April 19, 1966 J. W. HARRIGAN, JR., ETAL 3,246,708

ARMING SWITCH FOR SELECTIVE FIRING SYSTEMS

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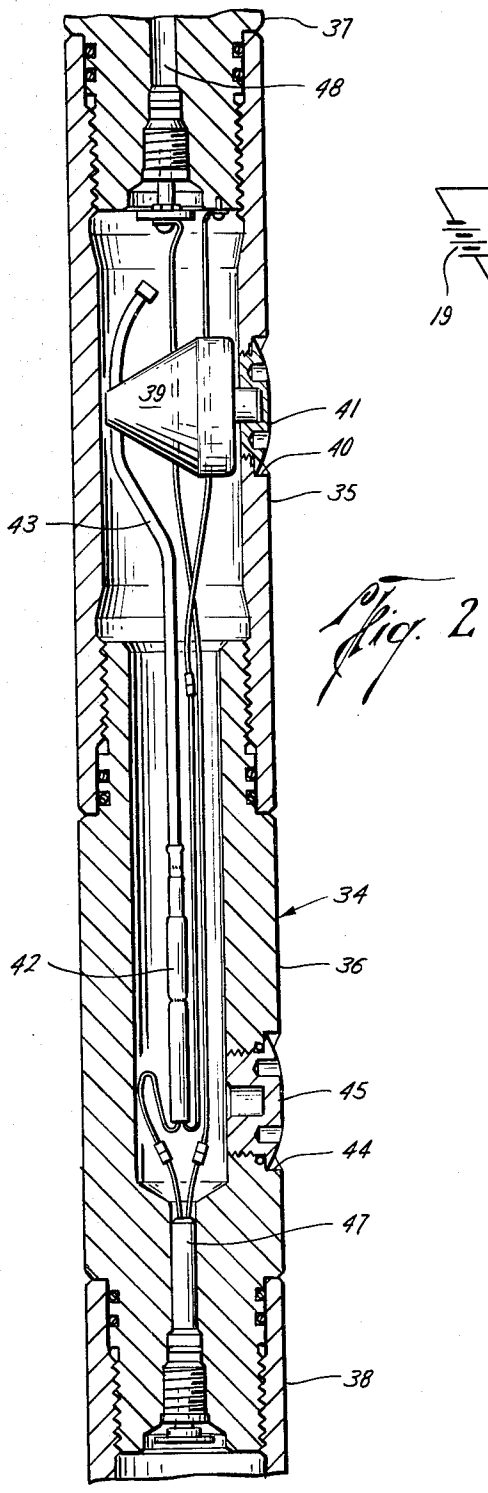
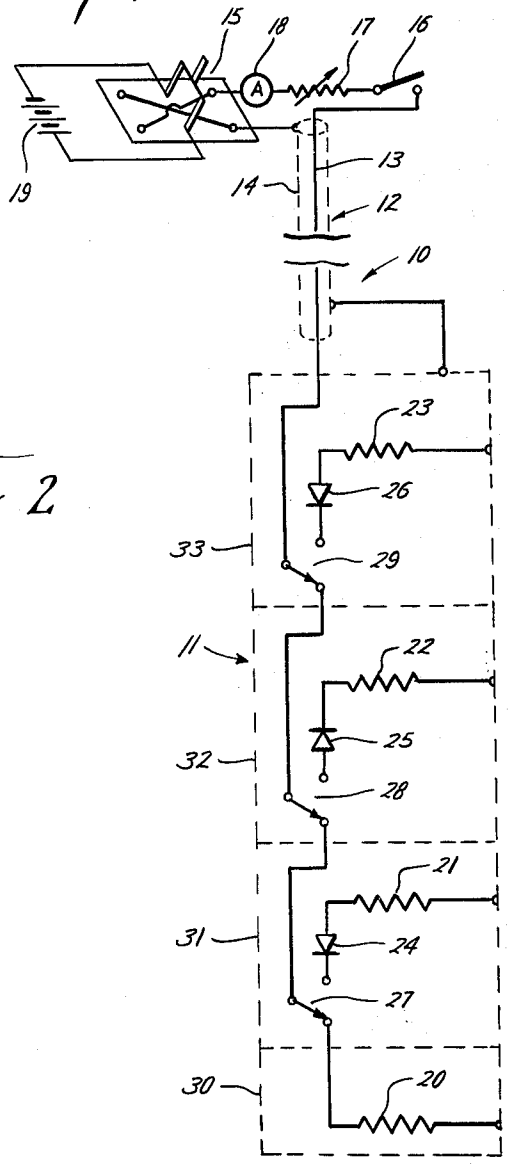


