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INVESTIGATION OF A HIGH CURRENT
SWITCH TUBE

R. O. Judkins

ABSTRACT

A gaseous discharge switch tube having an inductance of the order of 5 millimicrohenrys and jitter of 5 millimicroseconds was constructed and tested. Several modes of triggering were investigated, principally a r-f plasma electron source and a high field emission electron source. The high field emission mode operated particularly well and some jitter and delay measurements were made with it. A current viewing resistor was constructed to observe the waveform, and the inductance of the switch and associated circuit determined. Efforts to increase the stand-off voltage which is now around 15 KV are being made. For microsecond pulses the current limits are over 300 KA and appear not to be limited by the switch tube. Work is being continued on a new model of coaxial design.

Case No. 628.00

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INTRODUCTION

The ability to switch large amounts of peak power in short times is frequently important for laboratory and application purposes.

This memo presents work done to date on a gaseous discharge tube designed for this need.

The University of California Radiation Laboratory¹ developed a tube of this type for use with their 184-inch Cyclotron Electric Deflector. This tube had the following characteristics:

Peak current	100,000 amperes
Peak voltage	1,000 - 20,000 volts
Rise time	50 millimicroseconds
Time jitter	5 millimicroseconds
Lead inductance	5 millimicrohenrys
Repetition rate	180 pulses/second
Peak switching power	1800 megawatts

It was decided to make a copy of this tube to investigate its operation with respect to modifying or improving it for possible Sandia Corporation applications, our object being low inductance and low jitter.

OPERATION

The initial model (Figure 1) was designed by Clayton McDole² and constructed by the Sandia Corporation shop. The tube was continuously pumped and helium gas admitted by a valve regulating the pressure in the 100 to 1000 micron range.

The gas is maintained in an ionized state in the upper part of the tube by means of an r-f source connected between the grid-cathode and the trigger plate. The structure of the grid-cathode and the close spacing (less than the ionization mean free path of the gas molecule) between the grid-cathode and the anode prevent any appreciable ionization of the gas in the high field region between the two main electrodes. This arrangement limits the ionizing collision probability of an ion to less than unity and of an electron to much less than unity and prevents a spurious discharge from occurring from stray electrons or ions in the high field region. Although some electrons leak through the grid-cathode from the r-f plasma, they normally do not initiate a discharge.

¹High Current High Voltage Gas Discharge Tube by W. R. Baker, Q. A. Kerns, Jack Reidel, R. F. Edwards, University of California Rad. Lab., July, 1948.

²Now at Los Alamos Scientific Laboratory

The tube is fired by means of a negative voltage pulse from a delay line pulser³ applied to the trigger plate. This negative voltage pulse drives the electrons into the region between the anode and grid-cathode in sufficient numbers to ionize the gas in this region and thereby cause the tube to conduct. Cathode spots which form on the surface of the grid-cathode enable the tube to carry tremendous currents. The de-ionization time of the tube is of the order of 10 microseconds; thus, when used in an r-f oscillating circuit, the tube will pass currents in both directions once the tube has been triggered.

Tube No. 1

The first model was extremely erratic in operation. This fault was largely due to the continual outgassing of the commercial type copper used in construction. This outgassing prevented maintaining a constant known composition of gas within the switch-tube.

Tube No. 2

A second model of oxygen-free high conductivity copper gave improved performance. To facilitate outgassing and provide a faster flushing rate larger pump-outs were incorporated in this modification. Figure 2 shows a static breakdown curve for this model. Arcing across of the high potential lead prevented extending this curve beyond 10 KV. This curve corresponds to the Paschen curve¹ for gas breakdown on the low pressure side of the minimum. It is broadened and distorted because of impurities present from the outgassing of dirt and oxides from electrode surfaces. The helium used was about 99.9 percent pure and cold-trapped by an acetone-dry ice mixture to condense out water vapor.

Figure 3 presents the relation between the firing delay (defined as the time from the application of the trigger to the tube to the breakdown of the tube) and the main electrode potential which is switched. This curve is plotted for a gas pressure of 1140 microns of helium and a triggering voltage of 4 kilovolts.

Figure 4 plots firing delay against trigger voltage. This plot is similar to a conventional thyatron delay versus overvoltage curve. Five kilovolts was the largest trigger used, but the data indicate that a trigger voltage up to 10 KV would decrease the delay time appreciably. Also of note here was the observation that increase of r-f power lowers firing delay considerably. Only a few data were taken in this area due to lack of the necessary equipment; however, with a power oscillator which would deliver up to 100 watts to an unmatched load at 200 to 400

³ Technical Memorandum by Floyd McIver, 5133, to be published

¹ Meeks and Craggs, "Electrical Breakdown of Gases", p. 81

megacycles and a wattmeter such as the "Bird Tru-line" meter this effect could be more thoroughly investigated.

