

STUDY OF AN ELECTRIC DETONATOR WITHOUT
PRIMARY EXPLOSIVES.

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Summary

An electric blasting cap loaded with 3-4 mg PETN mixed with ca 12% carbon fibre and 35-55 mg pure PETN has been initiated by voltages down to about 30 V with an ignition energy of 20 mJ, and reproducibly initiated detonation in PETN and pressed 60 RDX/40 TNT (hexotol). Suitable compacting pressure for the carbon fibre PETN was found to be 1500-2000 kp/cm², and the carbon fibre content 10-15%. Reaction time after switching on the initiation voltage was about 50 μ s at a voltage of 30 V.

Introduction.

Common blasting caps or detonators have a bottom charge consisting of one or more secondary explosives, above which is applied a layer of primary explosive, usually lead azide. Electric detonators are initiated by means of an electric fuse head, consisting of a metallic fuse wire (bridge wire), surrounded by an explosive charge. When the current is switched on, the bridge wire becomes heated, and when the temperature has reached a certain level, the charge will explode and throw out a burning dustcloud against the primary explosive. The heating will cause the latter to detonate and, in its turn, initiate a detonation in the secondary charge. In connection with manufacture and application of detonators, the primary explosive, due to its ability to detonate very readily by heating, as well as its great shock sensitivity, requires far-reaching safety measures. The development of a detonator without a primary explosive would thus mean a great step forward.

Secondary explosives can be brought to detonation by heating, if confined in a very strong container, or if the heating is very vigorous and rapid. In the "exploding bridgewire"-detonator, a thin bridge wire surrounded by e.g. PETN is heated very powerfully by means of an electric discharge, by which the PETN charge becomes initiated. Such detonators, however, require igniting voltages around 2 kV and about 1 Joule igniting energy, while an ordinary lead azide detonator needs about 1 V and 3 mJoule. For the VA cap the corresponding data are 4,5 V and 30 mJ.

If electrically conductive fibres are mixed into an explosive, the latter will become electrically conductive at a fibre content as low as 5%. (A Lovecy, British patent no 1.196.114, Aug. 26, 1966). If an electric current is led through the explosive, the fibres and the adjacent grains of the explosive will become heated. This will cause a simultaneous thermal decomposition of a great part of the explosive, resulting in a very rapid pressure increase. By means of this rapid pressure increase, the explosive will be brought to detonation with small requirements on container strength and with a relatively small igniting energy.

Some points concerning the choice of fibres and explosive.

Let us suppose that a fibre-blended explosive is in electric contact with two electrodes, placed at a distance of l from each other. (Fig. 1). The electrodes are then connected by a system of fibres. This system may be considered as a number of shunt bridges between the electrodes, each of them

with the length of s , where $s \geq l$. In addition to this, each such bridge is supposed to consist of n fibres connected in series, the average length of which is Δs .

The resistance of such a bridge will be:

$$R = \frac{\gamma \cdot s \cdot 4}{\pi \cdot d^2} \quad (1)$$

where γ = resistivity, and d = fibre diameter.

The energy W which is required to increase the temperature of such a bridge ΔT° is:

$$W = \pi \cdot d^2 / 4 \cdot s \cdot \rho \cdot c \cdot \Delta T \quad (2)$$

where ρ = density, and c = specific heat of fibre material.

In each bridge with the resistance R the voltage U between the electrodes will generate the energy E during the time Δt :

$$E = U^2 \cdot \Delta t / R \quad (3)$$

If the time interval Δt is short it is possible to neglect heat losses to the environment, and the electric energy will be completely converted into thermal energy in the fibres, e.i.: $E = W$;

From (1), (2) and (3) we have

$$U = s \sqrt{\gamma \cdot \rho \cdot c \cdot \Delta T / \Delta t} \quad (4)$$

and

$$E = \pi \cdot s \cdot \rho \cdot c \cdot d^2 \cdot \Delta T / 4 \quad (5)$$

The effect of fibre material on igniting voltage and igniting energy.

