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AXO DETONATOR

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June, July, August 1969
Purchase Order Nos. 9316-75 & 9316-77

An investigation of some of the factors affecting performance of a coaxial type spark gap detonator.

ABSTRACT

A factorial spark gap detonator study is presented, with the results. UK PETN, (MF 81/10, 6200 cm²/g) at 1.12 g/cm³ had a higher voltage breakdown and a higher power deposition than others in the test.

A somewhat unusual firing system employed for these tests is described.

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DISCUSSION

A factorial type experiment was performed on AXO type detonators with 10-mil electrode spacing using preaged powders. The three-factor, three level experiment was performed for the purpose of determining the effect of specific surface areas (or particle sizes), density, and energy input (including rate of energy input) upon various dependent variables. The independent factors and the levels of each are outlined in Table I.

The fire set used for the tests was a triggered spark gap type with a modified output, shown schematically in Fig. 1. The output circuit capacitor C_2 , which electrically parallels the AXO detonator, is charged through the 15-ohm resistor by capacitor C_1 upon triggering the spark gap. By adjusting the value of C_2 one can control the slope of the voltage ramp as seen by the AXO detonator. This somewhat unorthodox fire set was chosen so that voltage profile could be monitored and power profile calculated.

The current contributed by capacitor C_1 , the current contributed by capacitor C_2 , di/dt of C_2 mixed with the AXO output pin pulse, and voltage across the AXO were recorded on Tektronix 519 oscilloscopes. A typical set of film records—PX PETN 8220 at 1.00 g/cm^3 fired with capacitor C_2 of $0.04 \mu\text{f}$ —is shown in Fig. 2. The currents were summed to obtain the total current through the AXO. Transmission time (t_e) was measured from voltage breakdown to pinswitch ionization using records 3 and 4; the fiducial marked was used for time orientation between the two records. Voltage breakdown is defined as the breakover point between the semi-linear voltage ramp and the exponential decay (sum of two exponentials each due to one of the capacitors discharging through the AXO).

Table I

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<u>Factors</u>	<u>Level I</u>	<u>Level II</u>	
Capacitance	.01 μ f	.02 μ f	.04 μ f
Powder Type	PX PETN 8227*	PX PETN 8220 [†]	UK PETN MF/81/10
Density	0.88 g/cm ³	1.00 g/cm ³	1.12 g/cm ³

*Preaged 96 hrs. @ 100°C, $S_o^p = 3200 \text{ cm}^3/\text{g}$ (FSSS), average particle diameter = 9.5 μ , LRL Quarterly Report for July, August, September 1968

[†]Preaged 300 hrs. @ 100°C, $S_o^p = 4500 \text{ cm}^3/\text{g}$ (FSSS), average particle diameter = 7.45 μ , LRL Quarterly Report for July, August, September 1968.

^{††}Preaged 300 hrs @ 100°C, $S_o^p = 6200 \text{ cm}^3/\text{g}$ (FSSS), average particle diameter = 5.5 μ , Sandia Quarterly Report for September, October, November 1967.

Fig. 1

Schematic Diagram of AX0 Firing Set

Fig. 2

AXO Test Records

(PX PETN Batch 8220, 4500 cm²/g, 1.00 g/cm³)

(C₁ = 2.0 μf; C₂ = 0.04 μf)

Display of the current delivered by capacitor C₁ (left) and capacitor C₂ (right). The CVR's were connected for negative polarity.

Display of the di/dt and pin switch (left) and the voltage across the AXO (right).

Data reduction included the assessment of breakdown voltage, transmission time, peak current, time rate of change of the voltage ramp, time rate of change of the current following breakdown, power profile from voltage breakdown to the peak power point, and peak power.

Power expended in the AXO detonator versus time measured from breakdown is plotted in Figs. 3 through 11.

An analysis of variance was computed for six dependent variables—breakdown voltage, transmission time, peak current, peak power, di/dt following breakdown, and dv/dt for the charging ramp. These results are given in Tables II through VII.

