Dec. 13, 1955 C. O. DAVIS ET AL 2,726,602

BLASTING DETONATOR

Filed July 1, 1952

FIG. 1

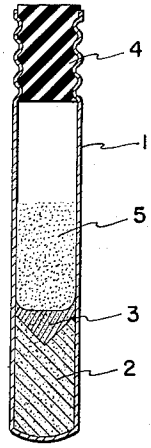


FIG. 2

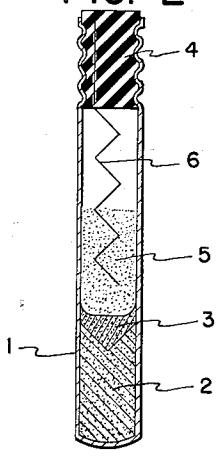


FIG. 3

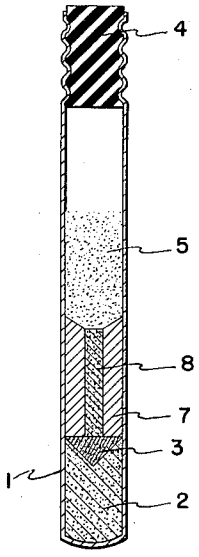


FIG. 4

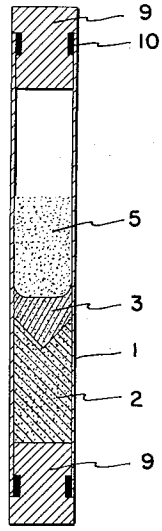


FIG. 8

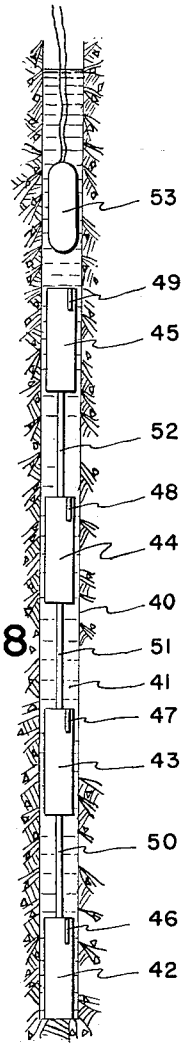


FIG. 5



FIG. 6

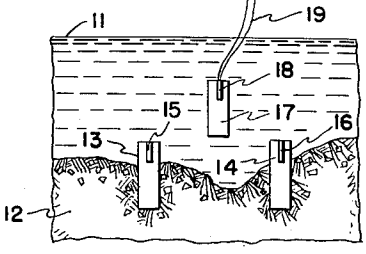
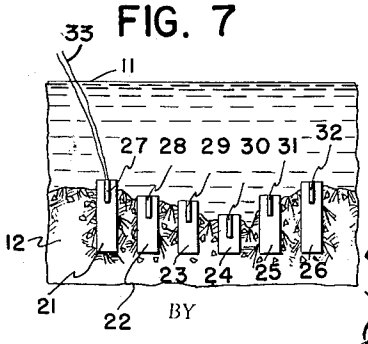


FIG. 7



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BLASTING DETONATOR

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Application July 1, 1952, Serial No. 296,546

10 Claims. (Cl. 102—29)

This invention relates to a novel detonator for use in blasting under liquid confinement and particularly to such a detonator which is fired without attached initiating means.

This application is a continuation-in-part of our copending application Serial No. 792,202, filed December 17, 1947 (now abandoned).

Underwater blasting operations are required for such purposes as the deepening of harbors and channels, the removal of rock obstructions, the destruction of sunken objects, and the like. In such work, it is customary to prepare the required number of boreholes spaced at suitable distances apart and to load high-strength explosive into each of said boreholes. Heretofore in such blasting, it has been necessary to follow one of two procedures, each of which involved serious disadvantages. One method consisted in spacing the boreholes sufficiently close together, loading each of the holes with explosive, initiating one of the charges by means of an electric blasting cap, and bringing about explosion of the other charges by propagation from hole to hole. The disadvantage of such a method was that the use of explosives of a high degree of sensitivity was required. As a matter of fact, it has been customary in such work to employ 60% straight dynamite, high-strength gelatin, or high-strength gelatine primed with 60% straight. The use of high explosives of such an order or sensitiveness is undesirable and unduly hazardous for large-scale rock blasting operations where a certain amount of rough handling is necessary. Furthermore, premature explosions on drill barges with consequent loss of life have occurred with these highly sensitive explosives.

