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CONTROLLED VELOCITY EXPLOSIVE CHARGE FOR SEISMIC EXPLORATION

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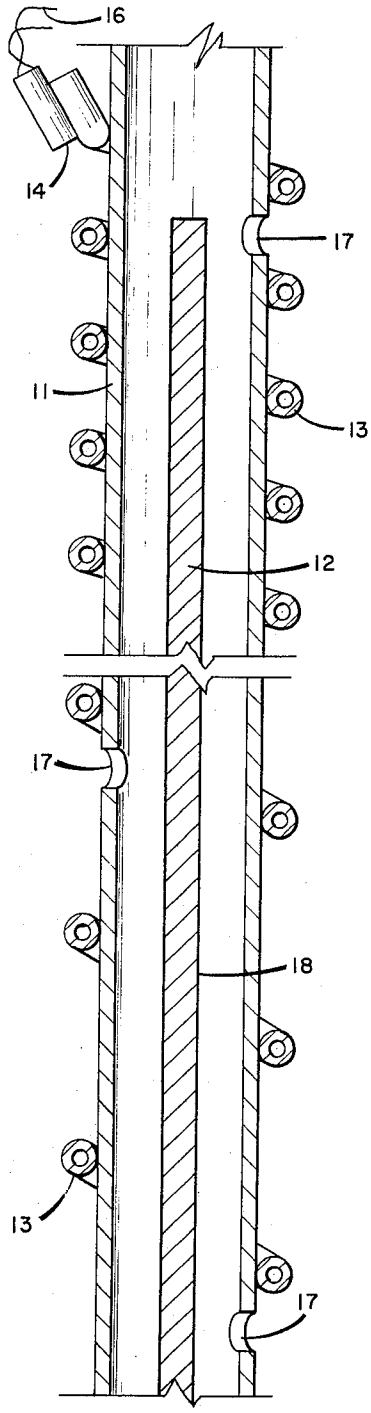


FIG.-1

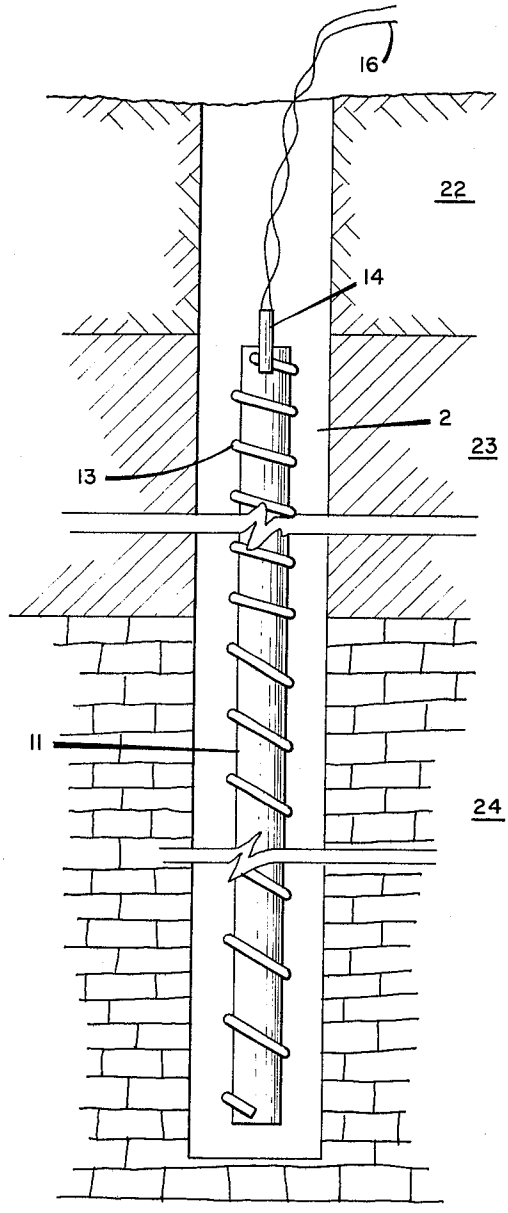


FIG.-2

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CONTROLLED VELOCITY EXPLOSIVE CHARGE FOR SEISMIC EXPLORATION

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This invention relates to controlled velocity explosive charges, and more particularly, it is directed to an improvement in the generation of seismic waves for use in geophysical surveying.

