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ENERGY REQUIREMENTS FOR THE
INITIATION OF WIRE AND CARBON BRIDGE
PRIMERS CONNECTED ELECTRICALLY IN
PARALLEL OR SERIES

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22 NOVEMBER 1961

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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ENERGY REQUIREMENTS FOR THE INITIATION OF WIRE AND
CARBON BRIDGE PRIMERS CONNECTED ELECTRICALLY IN PARALLEL OR SERIES

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ABSTRACT: In order to gain information about explosive train reliability, carbon bridge and wire bridge primer ignition assemblies were tested in parallel and in series by capacitor discharge. In addition, wire bridge assemblies were tested in parallel and in series by constant current. About twice as much energy was required to fire two carbon bridge assemblies as to fire a single one. It required 2.6 times as much energy by capacitor discharge to fire two wire bridge assemblies as to fire one. Under constant current conditions, two wire bridge ignition assemblies in series required the same current as a single unit but for two in parallel more than twice the current was needed than for a single unit.

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This report discloses information concerning the firing requirements of two ignition assemblies from production lots of Primers Mk 114 and Mk 121 when connected in parallel and in series. This work was carried out in the Explosion Dynamics Division of the Explosions Research Department, Naval Ordnance Laboratory, White Oak, Maryland, in connection with Wep Task RUME-3-E-016/212 1/FO08-10-004, Underwater Initiating Units.

The results of this investigation are intended for the information and use of the Naval Ordnance Laboratory and should be of interest to others working with electro-explosive devices.

W. D. COLEMAN
Captain, USN
Commander



C. J. ARONSON
By direction

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ENERGY REQUIREMENTS FOR THE INITIATION OF WIRE AND CARBON BRIDGE PRIMERS CONNECTED ELECTRICALLY IN PARALLEL OR SERIES

INTRODUCTION

1. Most modern weapons contain electro-explosive devices whose functioning reliabilities affect the overall weapon reliability. Most production lot primers have about 99.8 percent functioning reliability at a 95-percent confidence level. The 0.2 percent of unreliability is considered to be too great for many of our new weapon systems. To increase the reliability of a weapon an explosive train containing two primers (or detonators) is usually incorporated into the design with planned redundancy.

2. Considerable data are available on the energy required to initiate a single given electric initiator (1). When designing a dual initiator train, the assumption usually has been made that the energy requirement will be twice that which is necessary for a single unit. This assumption has been made with considerable reservation because of a lack of substantiating data. However, it appeared to be not too unreasonable a first approximation.

3. The purpose of this project was to study several typical primers to determine the energy required to initiate them when connected electrically singly, and as two identical units in parallel or in series. The methods of delivering the energy were by capacitor discharge and by constant current applied for a fixed time. Two electric primers were chosen for study; the Primer Mk 114 Mod 0, a wire bridge item; and the Primer Mk 121 Mod 0, a carbon bridge item. Since only the firing characteristic was of interest, only the response of the ignition assemblies (Figures 1 and 2) of each primer was considered in the tests.

4. The Primer Mk 114 Mod 0 Ignition Assembly consists of two insulated copper wires twisted together in a molded plastic plug. The wires extended up out of the plug approximately 0.07 inch. These leads are bridged with an 0.005-inch diameter nichrome wire with an effective length of about 0.025 inch. The bridge has a resistance range of 3 to 7 ohms. This bridge is loaded with a mixture of (75/25) DDNP/potassium chlorate as a buttered charge.

THE PRIMER MK 114 MOD O IGNITION ASSEMBLY TESTS

Capacitor Discharge Firing

5. The capacitor discharge tests on the ignition assemblies were made using the equipment arrangement shown in Figure 3. The statistical response of the ignition assembly to the energy stored in the capacitor was determined by the Bruceton Sensitivity Test (2) assuming a log normal distribution for the response of the ignition element to the initiating energy. The capacitance was varied and the potential held constant for each test.

6. Each Bruceton test was run using a sample size of 50 which gives a reasonably good estimate of the mean firing energy. Values of the standard deviation were also obtained from the Bruceton test runs and used to calculate the energy associated with 0.001 and 0.999 probability of functioning. While the mean firing energy is established with good precision the estimate of the standard deviation with a sample size of 50 is probably not too accurate. Consequently, the mean firing energy and not the extreme points of the distribution is best for making comparisons in analyzing the test results. (In addition, it has been shown for at least one conventional wire bridge electro-explosive device that the log normal distribution does not accurately predict the tails of the distribution(3) although the mean of the distribution is precisely known.)

7. In the dual initiator arrangement two firing criteria were used:

Both ignition assemblies had to function to be considered a fire.

Only one ignition assembly had to function to be considered a fire.

The input current to and the voltage across each assembly during firing were monitored by a dual beam oscilloscope. The test program was arranged to consider each criterion in separate tests.

8. Single Item Firing. A random sample of ignition assemblies was selected from the production lot for the testing. The results of tests to determine the response of a single item to different initiation energies delivered by capacitor discharge for potentials of 5, 15, 30, 50, and 100 volts are shown in Table 1 and graphically in Figure 4. Only 50 percent response conditions are shown in the Figure. Figure 5 shows a typical oscillogram of the firing

of a Primer Mk 114 Mod O Ignition Assembly by capacitor discharge. The open circuit oscillation on the voltage trace is caused by the burning out of the bridgewire. Its location on the curve is heavily dependent on the RC time constant of the firing circuit.

9. Firing of Two Items in Series. Samples were taken at random from the production lot. Two ignition assemblies were connected in series and tested in Bruceton tests for response to different initiation energies delivered by capacitor discharge for potentials ranging from 5 to 80 volts. Two series tests were performed; one on the basis of the single fire criterion, the other on the basis of the two fire criterion. The results of the testing are given in Table 1. Plots of the 50 percent response energies as functions of capacitor potential are shown in Figure 4. The data show that two ignition assemblies connected in series (considering the "double-fire" criterion) required approximately 2.57 times the energy to fire when compared to a single ignition assembly, while for the "single-fire" criterion, approximately 1.74 times the single ignition assembly energy is required.

10. Firing of Two Items in Parallel. Samples were collected at random from the production lot. Bruceton tests for response to different initiating energies delivered by capacitor discharge were run with two ignition assemblies connected in parallel. The range of initial capacitor potentials for which the tests were run extended from 5 to 100 volts. Two series of tests, one for each of the two firing criteria discussed above, were run. The results of the firings using both criteria are given in Table 1, and plots of the energies to produce initiation 50 percent of the time are shown in Figure 4. It can be seen that two ignition assemblies connected in parallel, considering the "double-fire" criterion, required approximately 2.57 times as much energy to fire as a single ignition assembly. For the "single-fire" criterion two assemblies connected in parallel required 1.88 times as much energy as a single ignition assembly.

Constant Current Firing

11. Primer Mk 114 Mod O Ignition Assemblies were also subjected to constant current initiating signals to determine their response to this form of initiating energy. The constant current apparatus functioned so that the current was started with a direct short across the ignition assembly. The short was removed and the current allowed to flow through the ignition assembly for approximately 15 seconds. By starting the current through an auxiliary short, the transient surges which occur during the starting period and which give erroneous results were eliminated (4).

