MAGNETIC MINE FIRING CONTROL MECHANISM

Filed April 6, 1942 5 Sheets-Sheet 1

FIG. 1.

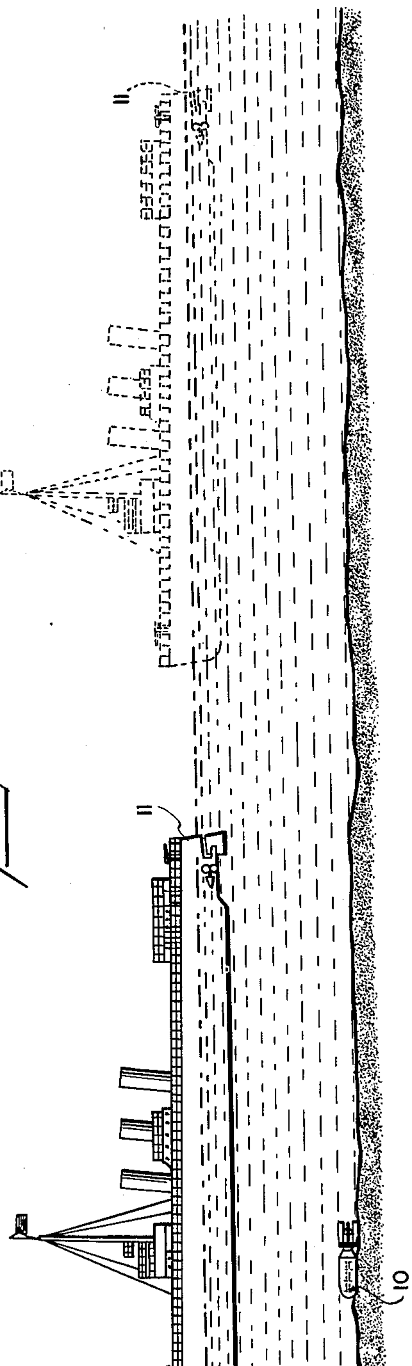
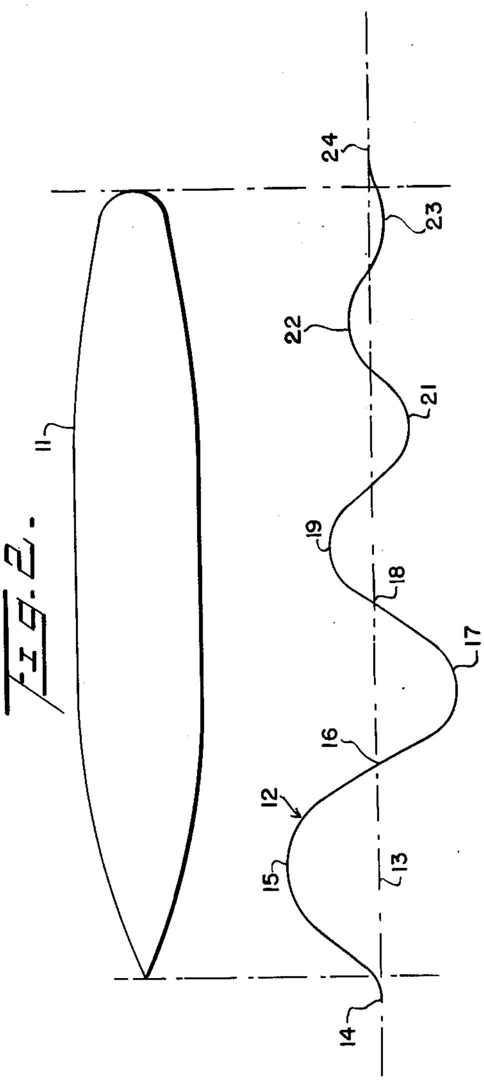


FIG. 2.



