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Starting Characteristics of a "Trigger" Tube with a Radioactive Cathode

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The Westinghouse WL-759 "trigger" tube is designed to operate small relays and yet is controlled by currents less than 10^{-11} amp. in the starting anode circuit. Investigation shows that this is possible because of an "avalanche" effect set off by the radioactivity of the cathode after the starting anode has attained the critical potential for the efficient development of the high ion density needed to bring about the complete development of a glow discharge between the cathode and the principal anode of the tube. Other electrical characteristics of the tube are also discussed.

INTRODUCTION

THE WL-759 "trigger" tube is a cold-cathode glow-discharge tube with a well-insulated auxiliary anode to control the starting of the discharge between a thoriated cathode and the principal anode. The minimum current which must be furnished by the outside starting circuit is less than 10^{-11} amp. and the maximum rated anode current (average) is 4 milliamperes. A peak anode current of at least ten times this value may be used. The normal anode voltage before discharge is about 300 volts and the critical starting anode voltage is about 180 volts both positive relative to the cathode. The normal tube drop is about 100 volts and the floating potential of the starting anode is about 78 volts while the tube is conducting.

Within the past fifteen years many gas discharge tubes have been developed to meet the need of placing currents large enough to operate relays under the control of currents millions of times smaller. Although, in general, it is necessary for the small control current to originate in a circuit of very high resistance the effective current amplification obtained often exceeds 10^7. The most sensitive Thyratrons such as the FG-17, FG-95 and FG-98 require a control current[1] of 4×10^{-10} amp. or more in the control grid circuit to bring about operation. Fundamental considerations[2] lead one to conclude that unless some new factor is introduced, a controlled discharge will require a minimum current of the order of 10^{-10} amp. for starting. Were it not for the introduction of radioactive material into the cathode, the WL-759 tube would not be an exception to this rule.

STARTING CURRENT WITH LOW RESISTANCE CIRCUIT SHOWING FIRST EFFECT OF CATHODE RADIOACTIVITY

With the circuit illustrated by the diagram of Fig. 1, it was possible to measure the current flowing in the starting anode circuit as a function of the voltage difference between the auxiliary anode and the cathode. The principal anode of the WL-759 tube is shown at P and is connected to a 300-volt battery through the 100,000-ohm resistance R_p and the message register L. For satisfactory operation the minimum value of L is about 0.5 henry and an appropriate value of its

[1] H. W. French, J. Frank. Inst. **221**, 83 (1936).
[2] I. Langmuir, J. Frank. Inst. **214**, 275 (1932).

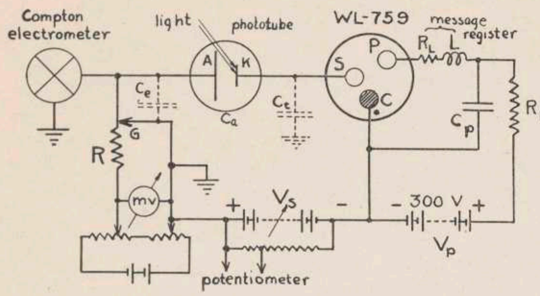

FIG. 1. Circuit for measuring characteristics of the WL-759 relay tube.

resistance R_L is about 1000 ohms or more. A suitable value of the capacitor C_p is 1 mf. The photo-tube used was of special construction with a filamentary cathode K and a concentric cylinder for the anode. A slit in the anode allowed the light to fall on the cathode through a thin-walled glass window blown in the Pyrex envelope. Sodium was evaporated from a side tube onto the cathode in order to activate it and at the same time by heating the anode support the high internal resistance required for the experiment was maintained. For the first experiments to be described it was necessary for the photo-tube to deliver all of the current required by the WL-759 starting electrode S with practically no drop in potential over the photo-tube. With a fairly bright light source, the current across the photo-tube was zero with a reverse potential of only 0.03 volt and yet rose to a value of 4×10^{-10} amp. with only 0.03 volt applied in the normal direction. The photo-tube was needed in the circuit in order to serve as a "current-limiter" after the start of a discharge in the WL-759. The resistance R represents any one of a collection of resistances ranging in value from 10^6 to 10^{10} ohms and G is a grounding key. The current measurements were made by using the Compton electrometer as a null instrument and observing the voltage mv required to balance out the IR drop produced by the current flowing through the high resistance R.