According to (4) and (5), the igniting voltage is proportional to $\sqrt{\gamma \cdot \rho \cdot c}$, while the ignition energy is proportional to ρc .

The effect of fibre dimensions and fibre content on ignition voltage and ignition energy.

According to (4) and (5), the length of a bridge and the fibre diameter d should be minimized in order to obtain low ignition energy and voltage respectively. s depends on Δs , $\Delta s/l$, $\Delta s/d$ and the fibre content k of the mixture. The fibre length Δs should be chosen as long as possible, with the additional condition that $d \ll \Delta s \ll l$. The fibre diameter should be small. The lower limit is set by the grain size d_p of the

explosive with which the fibres are to be blended. By way of a guess the condition $d > d_p/5$ should be fulfilled in order to reduce the risk of fibre rupture during pressing. The resistivity ρ of the fibre-explosive mixture is shown as a function of fibre content k in figure 2. Above a certain critical value of k , the total ignition energy required will increase with increasing k . The appropriate value of k would seem to be near the value k_c .

In the explosive used the ignition temperature, as well as the shock wave pressure required for initiation to detonation, should be low. Besides the critical diameter for detonation should be small. PETN and RDX with a grain size of 10-100 μ and a compacting pressure of 1500-2000 kp/cm^2 , might be considered suitable explosives to mix with fibres.

Some experiments with PETN containing carbon fibres.

A careful determination of effects on mixture properties caused by the parameters in question would require more experiments than those carried out during this investigation, which was mainly intended for surveying purposes, and to repeat the experiments reported by Lovecy. The purpose of the carbon fibre PETN tests described below was to develop a mixture which could be ignited by voltages of at most some twenty or thirty volts, and with a reasonably low igniting energy.

Effect of carbon fibre content on resistivity.

In order to determine the effect of carbon fibre content on resistivity, about 5 mg carbon fibre blendid PETN was filled into a device according to figure 3.

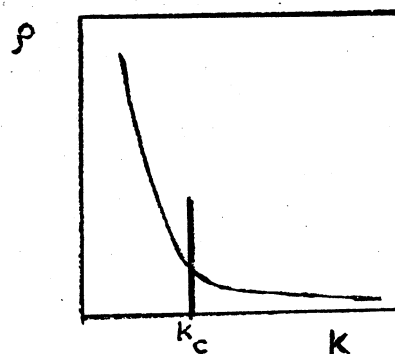
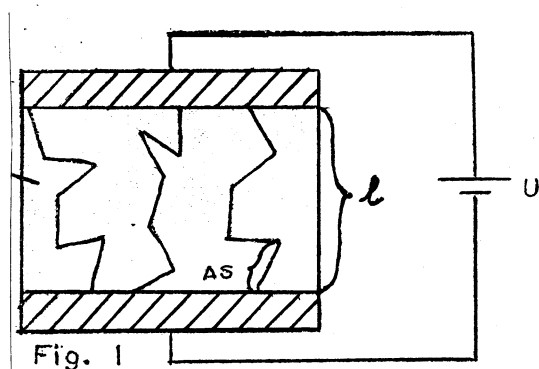


Fig. 2.

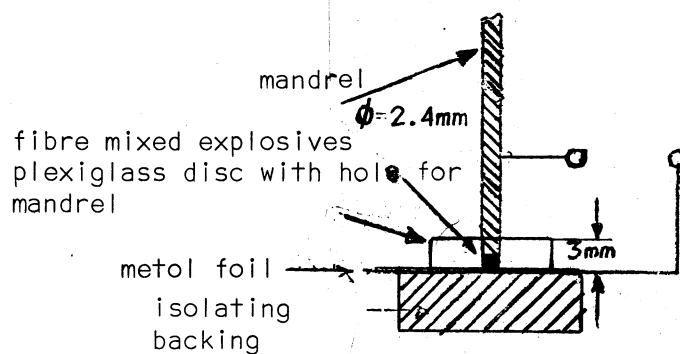


Fig. 3.