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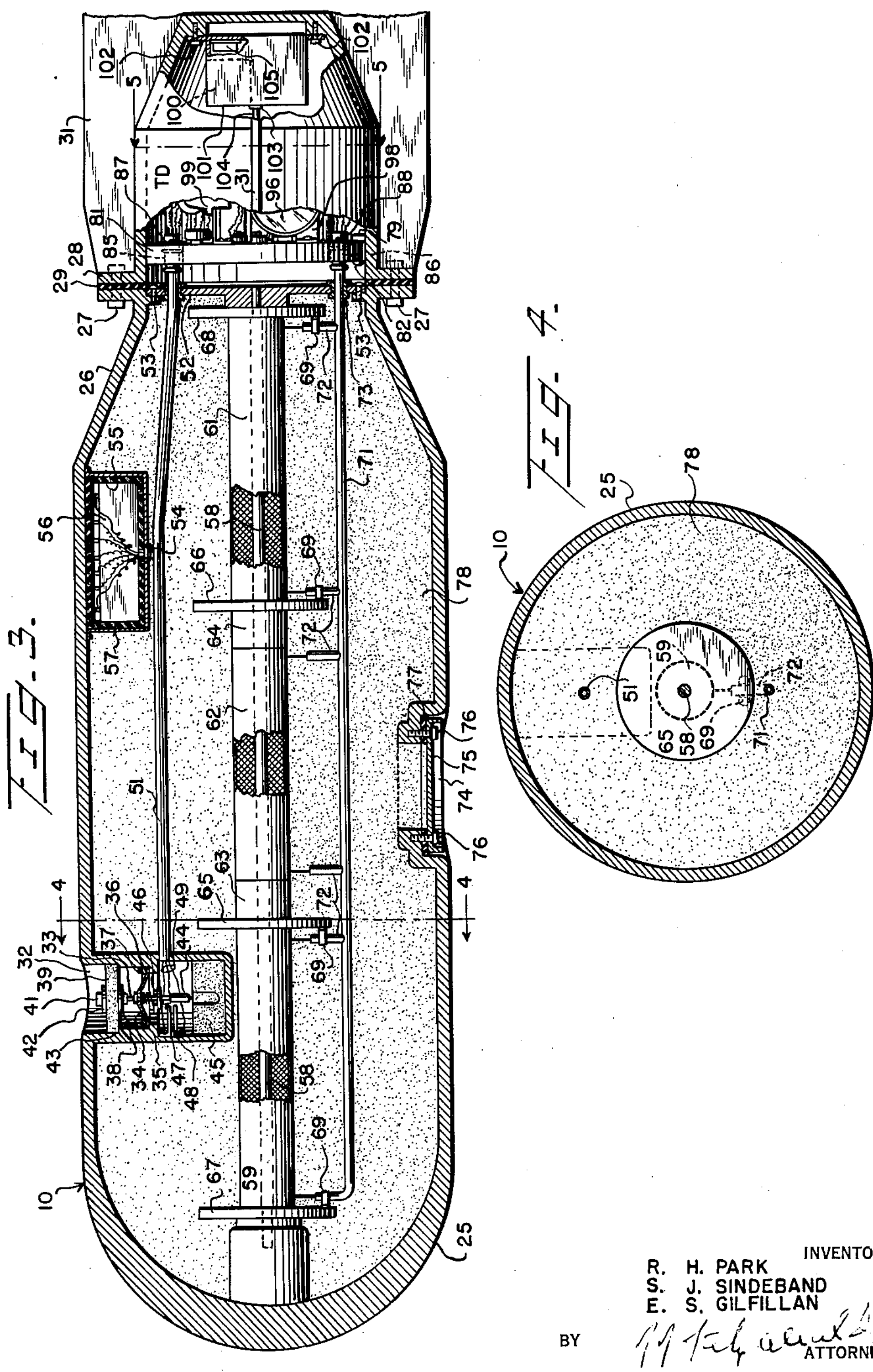

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FIG. 5.

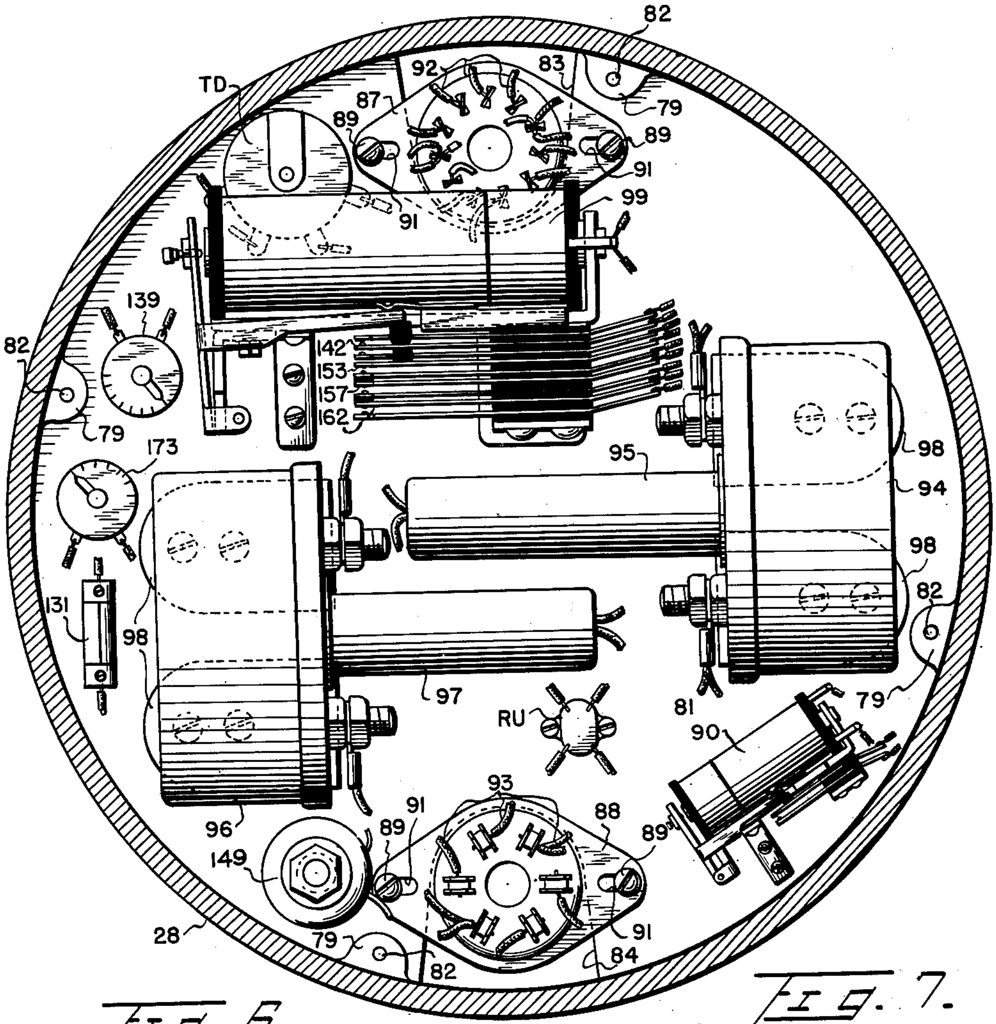


FIG. 6.

