Jan. 17, 1961 D. Q. BRUMBAUGH 2,968,241

SENSITIVE RELAY FOR MINE FIRING SYSTEM

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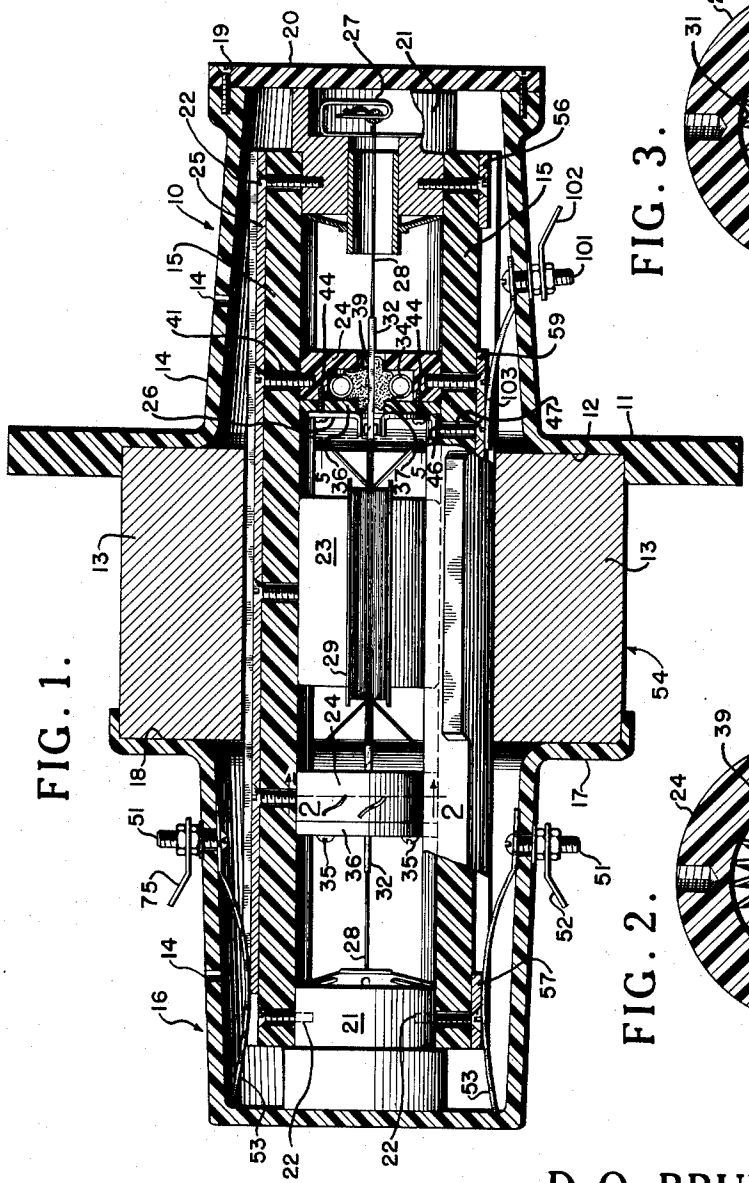

FIG. 1.

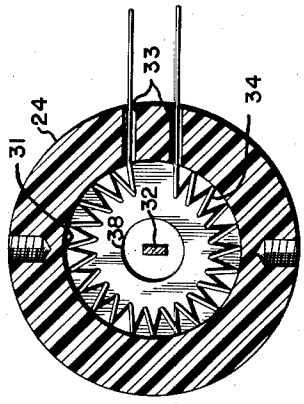

FIG. 3.

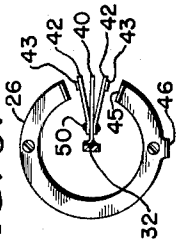

FIG. 5.

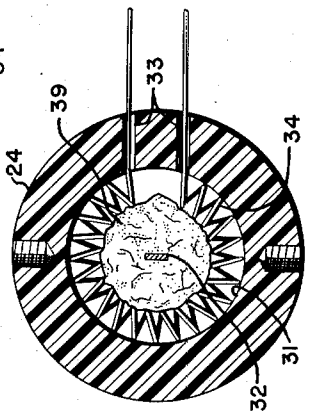

FIG. 2.

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SENSITIVE RELAY FOR MINE FIRING SYSTEM