Heretofore, elongated distributed explosive charges have been proposed for use in seismic surveying, wherein the effective detonation velocity of the charge is matched approximately to the seismic wave transmision velocities of the medium surrounding the charge. Such distributed charges have been found very useful in discriminating against the generation of seismic noise and in preventing undue damage to the surrounding medium. An example of the above-mentioned distributed charge is Silverman U.S. Patent 2,609,885 disclosing an explosive charge employing a helix of a linear explosive, such as Primacord detonating fuse, the helix having a pitch providing an effective detonation velocity equal to the wave transmission velocity of the surrounding formations in the direction of detonation. Also, Lang U.S. Patent 2,846,019 discloses a method of generating seismic waves employing an explosive mixture of fuel gas and oxygen wherein the composition of the explosive gas mixture is adjusted to provide a velocity of detonation matched with the seismic wave transmission velocity of the adjacent formations.

With such seismic charges as mentioned above, it is oftentimes desirable to increase the explosive weight of the charges over that inherent in the velocity matching charge itself so that a greater force is applied to the formation upon detonation of the charge. Certain limitations exist on the explosive weight of the helical linear explosive and the explosive gas method has so far found only limited use in its application. In the use of the helical linear explosive, a practice has been to supplement the charge weight by coupling spaced-apart packages of canned explosives, such as Nitramon, into the linear explosive array. However, such addition of explosives to the distributed charge assembly results in "lump" charges, which cause the flow of explosive energy into the earth to be pulsed, rather than providing a smooth flow of energy, as is desirable from a uniformly distributed charge. Also, these lumps usually detonate at a velocity greater than that of the helical linear explosive, presenting considerable difficulties in designing such a charge to match the velocity of a specified formation. Additionally, the concentrated energy of such a charge lump may damage the ensuing distributed charge elements to cause failure of the detonation.

A primary object of the present invention is an improved distributed charge useful as an energy source for generating seismic waves, which charge has a controllable velocity of detonation and an adjustable weight of explosive. A further object is such an energy source providing a uniform flow of explosive energy. Still a further object is such an energy source having a uniform detonation velocity. A still further object of the invention is such an energy source which is readily fabricated to provide the desired explosive weight and detonation velocity, while at the same time being relatively economical. These and further objects of the invention will become more apparent by reference to the following

description of the invention and to the accompanying drawings wherein:

FIGURE 1 illustrates a vertical cross-sectional view of a preferred form of an energy source according to the invention; and

FIGURE 2 illustrates a cross-sectional view of a bore hole with an energy source of the invention positioned in the bore hole.

According to the invention, the continuous priming principle is employed to provide a unique explosive charge having a controllable velocity of detonation. An elongated composite charge is provided utilizing a first explosive component producing a preselected effective velocity of detonation and being capable of self-sustaining detonation, and a second explosive component being incapable of self-sustaining detonation, but being detonable by the first component. The two explosive components are placed in detonation relation with each other so that, upon detonation of the first component, detonation proceeds along the length of the composite charge at a velocity substantially equal to the effective velocity of detonation of the first component.