In order to measure the true current flowing between the electrodes C and S as a function of the voltage V_s, it was necessary to proceed very slowly since otherwise the polarization current (sometimes called dielectric absorption current) far exceeded the true leakage current. This polarization current was shown to be entirely within the WL-759 by disconnecting the lead to S at the "grid-cap" outlet of the tube and leaving all wires in place. With this arrangement negligible polarization was observed. Most of the polarization was probably due to the high difference in potential impressed on the glass of the stem in the tube which furnishes the mechanical support for the starting anode even though its electrical connection comes out on a single lead at the opposite end of the tube.

As is shown by the curve of Fig. 2, the leakage current was about 5×10^{-14} amp. even with a difference in potential of over 180 volts between C and S. Although the curve shown applies to the particular tube designated by the Westinghouse Laboratory as J-8-8, it is similar to those taken on two other samples of WL-759 tubes, one of which is also shown and designated by J-8-1. The important range of this curve is that between 184 and 185 volts. The current observed here was not steady but came in random "shots" occurring with a mean time interval estimated at about one-half second. Between "shots" the current was less than 10^{-13} amp. The interpretation which is offered to account for this effect is that alpha-particles were shot out by the radioactive decay of the thorium in the cathode. Although the alpha-particle produced a relatively small amount of ionization along its path, the resultant electrons were accelerated in the field and finally

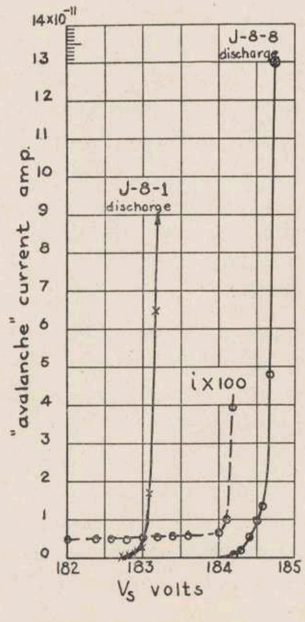

FIG. 2. "Avalanche" and leakage current in starting anode circuit before discharge when the potential is near the critical value.

gave a tremendous amplification in number thus creating a very considerable ion density momentarily. The fact that the cathode surface itself played an important part in this "avalanche" effect was demonstrated by observing that the critical potential at which this enormous increase in current took place depended upon the time elapsed since breakdown was last produced in the tube. The rapidity and extent of this change in cathode condition is indicated by the change in the critical starting anode potential with time shown in Fig. 3.

The highest observable point on curves similar to Fig. 2 was generally between 1.0 and 2×10^{-10} amp. since as soon as this value was attained conduction was set up in the tube. Ordinarily this curve would be sufficient proof that in order to obtain reliable operation of the WL-759 tube in a practical circuit, a control electrode current of at least this amount would have to be furnished by the control circuit. The fact that this limitation does not hold here will be demonstrated below.

Starting Currents with High Resistance Circuits

Experiment soon showed conclusively that WL-759 tubes could be controlled with photoelectric currents of less than 10^{-11} amp. if sufficient excess voltage were available in the battery V_s of Fig. 1. In order to see how this is possible a detailed analysis of the complete circuit is necessary.

Suppose that light falls on the cathode K and produces a photoelectric current i_p which for the range of voltage used may be assumed to be constant. The current flowing through the resistance R will be given by

$$i=i_p+dQ/dt \tag{1}$$

where Q is the charge stored in the internal capacity C_a of the photo-tube. If leakage currents and polarization currents may be neglected, then

$$dQ/dt=C_a dV/dt=-i_pC_a/(C_a+C_t) \tag{2}$$

and

$$i=i_p\left(1-\frac{1}{1+C_t/C_a}\right). \tag{3}$$

Here dV/dt is the time rate of change of the potential of S. In the experimental circuit the

