. At these levels the anode current pulse tends to stretch out and the grid current reverses to a negative direction at the end of the pulse. Stretching out of the anode current pulse usually is caused by primary emission from the grid because of overheating. Under the test condition however, the average power supplied to the grid was only about 20 watts; far below maximum rating of tube grid. Apparently at the point where the screen voltage was beginning to affect the grid current, the secondary electrons were beginning to be accelerated away from the grid by the screen. In the presence of the normal forward drive voltage the negative grid current was suppressed but at the end of the voltage pulse flat top, the grid goes toward cutoff and in doing so passes through the region where secondary voltages are easily emitted. These secondaries thus created a new driving pulse that kept the tube turned on. At this point, the driver stage was loaded with a total of 20 ohms resistance in parallel with the grid. The negative grid current spike was greatly reduced and plate current stretchout was virtually eliminated. Figure 3 shows the effect of screen voltage at 1700 volts prior to extra loading of the grid.

Without some way of regulating the bias voltage to the tube grid intercept electrons, the bias voltage will increase in proportion to the intercepted positive grid current. One could use (1) sturdy zener diodes (2) a fixed resistor drawing heavy current at all times (3) an electronic shunt regulator (4) a simple, yet rugged, "soft" regulator, able to absorb any increased voltage arising from grid interception yet not draw heavy shunt currents when the tube is not pulsing. A simple form of the "soft" type of regulator was found in a series of varistor disks made by General Electric. Six (6) each of the 150 VDC disks rated at 10 watts each were connected in series for a continuous current of 20 milliamperes of bias supply current when the X-2159 was not pulsing.

Anode Circuit Transient Suppression

A problem of considerable magnitude was that of controlling the induced voltage in the power supply-anode-cathode circuit which includes the energy storage capacitor bank. The rate of rise of current in the anode circuit is in the order of 1000 amperes/microsecond. Because of an excessive amount of inductance in the HV lead connecting the anode to the capacitor bank and its' return path, the anode plate voltage and current had a poor transient response.

Connecting the tube to the load capacitor bank with coaxial cable and adding an additional snubbing network directly at the tube anode helped make the transient response of the system manageable. Using the open bus type system, the anode voltage would rise to several times greater than the DC value at the end of the pulse causing anode breakdown. Figure 4 and 5 are photographs of anode voltage waveforms. The first is with the tube pulsing a resistive load while the second photo is with the load shorted. This latter one shows the transient effect of the circuits inductance quite clearly. An additional effect of inductance in the anode circuit is to cause the anode voltage to be momentarily reduced to near zero voltage until current builds up at the beginning of the pulse. This sudden drop in anode voltage causes the screen circuit to react by drawing heavy screen current until the anode voltage rises again to the level determined by the operating parameters of the tube. At this point the load should be mostly resistive and the pulse current essentially flat topped.

Protection Schemes

To protect the tubes from the effects of arcing, an open air type crowbar was used to discharge the capacitor bank and divert the power supply follow through current. Signals to trigger the crowbar were derived from (1) a current transformer in series with a spark gap connected between the screen and ground (2) an anode voltage sensing circuit consisting of a back biased diode and a small capacitor in series connected between anode and ground.

(3) bias failure circuit (4) excessive DC cathode current and (5) screen voltage interlock system.

Anode Voltage Level

The data sheet from the manufacturer lists the hold-off voltage as 40 KVDC. We have hipotted the tube to 90 KV. Eimac has had similar results in hipotting. Unfortunately this does not appear to be a safe operating voltage. The maximum anode voltage one could expect to operate is about 60-65 KVDC. The X-2159 has slightly over 1 cm of spacing between the anode and screen grid so at 60-65 KVDC arc-over could be expected under operating conditions. This voltage could be subject to the current loading also.