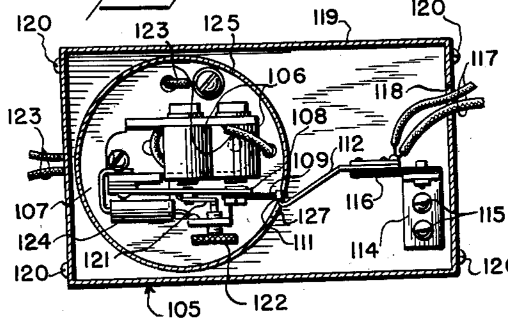
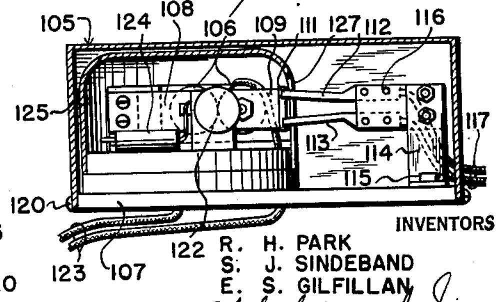


FIG. 7.



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MAGNETIC MINE FIRING CONTROL MECHANISM

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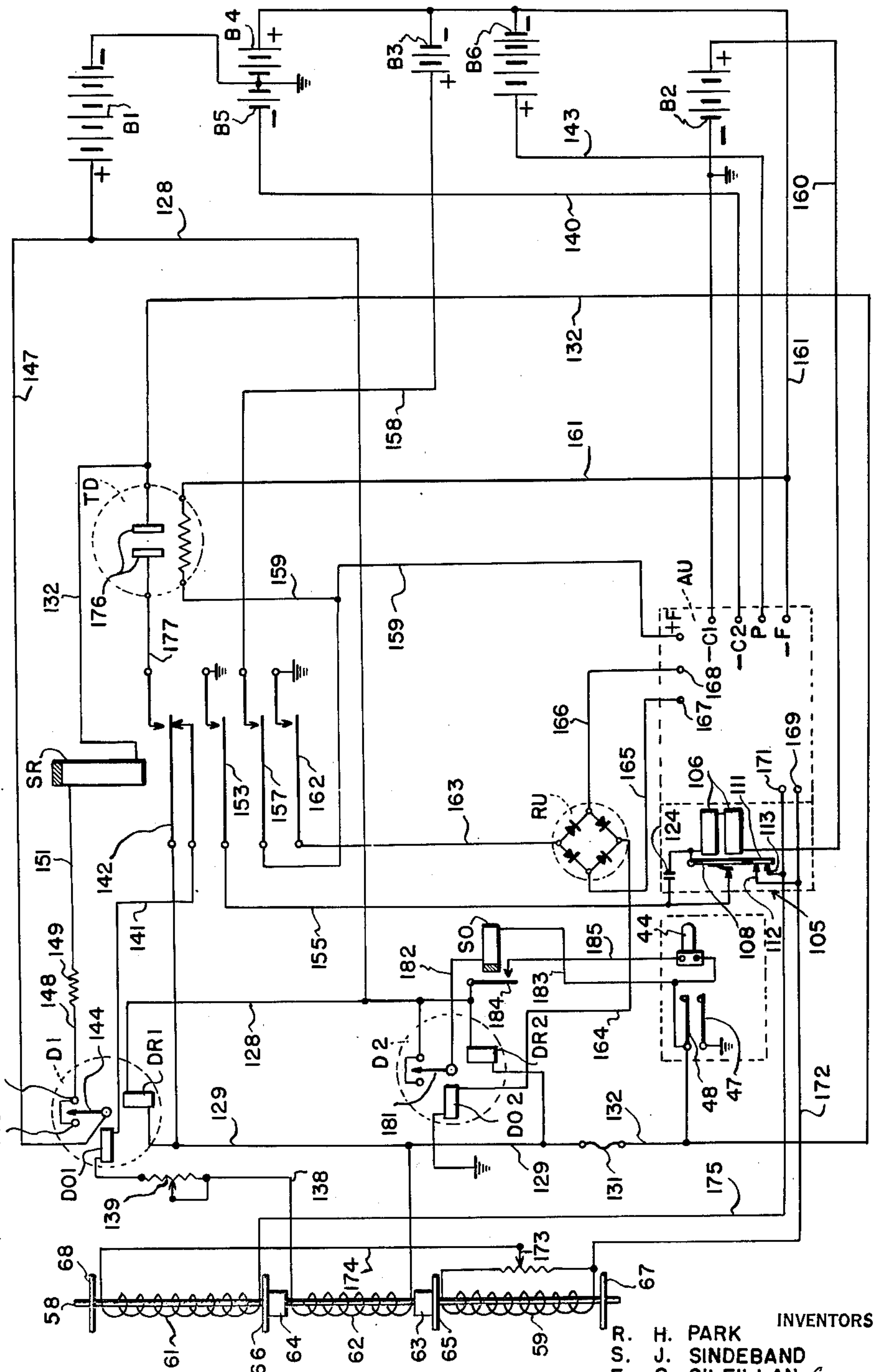
FIG. 4



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MAGNETIC MINE FIRING CONTROL MECHANISM

