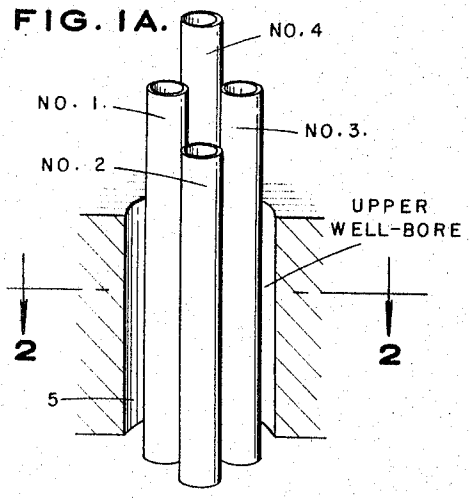
March 7, 1967 W. J. BIELSTEIN 3,307,626

COMPLETION OF WELLS

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FIG. 1A.



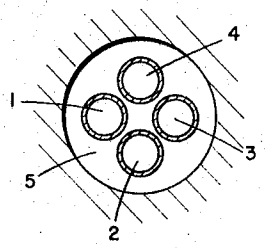


FIG. 2.

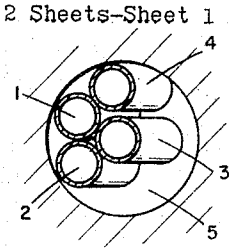


FIG. 3.

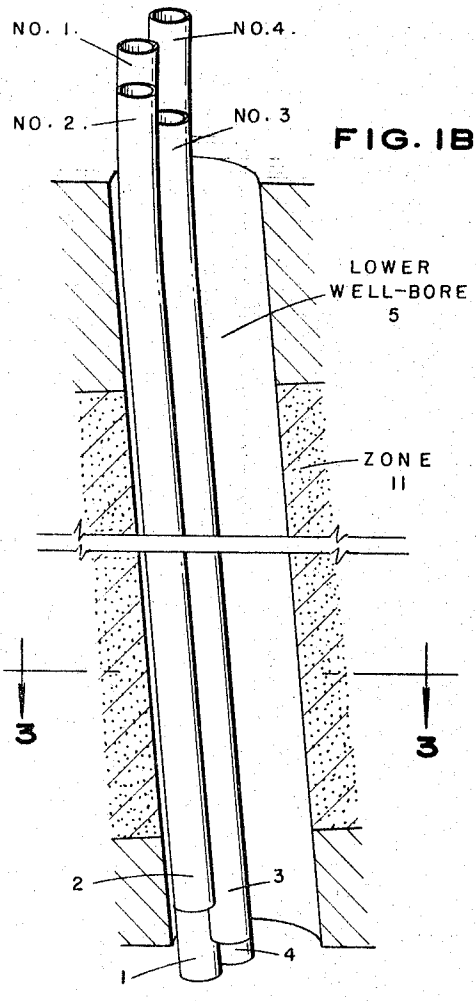


FIG. 1B.

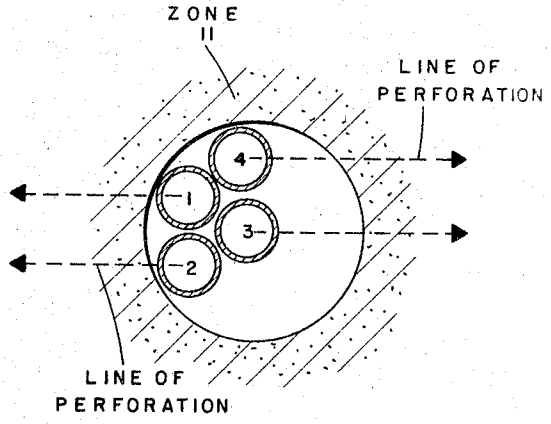


FIG. 4.