Determining the minimum anode voltage for maximum anode current has been somewhat of a problem. It appeared for awhile in the test that our data was following fairly closely with the test data taken by Eimac on the tube. After an extended shutdown period for repair of the regulator, the anode voltage during the pulse always appeared higher than our previous test indicated by about 3-8 KV. Suspecting that the calibration of voltage divider and current transformer were the problem, they were rechecked. Next the load was shorted out and a low current supply was used in place of the larger supply to charge up a large capacitor. This capacitor's voltage could then be measured more accurately with a precision meter as well as with a scope and HV probe. The results in this test were essentially the same i.e., the anode drop appeared to be too high.

The problem has not been resolved as yet. It is suspected that a shifting has taken place somewhere in the tube or that some other damage has occurred. The confusing thing is that the same levels of anode current can be achieved and voltage hold-off does not appear to have deteriorated.

A second tube is to be installed and tested to see if the same conditions exist.

Test Results

The following table gives some typical data points taken. The figures at the top of the table indicate earlier readings.

E_{bb} KV	I_{AVG} AMP	I_{PEAK} AMP	E_b KV	E_g VOLT	E_s VOLTS
40	5.39	680	4.8	225	1650
36	4.7	600	3.7	200	1500
29.5	3.4	440	5.7	200	1100
48		800	9.2	380	1500
51		1000	4.3	400	2050
51		1080	3.4	450	2300
60		1280	12.4	600	2400
60	8.2	1320	17.7	600	2400
		(1200)	9.2	340	2200

Maximum peak power switched has been up to 80 MW and average up to about 400 KW. Pulse lengths of 400 microseconds have been achieved at peak currents of 1000 amperes.

Conclusions and Recommendations

Although we have not conclusively determined what the expected anode voltage drop during the pulse is, it probably is about 5 KVDC at 1000 amperes pulse current. This is based on the output spacing of the tube and data taken at RADC and Eimac. To achieve this level the screen current is getting fairly high, 5-10% of the anode current The screen dissipation rating is adequate however so the screen primary emitter should be no problem. Another point to consider is secondary emission of electrons and resulting negative grid currents. Heavy grid circuit loading is necessary for stability.

Further testing to fully establish the maximum power that can be switched and the minimum anode drop will be performed as soon as our HV power supply is repaired at which time a full report will be available.

