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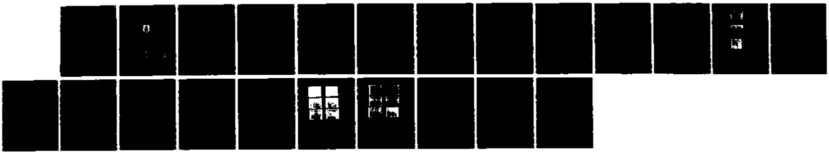

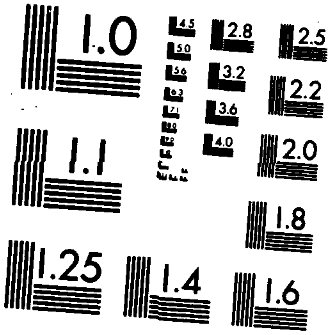
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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

HOLLOW CATHODE FOR ELECTRON BOMBARDMENT MERCURY ION THRUSTER PULSE IGNITION CHARACTERISTICS

by

Hu Yong-nian, Zhang Shi-linag, et al.

HUMAN TRANSLATION

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HOLLOW CATHODE FOR ELECTRON BOMBARDMENT MERCURY ION THRUSTER PULSE IGNITION CHARACTERISTICS

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A high voltage pulse ignitor with positive pulse output of 0.1kV-6kV has been developed. The pulse ignition voltage of the hollow cathode has been measured as a function of pulse width, pulse repeat freguencies and mercury blow rate, respectively. The comparison of the D.C. ignition voltage and pulse ignition voltage has been made under the same operation condition of the cathode. By lowering the cathode operation temperature, two group of photograph of pulse voltage and current waveform during the cathode fire extinction have been taken. Within the test range, the pulse ignition voltage decreases while the pulse width increases and the pulse ignition voltage decreases as a straight line function while the pulse repeat frequency increases. This paper discussed the advantages of the pulse ignition.

([illegible] TRANSLATION, [illegible])

HOLLOW CATHODE FOR ELECTRON BOMBARDMENT MERCURY ION THRUSTER PULSE IGNITION CHARACTERISTICS

Hu Yong-nian, Zhang Shi-linag, Hong Hui-Yen, Sun Yu-Zhu, Ren Ni, and Zhai Xiao-ming

(LanZhou Institute of Physics, China)

I. INTRODUCTION

The 8 cm mercury ion thruster used for an auxiliary propeller of a satellite operates in a discontinued form. According to the whole requirement of the satellite design, the thruster has to operate from thousands to tens of thousands of times during the lifetime of the satellite. In order to guarantee every reliable ignition within each defined time period, between the cathode of the discharge chamber, the cathode of the neutralizer and the collector must have reliable ignition so that the thruster can fire and be put into operation.[1] Reliable firing capability of the cathode is one of the major requirements of the thruster.

Whether the ignition between cathode and collector succeeds or not, mainly depends on the following three parameters : the temperature of the cathode (hot electron emission rate), the mercury blow rate and the amplitude of ignition voltage of the collector. While the cathode undergoes long time operation, the cathode ignition become harder and harder because of the ion bombardment of the cathode and the cathode size change. Then, to ensure reliable ignition, we must make the proper adjustment to the above parameters, find out the ignition parameter relationship, and define the operating range of parameters. This helps the design of thruster and related parts, saves energy supply and propellant, utilizes the cathode reasonably and provides reliable thruster ignition; all of these are quite meaningful.

The use of a low impedance positive pulse ignitor has some advantages over the use of D.C or A.C voltage for cathode ignition. We will describe this later. The earliest pulse ignition experiment of using a hollow cathode of the thruster is G.E. Wintucky of U.S.A.[2] Later, they changed to a low impedance pulse ignitor, by using a different pulse voltage rising rate to measure the relationship of break down voltage and pulse voltage rising rate[3].

This paper mainly introduces the relationship among pulse ignition voltage, pulse frequency, and pulse width, while, by providing the same cathode operation condition, making a comparison between pulse ignition and D.C ignition.