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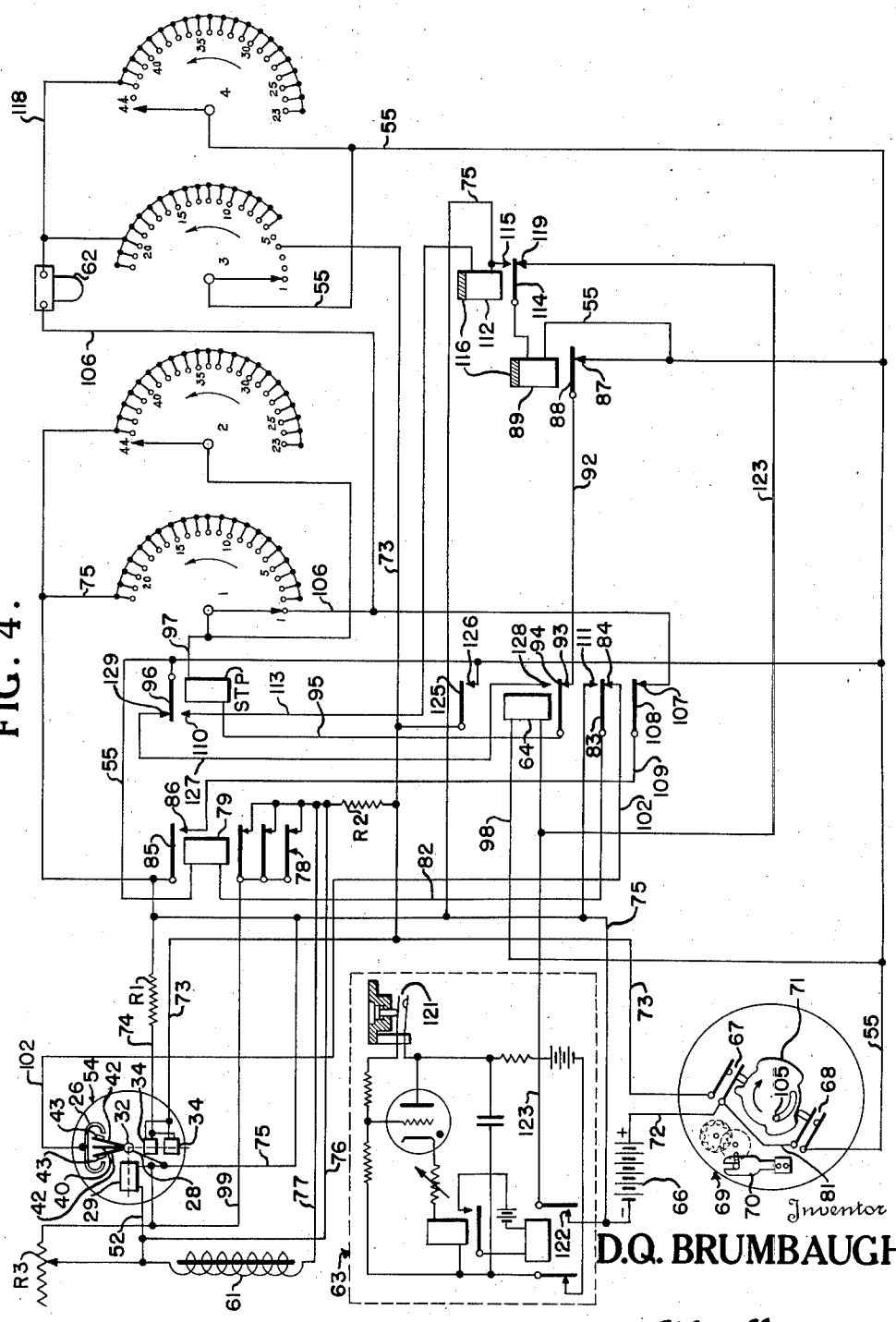
FIG. 4.



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SELECTIVE RELAY FOR MINE FIRING SYSTEM

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9 Claims. (Cl. 102—18)

(Granted under Title 35, U.S. Code (1952), sec. 266)

This invention relates generally to improvements in sensitive relays for use in marine mines and more particularly to a method and apparatus for preventing damage to the delicate torsion wires of the moving coil system of a sensitive galvanometer, or like instrument, during a period of rough handling and thereafter rendering the galvanometer effective for operation at the expiration of the rough handling period.

During the development of induction mines employing the search coil-sensitive relay combination, there has been a continuing and long felt need for a sensitive relay capable of operation in response to electrical signals having a strength in the order of less than one microampere in order to increase the sensitivity of the mines. It has been known heretofore that a device having a high degree of sensitivity of this order is obtainable from torsion wire type moving coil systems but the problem of supporting the delicate moving coil system so as to be shock resistant during periods of rough handling and launching of the mines remained unsolved.

The sublimatable protective lock of the present invention provides a solid support for the moving coil system while the sublimatable material is in a solid state and also operates upon the application of a predetermined amount of heat to completely free the moving coil system for movement in response to extremely small currents. This is accomplished by reason of the sublimation of the material comprising the protective lock whereby, as the material is converted to the gaseous state, there remains no portion of the material whatsoever on the moving coil system to restrict, obstruct, unbalance, or otherwise interfere with the free movement thereof in response to the weak signal current.

Sublimation of the material is accomplished by means of electric heat coils embedded therein and arranged to be energized after the mine has been planted in a body of water. Upon sublimation of the material, the gas thus formed is uniformly dispersed within the confined free space within the mine and thereafter becomes condensed as finely divided particles on the casing wall of the relay, or mine, as the case may be, where it does not interfere with the operation of the relay or other mine components.

According to the relay arrangement of the present invention, provision is made for resetting the contacts operated by the moving coil system by releasing energy which has been stored in one of the leaf springs which carry the movable contacts, the moving coil system being moved sufficiently to compress the aforesaid one of the springs in response to a resetting current supplied to the moving coil system from the battery for operating the mine firing mechanism, and novel circuit arrangements are provided for momentarily energizing the heat coils and simultaneously resetting the moving coil system when the mine is planted within the water. Provision is also made for resetting the sensitive relay at the termination of an initial "dead" period, following operation of the relay in response to a first signal current generated by the search coil and indicative of a vessel moving in

the vicinity of the mine. Provision is further made for resetting the relay at any time during the life of the mine in response to countermine shocks received thereby.

It may be of assistance in the comprehension of the present invention to state that the supporting mass initially formed between the galvanometer frame and the coil supports of the moving coil system employs a material such, for example, as ammonium benzoate, ammonium chloride or a like material which assumes a solid form at atmospheric temperatures and which will sublimate or change directly from the solid form to a gas when heat is applied to the material at a temperature in the order of 160° to 520° centrigrade.

An object of the present invention is to provide a method and apparatus for supporting a wire suspended moving coil system to prevent damage thereto during a period of rough handling or shock and for rendering the moving coil system responsive to signals of low magnitude after these periods have lapsed.

Another one of the objects of the present invention is to provide a mass of sublimatable material between the galvanometer frame and the coil supports of the moving coil system in a marine mine firing system to prevent damage to the torsion wires during launching operation of the mine and to sublimate the material after the mine comes to rest in the target area, thereby to free the moving coil system for operation in response to signals received thereby.

Another object is to provide a mine firing circuit for a marine mine having provision for applying sufficient heat to the sublimatable material to transform the material into a gas after the mine has come to rest in the target area.

A further object is to provide a wire suspended moving coil system having contact switch means therein and provision for resetting the switch means to an initial unoperated condition of the system.