The mixture was pressed with a mandrel at 800 kp/cm^2 , whereafter the resistance of the mixture was measured by connecting an Ohmmeter Type G-Norma (measuring voltage about 50 mV) between the mandrel and the bottom plate.

Data for carbon fibre:

Diameter 0.01 mm , length $0.3 \pm 0.1 \text{ mm}$,
 resistivity $2.4 \cdot 10^{-3} \text{ ohm.cm}$.

Data for explosive:

PETN, grain size $d_p = 5 - 15 \mu$
 The result is shown in fig. 4.

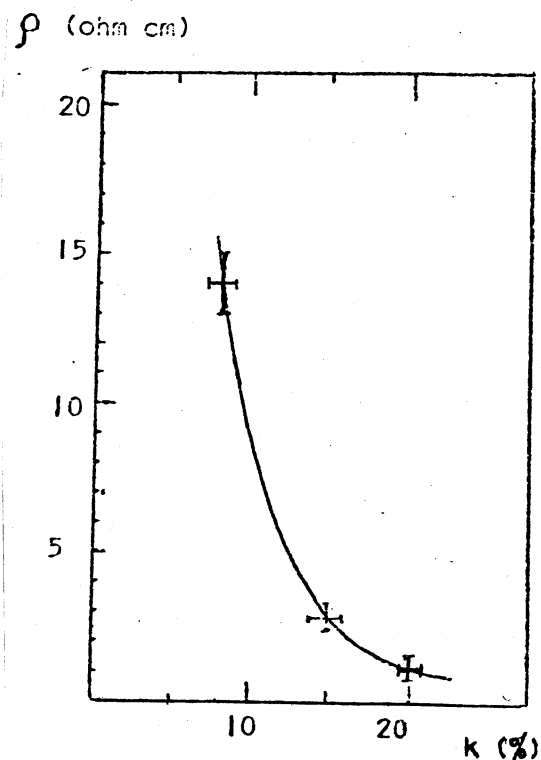


Fig. 4.

Effect of compacting pressure on resistivity:

The device above (fig 3) was filled with about 5 mg carbon fibre/PETN and then pressed. During pressing, the resistance of the blend was measured.

+ = Mixture No 1:

Carbon fibre content: $k = 12\%$

Carbon fibre: $d = 0.01 \text{ mm}$, $l = 0.2 \pm 0.1 \text{ mm}$

PETN: grain size $d_p = 5-15 \mu$.

0 = Mixture No 2:

The same as No 1 except that $d_p = 30-70 \mu$.

The result is shown in fig. 5.

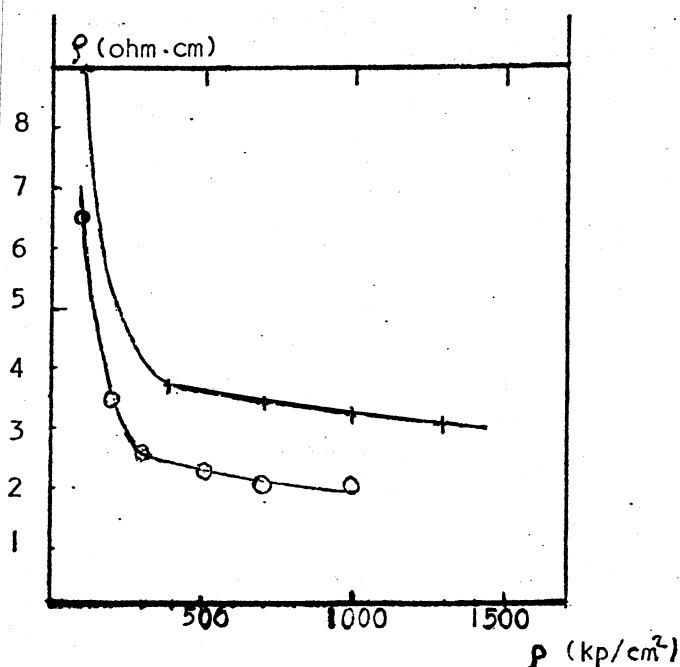


Fig. 5.

