March 1, 1955 J. H. CASTEL 2,703,053

FIRING CIRCUIT FOR PERFORATING GUNS

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Fig. 1

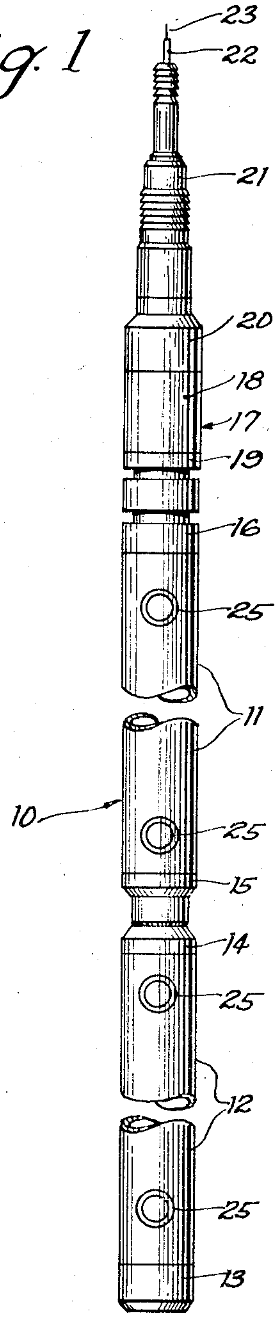
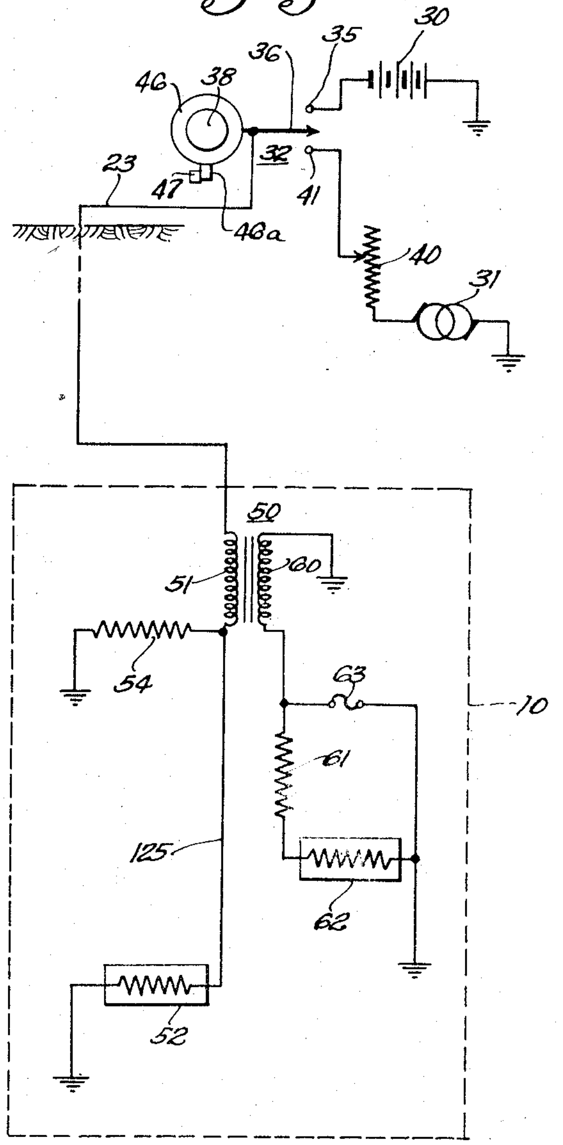


Fig. 2



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FIRING CIRCUIT FOR PERFORATING GUNS

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4 Claims. (Cl. 102—20)

The present invention relates to perforating guns of the type used for casing perforation work in oil field recovery and well completion operations and more particularly to an improved circuit for energizing the detonating elements associated with the explosive charges used in a so-called jet type perforating gun. This application is a division of applicant's copending application Serial No. 219,480, filed April 5, 1951 and assigned to the same assignee as the present invention.