Fig. 2

Fig. 1



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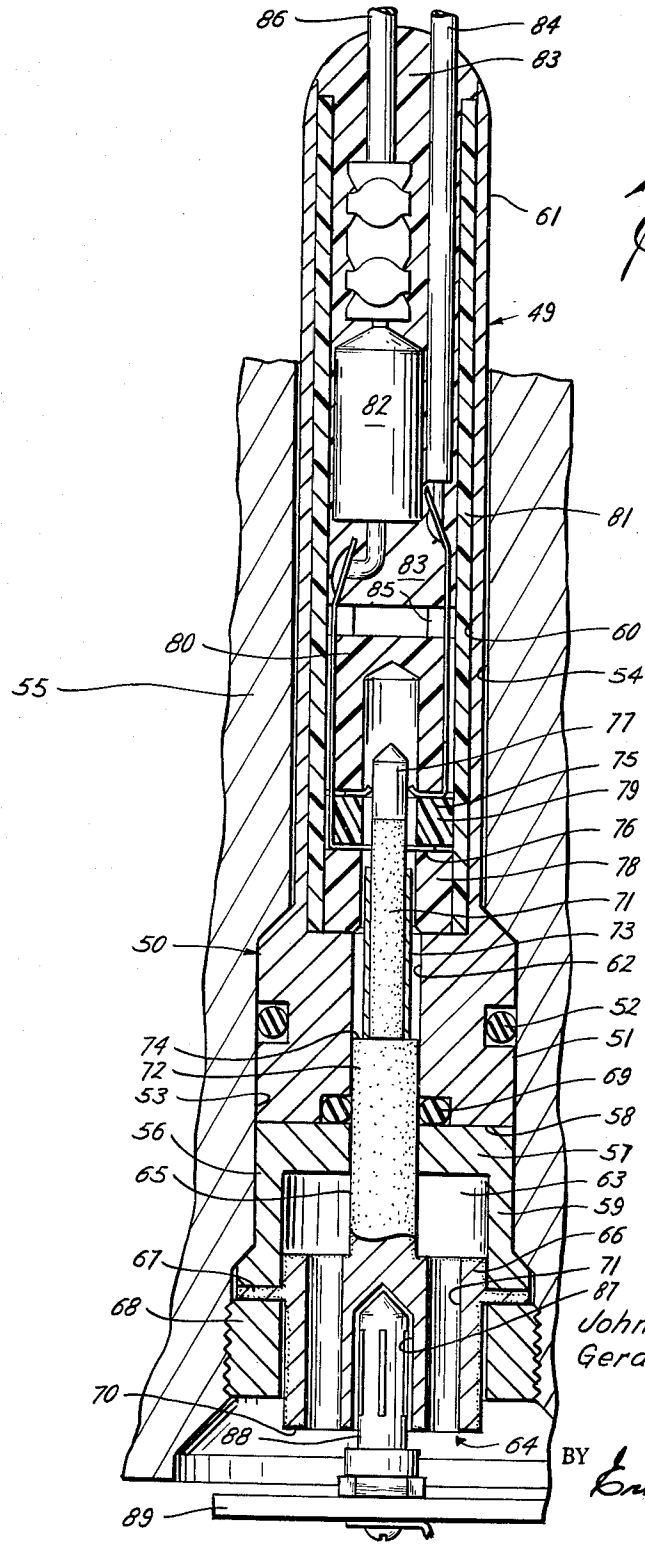
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Fig. 3



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ARMING SWITCH FOR SELECTIVE FIRING SYSTEMS

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This invention relates to shaped-charge perforating systems for perforation of oil wells, and more particularly to an arming switch for selectively arming individual shaped charges of a perforating tool.

There is a trend in well completion techniques away from closely-spaced multiple perforating of an interval or intervals of earth formations and toward single or very few perforations in each interval, or intervals. To provide signle perforations at various depths, apparatus having a number of shaped charges is lowered into a well to a particular depth where a perforation is to be made. One of the charges is detonated and, thereafter, the apparatus is repositioned to the next level where another perforation is desired. A second charge is then fired and this is continued until all of the desired perforations have been made.

It is recognized by those skilled in the art that when shaped charges are to be individually and selectively detonated, provisions must be made to detonate each shaped charge individually as well as to electrically isolate each charge from one another to prevent accidental detonation or "machine gunning" of the remaining shaped charges at the same time. Accordingly, a selective-firing shaped charge perforating carrier is generally comprised of a series of tandemly-arranged, pressure-sealed, hollow charge housings separated from one another by individual firing-heads subs or housings, with each charge housing and its firing-head constituting a single perforating unit. An explosive charge comprised of a single shaped charge and its associated detonating train is enclosed in each of the charge housings where the charge housing provides an expansion chamber around the shaped charge to minimize shock effects in the casing. The expansion chamber which is air-filled also attenuates the explosive forces so that the charge housing is not appreciably deformed and, therefore, may be re-usable any number of times.