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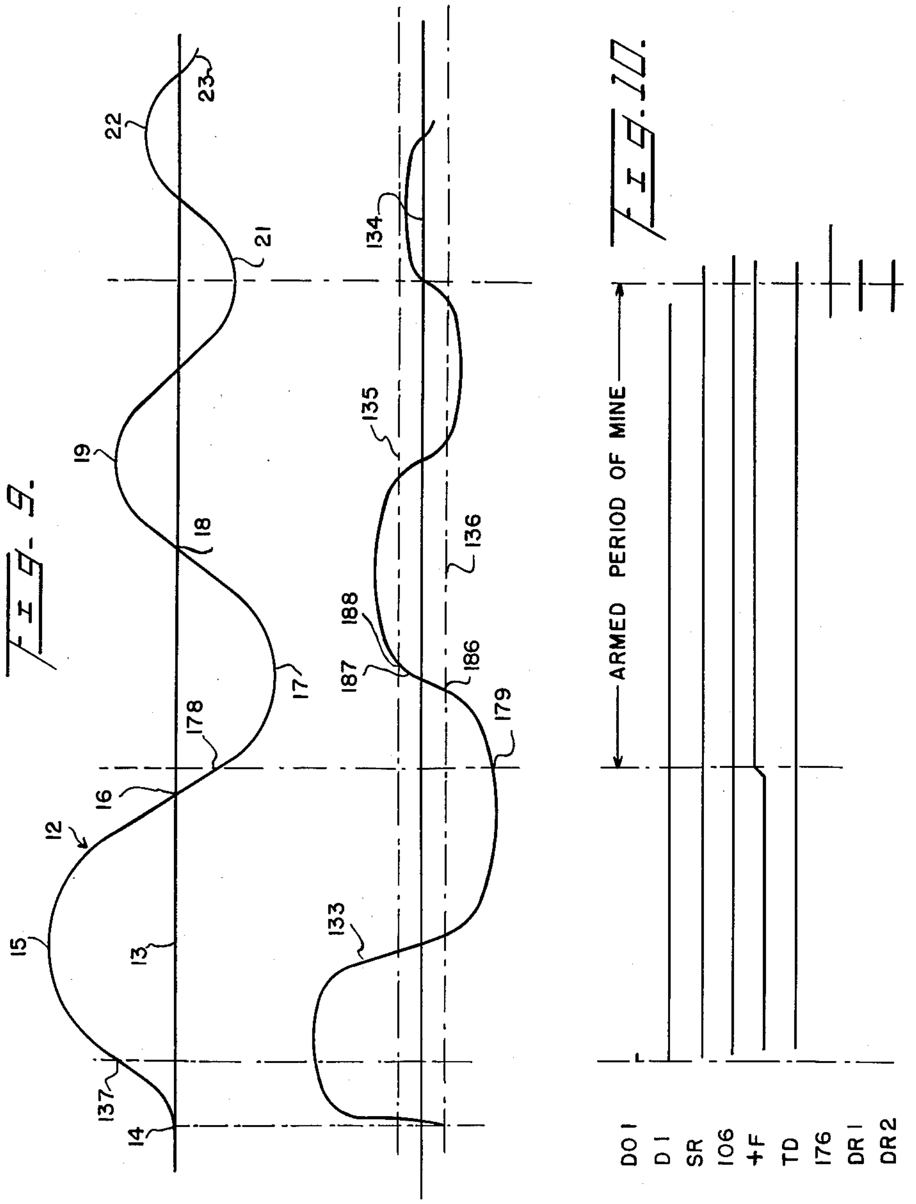

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MAGNETIC MINE FIRING CONTROL MECHANISM

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19 Claims. (Cl. 102—18)
(Granted under Title 35, U.S. Code (1952), sec. 266)

This invention relates to means for firing a submarine mine in which the mine is armed by a relatively slow change in the magnetic field adjacent thereto and fired by the rate of change of the magnetic field when the changing condition of the magnetic field has continued for a predetermined period of time. More specifically, the invention relates to a mine firing control mechanism in which the inductive effect of a changing magnetic field is employed to actuate certain relay switching devices thereby to energize a signal amplifying device and render effective a pair of opposedly connected induction coils arranged in predetermined spaced relation with respect to each other thereby to generate a signal in accordance with the rate of change of the gradient of the magnetic field, the signal being amplified by the signal amplifying device and caused to operate a firing relay thereby to energize an electro-responsive detonating device arranged within a primer charge and explode the mine.

In certain types of mine firing control mechanisms heretofore proposed in which the presence of a ship or other ponderous mass of iron moving within the vicinity of the mine is detected by a disturbance in the magnetic field adjacent the mine, it has been the usual practice to employ an inductive pickup coil or a combination of pickup coils adapted to generate a signal in accordance with changes in the number of flux linkages between the pickup coil, and the field signal thus generated is employed to initiate a cycle of operations and thus bring about the firing of the mine. Considerable difficulty has been experienced with these types of mines as the result of signals received from magnetic storms by reason of the changes in the magnetic field adjacent the mine produced by the storms. Furthermore, it has been found possible to cause the mines to explode prematurely by motion of the mine when in an armed condition such, for example, as may be produced by the action of tidal currents or by countermining operations.

In the system of the present invention the possibility of firing a mine as the result of magnetic storms or motion of the mine is greatly reduced by reason of the novel arrangement of circuits and instrumentalities provided for controlling the mine firing mechanism thereof, and in which all of the advantages of the present types of mines are retained and in which the disadvantages have been eliminated.