One of the serious problems involved in successful use of casing perforating guns and particularly perforating guns of the so-called jet type is that of providing adequate safety facilities for insuring that one or more of the explosive charges with which a gun is loaded is not inadvertently detonated before the gun is lowered into the borehole or before the gun is moved to the desired position in the borehole. In modern perforating guns, electrical firing systems utilizing electrically excited detonating elements individually associated with the explosive charges are universally used in detonating the gun charges. Such electrical firing systems include rather extensive wire runs and hence are subject to the pick-up of stray currents, primarily by induction, which are fed to the detonating elements of the gun over the cable conductors. Accordingly, the problem of preventing inadvertent firing of one or more charges of a perforating gun resolves itself down to one of preventing stray currents introduced into the electrical firing system from effecting sufficient energization of the gun charge detonating elements to produce detonation of the charges associated with these elements.

It is an object of the present invention, therefore, to provide an improved firing system for perforating guns which is so arranged that the likelihood of inadvertent firing of the gun charges is reduced to a minimum.

It is another object of the invention to provide an improved electrical circuit for energizing a charge detonating element of a perforating gun which is so arranged that the gun charge detonating element is rendered ineffective to produce charge detonations in response to electrical transients or other currents which may be spuriously developed in the firing system of the gun and applied to the circuit.

In general, the above objects are realized in accordance with the present invention by including each explosive charge detonating element of a perforating gun firing system in a high impedance path over which energizing current is fed to the element, and by shunting the high impedance path with a low impedance path which includes current responsive means for interrupting the low impedance path only when current of a predetermined magnitude traverses the low impedance path for a predetermined interval of time. With this improved arrangement, the low impedance path prevents sufficient current from traversing the detonating element to produce detonation of the explosive charge associated with the element until such time as the current responsive means operates to interrupt the low impedance path.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings, in which:

Fig. 1 is a side perspective view of a perforating gun assembly embodying the sequential firing system of the present invention; and

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Fig. 2 is a schematic diagram of a sequential firing system embodying the present invention.

Referring now more particularly to Fig. 1 of the drawing, the invention is there shown in its embodiment in an improved jet type perforating gun indicated generally at 10. In general, the perforating gun 10 comprises an upper gun section 11 and a lower gun section 12, the gun section 12 being provided with a lower end cap or closure member 13. The gun sections 11 and 12 are connected together by means of a bottom detonating cord sub-assembly 14, and a contact sub-assembly 15. At its upper end the gun section 11 is connected to an upper detonating cord sub-assembly 16, the upper end of the sub-assembly 16 being connected to a jet selector mechanism indicated generally at 17. The jet selector mechanism 17 comprises a housing sub-assembly 18 and a mounting sub-assembly 19, the sub-assembly 19 being connected to the upper end of the detonating cord sub-assembly 16. The upper end of the housing sub-assembly 18 is connected to the lower end of a cable head sealing sub-assembly 20, which in turn is connected to the lower end of a rope socket assembly 21. The latter assembly is employed to anchor the lower end of a cable 22, which is employed to lower the perforating gun 10 into and out of the cased well which is to be perforated. All of the described parts of the perforating gun are preferably secured together by means of threaded connections therebetween in order to provide a rigid over-all assembly and to facilitate assembly and disassembly of the gun structure.

Each of the gun sections 11 and 12 is provided with a plurality of explosion ports 25 which are spaced apart along the length of each gun section. The ports 25 may also be spaced circumferentially of each gun section in any desired manner. A shaped jet-producing explosive charge is positioned within the gun barrel sections 11 and 12 opposite each explosion port 25 so that the explosive forces developed upon detonation of the charge are discharged through the port. Preferably the explosive charges disposed in one of the gun barrel sections 11 or 12 are detonated substantially simultaneously by means of a detonating cord which extends longitudinally of the barrel and is threaded through the explosive charges. Also, it is preferred to employ an explosive charge supporting device of the type described and claimed in copending application Serial No. 209,972 filed February 8, 1951, Jacques H. Castel, and assigned to the same assignee as the present invention, so that the explosive charges are accurately aligned with the explosion ports of the gun barrel regardless of relatively large variations in the physical dimensions thereof.