The relative importance of the independent variables can be estimated from the size of the mean square deviations listed in Tables II through VII: the greater the number, the higher the probability of significance. Actual significance cannot be presently computed because the experimental error is not determinable. (There was no replication because of cost and availability of hardware.) Main and first-order effects of the independent variables on breakdown voltage and transmission time are plotted in Figs. 12 through 27 with plus or minus one sigma bars which, it should be remembered, represent the effect of the factors that are averaged into each point. The other dependent variables and second-order effects are not plotted because they are apparently not significant.

Fig. 4

Power versus Time from Breakdown

PX PETN Batch 8220

$C_2 = .01 \mu f$

$C_1 = 2.0 \mu f$

— Δ $\rho = .88 \text{ g/cm}^3$

— $\circ$ $\rho = 1.00 \text{ g/cm}^3$

— $\square$ $\rho = 1.12 \text{ g/cm}^3$

Fig. 5

Fig. 6

Power versus Time from Breakdown

Fig. 7

Power versus Time from Breakdown

Fig. 8

Fig. 9

Power versus Time from Breakdown

PX PETN Batch 8227

$C_2 = 0.04 \mu f$

$C_1 = 2.00 \mu f$

— Δ $\rho = 0.88 \text{ g/cm}^3$

- - - $\circ$ $\rho = 1.00 \text{ g/cm}^3$

— $\square$ $\rho = 1.12 \text{ g/cm}^3$

Power
in AX0
(Mw)

Fig. 10

Fig. 11

Table II
Analysis of Variance
 Breakdown Voltage (Kv)

<u>Source of Variation</u>	<u>Sums of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Squares</u>
Capacitance (C_2)	1822091	2	911045.5
Specific Surface Area (S_O^P)	5952066	2	2976033
Density (ρ)	11174779	2	5587389.5
$C_2 \times S_O^P$	3079710	4	769927.5
$C_2 \times \rho$	17666984	4	4416746
$S_O^P \times \rho$	16349915	4	4087478.75
$C_2 \times S_O^P \times \rho$	11650301	8	1456287.625
Total	67695847	26	
Grand Mean	4640		

Table III
Analysis of Variance
 Transmission Time (μsec)

<u>Source of Variation</u>	<u>Sums of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Squares</u>
Capacitance (C_2)	0.09179	2	0.045895
Specific Surface Area (S_O^P)	0.82801	2	0.414005
Density (ρ)	0.00192	2	0.00096
$C_2 \times S_O^P$	0.09259	4	0.0231475
$C_2 \times \rho$	0.12068	4	0.03017
$S_O^P \times \rho$	0.01393	4	0.0034825
$C_2 \times S_O^P \times \rho$	0.04821	8	0.00602625
Total	1.19712	26	
Grand Mean	0.683		

Table IV
Analysis of Variance
 Peak Current (Amps)

<u>Source of Variation</u>	<u>Sums of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Squares</u>
Capacitance (C_2)	2181842	2	1090921
Specific Surface Area (S_O^P)	656021	2	328011
Density (ρ)	666048	2	333024
$C_2 \times S_O^P$	376579	4	94145
$C_2 \times \rho$	809659	4	202415
$S_O^P \times \rho$	541740	4	135435
$C_2 \times S_O^P \times \rho$	317551	8	39694
Total	5549441	26	
Grand Mean	1060		

Table V
Analysis of Variance
 Peak Power (kw)

<u>Source of Variation</u>	<u>Sums of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Squares</u>
Capacitance (C_2)	3519789	2	1759894
Specific Surface Area (S_O^P)	3053826	2	1526913
Density (ρ)	5862466	2	2931233
$C_2 \times S_O^P$	2599227	4	649807
$C_2 \times \rho$	4179889	4	1044972
$S_O^P \times \rho$	5939566	4	1484892
$C_2 \times S_O^P \times \rho$	2483699	8	310463
Total	27638462	26	
Grand Mean	1850		

Table VI
Analysis of Variance
 di/dt @ Breakdown (Amps/ μ sec)

<u>Source of Variation</u>	<u>Sums of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Squares</u>
Capacitance (C_2)	6235642	2	3117821
Specific Surface Area (S_O^P)	3201606	2	1600803
Density (ρ)	55239948	2	27619974
$C_2 \times S_O^P$	237750212	4	59437553
$C_2 \times \rho$	101211025	4	25302756
$S_O^P \times \rho$	13538623	4	3384656
$C_2 \times S_O^P \times \rho$	314232893	8	39279112
Total	731409949	26	
Grand Mean	18200		