The mine firing control system of the present invention comprises an induction pickup coil operatively connected to a sensitive relay adapted to be operated by signals received from the induction coil in response to a predetermined change in the magnetic field adjacent thereto. The sensitive relay controls the operation of a switching relay adapted to initiate a cycle of operations of the mine firing control mechanism in which a time delay device is caused to close a circuit to a certain electroresponsive control device included within the aforesaid sensitive relay thereby to restore forcibly the sensitive relay to an initial unoperated condition. The switching relay also causes a signal amplifying device to be energized and thus be rendered effective to amplify signals received from the opposedly connected gradient coils after a predetermined period of time has elapsed sufficient to bring the filaments of the amplifying tubes to operating temperature, the signal circuit to the coils including the contacts of an interrupting device set in operation by the aforesaid switching relay.

As the sensitive detecting relay is restored to normal the circuit to the switching relay is interrupted thereby causing the switching relay to release and deenergize the signal amplifying device and the time delay device and cause the interrupter to come to rest in the event that the signal detected by the aforesaid opposedly connected gradient coils during the time that the signal amplifying device is energized, is insufficient to cause the firing relay to operate and explode the mine. On the other hand, when the changing field conditions adjacent the mine continue for a relatively long period of time such, for example, as is occasioned by the movement of a steel vessel or other preponderous mass of magnetic material within the vicinity of the mine, the signal generated by the gradiometer coils during the time that the amplifier is operatively energized is sufficient to operate the firing relay and cause the mine to explode.

One of the objects of the present invention is the provision of new and improved means for arming a mine in response to one of the characteristics of a changing magnetic field adjacent thereto and causing the mine to fire in response to another of the characteristics of the field.

Another of the objects is the provision of means for arming a submarine mine in response to a variation in the magnetic field adjacent thereto, and maintaining the mine in an armed condition for a predetermined period of time.

Another of the objects is to provide a mine firing mechanism in which the mine is armed by magnetic induction for a predetermined period of time in response to a change in the magnetic field adjacent thereto and fired selectively in accordance with the rate of change of the gradient of the magnetic field while the mine is in an armed condition.

Another object is to provide a mine firing control mechanism within a submarine mine in which the mine is armed by a change in the magnetic field adjacent thereto in response to the approach of a vessel within the vicinity of the mine and fired when the rate of change of the gradient of the magnetic field reaches a predetermined value.

Still another object is the provision of a new and improved mine firing mechanism adapted to be fired by a predetermined rate of change in the gradient of the magnetic field adjacent thereto in which a normally inactive signal amplifying device is energized for a predetermined period of time in response to electric currents induced in an inductive pickup device and in which the amplifying device is restored to an unenergized condition when the predetermined period of time has expired after the device is first energized in the event that the mine is in the meantime not exploded by a passing vessel.

Still other objects, advantages and improvements and other instrumentalities and arrangements will be apparent from the following description taken in connection with the accompanying drawings of which:

FIG. 1 shows in diagrammatic form a submarine mine in accordance with the present invention arranged within the path of travel of a vessel;

FIG. 2 shows in diagrammatic form variations in the magnetic field adjacent the mine corresponding respectively to various portions of a vessel passing over the mine;

FIG. 3 is a view in section partly broken away of the mine of FIG. 1;

FIG. 4 is a sectional view taken along the line 4—4 of FIG. 3;

FIG. 5 is a view taken along the line 5—5 of FIG. 3;

FIG. 6 is a plan view with the covers in section of the interrupting mechanism employed with the present invention;

FIG. 7 is a view in elevation with the covers in section of the interrupter of FIG. 6;

FIG. 8 illustrates in diagrammatic form the complete system;

FIG. 9 illustrates in diagrammatic form the gradient variations of the magnetic field of the vessel of FIG. 2; and,

FIG. 10 illustrates diagrammatically the operation of the system of FIG. 8.

Referring now to the drawings, and more particularly to FIG. 1 thereof there is shown thereon a submarine mine indicated generally by the numeral **10** arranged on the bed of a body of water within the path of travel of the vessel **11**, the vessel being indicated in dashed outline in a position in which the vessel is approaching the submarine mine, and in solid outline in a position substantially above the mine. The change in the magnetic field adjacent the mine caused by the passage of the vessel past the mine is indicated diagrammatically on FIG. 2 by the curve **12** thereof, the dashed line **13** being employed to indicate the magnetic field adjacent the mine when no vessel or other ponderous mass of magnetic material is brought into the vicinity of the mine. For example, when the vessel **11** has proceeded approximately one-half a ship length beyond the reference point **10**, the magnitude of the magnetic effect is represented by the point **19** on the curve **12**. The vessel **11**, it may be assumed, has preferably been subjected to a predetermined electromagnetic field thereby to neutralize somewhat the permanent and the induced magnetism of the vessel, this neutralization of the magnetism of the vessel being referred to herein as degaussing.

A degaussed vessel, however, possesses certain magnetic irregularities which are not entirely compensated for by the degaussing process. These irregularities, it will be understood, usually result from the unequal distribution of the magnetic material of the vessel, certain portions of the vessel being positively magnetic and other portions of the vessel being negatively magnetic with respect to the earth's magnetic field and the unequal distribution of the magnetic flux of the degaussing coils. As the vessel **11** approaches the mine the magnetic field adjacent the mine may be assumed to be increased positively beginning at a point **14** of the curve **12** somewhat in advance of the bow of the vessel. The magnetic field continues to increase until the point **15** of the curve **12** is reached at which time the magnetic field adjacent the mine begins to decrease and as the point **16** of the curve is reached the magnetic field is reduced to equality with the earth's magnetic field indicated by the dashed line **13**.

