EG&G
ELECTRO-OPTICS DIVISION

APPLICATION NOTE H5005A-1

GROUNDED GRID THYRATRONS

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Reprint of original paper
presented on February 4, 1976,
at the Twelfth Modulator Symposium
in New York City

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SUMMARY

This paper describes the development of grounded grid thyratrons and the observed characteristics of these tubes.

Grounded grid thyratrons are modified versions of hydrogen thyratrons used in low impedance systems. These tubes are operated with the control grid as the negative electrode and with the hot cathode as the trigger electrode. The main current pulse is carried by a metal vapor arc between grid and anode. This mode of operation gives the tube a peak current capability of several tens of thousands of amperes, with an inductance of the order of 15 nanohenries.

The principal uses of these tubes have been in spark chambers and in pulsed nitrogen UV lasers.

INTRODUCTION

Recent developments, particularly of large spark chambers and of high power gas lasers, have created new switching requirements not well met by conventional devices. These are typically:

1) Load impedance less than 1 ohm

2) Operating voltage 10 to 35 kV

3) 0.001 to 0.005 coulomb per pulse

4) di/dt 100 to 1000 kiloamp/microsec

5) Peak currents of several kiloamps to tens of kiloamps

For spark chambers a total switching time, delay plus load voltage rise time, of 50 to 100 ns or less is needed, and time jitter may be critical. Delay time has not, so far, been very important in high-power laser circuits. Repetition rates have been less than 100 pps in most operational systems, but there is interest in laser operation at much higher rates.

Spark gaps have been widely used in these circuits, particularly in laboratory models, but have several serious drawbacks. High pressure gaps of the type used in low impedance systems have an operating voltage range of about 3 to 1, and an upper limit on repetition rate of a few hundred pps. For some systems, the high trigger voltage requirement, 5 to 20 kV, is particularly undesirable. The life time of a sealed spark gap, under optimum conditions, is presently on the order of 20,000 coulombs of total conducted charge.

A number of successful circuits, particularly at somewhat higher impedance levels, have used standard hydrogen thyratrons. Spark chambers at CERN[1, 2] and at Brookhaven[3] use tetrode thyratrons at up to several thousand amperes peak with 20 ns rise times. Similarly, a number of high power nitrogen lasers have been built using conventional thyratrons[4]. If the circuit conditions do not force the thyratron into an arc, the thyratron generally has several advantages over a spark gap.

Of the various gaseous switching devices, the thyratron has the most stable shot-to-shot characteristics (time and impedance jitter). It has been shown[4, 5] that a laser's electrical discharge condition may be somewhat independent of switch and capacitor inductance. The transmission lines near the channel are usually more critical. Even so, variations in switch tube impedance, which are important to most systems, are often critical to lasers. In gas lasers, variations of a few percent in the switch tube impedance may produce large amplitude fluctuations in laser output. The thyratron's relatively low, stable shot-to-shot impedance minimizes output fluctuations due to impedance jitter.

Other advantages of the thyratron are lower trigger voltage requirements, very much higher repetition rate capability, and a far longer life.

The requirements of low-impedance circuits, however, frequently exceed the capability of conventional thyratrons. Figure 1 shows typical circuit arrangements. A spark chamber circuit similar to Figure 1A is described by K. Foley et al[3]. In that particular system, the energy storage was provided by eight parallel 4-ohm strip lines, with a peak current of 15 kA. Under such conditions, a conventional thyratron would be quickly destroyed by arc damage to the cathode and clean-up of the gas fill.

It is possible, however, to obtain the necessary peak current and rise-time capabilities, while preserving most of the advantages of the thyratron, by operating the tube in the grounded grid mode. In this mode, the grid is used as the negative electrode for the main discharge, while the normal cathode is used only for triggering. In this way, some of the desirable triggering and operating range characteristics of thyratrons can be combined with the high peak current capability of spark gaps, in a fairly small, low-inductance structure.