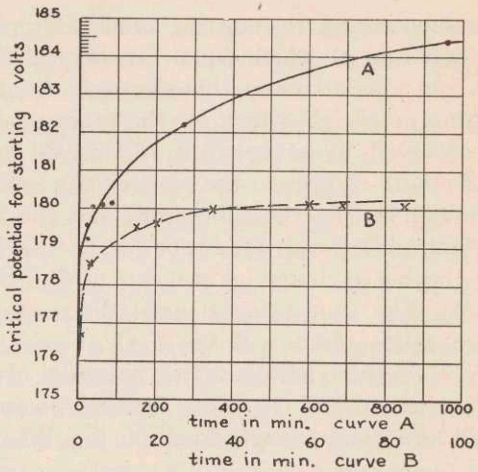

Fig. 3. Typical curve showing observed change in the critical potential for starting of WL-759 tube as a function of the time elapsed since last previous breakdown.

capacity $C_t=20\times10^{-12}$ farad and $C_a=10\times10^{-12}$ so that Eq. (3) reduced to $i=0.67\ i_p$. Furthermore

$$dV/dt=i_p/(C_a+C_t)=i/C_t. \tag{4}$$

These equations show that the apparent photoelectric current i is always less than the true current i_p and that the distributed capacity of the lead K to S and starting electrode S which are lumped as C_t may be determined by measuring i and dV/dt. This may be done with the circuit of Fig. 1.

With V_s set at some value well in excess of 180 volts as, for example, 230 volts, and sufficient light falling on the photo-tube, the starting anode charges up to the critical voltage in the neighborhood of 180 volts and the WL-759 tube suddenly becomes conducting and discharges condenser C_p through the message register L. Although the potential difference C to P is about 90 to 100 volts while the tube is conducting, the drop over C_p may go as low as 30 volts while the remaining 60 volts is being developed because of the $L(di/dt)$ generated by the falling current through the inductance. Finally under these conditions, conduction suddenly stops and the condenser starts to charge up through the resistance R_p. If the ion concentration left over from the previous discharge becomes sufficiently reduced in the time required for the drop across C_p to come up to about 100 volts, then the glow will not reignite. For these tubes, this time was found to be 1.5×10^{-3} sec. or slightly less. During the conduction period, the starting anode S drops to that potential at which equal numbers of electrons and ions arrive at this electrode, i.e., the "floating potential" which for the tubes studied was observed to be between 75 and 80 volts positive with respect to the cathode. As soon as conduction within the tube stops and the ions and electrons left over are swept out, the starting anode begins to charge up at a rate governed by Eq. (4). The time interval until the next discharge takes place will be $T=C_t(V_c-V_f)/i$, where V_c is the critical starting potential of the starting anode and V_f is its floating potential during the conduction period of the WL-759 tube.

The number of counts registered per minute will be given by

$$N=60i/C_t(V_c-V_f)\sim 0.6i/C_t, \qquad (5)$$

since for all practical purposes (V_c-V_f) may be taken as 100 volts.

In order to have Eq. (5) hold with satisfactory accuracy, the photo-tube should yield a current practically independent of the applied voltage over the range 50 to 150 volts. The one described above changed its output three percent for this range in voltage and the form of the saturation curve was independent of the light intensity over the range in photoelectric current from 10^{-6} amp. to 10^{-12} amp.

The WL-759 tube has been used for measuring the integrated light intensity obtained from various sources. This can be done with accuracy even though the photoelectric current is not independent of the voltage across the tube as long as the current output is strictly proportional to the light intensity and the changes in light intensity are small during the time T between message register counts. If the latter condition is not satisfied then a photo-tube must be selected which will have an output which is independent of the voltage.

In Fig. 4, the number of counts per minute is plotted against the measured current i using logarithmic scales for both. The experimental points follow the straight line reasonably well down to the cut-off at about 2.0×10^{-12} amp. Under these conditions the average time between counts of the message register was about 25 min. With a capacity $C_t=20\times10^{-12}$ farad and the limiting current above, the rate of change in