12. The ignition assemblies were tested singly, two in a series, and two in parallel for response to firing current. The criterion for a fire in the series and parallel cases was at least one of the assemblies firing. In these tests a given number of test setups were subjected to a fixed current for the 15-second time period and the percentage of fires occurring was recorded (Table 2). These data were then used to develop the firing distribution functions given in Figure 6. It is to be noted that under the criterion used two ignition assemblies connected in series require less current than a single ignition assembly. With two ignition assemblies in parallel approximately 2.3 times as much current is required for a single ignition assembly to assure initiation at a given level of response.

13. It was felt desirable also to measure "ignition lag" time in the ignition assemblies. A timing system was designed to determine the functioning time of the ignition assemblies. A barium titanate crystal was used in conjunction with a clipper circuit to trigger the timer stop circuit. The crystal stop probe is shown in Figure 7. The clipper circuit was used to limit the potential spikes from the crystal to 70 volts. The delay time of the thyatron circuit was approximately 1.7 microseconds.

14. "Ignition-lag" time was determined as a function of the constant current amplitude. A graphical representation of the data is shown in Figure 8. The single, series, and parallel circuits all indicated an increase of "ignition-lag" time with a decrease of current. The higher current values also give a lesser spread of ignition lag times. The "ignition-lag" time measured is the inherent delay time required for the functioning of an explosive unit or units, as the case may be, when a pulse of current of indicated amplitude is passed through the bridge.

THE PRIMER MK 121 MOD 0 IGNITION ASSEMBLY TESTS

15. The Primer Mk 121 Mod 0 Ignition Assembly consists of two insulated copper wires twisted together in a molded plastic plug. The gap between the wires caused by the insulation is made conductive with an aquadag spot. The spot is then covered with a charge of normal lead styphnate in a lacquer binder. The resistance of the ignition assembly varies between 750 and 15,000 ohms.

16. The Primer Mk 121 Mod 0 Ignition Assembly was tested by capacitor discharge using the same apparatus, test method, and criteria for firing as were used for the Primer Mk 114 Mod 0 Ignition Assembly. Random samples were collected from the production lot and tested by the Bruceton plan singly, in parallel,

and in series. The results are given in Table 3. Conditions for initiation 50 percent of the time are plotted in Figures 9, 10, and 11. Comparison of the curves shows that it takes slightly more than twice as much energy to reliably initiate two ignition assemblies in a parallel circuit than it does to initiate one. Also, that the minimum firing voltage is slightly higher to fire two ignition assemblies in parallel than it is to fire one primer.

DISCUSSION

17. The wire bridge Primer Mk 114 Mod O Ignition Assemblies exhibited firing characteristics about as expected. As given by Table 1 and Figure 4, the capacitor discharge tests were all run in the "adiabatic region"--the region where the firing energy is independent of the delivery time.

When two ignition assemblies are connected in series or in parallel, it is expected that to fire a single ignition assembly will take more stored energy than necessary to fire a single ignition assembly alone. This is so because there is an energy division between the two bridges. Further, since the bridge resistances are about equal and do not change appreciably during firing, and since only the most sensitive of the pair of primers must fire, it is expected that somewhat less than twice the energy required for a single ignition assembly must be provided.

For both fire criterion, results again were in line with expectations. Since both ignition assemblies must fire the least sensitive of the pair will control the necessary input. This is so because the bridgewires require more than just the ignition energy to burn out and both will be conducting during the entire firing period.

18. The constant current results for the series case were also in line with expectations.

When two ignition assemblies are connected in series and only one must fire the most sensitive of the pair will determine the current which must flow and this on the average will be less than the current required for a single ignition assembly alone.

The case of two ignition assemblies in parallel is not as clear cut. The same current does not flow through both units unless their resistances are identical (usually not the case). The lower resistance item will pass a larger current than the higher resistance item. Apparently, the

current division in the circuit and the current sensitivities of the ignition assemblies are so related that the less sensitive of the two items fires. This would account for a current requirement for the circuit of somewhat more than twice that for a single ignition assembly alone.

19. The results with the carbon bridge ignition elements were not as expected. The situation here is somewhat complex since there is a large variation in resistance from unit to unit and in addition firing is accompanied by very large changes (lower resistances) in resistance. Be this as it may, the fact that the same energy per ignition assembly was needed for firing regardless of the circuit arrangement indicates that a mechanism other than resistance heating is responsible for firing. Such a point of view is not inconsistent with the observation of others; and initiation by a local sparking or arcing mechanism has been suggested and appears consistent with the results obtained.

CONCLUSIONS

20. The following conclusions are drawn:

Firing of one of two Primer Mk 114 Mod 0 Ignition Assemblies by capacitor discharge in either series or parallel requires about 1.7 to 1.9 times the energy to fire a single ignition assembly alone.

Capacitor discharge firing of both of the two ignition assemblies in parallel or series requires about 2.6 times as much energy as that for firing a single assembly alone.

Firing of one of two Mk 114 Primer ignition assemblies in series requires less current than for firing a single ignition assembly alone.

Constant current firing of one of two Primer Mk 114 ignition assemblies connected in parallel requires more than twice the current needed to fire a single ignition assembly alone.

The above observations could be expected from simple circuit analysis and wire bridge electro-explosive device operation.

21. The results for the Primer Mk 121 Mod 0 Ignition Assemblies indicate that it takes about the same energy to fire an ignition assembly regardless of whether it is used singly or is in a series or parallel circuit. This suggests that a mechanism other than straight resistance heating is causing ignition. A local arcing or sparking mechanism seem reasonable.

Table 1

The Energy Requirements for Firing
the Primer Mk 114 Mod O Ignition Assembly

Circuit Arrangement	Sample Size	Potential (volts)	Energy to Fire (in ergs)		
			0.1% of the time	50% of the time	99.9% of the time
Single Item	50	5	1010	1700	2480
	50	15	840	1790	3630
	50	30	1350	1920	2800
	50	50	1140	1800	2650
	50	100	1345	2075	3200
Two Items in Series (Single-Fire Criterion)	50	5	1800	3190	5650
	50	15	2452	3015	3700
	50	30	1990	2950	4370
	50	50	2125	3040	4350
	50	80	2380	3260	4480
Two Items in Series (Double-Fire Criterion)	50	5	3110	4740	7190
	50	15	2770	4100	6090
	50	50	2240	4450	8830
	50	80	3260	4450	6048
Two Items in Parallel (Single-Fire Criterion)	50	5	1795	3205	5725
	50	15	2010	3300	5390
	50	30	1870	3400	6165
	50	50	2750	3325	4025
	50	80	1700	3650	7710
Two Items in Parallel (Double-Fire Criterion)	50	5	2155	4530	9520
	50	15	2680	4230	6690
	50	50	2960	4575	7087
	50	100	2830	5150	9300