Determination of minimum ignition voltage for a couple of carbon fibre/PETN-mixtures.

The abovementioned device (fig 3) was filled with c:a 5 mg mixture of carbon fibre and PETN according to formula 1 and 2 and then pressed. A 100 μ F condensor, charged to various voltages was then discharged

through the mixture. The condensor voltage at the moment of discharge was recorded by means of an oscilloscope and a camera, so that it became possible to measure the reaction time after switching on the ignition voltage, as well as the amount of electric energy delivered.

After pressing with 1000 kp/cm^2 , a condensor voltage of about 40 V was required to obtain a safe ignition (the plexiglass plate was shattered into small pieces). The electrical energy delivered could then be determined to about 30 mJ, with reaction time approximately 150 μs .

An increase in compacting pressure to 2000 kp/cm^2 resulted in a lowering of measured values to 25 V, 10 mJ and 50 μs respectively.

The distance between electrodes after pressing was about 0.7 mm.

Experiment with an electric detonator with carbon fibre/PETN-ignition.

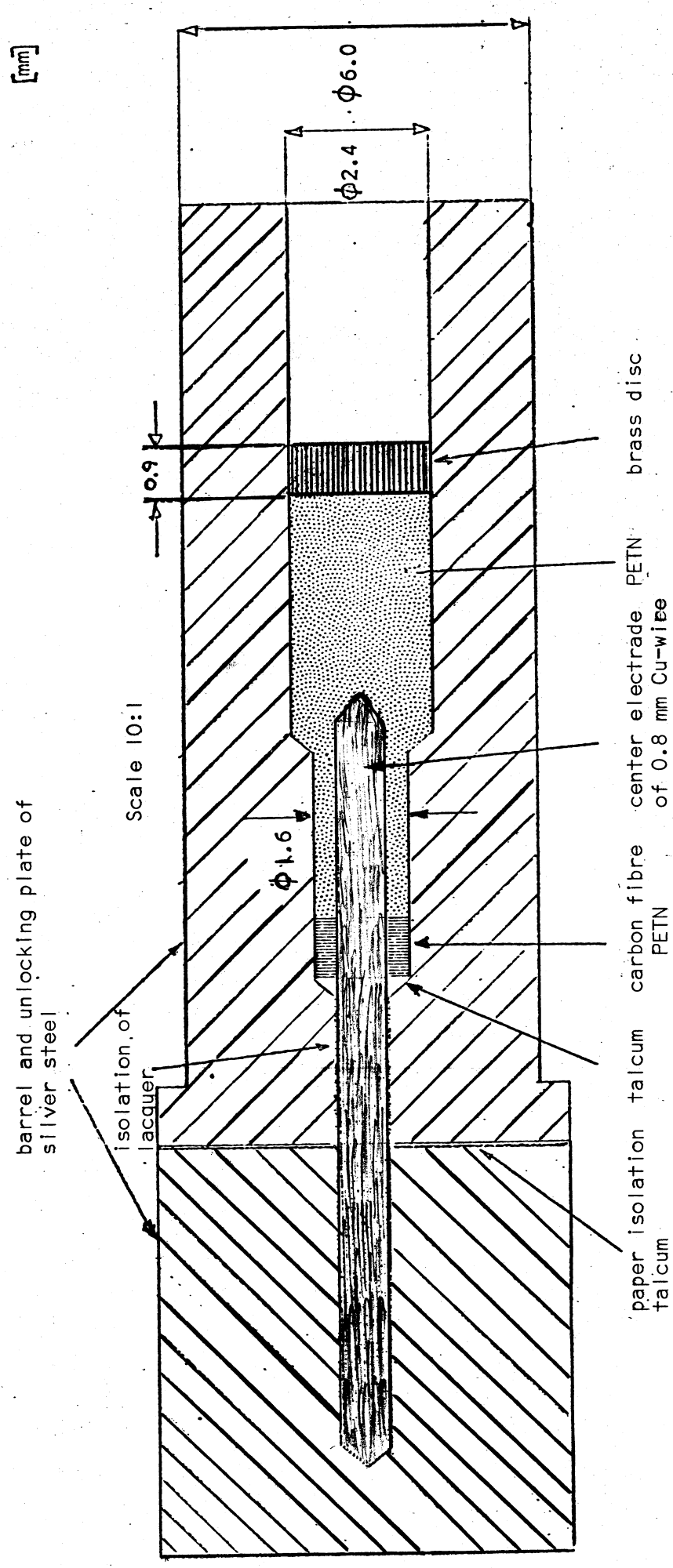
Dr Lovecy at the Ministry of Aviation Supply in England designed the detonator shown in fig. 6 (private Communication 1970, and British Patent Nr 1.196.114, 25.8.1966) and made some experiments with it. The device has a barrel consisting of a steel tube provided with an end-plug, and a central electrode in the rear part of the barrel which is electrically isolated from the pipe.