As the vessel continues its forward movement the strength of the magnetic field is progressively decreased until the point **17** of the curve is reached at which time the magnetic field begins to increase in value. As that portion of the vessel corresponding to the point **18** of the curve is opposite the point of reference, the magnetic field has increased to the original value of the earth's magnetic field. The continued movement of the vessel causes the magnetic field indicated by that portion **19** of the curve **12** to be positive in character and as the point **21** of the curve is reached the magnetic field is negative in character, the terms positive and negative as employed herein being defined as variations in the strength of the magnetic field in excess of or less than the terrestrial magnetic field respectively when uninfluenced by a ponderous mass of magnetic material. In a similar manner the magnetic field alternates between positive and negative as the portions **22** and **23** of the curve **12** are brought opposite the point of reference, the magnetic field being brought to equality with the earth's magnetic field at the point **24** of the curve. The magnetic signature represented by the curve **12**, it will be noted, comprises three portions **15**, **19** and **22** of positive polarity respectively followed by three portions **17**, **21** and **23** of negative polarity but it will be understood that this has been shown by way of illustration only and various other curvatures corresponding to different magnetic signatures may be employed to detonate the mine **10**, the specific contour of the curve depending upon the physical arrangement of the vessel and method of degaussing the same. It will also be noted that the mine **10** is adapted to be exploded by and destroy an undegaussed vessel in which all of the different portions of the vessel possess the same magnetic polarity.

The mine **10** is shown in somewhat enlarged form on FIG. 3 of the drawings, the mine comprising a casing **25** preferably provided with a tapered portion **26** to which is secured as by the bolts **27** a cap or housing **28**, a suitable gasket **29** being arranged preferably between the casing and the cap to effect a watertight joint therebetween. There is also provided a plurality of fins **31** secured in any suitable manner to the cap portion **28** whereby the mine is adapted to be launched from an aircraft in flight or from a vessel, as the case may be, the fins serving to guide the mine along a predetermined flight route until the mine comes to rest on the bed of the body of water.

The casing **25** is provided with a recessed portion or well **32** within which is arranged a hydrostat comprising a slidably supported plunger rod or shaft **33** having affixed thereto in any suitable manner a flexible diaphragm **34** sealed to a shoulder **35** within the well as by the clamping ring **36** and bolts **37**. The shaft or plunger **33** is provided with a shoulder or collar **38** to which is secured a soluble washer **39** as by the nut **41** and washer **42**. The soluble washer is prevented from movement by a shoulder **43** arranged within the well **32**. The shaft **33** is provided with suitable means for securing a detonating device **44** at the lower end thereof adapted to be inserted within a suitable recessed portion of an explosive priming charge **45** arranged within the lower portion of the recessed portion **32** of the mine casing. There is also secured to the plunger rod **33** a shoulder or collar **46** adapted to move the contact **47** into engagement with the contact **48** as the hydrostat operates. There is also provided a plurality of electrical conductors **49** arranged within the cable duct or tube **51** extending between the recessed portion **32** of the casing and a wall or partition **52** secured to the casing as by the bolts **53** whereby an electrical connection is established between the hydrostat device and the firing control mechanism within the cap **28**. The tube **51** has a branch **54** extending therefrom into the chamber **55** within which is arranged a battery **56** suitably insulated therefrom as by the pad or cushion **57** of suitable resilient material such, for example, as sponge rubber whereby the battery is protected from injury or damage during the assembly, transportation and planting of the mine.

There is also provided within the casing of the mine a rod **58** of magnetic material such, for example, as iron or a material known in the art as permalloy having a composition of substantially 87½ percent nickel, 8½ percent iron and 4 percent molybdenum about which is arranged a pair of opposedly connected gradiometer coils **59** and **61** and an induction pickup coil **62** intermediate the gradiometer coils. A spacing member **63** is employed preferably between the coils **59** and **62** and a similar spacing member **64** between the coils **61** and **62**, the spacing members **63** and **64** being of nonmagnetic material in abutting relation with the spoolheads **65** and **66**. There is also provided a pair of spoolheads **67** and **68** secured in any suitable manner to the rod **58**, each of the spoolheads **65**, **66**, **67** and **68** having means such as the clamps **69** illustrated for supporting a tube or duct **71** having branches as at **72** within which are disposed a plurality of conductors for establishing an electrical connection to the coils **59**, **61** and **62**. The other end of the tube **71** is secured to the partition **52** as by the bushing **73**.

The casing **25** is also provided with a recessed portion **74** having an aperture therein adapted to be closed by the cap **75**, a plurality of screws **76** and a gasket **77** being provided for this purpose thereby effecting an arrangement in which an explosive charge **78** is introduced within the casing of the mine. The cap **28** is provided with a plurality of tabs or bosses **79** to which is secured a base **81** as by the screws **82**, the base having cut away portions **83** and **84**, FIG. 5, adapted to receive the plugs **85** and **86** secured to the ends of the tubes **51** and **71** respectively. The base is provided with a pair of jack connectors **87** and **88** secured thereto as by the screws **89**, each of the jack connectors being provided with a slotted portion **91** whereby the jack connectors may be adjustably secured to the base **81** in operative relation with respect to the plugs **85** and **86** when the base is in the assembled position shown on FIG. 3. The jack connectors **87** and **88** are provided with a plurality of electrical conductors **92** and **93** extending therefrom to the various electrical elements of the firing control unit. The firing mechanism comprises, among other elements, a sensitive relay **94** hereinafter referred to as D1 having a reset mechanism **95**, hereinafter referred to as DR1, adapted to reset the relay to a neutral or initial position with the contact element thereof substantially midway between two electrical contacts. There is also provided a sensitive relay **96**, hereinafter referred to as D2, having a resetting mechanism **97** generally similar to the resetting mechanism of relay **94**. Each of the relays **94** and **96** are secured to the base **81** in any suitable manner as by the brackets **98**.

