ABSTRACT: In the invention disclosed herein, outwardly biased "side kicker" arms are arranged on the upper and lower ends of a directional perforator adapted for perforating the well casing in a multiple-completion well having two or more tubing strings of unequal length. The arms are initially retained in retracted positions by explosive squibs connected to diodes operatively arranged so that an electrical current of one polarity will detonate the squibs simultaneously and release the arms in unison. Once released, the outwardly biased arms cooperate in positioning the perforator so as to avoid perforating adjacent pipe strings. Once both arms are fully extended to bring the perforator into a safe position, switches coupled to the arms complete a firing circuit including additional diodes operatively arranged so that an electrical current of the opposite polarity is required for firing the perforator.
ORIENTED PERFORATING APPARATUS

In one common technique of completing oil wells having a number of productive earth formations, the well is cased and separate tubing strings are coupled to suitable packers set just above each of the several formation intervals. Thus, once the tubing strings and packers are in position, the well bore is divided into a series of vertically spaced intervals with only a single tubing string communicating with each isolated interval and, except for the lowermost interval, respectively have one or more of the outer tubing strings extending therethrough to the lower intervals.

Once this part of the completion operation is finished, the casing in each interval must, of course, be perforated to establish fluid communication with the earth formations. To accomplish this, laterally directed perforating apparatus such as that shown in U.S. Pat. No. 3,338,317 to James B. Shore is successively lowered through the tubing strings in turn and into the isolated interval below the lower open end of each string. As brought out in this patent, in all but the lowermost of these well bore intervals, the perforating apparatus must be properly oriented to avoid perforating the other tubing string or strings passing through that interval in the lower intervals.

This perforating apparatus is, therefore, arranged with a single selectively extendible arm for positioning the apparatus so as to face the perforating charges thereon away from any tubing strings passing through that interval.

Experience has shown, however, that in some instances one or more of the tubing strings passing through a given well bore interval will often be so badly twisted or "cork screwed" that the tubing is not in a consistent angular position along the entire interval. As a result, although such tools are properly oriented at one end of the tool, in some circumstances one or more of the perforating charges at the other end of the tool have inadvertently perforated one portion of an adjacent tubing string even though the other charges safely pass the other portions of the cork screwed tubing string.

In recognition of this problem, oriented perforating apparatus such as shown in U.S. Pat. No. 3,419,088 to Richard H. Gray has been recently proposed. In this proposed apparatus, a pair of similar extendible orienting arms are mounted at the upper and lower ends of a directional perforator and electrical circuitry is appropriately arranged so that the perforator cannot be actuated until both of the orienting arms have been extended to their predetermined positions. As described in the Gray patent, the electrical circuitry is also arranged so that one of the orienting arms must be released and fully extended before the other arm can be released and, hopefully, fully extended.

It will be appreciated, however, that a badly skewed tubing string must often be so situated that a considerable laterally directed force must be applied to the perforating apparatus just to guide it around the tubing and bring the perforator into a safe firing position. As a result, with such proposed apparatus, the laterally directed force applied by only one arm is frequently inadequate to shift the entire tool past a skewed tubing string and into a safe position. Thus, unless the proposed perforating apparatus can be moved into a safe position where both its upper and lower ends are clear of the adjacent tubing string or strings, the perforating operation cannot be completed.

Accordingly, it is an object of the present invention to provide new and improved directional perforating apparatus having orienting means that can reliably position the apparatus in multiple-completion wells having irregularly-situated tubing strings.

This and other objects of the present invention are attained by arranging directional perforating apparatus having a pair of selective released orienting arms mounted at spaced intervals thereon and cooperatively arranged for working in unison to impose a substantial biasing force on each end of the perforating apparatus for cooperatively guiding it around even badly skewed tubing strings and into a safe operating position. Appropriately connected switches and diodes are arranged into a control circuit for selectively releasing the orienting arms in unison upon application of electrical current of one polarity and for actuating the perforator only when both of the two orienting arms are extended to predetermined positions and the polarity of the electrical current is reversed.

The novel features of the present invention are set forth with particularity in the appended claims. The invention together with further objects and advantages thereof, may be best understood by way of the following description of exemplary apparatus employing the principles of the invention as illustrated in the accompanying drawings, in which:

FIG. 1 is an elevational view showing oriented perforating apparatus in accordance with the present invention as it may appear in a well bore;

FIG. 2 is a schematic wiring diagram of one embodiment of the electrical circuitry for the perforating apparatus of FIG. 1;

FIG. 3 is a view similar to FIG. 2 but showing the operating condition of the electrical circuitry depicted there after the release of both of the orienting arms; and

FIGS. 4 and 5 are views generally similar to FIGS. 2 and 3 but showing an alternative embodiment of electrical circuitry also arranged in accordance with the principles of the present invention.

