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JET PERFORATING GUN

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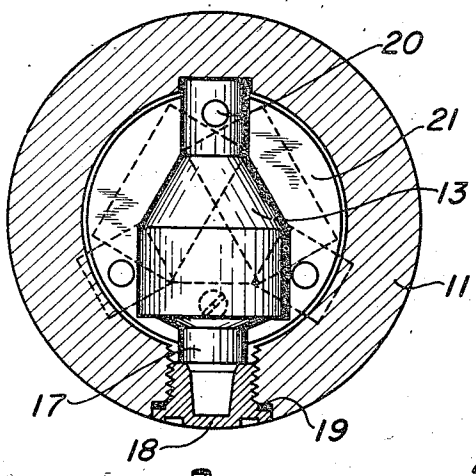

FIG. 2.

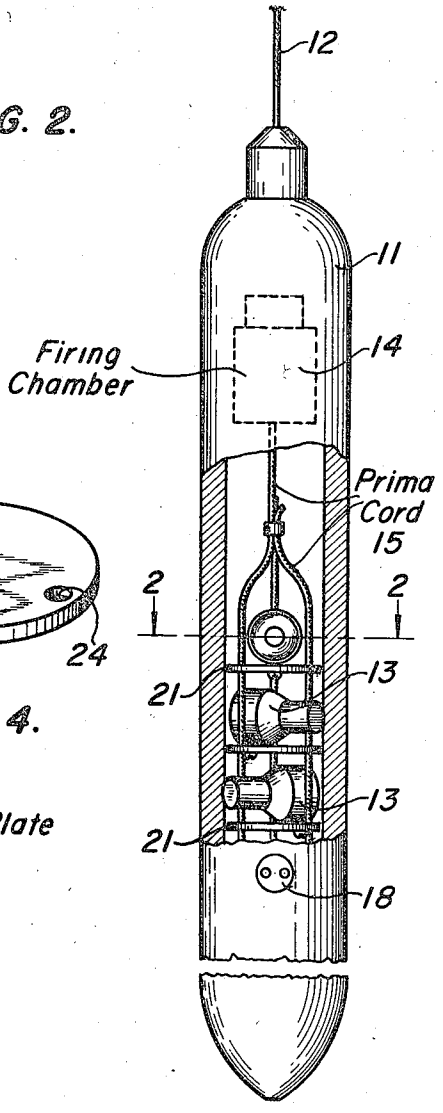

FIG. 1.

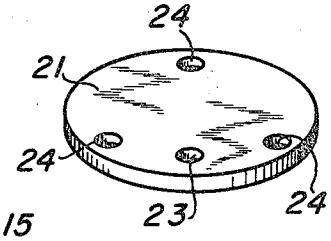

FIG. 4.

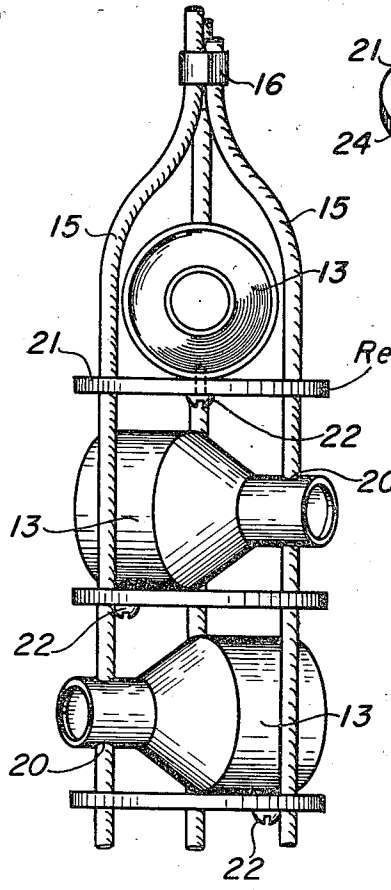

FIG. 3.

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JET PERFORATING GUN

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1 Claim. (Cl. 102—20)

This invention relates to jet perforating guns for use in oil wells or the like and more particularly to an arrangement for enabling casing in a well to be properly perforated with less spacing between the shaped charges used for this purpose than has heretofore been the case.

After casing is set and cemented in an oil producing formation, it is common practice to perforate it. The number of perforations per lineal foot of casing depends upon the character of the formation, the pressure and viscosity of the oil and the thickness of the cement behind it. Ordinarily, formations of low porosity and low permeability require more perforations per foot of casing. A large number of perforations are sometimes desired where the formation is to be acidized or subjected to hydraulic fracturing.

Before the present invention was made, where shaped charges of explosive were used to perforate casing in wells, it was standard practice to mount the charges three inches between centers (four jets to the foot). It was thought to be impossible to mount them any closer than that because of interference of one charge with the jet of another. The proper operation of shaped charges is dependent upon the "Monroe effect," which involves the behavior of pressure waves in gases, and the jets cannot function to perforate casing properly if a pressure wave from one shaped charge modifies that set up by another. A pressure wave from the first charge forces the jet of the next "out of focus," results in "key-hole shaped" perforations in the casing, and greatly reduces penetration.