A second method practiced heretofore has allowed the use of many types of cap-sensitive explosives but has necessitated the insertion of at least one electric blasting cap into each borehole charge. This has not only been wasteful in its requirements of relatively expensive electric blasting caps but has introduced complications because of the presence of the many cap wires of considerable length, which could readily become tangled or fouled by material floating on or submerged in the water, by passing vessels, etc. A distinct hazard is involved also in the event of electrical storms, not necessarily in the immediate vicinity, which in a number of cases have brought about the explosion of underwater charges with emergent cap wires.

In view of the disadvantages present in previous procedures for submarine blasting, where a plurality of explosive charges is to be fired, it will be apparent that a method that allows the use of relatively insensitive explosives without requiring electric blasting caps wired to each charge will represent a highly desirable advance.

An object of the present invention is a novel method of carrying out blasting operations beneath the surface of or in contact with a dense liquid medium and particularly for underwater blasting. A further object is such a method permitting the employment of relatively insensitive blasting explosives and not requiring electric blasting caps and their wires for the various charges. A still further object is a method for submarine blasting employing a novel type of detonator. A further object is a detonator adapted for underwater blasting characterized by simplicity of construction and high reliability of action, free from electrical or flame-action means of detonation, and adapted to be initiated under the effect of suddenly applied external pressure. Additional objects will be disclosed as the invention is described at greater length hereinafter.

We have found that the foregoing objects are accomplished when we carry out submarine blasting operations by a method comprising introducing a plurality of explosive charges into the desired subsurface blasting positions; locating at least one of the novel detonators adjacent to each of the explosive charges and in detonating relationship therewith, said detonator being free from electrical firing arrangements and adapted to become initiated as a result of the sudden collapse of the shell walls under the effect of pressure from the explosion of a nearby charge; locating an explosive priming charge in suitable proximity to said pressure-responsive detonator; bringing about the explosion of said priming charge; and thereby causing the collapse of the shells of the pressure-responsive detonators, the initiation of the respective detonator charges and the detonation of the main explosive charges adjacent thereto. The detonators adapted to collapse under pressure, as described, will contain in a completely sealed tubular metal shell of definite minimum strength a high-density, high-velocity base charge, a compressed intermediate charge, and, in a portion of the shell in igniting relationship with the intermediate charge, a loose, granular explosive composition of the ignition type, which composition does not fill the said portion of the shell. The ignition charge will become ignited as a result of the impact of the collapsing walls. The high-velocity, high-density detonating explosive base charge within the cap will be brought to explosion by the loose charge by way of the compressed intermediate charge.

The invention will be illustrated more clearly by reference to the attached drawing, in which Figure 1 is a longitudinal section of a pressure-responsive detonator according to the invention. Figure 2 is a similar view of such a pressure-responsive detonator of modified construction. Figure 3 represents a delay detonator according to the invention. Figure 4 is a detonator similar to that of Figure 1 except that different sealing means are employed. Figure 5 is a cross-section of an empty shell after collapse. Figures 6, 7, and 8 are diagrammatic views of different arrangements of explosive charges under liquid media, adapted to employ the principle of the invention.

With special reference to Figure 1, 1 is a metal shell of such dimensions and wall thickness as to permit the shell to withstand static pressures of more than 2000 lb./sq. in. Within this shell at its base or initially closed end is a compressed charge 2 of pentaerythritol tetranitrate or other high-velocity explosive suitable for use as base charge. The primer charge 3 is a pressed composition more readily ignitible by flame than the base charge, and a suitable material comprises a lead azide composition. This charge 3 is shown in the drawing as embedded in a preformed cavity in the base charge for purposes of protection. The shell is closed at its upper end by a closely fitting rubber plug 4, which has been crimped into completely water-tight relationship with the shell wall. Between the rubber plug and the primer charge is a space in the shell into which has been introduced so as not to fill the space a loose, granular charge of an explosive composition of the ignition type 5, adapted to become ignited when the unsupported metal walls are caused to collapse inwardly as the result of suddenly applied pressure de-

veloped by the detonation of a nearby explosive priming charge. A suitable composition for this friction-ignitible charge is a blend of mercury fulminate and potassium chlorate in a 90/10 ratio.

In Figure 2 a detonator of similar construction is shown, with the exception that a zig-zag metal wire **6** has been secured in predetermined position within the rubber plug **4** so that the end projects beyond the surface of said plug, the wire extending into the space containing the ignition-type composition **5**, which is adapted to function in the manner described for Figure 1. A suitable composition is a 50/25/25 blend of smokeless powder, a complex salt of lead nitrate with the bis basic lead salt of 4,6-dinitro-ortho-cresol, and potassium chlorate. Although the presence of the bent wire is not essential to the invention, it increases the frictional effect on collapse of the shell walls in the unsupported portion and allows the utilization effectively of a less sensitive explosive composition in this portion of the detonator.