For ignition, first a few mg of carbon-fibre PETN is loaded around the central electrode, whereafter pure PETN is loaded up to about 5 mm from the tube orifice, and finally, a brass disc is pressed on top of the pillar of explosive.

According to Lovecy's theory of the functioning of the device, the pressure generated at the ignition of the carbon-fibre PETN and the PETN in the bottom of the barrel, will drive the column of explosives towards the muzzle. If an object, e.g. an explosive, is placed in the immediate vicinity of the muzzle, the disc and the column of explosives will collide with it. Upon collision, a shock wave will be sent back through the explosive column. When this shock wave reaches the zone of deflagration or combustion, the combustion will pass into a detonation which will propagate forward towards the muzzle, where the explosive placed immediately nearby will become initiated. Lovecy calls this transition from combustion to detonation in the column of explosives, initiation "Agumentation by Collision Pressure" (ACP), a mechanism for initiation hitherto unknown.

The purpose of our tests was to find out something about the functioning of the device, its ability to initiate explosives, and its development potential.

[mm]



Detonator

Fig. 6

Loading of detonator.

About 2 mg of talcum powder was vibrated down to the bottom of the detonator barrel (fig 6) as an electric isolation layer between the bottom and the carbon-fibre/PETN. After that, the device was filled with about 3 mg carbon fibre/PETN which was pressed by means of a mandrel, which had been especially bored for the electrode. Then pure PETN, about two charge diameters at a time, was pressed down into the pipe. Finally, the brass disc was pressed into place on top of the pillar of explosives.

Brass disc velocity.

The velocity of the brass disc was measured as follows. After leaving the muzzle, the disc was allowed to pass through two thin barriers placed a known distance from each other, each consisting of two thin Al-foils (thickness 0.009 mm). When the disc passed through a barrier, the two Al-foils were short-circuited, and an electric pulse was obtained from a pulse circuit. The two pulses thus obtained were fed into an electronic counter which gave the time of travel between the barriers, from which the velocity could be calculated.

Energy for initiation and action time.

By means of an oscilloscope, the Voltage-time curve could be recorded (fig 7), and the delivered electric energy W could thus be calculated from

$$W = \frac{c}{2}(U_0^2 - U_1^2)$$

where c = capacitance of the condensor, U_0 = the initial condensor voltage, and U_1 = voltage of the condensor at the moment when the barrel charge is ignited and the combustion gases leave the muzzle. By placing

a metal "witness plate" 15x15x2 mm by the muzzle, electrically isolated from the latter, an electric pulse from a pulse circuit is obtained when the plate leaves the muzzle.

Simultaneous recording of the discharge process of the condensor shows that the characteristic voltage increase, which can be seen on fig 7, corresponds in time to the moment when the plate leaves the muzzle.