An additional object is to provide a mine firing circuit including a wire suspended sensitive moving coil detecting system and having provision for sublimating an initial lock for the system thereby to free the system for operation in response to signals of extremely low magnitude and having further provision for resetting the system following response thereof to a signal received thereby.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a view partly in section and partly broken away of the moving coil system of a galvanometer type mechanism illustrating the preferred form of the protective device for preventing damage to the coil suspension as the mine is planted in a target area;

Fig. 2 is a somewhat enlarged sectional view taken along line 2—2 of Fig. 1 and illustrating the sublimatable mass of material in place for supporting the moving coil system of the galvanometer during the launching operation;

Fig. 3 is a view similar to Fig. 2 showing the coil supports of the galvanometer freed of the supporting mass of material after the mine has come to rest in the target area;

Fig. 4 illustrates in diagrammatic form the electrical system employed in connection with the relay of the present invention for arming and firing the mine; and

Fig. 5 is a somewhat enlarged sectional view taken along line 5—5 of Fig. 1 and illustrating the arrangement of the switch contacts of the galvanometer.

Referring now to the drawings in which like numerals of reference are employed to designate like parts throughout the several views, there is shown in Fig. 1 a galva-

nometer relay generally indicated by the numeral 54 and comprising tubular casings 10 and 16 preferably vented as at 14 and molded of nonconducting material such for example as Bakelite, and provided with outwardly extending flanged portions 11 and 17 respectively, casing 16 being cup-shaped. Recesses 12 and 18 are formed in the casings for receiving a pair of oppositely positioned permanent magnets 13. Slideably arranged within casing 10 and 16 is a pair of opposedly disposed nonconducting supporting strips 15. The open end of casing 10 is closed by phenolic cover 20 which is secured in place by screws 19.

Supporting strips 15 are provided with longitudinal grooves for receiving conducting strip 25 on the upper supporting strip, as viewed in Fig. 1, the lower supporting strip having short metallic strips 56, 57 and 59 secured thereto in spaced relation along the length thereof. Supporting strips 15 also carry a pair of spaced support members 21, a pair of insulating flanged portions or collars 24, a conducting ring 26 and a cylindrical iron core 23. Support members 21 are threaded to receive set screws 22 for binding the support members to the supporting strips 15 and to provide a conducting path from conducting strip 25 to the right support member and from strip 57 to the left support member. Support members 21 have secured thereto spring members 27 for holding the delicate torsion wires 28 in tension to form a connection with the somewhat more rugged wire coil supports 32 which together with the wire supports suspend the moving coil 29 about the iron core 23 after the coil has been unlocked and provide an energizing current path from the support members 21 through the torsion wires and wire supports to coil 29.

Collars 24 are each provided with an annular recess 31 and a pair of radially extending openings 33. A heat coil 34 is disposed within the recess 31 and the wire ends of the heat coil 34 are brought out through the openings 33. These wires of 34 then pass through suitable openings (not shown) through casings 10 and 16 respectively, to form an electrical connection into the mine firing circuit of Fig. 5 as will hereinafter be more fully explained. Secured to collars 24 by set screws 35 are phenolic covers 36 having axial openings 37 arranged in registry with openings 38 through the collars for passing the coil supporting wires 32 through the openings. A solid mass of sublimatable material 39 such, for example, as ammonium benzoate, is formed about coil supports 32 and heating coil 34 to entirely fill the recesses 31 of the collars 24 to provide a supporting mass for the coil 29 when assembling the parts together. Collars 24 are secured in place on strips 15 by set screws 41.

As seen more clearly in Fig. 5, the right hand wire coil support 32 has secured thereto a radially extending stop member 40 to which a pair of high compliance leaf springs 42 are held by rivet 50. Springs 42 are provided with magnetic contact tips 43 permanently magnetized, the springs being of sufficient length so that the tips 43 are disposed within the opening 45 of the iron contact ring 26 which is secured in place between supporting strips 15 concentrically with respect to wire support 32 by screws 44 threaded to the right hand collar 24. Contact ring 26 is composed of magnetic material and provided with an axial extension 46 which is bent at right angles to receive the end of screw 47 which forms a conducting path from extension 47 to strip 59. The ends of contact element 26 are bent at right angles adjacent opening 45 to provide contact surfaces for electrical and magnetic engagement with either one of magnetic contact tips 43 as the galvanometer operates.

Casing 16 is provided with a pair of binding posts 51 having conductors 52 and 75 secured on the outer ends thereof and a pair of compression leaf springs 53 respectively secured on the inner ends with the upper spring arranged to engage conducting strip 25 to form an electrical connection through the conductor 75, upper post 51, upper spring 53, conducting strip 25, screw 22, right hand support 21, right tension spring 27, right torsion wire 28, right coil support 32 to coil 29, from whence the circuit is continued through left coil support 32, left torsion wire 28, left coil support 21, screw 22, strip 57, lower spring 53, lower binding post 51 and to lower conductor 52.

Casing 10 is provided with binding post 101 having a conductor 102 secured to the outer end thereof with a compression leaf spring 103 secured on the inner end to engage conducting strip 59 thereby to complete a circuit from conductor 102 through the post 101, spring 103, plate 54 and screw 47 to the contact ring 26.

The detecting relay such as shown in Fig. 1 is well suited for use in the arming and firing circuit of an induction type marine mine which is adapted to be launched within a body of water.

The adaptation of relay 54 of Fig. 1 to the arming and firing circuit of the copending application is schematically illustrated in Fig. 4 and will best be understood from the statement of operation of the mine firing system presently to appear. For further details as to the structure and operation of the mine firing system reference may be had to the aforesaid copending application.

Assuming the parts of the mine firing system to be in the positions disclosed in Fig. 4, when the mine is launched into a body of water, a clock mechanism 69 is set in operation by a clock starter mechanism 70 which responds to the pressure of the surrounding water. The clock mechanism drives a cam 71 in the direction of the arrow. As the cam rotates, it first momentarily closes a switch 67 to energize the electric heat coils 34 of relay 54 from battery 66 by way of conductor 72, switch 67, conductor 73, heat coils 34 in parallel, conductor 74, current limiting resistor R1, and thence by way of conductor 75 to the other side of battery 66. The heat coils 34 in response to the energy received thereby from the battery 66, generate sufficient heat to sublimate the sublimatable material 39 and cause it to be widely dispersed throughout the free space within the mine and to condense as finely divided particles on the relatively cooler inner surfaces of the mine casing in contact with the surrounding water. Sublimation of the material leaves the moving coil system 29 freely suspended by the torsion wires 28.