Table 2

Constant Current Firing of Primer
Mk 114 Ignition Element

<u>Current (milliamperes)</u>	<u>Sample Size</u>	<u>Circuit Arrangement</u>	<u>Percent Fired</u>
80.0	20	Single Primer	5
85.0	20	Single Primer	30
87.5	20	Single Primer	70
90.0	20	Single Primer	90
95.0	20	Single Primer	100
80.0	15	Two-Series	6.7
85.0	20	Two-Series	70
90.0	20	Two-Series	100
197.0	20	Two-Parallel	30
200.0	20	Two-Parallel	60
210.0	20	Two-Parallel	95
217.0	10	Two-Parallel	100

Table 3

The Energy Requirements for Firing
the Primer Mk 121 Mod 0 Ignition Assembly

Circuit Arrangement	Sample Size	Potential (volts)	Energy to Fire (in ergs)		
			0.1% of the time	50% of the time	99.9% of the time
Single Item	50	18	420	720	1220
	50	20	96	378	1492
	50	25	80	150	290
	50	30	15	90	530
	50	50	73	80	90
Two Items in Series (Single-Fire Criterion)	50	30	350	2400	16,425
	50	40	320	540	890
	50	50	280	360	470
	50	60	15	95	680
	50	70	10	110	1400
Two Items in Series (Double-Fire Criterion)	50	30	60	4440	30,700
	50	40	70	690	6920
	50	50	60	410	2915
	50	60	60	200	640
	50	70	30	165	820
Two Items in Parallel (Single-Fire Criterion)	50	17	100	590	3310
	50	20	40	230	1020
	50	30	42	98	230
	50	40	35	73	150
	50	50	34	84	210
	50	60	11	104	990
	50	70	34	100	290
Two Items in Parallel (Double-Fire Criterion)	50	20	210	1370	8960
	50	30	10	270	1026
	50	40	48	230	970
	50	50	20	210	2175
	50	60	60	220	830
	50	70	27	200	1475