II. Pulse Ignitor

In the past, we used a high voltage DC power supply (0-5kV) for ignition test and a high voltage-high resistance ignition coil (resistance 4.8k) for high voltage pulse ignition. Figure (a) and (b) show the circuit diagram of the two methods. In order to prevent damage to the collector power supply from high voltage, we connected blocking diodes serially to the power supply output terminal of the collector. These blocking diodes have the following shortcomimgs: first, at normal thruster operation, the collector current to the neutralizer cathode is about 0.5 ampere, causing a voltage drop across the blocking diodes and has a power dissipation of 3.5 watts. This is undesirable because of the limited energy source of the satellite. Second, the blocking diodes have a forward voltage which varies with the temperature so the voltage of the collector also varies with environment temperature. The stability of mercury blow rate of a neutralizer cathode is controlled by changing collector voltage. Therefore, the changing of environmental temperature can cause an unstable mercury blow rate of the cathode and finally cause thrust change. This is anothoer disavantage of blocking diodes.

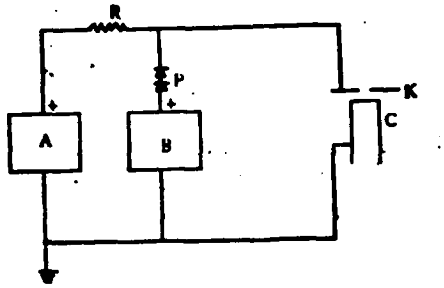


Fig. 1 (a) D.C High Voltage Ignitor Circuit Diagram
A - High Voltage power supply 0-5kV, B - collector, power supply 0-50V, K - collector, C - cathode, R - resistor, P - blocking diodes

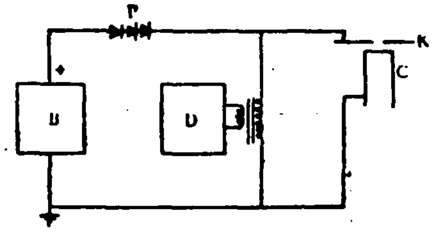


Fig. 1 (b) High Resistance-High Voltage Ignitor Circuit Diagram
K - collector, B - collector power supply 0-50V
C - cathode, P - blocking diodes, D - pulse circuitry

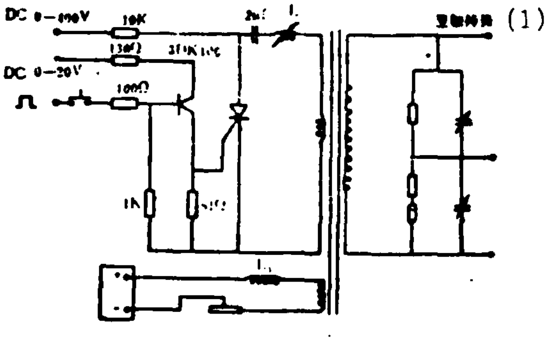


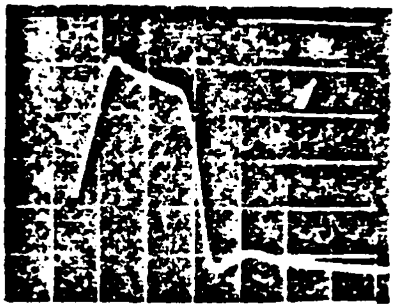
Fig. 2 Pulse ignitor used in the test
Key: (1) to collector

The experimental low impedance pulse ignitor outputs positive pulse. The secondary winding of the pulse transformer is connected serially with the power supply output terminal of the collector. The blocking diodes have been eliminated. Because the resistance of the secondary winding of the pulse transformer is 0.45 ohm, the power dissipation caused by the current of the collector through the secondary winding is under 0.12 watts at the thruster under normal operation. Hence, this method has eliminated the two shortcomings mentioned before. Figure 2 shows the pulse ignitor used in this experiment. The winding ratio of the pulse transformer is 80 : 3. L is the inductance used to adjust the rising time of the pulse so that different widths of the pulse may have the same rising time. Due to the positive pulse, after each pulse, we use L_1 to adjust the residual magnet of the core so that the magnetic core can return to its original operating point. By varying the current of L_1 , we can improve and stabilize the wave form of pulse. The pulse width is mainly adjusted by the capacitance value of the resistor-capacitor voltage divider. The width of the output pulse is between 1.5 micro-second and 2.0 microsecond. The amplitude is between 0.1 kV and 6kV. The repeat frequency is between 1 and 500 Hz. In Figure 3, 1, 2, 3, show different widths of pulse waveform. The choice of the magnetic core has great effects on the waveform.