Attempts have heretofore been made to devise some means to enable shaped charges to be mounted and fired in wells with short spacing between centers. These charges are fired with "Primacord," and one improvement that has been made along this line is the devising of "Primacord" having a velocity in excess of 6,500 meter/second. But even with "Primacord" which burns at this extremely high velocity, much higher than the speed of travel of a pressure wave in air, nevertheless it cannot cause all the jet charges to fire simultaneously. Since the charges must fire in sequence, even though the time interval between each firing is measured only in micro-seconds, there is sufficient delay in the firing to enable a pressure wave from one charge to interfere with the jet set up by the next if the distance is small. It is for this reason that a standard of not less than three inches between centers has been adopted.

For further discussion of prior theories on the limitations on spacing between shaped charges used in perforating casing in oil wells, see "Dupont Jet Perforators," copyright 1949, E. I. du Pont de Nemours and Company (Inc.), Wilmington, Delaware, and "The jet perforation process" by W. T. Box and R. F. Meiklejohn, Byron Company, Los Angeles, appearing in "World Oil," March, 1950.

In accordance with the present invention means has been devised for enabling the firing of shaped charges spaced less than three inches between centers while preventing the pressure waves of the charges from interfering with each other. Spacing as small as two inches between centers (six jets to the foot) has been employed successfully and such guns are now in commercial use. This result has been brought about by the addition of two features to the known technique: (1) a rearrangement of the "Primacord" to shorten its length between successive charges of the explosive, and (2) the provision of acoustical reflection plates or barriers between the shaped charges, so mounted and of such material and dimensions as to reduce the magnitude of the pressure wave traveling from one charge to the others to a negligible amount.

Thus by using the present invention, a distinct advantage is obtained, especially in those cases where an operator desires to perforate casing set in tight formations or similar situations where more than four perforations per foot of casing are required.

The objects of the invention will be clear from the above discussion, and from consideration of the following detailed description of an arrangement for carrying out the invention, taken in connection with the accompanying drawings, in which:

Figure 1 is a view in side elevation, with a portion of the carriage cut away, of a jet perforating gun constructed in accordance with the invention;

Figure 2 is a cross-sectional view of the gun of Figure 1, taken on the line **2—2** thereof;

Figure 3 is an enlarged view in side elevation of the shaped charges and associated parts of the gun of Figure 1; and

Figure 4 is a perspective view of one of the acoustical reflectors used in the gun of Figure 1.

Referring to the drawing in detail, it will be seen that a jet perforating gun is there illustrated as consisting of a carriage **11** suspended on an electrical cable **12**.

Within the carriage **11** are a number of shaped charges of explosive **13**. These are of conventional design and are stacked in series one beneath the other and each so arranged as to discharge its jet outwardly through casing at an angle of 120 degrees from the jets of the immediately adjacent shaped charges.

The carriage **11** contains a firing chamber **14** which sets off a Primacord **15** to cause the shaped charges **13** to explode. The firing chamber is shown at the upper end of the carriage, but it could be placed at the lower end. It is connected to the conductor of the cable **12** and contains a fuse, blasting cap, or the equivalent so that when current is sent down the cable **12** from the surface of the ground, the Primacord will be set off and this will cause the shaped charges **13** to explode in rapid sequence.

The Primacord used should preferably be high speed, but the invention is not limited to the use of high speed Primacord.

It will be observed that between the firing chamber **14** and the nearest shaped charge **13**, the Primacord is divided into three parallel paths. This may be accomplished by merely fastening two additional sections of Primacord to the section leading from the firing chamber, as by means of a clip **16**.

Thus at the clip **16**, the path of burning of the Primacord **15** divides into three. Each section then causes every third one of the shaped charges to explode.

In the gun illustrated, the shaped charges **13** are mounted successively at 120 degree angles from one another as illustrated. They are fired in regular uni-directional sequence however. By using three sections of Primacord laying in straight lines, in accordance with the invention, the time between their explosions is less than would be the case if but a single section of Primacord were employed, because if only one section of Primacord were employed, it would have to be laid in a spiral to get from one shaped charge to the next

The shaped charges **13** may be mounted in the carriage **11** in the conventional manner. As illustrated, particularly in Figure 2, the carriage may be provided with sockets to receive the rear portions of the shaped charges **13** while the front ends thereof are provided with "stand-off rings" **17**, port plugs **18**, and sealing rings **19**. The rear portion of each shaped charge is provided with a hole **20** through which one or the other of the three sections of Primacord **15** is threaded, as illustrated.

An important feature of the invention resides in the use of disks or reflection plates **21**. These coact with the three section Primacord in such a way as to enable the shaped charges to be located much nearer each other than in any jet perforating gun heretofore devised.

The reflection plates are of such material and dimension, and are so mounted as to reflect or re-direct the pressure wave created in the gun carriage by the explosion of one shaped charge sufficiently to enable the Primacord to set off the next adjacent shaped charge and cause its jet to form and perforate the casing before the pressure wave from the previous one can interfere to any material extent.