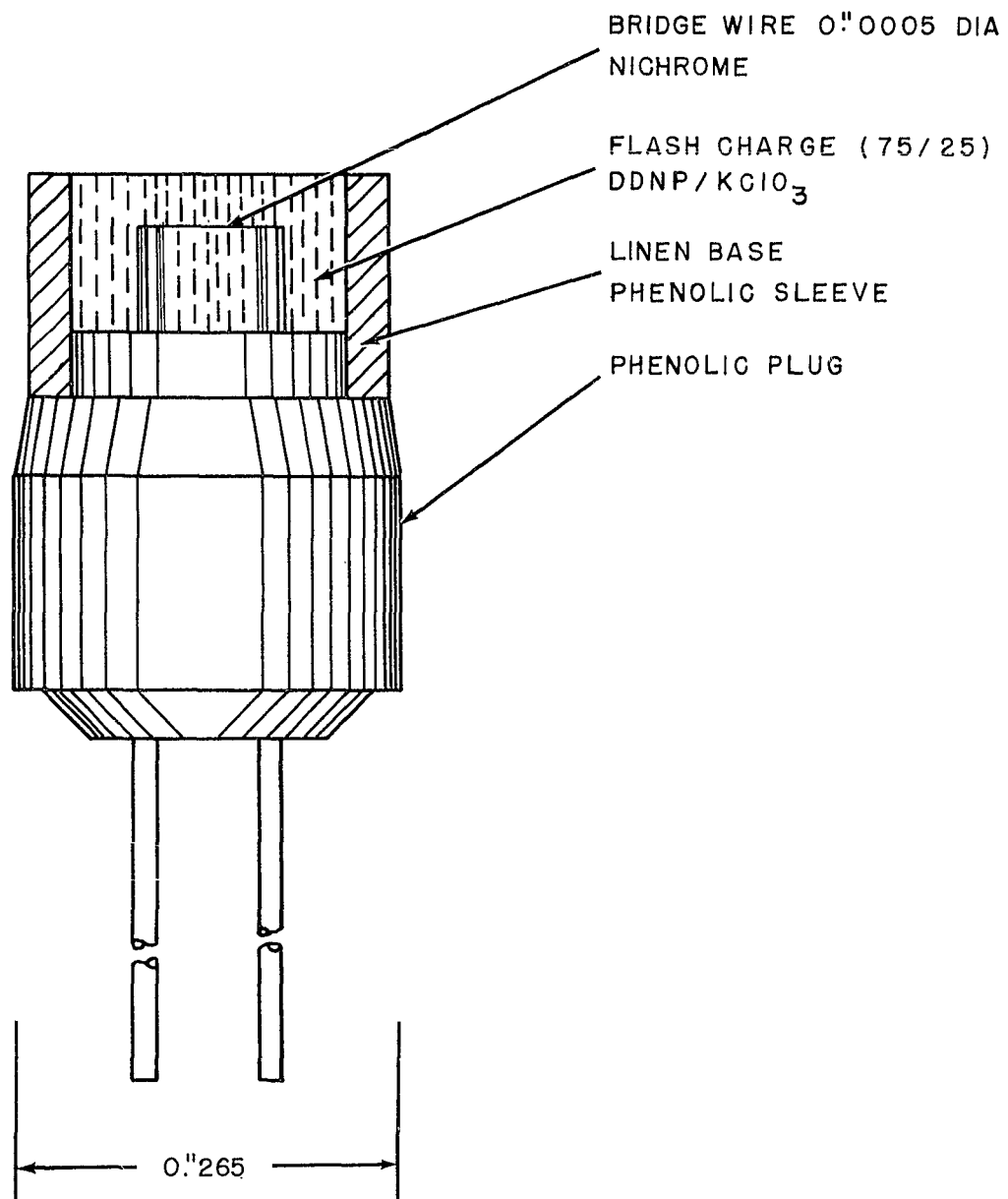


FIG. 1 PRIMER MK II 4 MOD. 0 IGNITION ASSEMBLY

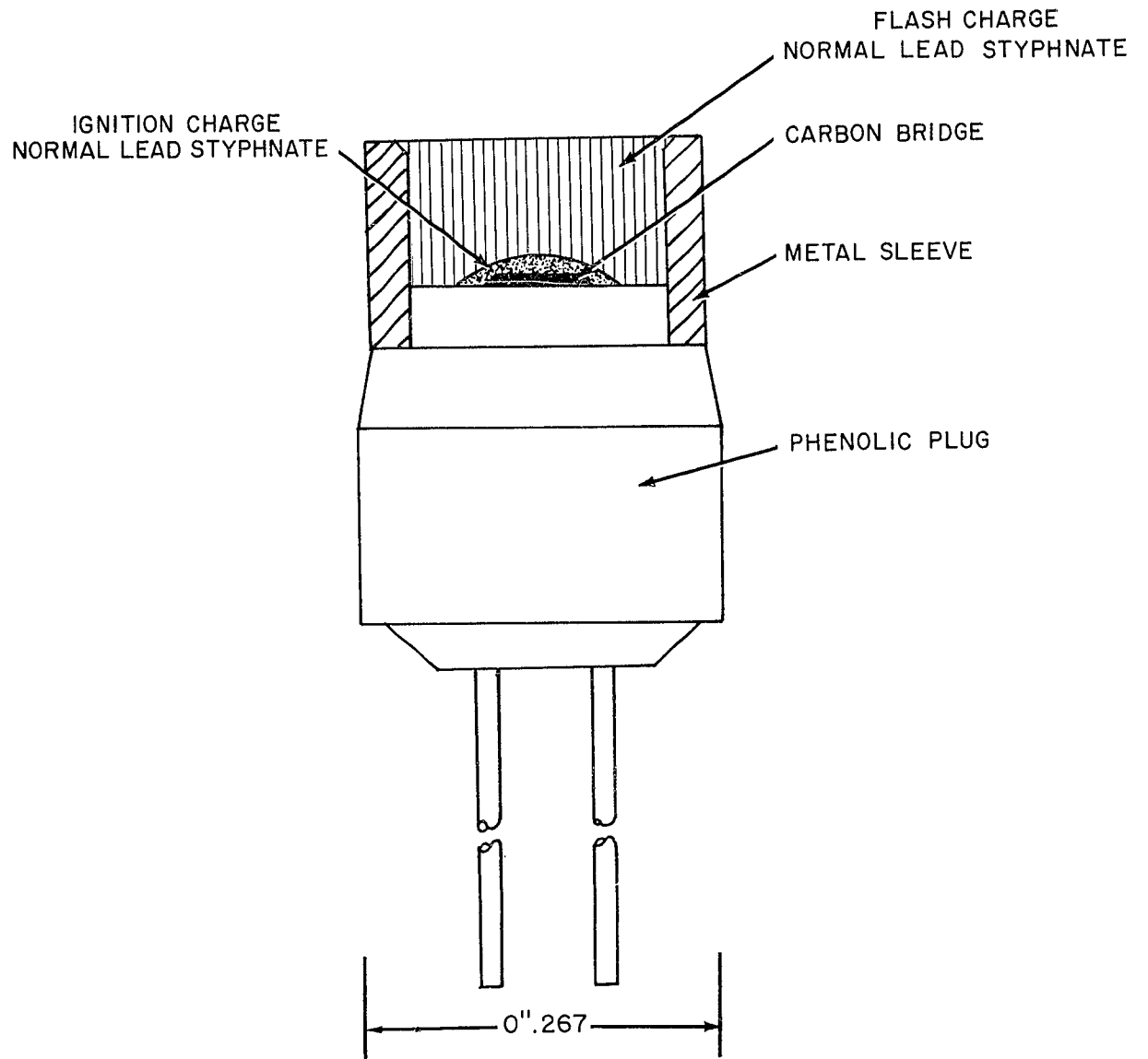


FIG. 2 PRIMER MK121 MOD 0 IGNITION ASSEMBLY

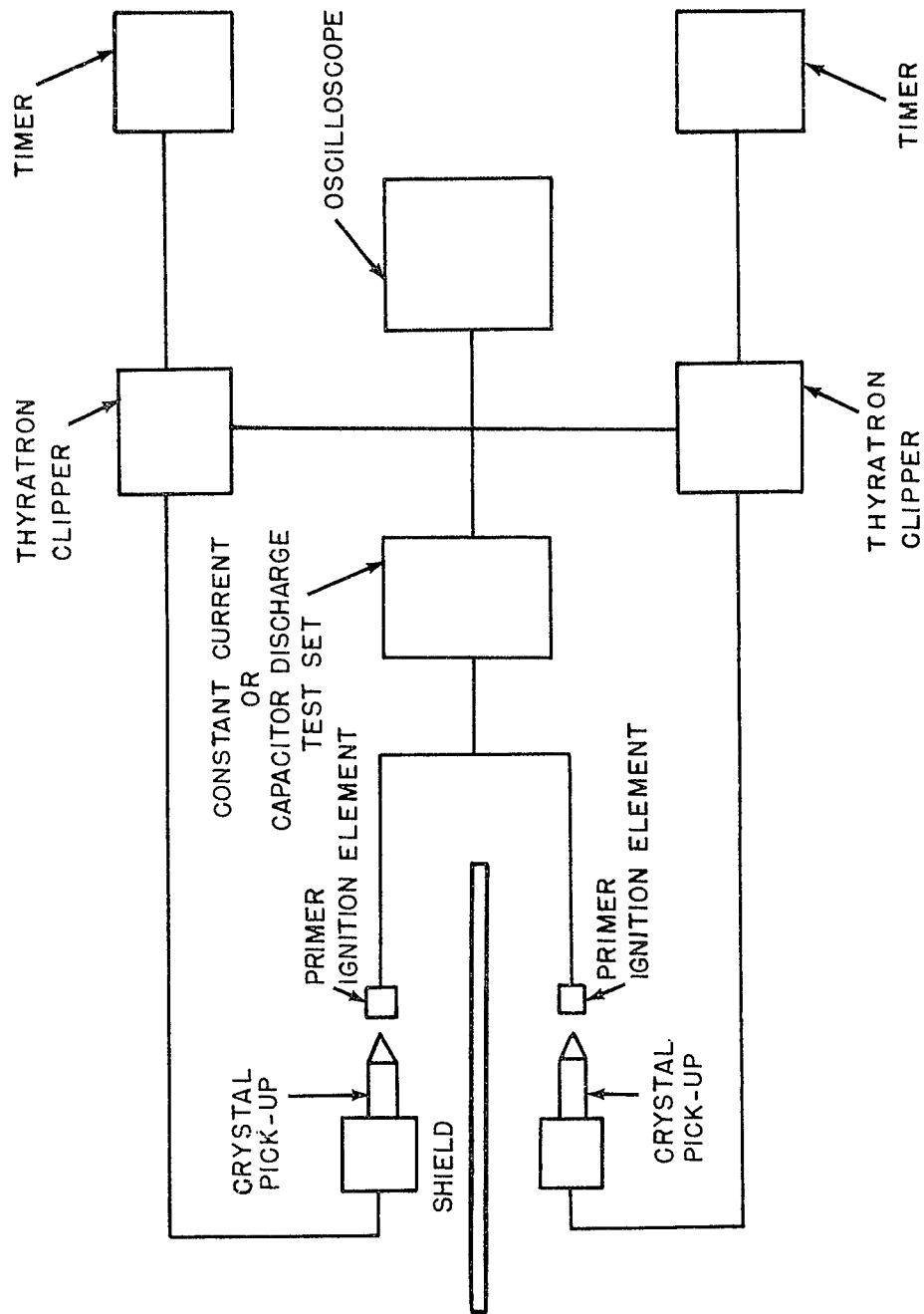


FIG. 3 MULTIPLE FIRING CIRCUIT ARRANGEMENT