In accordance with the present invention an improved firing system is provided for sequentially firing the explosive charges of the gun sections 11 and 12. Specifically, the explosive charges disposed in the gun sections 11 and 12 are electrically ignited in sequence from the earth's surface over an electrical circuit, schematically shown in Fig. 2, which comprises the single insulated conductor 23 of the cable 22. As shown, this circuit comprises a source of unidirectional potential indicated by the battery 30 and a source of alternating current 31 which are located at the earth's surface. The unidirectional source 30 and the alternating current source 31 are adapted to be selectively connected to the cable 22 by means of a rotary selector switch indicated generally at 32. One side of each of the sources 30 and 31 is connected to ground along with the armored sheath of the cable 22 so that a closed return circuit is provided. The ungrounded side of the battery 30 is connected to a stationary contact 35 of the switch 32 which cooperates with the movable contact 36. The alternating current source 31 is connected through a potentiometer 40 to the other stationary contact 41 which also cooperates with the movable contact 36. The movable contact 36 is connected as shown to the single center conductor 23 of the cable 22. It will be understood that the usual facilities are provided for raising and lowering the cable 22 while maintaining electrical contact with the central conductor 23 and sheath thereof.

In order to prevent the alternating current source 31 from being connected to the cable 22 before the unidirectional source **30** is connected thereto, the movable contact **36** may be arranged for movement only in a counterclockwise direction away from the illustrated normal or off position thereof. To this end, the movable contact **36** may be mounted for rotation with a rotor element **46** having a lug **46***a* engageable with a fixed stop **47** to prevent clockwise rotation of the movable contact **36** beyond the illustrated normal position thereof. The rotor element is preferably spring biased by a coil spring, not shown, to maintain the lug **46** in engagement with the fixed stop **46***a*, so that if the rotor element **46** and movable contact **36** are rotated to any off-normal position and then released they will be automatically returned to their normal positions. A knob **38** mounted on the rotor shaft may be used to rotate the rotor element **46** and movable contact **36** against the bias of the coil spring. With this arrangement, the contacts **36** and **35** must be closed before the contacts **36** and **41** are closed, all in response to counterclockwise movement of the rotor element **46** and the movable contact **36**. When the movable contact **36** is rotated in the counterclockwise direction from the normal or off position illustrated, the contacts **35** and **36** are first closed, and upon further rotation these contacts are opened, and thereafter the contacts **41** and **36** are closed.

Within the perforating gun **10** the firing circuit includes a coupling transformer **50** which is provided with a primary winding **51** having one end connected to the single conductor **23** of the cable **22** and the other end connected through the ignition element of a blasting cap **52** to ground potential through the walls of the perforating gun and the sheath of the cable **22**. The blasting cap **52** is paralleled by a resistor **54** which is preferably positioned at a point removed from the blasting cap **52** so as to be physically isolated therefrom. One end of the secondary winding **60** of the transformer **50** is connected to ground and the other end of this winding is connected through an isolating resistor **61** and the ignition element of a second blasting cap **62** to ground. A low resistance fuse **63** is connected from the ungrounded end of the winding **60** to ground in shunt with the resistor **61** and the ignition element of the blasting cap **62** in order to protect the cap **62** against accidental firing due to transient surges which may occur in the circuit when the battery **30** is connected to or disconnected from the circuit by the contacts **35** and **36**. The blasting cap **52** is contiguous to the detonating cord associated with the explosive charges in the bottom gun section **12** and when the blasting cap **52** is ignited the detonating cord operates to fire all of the exposive charges in the gun section **12** substantially simultaneously. Likewise, the blasting cap **62** is contiguous to the detonating cord associated with the charges of the upper gun section **11** so that when the cap **62** is ignited the charges in the upper gun section **11** are substantially simultaneously fired.