Figure 3 shows the construction of a pressure-responsive detonator of the delay type, in accordance with the invention, adapted to become initiated by the pressure from a nearby explosion and to bring about the detonation of its explosive charge after a predetermined time interval following the burning of the initial charge. In this figure, **1** designates a metal shell containing at its base a pressed charge **2** of a suitable high-velocity explosive such as tetryl, with a primer charge **3** of pressed lead azide in detonating relationship with the base charge and loaded into a formed cavity in said base charge. Above the primer charge and in ignition relationship therewith is a metal carrier **7** having a centrally located longitudinal bore, into which is pressed a slow-burning charge **8** controlled to burn at a predetermined speed. This slow-burning charge should desirably be one that burns without substantial evolution of gas so that no great pressure will be developed to burst the shell walls during the delay interval. A suitable composition will be, for example, a mixture of metallic selenium and barium peroxide. The upper end of the metal shell is closed by means of a water-tight rubber plug **4** crimped into position. Between this rubber plug and the delay carrier **7** is a chamber into which has been introduced so as not to fill the chamber entirely a loosely-packed charge of a composition of the ignition type **5** adapted to become ignited when the shell walls at this position collapse suddenly under the effect of the pressure from a nearby exploding charge.

Figure 4 shows a pressure-responsive detonator similar to that of Figure 1, except that the sealing is accomplished in another manner. Whereas in Figure 1, a closure that is liquid-tight under pressure is accomplished by means of the closed end of metal shell **1** and the rubber plug **4** inserted and crimped in the previously open end of shell **1**, in Figure 4 the tubular shell **1** is initially open at both ends and is sealed at each of these ends by a metal plug **9** which fits exactly into the tubular shell **1** and is provided with a head of the same diameter as the outer diameter of the shell and with a groove below the head into which is introduced a sealing composition **10**. The structure of Figure 4 is particularly applicable to relatively thick-walled detonators.

Figure 5 is a cross-section of the chamber for containing the ignition-type charge as it ordinarily appears after it has been collapsed by high static pressures in the absence of an ignition charge. (When the shell collapses in the presence of the ignition charge, it is, of course, destroyed.) It will be seen that collapse has occurred from all sides and that the cross-section has assumed a pleated form. Although this is the usual manner of collapse of the shells, the detonators will function if collapse occurs in other manners, as by flattening of the tubular wall of the "collapse" chamber, for example.

In Figure 6 is shown an assembly for underwater blasting using the pressure-responsive detonator of the present invention. In this figure, **11** represents the surface of a body of water, beneath which, and confined by said body, have been placed explosive charges **13** and **14**, in boreholes in the rock bottom **12**. Inserted in these charges are pressure-responsive detonators **15** and **16**, of the type described in Figures 1, 2, and 4. An explosive charge **17** has been lowered into a position in proximity to detonators **15** and **16**, and an electric blasting cap **18** is in detonating relationship with this charge, having insulated cap wires **19**. When ready for the blast, the cap wires are thrown into circuit with a source of electric current (not shown) and the charge is fired. The pressure resulting from the detonation of charge **17** brings about the sudden inward collapse of the walls of pressure-responsive detonators **15** and **16**, with consequent detonation of the charges **13** and **14**. In this figure, two explosive charges have been shown containing inserted pressure-responsive detonators and in position to be exploded under the influence of pressure.

Figure 7 shows another and a preferred assembly of charges for underwater blasting employing the pressure-responsive detonator of the present invention. In this figure, six explosive charges **21**—**26**, are shown loaded into their respective boreholes in the rock bottom **12**, spaced from one another at reasonably short distances. Into charge **21**, an electric blasting cap **27** has been inserted, having insulated cap wires **33**. Spaced from charge **21** are the successive explosive charges **22**, **23**, **24**, **25**, and **26**, into each of which has been introduced a non-electric closed detonator of the type described in Figures 1, 2, and 4, these detonators being designated by **28**, **29**, **30**, **31**, and **32**, respectively. At the time of firing, the wires from the cap in explosive charge **21** are connected with a source of firing current, and electric blasting cap **27** and charge **21** are brought to detonation. The adjacent explosive charges **22**—**26** are not sufficiently sensitive to propagation to be detonated sympathetically by the first charge **21**, but the resulting hydrostatic pressure generated by detonation of charge **21** causes the collapse of the walls of detonator **28** and the detonation of this and its charge **22** and the subsequent successive detonation of charges **23**—**26** by means of the inserted pressure-responsive detonators. It will be understood that, in the illustration of the invention according to Figure 7, the explosive charges in the different boreholes may consist of single cartridges in each hole or a column or group of cartridges. Where a number of cartridges are present in each hole, a single pressure-responsive detonator in the top cartridge may be sufficient, the explosion propagating from one cartridge to another, or, if desired, pressure-responsive detonators may be present in all or in any chosen number of the cartridges, depending on the sensitiveness of the explosive and the continuity of the column.