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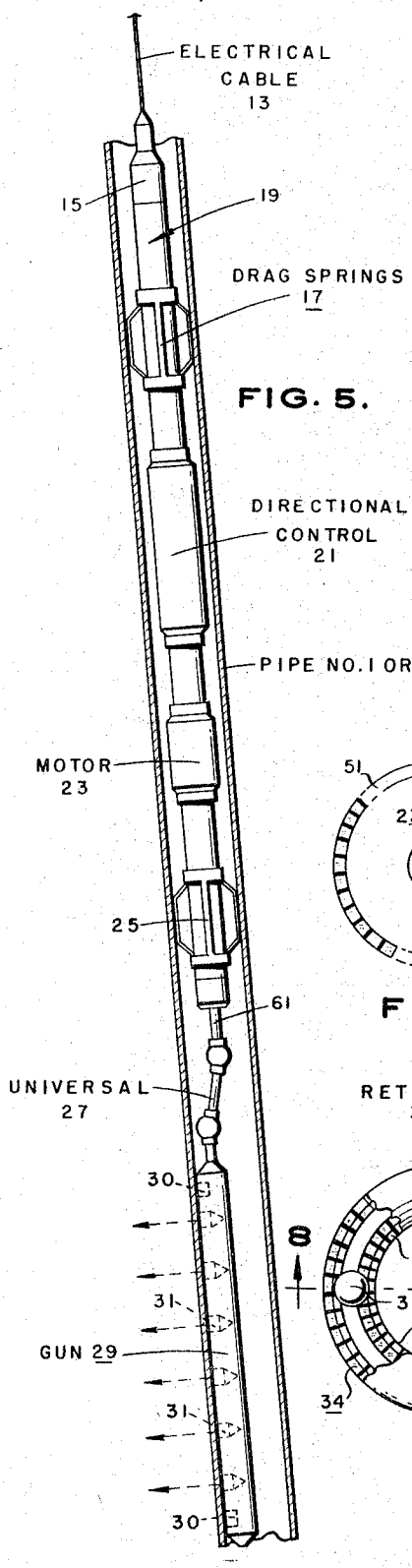


FIG. 5.

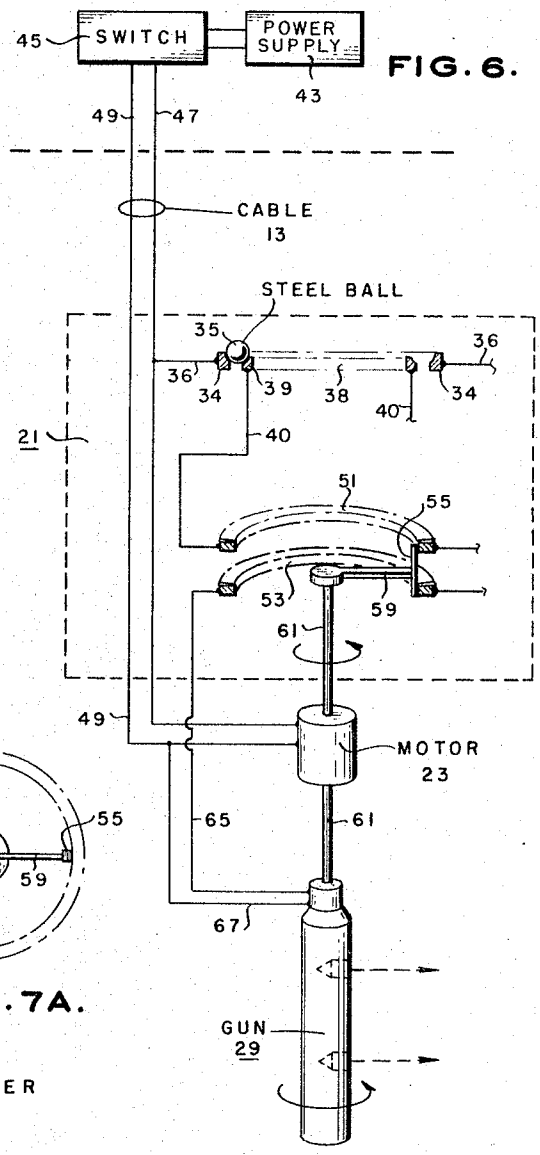


FIG. 6.