Considering now the operation of the above-described sequential firing system in sequentially firing the explosive charges of the gun sections **11** and **12** it will be understood that either of the gun sections **11** or **12** may be employed to perforate the well casing at a desired location. However, it is absolutely necessary to fire the charges of a particular gun section at the correct location in the borehole, since otherwise, the casing would be perforated at the wrong point, which always causes trouble and expense and may even result in the loss of the well. Accordingly, it is desirable to establish a sequence of firing and to correlate the positions of the gun sections with the firing sequence so that the point at which the casing is perforated is very accurately determined. In the illustrated embodiment of the present invention the bottom gun section **12** is always fired first, after which the perforating gun is moved to the desired perforating point and the top gun section **11** is fired. In order to prevent firing of the top gun when the bottom gun is fired, the above-described protective fuse is provided in shunt with the ignition element of the blasting cap **62** so that secondary currents which may be caused by switching transients, or the like, when the contacts of the switch **32** are opened and closed, are ineffective to fire the top gun section. Furthermore, the correct firing sequence is assured by providing the above-described means for preventing firing of the top gun section before the bottom gun section is fired. Thus with the selector switch **32** made to rotate only in a given direction from its normal or off setting in the manner described above the unidirectional source **30** is first applied

to the cable **22** after which the alternating current source is connected thereto. In the alternative, the arm of the potentiometer **40** may be normally biased to its uppermost position by any suitable means so that closure of the contacts **41** and **36** of the switch **32** will be ineffective to fire the top gun section without further adjustment of the potentiometer.

Considering the manner in which the explosive charges of the bottom gun section **12** are fired, when the source **30** is connected to the cable conductor **23** through the contacts **35** and **36** of the selector switch **32**, for example, direct current flows from the source **30** through the central conductor **23** of the cable **22**, the primary winding **51** of the transformer **50** and the ignition element of the blasting cap **52** to the grounded terminal of the source **30**. The potential of the source **30** is so chosen that a direct current of sufficient magnitude flows through the ignition element of the blasting cap **52** to ignite the same so that the detonating cord associated with the cap **52** is ignited and substantially simultaneously fires the explosive charges of the bottom gun section **12**. After the blasting cap **52** is ignited, the electrical circuit through this cap is broken, and without further provision for maintaining a closed circuit through the cable **22** it would be impossible to send further electrical currents through the cable and therefore to utilize the cable to fire the upper gun section **11**. However, this problem is obviated by providing the resistor **54** which is physically remote from the blasting cap **52** and is connected from the winding **51** to ground so that a closed circuit through the cable **22** is maintained. This resistor has a resistance many times greater than the resistance of the ignition element in the cap **52** so that it does not interfere with current flow through this ignition element to any appreciable extent.

After the bottom gun section **12** has been fired the perforating gun **10** is moved to bring the upper gun section **11** in to the desired perforating position, after which the latter gun section is fired. This is accomplished by first connecting the alternating current source **31** to the cable conductor **23** through the contacts **41** and **36** of the step selector switch **32**, for example. When this is done, alternating current flows from the source **31** through the potentiometer **40**, the conductor **23**, the primary winding **51** of the transformer **50**, and the resistor **54** to ground. The above-described flow of current through the primary winding **51** induces a voltage in the secondary winding **60** so that a secondary current flows through the circuit elements **61**, **62** and **63** connected thereacross. As stated above, the resistance of the fuse **63** is very low as compared with the series resistance of the resistor **61** and the ignition element of the cap **62**. Accordingly, the ignition element of the cap **62** is effectively by-passed for current flow therethrough until the fuse **63** is blown. Initially, current flow in the above-traced secondary current is not large enough to blow the fuse **63**. However, by decreasing the resistance of the potentiometer **40**, the secondary current is increased to a point at which the fuse **63** blows. By operating the potentiometer **40** to increase the current flow in the secondary circuit of the transformer still further, the ignition element of the blasting cap **62** becomes sufficiently energized to ignite the cap. When the blasting cap **62** is ignited, the detonating cord associated therewith operates to fire the explosive charges of the upper gun section **11** substantially simultaneously. Thus with the described arrangement it is possible accurately to control the firing of each gun section and to be absolutely certain that the bottom gun section **12** is fired before it is possible to fire the upper gun section **11**.