The heating problem encountered with a sixty-watt power oscillator indicates that one hundred watts is as much power as can be dissipated without forced cooling of the switch tube.

The justification for so much emphasis on delay time is that the jitter is usually reduced proportionally as the delay time is reduced. Jitter is defined as variation of firing delay time for identical firing conditions.

It was found that at the frequency used (200 MC) the dimensions of the r-f cavity and position of the trigger plate were critical. Figure 5 indicates the condition where the r-f plasma disappears from the region between the trigger plate and grid-cathode and either is completely extinguished or is contained in the space above the trigger plate.

The dependence of an r-f discharge on the pressure of the gas and the dimensions of the cavity has been investigated by the "Research Laboratory of Electronics" at MIT.

The shortest firing delay time for this tube was 60 to 70 millimicroseconds. The data indicate that more r-f power and/or better location of r-f plasma along with a capability for a higher voltage trigger would probably result in operation comparable with the switch tube of the University of California.

Some parameters which might be investigated are:

1. Main electrode voltage
2. Main electrode spacing
3. Grid-cathode spacing
4. Grid width
5. Trigger plate to grid separation
6. R-F power and frequency
7. Triggering voltage and waveform
8. Gas composition and pressure

The dependents which might be plotted are:

1. Firing delay
2. Delay time jitter
3. Static breakdown potential
4. Rise time of current
5. Minimum trigger voltage
6. Minimum main electrode voltage
7. R-F plasma leakage current
8. Pressure range

However, at this time due to the highly variable nature of gas discharges it was thought preferable to go on to other variations and types of switch tubes rather than undergo the expense of taking precise data on this one model.

Tube No. 3

Three other modes of obtaining a cloud of electrons for triggering were considered; a spark plug with gas multiplication, a hot tungsten wire filament, and high field emission from sharp points.

The tungsten filament was tried first. The arrangement of the filament and trigger plate was such that the trigger pulse arced across to the filament wire burning it out. However, one of the coaxial type switch tubes which is now under construction uses a filament and was designed to prevent such arcing.

The high field emission method has the advantage of requiring no stand-by power. The electron cloud is produced by the triggering pulse at the time it is applied. This system would require a minimum of auxiliary equipment and promises to have a high efficiency of operation. For this reason it was investigated next. Figure 6 is a sketch of the emitter consisting of about two thousand phonograph needles soldered to a copper base. The capacitive voltage divider and small wire grid serve to provide a very high field close to the points, starting a discharge very quickly due to the extremely high gradient. The 217 micromicrofarad capacitance is soon charged (one RC time constant equal to ~10 millimicroseconds) by the emission current at which time the trigger voltage is transferred to the grid-cathode to drive the electrons which have been generated through the slots into the main electrode gap to fire the tube.

With this setup, delays of 46 millimicroseconds with maximum jitter of + 5 millimicroseconds were measured with the apparatus in Figure 7. Further possibilities for improving performance are:

1. Reduction of stray capacities in trigger input; this will result in the full trigger pulse being more quickly applied.
2. Higher trigger pulse, providing more electrons by brute force.
3. Determination of optimum capacitive voltage divider ratio.
4. Determination of minimum depth and maximum width of grid-cathode slots that can be used without causing premature breakdowns.
5. Optimization of needle points to grid-cathode distance.

Current Capabilities

Different combinations of capacitors have been connected to ascertain the current capabilities of the tube. Forty-two microfarads at 4.5 KV have been discharged and a current of over 300 KA measured. The major limitation is the design of a current viewing resistor to carry this

current without burning out. This current rings at from 0.1 to 10 megacycles so it becomes difficult to keep the inductive reactance across the current viewing resistor appreciably smaller than the resistive component which is of the order of .0001 ohm. Figure 8 shows the disk type current viewing resistor used in measuring the 300 KA discharge.

It has been suggested that a mutual inductance coil giving $\frac{di}{dt}$, followed by an integrating circuit could be used to advantage instead of the current viewing resistor.*

An interesting phenomenon occurring after discharges of over 100 K amps is a rise in pressure in the tube of about a thousand microns lasting ten to thirty seconds. Possible causes may be heating of the gas, or release of occluded gases from the metal or vaporization of metal from the electrodes.