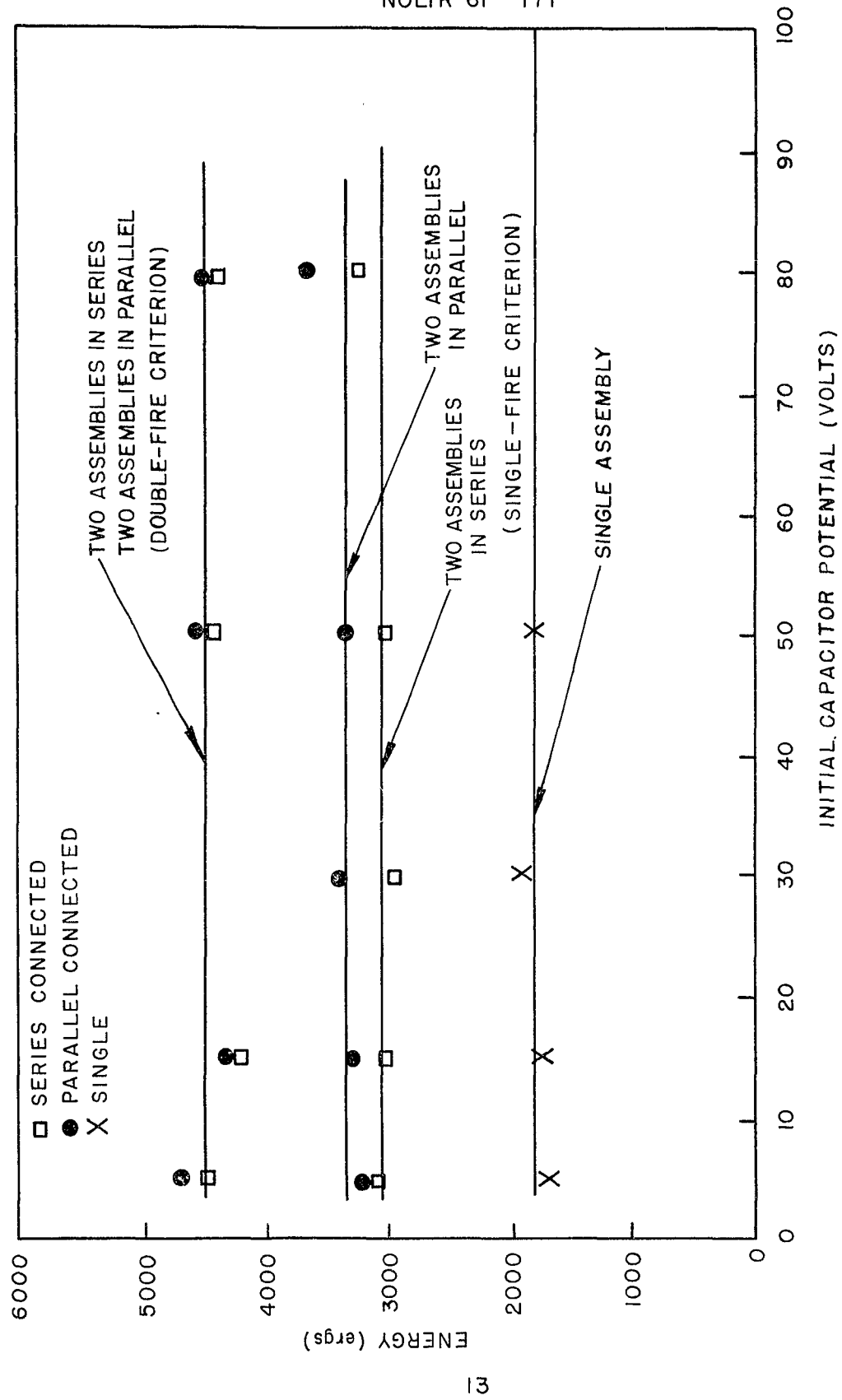


FIG. 4 ENERGIES AT WHICH 50 PERCENT OF THE PRIMER MK 114 MOD. 0 IGNITION ASSEMBLIES FIRE FROM CAPACITOR DISCHARGE INITIATION

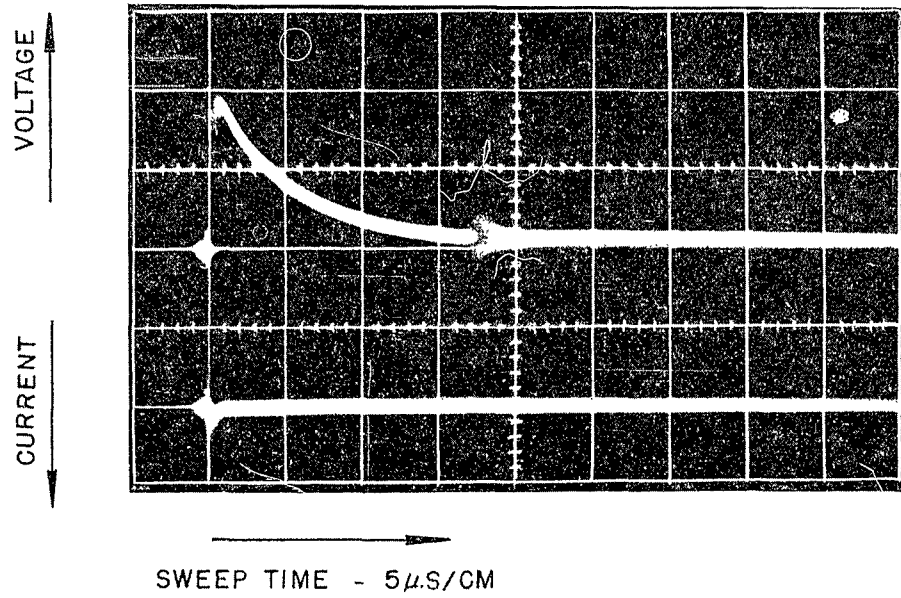


FIG. 5 TYPICAL CAPACITOR DISCHARGE CURVE FOR THE
PRIMER MK 114 MOD. 0 (PRIMER FIRE)