Turning now to FIG. 1, perforating apparatus 10 arranged in accordance with the principles of the present invention is shown in position within a typical borehole 11 lined with cement 12 to secure a casing 13 extending through a productive earth formation 14 and other formations (not shown) therebelow. One tubing string 15 depending from conventional wellhead equipment (not shown) at the earth's surface is arranged in the casing 13 wherein its lower open end terminating just above the earth formation 14. Second and third tubing strings 16 and 17 are similarly dependently secured from the wellhead at the surface and respectively extended through the casing 13 to other productive earth formations (not shown) below the formation 14. To isolate the productive formation 14 from the upper portion of the well bore, a conventional packer 18 is set in the casing 13 and is arranged to seal the space between the inner wall of the casing and the outer walls of the tubing strings 15-17 above the formation.

Another conventional packer 19 is arranged below the formation 14 for packing-off the annulus around the longer tubing strings 16 and 17.

The new and improved perforating apparatus 10 preferably includes a casing-collar locator 20, upper and lower orienting devices 21 and 22, and a directional perforator 23 between the two orienting device. As is typical, the apparatus 10 is dependently suspended from an electrical cable 24 spoiled from a winch (not shown) at the surface of the earth and, as illustrated, has been lowered through the tubing string 15 to a position therebelow between the tubing strings 16 and 17. It will be understood, of course, that although the perforator 23 is depicted in FIG. 1 as a so-called "retrievable" perforator (such as that shown in U.S. Pat. No. 3,048,102) which includes a tubular steel carrier 25 enclosing shaped charge means including a plurality of shaped charges, as at 26, facing the forward wall of the carrier, other types of perforators can also be employed so long as their perforating devices are arranged to fire in substantially the same lateral direction.

After the perforating apparatus 10 has emerged from the lower open end of the shorter tubing string 15, it is, of course, free to rotate or to be shifted laterally in any direction with little or no restraint or guidance from the cable 24. It will be recognized, therefore, that there are a great number of angular positions which the perforating apparatus 10 can assume once it is lowered into an isolated zone. For example, it is quite possible that as the lower end of the perforating apparatus 10 emerges from the tubing string 15, it will be guided by the skewed tubing strings 16 and 17 into such an angular position relative thereto that the perforator 23 cannot be safely positioned even though the perforating apparatus 10 and 15 are upwardly and downwardly by repeatedly reciprocating the cable 24. It should also be recognized that there may be situa-
tions where the perforating apparatus 10 may have to be slightly tilted before it can be safely actuated. Accordingly, to accomplish the objects of the present invention, the orienting devices 21 and 22 are preferably arranged as shown in the aforementioned Shore patent and respectively include switch contacts 36 and 37. The central conductor 27 is mounted in vertical alignment along the rearward wall of the carrier 25, with these arms being forcibly urged to their respective extended positions (as illustrated) once the arms are selectively released. Thus, inasmuch as the perforating apparatus 10 is freely suspended from the cable 24, it will be appreciated that when both the upper and lower arms 27 and 28 are forcibly biased in unison against one side of the casing 13, the perforator 23 will be urged in the opposite direction so as to position the shaped charges 26 adjacent to and facing the other side of the casing.

Accordingly, as best seen in FIG. 2, to be certain that the upper and lower arms 27 and 28 can be released without relation to each other position, the present invention includes control means for simultaneously releasing both of the orienting arms without risking the accidental actuation of the perforator 23. Inasmuch as the mechanical arrangement of the upper and lower orienting devices 21 and 22 is preferably the same as the orienting apparatus disclosed in U.S. Pat. No. 3,338,317, these orienting devices have only been schematically illustrated in FIG. 2. It will be appreciated that said orienting devices 21 and 22 need not necessarily include means (as shown generally at 36 in the Shore patent) for returning the orienting arms 27 and 28 to their respective retracted positions.

In general, as fully described in the aforementioned Shore patent the upper and lower orienting arms 27 and 28 are respectively secured in a generally retracted position along the body of the perforating apparatus 10 by electrically responsive means including pivoted latches 29 and 30 releasably retaining the free ends of the orienting arms so long as the rigid bodies of electrically initiated explosive squibs 31 and 32 have not been blown apart by the passage of a detonating current therethrough. Springs 33 and 34 (such as that shown at 54 in the Shore patent) are arranged for forcibly urging the orienting arms 27 and 28 outwardly whenever their respective explosive squibs 31 and 32 are fragmented.