The pressure wave created by the explosion of a shaped charge is of high magnitude. It is well known that only a fraction of the force created by the explosion results in the jet which is directed forward through the casing and into the surrounding earth formation. The main part of the explosive force causes a pressure wave to travel away from the charge in all directions. This pressure wave follows the laws of sound waves and can be reflected, just as pressure waves are reflected in the seismograph methods used in the exploration for oil. There is a partition or division of the energy of a pressure wave at a reflecting surface. Some of the energy goes on through the surface, but if conditions are just right, practically all of the energy is reflected back.

The problems arising in attempting to cause nearly complete reflection of a sound at the boundary between two media having different densities and through which sound travels at different velocities depends on the wave length of the sound and the dimensions of the objects, and become quite involved. See "A Textbook of Sound" by A. B. Wood, published by G. Bell and Sons, Ltd. of London, 1949, particularly pages 301 to 322.

Theoretical considerations, as well as the practical results obtained, lead to the conclusion that the best material to use for the disks **21** in the gun of the present invention is steel. It is desirable to use a medium which has a high acoustical resistance. Acoustical resistance of a medium is defined as the density of that medium times the velocity of sound through it.

Other metals could be used. Lead has a higher density but the velocity of sound through lead is much less. The velocity of sound through aluminum is high, but its density is so much lower than iron or steel that its acoustical velocity is not nearly as high.

The thickness of the plates **21** is also a factor in effectively reflecting the pressure waves and causing proper operation of the gun. The pressure wave enters a plate **21** and reflects from the surface opposite that from the shaped charge which caused the wave. Care must be exercised to prevent the echo from coming back and interfering with the jet stream of the shaped charge which initiated the pressure wave. With shaped charges each having 15 grams of standard explosive and spaced two inches between centers, steel plates $\frac{7}{32}$ inch has been found to be satisfactory.

The location of the disks is also important. It will be observed that the steel disks **21** shown in the drawing are loosely connected to the shaped charges **13** by the screws **22**. As shown, each disk is mounted immediately adjacent and beneath the shaped charge, the pressure wave of which it is to reflect. Of course, if the firing chamber **14** is located in the lower end of the gun instead of in the top as illustrated, the plates **21** would be located above their respective shaped charges, since the sequence of firing of the charges would then be from the bottom up. The disks may thus be said to be located immediately adjacent and on the rear side of the charges insofar as the direction of the sequence of firing of the charges is concerned.

The holes **23** in the plates **21** are larger than the shanks of the screws **22** and the screws **22** are not made up tight. Thus a limited amount of play or wobble is left in the connection. The purpose of this is to permit a certain amount of travel of each plate as its shaped charge explodes. This movement assists in preventing an echo from a plate from distorting, or moving out of focus, the jet stream of its own shaped charge.

With the reflecting plates **21** mounted as illustrated, the three sections of the Primacord pass through them at right angles, holes **24** spaced 120 degrees being provided for that purpose.

It will be apparent that there is a special coaction between the Primacord and the reflection plates. The Primacord is firing the charge in rapid sequence. The reflection plates are delaying the pressure waves from one charge to the next and preventing those waves from distorting the jets, not only the adjacent jets but also the jet of the charge to which each plate is attached. As each charge explodes, the plate attached to it moves slightly and while it is moving, it reflects practically all of the pressure wave created by that explosion.

The density of iron being 8 compared with 0.001 for air and the velocity of sound in iron being somewhere between 16,000 and 17,000 feet per second compared with 1,100 feet per second in air, the difference in acoustical resistance between these two media is tremendous, a ratio of about 120,000 to 1. With such a difference in acoustical resistance as this, for example, it becomes possible to select reflection plates of proper dimensions, location, and inertia to provide protection for the jets of shaped charges even though they are closely mounted, if care is exercised in controlling, at the same time, the speed with which the Primacord is firing the shaped charges.

While only one embodiment has been shown and described in detail herein, it is obvious that various changes may be made without departing from the spirit of the invention or the scope of the annexed claim.

I claim:

In a jet gun for perforating casing in oil wells or the like, the combination of a carriage, a series of shaped charges of explosive stacked in the carriage in such a way that each charge is adapted to direct a jet outwardly through casing at an angle of 120 degrees from the jets of the immediately adjacent shaped charges, a Primacord for firing said charges, said Primacord having three sections to provide three parallel burning paths of travel, each section passing through every third charge to cause the charges to fire in rapid and regular uni-directional sequence but with the sections of Primacord laying in straight lines, and reflection plates, one for each charge, placed between the charges, said reflection plates being made of iron or steel, means for supporting said plates on the sides of said charges for free oscillation in said carriage and with each reflection plate in substantial contact with one of said charges on the rear side thereof insofar as the direction of the sequence of firing of the charges is concerned.

References Cited in the file of this patent

UNITED STATES PATENTS

2,450,366	Williams	Sept. 28, 1948
2,586,706	Parr	Feb. 19, 1952
2,587,244	Sweetman	Feb. 26, 1952
2,655,619	Neal	Oct. 13, 1953
2,669,928	Sweetman	Feb. 23, 1954
2,680,406	Austin	June 8, 1954
2,733,657	Bryant et al.	Feb. 7, 1956