The detonating train for a shaped charge includes a length of detonating cord and an electrically-fired blasting cap connected through an arming means in the firing-head sub or housing to an electrical firing circuit which leads to a voltage source at the surface of the ground. These arming means typically are actuated in response to the firing of a shaped charge immediately adjacent thereto. Upon firing of a one shaped charge, the arming means for the next adjacent perforating unit is operated to connect its related blasting cap into the electrical firing circuit to ready that shaped charge for firing as needed. Thus, as each shaped charge is fired, the next adjacent perforating unit is armed. It is customary to arrange the firing circuit to detonate the charges from the bottom of the tool upwardly.

In general, the electrical firing circuits used with selectively-fired shaped charge systems fall into one of three types. In one type, the firing circuit is a series-parallel arrangement of blasting caps having filament igniters requiring different intensities of current for their ignition and individual arming means for each blasting cap except for the one to be fired first. The igniters are serially connected in one side of the firing circuit, with the arming device being in parallel for electrically connecting each igniter in turn to the return side or path of the firing circuit. Initially, the igniter

of the first-fired blasting cap is the only one connected to the return path of the firing circuit and this igniter requires the lowest level of ignition current. The other igniters are successively arranged with each succeeding igniter requiring a progressively greater ignition current before it will fire. Thus, when a shaped charge is detonated, the resulting explosion closes the arming device of the next perforating unit to connect its associated blasting cap to the return path of the firing circuit.

A second conventional firing circuit employs a parallel circuit of equal-sensitivity blasting caps with each filament igniter, except for the first-fired cap, being in series with a polarity-sensitive means, such as a rectifier or diode, and a normally-open switch portion of an armnig device. In a perforating tool, these rectifiers are alternately oriented with every other rectifier being arranged to pass only voltage of one plurality from the main conductor and the intermediate rectifiers being arranged to pass only voltage of the opposite polarity from the main conductor. With this arrangement, only the first blasting cap will be detonated when voltage of a first polarity is applied to the main conductor. Even though the resulting explosion closes the next arming device and connects the next blasting cap to the main conductor, this second blasting cap cannot be detonated until voltage of the opposite polarity is applied to the main conductor. Thus, to detonate each successive shaped charge, it is necessary that the polarity of the firing voltage be reversed each time.

A third commonly-used firing circuit employs a rotary selector switch for sequentially applying a firing voltage to each blasting cap as required.

These firing circuits are generally used with a suspension cable, called a "monocable," which includes a single main electrical conductor protected by a conductive armored sheath which serves as the other conductor or return path of the firing circuit.

It will be appreciated that if an intermediate unit is inadvertently fired out of sequence, the well will be perforated at a point removed from the desired depth of perforation without the operator being aware of this. Consequently, all successive shots will unwittingly be "off-depth" by whatever distance the intermediate unit is above the lowest unit which was to be fired first.

Thus, if well liquids leak into a carrier prior to firing, it is best that the firing circuit for the perforating units above the leaking unit cannot be rendered operative by hydrostatic pressure so that these units cannot be fired out of sequence.

It is also preferred to progressively disconnect the main conductor of a parallel-arranged firing circuit from each perforating unit after it is fired. It will be appreciated that if this is not done, the main conductor may be shorted to the carrier in a lower unit which will prevent the subsequent application of full firing voltage to a perforating unit thereabove. Thus, a well-designed arming device for such a firing circuit should progressively disconnect the main conductor when a perforating unit is fired as it simultaneously connects the main conductor to the next unit to be fired.

Arming devices of certain prior-art units which depend upon engagement of an isolated electrical contact with the carrier housing to complete the firing circuit are often unreliable. For example, in those firing circuits employing variable-sensitivity blasting cap igniters in series with each other, an arming device of this type may not establish a sound electrical connection when it is first engaged because of an imperfect contact or an oxide film on the housing. In this event, the electrical resistance added to the circuit may require a substantial increase of voltage to attain the particular current level needed to fire the

next blasting cap. Accordingly, it frequently happens that as the voltage is being increased to bring the current to the proper level for firing the next cap, an arc is formed across such an imperfect contact which suddenly establishes a more perfect contact and reduces the contact resistance. This sudden lowering of the total circuit resistance will naturally cause the current to increase rapidly and often causes a current surge of sufficient intensity to fire one or more successive caps simultaneously.