Figure 8 is a longitudinal sectional view of the bottom of an oil well showing relative positions therein of a series of explosive charges provided with pressure-responsive detonators in accordance with this invention. There is shown the bottom portion of a well **40** filled with liquid **41**. In the well, containers **42**, **43**, **44**, and **45** of any suitable form which enclose explosive charges of any suitable, relatively insensitive type, which charges have inserted therein pressure-responsive detonators **46**, **47**, **48**, and **49**, are spaced from one another by lengths of rigid tubing **50**, **51**, and **52**, or other conventional means. When an explosion is caused in the vicinity of the uppermost charge **45** by an oil-well time bomb **53** suspended above the uppermost charge **45** or by another usual initiating charge for oil-well blasting such as a percussion-initiated squib, for example, the pressure-responsive detonators **46**, **47**, **48**, and **49** inserted in the explosive charges in containers **42**, **43**, **44**, **45** all are collapsed by the increase in pressure in the well in their vicinity caused by the explosion and are initiated, whereby the initiation of the explosive charges in containers **42**, **43**, **44**, **45** is brought about.

The method described in the foregoing will be applicable in blasting operations beneath the surface of a dense liquid medium, and particularly in submarine blasting, for the deepening of harbors and channels, the removal of rock obstructions, the destruction and disintegration of sunken objects, shaft sinking, and the like. It has other sub-liquid applications, however, for example in oil-well shooting and in various uses of explosives in the oil-production industry. By the words "dense liquid medium" we intend to include all liquids and suspensions of solids in liquids, e. g. mud, wet sand, and all solid-containing mixtures that may be caused to flow under pressure. The method is advantageous, for example, in ditch blasting in that explosives may be used which are more insensitive, and hence safer to handle, than the usual straight dynamites which have heretofore been required to permit propagation from cartridge to cartridge by sympathetic detonation through a wet soil medium.

With respect to explosive compositions for use in pressure-responsive detonators, the usual requirements will hold for base and intermediate charges. As base charges, a high-velocity explosive should be employed that accelerates rapidly to its maximum velocity when properly primed. This charge should be compressed to high density, e. g. around 1.6 g./cc., and suitable materials for use are pentaerythritol tetranitrate, tetryl, cyclotrimethylenetrinitramine, and the like. Such highly compressed charges are not sufficient readily ignitible by flame, and an intermediate or primary charge is customarily introduced, for example, mercury fulminate and its blends with chlorate, lead azide, nitromannitol, diazodinitrophenol, etc. While such a charge has been shown in the drawings as enclosed in a cavity in the base charge, this primary charge may occupy for a short length, around ¼ inch for example, the entire shell column. The intermediate or priming charge is likewise loaded under compression, for example about 4000 lb./sq. in. Hence, both the base charge and the primary charge are so consolidated as to remain fixed in position within the shell and to prevent the collapse in that portion of the shell which they occupy.

By explosive composition of the ignition type is meant an explosive compound or mixture commonly used in the explosive art as an ignition composition, i. e. a compound or mixture susceptible when in loose, uncompacted condition to ignition by an incandescent wire, such as by an electrically heated small-diameter platinum or Nichrome bridge wire as commonly used in the art. Examples of such compositions of the ignition type include mercury fulminate or its mixtures with potassium chlorate; mixtures of lead sulfocyanate with potassium chlorate and finely ground smokeless powder or sulfur or calcium silicide; a complex lead salt of lead nitrate with a bis basic lead salt of a nitrophenol (U. S. 2,175,249) or mixtures of such a salt with lead azide, with lead sulfocyanate, with potassium chlorate, or with potassium chlorate and finely ground smokeless powder; lead styphnate or its mixtures with tetryl; diazodinitrophenol or its mixtures with potassium chlorate; lead azide; mixtures of bismuth and selenium with a small amount of potassium chlorate; mixtures of boron and red lead; tetrazene or its mixtures with finely ground smokeless powder, or with aluminum and nitromannitol; and many others.