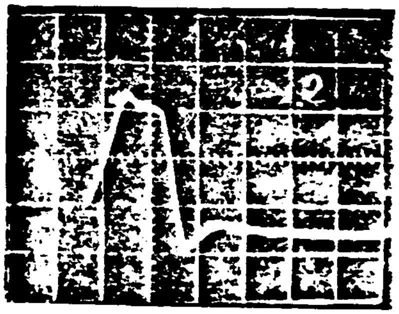
III. Test equipment and methods

Figure 4 shows the circuit diagram for the pulse ignition test. The test is undergone in a vacuum container which is cooled by liquid nitrogen. While in testing, the pressure of the container does not exceed four one-millionths torr. The mercury blow rate is calculated by a precision capillary tube in a fixed time period.

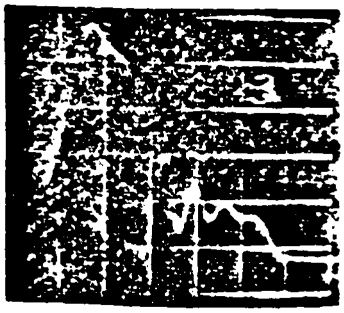
Figure 5 shows the structure of the vacuum cathode used in this test. The cathode of the neutralizer of the 8cm thruster has the same basic structure as that of the discharge chamber cathode except for size of the difference. The cathode is made of a tantalum tube and its top is made of a pure round tungsten disc with a small hole in the center which is welded to the tantalum tube by an electron beam. The collector is made of tantalum. The emitter is made of aluminate tungsten. The cathode heater is made of a rhenium-tungsten filament. Ionized aluminate trioxide is sprayed for insulation purposes. A platinum-rhodium thermo-couple is point-welded into 0.5 millimeter to the surface of the cathode tantalum tube to monitor the surface temperature of the cathode. The temperature is also monitored by a high temperature optic-thermometer. The cathode used in this test is an old one. Because of numerous tests and exposure to atmosphere and being stored under ten times atmospheric pressure when not in use, the emitting capability has decreased significantly.



(a) vertical 400 v/scale, horizontal 5 microsecond/scale



(b) vertical 1 kv/scale, horizontal 5 microsecond/scale



(c) vertical 1 kv/scale, horizontal 2 microsecond/scale

Fig. 3 voltage waveform

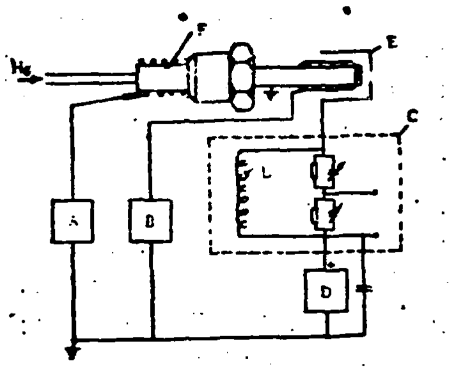


Fig. 4 Pulse ignitor wiring diagram
A - Vaporizer heater power supply, B - cathode heater power supply, C - pulse ignitor, D - collector power supply, E - collector, F - vaporizer, L - pulse transformer secondary winding

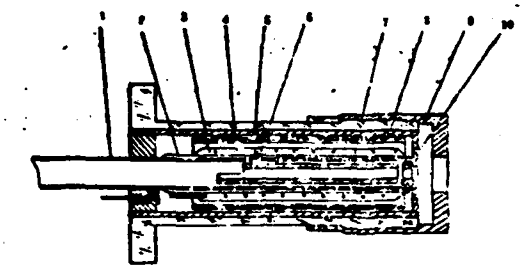


Fig. 5 Cathode structure chart
1 - tantalum tube, 2 - sprayed tungsten layer, 3 - aluminateoxidite layer, 4 - heater, 5 - socket, 6 - emitter, 7 - ceramic tube, 8 - heat grid, 9 - collector, 10 - cathode top