The problems involved in designing an arming device or switch are multiplied when a perforating tool is operated in a small diameter well bore at high pressures. The arming switches must not only be compact to accommodate a small bore but still be well insulated electrically and be capable of being fluidly sealed.

From the foregoing it should be apparent that an arming switch for selective firing of shaped-charge perforators should (1) be reliable and capable of withstanding the rigorous conditions found in the oil field, (2) include a positive firing selectivity, (3) positively disconnect the main conductor from each perforating unit after it is fired, which eliminates the possibility of "machine gunning," (4) withstand high pressures encountered in a well bore, (5) be simple in construction, and (6) remain in a deactivated position should well fluids leak into a housing in the tool.

It is, therefore, an object of the present invention to provide a reliable and compact arming switch for selectively and separately arming a plurality of shaped charges in accordance with a predetermined sequence.

It is another object of the invention to provide a selective firing switch for use with a plurality of perforating units which is easily installed, ruggedly constructed and well insulated electrically to provide safe and reliable operation under service conditions in the field.

It is a further object of the invention to provide a positively-acting arming switch which is capable of being fluidly sealed and fails-safe in the event that well fluids leak into an adjacent perforating unit.

It is yet another object of the invention to provide a positively-acting arming switch which will be actuated only when the preceding shaped charges have been detonated in a predetermined sequence.

It is an additional object of the invention to provide an arming switch of a rugged construction which is inexpensive to manufacture and will always make a positive electrical contact whenever it is closed.

It is a still further object of the invention to provide a positively-sealed arming switch which prevents leakage of well fluids into the next adjacent perforating unit of a perforating tool.

These and other objects of the present invention are provided by an arming switch for use in a perforating unit which preferably is comprised of a firing head coupled to a charge housing. In the charge housing is an explosive charge, which includes an electrically-fired blasting cap connected to a shaped charge by a length of blasting cord, with the blasting cap being arranged for detonation upon application of a firing voltage. The blasting cap is serially connected to the arming switch so that the cap cannot be fired until the arming switch is positively closed.

In general, the arming switch of the present invention includes an explosively-impelled metal plunger member adapted to travel within a longitudinal bore through a housing member mounted between adjacent units of a perforating tool. At least two electrical contacts are operatively arranged relative to the plunger member to be closed whenever the plunger member is impelled from a first to a second longitudinally-spaced position within the bore.

The outer surfaces of the plunger member provide electrical insulation between the plunger and the housing member and thus allow the inner portion of the plunger to be used as a separate electrical conductor. This enables the switch to be compactly arranged while requiring only a single seal member to positively fluidly seal the plunger relative to the housing.

In the preferred embodiment of the switch of the present invention, the plunger member is arranged with an enlarged diameter piston head received in an enlarged portion of the housing bore and its other end sealingly disposed in a reduced diameter portion of the bore and operatively positioned relative to the electrical contacts. The plunger is positioned so as to form a chamber between the inwardly-directed face of the piston head and the sealing member around the reduced-diameter portion of the plunger, and is preferably positively retained in this first or "off" position by a yieldable restraining member. Thus, when the perforating unit immediately below the switch is fired, the dynamic explosive forces produced by either one or both the concussion of the explosion and the sudden inrush of well fluids into the housing therebelow act against the outwardly-directed face of the piston head to shear the restraining member and impel the plunger inwardly to interconnect the electrical contacts. The hazard that the arming switch of the present invention might be prematurely closed by undetected leakage of well fluids into the perforating unit beneath the switch is positively eliminated by providing a leakage passage across the piston head portion of the plunger member into the chamber. Thus, should well fluids leak into the lower perforating unit, the fluids will enter this chamber to equalize the pressure on each side of the piston and prevent the hydrostatic pressure from moving the plunger to its second or "on" position.

Additional objects and advantages of the invention will become apparent from the following detailed description of representative embodiments thereof, taken in conjunction with the accompanying drawing, in which:

FIG. 1 illustrates schematically a firing circuit which may be used in conjunction with the preferred embodiment of an arming switch constructed in accordance with the present invention;

FIG. 2 shows an assembly of perforating units using selective firing heads including the switch of the present invention coupled to charge housings; and

FIG. 3 shows in detail a preferred embodiment of the arming switch of the present invention.

Turning now to FIG. 1, a perforating apparatus **10** is schematically illustrated with a polarity-sensitive firing circuit which may be employed for selective detonation of a series of shaped charges (not shown) in a carrier **11**. The carrier **11** is suspended in a well bore by a "monocable" **12** which has a single inner electrical conductor **13** and an outer armor sheath **14** enconnected to the carrier for the electrical return path.