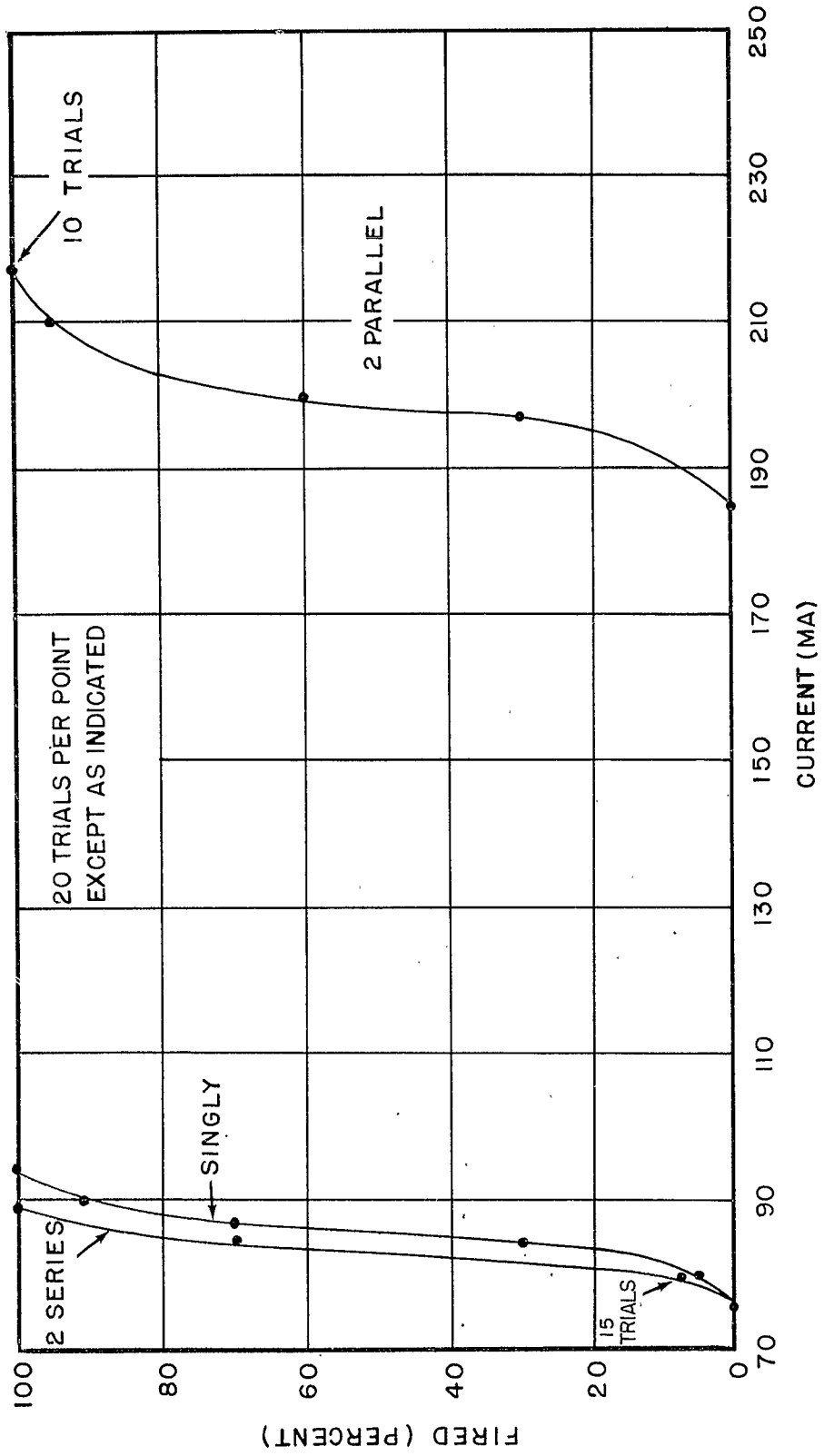


FIG. 6 FIRING OF PRIMER MK114 MOD 0 IGNITION ASSEMBLY
AS A FUNCTION OF CURRENT

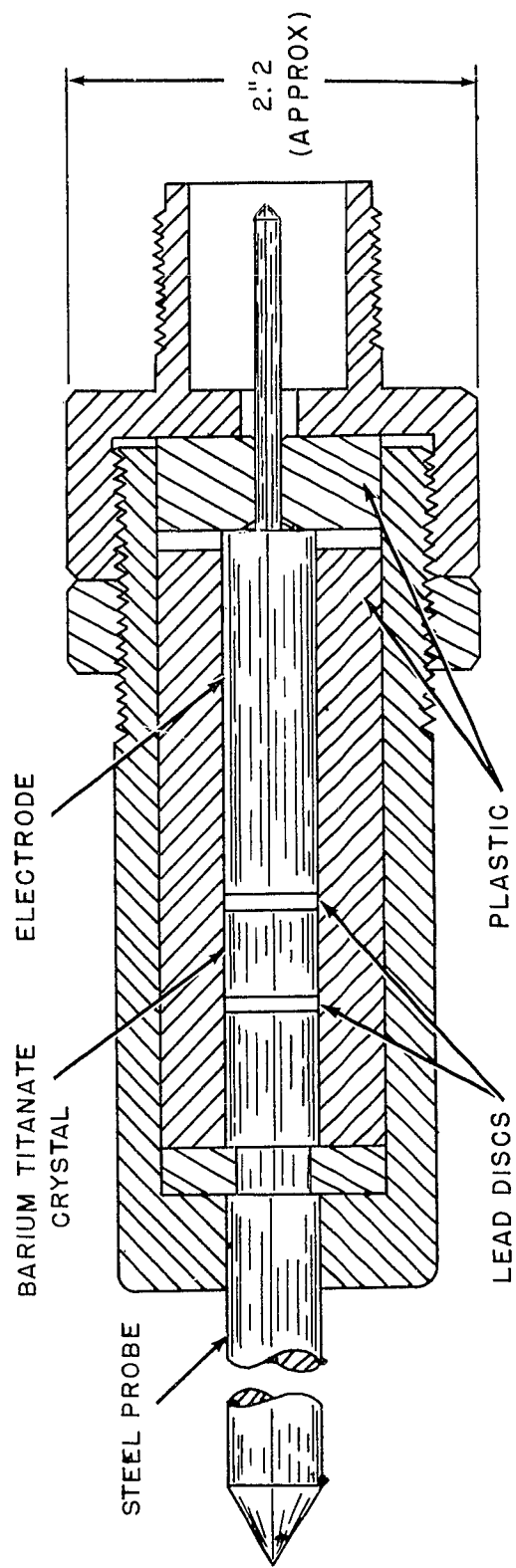


FIG. 7 CRYSTAL PICKUP ASSEMBLY

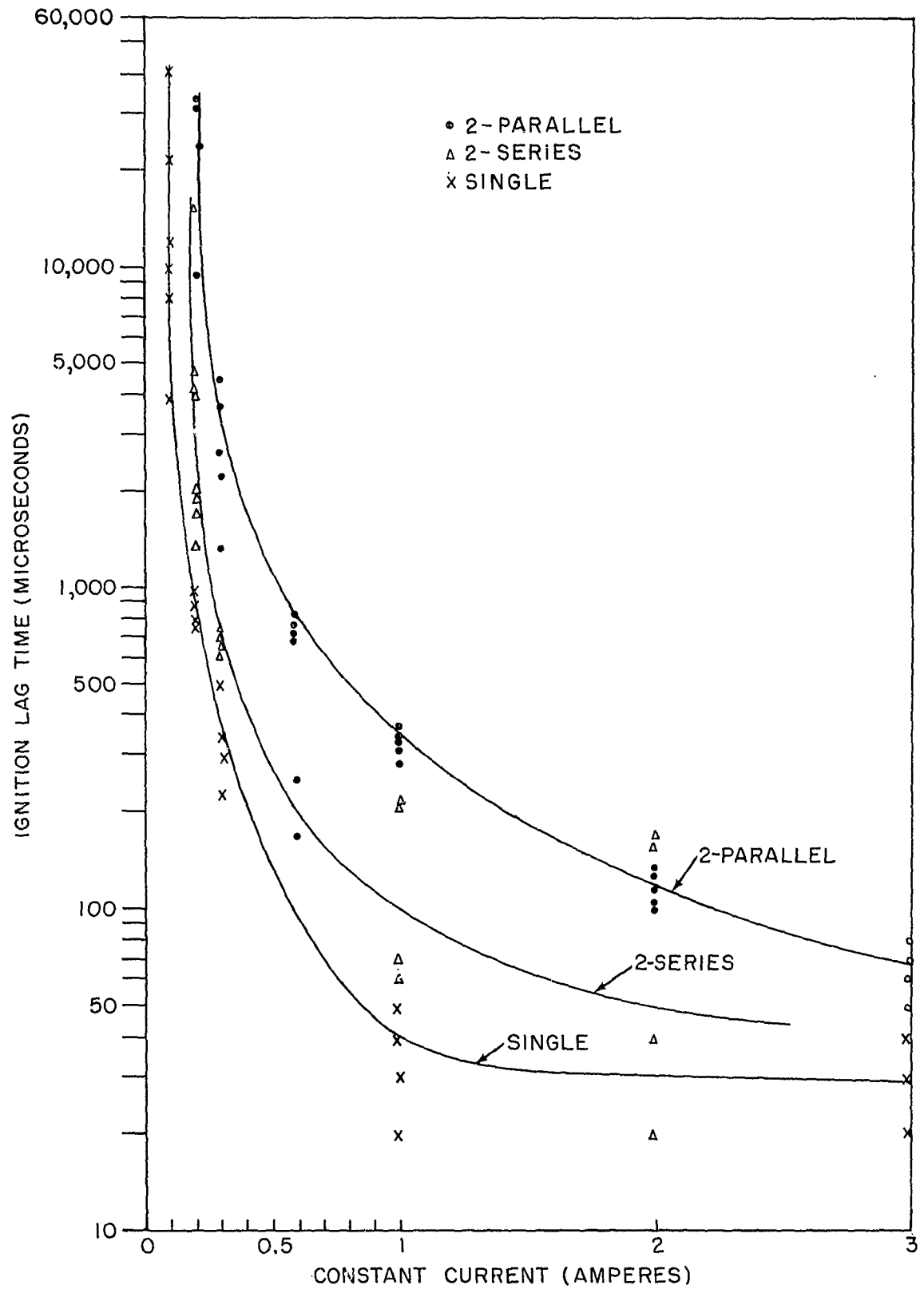