The pulse voltage of the collector is adjusted by hand. At fixed pulse voltage, continuously operate four times via an on-off switch. Each connecting time lasts only at milliseconds range (about hundred millisecond). In the case of not being able to ignite, then the voltage is considered as inadequate voltage. Because of the bombardment of the ion to the cathode, the temperature rises very quickly. In order to avoid causing the temperature of cathode unstable, each fire extinction of cathode has a 3 minute-interval before the next experiment. In addition, a digital millivoltmeter is used for mornitoring cathode temperature.

IV. The Test Result and Discussion

1. The comparison of D.C ignition voltage and pulse ignition voltage

High voltage DC power supply ranges from 0 to 5kV. The collector discharge voltage ranges from 0-50V. In order to prevent the cathode power supply from being broken down by the high voltage power supply, those two are connected in parallel. R is a current limiting resistor, as shown in Figure 1 (a). The test result is shown in Fig. 6. While at the same cathode temperature and mercury blow rate, D.C ignition voltage is lower than that of pulse ignition. Meanwhile as the cathode temperature decreases, the pulse ignition voltage rises more rapidly than D.C ignition voltage. In the test range, the pulse ignition voltage is three to four times that of D.C ignition voltage.

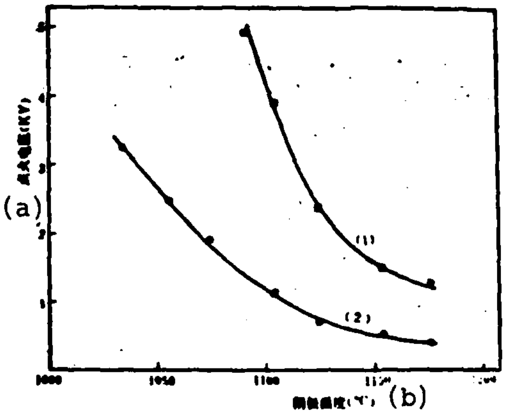


Fig. 6 Comparison of D.C ignition and pulse ignition
blow rate m = 105 ma (equivalent effect)
1 - pulse width τ = 1.5 microsecond, f=80 Hz
2 - D.C
Key: (a) ignition voltage, (b) cathode temperature

2. Relation between pulse ignition voltage and mercury blow rate

Figure 7 shows the relation between ignition voltage and mercury blow rate when using narrower pulse. The variation of the mercury blow rate is controlled by adjusting the temperature of the vaporizer. When pulse voltage varied from 100v to 4kv, the pulse width varied within +/- 0.5 microsecond range. As we can see from this figure , the ignition voltage decreases significantly as the mercury blow rate increases. The curve shows the similar result obtained from the relation between D.C ignition and mercury blow rate.[1] We may observe from this figure that, when the neutralizer cathode ignites, it is better to keep the mercury blow rate over 25 milliamperes if a narrower pulse is used. When the blow rate is over 50 milliamperes, the ignition voltage drops much slower.

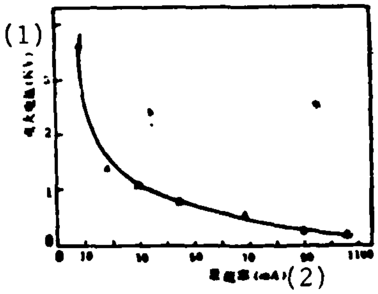


Fig. 7 Relation between pulse ignition voltage and mercury blow rate
pulse frequency: f=20 Hz, pulse width: τ = 1.5 microsecond
cathode temperature: 1159°C
Key: (1) ignition voltage, (2) mercury blow rate