At the surface of the ground, the armor sheath **14** is connected to one side of a polarity-reversing switch **15**; and the central cable conductor **13** is connected in series to the other side of the polarity-reversing switch through a control switch **16**, a potentiometer **17** and an ammeter **18**. The polarity-reversing switch **15** is arranged in the conventional manner so as to selectively connect the positive side of an electrical source, such as a battery **19**, to either the central conductor **13** or the armor sheath **14** while respectively and simultaneously connecting the negative side of the D.C. source to either the armor sheath or the conductor.

Disposed within carrier **11** are a number of electrically-fired blasting caps **20–23** with filament igniters of equal current sensitivity for selectively detonating a number of shaped charges (not shown). The blasting caps are in parallel with one another with one side of each igniter being connected to the reversing switch **15** through the cable sheath **14** and carrier **11**. With the exception of blasting cap **20** which is fired first, the other end of each igniter is serially connected to a rectifier or diode **24–26**, respectively, each of which are connected to the normal-

ly-open contact of a single-pole double-throw arming switch 27–29.

Blasting cap 20, which is in the lowermost perforating unit 30 to be fired first, is connected to the normally-closed contact of arming switch 27 which has its normally-open contact connected to diode 24 and its moving contact or switch arm connected to the normally-closed contact of arming switch 28. The moving contact or switch arm of arming switch 28 is in turn connected to the normally-closed contact of arming switch 29 and the normally-open contact of switch 28 is connected to diode 25. Arming switch 29 has its normally-open contact connected to diode 26 and its switch arm connected to the central conductor 13 of "monocable" 12.

Diodes 24, 25 and 26 are alternatively oriented so that diodes 24, 26 are responsive only to voltage of one polarity and the intermediate diode 25 is responsive only to voltage of the opposite polarity. As previously explained, with this arrangment voltage of a first polarity is applied to detonate the first shaped charge in the tool, which explosion closes the next adjacent arming switch. Accordingly, before the next explosive charge can be detonated, the reversing switch 15 must be first thrown to reverse the polarity of the firing voltage.

From the foregoing description, it will be appreciated that if the negative side of the D.C. source 19 is connected to the armor sheath 14 and the positive side connected to the central conductor 13, whenever voltage is passed through the lowermost blasting cap 20 in perforating unit 30 and detonates the shaped charge associated with that blasting cap, the explosion will actuate the arming switch 27 of the next perforating unit 31. Actuation of arming switch 27 will then connect diode 24 associated with that switch into the firing circuit in preparation for the selective detonation of perforating unit 31. Because of the polarity orientation of diode 24, however, although voltage is still applied to arming switch 27 after it is actuated, current cannot pass through the reversed diode 24 to blasting cap 21. Furthermore, neither of the remaining blasting caps 22, 23 in perforating units 32, 33, respectively, will be detonated since they are disconnected from the firing circuit by their respective arming switches 28, 29. Thus, after firing of the first perforating unit 30 and actaution of the next successive arming switch 27, it is mandatory that the operator first reverse the polarity of the firing voltage before the next perforating unit 31 can be fired. Firing of the remaining perforating units 32, 33 continues in like manner until all units have been fired.

Turning now to FIG. 2, a single perforating unit 34, comprised of a charge housing 35 and a selective-firing head sub or housing 36, is shown with portions of a second selective-firing head 37 of the perforating unit immediately thereabove and another charge housing 38 of the perforating unit immediately below. A shaped charge 39 is mounted adjacent to an explosion port 40 in the charge housing 35, which port is sealingly closed by a closure member 41. A blasting cap 42, dependently attached to a length of detonator cord 43 connected to the shaped charge 39, is disposed adjacent to an access port 44 and closure 45 to provide convenient access to the electrical contacts 46 of the blasting cap 42.

An arming switch 47, such as that illustrated in greater detail in FIG. 3, is shown in the lowermost selective-firing head 36 as being in its second or active position, while the arming switch 48 in the upper selective-firing head 37 is still in its inactive position. Thus, it will be understood that in FIG. 2 the explosive charge which had been contained in the charge housing 38 of the perforating unit immediately below the intermediate perforating unit 34 has already been fired to actuate the arming switch 47 of the intermediate perforating unit 34.

It is preferred that separate housings be used for containing the explosive charge and for mounting the arming switch of the present invention. It is nevertheless within the scope of the invention to use an integral housing for each perforating unit and to mount an arming switch at either end of this integral housing. Furthermore, it is contemplated that the arming switch could be employed in perforating tools with a single carrier or housing divided into isolated compartments. Access ports appropriately located in the carrier would allow the insertion of the arming switches into the dividing compartments.