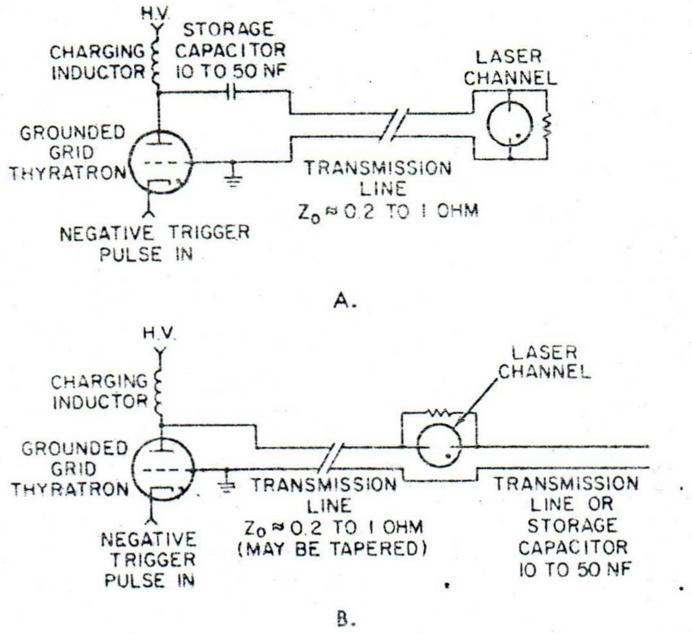

Figure 1. Typical Laser Discharge Circuits.

Originally, standard thyratrons were tried for operation in the grounded grid mode, with some success, but short life. At EG&G, we have developed a number of tubes specifically for use in grounded grid circuits, and we are now engaged in an evaluation and improvement program.

Design and Construction of Grounded Grid Thyratrons

Figure 2 shows a cross section of one of the tubes now being produced by EG&G, the HY-1102. The internal spacings are basically the same as a standard thyratron. The major structural differences are in the treatment of the grid and anode structures, which are made of refractory materials. Also, the mounting flange is attached at the grid seal.

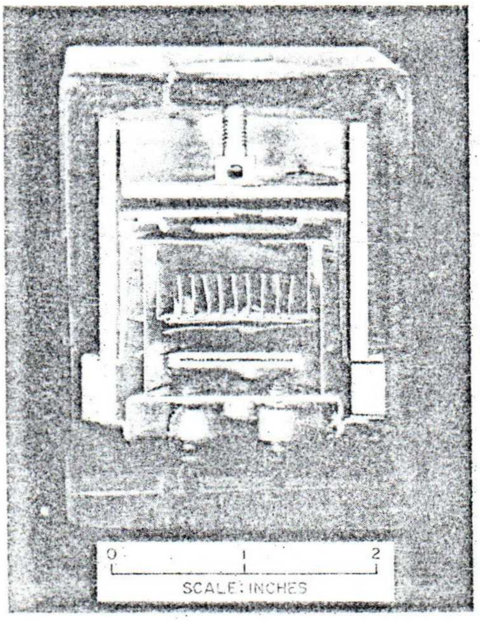

Figure 2. Cross Section of HY-1102 Grounded Grid Thyratron.

In use, the hot cathode is pulsed negative, to form a low density plasma in the grid-cathode region, just as in a standard thyratron. This plasma supplies electrons to the anode field penetrating the grid slots, and thus initiates anode-grid breakdown. The arrangement of the external circuit then forces transition to a grid-anode metal vapor arc. Examination of the tube parts after some operation shows arc erosion on the grid baffle and on the side of the grid facing the hot cathode. Evidently the negative arc spot is formed on the cathode side of the grid.

Figure 3 shows the grid of a tube after about 10^8 shots in a laser system. The arc has favored one position, and has eroded a round channel through the grid structure. The discharge was 0.00125 coulomb per shot at 10 to 30 kiloamps peak. The corresponding anode damage was minimal.

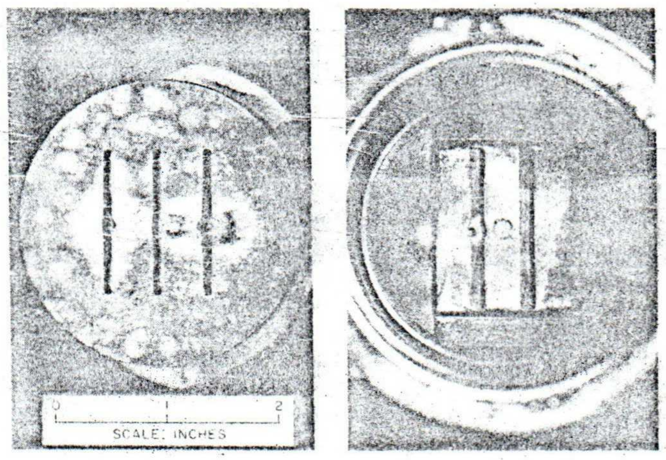

Figure 3. Arc Damage to Grid.

The hydrogen reservoirs used in these tubes are essentially the same structures used in standard thyratrons, but of greater capacity.