As disclosed by the above-mentioned U.S. Patent 2,609,885, a linear explosive having a known velocity of detonation, which is at least as great as the seismic wave velocity of the surrounding medium, may be arranged in a helix or other suitable shape to provide a vertical distributed charge having an effective velocity of detonation matched with the seismic wave transmission velocity of the formations surrounding the charge. As used herein, the term "effective detonation velocity" refers to that component of the detonation velocity in the direction of the vertical axis of the charge. Various linear explosives may be employed in practicing the present invention to provide the desired velocity and directional properties and to continuously prime the supplemental charge. Preferably, a detonating fuse, such as the material known as Primacord, is employed as the linear explosive. Primacord is granular pentaerythritol tetranitrate (PETN) in a braided cord with a plastic sheath confining and protecting the explosive. Other similar explosives, such as cyclotrimethylenetrinitramine (RDX), or the like, suitable for use as a detonating fuse or priming material may be used. Other forms such as a tube or rod of the explosive, typically formed by inserting a powder or granules of explosive in a sheath, such as flexible plastic tube, or a precast rigid groove may be utilized. Certain explosives of this type must be waterproofed. Various linear explosives are available in differing explosive weights and velocities of detonation, and the shape of the particular linear explosive selected may be varied to produce the desired effective velocity of detonation, as by controlling the pitch of the helical turns. Generally, when employing a helical shape it is advantageous to have the turns spaced as closely as possible and the smallest linear explosive capable of initiating and sustaining detonation of the supplemental explosive is therefore preferred so that the possibility of cross-firing, i.e., firing across the turns, is reduced.

The composite charge comprises a second explosive component employed as a booster charge to supplement the linear explosive and provide the desired total charge weight. It is an essential feature of the invention that the booster charge be formed of an explosive which is incapable of self-sustaining detonation, but which is detonable by the continuous priming action of the adjacent linear explosive. It has been determined that elongated slender cartridges, or slender columns, of ammonium nitrate explosives, such as a mixture of ammonium nitrate and fuel oil (AN/FO), are incapable of self-propagation of detonation when the diameter of the column falls below a critical minimum diameter, although

the explosive is self-sustaining when formed into large diameter columns. For example, a well-packed column of AN/FO with a diameter of 1½ inches is capable of self-sustaining detonation, while for diameters less than about 1½ inches, detonation, once beyond the influence of the primer, will slow and fail in about 2½ column diameters. Other of the well-known explosives are likewise incapable of self-sustaining detonation when formed into a shape having a cross section less than the minimum necessary, and these are suitable for use in the practice of our invention, although all are not necessarily of equal effectiveness for this purpose. For example, the various ammonium nitrate explosives, such as ammonium nitrate mixed with up to about 10 percent of a carbonaceous material may be used. Typically, about 4 to 8 percent of a liquifiable hydrocarbon, such as fuel oil is employed. The ammonium nitrate explosive may be formulated with any of the well-known organic or inorganic sensitizers, and a light metal, such as magnesium or aluminum, may be incorporated in the explosive, if desired. Also, the straight dynamites, ammonia dynamites or gelatine dynamites may be employed.

The critical minimum cross section of the booster charge will vary, depending upon the particular explosive formulation, the method of manufacture, the density and other such factors. It is known that certain explosives, such as AN/FO or the like, are rendered less sensitive to detonation by moisture pick-up or by an increase in density, so that a charge of the explosive which is otherwise capable of self-sustaining detonation may be made incapable of self-sustaining detonation when such factors are varied. If the cross section of such a charge is increased above the critical dimension, the charge will again become self-propagating. However, the critical cross section may be determined readily by various well-known tests. For example, a cone-shaped sample of the explosive may be detonated at the base of the cone and the diameter of the point of failure of propagation determined. It is critical to the invention that this critical diameter of the booster charge not be exceeded, or the booster will become self-propagating, and the effectiveness of the composite charge will be reduced.

As mentioned above, a preferred construction of the composite explosive charge comprises a helical linear explosive surrounding a long slender column of otherwise nondetonable booster charge. The linear explosive and the booster charge are positioned closely adjacent each other, so that the two are in detonation relation over the length of the charge. The linear explosive continuously primes the otherwise nondetonable booster, and the two must be positioned so that the shock wave from the primer is of great enough magnitude to induce and sustain detonation in the column of booster. If this condition is absent, detonation of the column of booster charge will not proceed along its length, but will slow and fail, even though once begun. If the two explosive components are in detonation relation, the detonation will proceed at a velocity substantially equal to the effective velocity of detonation of the linear explosive.