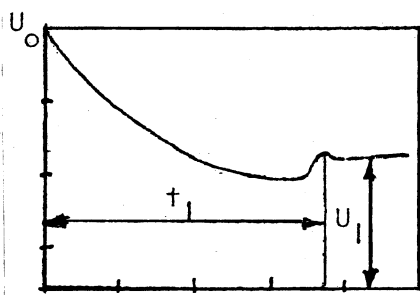


Fig. 7. Discharge of ignition condensor.

Test results.

In order to determine to which velocity the brass disc in the barrel would be accelerated by a detonating PETN charge, confined in a way similar

to that of the Lovecy detonator and of the same dimensions, a control/experiment was made with the device shown in fig 8. The disc was accelerated by the detonation in the PETN which had been initiated by means of an detonating Hx-20 fuse head. Measured velocity: 1150 m/s.

Table I on page 13 shows the results of some measurements made on Lovecy detonators.

Action time. From the table is to be seen that a rise in ignition voltage by approximately a factor of 3 (from 30 to 100 V) will reduce the action time in a corresponding degree. Detonators, where the carbon fibre/PETN had been pressed at 2000 kp/cm^2 , showed a considerably shorter action time than those pressed at 1000 kp/cm^2 .

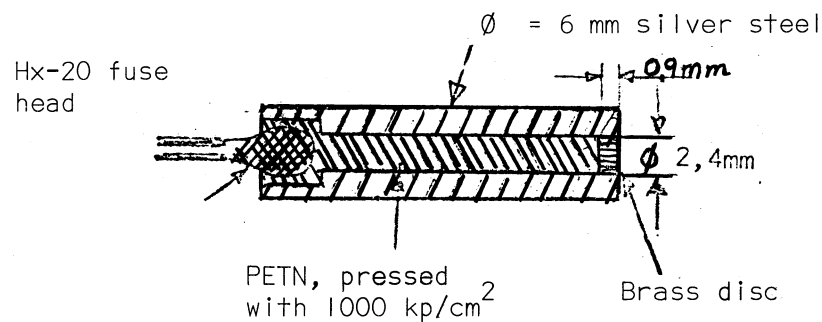


Fig. 8. Device for acceleration of brass disc.

The brass disc velocity did not markedly change due to different ignition voltages or compacting pressures of carbon fibre/PETN or PETN.

If, however, the PETN 30-70 μ was substituted for PETN 5-15 μ , the velocity decreased from about 1100 m/s to approximately 850 m/s. This was also manifested in different ability to initiate explosives.

In order to study the acceleration of the disc the barrel of detonator No 8 in table I was shortened 4 mm, whereafter it was loaded in the same way as for example No 1, 2, 3 and 4. The front of the disc was now at the same level as the muzzle, with an acceleration distance of only 0.9 mm before completely leaving the muzzle, compared, with 5 mm earlier.

The velocity then dropped from 1100 m/s to about 750 m/s. When loading the detonators No 11 and 12 about 4 mm higher up in the barrel than normally, the disc front reaching the same level as the muzzle, the velocity was 880 m/s.

Ignition energy.

An increase in the compacting pressure of the carbon fibre PETN from 1000 kp/cm² to 2000 kp/cm² decreased the ignition energy at 100 V from about 120 mJ to c:a 90 mJ. The ignition energy will also decrease when the ignition voltage is lowered (compare in Table I 10 and 11). The lowest ignition energy recorded (about 20 mJ) was found in detonator No 11, where carbon fibre PETN had been pressed at 2000 kp/cm². It was fired by the 100 μ F condensator charged to 30 V.

Ability to initiate secondary explosives.

- a. Detonators, barrel loaded with PETN (30-70 μ) so that the front of the brass disc was c:a 4 mm from the muzzle:

Initiated:

1. Pressed PETN ($\rho = 1.65 \text{ g/cm}^3$) diameter 6 mm, length 8 mm, in direct contact with the muzzle.
2. PETN as above, placed 20 mm in front of the muzzle.

