

# Holdover in Xenon Flashlamps

By HAROLD E. EDGERTON and DAVID A. CAHLANDER

*When a flashlamp is required to flash at high rates, the charging circuit is required to supply more current. Eventually, a condition arises where the flashlamp does not deionize but goes into a continuous arc that is called "holdover." Conditions for the limiting frequency in terms of circuit and lamp volt-ampere characteristics are given. Experimental data on several flashlamps are presented. Circuits which force a flashlamp to operate at high frequency even if it does not deionize are discussed.*

**XENON-FILLED** electronic flashlamps have found many uses in high-speed motion-picture photography and multiple-exposure photography, as well as the more common single-flash photography. The maximum flashing rate for a flashlamp is often limited by arc "holdover." A flashlamp is said to be in a state of "holdover" when it stays in a continuously conducting condition instead of deionizing, which is the desired performance. Large continuous currents can flow in the flashlamp when it is in the holdover condition. This may cause the electrodes and the tube to overheat, depending upon the properties of the energy source and the charging circuit.

The ability of an electrical-discharge flashlamp to give repetitive flashes of light from a condenser discharge in rapid succession depends upon the characteristics of the ionized gas in the lamp during deionization and the characteristics of the charging circuit. The evaluation of the upper frequency limit of a flashlamp and circuit is the object of this paper.

Normal operation of a simple type of flash circuit is shown in Figs. 1 and 2. At the start of the flash the condenser voltage is at the rated value depending upon the

particular conditions. This is shown on the accompanying time-voltage diagram, Fig. 2. During discharge, the tube current,  $i_1$ , rises to a high value within a short time and then decreases to zero as the condenser voltage decreases to a low value, and the charging current,  $i_2$ , from the source begins to flow into the condenser. The maximum discharge current in the lamp is usually much larger than the maximum charging current. The condenser voltage rises slowly to its initial value during the charging cycle while the charging current decreases slowly to zero. This is shown on the time diagram.

Should the tube exhibit holdover difficulties, the condenser voltage will remain at a low value and the charging current,  $i_2$ , will flow continuously through the flashlamp. After the initial flash the tube will emit a feeble glow which is very dim in comparison to the flash. No more flashes can be obtained from the lamp until the glow has been extinguished by interrupting the circuit and the storage condenser is recharged. The lower three curves of Fig. 2 show the electrical conditions during holdover.

Whether or not a given tube will holdover under specified conditions is an important question. The external factors which influence holdover for a specific flashlamp are: (1) the voltage to which the condenser is charged; (2) the energy per flash; and (3) the rate at which the lamp is to be flashed.

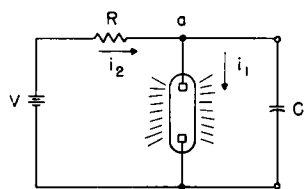


Fig. 1. Simple type of flash circuit. Discharge circuit,  $i_1$ , charge circuit,  $i_2$ .

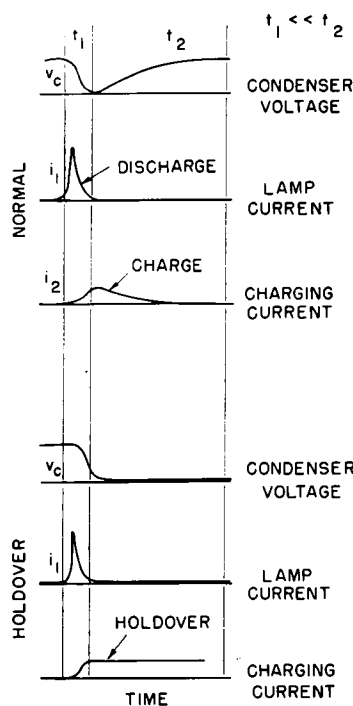


Fig. 2. Normal operation of flashlamp is shown in the upper three curves. The holdover condition is shown in the lower three curves.