These ignition compositions are used in our pressure-responsive detonator, wherein no electric connections nor bridge wire are present, in loose, granular form, i. e. without compression and without the use of a binder. In this condition they are essentially free-flowing. The ignition composition is introduced into its portion of the detonator shell in such quantity that a considerable majority of the chamber which it occupies is free air space. The free air space, which air space includes the total volume of the voids between the particles, is equal to 70–85% of the volume of the "collapse" chamber. When pressure-responsive delay detonators are used, it is preferable that the ignition composition be one that produces little or no gas on burning, e. g. a mixture of boron and red lead or a mixture of bismuth and selenium with a small percentage, no more than about 5%, of potassium chlorate.

The wall of the detonator according to the invention may be made of any suitable metal such as gilding metal, brass, aluminum, copper or steel. The walls will desirably be of somewhat greater strength than those of ordinary detonators. In any event, the walls should be of such strength that the tubular container will withstand static pressures of more than 2000 lb./sq. in. in that portion containing the ignition composition. If the walls are of lesser strength, the hazard exists of the accidental detonation of the detonator by unintentional squeezing, as by being stepped on, for example. In many cases, even greater wall strengths are desirable. For example, when the pressure-responsive detonators are to be used in deep oil wells where high hydrostatic pressures are to be expected, it may be necessary to provide shells having wall strengths which will withstand pressures greater than 10,000 lb./sq. in. before collapse occurs.

When wall strengths which will withstand high pressures such as those greater than 10,000 lb./sq. in. are used, the eventual collapse, under still higher pressures, of the detonator in the portion loosely filled by the ignition composition is of such force that the ignition composition is fired with certainty. When, however, wall strengths in the vicinity of those which will withstand static pressures of about 2500 lb./sq. in. are used, it is often desirable to include in the "collapse" chamber at least one solid, non-reacting hard object of irregular shape, which may, for convenience, be designated as an anvil, in order to provide a friction surface which will facilitate ignition of the ignition composition upon collapse of the shell wall. Such an object has been shown in the bent wire **6** of Figure 2. Other elongated wires or rods of irregular shape, e. g. serrated rods, may also be used. When large, rigid objects of the type of wires are introduced, it is desirable for the sake of safety that they be fastened in position within the "collapse" chamber. For example, they may be inserted in the closing plug of the detonator shell, as illustrated in Figure 2. Other, smaller hard objects of irregular shape may also be introduced into the "collapse" chamber along with the ignition composition. For example, it may be desirable to introduce grains of sand or quartz to insure adequate friction surface in detonators having walls of the lower strengths, i. e. those approaching the lower limit of 2000 lb./sq. in. It will be understood that suitable adjustments may be made in wall strength, choice of ignition composition, amount of space in the "collapse" chamber filled by the ignition composition, and inclusion or not of an anvil to fit the detonator to its particular conditions of use.

For example, a satisfactory pressure-responsive detonator for use at a collapse pressure of about 2500 lb./sq. in. may be prepared by pressing a base charge of cyclotrimethylenetrinitramine into a gilding metal shell of the type shown in Figure 2 of a diameter of 0.279 in. and a wall thickness of 0.009 in. A priming or intermediate charge of lead azide is loaded at a pressure of 4000 lb./sq. in. into the cavity in the base charge. Above this charge a section of the tubular shell 1 in. in depth is filled to a depth of about ½ in. with a loose, granular mixture of 50 parts by weight lead sulfocyanate, 40 parts potassium chlorate, and 10 parts sulfur. The one-inch section of tube is closed by a rubber plug containing a waved wire anvil such as is illustrated at **6** in Figure 2, which plug is crimped tightly in place. The one-inch section containing the loose, granular charge to one-half its depth thus has no internal support, in contrast to those portions of the detonator containing the pressed charges and the closing plug. When a detonator constructed and loaded in this manner is subjected to test by being introduced into a heavy-walled pipe filled with a liquid the hydrostatic pressure of which is increased by means of a pump until

the detonator collapses and detonates, it is found that the collapse occurs at about 2500 lb./sq. in. When such detonators are used in an underwater blasting assembly such as is shown in Figure 7, for example, all the explosive charges containing these detonators are exploded by the sudden increase in pressure brought about by the detonation of an explosive charge under water in their vicinity.