Various other electro-responsive and circuit controlling devices are secured to the base **81** in the manner illustrated, the devices including a slow operating relay **90** and a relay **99** having a plurality of electrical contacts adapted to make and break a plurality of electrical circuits in predetermined sequential order thereby to effect certain switching operations for controlling an interrupter device and causing a vacuum tube amplifying unit **100**, FIG. 3, to be effective for a predetermined period of time in response to the operation of the relay, the relays **90** and **99** being hereinafter referred to as SO and SR respectively. The switching relay **99** also controls the operation of a time delay device TD for restoring the mine firing control mechanism including the amplifying unit to an initial condition in the event that the mine is not fired during the predetermined period of time after the mine is armed. The vacuum tube amplifier **100** may conveniently be mounted within the casing **101** affixed to the cap **28** as by the bolts **102**, the casing being provided with a suitable bushing **103** within which is disposed a cable **104** having a plurality of electrical conductors therein for establishing an external electrical circuit to the amplifier and to a self-interrupting device **105** mounted within the casing **101**.

The interrupter **105** comprises preferably a pair of electromagnets **106** secured to a base **107** and provided with an armature **108** to which is secured as by the insulating strip **109** a contact piece **111** adapted to establish an electrical connection between the contact springs **112** and **113** when the armature is in a released position. The contact springs are supported by a bracket **114** secured to the base in any suitable manner as by the screws **115**, the contact springs being insulated from each other and from the bracket as by the insulating strip **116** which may be composed of any material suitable for the purpose such, for example, as hard rubber, bakelite or the like. The contact springs **112** and **113** are adapted to be connected externally as by the conductors **117** arranged within an aperture **118** within the cover **119** affixed to the base **107** as by the screws **120**.

The armature **108** is provided with a contact **121** adapted to be maintained in engagement with the contact screw **122** when the interrupter is in a state of rest, the contacts

121 and **122** being arranged in series with the electromagnets **106** whereby the interrupter is adapted to be self-interrupting when a source of electrical power is applied to the conductors **123** connected thereto. A condenser **124** is preferably connected across the contacts **121** and **122** to prevent deterioration of the contacts. The interrupter may, if desired, be provided with a cover **125** affixed to the base **107** and having an aperture **127** therein within which is disposed the contact springs **112** and **113**. The base **107** is provided with suitable apertures within which are arranged the conductors **123**.

The operation of the system will best be understood by reference to FIG. 8 in which the entire system is shown in diagrammatic form. Let it be assumed, by way of example, that the mine has been launched within a body of water adjacent the path of travel of a vessel for a period of time sufficient to cause the soluble washer **39** to dissolve sufficiently to permit the plunger rod **33** of the hydrostat to be moved to the operated position by the pressure of the surrounding water against the flexible diaphragm **34**. When this occurs, the contact **47** is moved into engagement with contact **48** thereby closing a circuit from battery B1 by way of conductor **128**, windings of the reset magnets DR1 and DR2 in parallel, conductor **129**, fuse **131**, conductor **132**, contacts **48** and **47** and thence to ground thereby causing the reset magnets DR1 and DR2 to operate and adjust the tongues of the relays D1 and D2 to an initial or neutral position intermediate the relay contacts. The fuse element **131** is of sufficient small size as to cause the fuse to blow and interrupt the circuit to the reset magnets thereby releasing the tongues of the sensitive relays D1 and D2 for operation. The fuse **131** is of the slow acting type and does not blow until sufficient time has elapsed for the relays D1 and D2 to be set to their neutral or initial positions. The mine is now in readiness to detect the approach of a vessel or other ponderous mass of iron within the vicinity of the mine.

The variation in the magnetic field adjacent the mine caused by the approach of a vessel such, for example, as the vessel of FIG. 1 having a magnetic signature generally in accordance with the curve **12** of FIGS. 2 and 9 in which the magnetic field adjacent the mine is caused to undergo a series of changes or variations of the field in which the changes are gradually decreasing in character after the first change has been received as the vessel continues to travel across a point of reference. The gradient of the magnetic signature of FIG. 9 is shown in diagrammatic form by the curve **133** in which the gradient changes are represented by the degree of departure of the curve **133** from a reference line indicated generally by the numeral **134**, the curve **133** being arranged below the curve **12** and in timed relation thereto such that the gradient of the magnetic field of the curve **12** is shown by corresponding portions of the curve **133**. The gradient of the magnetic field, as is well known, is proportional to the rate of change of the magnetic field measured at different points of reference such, for example, as the points of reference embraced by the gradiometer coils **59** and **61** of the mine. The curve **133**, it will be understood, is shown for the purpose of description, the peaks thereof corresponding generally to the portions of the curve **12** in which the slope or tangent of the angle of the curve **12** with a horizontal reference line is a at a maximum. In a similar manner when the tangent of the curve **12** is at zero such, for example, as at the peaks of the curve **12**, the curve **133** crosses the reference line **134**. It will also be noted that the strength of the induced signal corresponding to the gradient of the magnetic field illustrated by the curve **133** decreases somewhat as the vessel continues its movement past the point of reference, this decrease in the strength of the gradient of the magnetic field being brought about by the decrease in the slope of the corresponding portions of the curve **12**. There is also shown on FIG. 9 the threshold of sensitivity or minimum response of the relay D1 to the gradient signal received by the coils **59** and **61**, this being indicated generally by the dashed lines **135** and **136**.