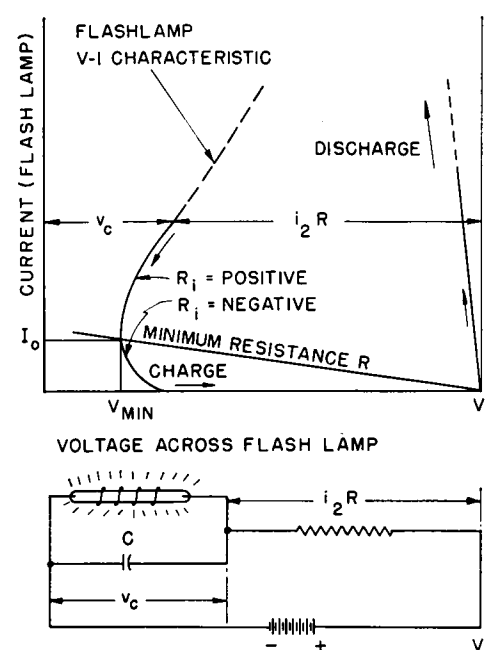


Fig. 3. Circuit and V-I diagram to explain transient excursion of discharge and charge currents.

### Deionization Conditions

The electrical conditions at the terminals of the flashlamp will now be examined at the time of discharge, for the simple resistance charging system from a battery or power supply (Fig. 1). A high-resistance flashlamp in which the discharge current is not oscillatory will discharge the capacitor to about 50 or 100 v. At the end of the discharge there is an important three-way division of the current at the point "a."

As long as the current into the lamp is greater than some limiting value, the light will not extinguish. This current,  $I_0$ , is the current at the minimum voltage point,  $V_{\min}$ , of the characteristic curve of the flash tube. At low currents the incremental resistance,  $R_t = \Delta V/\Delta I$ , of the tube goes through zero and then negative (Fig. 3). If the power supply load line intersects the  $V$ - $I$  curve above the minimum voltage point, a stable condition can occur where the power supply continues to supply current to the flashtube, i.e., holdover. If the load line intersects the  $V$ - $I$  curve below the minimum voltage point, the unstable condition of a negative resistance in parallel with a capacitor occurs and the lamp will deionize. (Overheated electrodes will cause a change in the  $V$ - $I$  characteristics.)

Therefore, holdover will not occur if the residual flashlamp current at the end of the discharge is less than  $I_0$ , the lamp current at the minimum voltage point on the lamp transient  $V$ - $I$  characteristic. Referring to Fig. 1, the maximum charging current must be less than  $I_0$ , to insure deionization.

The  $V$ - $I$  characteristic of the lamp is only slightly different for steady state and transient conditions due to heating and residual ionization left by the large discharge conditions. An inductance in the lamp discharge circuit will enable the experimental procurement of the entire  $V$ - $I$  curve, since the current through the lamp is then forced to go to small values in the negative resistance region of the characteristic curve.

Figure 4 shows both steady state and transient curves for the GE FT-506 Flashlamp. The minimum voltage point for this lamp is about 80 v, and occurs at a current of 0.6 amp.

### Minimum Resistance

The minimum charging resistance can now be calculated for the FT-506 Flashlamp. At the deionization point the voltage across the resistor is  $(V_0 - V_{\min})$  and the maximum allowable charging current is  $I_0 = 0.6$  amp. Thus,

$$R = \frac{V_0 - V_{\min}}{I_0} = \frac{900 - 80}{0.6} = 1400 \text{ ohms for a 900-v power supply}$$

where  $R$  = minimum charging resistance  
 $V_0$  = supply voltage  
 $V_{\min}$  = minimum voltage on the  $V$ - $I$  curve of the flashlamp  
 $I_0$  = current at the minimum voltage point

That is, the FT-506 Flashlamp will tend to exhibit holdover if the charging resistance is less than 1400 ohms.

### Maximum Flashing Frequency and Minimum Time Between Flashes

The charging time constant for the flash capacitor charging circuit is  $RC$  sec, where  $C$  is the discharge capacitance in farads and  $R$  is the charging resistance in ohms. If we consider three times the time constant to be