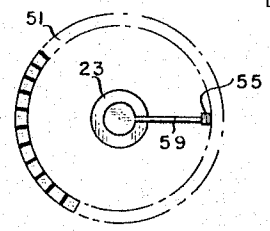


FIG. 7A.

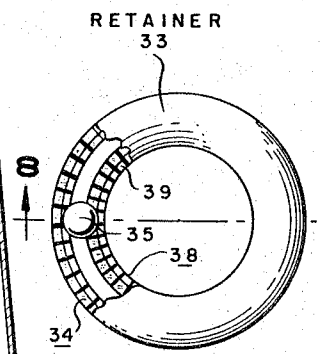


FIG. 7.

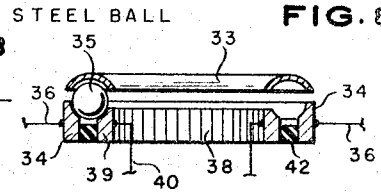


FIG. 8.

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COMPLETION OF WELLS

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Filed June 15, 1964, Ser. No. 375,105
5 Claims. (Cl. 166—4)

This invention relates generally to completion of wells in the earth, and more particularly to the perforation of selected ones of a plurality of pipe strings disposed side by side in a well bore.

Often it is desired to complete wells drilled through productive hydrocarbon-containing earth formations by lowering a plurality of pipe strings side by side into a well bore, circulating cement through the pipe strings to bond the pipe strings to the earth formations, and perforating the pipe strings and surrounding cement to permit the flow of connate earth fluids into the pipe strings. Only one of the pipe strings should be perforated for each of the producing formations penetrated by the well bore. If a perforating gun is randomly oriented in a pipe string, it will be quite probable that more than one pipe string will be perforated when the gun is fired. Manifestly, it is necessary to insure that the gun is aimed away from other pipe strings in the well bore at the time that the gun is fired.

It has been known for many years that well bores are not absolutely vertical and straight, but actually corkscrew down through the earth. The pipe strings, instead of being suspended in the middle of the well bore tend to lay on the side of the well bore as a result of gravitational forces acting to force the pipe into an absolute vertical position. Through reasoning and study of round pipe positioning in a round well bore, it has been determined that the first pipe string run into a well bore to a given level will always lie against the lower side of the well bore. By "low side of the hole" is meant that at any point in the nonvertical hole the low side of the hole will be the one that corresponds to the lower point of a section normal to the longitudinal axis of the well bore passing through that point. In a properly sized well bore in which properly sized pipe is run, the second string of pipe run into the hole will also seek the lower side of the hole for support. The third and fourth strings run into a hole will position themselves against the first two strings and be located nearer the high side of the borehole drilled in a nonvertical position. The first two strings will not be displaced from the sides of the well bore by subsequently run strings.

The present invention contemplates perforating the first and second strings run into the well bore in a direction toward the low side of the well bore at perforating level thereof, and perforating subsequently run pipe strings toward the high side of the well bore at perforating level thereof. If all strings are not run to the same level and one string is to be perforated at a level to which no other pipe extends, random direction perforating may be used at this lower level. The first two pipe strings run into the well bore at all levels will gravitate toward the low side of the well bore so that only one pipe string will be perforated when they are perforated in a direction toward the low side of the hole. Likewise, only one pipe string will be perforated when a pipe string run subsequently to the first two pipe strings is perforated toward the high side of the well bore.