Table VII
Analysis of Variance
 dv/dt of Voltage Ramp (v/ μ sec)

<u>Source of Variation</u>	<u>Sums of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Squares</u>
Capacitance (C_2)	1146937177	2	573468588
Specific Surface Area (S_O^P)	53274184	2	26632091
Density (ρ)	99561529	2	49930765
$C_2 \times S_O^P$	87019032	4	21754758
$C_2 \times \rho$	296755728	4	74188932
$S_O^P \times \rho$	59251807	4	14812952
$C_2 \times S_O^P \times \rho$	192860786	8	24107595
Total	1935460240	26	
Grand Mean	13700		

Fig. 12

Breakdown Voltage versus Density
(Vertical bands are plus and minus σ)

Fig. 13

Breakdown Voltage versus Average Particle Diameter (FSSS)
(Vertical bands are plus and minus σ)

Fig. 14

Breakdown Voltage versus Specific Surface Area (FSSS)
(Vertical bands are plus and minus σ)

Fig. 15

Breakdown Voltage versus Density
(Vertical bands are plus and minus σ)

Fig. 16

Breakdown Voltage versus Capacitance (C_2)
(Vertical bands are plus and minus σ)

Fig. 17

Breakdown Voltage versus Density
(Vertical bands are plus and minus σ)

Fig. 18

Breakdown Voltage versus Average Particle Diameter (FSSS)
(Vertical bands are plus and minus σ)

Fig. 19

Breakdown Voltage versus Specific Surface Area (FSSS)
(Vertical bands are plus and minus σ)

Fig. 20

Transmission Time versus Capacitance (C_2)
(Vertical bands are plus and minus σ)

Fig. 21

Fig. 22

Transmission Time versus Specific Surface Area (FSSS)
(Vertical bands are plus and minus σ)

Transmission Time versus Density
(Vertical bands are plus and minus σ)

Fig. 23

Transmission Time versus Capacitance (C_2)
(Vertical bands are plus and minus σ)

Fig. 24

Transmission Time versus Capacitance (C_2)
(Vertical bands are plus and minus σ)

Fig. 25

Transmission Time versus Average Particle Diameter. (FSSS)
(Vertical bands are plus and minus σ)

Fig. 26

Transmission Time versus Specific Surface Area (FSSS)
(Vertical bands are plus and minus σ)

Fig. 27

FUTURE WORK; COMMENTS; CONCLUSIONS

Some qualitative conclusions may be drawn from visual inspection of the plots as to the relative effects of each parameter.

As might be expected the breakdown voltage exhibits significant dependence upon ρ , and possible S_0^P . In addition the interaction of ρ with S_0^P appears to affect the breakdown voltage.

In all tests performed UK PETN at 1.12 g/cm³ showed high dielectric strength (high V_{BD}). The main-effect plot of the action of density on V_{BD} gives an indication of the packing properties of each powder type since V_{BD} is related to the arc path length and shape through the powder.

The power curves for the high density UK PETN illustrate the enormous power which can be delivered to the AXO detonator. Note that the power curve may maximize at a different density for each batch although the overall trend is to maximize at the higher density.

Transmission time, t_e , shows an inverse dependence upon S_0^P (thus a direct dependence on average particle diameter). This is the most clearly observed effect in the experiment. But t_e shows no dependence upon density within the limits tested. This result may be due to canceling effects of induction time versus detonation velocity.

Shorter t_e at lower C_2 values are attributable to the higher di/dt attained.

UK PETN proved to be unique among the three powders tested; its properties appear to be quite different from those of PX PETN in the AXO configurations. Thus, in

some ways (e.g., direct comparison of those levels of S_0^P) its choice was not rigorously optimum for this experiment; but the unexpected difference information outweighs the loss of rigor in the third level of S_0^P .

A method to measure the time of ignition should be developed in order to obtain more useful information about the amount of input energy actually expended in the detonation process. Cutback studies should be performed to ascertain the minimum HE thickness required for detonation.

Some of the other spark gap detonator factors which require investigation are potential hazards in the field or other safety aspects, environmental effects, and specific applications.

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