For a pressure-responsive detonator to be used at higher pressures, about 12,000 lb./sq. in., for example, a tube such as is shown in Figure 4 of gilding metal about 0.311 in. in diameter and of 0.025 in. wall thickness is provided with a closing plug **9** at one end. A base charge of pressed cyclotrimethylenetrinitramine and an intermediate charge of lead azide pressed at 4000 lb./sq. in. are introduced into the bottom of the closed tube. Into a space within the tube about 1 in. in depth is introduced to a depth of about ½ in. a loose, granular ignition charge comprising a mixture of 50% by weight of ground smokeless powder, 25% of a complex salt of lead nitrate with a bis basic lead salt of 4,6-dinitroortho-cresol, and 25% of potassium chlorate. The one-inch section of tube is closed by a second plug **9**. No anvil is required in the detonator here described because the detonator is constructed to collapse at the internally unsupported portion at such high pressure that collapse, when it does occur, is so sudden and energetic that an additional friction-promoting element is superfluous. When a detonator constructed and loaded in this manner is subjected to test by being introduced into a heavy-walled pipe filled with a liquid the hydrostatic pressure of which is increased by means of a pump until the detonator collapses and detonates, it is found that the collapse occurs at about 12,000 lb./sq. in. When such detonators are used in a blasting assembly such as is shown in Figure 8, for example, at the bottom of a deep oil well, where high hydrostatic pressure exists, they resist collapse at the high hydrostatic pressures in the well, but the pressure-responsive detonators in the assembly, and consequently the explosive charges, are exploded by the sudden increase in pressure brought about by the detonation of an explosive charge in the liquid medium of the well in their vicinity.

It is believed that the functioning of our detonator depends on the pinching of the ignition composition in thin layers between the folds of the suddenly collapsing metal walls or between the wall and the anvil and that the heat generated thereby initiates the ignition composition, which, in its turn, starts the intermediate charge or the delay charge, if a delay charge is present, and that the large amount of free air space is necessary to permit the free movement of the flowable granular solid ignition composition. When an ignition composition is packed tightly, ignition is likely not to occur. Although the various ignition compositions vary in specific gravity and grain size, with consequent variation in the volume of the voids between the solid particles, we ordinarily prefer to fill the unsupported "collapse" chamber to about one-half with the ignition composition, on a bulk basis. The remaining half of free air space combined with the volume of voids between the solids provides a large amount of space within which the ignition composition can move. We have found that when the combined air space plus the voids is equal to 70–85% of the volume of the chamber satisfactory ignition occurs. When the total air space is greater than 85%, there may be too little of the ignition composition present to assure ignition, and when the total air space is less than 70% it is possible that sufficient frictional compression of the ignition composition will not take place.

Furthermore, in order to assure collapse of the shell in the internally unsupported portion containing the loose, granular ignition composition to a degree to bring metal surfaces in contact, it is necessary that this internally unsupported portion be at least twice as long as the diameter of the shell.

It will be understood that the pressure-responsive detonators of the present invention differ from the percussion caps which have been used in military explosives in that no percussion pin or other object is required to come into contact with the detonator. In fact, such an object would indent the detonator to such an extent as to cause internal metal-to-metal contact only with difficulty because of the strength of the shell wall. If, on the other hand, an object were to penetrate the shell wall, liquid would enter, and the detonator would fail to function. Furthermore, either indentation or penetration would be unlikely to find sufficient explosive composition at the point of percussion to become ignited because of the free space within the "collapse" chamber and the freely flowing nature of the loose, granular ignition composition.

Whereas examples have been given of various diameters and wall thicknesses of the detonator shell, these are not limiting because one skilled in the art can readily determine the diameter and the wall thickness required for any particular metal to attain the collapse strength desired, which strength may be tested by controlled hydrostatic collapse of the shell in the absence of the ignition composition.

It is essential that the shell be sealed tightly, and the seal will desirably be such as to be maintained under considerable pressure. The sealing means shown in Figures 1–4 are effective means for achieving closures which are resistant to high pressures. Other means may also be used. It may, however, be desirable to seal the shell in such manner that the sealing means will be resistant to the pressure of the surrounding medium but will give way under the pressure developed by the explosive charge fired in the vicinity of the propagation detonators and be instrumental in effecting ignition. When so used, the sealing means will desirably be coated or tipped with metal on the inner side. It will be understood that such an arrangement comes within the scope of the invention.

The method of underwater blasting according to the present invention is outstanding in its advantages. The pressure-responsive detonators used are simpler in design and more economical in cost of materials than electric blasting caps. Since only one electric blasting cap is required for a group of shots, this means a very considerable savings, particularly in cap wires and electrical firing means. At the same time the disadvantages are avoided of a large number of sets of cap wires that may become fouled by floating or submerged objects and may constitute a hazard during the occurrence of electrical storms, even at a considerable distance from the place of blasting.