Objects and features of the invention not apparent from the above discussion will become evident upon consideration of the following description thereof taken in connection with the accompanying drawings, wherein:

FIGS. 1A and 1B are fragmentary views of two portions of a multiple completion, tubingless well installation

illustrating the relative disposition of well pipes at an upper level and a lower level in a well bore;

FIG. 2 is a sectional view taken along section 2—2 of FIG. 1A;

FIG. 3 is a sectional view taken along section 3—3 of FIG. 1B;

FIG. 4 is a view taken along the longitudinal axis of the portion of the well bore illustrated in FIGS. 1B and 3 illustrating the directions of perforation of the various well pipes in accordance with the invention;

FIG. 5 is an elevational view of apparatus in accordance with the invention, the apparatus being illustrated as being disposed in a well pipe, which pipe is illustrated in section;

FIG. 6 is a schematic diagram of the electrical circuit of the apparatus of FIG. 5;

FIG. 7 is a top view, partially cut away, of a component of the directional control apparatus of the apparatus illustrated in FIG. 5;

FIG. 7A is a top view of another component of the directional control apparatus; and

FIG. 8 is a sectional view taken along section 8—8 of FIG. 7.

With reference now to FIGS. 1A, 1B, 2, and 3, there is illustrated a plurality of well pipes 1, 2, 3, and 4 disposed in a well bore 5 prior to the cementing step of a multiple tubingless completion well installation. Multiple completions having more than four pipe strings are not generally common in the industry, and at this point in the development of the art the fifth and sixth strings are generally concentric strings in that they are run inside of one or more of the four strings shown in FIG. 1A and packers used for isolating the perforated zones within the single casing string. Running of five or six strings is not precluded in this disclosure in that the direction of perforating strings 3 and 4 will be in opposite quadrants of the hole and approximately 90 degrees to a line joining the high and low side of the hole. In the upper portion of the well bore illustrated in FIG. 1A, the well pipes are suspended in the well bore more or less away from the sides of the well bore inasmuch as the uppermost portion of the well bore is substantially vertical. However, as the well bore progresses downwardly it begins to corkscrew so that the axis thereof is always inclined away from the vertical. This situation is illustrated in FIG. 1B. The well pipes 1 and 2, which were the first to be run into the well, will lay against the low side of the well bore as is illustrated most perspicuously in FIG. 3. Well pipes 3 and 4 will either lay against pipes 1 and 2 or against one of the pipes and the side of the well bore, but will always be toward the high side of the well bore relative to pipes 1 and 2. Similarly, a fifth pipe string will lay against pipe string 2 and away from pipe string 3. Mulitple completions having more than four pipe strings are so rare as to pose very litle problem to the industry, although it is to be noted that when it is necessary to make a quintuple or sextuple completion, the problems attendant thereto are quite substantial. The reason that the fifth pipe string run into the well will not lay on top of pipe strings 3 and 4 is that if a well is properly planned and proper hole size drilled, there is simply not enough space in the well bore above pipe strings 3 and 4 for an additional pipe string.

In FIG. 4 the directions for perforation of the pipe strings illustrated in FIGS. 1A through 3 are illustrated. If pipe strings 1 and 2 are to be perforated, the direction of perforation is always toward the low side of the well bore. If pipe strings 3 and 4 are to be perforated, the direction of perforation is always toward the high side of the well bore.

With reference now to FIG. 5, there is shown apparatus for perforating a well bore in accordance with the in-

vention. An elongated housing 19 is suspended from an electrical cable 13 by means of a cable head 15 and has affixed thereto drag springs 17 and 25 for aligning the housing substantially parallel to the longitudinal axis of the pipe string in which it is disposed. A perforating gun 29 is connected to the housing by means of a universal joint 27. The perforating gun includes a number of shaped charges, bullets, or other perforating means 31. The purpose of the universal joint is to allow flexibility of the assembly and to facilitate the gun laying against the inner surface of the well pipe within which it is disposed. A plurality of electromagnets 30 are disposed in the gun housing to attract the face of the gun from which the projectiles are directed against the inner surface of the well pipe. The electromagnets preferably are energized through separate electrical leads in cable 13 leading to the earth's surface. The gun is rotated by an electric motor 23 energized by leads 47 and 49 (see FIG. 6) in cable 13. The firing circuit for the gun is energized by directional control apparatus 21 which is illustrated in FIG. 6.