As illustrated in FIG. 2, the upper and lower orienting devices 21 and 22 are preferably identical to one another so as to make these units interchangeable with one another. The control means of the present invention includes a single-pole double-throw switch 35 in the upper orienting unit 21 having a common contact 36 and a movable switch member 37 that is normally connected to a first contact 38 and, by means of a suitable actuator 39 operatively connected to the arm 27, adapted for movement to a second contact 40 whenever the extendible arm is moved outwardly to a predetermined extended position. Reversely oriented diodes 41 and 42 are respectively connected to the switch contacts 38 and 40, with the first diode being, for example, adapted to pass a positive current and the second diode being adapted to pass a negative current. A manually operated switch 43 is connected in series with a third diode 44 and the combined elements are respectively connected by suitable conductors 45 and 46 to the common switch contact 36 and the opposite end of the diode 42 in such a manner so as to shunt that diode whenever the manual switch is closed.

The control means of the present invention further includes a single-pole double-throw switch 47 in the lower orienting device 22 having a common contact 48, a movable switch member 49 and second contacts 50 and 51 having oppositely oriented diodes 52 and 53 respectively connected thereto. The switch member 49 is similarly coupled by an actuator 54 to the extendible arm 25 for operating the switch 47 in response to extension of the arm to a selected position. A manually operated switch 55 and diode 56 are also shunted by conductors 57 and 58 between the switch contact 48 and the other side of the diode 53, with the junction 59 between these two diodes being connected, as at 60, to the body of the apparatus 10.

The central conductor 61 of the perforating cable 24 is passed through an appropriate fluid seal 62 into the upper orienting device 21 and connected to the common switch contact 36. The centrally mounted arm 27 of the cable 24 is electrically connected, as at 64, to the body of the apparatus 10 to provide a return electrical path. A second main conductor 65 is connected between the junction 66 of the diodes 42 and 44 in the upper unit 21 and the common contact 48 of the switch 47 in the lower unit 21. The shaped charge means further include means for detonating the shaped charges 26 which, in a typical fashion, may comprise a length of detonating cord coupled to an electrically initiated detonator 67 which is connected in series with a diode 68 and these two elements are in turn respectively shunted across a reversely oriented diode 69 and serially connected in the main conductor 65. Other fluid seals, as at 70 and 71, are arranged as required for passage of the conductor 65 through the perforator 23.

It will be appreciated, therefore, that by arranging the diodes 42, 53 and 68 to pass electrical current of one polarity and by arranging the remaining diodes 41, 44, 52, 56 and 69 to pass electrical current of the opposite polarity, operation of the perforating apparatus 10 will be governed by both the electric polarity of a direct-current voltage source, as at 72, connected at the switch, a momentary current, be appreciated as a result of the orienting devices 21 and 22 need not necessarily include means (as shown generally at 36 in the Shore patent) for returning the orienting arms 27 and 28 to their respective retracted positions.

As illustrated in FIG. 2, when the power source 72 is connected as illustrated with its positive pole to the central cable conductor 61 and its negative pole to the external conductor 65, and to the shaped charges 69 and 70, the shaped charges 69 and 70 are to be detonated only whenever this polarity is reversed and, of course, both arms are extended.

Accordingly, as illustrated in FIG. 2, when the power source 72 is connected as illustrated with its positive pole to the central cable conductor 61 and its negative pole to the external conductor 65, and to the shaped charges 69 and 70, the shaped charges 69 and 70 are to be detonated only whenever this polarity is reversed and, of course, both arms are extended.

Comparison of FIGS. 2 and 3 will also illustrate that initiation of the detonator 67 cannot be accomplished unless: (1) the main conductor 65 is at a negative polarity and (2) both the upper and lower switches 35 and 47 are in their respective positions illustrated in FIG. 3. When both of these conditions have been met, the central arm 27 of the cable 24 is electrically connected with its positive pole now connected to the armor sheath 63 and its negative pole connected to the central cable conductor 65 will enable current of sufficient magnitude to flow through the diodes 42, 53 and 68 and through the detonator 67 to accomplish its detonation.

It will be appreciated, however, that should, for example, the upper arm 27 not be extended to its designated position,
the switch 35 will remain in the position illustrated in FIG. 2 and a negative current cannot flow to the main conductor 65. Conversely, even when the upper arm 27 is extended, so long as the lower orienting arm 28 is not sufficiently extended, the lower switch 47 will remain in its position illustrated in FIG. 2 and the firing circuit will be inoperative so long as the lower switch has not connected the diode 53 to the main conductor 65.

It will be recognized that the upper manually positioned switch 43 also plays a significant part in the present invention. For example, if the upper manually positioned switch 43 is inadvertently left open, the lower orienting arm 28 cannot be released since the diode 44 provides the only path between the upper and lower units 21 and 22 for passage of electrical current to the lower squir 32 when the positive pole of the power source 72 is connected to the cable conductor 61. This would, of course, positively prevent the release of the lower arm 28. Thus, as previously mentioned, so long as the lower orienting arm 28 is not released, the shaped charges 26 cannot be detonated. It will be appreciated, therefore, that the upper manually positioned switch 43 must be closed in order to activate the perforator 23.