From the foregoing explanation it will be understood that the fuse **63** effectively constitutes a low impedance path shunting a second and high impedance path which serially includes the detonating element **62** and the resistor **61**. In one embodiment of the present improved firing circuit a one-half ampere fuse **63** is employed in the low impedance shunt path and a fifty-four ohm resistor **61** is used in the high impedance path. When these circuit constants are employed, a current of at least one-half ampere and a voltage across the parallel paths of about thirty volts minimum are required to blow the fuse **63** and then effect sufficient energization of the detonating element **62** to cause detonation of the charge associated with this element. This compares with a current of .2 to .3 ampere and a voltage of one volt maximum required to produce sufficient excitation of the detonating element **62** to detonate the associated charge when the detonating element is energized directly from the current source. Stated otherwise, the high impedance-low impedance firing circuit requires approximately ten watts of electrical energy to produce sufficient energization of the detonating element **62** to effect detonation of the explosive charge associated with this element, whereas only .1 watt is required for this purpose when the detonating element is directly energized from the source. Thus, stray currents which may be introduced into the electrical firing system either directly or by induction cannot effect sufficient energization of the detonating element **62** to detonate the associated explosive charge. Moreover, the fuse **63** is the type of current responsive circuit interrupting device which has a definite time-current characteristic, such that energization thereof with current of a predetermined magnitude for a predetermined interval of time is required in order to rupture the fusible element of the fuse. As a consequence, high voltage transients of short duration which appear in the electrical system will not blow the fuse and hence cannot be impressed upon the detonating element **62.**

Although the present improved detonating element energizing circuit has been described with particular reference to the detonating elements associated with the explosive charges of the upper gun section **11**, it will be understood that the same circuit is preferably used in conjunction with each detonating element used in the lower gun section. Thus by connecting a high resistance resistor in series with the detonating element **52** and shunting the series connected elements with a low resistance fuse, this detonating element is protected against inadvertent energization. Physically the protective resistors and fuses are preferably located in very close proximity to the detonating elements with which they are respectively interconnected, thereby to permit the use of very short leads in interconnecting each set of three components and thus provide maximum protection against stray current energization of the detonating elements.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be understood that various modifications may be made therein which are within the true spirit and scope of the invention as defined in the appended claims.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A circuit for energizing the electrical detonating element associated with one of the explosive charges used in a perforating gun, comprising a source of energizing current remote from said perforating gun, a high impedance path included in said perforating gun and serially including said detonating element, means for energizing said high impedance path from said source, a low impedance path included in said perforating gun and shunting said high impedance path to prevent substantial energization of said detonating element over said high impedance path, and current responsive means included in said low impedance path to interrupt said low impedance path in response to predetermined current flow over said low impedance path from said source, thereby to

permit substantial energization of said detonating element from said source over said high impedance path.

2. A circuit for energizing the electrical detonating element associated with one of the explosive charges used in a perforating gun, comprising a source of energizing current remote from said perforating gun, an impedance element included in said perforating gun and connected in series with said detonating element, means for energizing said series connected impedance and detonating elements from said source, a low impedance path included in said perforating gun and shunting said series connected elements to prevent substantial energization thereof until said path is interrupted, and current responsive means included in said path to interrupt said path in response to predetermined current traversal of said path, thereby to permit substantial energization of said detonating element from said source through said impedance element.

3. A circuit for energizing the electrical detonating element associated with one of the explosive charges used in a perforating gun, comprising a source of energizing current remote from said perforating gun, an impedance element included in said perforaitng gun and connected in series with said detonating element, means for energizing said series connected impedance and detonating elements from said source, a low impedance path included in said perforating gun and shunting said series connected elements to prevent substantial energization thereof until said path is interrupted and a fusible element serially included in said path to rupture and thus interrupt said path in response to predetermined current traversal of said path, thereby to permit substantial energization of said detonating element from said source through said impedance element.

4. A circuit for energizing the electrical detonating element associated with one of the explosive charges used in a perforating gun, comprising a source of energizing current remote from said perforating gun, a resistance element having substantial resistance to current flow therethrough included in said perforating gun and connected in series with said detonating element, means for energizing said series connected resistance and detonating elements from said source, and a low resistance fusible element included in said perforating gun and shunting said series connected elements to prevent substantial energization of said series connected elements until said fusible element is ruptured, said fusible element being ruptured in response to predetermined current flow therethrough from said source, thereby to permit substantial energization of said detonating element from said source through said resistance element.

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