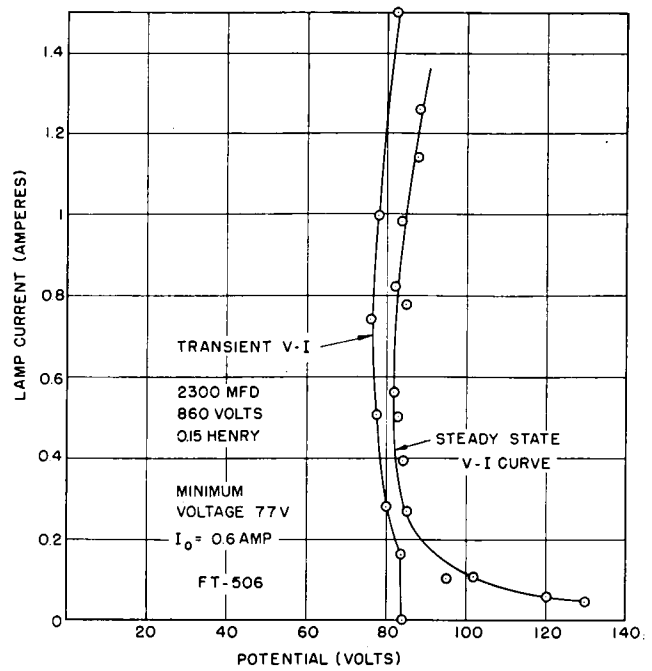


Fig. 4. Volt-ampere characteristics of the GE FT-506 Flashlamp.

ample for charging the capacitor (about 90% of full energy), then the minimum time between flashes,  $T$ , is given by

$$T = 3 RC \text{ (sec)}$$

Substituting for  $R$

$$T = 3 \left( \frac{V_0 - V_{\min}}{I_0} \right) C$$

or approximately

$$T = \frac{3 CV_0}{I_0} \text{ if } V_{\min} \ll V_0$$

In terms of stored energy  $W = \left( \frac{CV^2}{2} \right)$ , the minimum time between flashes is:

$$T = \frac{6W}{I_0 V_0} \text{ (sec)}$$

The maximum flashing frequency is

$$f = \frac{1}{T} = \frac{I_0 V_0}{6W} \text{ (flashes/sec)}$$

*Example:* Consider the FT-506 flashlamp with 1000 w-sec stored energy, on a 900-v circuit.

$$I_0 = 0.6 \text{ amp, } V_0 = 900 \text{ v, and } W = 1000 \text{ w-sec}$$

$$T = \frac{(6)(1000)}{(0.6)(900)}$$

or  $T = 11$  sec between flashes (minimum)

$$f = \frac{1}{T} = 0.09 \text{ flashes/sec (maximum)}$$

With reduced energy per flash the charging time becomes shorter. Consider a 10 w-sec condition. Then,

$$I_0 = 0.6 \text{ amp, } V_0 = 900 \text{ v, and } W = 10 \text{ w-sec}$$

$$f = \frac{(0.6)(900)}{(6)(10)}$$

i.e.,  $f = 9$  flashes/sec (maximum)

This flashing frequency is 100 times the 1000 w-sec value, since the maximum flashing rate is inversely proportional to the energy.

Table I, shows the holdover current,  $I_0$ , for several flashlamps of common interest.

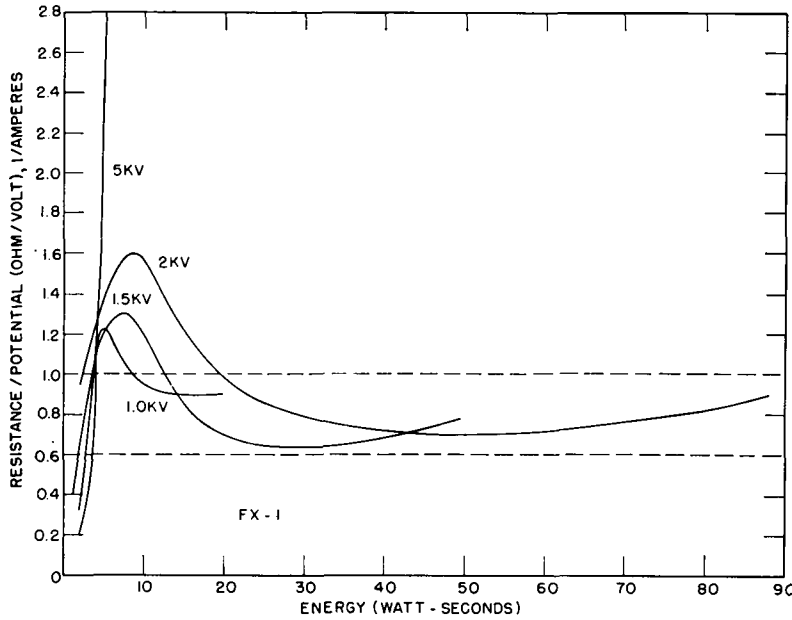


Fig. 5. Experimental data of FX-1 Flashlamp showing limiting current as a function of watt-second loading (Robert Flieder).