Turning now to FIG. 3, a preferred embodiment of an arming switch 49 is illustrated which includes an elongated tubular housing or case 50 of an easily-machined metal, such as aluminum. The enlarged diameter lower-end portion 51 of case 50 is encircled by an O-ring 52 and arranged for sealing reception in a complementarily-shaped portion 53 of an axial bore 54 through the firing head 55. An annular cup-shaped member 56 of a stronger metal, such as hardened steel, has a base portion 57 engaged against the lower end 58 of case 50 and a circumferential skirt portion 59 extending away from the case 50.

An axial bore extending through the switch case 50 includes enlarged bore portion 60 at the upper end 61 of the case and reduced-diameter bore portion 62 at the lower end 58 of the case in axial alignment and communication with recess 63 within the skirt portion 59 of annular member 56. A plunger member 64 having a reduced-diameter shank portion 65 and an enlarged-diameter piston-head portion 66 is disposed in the switch case 50 and annular member 56 and so arranged that shank portion 65 extends through reduced diameter bore 62 and on into enlarged bore portion 60. Piston head 66 is partially received within recess 63 of annular member 56 with an integral circumferential flange member 67 around the piston head being engaged around the outer end of skirt portion 59 of annular member 56. A locking nut 68 engaged with the lower face of flange 67 secures the plunger 64, annular member 56 and switch case 50 within the axial bore 54 through the firing-head housing 55. An O-ring 69 sealingly engaged between the plunger shank 65 and the wall of reduced bore portion 62 fluidly seals the plunger member 64 relative to the case 50.

Circumferential flange 67 is sized to hold plunger 64 in an inactive first position until an explosive force acting on the outwardly-directed face 70 of piston head 66 shears the flange 67 against the harder skirt portion 59 of annular member 56 and drives the plunger inwardly to an active second position.

Piston 66 is pressure-equalized by providing small passages 71 through the piston head 66. Thus, should well fluids leak into the charge housing below the outwardly-directed face 70 of the piston head 66, the fluids will fill the space or chamber 63 above the piston head 66 to equalize the pressure across the piston. It will be realized, of course, that in this event the hydraulic forces directed against the plunger member 64 will effectively act only on the cross-sectional area of the shank portion 65 since the hydraulic pressure will be equal on both sides of the piston head 66. Accordingly, the diameter of the shank 65 is purposely reduced and the shear flange 67 is made of sufficient strength that the greatest expected total static hydraulic pressure which might be applied on this small effective area will be inadequate to fracture the shear flange 67 and force the plunger member 64 upwardly into its operative position.

By employing conventional blasting caps which are rendered inoperative when contacted by fluids, the blasting cap in a leaking housing will be deactivated to prevent firing of that perforating unit. Thus, in the event that well fluids do leak into a perforating unit of a carrier equipped with arming switches of the invention and such fluid-sensitive blasting caps, the leaking unit cannot be fired and the next higher unit cannot be armed. The succeeding units are also effectively deactivated since they

cannot be armed. Accordingly, it will be appreciated that positive assurance is provided against perforating "off-depth."

In the preferred embodiments shown in detail in FIG. 3, the outermost portion 71 of the shank 65 is of a smaller diameter than the innermost portion 72 of the shank which is adjacent to the piston head 66. A short electrically-conductive sleeve member 73 is slipped over this outer or smaller diameter portion 71 of the shank 65 and arranged with its lower end engaged by the shoulder 74 formed where the smaller outer shank portion 71 joins the larger shank portion 72. The sleeve 73 is electrically insulated from the shank 65, as will be later described in detail, and is terminated at a point remote from the upper or outer extremity of the shank.

A pair of spaced-apart electrical contacts 75, 76 are disposed in the enlarged bore portion 60 within the switch case 50 and are arranged so that the outermost contact 75 is engaged with the uninsulated outermost tip 77 of the plunger shank and the innermost contact 76 is engaged with or proximate to an insulated portion of the plunger shank portion 71 intermediate the shank tip 77 and the upper end of the conductive sleeve member 73.

In the preferred form of the arming switch, these contacts are annular copper rings disposed around the smaller diameter shank portion 71 with the central hole of contact ring 75 being flared upwardly during insertion of the plunger shank thus providing a reliable electrical contact with the uninsulated tip portion 77. The contact rings are held in place by a series of insulator rings 78, 79 and 80 on each side of contact rings 75, 76, and all being preferably disposed inside a tubular insulating sleeve 81 which is itself snugly received within the enlarged bore portion 60 of the switch housing 50. If desired, small circuit components, such as a diode 82, may be disposed within the insulating sleeve 81 and the entire cavity filled with a resilient plastic insulating material 83 to insulate the leads and components as well as to seal the upper end of the switch case and shock-mount the components.