INDUCTANCE MEASUREMENT

With the current viewing resistor placed in the circuit, the resulting waveform observed on an oscilloscope is an underdamped sine wave as in Figure 9. By measurement of period T and logarithmic decrement δ from the wave shape, and knowing the capacitance, the inductance of the circuit can be found by solving the simultaneous equations:

$$T = 2 \frac{2LC}{(4LC - R^2 C^2)^{1/2}}, \quad \delta = \frac{R}{2L} T$$

This is not rigorous as R is not a constant for a gas discharge. However, in computing the inductance the resistance comes in only as a correction term.

The particular arrangements on which computations were made had twenty .01-microfarad "glas-mike" capacitors mounted cylindrically between two disks providing low inductance connection to the tube proper. Photograph 2 is a picture of this setup.

From measurement on the wave form across the current viewing resistor and solving the two above equations, the inductance is computed at 6.1 millimicrohenrys.

If the tube is considered as a series connection of a number of sections, each section being a cylinder with a concentric cylinder within it, and the individual inductance of each section computed by the formula for the inductance of a circuit consisting of two concentric cylinders

* W. L. Briscoe, Division K-3, LASL, Private Communications

$$L = \ell (.14 \log_{10} \frac{r_2}{r_1})$$

microhenrys where ℓ is in feet and r_2 and r_1 the radii of the outer and inner conductor, respectively; the following inductance values are computed:

Tube proper	2.55 millimicrohenrys
Capacitors	.40 "
Connecting pins	.92 "
Current viewing resistor	2.04 "
Connecting flange	<u>.32</u> "
Sum	6.21 millimicrohenrys

This correlation indicates that the inductance of the conducting gap itself must be somewhat less than one millimicrohenry which means that the entire electrode area must be conducting and the discharge is not pinching down, at least during the short period of the measurements.

Upper Voltage Limits

Theoretically three factors limit the stand-off potential the tube will maintain:

1. The Paschen curve limit
2. High field emission from the electrodes
3. Breakdown across the insulation between electrodes.

The second criterion appears the most important. The Paschen curve limit can be raised by increasing electrode separation or decreasing gas pressure; the insulation limit has not become critical in experiments up to now; however, the high field emission limit is important. Merely increasing the separation of electrodes does not reduce the voltage gradient at electrode surfaces.*

A judicious choice of electrode material can raise the limit.* By increasing the electrode separation to 0.2 inch and decreasing gas pressure to about 50 microns a copper electrode tube stood off 20 KV. A provision has been made in the coaxial type tube under construction to test this condition with stainless steel electrodes. Stainless steel has a high field emission breakdown characteristic of 490 KV/in. as compared to 220 KV/in. for copper.*

*"High Voltage Breakdown Due to Field Emission Processes", by D. H. Goodman, University of California Electronics Research Lab., 2-1-53, Contract No. W-33-038 ac-16649.

CONCLUSIONS

This device appears to have possibilities as a laboratory tool which combines the advantages of a spark gap and thyatron. It will switch the heavy peak current of a spark gap with the low jitter and delay of a thyatron without the inductance and varying impedance of a spark-gap or the low current capability and lead inductance evident in most thyatrons. Disadvantages of the present model are physical size and necessity of auxiliary equipment such as r-f power oscillator or filament supply, and a questionable voltage stand-off limit.

The efficiency and simplicity of the high field electron trigger point to a likely direction for further work. The voltage limit depends on the care taken in cleaning and polishing electrodes and the amount of compromising which can be tolerated by using electrodes of low conductivity and by increasing electrode separation and decreasing gas pressure.

From the experience and information gained from these early models and to answer better the above questions, two switch tubes have been designed and are under construction. Both have coaxial type electrodes. In the first the anode is the inner cylinder and the grid-cathode the outer cylinder with a hot wire filament. The second has a fine wire high field emission trigger source surrounded by the grid-cathode which is enclosed by the anode. This second tube approximates a 50-ohm characteristic from input to output.

Provisions are being made to attempt to operate these tubes up to 50 KV main switching potential with delay line or capacitor energy storage. Provisions have been made to use either copper electrodes or stainless steel electrodes.

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R F SWITCH TUBE
FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

K&E '10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 5

14

FIELD EMISSION TRIGGERING SOURCE

INPUT AND OUTPUT WAVEFORMS

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SET-UP FOR MEASURING DELAY & JITTER

FIGURE 7

308 14

DISK TYPE CURRENT VIEWING RESISTOR

FIGURE 8

EQUIVALENT CIRCUIT AND TYPICAL WAVEFORM
ACROSS CURRENT VIEWING RESISTOR

FIGURE 9

17 PHOTOGRAPH -1

Photograph 1

-17-

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