Turning now to FIGURE 1, there is shown a preferred embodiment of the explosive charge of the invention. An elongated, slender cartridge, or column which may be solid or cored, of AN/FO explosive is formed from a mixture of commercial grade ammonium nitrate and about 2 to 10 percent fuel oil. The mixture is inserted into a long, relatively thin-wall tubular mandrel **11** having an internal diameter suitable for holding a column of booster charge of a diameter less than the critical minimum diameter required for self-propagation of detonation of the ammonium nitrate explosive. Typically, the tube, or mandrel, is formed of fiber or cardboard which may be waterproofed by impregnation with paraffin or a suitable resin. Within the above-mentioned limits the diameter and length of the column **12** of the ammonium nitrate explosive may be varied according to the total explosive charge weight desired. In the instance of the ammonium nitrate explosive referred to above, this diameter typically may vary from ¼ inch to 1¼ inches.

Wrapped around the mandrel **11** and in detonation relation with the ammonium nitrate booster is a helix of linear explosive **13**, formed of Primacord detonating fuse which encloses the ammonium nitrate column for substantially its complete length. Connected to one end of the linear explosive is an electric blasting cap **14**, or another suitable detonator, connected by electrical leads **16** to a suitable power source. If desired, perforations **17** may be provided in the mandrel wall to permit the entry of fluids into the mandrel interior to reduce buoyancy so that the explosive charge may be more easily placed at a desired depth in water of a fluid-filled bore hole. The column of booster may be enclosed in a waterproofed container, such as flexible plastic bag **18**. The pitch of the helix is chosen to provide the desired effective velocity of detonation in the manner herein described, and a suitable weight of linear explosive is employed so that the total explosive weight is as desired, the weight and spacing of the turns are such as to prevent cross-firing from one turn to another.

The above-mentioned elongated composite explosive charge typically may be made up in 3- to 8-foot lengths and these lengths may be coupled together with a suitable coupling unit to provide a unit of the desired overall length. FIGURE 2 shows the above embodiment of the invention positioned in a bore hole **21** penetrating a plurality of formations **22**, **23** and **24**. Typically, formation **23** and **24** are the formations of interest, and each has a different seismic-wave-propagation velocity. The helix diameter and pitch in that portion of the charge traversing each formation of interest are varied to provide an effective velocity of detonation approximately matching the velocity of the formation.

As mentioned above, the total explosive weight will be determined by the amount of the ammonium nitrate in the booster cartridge and the weight and length of the linear explosive. Typically unit charges of varying lengths and varying angles of helical pitch may be made up beforehand. Similarly, modular units of the AN/FO mixture may be provided, with the supplemental charge units inserted into the mandrel in the desired charge weight.

While the above-described helical configuration of linear explosives mounted upon a slender column of ammonium nitrate has been found to provide exceptional results, it is within the scope of the invention to employ other shapes of linear explosive and booster charge. For example, the linear explosive may be placed on the inside of the tube or in the tube wall, and the booster charge may be provided by an elongated slender sheath of AN/FO which is attached to the outside of the tubular mandrel so that it is in detonation relation with the linear explosive. Similarly, the booster charge may be in tubular form, and the linear explosive may be in a suitable form other than a helix. Also, the booster charge may be placed in a tube, such as a flexible plastic tube, with the linear explosive positioned directly on the surface of the tube, so that the composite charge may be wound upon a reel. In this latter instance the charge is used by unwinding and allowing it to be pulled down into the bore hole by a suitable weight.

The following examples illustrate the effectiveness of the energy source described above. A number of tests were conducted in a shot hole in the earth at depths ranging from 135 to 150 feet. The explosive charges comprised long, slender plastic bags filled with an AN/FO mixture upon which were wound lengths of Primacord detonating fuse. A high-speed recorder was used to record the time interval required for detonation to proceed from end-to-end of the elongated test charge assembly, and a seismometer placed near the mouth of the shot hole was employed to measure the increase in seismic energy produced by the supplemental explosive detonated within

the Primacord helices. The output of the seismometer was recorded on the recorder with the detonation velocity data.