FIG.8 THE IGNITION LAG TIME OF THE PRIMER MK114 MOD 0 IGNITION ASSEMBLY AS A FUNCTION OF CURRENT

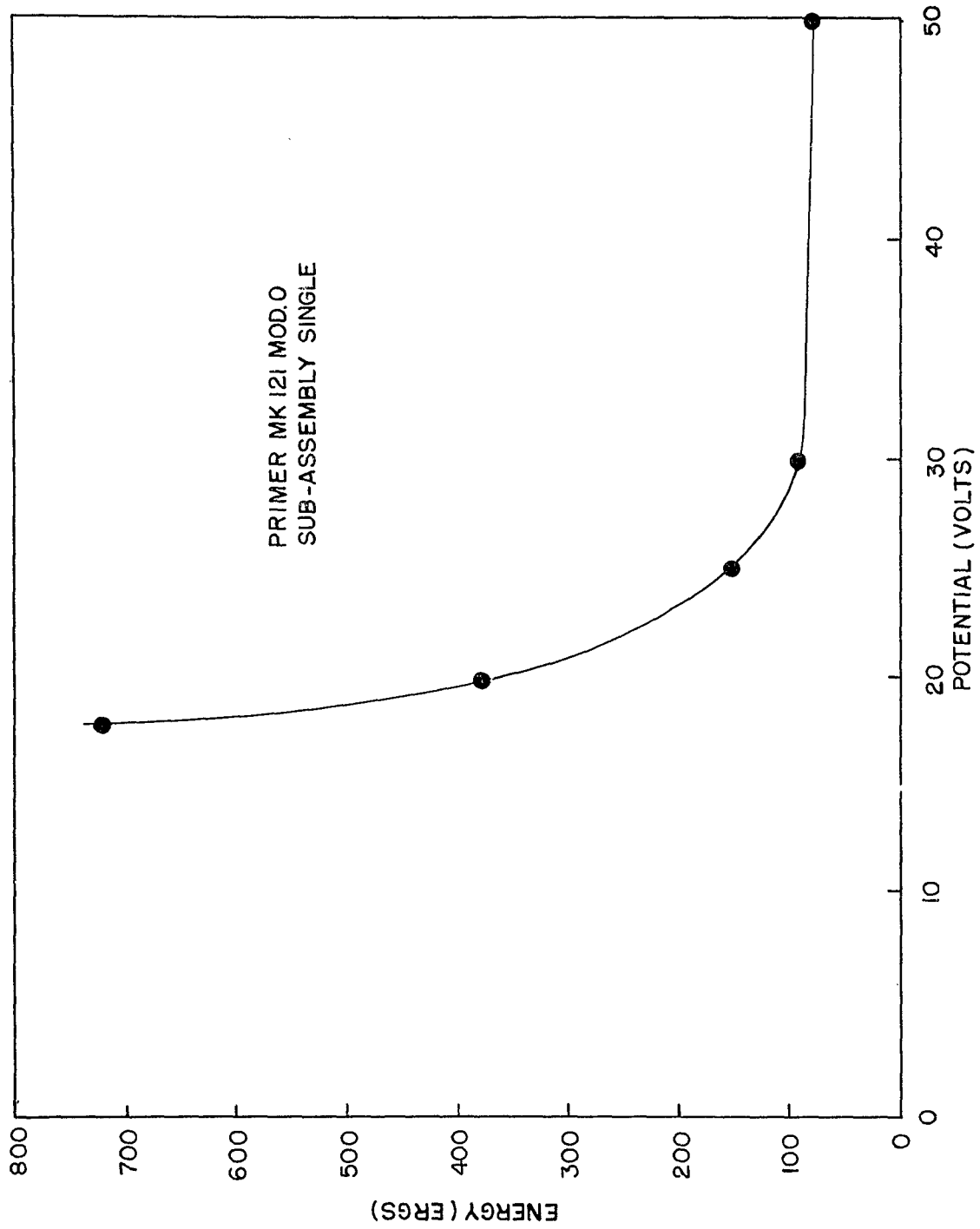


FIG. 9 THE MEAN ENERGY REQUIREMENT AS A FUNCTION OF THE
POTENTIAL, PRIMER MK 121 MOD. 0 IGNITION ASSEMBLY

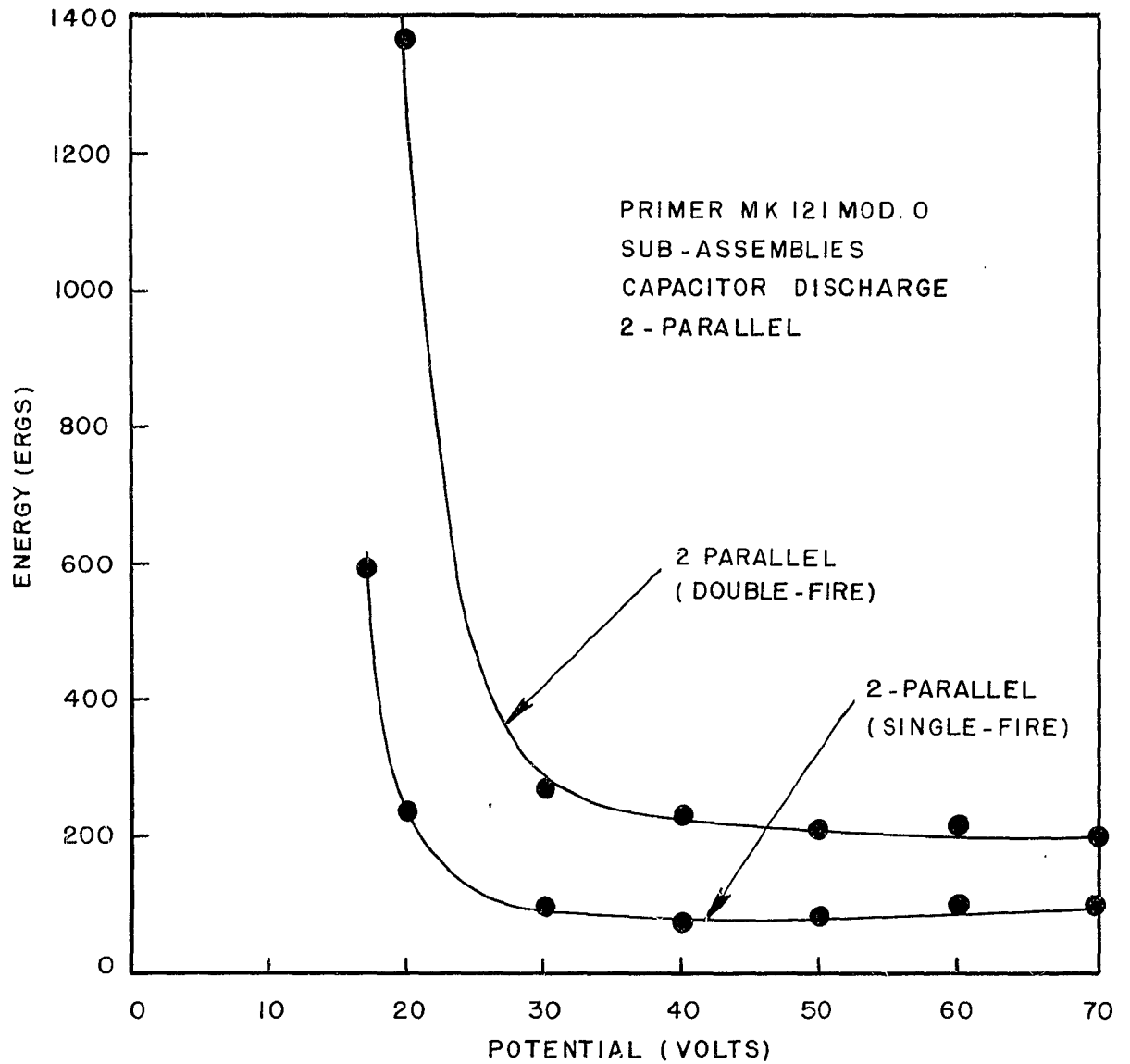