The hot cathodes used are identical with the standard tubes. Since in this case the cathode is used only as a trigger element, it could probably be greatly reduced in size. At the present time, however, the cathode is used during processing, since these tubes are first run in as standard thyratrons at full power.

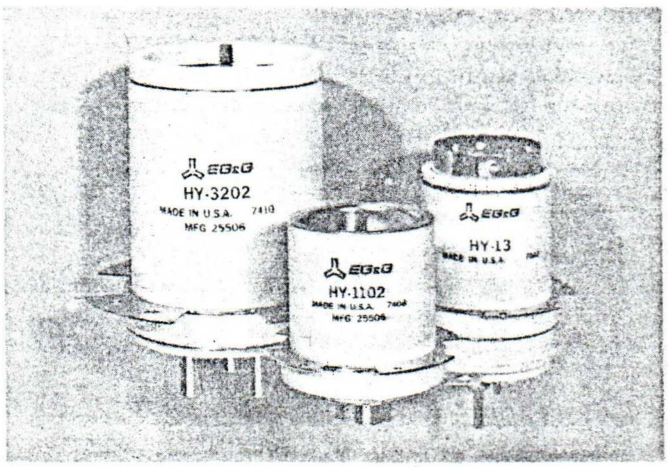

Figure 4. Grounded Grid Thyratrons.

Figure 4 shows the three types of thyratrons currently manufactured. The largest of these, the HY-3202, based on the 7322 configuration, is rated at 35 kV. The 20 kV HY-1102 is more compact to allow a lower inductance mounting arrangement. The third tube, the HY-13, is similar to the HY-1102, but is a tetrode structure for short delay time. This tube is intended for spark chamber applications with delays of the order of 50 ns. The open baffling in this tube somewhat compromises the high voltage hold-off reliability.

CHARACTERISTICS

Switch Impedance

Figure 5 shows one experimental apparatus used at EG&G to measure tube characteristics. Figure 6 shows the circuit diagram. In this array, for example, we have been able to operate at up to 7500 amps peak, with di/dt = 275 kiloamp/μsecond, into a 0.45-ohm load, at 20 kV.

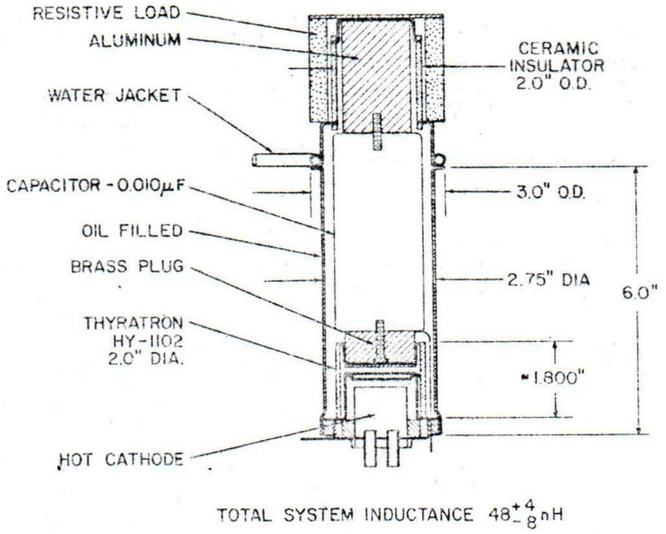

Figure 5. Experimental Apparatus - HY-1102.

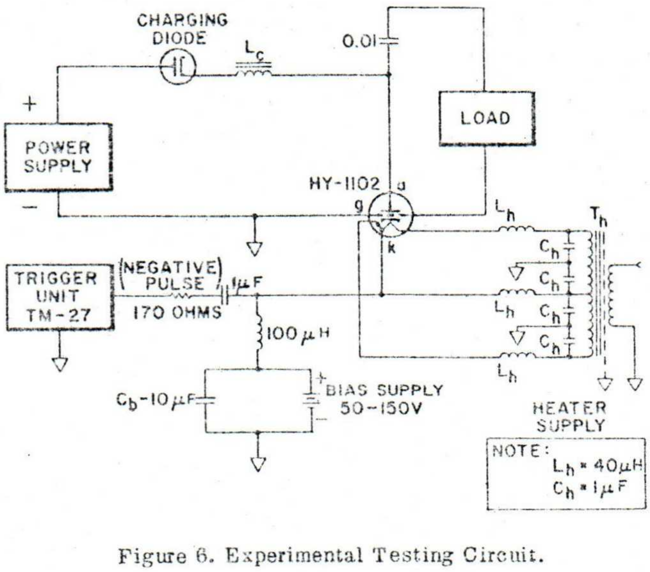

Figure 6. Experimental Testing Circuit.