Did not initiate:

3. 60 RDX/40 TNT (compacting pressure 1000 kp/cm²), diam. 6 mm, length 8 mm, in direct contact with the muzzle (3 tests).
4. PETN (Bofors $\rho = 1.53$; phlegmatized with 10% paraffine) diam. 15 mm, length 6 mm, placed 10 mm in front of the muzzle.
5. PETN as in (4), placed in immediate with the muzzle.

- b. In case the barrel was loaded with PETN 5-15 μ instead of 30-70 μ :

Did not initiate:

6. PETN as in (1).

- c. Detonator as in (1) but without a brass disc:

Initiated:

7. PETN as in (1) in immediate contact with the muzzle.

- d. Detonator loaded with PETN 30-70 μ in the pipe up to the very muzzle orifice (no brass disc).

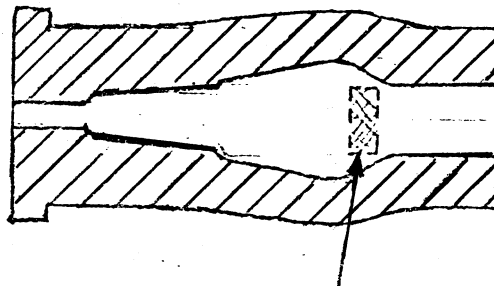
Initiated:

8. Pressed PETN (Bofors $\rho = 1.53 \text{ g/cm}^3$, phlegmatized with 10% paraffine), diam. 15 mm, length 8 mm, in contact with the muzzle.
9. Pressed 60 RDX/40 TNT ($\rho = 1.57 \text{ g/cm}^3$), diam. 10 mm, length 15 mm, in contact with the muzzle.

Functioning of detonator.

The kinetic energy of the disc as for detonators loaded with PETN 5-15 μ , was approximately 50% of that when PETN 30-70 μ was used. When the barrel was loaded with PETN 5-15 μ the detonators showed a slight diameter expansion all over the barrel length after firing, which indicates a comparatively slow reaction under low pressures. These detonators were not even able to initiate unphlegmatized PETN at the muzzle.

Detonators, loaded with PETN 30-70 μ in the barrel, showed a considerably bigger barrel deformation. In fig 9 is shown a cross section of such a detonator after firing, loaded so that the brass disc was c:a 4 mm from the muzzle.



Place of disc before firing.

Fig. 9. Cut of detonator after firing.

The deformation indicates that the pressure reached its maximal value at the end of the barrel charge. The pressure, and the acceleration as well is comparatively big during the first millimeter of disc movement but then decreases sharply. Let us suppose that the disc has been accelerated by a constant pressure when inside the barrel, and that it will be possible to neglect the increase in velocity of the disc after leaving the barrel. The disc velocity of 1150 m/s (weight of disc 35 mg), reached in the distance of 5 mm (detonator No 2), will then correspond to an average pressure of about 10 kbar. The velocity of 750 m/s, reached in the distance of 1 mm (barrel shortened with 4 mm) will correspond to a mean pressure of approximately 22 kbar (detonator No 9). When loaded so that the front of the brass disc reached the same level as the muzzle (4 mm longer pipe charge than No 9), the detonator accelerated the disc to 870 m/s, which corresponds to a mean pressure of about 30 kbar. When loaded so that the disc front was c:a 4 mm from the muzzle, detonators

were unable to initiate pressed 60 RDX/40 TNT, while initiation was possible in case the brass disc was omitted and the pipe charge reached up to the very muzzle.

The experiments which have been carried out do not give any support to the contention that Lovecy's "ACP"-mechanism (see page 6) would be of significance for the initiation process. Instead, the experiments above seem to indicate the following way of functioning. The electric current causes a rapid heating of the carbon fibres up to a temperature which is considerably above the ignition temperature of the surrounding PETN. At a great number of places, a rapid thermal decomposition of the carbon fibre blended PETN will take place (volume ignition), which will cause the pressure to rise sharply.