In the event that one of the contacts 43 of the relay is in engagement with ring 26, or the contact is in such close proximity to the ring as to be attracted thereto by the magnetic attraction of the contact 43 when the moving coil system has been freed as aforedescribed, a circuit which was completed by the closing of switch 67 concurrently with the circuit to the electric heat coils 34 is established between coil 29 and the battery 66 for resetting the contacts of relay 54 to an unoperated position with respect to the contact ring 26, this circuit being traced from battery 66 by way of conductor 72, switch 67, conductor 73, resistor R2, conductor 76, moving coil 29, and conductor 75 to the other side of battery 66. Completion of the circuit causes sufficient energization of the moving coil system 29, as controlled by the value of resistor R2, to cause the stop member 40 to move into engagement with the leaf spring 42 whose contact 43 is in engagement with the contact ring 26, thereby to develop a spring force in the leaf spring sufficient to break the magnetic attraction between the contact and the contact ring and to restore the contacts to an unoperated position with respect to the contact ring upon release of the power stored in the spring when the aforedescribed circuit to the moving coil system 29 is interrupted as continued movement of the clock cam 71 causes switch 67 to be opened. It will be understood that the circuit for energizing coil 29 from battery 66 moves the coil in one direction only to bring the right contact 43, for example, into engagement with ring 26.

Consequently, if the left contact is in engagement with the ring prior to resetting, energy received from battery **66** will first break engagement of the left contact and thereafter move the right contact into engagement with ring **26** followed by compression of its leaf spring by stop **40**.

It will be noted that there is a closed circuit from the moving coil system **29** by way of the sensitivity control resistor R3 which is shunted thereacross and connected thereto by conductors **52** and **99**. There is also a closed circuit for the moving coil system by way of conductor **52**, search coil **61**, conductor **77**, the normally closed search coil break contacts **78** of relay **79** and thence by way of conductor **99** to the other side of moving coil system **29**. By reason of these closed circuits, the moving coil system is sufficiently damped electrically to prevent movement of contact assembly **40**, **42** and **43** beyond a desired null position in which the contacts **43** are maintained out of engagement with the contact ring **26**.

Clock cam **71** continues to rotate until stopped by a pin **105**, at which time the cam is effective to close the clock switch **68** which applies positive potential from battery **66** by way of conductor **72**, conductor **81**, and clock switch **68** to conductor **55**. The mine is now armed and is in readiness to receive a signal from a vessel moving within the vicinity of the mine.

As the vessel moves in relation to the search coil **61**, an electrical signal is generated thereby in response to the change in the magnetic field threading through the search coil and due to the magnetic influence of the vessel. This signal is supplied to the moving coil system **29** of relay **54** through the aforedescribed closed circuit including the search coil **61**, coil **29**, and break contacts **78** of relay **79**. The signal thus supplied by the search coil **61** is usually a weak signal current in the order of one micro-ampere at a low frequency and is just of sufficient strength to move the moving coil system **29** so as to bring one of the magnetic contacts into the zone of magnetic attraction with respect to the contact ring **26** whereupon engagement thereof is completed by reason of the magnetic attraction therebetween. It will be understood that the original signal received from the search coil will be of either polarity. Consequently, the right or left contact may be moved to engage the ring selectively in accordance with the polarity of the search coil signal.

As the contacts of relay **54** become engaged, a circuit is completed thereby for energizing relay **79** from battery **66** by way of conductors **72**, **81**, contacts **68**, conductor **55**, winding of relay **79**, conductor **82**, the armature **83** and the break contact **84** of relay **64**, conductor **102**, contact ring **26** and one of contacts **43** of relay **54**, its associated leaf spring **42**, stop **40**, its associated coil support **32**, torsion wire **28**, Fig. 1, suspension spring **27**, support member **21**, screw **22**, conducting strip **25**, spring **53**, binding post **51** and thence by way of conductor **75**, Fig. 4, to the other side of battery **66**. As relay **79** operates, the aforementioned break contacts **78** operate to interrupt the circuit between the search coil and the moving coil system, and armature **85** of relay **79** is moved into engagement with make contact **86**. As these last named contacts are closed, a circuit is completed for operating stepping switch STP from battery **66** by way of positive potential on conductor **55**, break contact **87** and armature **88** of slow releasing relay **89**, conductor **92**, break contact **93** and armature **94** of relay **64**, conductor **95**, winding of the stepping switch STP, conductor **97**, wiper and contact **1** of contact bank **1** of the stepping switch STP, conductor **106**, break contact **107** and armature **108** of relay **64**, conductor **109**, make contact **86** and armature **85** of relay **79** and thence by way of conductor **75** to the negative side of battery **66**.

As the winding of the stepping switch STP is energized, the armature **96** engages the make contact **110** of the switch to complete a circuit for energizing the slow release relay **112** from battery **66** by way of positive potential on conductor **55**, armature **96** and make contact **110** of the stepping switch STP, conductor **113**, winding of relay **112**, and thence by way of conductor **75** to the negative side of battery **66**. As relay **112** is operated, armature **114** engages the make contact **115** thereof to complete a circuit for operating relay **89** from the battery by way of positive potential on conductor **55**, the winding of relay **89**, armature **114** and make contact **115** of relay **112**, and thence by way of conductor **75** to the other side of battery **66**.

As relay **89** operates, armature **88** is disengaged from break contact **87** of the relay, thereby to interrupt the hereinbefore traced circuit for energizing the stepping switch STP whereupon the operating armature thereof is released to advance the wipers of the switch one step or contact on each of the contact banks **1**, **2**, **3** and **4** of the stepping switch STP.