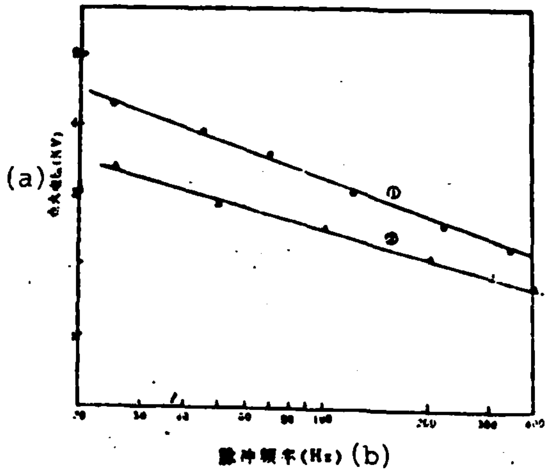


Fig. 8 Relation between pulse ignition voltage and pulse frequencies
cathode temperature = 1154 °C, pulse width: $\tau = 1.5\,\mu s$.
1 - mercury blow rate 28ma (equivalent effect)
2 - mercury blow rate 50.4 ma (equivalent effect)
Key: (a) ignition voltage, (b) pulse frequency

3. Relation between pulse ignition voltage and pulse repeat frequency.

Figure 8 shows the relation between pulse ignition voltage and pulse frequencies. We can see that as the pulse frequencies increase, the ignition voltage decreases in a straight line relationship. The slope of this line has something to with the mercury blow rate. When the mercury blow rate is higher, the slope of the line is smaller. Relating it to figure 7, one may imagine when the mercury blow rate increases to a certain extent, the curve will become leveled if this cathode temperature is kept the same. At this point, the ignition voltage is mainly determined by mercury blow rate and has little to do with pulse frequencies. We can also see from Fig. 8, pulse frequency increases to 10 times, the ignition voltage decreases to 1/2 of the original value.

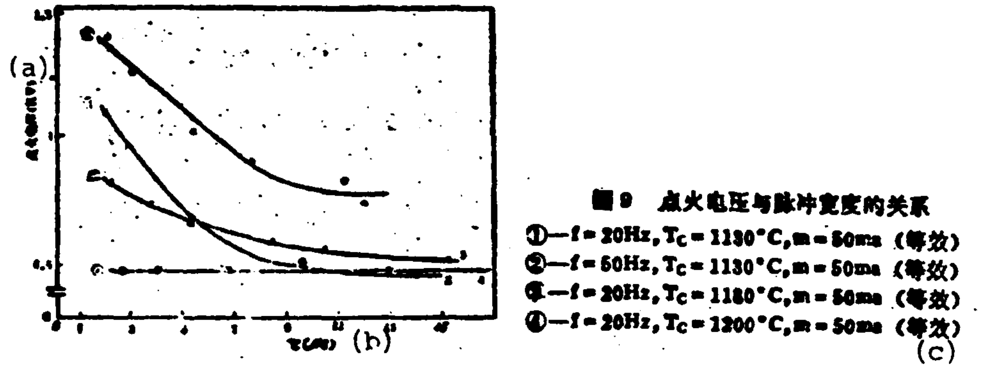


Fig. 9 Relation between ignition and pulse width
Key: (a) ignition voltage, (b) pulse width, (c) equivalent effect

4. Relation between ignition volage and pulse width

Figure 9 shows the relation between the pulse ignition voltage and pulse width at different cathode temperatures. From curve 1, 2, 3, it shows, as pulse width increases, ignition voltage decreases. At a lower cathode temperature, the narrower pulse has a faster ignition voltage decreasing rate. As cathode temperature rises, it turns into the major factor on the ignition. Curve 4 cannot show the effect of pulse width. Curve 1 and 2 again show that as pulse frequency increases , ignition voltage decreases.

During the test of Fig. 9, we considered the effect of voltage rising rate ($\Delta V/\Delta t$) of ignition voltage to the amplitude of the ignition voltage. So we limited $(\Delta V/\Delta t)^{1/2}_{\text{[illegible]}}-(\Delta V/\Delta t)^{1/2}_{\text{[illegible]}}$ to a value of 0.2 range.[3]

We can see from Fig. 9, when the neutralizer cathode ignites, it is better to keep the pulse width from 6 microseconds to 8 microseconds since the wider pulse can not decrease ignition voltage effectively. Reversely, it requires a higher pulse voltage to ignite the cathode when the pulse width is too narrow. Figure 10 and 11 were taken while slowly decreasing the temperature of the cathode which shows the fire extinction voltage and process and the relation between temperaure and pulse width. Two pictures were taken at m=120 ma (equivalent effect), and a repeat frequency of 50 Hz. Photos 4, 6, and 8 were taken at a different pulse width to show voltage and current waveform of fire extinction. Photos 5, 7, and 9 were voltage waveforms after fire extinction of photos 4, 6, and 8 correspondingly. Figure 11 is another set of photos similar to those in figure 10. We can see a common trend from them, i.e., as pulse width changes from wider to narrower, fire extinction voltage and cathode temperature are changing from low to high. Table 1 shows the numerical value from photos.