A particular advantage comes from the fact that the method allows the satisfactory and effective use of explosives of a lower order of sensitivity than has been possible heretofore in the usual procedures followed. It has previously been the practice in submarine blasting to employ 60% straight dynamite, in order to assure complete detonation where propagation from hole to hole was desired. This 60% straight dynamite is of a high degree of sensitivity, and its use in large-scale blasting operations is not desirable because of the rough treatment involved, and the care required in such handling. By using the method of the present invention, any cap-sensitive explosive may be employed, and we find highly desirable explosives relatively insensitive to impact such as those high in ammonium nitrate content, for instance over 60% ammonium nitrate, nonnitroglycerin explosives containing solid sensitizers, granulated cast mixtures of ammonium nitrate and trinitrotoluene, blasting agents of the "Nitramon" type where a cap-sensitive booster charge is required, and many others. With such explosives having a pressure-responsive detonator inserted in each cartridge or in each group of cartridges, the advantages

are obtained of excellent blasting execution, simplicity of assembly, and freedom from the hazards of sensitive explosives. It will be understood that, when the term explosive charge is used, this may designate either a single explosive cartridge or a group of cartridges in substantial contact or in detonating relationship with one another.

The invention has been disclosed at length in foregoing, but it will be understood that many changes in details of charges, arrangement of charges, assembly and detonator design may be made without departure from the scope of the invention.

We intend to be limited, therefore, only by the following claims.

We claim:

1. A detonator for use in blasting operations in contact with a dense liquid medium and adapted to be initiated by pressure resulting from a nearby explosion, said detonator comprising a completely sealed tubular metal shell containing a base charge of a dense, high-velocity explosive, a compressed priming charge, and, in a portion of the shell in ignition relationship with the priming charge, said portion being at least twice as long as the diameter of the shell, a loose, granular ignition composition susceptible to ignition by an incandescent wire, the combined air space plus the voids within said portion amounting to 70–85% of the volume of said portion, the walls of said shell being of a strength such as to undergo substantial collapse at static pressures greater than 2000 lb./sq. in., whereby the shell wall is collapsed under the effect of pressures greater than 2000 lb./sq. in. transmitted through a dense liquid medium and wherein the ignition of the loose ignition composition is produced by such wall collapse.

2. A detonator in accordance with claim 1, in which at least one solid, nonreacting hard object of irregular shape is present in the portion of the shell containing the loose, granular ignition composition.

3. A detonator in accordance with claim 1, wherein the shell wall is of a strength such as to undergo substantial collapse at pressures greater than 10,000 lb./sq. in.

4. A delay detonator for use in blasting operations in contact with a dense liquid medium and adapted to be initiated by pressure resulting from a nearby explosion, said delay detonator comprising a completely sealed tubular metal shell containing a base charge of a dense, high-velocity explosive, a compressed priming charge, a delay charge in ignition relationship with the priming charge, and, in a chamber contiguous to the delay charge, said chamber being at least twice as long as the diameter of the shell, a loose, granular explosive composition susceptible to ignition by an incandescent wire and which produces little or no gas on burning, the combined air space plus the voids within said chamber amounting to 70–85% of the volume of the chamber, the walls of said shell being of a strength such as to undergo substantial collapse at static pressures greater than 2000 lb./sq. in., whereby the shell wall is collapsed in liquid media under the effect of pressures greater than 2000 lb./sq. in. and wherein the ignition of the loose, ignition-type explosive composition is produced by such wall collapse.

5. A detonator for use in blasting operations in contact with a dense liquid medium and adapted to be initiated by pressure resulting from a nearby explosion, said detonator comprising, in a metal shell closed at one end and of a strength such as to undergo substantial collapse at static pressures greater than 2000 lb./sq. in., a high-density base charge, a compressed priming charge, and, in a chamber between the priming charge and a plug sealing the top of the shell in a water-tight manner, said chamber being not less in length than twice the diameter of the shell, a loose, granular explosive composition capable of ignition by an incandescent wire, the combined air space plus the voids within said chamber amounting to 70–85% of the volume of the chamber, whereby the detonator is initiated in liquid media by pressures greater than 2000 lb./sq. in. acting on the shell of the detonator.