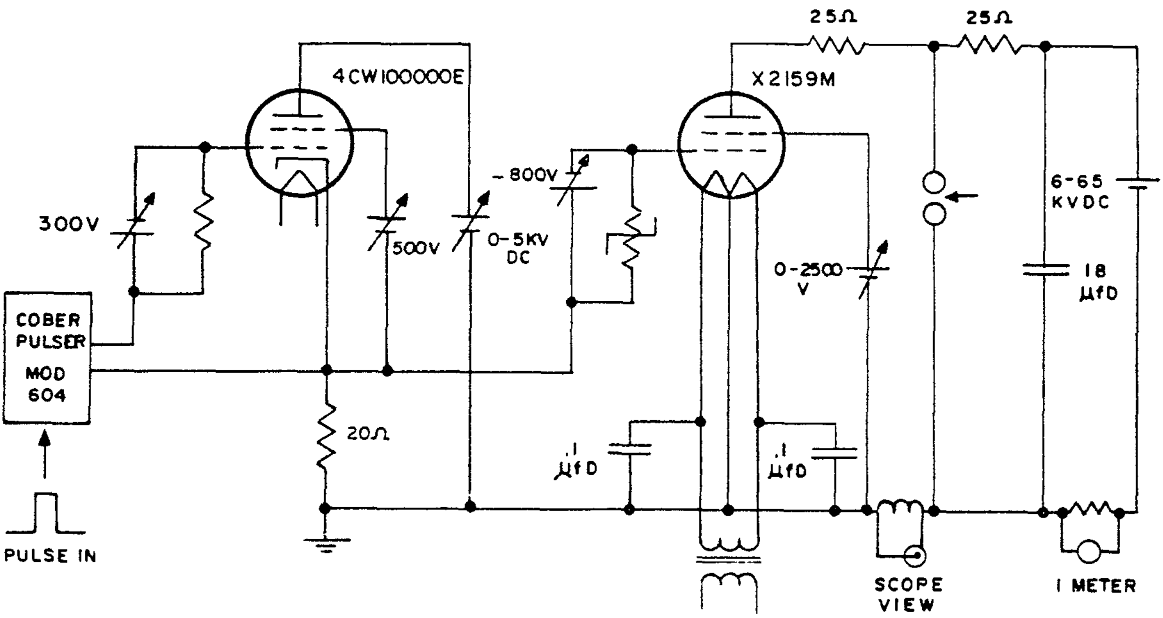

Figure 1. Simplified Schematic of Pulser

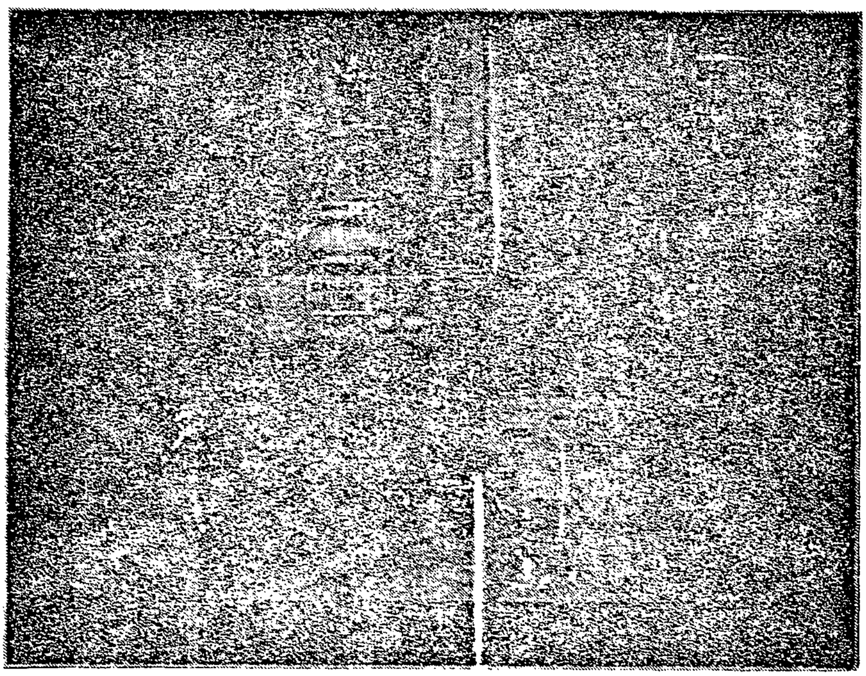

Figure 2. Photograph of Tube and Pulser

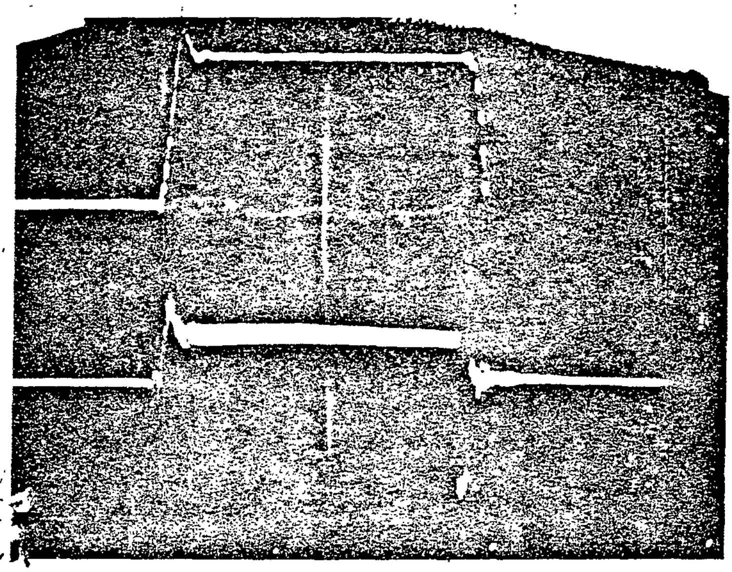

Figure 3. Negative Grid Current Spike at Pulse Tailend (Bottom) and effect on Anode Current Pulse (Top) Time: 40 usec/cm