Conclusion: the test shows this experimental low impedance high voltage pulse ignitor can perform reliable ignition and eliminates the shortcomings of the serially connected blocking diodes.

At same cathode operation condition, pulse ignition voltage is three to four times that of D.C ignition voltage. Within the test range, pulse ignition voltage decreases as the pulse repeat frequency increases in a straight line function; pulse voltage decreases as pulse width increases. To ignite the neutralizer cathode with a mercury blow rate of 50 milliampere(equivalent effect) and using 6 to 8 microseconds pulse width is better.

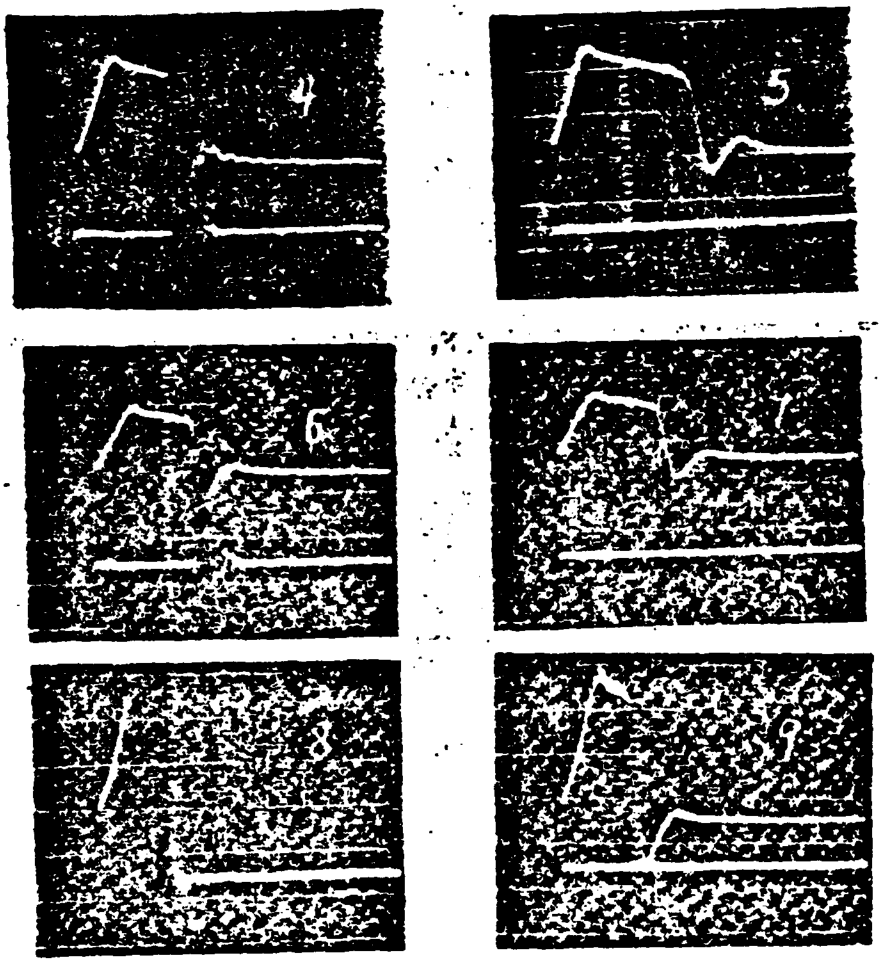


Fig. 10 Voltage and current waveform during cathode fire extinction
Photos 4, 5 (upper) voltage waveform vertical 400v/scale, horizontal 5 microsecond/scale, (lower) current waveform 50 A/scale, horizontal 5 microsecond/scale, photo 6,7,8,9 (upper) voltage waveform, vertical 1KV/scale, horizontal 5 microsecond/scale, (lower) current waveform, vertical 50A/scale, horizontal 5 microsecond/scale