As armature **96** disengages make contact **110** of the stepping switch STP upon de-energization thereof, the circuit hereinbefore traced therethrough for energizing the slow releasing relay **112** is interrupted whereupon the relay is de-energized. Armature **114** does not immediately disengage contact **115** thereof, however, because of the delayed release operation produced by the copper slug, or the like, designated **116**. After a short interval of time controlled by the size of slug **116**, the circuit heretofore traced through armature **114** and contact **115** for energizing relay **89** is interrupted as these contacts disengage, thereby to de-energize relay **89** which in a manner similar to the operation of relay **112** causes its contacts **87** and **88** to again become engaged after a short interval following de-energization of relay **89** by reason of its slug **116**. When this occurs, a circuit is again completed for operating stepping switch STP from battery **66**, the circuit in this case being completed from the winding of the stepping switch through the wiper and the contact of bank **1** and thence by way of conductor **75** to negative battery rather than through contact **1** of bank **1**, as aforetraced, it being recalled that the wipers have advanced to contact **2** on the banks.

The stepping switch STP, it will be noted, is provided with 4 wipers, **1** through **4**, of which the wipers **1** and **3** are adapted to engage the contacts of their respective switch banks during the first half revolution of the wipers and the wipers **2** and **4** are adapted to engage the contacts of their respective switch banks during the latter half of the revolution of the wipers. The switch is, therefore, adapted to step the wipers ahead for 44 successive steps before the wipers are brought to rest in the initial home position thereof with the wipers **1** and **3** in engagement with the contacts **1** of their respective switch banks and wipers **2** and **4** disengaged from contacts **44** of their respective switch banks. Furthermore, wipers **1** and **2**, it will be noted, are electrically connected together and to the winding of stepping magnet STP and are electrically connected to contacts **2** to **22** of bank **1** and to **23** to **44** of bank **2** of the stepper switch as the switch rotates. These banks are connected to conductor **75** in electrical connection with the negative terminal of battery **66** and the wipers are preferably of the bridging type adapted to engage the next succeeding contact of their respective switch banks before moving out of engagement with the preceding bank contact thereby providing an arrangement in which the negative potential of battery **66** is applied continuously to the winding of stepping magnet STP in all positions of the switch except when the wiper of bank **1** is in the initial position thereof.

Accordingly, when armature **88** of relay **89** re-engages its break contact **87**, a circuit is completed for energizing the stepping switch from battery **66** by way of positive potential on conductor **55**, break contact and armature of relay **89**, conductor **92**, break contact **93** and armature **94** of relay **64**, conductor **95**, winding of the stepping switch STP and thence from conductor **97** through wiper of

bank 1 to contact 2 of the stepper switch to the negative side of the battery by way of conductor 75, thereby to cause stepping magnet STP to become energized. Operation of the stepping magnet STP causes relays 112 and 89 to operate in succession, as described heretofore, thereby to interrupt the operating circuit to the stepping magnet and to cause the stepping switch to make an additional step. Thereafter, relays 112 and 89 again release in succession after a short interval such, for example, as .74 second, to apply battery potential again to the stepping magnet STP. Accordingly, when stepping magnet STP and relays 112 and 89 are energized and de-energized a sufficient number of times, wipers 1 through 4 are moved through a full revolution to return again to the initial position. After a time delay of .74 second, therefore, following the return of the wipers to their initial positions, the circuit is again restored to its initial condition in which further operation of the switch is initiated only in response to the operation of the sensitive relay 54.

When the wipers of the stepper switch engage contact 4 of their respective switch banks, a circuit is closed from positive potential on conductor 55 by way of wiper 3 and contact 4 of switch bank 3, conductor 73, resistance R2, conductors 76 and 52, moving coil 29 of relay 54 and by way of conductors 75 to the negative side of battery 66, thereby causing the coil 29 to rotate about the core 23 to force stop member 40 against leaf spring 42, thereby to develop a spring force in the leaf spring sufficient to break the magnetic attraction between the contact 43 and contact ring 26 as the wiper arm for contact bank 3 of the stepping switch moves to its contact 5 to interrupt the circuit to coil 29 to again restore the contacts to the unoperated positions, as shown in Fig. 5. As contact element 43 of the sensitive relay 54 moves out of engagement with contact ring 26 the operating circuit of relay 79, previously traced, is interrupted thereby causing relay 79 to release and to restore the circuit between the relay 54 and the search coil 61.

Thus it is seen that from the initial operation of the relay 54 until the wipers of the stepper switch have moved into the 5th position, relay 54 is rendered unoperative to signals generated by the search coil 61 for the reason that magnetic element 43 is locked to the contact ring 26 by magnetic attraction between the contacts 43 and ring 26 for a period of time during which the circuit between the moving coil 29 and the search coil 61 is also interrupted and thereafter is locked for an additional interval of time in the closed position thereof during the aforedescribed energization of coil 29 through contact 4 of switch bank 3.

It will be noted that the wipers of switch banks 3 and 4 of the stepper switch are electrically connected together and that contacts 6 through 22 of bank 3 and contacts 23 through 43 of bank 4 of the stepper switch are electrically connected together and to the detonator 62 by way of conductor 118 thereby to apply positive battery to the detonator during the time measured by the movement of the stepper switch from the 6th through the 43rd positions thereof. During the time the wiper arms are moving from contact 6 to 43, the mine is armed for the reason that a disturbance in the magnetic field adjacent the mine caused by a vessel moving into the vicinity thereof generates a signal current in the search coil 61 sufficient to move the moving coil 29 to bring one of its contacts 43 into engagement with contact ring 26. This causes energization of relay 79 through a circuit heretofore traced. As relay 79 operates, a circuit is completed for applying negative battery to the other terminal of the detonator by way of conductor 75, armature 85 and make contact 86 of relay 79, conductor 109, armature 103 and break contact 107 of relay 64, and thence by way of conductor 106 to the detonator, and cause the mine to be exploded beneath a vulnerable portion of the vessel.