The test charge assemblies were constructed using a mixture of prilled ammonium nitrate fertilizer and No. 2 diesel fuel in an amount of 6 percent by weight. The mixture was formed by pouring the oil over a measured quantity of ammonium nitrate and stirring in a plastic vessel to uniformly distribute the oil throughout the mass. The AN/FO mixture was inserted in polyvinyl chloride tubing having a wall thickness of about 0.020 inch and the ends were sealed with electrical tape and petroleum wax to provide a watertight enclosure for the explosive. The tubes were ¾-inch I.D. by 36-inches long and contained a net charge weight of ½ pound.

The tubes filled with the explosive mixture were then inserted into larger diameter fiber tubes having an I.D. of approximately ¾ inch and which had been boiled in paraffin to increase their water resistance. The fiber tubes were then coupled end-to-end by inserting into their ends lengths of smaller tubing serving as couplings which provided a strong, forced fit. Primacord detonating fuse was then wound upon the outside of the tubes in the form of a helix and the ends of the Primacord winding were protected from water entry by aluminum thimbles. Detonation of the Primacord from one length of tube to the next was assured by lapping the ends of the cord from adjacent tubes and taping them in this position. An electric blasting cap was connected to the lower end of the Primacord. The time interval used in determining the velocity of detonation was measured between the instant of rupture of the cap at the lower end of the charge assembly and an electrical conductor broken by the blast as detonation neared the upper end of the Primacord helix.

In test A and test B, 100 grain/foot Primacord was wound upon the mandrel with a helix spacing of 1½ inches to provide a total Primacord length of 17 feet over each of three 56-inch long by 1½-inch outside diameter fiber tubes described above. In test A no ammonium nitrate booster was employed, while in test B three of the ¾-inch diameter by 36-inch long tubes of AN/FO mixture were employed as boosters, one in each of the above fiber tubes. The explosives were detonated in a bore hole under approximately 150 feet of water and the measured velocities were 7,610 feet per second for both tests. The measured seismic amplitude of test B was approximately double that measured in test A.

A similar test was carried out as described above employing 60 grain per foot Primacord helically wound upon the above tubes with a 1¼-inch spacing between the turns to provide a total Primacord length of 20½ feet on each 5-foot mandrel. Three mandrels were employed as before, with test D using no booster, while test C employed three of the boosters described above. The measured velocity of each of the detonations was 6,860 feet per second. The measured seismic amplitude in test C was approximately double that of test D.

From the above-described tests it is apparent that the present invention provides an improved method of increasing the total explosive weight of the charge while maintaining the desired velocity of detonation, so that a more powerful, smoth-flowing energy source can be provided readily and economically.

The above description and examples have been given for the purpose of illustrating our invention, and from the foregoing, various modifications and alterations in the details of construction and operation, falling within the spirit and scope of our invention will become apparent to the artisan.

We claim:

1. A controlled velocity explosive charge for use in seismic surveying which comprises:

(a) a first explosive element including
a rigid tube of a selected length, and
a continuous helix of linear explosive composition wrapped around said tube with said helix having a pitch providing an effective selected detonation velocity along the length of said tube;

(b) a second explosive element comprising a selected material in a slender cylindrical shape having a diameter D substantially smaller than the inner diameter of said tube so that said material can be freely inserted into said tube in a loosely fitting manner so that there is space between the interior of the tube and the second explosive element, said material chosen such that when in the form of a cylinder of diameter D it is not capable of self-sustaining detonation; and

(c) means to detonate said first explosive element.

2. An explosive charge as defined in claim 1 in which said selected material of said second explosive element is enclosed in a water-proof bag and said rigid tube has a perforation in the wall thereof whereby when such explosive charge is placed in a hole containing water the buoyancy thereof is reduced so that the explosive charge may be more easily placed at a desired depth.

3. An explosive charge as defined in claim 1 in which said material of said second explosive element comprises an ammonium nitrate explosive having not over 10% carbonaceous fuel and a diameter in the range from about ¼" to about 1¼" such that it is incapable of self-sustaining detonation.

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