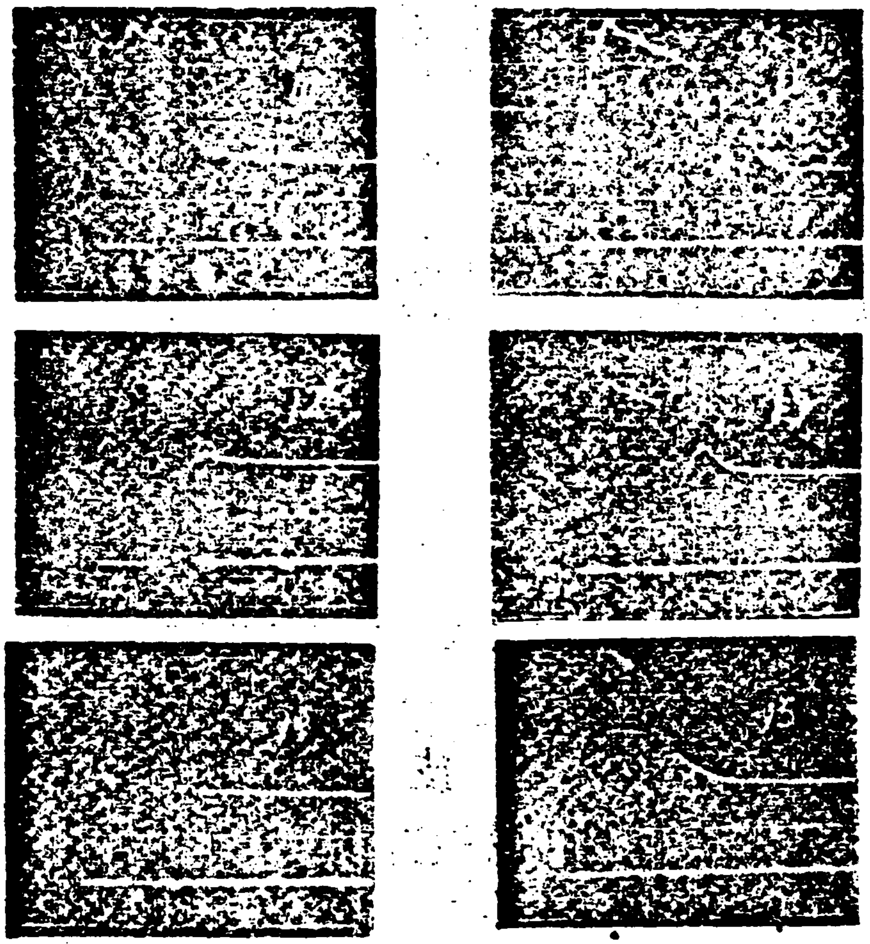


Fig. 11 Voltage and current waveform during cathode fire extinction
Photo 10, 11 (upper) voltage waveform vertical 400v/scale, horizontal 5 microsecond/scale, (lower) currrent waveform vertical 50A/scale, horizontal 5 microsecond/scale, photo 12, 13, 14,15 (upper), voltage waveform 1KV/scale, horizontal 5 microsecond/scale, (lower) current waveform, vertical 50A /scale, horizontal 5 microsecond/scale

	照片编号(1)	脉冲宽度 (μs)(2)	熄火电压 (V)(3)	阴极温度 (°C)(4)
第一组 (5)	4	14	2×400	813
	6	10	1.2×1000	842
	8	7	2.6×1000	864
第二组 (6)	10	13	2.2×400	802
	12	9	1.6×1000	845
	14	6	2.8×1000	865

Table 1 Pulse voltage and cathode temperature during fire extinction
Key: (1) photo number, (2) pulse width (us), (3) fire extinction voltage, (4) cathode temperature, (5) set 1, (6) set 2

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〔2〕 E.G Wintucky, AIAA paper, 1140, 1973

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