It will be understood that switch banks 3 and 4 of the stepper switch may be wired such that any desired shorter interval may be provided for firing the mine, however, contact 44 of switch bank 4 must be left unconnected from conductor 118 by reason of the bridging of the wipers which are employed. A circuit otherwise would be completed to the detonator by way of the positive terminal of battery 66 on conductor 55, wiper of contact bank 4, contact 44 of bank 4, conductor 118, detonator 62, conductor 106, wiper of bank 1 and wiper of bank 2 and thence by way of conductor 75 to the opposite side of battery 66.

The operations of the system in response to sweep operations by an aircraft towed mine sweeper will now be considered. It is the practice to tow sweeping apparatus which produces rapidly varying magnetic fields adapted to induce surges of current in the search coil, the sweep apparatus being towed by an aircraft whereby a large area of the surface of the sea may be rapidly swept, thereby reducing the amount of equipment necessary for such purpose. By reason of the unresponsive period provided in the firing circuit, the system is rendered unresponsive to a second signal in the search coil for an appreciable period of time such, for example, as 2¼ seconds thereby to eliminate the possibility of sweeping the mine by employing a sweep apparatus towed by an aircraft which will pass from the magnetic influence of the coil within such a short interval that the system will not respond to a second signal. In such case, therefore, the response of the system to such rapid changes in magnetic influence merely initiates the operation of the selector switch to cause the same to operate through a cycle of operation without firing the detonator.

The firing circuit also includes a countermine device generally designated 63 which comprises an inertia switch 121 and circuits controlled thereby which are adapted to close a pair of contacts 122 in response to the operation of switch 121 as a countermine shock or pressure impulse is received through the surrounding water. Contacts 122 are arranged to operate relay 64 from battery 66, and the armatures 108, 83, 94, and 125 controlled by the relay respectively open the circuit to detonator 62, operate relay 79 thereby to open the search coil circuit, operate the stepping switch on self-operated pulses, and energize coil 29 to store energy in leaf spring 42.

A type of inertia switch and its associated circuits suitable for this purpose is disclosed in the copending application of Seth W. Booth for Inertia Switch and Means Controlled Thereby, Serial No. 484,854, filed April 28, 1943. Suffice it to state that such a switch as 121 in response to shocks received thereby is adapted to close a pair of contacts 122 for a predetermined period of time such, for example, as 3 seconds.

Assume, for example, that stepper switch STP is in the initial position when a shock is received by the mine through the water, the intertia switch 121 operates to close the contacts 122 for a relatively short interval of time such, for example, as 3 seconds thereby to close a circuit from the positive terminal of battery 66 on conductor 55 by way of the winding of relay 64, conductor 123, and thence by way of contacts 122 of the countermine device 63 to the negative side of battery 66 thereby to operate relay 64. A circuit is also completed from the positive side of the battery by way of conductor 55 through relay 89, armature 114 and break contact 119 thereof, conductor 123, contacts 122 of the countermine device to the negative side of battery 66, thereby to operate relay 89 for a purpose hereinafter to appear.

As relay 64 operates, armature 125 engages make contact 126 thereof, which is connected to positive lead 55, to complete a circuit through resistance R2, conductor 76, moving coil 29, and thence by way of conductor 75 to the negative side of battery 66, thereby to cause sensitive relay 54 to operate to engage right contact 43 with ring 26 to store energy in associated spring 42. Thus, the contacts of relay 54 are locked in engagement during the three second interval provided by the countermine device and the energy in spring 42 is released as relay 54 is deenergized at the termination of this interval,

thereby to restore the contacts 43 to an initial unoperated position, as aforedescribed. It will be noted, that locked engagement of the contacts of relay 54 during countermine shock serves to support the moving coil system during the countermine period and until the shock has subsided.

As armature 83 engages its make contact of relay 64, a circuit is completed for operating relay 79 from battery 66 by way of conductor 55, winding of relay 79, conductor 82, armature 83 and make contact 111 of relay 64, and thence by way of conductor 75 to the negative side of battery 66, thereby to cause relay 79 to operate. Operation of relay 79, as previously described, opens contacts 78 and interrupts the circuit between the search coils and the moving coil 29 of sensitive relay 54, thereby to prevent storing of inductive energy in the search coil 61 as a result of changes in the magnetic field adjacent thereto caused by shock.

As relay 79 operates, armature 85 engages contact 86. However, armature 108 and brake contact 107 of relay 64, which are also included within the arming and firing circuits of the system in series with contacts 85, 86 of relay 79 open to interrupt such circuits as relay 64 operates.

As armature 94 and make contact 128 of relay 64 engage, a circuit is completed for applying positive battery to the windings of stepping switch STP from positive battery on conductor 55 by way of armature 96 and break contact 129 of stepper switch STP, conductor 127, make contact 128 and armature 94 of relay 64, and thence by way of conductor 95 to the winding of stepping magnet STP. Positive battery thus applied by way of interrupter contacts of the stepping magnet is for the purpose of operating the stepper switch on self-interruptions when the inertia switch 121 closes at a time when the switch is moved out of the initial position during a cycle of operations thereof as will appear in greater detail hereinafter.