With reference now to FIG. 6, there is illustrated an electrical schematic diagram for controlling the energization of motor 23 and the actuation of perforating gun 29. It is assumed that the shaped charges or the projectiles fired by gun 29 are electrically activated through leads 65 and 67. The electrical energy for rotation of motor 23 and actuation of the gun 29 is derived from a power supply 43 at the earth's surface through leads 47 and 49 controlled by switch 45. The leads 47 and 49 are directly connected to motor 23. Leads 67 is connected directly to lead 49. The circuit for firing the gun is completed through lead 65, a switch assembly including a segmented ring member 51 and another ring member 53, which may or may not be segmented, and is spaced apart from ring 51 so that the individual segments of ring 51 are bridged to ring 53 by a movable contact member 55 which is rotated around the inner surface of the rings. The rotation of bridging member 55 is effected by attaching the support arm 59 therefor to shaft 61 of electric motor 23. The individual segments of ring 51 are spaced apart by electrically insulated spacing means as shown more clearly in FIG. 7A. The firing circuit further includes a multiplicity of electrical leads 40 individually connecting the segments of ring 51 to segments of another segmented ring 38. The segments of this ring likewise are spaced apart by insulative spacing means. Ring 38 comprises the inner member of a race for a conductive metal ball 35 which individually bridges the segments 39 or ring 38 to an electrically conductive ring 34, which comprises the other member of the race. The ball 35 may be formed of steel, copper, mercury, or other electrically conductive material and may be spheroidal, ovular, or, in the case of mercury, may be of no particular shape as long as it bridges the gap between the rings and rolls around the race in accordance with the forces of gravity exerted thereon. The construction of the race is best illustrated in FIGS. 7 and 8. It is to be noted that the outer race may be segmented or solid. If the race is segmented, the individual members thereof are electrically connected together and are connected to lead 36, which completes the firing circuit to line 47. The inner and outer rings 38 and 34 of the race are spaced apart by electrically insulative spacer means 42. The ball 35 is retained in the race by a retainer means 33.

The operation of the apparatus described above is as follows. Let it be assumed that it is desired to perforate either of pipe strings 1 and 2 toward the low side of the well bore. The gun will be aligned on shaft 27 so that the firing direction of the gun and the support arm 59 for bridging member 55 are pointed in the same direction. It is to be noted that this also may be done by positioning arm 59 on shaft 61. The apparatus is lowered into the well bore through one of pipe strings 1 and 2. The conductive metal ball 35 will roll about on the raceway

thereof and will always be on the low side of the raceway. When the gun is positioned adjacent productive earth formation 11 (see FIG. 3), switch 45 is closed. Motor 23 will rotate until bridging member 55 bridges conductive segment of ring 51 electrically connected to the conductive segment of ring 39 being bridged to ring 34 by ball 35. At this instant the electrical circuit to gun 29 will be completed to fire the gun and perforate the pipe string within which the gun is disposed.

When it is desired to perforate one of the pipe strings 3 or 4 run into the well subsequent to pipe strings 1 and 2, it is only necessary to position arm 59 so that it is pointed oppositely to the firing direction of gun 29. Thus, when bridging member 55 contacts the segment of ring 51 electrically connected to the segment of ring 39 being contacted by ball 35, the firing direction of gun 29 will be toward the high side of the well bore.

It should be noted that the ball 35 may bridge two of the segments of ring 39 to ring 34 at the same time. This, however, will not result in any damage when the gun is activated inasmuch as the firing direction will be sufficiently toward the high side of the well bore that other pipe strings in the well bore will not be damaged.

While the direction of control means 21 illustrated is simple and straightforward and will be found to be quite effective in connection with the invention, manifestly, other types of control means may be used. For example, an orienting tool using the gyro instrument manufactured by the Sperry Sun Well Surveying Corporation may be used. When the well bore has been surveyed so that the low side thereof for any given depth is always known, it is only necessary to orient the gun in the well bore using the gyro instrument so that it is pointed at the high side of the well bore at the time that the gun is fired.