The combustion will spread forward in the PETN charge in the barrel with increasing pressure and velocity. In case the barrel is loaded with PETN 30-70 μ , this will happen so rapidly that the high pressure and high temperature gases formed by the combustion will not have time to push unreacted PETN in front of itself in the barrel. When loading detonators so far up in the barrel that the brass disc front reached the same level as the muzzle the plate velocity indicates that a fully developed detonation does not take place at the muzzle (870 m/s compared with 1150 m/s in case of fully developed detonation in the control experiment with the device in fig 8).

When loading the barrel with PETN 5-15 μ , the combustion has obviously been so slow that a great amount of PETN has been able to leave the barrel before decomposition.

The more fine-grained (5-15 μ) PETN has a considerably lower gas permeability than the coarse-grained one (30-70 μ) after pressing in the barrel. Having a high gas permeability without too low a loading density facilitates the transition to rapid deflagration and detonation /1/.

Development potential.

The problem concerning delayed initiation in Lovecy type detonators with carbon fibre ignition is not possible to solve by means of conventional methods where pyrotechnical delay elements are used. One way could consist in utilizing a simple miniature delay circuit in connection with the detonator, and thus produce a delay of ignition current electronically.

Among other things, the experiments related above have contributed to our knowledge about the deflagration to detonation transition in secondary explo

Table 1.

No	Voltage of 100 μ F ignition condensor (V)	k-PETN 1) quality	PETN 1) quality	Compacting pressure (kp/cm ²)		Plate velocity μ s	Action time μ s	Ignition energy mJ	Notes
				k-PETN	PETN				
1	100	kP 1	P 1	1000	1000	1180	-	-	Loaded so that 4 mm of the pipe up to muzzle was free
2	"	"	"	"	"	1120	46	-	"
3	"	"	"	"	"	1100	52	-	"
4	"	"	"	"	"	990	-	-	"
5	"	"	"	"	"	-	53	ca 130	"
6	30	"	"	"	"	-	157	-	"
7	"	"	"	2000	2000	1070	65	ca 25	"
8	"	"	P 2	2000	1000	850	-	-	"
9	100	"	P 1	1000	1000	750	56	ca 120	Barrel shortened 4,0 mm so that brass disc front was at the same level as the muzzle
10	"	"	"	"	"	-	55	ca 120	
11	30	"	"	2000	1500	880	57	ca 20	Loaded so that the brass disc. was at the same level as the muzzle
12	100	"	"	"	1000	880	20	ca 90	

1) k-PETN 1: carbon fibre/PETN 1/8P 1: PETN: 30-70 μ nearly spherical grainscarbon fibre: $\emptyset = 0,01$ mm $l = 0,2 \pm 0,1$ mmP 2: PETN: 5-15 μ irregularly shaped grainsPETN: 5-15 μ

sives, and thus given experience which can be applied when designing a detonator without a primary explosive, where the conventional fuse head and the delay element would serve as a basis. In table II below we present comparative data for some instantaneous detonators.

Table II. Comparative data of some instantaneous detonators.

Type	Minium ignition voltage (V)	Minimum ignition energy (mJ)	Minimum ignition impulse ($A^2.ms$)	Resis- tance	Minimum ignition current (A)
Lovecy detonator	c:a 20	c:a 15	c:a 20	c:a 2 ¹⁾	c:a 15-25
SE	" 1	" 3	" 4	" 4	" 0,3
VA	" 4,5	" 30	" 100	" 3,5	" 1,3
Hx-20	" 15			" 20	" 0,7

1) Measured with G-Norma ohmmeter (measuring voltage 50 mV). When the ignition voltage (30-100 V) is turned on, the resistance will decrease to 0.5 - 1 Ω .

References.

1. Belayev A.F., Korotkov A.I., Sulimov A.A. "Breakdown of Surface Gas-Permeable Porous Systems", Combustion, Explosion, and Shock Waves, Vol 2, nr 3, 1966.
2. Brown A J, Collins M. "Explosion Phenomena Intermediate between Deflagration and Detonation". Office of the chief research and development. Department of the Army, Washington DC. 20310, 1967.

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