By reason of these successive operations of relays 64 and 79 in response to a countermine shock, armature 108 and break contact 107 of relay 64 close before armature 85 and make contact 86 of relay 79 open when the operating circuit of relay 64 is interrupted as contacts 122 of anticountermine device 63 open at the end of the aforesaid 3 second interval provided thereby. Accordingly, negative battery is momentarily applied by way of conductor 75, armature 85 and make contact 86 of relay 79, conductor 109, armature 108, break contact 107 of relay 64, conductor 106 and thence, by way of contact 1 of wiper 1 of the stepper switch to the stepping magnet STP thereof. Spurious operation of the stepping magnet is prevented, however, by reason of the fact that the operating circuit therefor is interrupted by the armature 88 and break contact 87 of relay 89, it being recalled that the relay 89 operated when contacts 122 of the countermine device 63 closed in response to the shock received by the mine. Accordingly, the operating circuit to the stepping magnet STP is maintained in an open position for approximately .37 second after the operating circuit of relay 89 is interrupted as contacts 122 of the countermine device open at the end of a 3 second interval provided thereby when the switch 121 operates at a time when the mechanism is in operation. Relays 64, 79 and 89 operate in the same aforedescribed manner when a shock occurs at a time when the stepper switch mechanism is in the initial position thereof, thereby to restraing relay 54 forcibly in an operated condition thereof, to interrupt the circuit between the windings of the moving coil 29 thereof and the search coil 61, and to interrupt the operation initiating and firing circuits of the system during the entire protective interval provided by the countermine device 63. During the protective interval the stepping switch additionally is caused to step rapidly to the initial position thereof on self-generated current impulses, the current for this purpose being traced as follows, positive battery on conductor 55, armature 96 and break contact of stepper switch STP, conductor 127, make contact 128 and armature 94 of relay 64, conductor 95, winding of stepping magnet STP, and thence by way of wipers 1 and 2 and their associated switch banks to negative battery on conductor 75. With the stepping switch in the initial position, spurious stepping of the switch beyond the initial position at the end of a 3 second interval provided by the countermine device is prevented by the delay in closing of a contact 87 and armature 88 of relay 89 as previously described.

The stepping switch is preferably of a type adapted to make approximately 50 steps per second when operating on self-generated impulses, in order to insure that the switch will be restored to the initial position thereof within the protected period provided by the countermine device. For this reason, a countermine device adapted to provide an interval which safely exceeds the self-restoring time of the switch must be employed, it being recalled that negaitve battery is applied to one terminal of the detonator momentarily when the operating currents to relays 79 and 64 are interrupted at the end of the protective interval provided by the countermine device and that positive battery is applied continuously to the other terminal of the detonator when wipers 3 and 4 of the stepper switch engage contacts 6 through 43 of the respective switch banks 3 and 4.

Briefly stated in summary, the present invention provides a new and improved sensitive relay for a mine firing system adapted to be controlled by a plurality of changes in the magnetic field received within predetermined intervals of time in which a predetermined number of such changes are required to fire the mine as an enemy vessel moves within the vicinity thereof. The improved relay also comprises novel protective and resetting means operable in the mine firing system to prevent premature detonation of the mine during launching, by airborne sweeping operations, or as a result of countermine shocks received within the vicinity of the mine.

Obvoiusly many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

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

1. A device for protecting the moving coil system of a galvanometer having delicate torsion suspension wires during a period of rough handling comprising a pair of support members secured to the torsion wires and to the coil, a solid mass of sublimatable material formed about said support members and interposed between the members and the galvanometer frame to prevent movement of the coil system and the support members therefor during said period, an element arranged in heat transfer relation with respect to said mass and adapted to generate sufficient heat when energized to transform said material into a gas, and means for energizing said element sufficiently to sublime said mass at the expiration of said period thereby to completely remove all restriction to the free movement of the coil system in response to weak signal currents received thereby.

2. In a detecting circuit, the combination of a moving coil system having delicate suspension wires and included in said circuit, a pair of relatively rigid suport members for connecting said wires to the coil, a solid mass of sublimatable material formed about said support members for releasably locking said coil and suspension wires therefor against movement prior to utilization thereof, an element arranged in heat transfer relation with respect

to said mass of material and adapted to generate sufficient heat when energized to sublime said material, and means for energizing said element sufficiently to transform the material into a gas thereby to completely free said moving coil system for movement in response to weak signal currents received thereby.

3. In a submarine induction mine of the character disclosed adapted to be launched within a body of water, the combination of a pick-up coil adapted to generate electrical signals of opposite polarity selectively in response to changes in the magnetic field of the coil as a vessel passes within the vicinity thereof, galvanometer connected to the pick-up coil and adapted to be operated by said signals, said galvanometer having a frame, a moving coil enclosed within the frame, delicate torsion suspension wires secured to the frame and to the coil, support members forming a connection between said torsion wires and said coil, a solid mass of sublimatable material formed between said frame and said support members for initially locking the coil support members to the galvanometer frame thereby to prevent movement of said coil and damage to the torsion wires in response to shocks received by the mine during the launching operations thereof, an electroresponsive heating element arranged within said mass of material in heat transfer relation therewith and adapted to transform the material into a gas when the element is energized, a source of electrical energy, a hydrostatically controlled clock mechanism adapted to be set in operation as the mine descends within the water, a first circuit controlling device operated by said clock mechanism, means including said device for operatively connecting said heating element to said electrical source for an interval sufficient to completely sublime said mass of material at the termination of a first predetermined interval measured by the clock mechanism, a contact element carried by said galvanometer coil for movement therewith, a pair of spaced contacts adapted to be engaged selectively by said movable contact as the galvanometer coil moves from an initial unoperated position in response to signal currents of opposite polarity received from said pick-up coil, a firing circuit including a rotary selector switch adapted to be stepped ahead from an initial unoperated position through one complete rotation thereof as the movable contact engages one of said spaced contacts, a second circuit controlling device operated by said clock mechanism, means including said second device for operatively connecting said firing circuit to said electrical source a predetermined interval after said heating element has been de-energized, means controlled by said switch for rendering said firing circuit effective to fire the mine during a predetermined interval of time when the switch has stepped ahead a predetermined number of steps beyond said initial position, and means controlled by said galvanometer and said switch for firing the mine when the galvanometer responds to a second signal corresponding to a second change in the magnetic field caused by movement of said vessel within the vicinity of the mine during said last named predetermined interval of time.