On the other hand, should the lower manually positioned switch 55 be inadvertently closed, the diode 56 would shunt a major portion of current flow through the diode 52 and lower explosive squib to the body of the apparatus 10 and, in most instances, make it unlikely that sufficient positive current flow could be attained to detonate either or both of the explosive squibs 31 and 32. If, however, sufficient positive current could be passed through the circuit to successfully detonate the upper and lower explosive squibs 31 and 32, once the upper and lower switches 35 and 47 are moved to their respective positions illustrated in FIG. 3, successful detonation of the shaped charges 26 could then be accomplished. Thus, should the lower manually positioned switch 55 be inadvertently closed, the worst thing that can occur is a misfire. It will be recognized, therefore, that the interchangeability of the two units 21 and 22 poses no safety hazard.

Turning now to FIGS. 4 and 5, perforating apparatus 100 employing a slightly modified embodiment of the control means of the present invention is illustrated. It will, of course, be appreciated from inspection that the circuitry illustrated in FIG. 4 is identical to that shown in FIG. 2 except that a pair of reversely acting switches 101 and 102 (as well as 103 and 104) are substituted for the upper and lower switches 35 and 47 in the upper and lower orienting units 105 and 106 respectively. As illustrated, the upper switches 101 and 102 are arranged so that when the upper orienting arm 107 is retracted, the switch 101 will be closed to provide an electrical connection to the upper squib 108 and the other switch 102 will be open so long as the orienting arm has not been extended. Similarly, the reversely actuated switches 103 and 104 function in the same manner as their counterpart part switch 47 in the perforating apparatus 10.

Accordingly, it will be appreciated that by adapting the upper and lower arms 27 and 28 (or 107 and 109) for simultaneous release, once the perforating apparatus 10 (or 100) has been moved into position between the packers 18 and 19, connection of the power source 72 as illustrated in FIG. 2 to the perforating cable 24 will simultaneously release both of the orienting arms. Then, by moving the perforating apparatus 10 (or 100) upwardly and downwardly by way of the cable 24, the combined lateral thrust of the arms 27 and 28 (107 and 109) against the casing 13 will cooperatively shift the perforating apparatus into a position where the shaped charges 26 (or 110) are safety directed away from the adjacent pipe strings 16 and 17 in the wellbore.

I claim:

1. Perforating apparatus adapted for suspension in a well bore including at least two pipe strings of unequal length terminating at vertically displaced intervals and comprising: a perforator adapted for passage through the shorter of such pipe strings and including electrically detonable shaped charge means having a selected lateral direction of perforation facing one side of said perforator; first and second orienting arms operatively mounted at vertically spaced intervals on the opposite side of said perforator for movement in the diametrically opposite lateral direction between a retracted position adjacent to said perforator and an extended position, first and second spring means respectively biasing said first and second orienting arms toward their said extended positions to urge said one side of said perforator against a well bore wall, and first and second electrically responsive release means releasably securing said orienting arms in their respective retracted positions; and control means including conductor means adapted for connection to a source of direct current, first and second switch means operatively associated with said first and second orienting arms respectively for independent movement thereby from first switching positions to second switching positions upon extension of said orienting arms to their extended positions, first means including first diode means operatively interconnecting said conductors to said first and second release means in parallel for the passage of direct current of a selected polarity thereto for simultaneously releasing said orienting arms for movement to their respective extended positions when said first and second switch means are in their respective first switching positions, and second means including second diode means operatively interconnecting said conductors to said electrically detonatable shaped charge means for passage of direct current of the opposite polarity thereto only when said first and second switch means have both been moved to their respective second switching positions by extension of both of said first and second orienting arms to their respective extended positions so as to position said one side of said perforator against a well bore wall with said shaped charge means being directed away from an adjacent pipe string in the wellbore.

2. The perforating apparatus of claim 1 wherein said first and second switch means respectively include a switch having a common contact and a movable member connected thereto and movable between a normally closed contact and a normally open contact upon movement of said orienting arms to their said extended positions; said first diode means include first and second diodes respectively connected between said first and second normally closed switch contacts and said first and second release means, and third and fourth diodes in series and interconnected between said common contacts of said first and second switches; and said second diode means include a fitth reversively poled diode interconnected between said first normally open switch contact and the common junction between said third and fourth diodes, a sixth reversively poled diode serially connected with said shaped charge means with said sixth diode and shaped charge means being shunted across said fourth diode, and a seventh reversively poled diode connected to said normally open contact of said second means for providing a return electrical path upon detonation of said shaped charge means.