In this sort of an apparatus we generally find switch inductance 10 to 15 nhy, effective switch resistance on the order of 0.2 ± 0.1 ohm, and load current rise time 20 ns ± 20% (10 to 90%) with the circuit underdamped. We also find that the switch resistance is dependent on tube pressure, varying by about 0.07 ohm with a reservoir voltage swing of one volt (or a pressure swing of about 0.15 torr).

We do not find a corresponding change in inductance or rise time. In fact, the 20 ns rise time seems to be a constant for these devices, this rise time having been found in the Brookhaven spark chamber[3], in our experiments, and in some laser systems which we have measured. Using the apparatus shown in Figure 5, a load current waveform, with a typical rise time and also a typical knee at the beginning of the pulse, was found. This current wave form is shown in Figure 7.

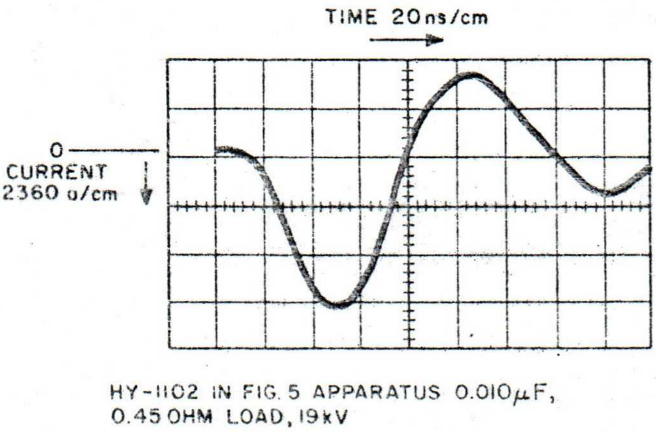

Figure 7. Current Pulse with Resistive Load.

Figure 8 shows a current waveform in a high energy nitrogen laser near threshold. Again we have the 20 ns initial rise. The circuit here was of the type of Figure 1B, and the time between the two peaks is, at least in part, due to time delay in the laser channel discharge formation. At full power, the current values shown here are about doubled. This current waveform was of particular interest because the circuit itself is very tightly coupled, leading to the original supposition that the peak current was much higher, and the pulse width

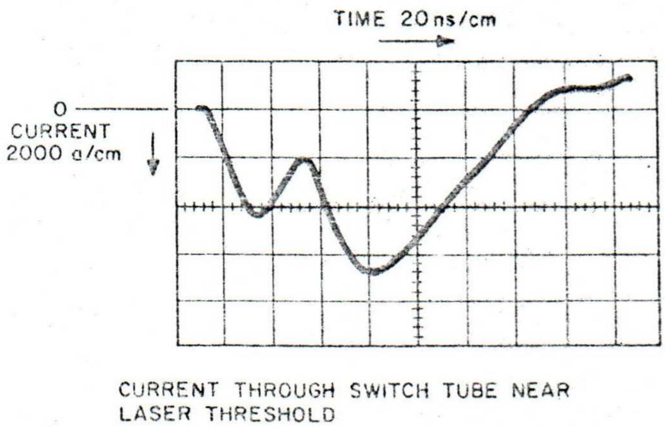

Figure 8. Current Pulse in Laser.

much shorter, than was actually the case. This has been our general experience so far with pulsed lasers, where current measurements are very difficult and often nearly impossible.

A comparison between a grounded grid thyratron and its corresponding standard thyratron version is shown in Figure 9. The apparatus of Figures 5 and 6 was used. Load resistance was 0.45 ohm, and charging voltage was 10 kV. The grounded grid tube gives 3800 amperes peak current with a 20 ns rise time. The standard tube, capable of 2000 amperes peak in a short pulse, is here driven past its limits and gives only 3000 amperes peak and a 30 ns rise time.