Table I. Holdover Currents for Some Flashlamps.

Flashlamp Type	Arc length, cm	Tube ID, cm	V <sub>min</sub> , v	I <sub>0</sub> , amp
FT-506 . . . . .	.15	0.5	80	0.6
FT-118 . . . . .	.7	0.4	45	1.5
FT-503 . . . . .	.35	0.7	200	1
FX-1 . . . . .	.15	0.4	80	1.1
FX-29 . . . . .	.10	0.9	75	2

**Methods of Decreasing I<sub>0</sub>**

For flash units that require a shorter charging time than that which has been derived above, one has to devise some special methods of reducing the charging current until deionization occurs. Holdover can be prevented or avoided in several ways. Some methods will now be discussed in detail.

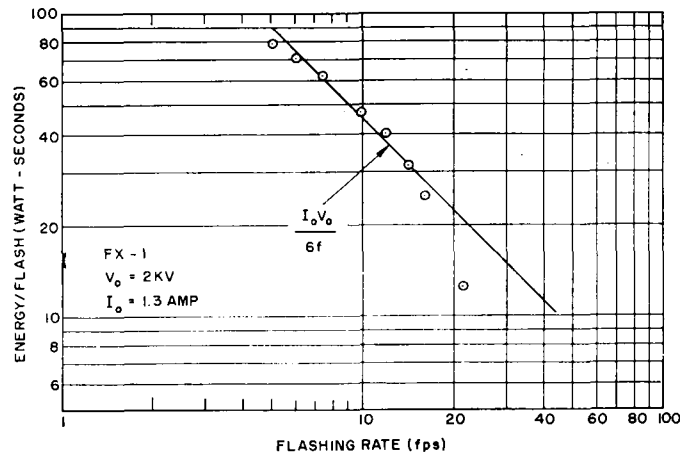
(1) *Use of a Relay.* A relay can be used to disconnect the charging circuit from the capacitor bank immediately after the discharge. The timing is accomplished by capacitor coupling a relay to the main capacitor bank. When the voltage on the main bank decreases (during discharge), the relay is operated, disconnecting the charging circuit until after the flashtube has deionized. When the relay capacitor is discharged, the relay closes, reconnecting the charging circuit to the main capacitor bank, and the capacitors start to charge.

(2) *Constant Current Charging.* A constant current charging circuit can be used to decrease the charging time by a small amount.

(3) *Series Tube.* A mercury connectron or a hydrogen thyratron may be used in series with the flashtube to aid in deionization. The effect of these tubes is to increase the effective I<sub>0</sub> to a value of about 10 amp, thus decreasing the necessary charging time by as much as a factor of 10 or 20.

(4) *Inductive Charging.* With a critically damped RLC network for charging the capacitor, the available charging current immediately after discharge is quite low. This current must, however, remain below I<sub>0</sub> until

Fig. 6. Theoretical (solid curve) and experimental data (circles) showing the maximum flashing frequency as a function of the watt-second loading at a particular voltage.



deionization occurs. This is not a practical circuit for high-energy discharges since the energy storage capacity of the inductor must be one-fourth that of the capacitor bank.

**Experimental Tests**

A series of experiments on the limiting charging resistance were made by Robert Flieder on the EG&G FX-1 Flashlamp at M.I.T. for a thesis in the Electrical Engineering Department in 1954. Figure 5 shows those data replotted in terms of stored energy and limiting current, I<sub>0</sub>. It is obvious that the simplified theory presented before applies only to a limited portion of the operation. For example, with a small energy such as 10 w-sec, the limiting current can be less than it is with the rated energy of 100 w-sec. The 5 kv data should be disregarded since the self-flashing voltage of the FX-1 tube is usually 4.5 kv.

Figure 6 shows a plot of the flashing rate of the FX-1 Flashlamp as a function of the w-sec loading. The solid line is calculated from the simplified theory of this paper. The circles are experimental data from Flieder's thesis, previously mentioned. Correlation is good over part of the range.