4. In a sensitive relay of the character disclosed, the combination of a housing, a ferrous core secured within said housing, means for setting up a constant magnetic field in said core, a coil disposed in proximate spaced relation about said core and adapted to rotate thereabout as a current passes through said coil, a pair of supports for said coil, a pair of delicate torsion suspension wires secured to said housing and to the coil supports, a ferrous contact element secured to said housing and having an opening therein, a pair of low compliance spring members secured to one of said coil supports and extending radially therefrom into said opening normally in spaced relation with respect to said element and with respect to each other, a pair of permanent magnet contact tips secured respectively to said spring members, and a stop member secured to said one of the coil supports and having said spring member secured thereto, said stop member being interposed between said spring members and arranged to engage and compress the spring members selectively as one of said contact tips engages said ferrous element when a current of predetermined value and polarity is passed through the coil, the energy stored in said spring members upon compression thereof being sufficient to break the magnetic attraction between said ferrous contact element and the contact tip in engagement therewith when the coil is de-energized thereby to reset the spring members and contact tips carried thereby to an initial unoperated position with respect to said ferrous contact, said contact tips having sufficient magnetic attraction with respect to said ferrous contact element to move the tips selectively into engagement therewith when one of the tips has first been moved into proximate spaced relation with respect thereto upon movement of the coil in response to a current of low value.

5. In a galvanometer type sensitive relay having a core and a coil disposed thereabout for rotational movement with respect thereto as the coil is energized comprising, in combination, a stationary ferrous contact element having an opening therein, a rigid stop member disposed in spaced relation with respect to said opening and movable therein as said coil rotates, a pair of spring members secured on opposite sides of said stop member and extending radially from the axis of said coil into the opening of said contact element, and a pair of magnetized tips secured respectively to said spring members and adapted to selectively engage said ferrous contact element in releasable magnetic locking engagement as said coil is energized by a current of predetermined polarity and low value, said stop member being arranged to engage and sufficiently compress the one of said spring members having said contact tip thereof in engagement with said ferrous contact element as a second predetermined current of higher value is passed through said coil to cause said engaged tip to spring away and be released from said ferrous element when said coil is de-energized.

6. In a wire suspension type relay having a moving coil system, the combination of an open ring-shaped ferrous contact element disposed concentrically with respect to the axis of the moving coil system, at least one spring member secured to said coil system for rotary movement therewith and extended radially from said axis thereof into the opening in said ring-shaped member, a permanent magnet contact tip secured to said spring member and arranged to be magnetically attracted and locked to said ring-shaped member when the tip has been moved into predetermined proximate spaced relation with respect thereto upon movement of the coil system in response to a weak current, said spring member having a compliance of predetermined value for rendering the spring member effective upon movement of the coil system in response to a large current of predetermined value to store energy in the spring member sufficient to break said locked engagement of the element and tip to restore the tip to said initial position when the coil system is de-energized and means including a sublimatable material for immobilizing the relay suspension prior to utilization, said means including heater means for providing sublimation of said material thereby to release said suspension for operation.

7. In a wire suspension type relay having a moving coil system, the combination of an open ring-shaped ferrous contact element disposed concentrically with respect to the axis of the moving coil system, at least one spring member secured to said coil system for rotary movement therewith and extended radially from said axis thereof into the opening in said ring-shaped member, a permanent magnet contact tip secured to said spring member and arranged to be magnetically attracted and locked to said

ring-shaped member when the tip has been moved into predetermined proximate spaced relation with respect thereto upon movement of the coil system in response to a weak current, said spring member having a compliance of predetermined value for rendering the spring member effective upon movement of the coil system in response to a large current of predetermined value to store energy in the spring member sufficient to break said locked engagement of the element and tip and return the tip toward said initial position when the coil system is de-energized, means including a sublimatable material for immobilizing the relay suspension prior to utilization, said means additionally including heater means for providing sublimation of said material thereby to release said suspension for operation, and a closed circuit for said coil system having sufficient electrical damping therefor to stop said tip at said initial position.

8. In a submarine mine of the character disclosed arranged within a magnetic field, a pick-up coil arranged within said field and adapted to generate electrical signals as the field is changed, a wire suspension type relay having a moving coil system connected to said pick-up coil and adapted to be operated thereby in response to said signals, said relay including a solid mass of sublimatable material for locking the moving coil system prior to planting of the mine within a body of water, means including a hydrostatically controlled device for sublimating said mass to free the moving system after the mine has come to rest within the water, said relay comprising a stationary ferrous contact element having an opening therein, a pair of spaced spring members connected to said moving coil system and movable therewith as the relay operates, a pair of permanent magnet contact tips secured respectively to said spring members and disposed within said opening in the contact element, said contact tips being arranged to selectively engage said ferrous element upon movement of the coil system in response to a weak signal current of predetermined polarity and magnitude generated in said pick-up coil, a rotary selector switch having a plurality of wipers adapted to be stepped ahead into engagement with the contacts of their associated switch banks in succession as the switch operates, means including the operating winding of the selector switch and certain ones of the contact banks of the switch for causing the selector switch to be stepped ahead at predetermined intervals of time and through one complete rotation after the operation thereof is initiated, means including said contact tips and said contact element for initiating the operation of the selector switch as one of the contact tips engages the contact element in response to a signal current received from the search coil, means controlled by the selector switch when the switch has stepped ahead a predetermined number of contacts for momentarily passing a current through the moving coil system of a value sufficient to flex one of said spring members against said contact element sufficiently to store a predetermined amount of energy therein, said energy stored in said one of the spring members being sufficient to break the magnetic attraction between the contact element and the contact tip in engagement therewith to return the contact tips toward an initial disengaged position when the moving coil system is de-energized, a closed circuit including the moving coil system for damping movement thereof beyond said initial position, an electroresponsive detonator, and means including said contact tips and said contact element and certain other of the contact banks of said selector switch for firing said detonator to thereby explode the mine as one of the contact tips engage the contact element in response to a signal current received from the search coil during the remaining stepping movement of the selector switch beyond said predetermined number of contacts.

9. Mine firing apparatus according to claim 8 further characterized by the provision of means including an element responsive to sudden changes in the pressure of the surrounding water for momentarily passing said last mentioned current through the moving coil system when countermine shocks are received by the mine, thereby to restore the contact tips to said initial disengaged position in response to said shocks.

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