It is preferred that the plunger member 64 be constructed from aluminum and that, as indicated by the dotted markings in FIG. 3, the greater portion of its outer surfaces be hard-anodized, preferably to a depth of about 0.001 to 0.002-inch. It has been found that in the relatively low range of voltages customarily employed in the perforating art, such anodizing provides an excellent electrically-insulative surface on the plunger 64 while still allowing transmission of current from the uninsulated tip portion 77 of the shank through the body of the plunger member 64 to its opposite end. Thus, it will be appreciated that when the plunger member 64 is in the inactive position shown in FIG. 3, electricity can pass along conductor 84, through contact ring 75 to the outermost tip 77 of the shank 65, and on through the body of the plunger member 64 to an electrical connector attached to the outwardly-directed face 70 of the piston head 66.

It will be further appreciated that when the plunger 64 is explosively impelled upwardly to its second or active position, the conductive sleeve 73 will be driven through both contact rings 75, 76 to electrically interconnect the rings and allow current to flow through the switch conductors 84, 85 and 86 to complete the firing circuit to the blasting cap associated with the switch. At the same time, since sleeve 73 is insulated from plunger shank, 65, when tip 77 moves upwardly, the body of plunger member 64 is removed from electrical contact with the contact members thereby breaking the firing circuit to perforating units below the switch.

Other switching arrangements would be equally feasible. For example, one or more single-pole double-throw switching sections could be arranged in addition to the single-pole single-throw arrangement from the uninsulated tip through the body. An insulated conductive sleeve member for each switching section would protrude through first and second spaced contacts and would be switched whenever the plunger was explosively impelled from a first position to a second position in which the sleeve would then engage the second contact and a third spaced contact.

Although the above-described hard anodizing is preferred, it would be equally feasible to use other materials which would give the equivalent results. For example, an insulating surface film could be provided by varnishing the plunger, by nitriding or phosphating processes, or by coating the plunger with "Teflon" or other similar bondable insulating materials. Furthermore, simple spring contacts could be used for the electrical contacts.

As seen in FIG. 3 the outwardly-directed face 70 of the piston head 66 is preferably provided with an axial recess 87 which is adapted to receive a banana-plug connector 88 carrying a disc 89 on its outer end. The disc 89 is of larger diameter than the piston head 66 so that the explosive forces will be initially applied against a larger area than that of the piston head alone.

It will be appreciated that when well fluids enter a perforating unit that has just been fired, the hydrostatic pressure will assist in moving the plunger as well as hold the plunger member closed to maintain the electrical connections. If, however, no fluids entered, the concussion forces of such an explosion would usually be sufficient to close the arming switch and the switch would be held closed by the frictional engagement of the shank within the contact rings 75, 76.

It is also contemplated that a particular tool configuration might result in locating a shaped charge too far from the arming switch of the adjacent perforating unit, and that if the perforating tool is being operated in a dry well bore, the concussion forces alone might be ineffective to positively close the arming switch. In such cases, it is preferred to extend the blasting cord upwardly into close proximity of the piston face to utilize the explosive force of the blasting cord to ensure the closing of the switch.

The arming switch as described herein accordingly affords an inexpensive, expendable, integral switch assembly which can be easily replaced in firing heads while still ensuring that a positive fluid seal is maintained at all times between adjacent perforating units. The plunger employed is uniquely insulated electrically from the other elements to provide a smaller moving element than heretofore possible which permits the design of selectively-fired perforating units to accommodate even the smaller well bores. The unique pressure-equalizing arrangement positively prevents arming of the explosive charges above a perforating unit which has inadvertently leaked to guard against perforating off-depth.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention and in its broader aspects and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. For use in perforating apparatus including a housing having a bore therein, an arming switch comprising: a movable electrically-conductive plunger member adapted for reception in the bore and arranged for travel therein between first and second longitudinally-spaced positions in repsonse to a pressure force at one end thereof; an electrically-conductive member mounted along a portion of said plunger member and arranged to be spaced from the walls of the bore; means on said plunger member for providing electrical insulation between said plunger member and said conductive member and housing consisting of an electrically nonconductive surface along those portions of said plunger member which contact the housing and said conductive member; and first and second electrical contact members adapted for longitudinal spacing from one another and arranged for said first contact member to

electrically contact said plunger member whenever said plunger member is in said first position and for said conductive member to electrically interconnect said contact members whenever said plunger member is in said second position; and means on another portion of said plunger member adapted for establishing an electrical path including said plunger member and said first contact member whenever said plunger member is in said first position.