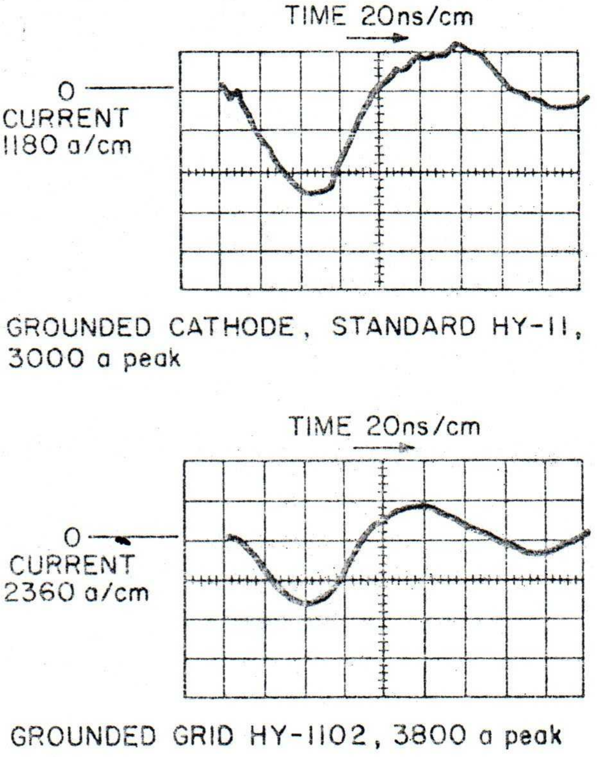

Figure 9. Current Pulses of Standard and Grounded Grid Thyratrons (0.45-ohm load, 10kV, 0.01μF).

The grounded grid tube, on the other hand, has an important low-current limitation. Because conduction current is supplied by an arc from the grid, rather than by the freely emitting hot cathode, it is necessary to use peak currents high enough to form a low-impedance discharge. At currents of less than 600 to 1000 amperes, a high-impedance, unstable arc condition occurs, causing large current fluctuations from pulse to pulse, or during a pulse. In circuits of a few ohms, this has been seen as steps and slope discontinuities on both leading and trailing edges of the load voltage (or current). In a series of tests at 500 to 1500 amperes, in a 2-1/2 microsecond line type modulator, and at about 1/2 ampere average, this behavior was shown dramatically by 150°C fluctuations in the tube envelope temperature. These changes corresponded to fluctuations in tube dissipation of one to several hundred watts. From a number of experiments, it appears that, for best results, the present generation of grounded grid tubes should be operated at peak currents greater than 1-1/2 kiloamperes.

Another limitation is found in average heating effects. From several experiments under diverse conditions, it is found that we encounter severe grid heating, or hot spot problems, at average currents of about one ampere, and sometimes less. The usual symptom is forward hold-off failure, which may persist for several seconds or even minutes. This effect is approximately the same for all of the present generation of tubes, which are not reliable at greater than 1/2 ampere average.

Repetition Rate

Most of the actual operational results so far are at less than 100 pps, with some tests at up to a few hundred pps. At EG&G we have recently conducted a series of experiments with a 2500 pps charging rate, and an actual pulse rate of 2000 pps. No forward hold-off or recovery problem was found. A conventional charging inductor and diode arrangement was used. Bias was applied (in this case, positive cathode bias) and the bias supply current was found to be higher than expected, about 20 milliamperes. It was also found that we needed a fairly low drive impedance to avoid missing pulses. A drive impedance of 125 ohms, at 400 volts (open circuit voltage), gave reliable triggering.

The actual upper limits of pulse rates are not yet known, and while these tubes will probably not achieve the 10-microsecond recovery times of standard thyratrons, the short spacings and low pressures should give at least several kilohertz.

Triggering

In general, the trigger requirements are basically the same as the similar conventional thyratron. Some problems with arc stability, missing pulses, and recovery, however, have been found to be related to the trigger generator characteristics. It is found to be desirable to keep the driver impedance relatively low, 50 to 125 ohms, if possible. Ideally, the driver pulse should be matched, or at least rapidly damped. Resistive, not inductive, isolation should be used between the tube and the driver.

In spite of the apparent physical isolation of the trigger element (the hot cathode) from the main arc, a positive spike is produced on the trigger when the tube fires. This spike may be several kilovolts, and needs to be clamped. A GE MOV varistor or an NL silicon carbide varistor mounted close to the tube, between grid and cathode, can provide the necessary spike protection. A spark gap across the driver often produces worse problems than the original spike, and should be avoided.

Life

Not very many life test results are available yet, and therefore it is difficult to predict life in particular applications. In laser systems, we have had life times of 10^7 to 10^8 pulses, with failure due to gas clean-up. These numbers correspond to 20,000 to 100,000 coulombs of total conducted charge. In spark chamber systems, the results have not been as good, with life times of 10^6 to 10^7 shots, often ending in hold-off failure, which again may be related to damage caused by gas clean-up. Life time is clearly capable of considerable improvement, and is the object of current work at EG&G, but it is already clear that thyratrons specifically designed for grounded grid service in fact do combine the best features of spark gaps and conventional thyratrons as switch tubes for low impedance systems.

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