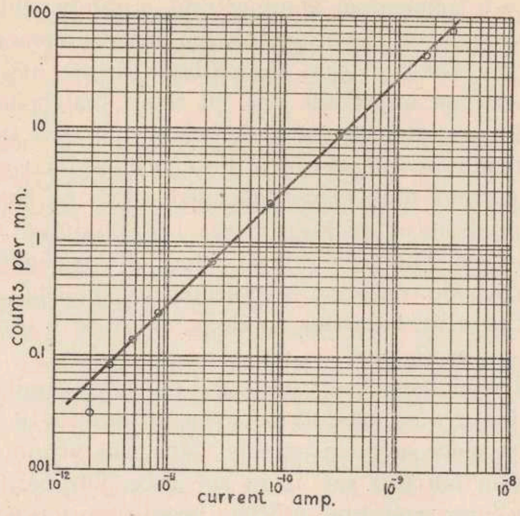

FIG. 4. Message register counts per minute as a function of measured current i with capactity $C_t=20\times10^{-12}$ farad.

potential $dV/dt=0.1$ volt per sec. With this extremely small current it was difficult for the starting anode S to build up the three- or four-tenths of a volt as required by the characteristic curve shown in Fig. 2. After the potential of S became high enough so that each alpha-particle created a fairly intense ionization, the electrometer was observed to "kick" very noticably for each alpha. With the very smallest current, this was observed to occur over a period of some minutes until, owing to the randomness of the radioactivity, a sufficient time elapsed between "kicks" for the electrode to charge up the last 0.3 volt. If this explanation of the phenomena is

TABLE I. *Technical information as furnished by the Westinghouse Electric and Manufacturing Company on the WL-759 glow relay tube characteristics.*

Main use	Intermittent d.c. Service
Number of electrodes	3
Type of cathode	Cold
Gas	Argon
Base	Small UX
Type of cooling	Air
Maximum over-all length	4 inches
Maximum over-all diameter	$1\frac{3}{16}$ inches
Maximum crest anode current	25 milliampere
Maximum average anode current	4 milliampere
Maximum trigger anode current	0.5 milliampere
Aver. potential drop between cathode and anode	85 volts
Aver. potential drop between cathode and trigger anode	85 volts
Operating anode voltage	250–325 volts
Trigger anode to cathode breakdown voltage	150–180 volts
Anode breakdown voltage with no voltage on trigger anode	350–380 volts

entirely correct, it would indicate that a surface concentration of thorium of approximately half the present amount might make it a little easier for the tube to operate with currents of the order of 10^{-12} amp. With a current of 6×10^{-12} amp. and the corresponding dV/dt of 0.3 volt per sec., operation was very reliable.

The upper limit of counts per minute was set mainly by the mechanical properties of the particular message register used. Increasing the capacity C_t decreased the counting rate for a given photoelectric current the amount expected from the equations and at the same time it increased the minimum current required for operation nearly in proportion. One would conclude from this that as long as the capacity C_t is less than about 200 micromicrofarads the period T will not exceed twenty to thirty minutes if the tube is to operate at all. Attention should perhaps be called to the fact that the average counts as shown in Fig. 4 were all based on thirty or more counts for each observation.

Remarks on Operating Characteristics

Over the range of plate current from 1.0 to 15 mils, the tube drop was observed to remain nearly constant at 100 volts while an increase of current to 20 mils resulted in an increase in tube drop. An observable increase in tube drop took place in a few minutes time when the tube was carrying 15 mils which seems to indicate that 10 mils is probably a safe maximum average current. Attention should be called to Table I for here a maximum current of only 4 mils is recommended by the manufacturer.

Although WL-759 tubes can be started with as low as 220 volts on the principle anode P, the current required by the starting electrode is large. The minimum plate voltage for good operation is 250 volts and the maximum about 325 volts.

These tubes were operated as "relaxation" oscillators up to a frequency of 300 operations per second which indicates that the maximum counting rate which can be used in a circuit similar to that of Fig. 1 will be set by the properties of the message register. Of course, for high speed operation due consideration must be given the selection of the resistance R_p and the capacity C_p.

In every installation using WL-759 tubes under control of currents of the order of 10^{-11} amp., the greatest of care must be exercised in order to eliminate stray leakage currents which are likely to flow through mechanical supports of the tube, photo-tube or other auxiliary apparatus. Polarization effects, stray light and stray electrical disturbances must be reduced to a minimum by the proper selection of materials and construction of shielding.

I wish to thank Dr. H. C. Rentschler of the Westinghouse Electric and Manufacturing Company for introducing me to these very interesting "trigger" tubes and hope that future users will derive help from these studies.

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