2. For use in perforating apparatus including a housing having a bore therein, an arming switch comprising: a movable aluminum plunger member adapted for reception in the bore and arranged for travel therein between first and second longitudinally-spaced positions in response to a pressure force at one end thereof; an electrically-conductive member mounted along a portion of said plunger member and arranged to be spaced from the walls of the bore; means on said plunger member for providing electrical insulation between said plunger member and said conductive member and housing consisting of an electrically nonconductive anodized surface along those portions of said plunger member which contact the housing and said conductive member; first and second electrical contact members adapted for longitudinal spacing from one another and arranged for said first contact member to electrically contact said plunger member whenever said plunger member is in said first position and for said conductive member to electrically interconnect said contact members whenever said plunger member is in said second position; and means on another portion of said plunger member adapted for establishing an electrical path including said plunger member and said first contact member whenever said plunger member is in said first position.

3. As a sub-combination, an arming switch comprising: a switch case adapted to be sealingly received in one end of a perforating unit, said case having a bore therethrough; a movable aluminum plunger member having an enlarged portion and a reduced portion received in said bore and arranged for travel therein from a first position to a second position longitudinally spaced therefrom in response to a pressure force on said enlarged portion, said plunger member having anodized surfaces extending substantially its full length from said enlarged portion for electrically insulating the major portion of said plunger member and terminating short of the end of said reduced portion to provide an electrically-conductive surface thereon; an electrically-conductive sleeve member mounted around said reduced portion intermediate said enlarged portion and said conductive surface; a sealing member encircling said reduced portion and sealingly engaged with said case; first and second electrical contact members longitudinally spaced from one another and adjacent said reduced portion, said first contact member being in electrical contact with said electrically-conductive surface and said second contact member being disposed intermediate said first contact member and one end of said sleeve member whenever said plunger member is in said first position, said contact members being operatively arranged relative to said sleeve member for engagement thereby to electrically interconnect said contact members whenever said plunger member is in said second position; means on said enlarged portion adapted for establishing an electrical path including said first contact member and said plunger member whenever said plunger member is in said first position and releasable therefrom whenever said plunger member is moved to said second position; and means adapted for preventing travel of said plunger member whenever liquid under pressure fills a spaced adjacent to said enlarged portion including flow restriction means adapted to provide flow

communication between the adjacent space and said bore intermediate of said enlarged portion and sealing means and restraining means yieldably holding said plunger member in said first position and releasable only upon application of a pressure force on said enlarged portion in excess of the cross-sectional area of said reduced portion multiplied by the pressure of such liquid.

4. The arming switch of claim 3 further comprising: a polarity-sensitive current means disposed in said bore intermediate said first contact member; a plurality of electrical conductors serially interconnecting said polarity-sensitive means and electrical contact members, one of said conductors being connected to said first contact member and extending out of said case; and electrical insulating means disposed within said bore for insulating said contact members from each other and for insulating said case from said conductors, polarity sensitive means and contact members.

5. In the combination of a sealed perforating apparatus having separate chambers each containing electrically-actuated explosive perforating means with a bore interconnecting the chamber with an arming switch including an electrically-conductive piston member having enlarged and reduced portions with the reduced portion being received in the bore and arranged for travel between spaced longitudinal positions, means for fluidly sealing said reduced piston portion relative to the bore, means restraining said piston member in one of its positions and responsive to dynamic explosive pressures in one of the chambers against said enlarged piston portion to release said piston for travel to another of its positions, and means preventing release of the restraining means whenever liquid fills the aforementioned one chamber including flow restriction means in fluid communication between that one chamber and the bore intermediate of said enlarged piston portion and sealing means, the improvement comprising: first and second electrical contacts longitudinally spaced from one another and disposed along the bore, said first contact being in electrical contact with a surface of said reduced piston portion whenever said piston is in said one position; an electrically conductive member mounted along a portion of said piston away from said piston surface and spaced from the walls of the bore, said conductive member being arranged to electrically interconnect said contacts whenever said piston is in said other position; means on said piston for providing electrical insulation between said piston and said conductive member consisting of an electrically-nonconductive surface along those portions of said piston which contact the walls of the bore and said conductive members; and means on said enlarged piston portion adapted for establishing an electrical path including said first contact member and said piston whenever said piston is in said one position and releasable from said enlarged piston portion whenever said piston is moved to said other position.

6. The apparatus of claim 5 wherein said piston is of aluminum and said insulating means is an electrically-nonconductive anodized surface.

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