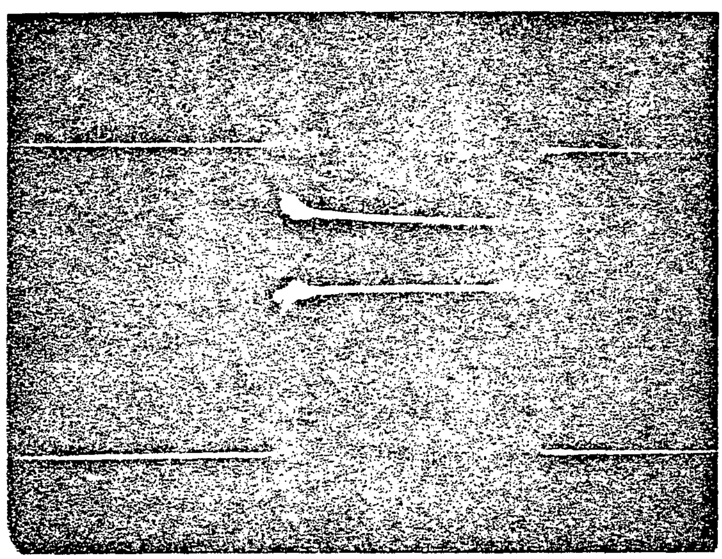

Figure 4. Scope Photograph of Anode Voltage Pulse and Current at 60 KVDC
Anode Voltage and 1220 Amp Pulse Current
Time: 10 usec/cm

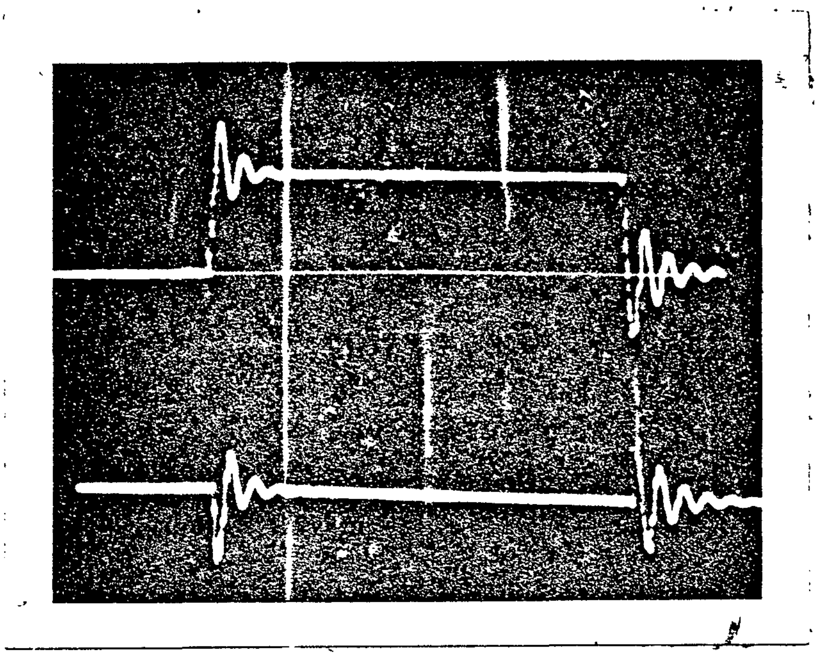

Figure 5. Scope Photograph of Anode Voltage and Current with Load Shorted.
Anode Voltage 12 KVDC and Current 1200 Amps.
Time 5 usec/cm