The invention is not to be restricted to the specific structural details, arrangement of parts, or circuit connections herein set forth, as various modifications thereof may be effected without departing from the spirit and scope of this invention.

What is claimed is:

1. In a well installation wherein a plurality of pipe strings coextend side by side from the earth's surface through a borehole and are bonded to the sides of the borehole by a cementitious sheath, the method of opening fluid communication between productive earth formations penetrated by at least two pipe strings, comprising:

detecting the low side of the borehole;

perforating a selected one of the first and second pipe strings run into the well on the low side thereof with respect to the inclination of the borehole at the level of a first earth formation; and

at the level of another productive earth formation penetrated by at least three pipe strings, perforating a pipe string run into the well bore after the second pipe string on the high side thereof with respect to the inclination of the borehole at said level of said another productive earth formation.

2. In a well installation wherein a plurality of pipe strings coextend side by side from the earth's surface through a borehole and are bonded to the sides of the borehole by a cementitious sheath, the method of opening fluid communication between productive earth formations penetrated by at least two pipe strings and selected pipe strings, comprising:

at the level of a productive earth formation penetrated by two pipe strings, detecting the low side of the borehole with respect to the inclination of the borehole at said level, and perforating one of the pipe strings either on the high side or the low side with respect to the inclination of the borehole at said level;

at a selected level of an earth formation penetrated by more than two pipe strings, detecting the low side of the borehole with respect to the inclination of the

borehole at said level, and perforating one of the first two pipe strings run into said hole to said selected level on the low side of the borehole with respect to the inclination of the borehole at said level; and

at a given level of a formation penetrated by more than two pipe strings, perforating a pipe string run into said borehole to said given level after two pipe strings have already been run to said given level toward the high side of the borehole with respect to the dip of the borehole at said given level.

3. In a well installation wherein a plurality of pipe strings coextend side by side from the earth's surface through a borehole and are bonded to the sides of the borehole by a cementitious sheath, the method of opening fluid communication between productive earth formations penetrated by at least two pipe strings and selected pipe strings, comprising:

lowering a perforating gun into a selected pipe string to a level thereof whereat only one additional pipe string is adjacent thereto;

detecting the low side of the borehole at said level;

rotating said gun until its perforation direction is toward either the high side of the low side of the well bore with respect to the inclination of the borehole at said level;

actuating said gun to perforate the selected pipe string;

lowering said perforating gun into another pipe string to a second level thereof whereat said pipe string has two pipe strings thereadjacent which were run into the well before said another pipe string;

detecting the low side of the borehole relative to the inclination of said borehole at said second level;

rotating said gun until its perforation direction is toward the high side of the well bore with respect to the inclination of the well bore at the level of said gun; and

actuating said gun to perforate said another pipe string.

4. In a well installation wherein a plurality of pipe strings are run into a well bore in succession to coextend from the earth's surface, and are bonded to the sides

of the well bore by a cementitious sheath, the method of opening fluid communication between earth formations and selected pipe strings; comprising:

at the level of a productive earth formation penetrated by two pipe strings, detecting the low side of the borehole and perforating one of said two pipe strings either on the low side thereof or the high side thereof with respect to the dip of the borehole at the perforating level;

at the level of a selected productive earth formation penetrated by at least three pipe strings, detecting the low side of the borehole and perforating one of the pipe strings run into the well bore after the second pipe string run into the well bore on the high side thereof with respect to the inclination of the borehole at the perforating level in said selected productive earth formation.

5. A method of opening fluid communication from the interiors of a plurality of pipe strings to surrounding earth formations, said plurality of pipe strings being suspended from the earth's surface side by side in the same well bore, comprising:

detecting the low side of the borehole at levels thereof selected for perforation;

perforating each of the first and second pipe strings to be run into the well bore toward the low side of the well bore at perforating level thereof; and

perforating pipe strings subsequently run into the well bore toward the high side of the well bore at perforating level thereof.

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