6. A detonator for use in blasting operations in contact with a dense liquid medium and adapted to be initiated by pressure resulting from a nearby explosion, said detonator comprising, in a metal shell closed at one end, a dense, high-velocity base charge, a compressed priming charge, and, in a chamber between the priming charge and a plug sealing the top of the shell in a water-tight manner, said chamber being at least as long as twice the diameter of the shell and containing at least one solid, nonreacting hard object of irregular shape, a loose, granular ignition composition susceptible to ignition by an incandescent wire, the combined air space plus the voids within said chamber amounting to 70–85% of the volume of the chamber, the walls of said shell being of a strength such as to undergo substantial collapse at static pressures of about 2500 lb./sq. in.

7. A detonator for use in blasting operations in contact with a dense liquid medium and adapted to be initiated by pressure resulting from a nearby explosion, said detonator comprising, in a completely sealed metal shell, a high-density, high-velocity base charge, a compressed priming charge, and, in a portion of the shell in ignition relationship with the priming charge, said portion being at least twice as long as the diameter of the shell, a loose, granular ignition composition susceptible to ignition by an incandescent wire, the combined air space plus the voids within said portion amounting to 70–85% of the volume of said portion, the walls of said shell being of a strength such as to undergo substantial collapse at static pressures of about 12,000 lb./sq. in.

8. A detonator for use in blasting operations in contact with a dense liquid medium and adapted to be initiated by pressure resulting from a nearby explosion, said detonator comprising a completely sealed tubular shell of a metal selected from the group consisting of gilding metal, brass, aluminum, copper, and steel, said shell containing a base charge of a dense high-velocity explosive, a compressed priming charge, and, in a portion of the shell in ignition relationship with the priming charge, said portion being at least twice as long as the diameter of the shell, a loose, granular ignition composition susceptible to ignition by an incandescent wire, the combined air space plus the voids within said portion amounting to 70 to 85% of the volume of said portion, the walls of said shell being of a strength such as to undergo substantial collapse at static pressures greater than 2000 lb./sq. in., whereby the shell wall is collapsed under the effect of pressures greater than 2000 lb./sq. in. transmitted through a dense liquid medium, and wherein the ignition of the loose, granular ignition composition is produced by such shell collapse.

9. A detonator for use in blasting operations in contact with a dense liquid medium and adapted to be initiated by pressure resulting from a nearby explosion, said detonator comprising a completely sealed tubular metal shell containing a base charge of a dense, high-velocity explosive, a compressed priming charge, and, in a portion of the shell in ignition relationship with the priming charge, said portion being at least twice as long as the diameter of the shell, a loose, granular ignition composition selected from the group consisting of mercury fulminate alone and with potassium chlorate; lead sulfocyanate-potassium chlorate mixtures (1) with smokeless powder, (2) with sulfur, and (3) with calcium silicide; a complex lead salt of lead nitrate with a bis basic lead salt of a nitrophenol (1) alone, (2) with lead azide, (3) with lead sulfocyanate, (4) with potassium chlorate, and (5) with potassium chlorate and smokeless powder; lead styphnate alone and with tetryl; diazodinitrophenol alone and with potassium chlorate; lead azide; mixtures of bismuth and selenium with potassium chlorate; mixtures of boron and red lead; tetrazine (1) alone, (2) with smoke-

less powder, (3) with aluminum, and (4) with nitromannitol; the combined air space plus the voids within said portion amounting to 70 to 85% of the volume of said portion, the walls of said shell being of a strength such as to undergo substantial collapse at static pressures greater than 2000 lb./sq. in., whereby the shell wall is collapsed under the effect of pressures greater than 2000 lb./sq. in. transmitted through a dense liquid medium and wherein the ignition of the loose ignition composition is produced by such wall collapse.

10. A detonator for use in blasting operations in contact with a dense liquid medium and adapted to be initiated by pressure resulting from a nearby explosion, said detonator comprising a completely sealed tubular metal shell containing a base charge of a dense, high-velocity explosive, a compressed priming charge, and, in a portion of the shell in ignition relationship with the priming charge, said portion being at least twice as long as the diameter of the shell, a loose, granular ignition composition, the combined air space plus the voids within said portion amounting to 70 to 85% of the volume of said portion, the walls of said shell being of a strength at least of the order of magnitude of that of a gilding metal shell having a wall thickness of 0.025 inch, so as to undergo substantial collapse at selected static pressures greater than 2000 lb./sq. in., whereby the shell wall is not collapsed below 2000 lb./sq. in. but is collapsed under the effect of selected pressures greater than 2000 lb./sq. in. transmitted through a dense liquid medium and wherein the ignition of the loose ignition composition is produced by such wall collapse.

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