FIG. 10 THE MEAN ENERGY REQUIREMENT AS A FUNCTION OF THE
POTENTIAL PRIMER MK 121 MOD 0 IGNITION ASSEMBLY

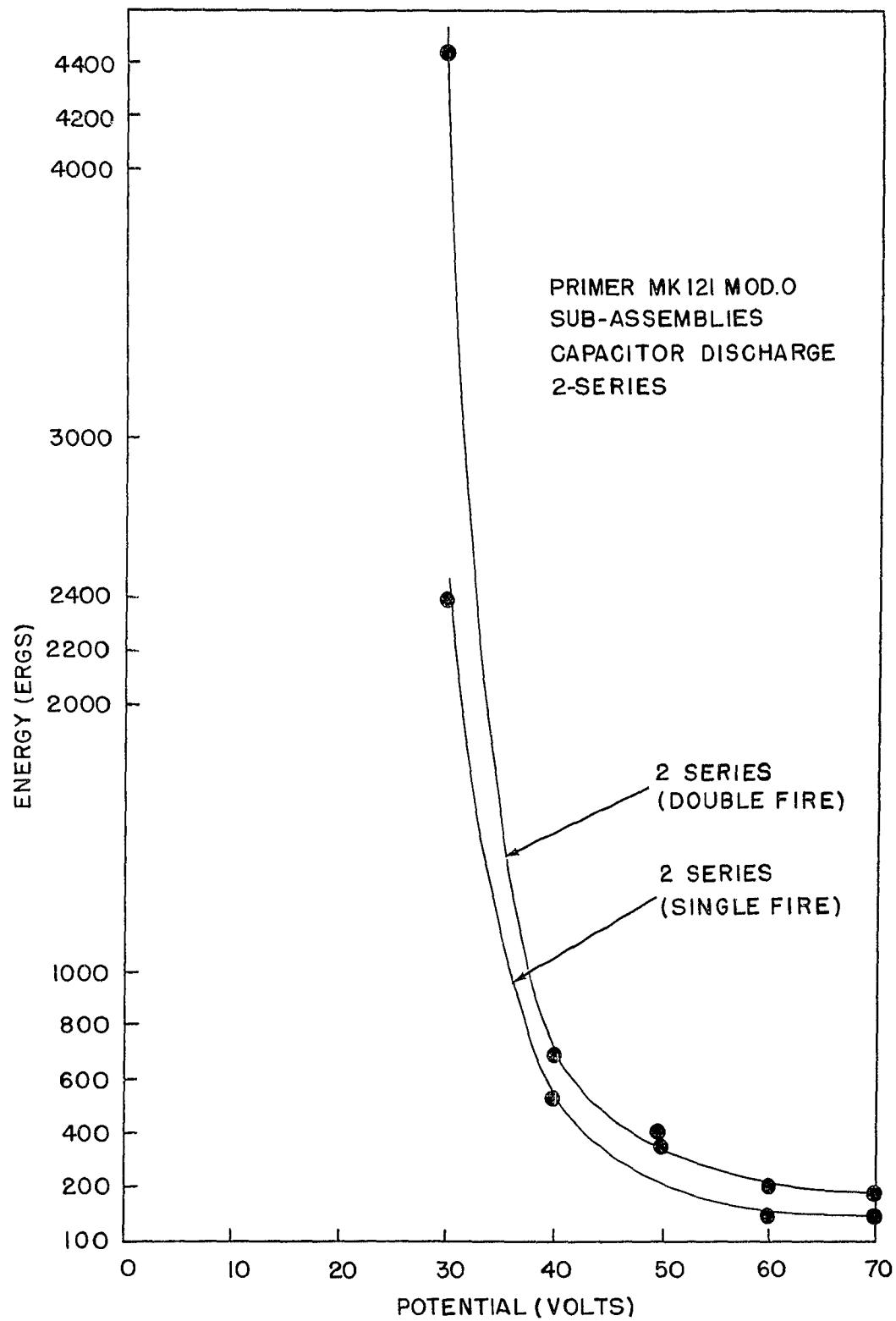


FIG.II THE MEAN ENERGY REQUIREMENT AS A FUNCTION OF THE POTENTIAL
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