The system of FIG. 8 comprises, among other elements, a sensitive detecting relay D1 having an operating winding adapted to respond to a change in the magnetic field adjacent the mine picked up by the induction coil **62** and thereby cause the relay to operate. It may be assumed, for the purpose of description, that the operation of the relay D1 occurs at the point **137** of the curve **12**, FIG. 9, in response to a signal received over the following circuit: one terminal of the induction pickup coil **62**, conductor **138**, variable resistance **139**, operate magnet DO1 of relay D1, conductor **141**, break contact and armature **142** of relay SR, conductor **129** and thence to the other terminal of the induction coil **62**. The variable resistance **139** is employed to vary the degree of sensitivity of response of the relay D1 to the signals received from the induction pickup coil **62** whereby the mine may be made responsive to changes of different degrees in the magnetic field in accordance with the setting of the variable resistance element **139**.

As armature **144** of relay D1 moves into engagement with contact **145** or **146**, as the case may be, a circuit is closed from the positive terminal of battery B1 by way of conductor **147**, armature **144** and make contact of relay D1, conductor **148**, resistance **149**, conductor **151**, winding of relay SR, conductor **132**, contact springs **48** and **47** and thence to ground thereby causing relay SR to operate. As armature **142** of relay SR moves away from its break contact the circuit to the operate magnet DO1 of relay D1 is interrupted but relay D1 does not release at this time for the reason that the tongue **144** thereof is maintained in engagement with the operated contact by reason of the provision of a small permanent magnet arranged within the relay adjacent each of the contact elements thereof and adapted to attract either the tongue of the relay or a small piece of magnetic material secured thereto and yieldably maintain the relay in either of its operated positions until the relay is forcibly restored by the operation of the reset magnet DR thereof.

As armature **153** of the relay SR moves into engagement with its make contact, a circuit is closed from positive terminal of battery B2 by way of conductor **160**, electromagnets **106** of the interrupter **105**, armature **108** and a break contact thereof, conductor **155**, armature **153** and make contact of relay SR from whence the circuit is continued to ground thereby energizing the electromagnets **106** and setting the interrupter in operation. As heretofore stated, the interrupter device is of the self-interrupting type in which the armature **108** thereof continues to vibrate for as long a time as the armature **153** of relay SR remains in engagement with the make contact thereof. As armature **157** of relay SR moves into engagement with the make contact thereof a circuit is closed from positive terminal of battery B3 by way of conductor **158**, make contact and armature **157** of relay SR, conductor **159** to terminal +F of the vacuum tube amplifier unit AU thereby applying battery potential to the filaments of the vacuum tubes within the amplifier, the circuit being continued by way of the terminal —F of the amplifier unit, conductor **161** and thence to the negative terminal of battery B3 thereby causing the filaments of the vacuum tubes to become heated sufficiently to activate the tubes and set the amplifier in operation. As armature **162** of relay SR moves into engagement with the make contact thereof ground is applied to conductor **163** extending to the rectifying unit RU, the circuit continuing by way of conductor **164** and operate winding DO2 of relay D2 to ground. The rectifying unit RU, it will be noted, is connected by the conductors **165** and **166** to the output terminals **167** and **168** respectively of the amplifier unit. The iuput terminals **169** and **171** are normally short-circuited by the contact springs **112** and **113** of the interrupter **105** and connected to the gradiometer coils over the following circuit: terminal **169**, conductor **172**, winding of gradiometer coil **59** in parallel with the adjustable resistor **173**, conductor **174**, winding of the gradiometer coil **61**, conductor **175**, and thence to the terminal **171**. The operation of the interrupter **105** at the contact springs **112** and **113** thereof periodically short-circuits the input signal received from the gradiometer coils **59** and **61** thereby modulating the input signal and increasing the sensitivity of the device to gradient signals.

The pickup power of the gradiometer coil **59** is preferably somewhat greater than the pickup power of the gradiometer coil **61** and the variable resistor **173** connected across the coil **59** is employed, as will be readily understood, to adjust the signal of the pickup coil **59** to equality with the pickup signal of the coil **61** whereby the coils **59** and **61** are opposedly connected and balanced sufficiently to prevent the generation of a signal at the input terminals **169** and **171** of the amplifying unit of sufficient strength to fire the mine as the result of movement or disturbance of the mine from the rest position thereof. As armature **157** of relay SR moves into engagement with the make contact thereof a circuit is closed from the positive terminal of battery B3 by way of conductor **158**, contact and armature **157** of relay SR, conductor **159** electroresponsive element of the time delay device TD from whence the circuit is continued by way of conductor **161** to the negative terminal of battery B3. The time delay device TD may be of any suitable type in which the contacts **176** thereof are moved into engagement with each other when a predetermined period of time has elapsed after the energizing circuit to the time delay device has been operatively connected to a source of electrical power such, for example, as a thermostatically controlled relay in which the contacts are adapted to close when the actuating element thereof has been heated to a predetermined degree of temperature or a device in which the closure of the contacts **176** is delayed by reason of the provision of a dash pot or a clock escapement mechanism or the like.

In the event that the signal received from the gradiometer coils **59** and **61** is insufficient to cause the amplified signal to operate the firing relay D2 during the time that the audio amplifier is in an energized condition, the contacts **176** of the time delay relay TD are brought into engagement with each other after a predetermined time delay thereby closing a circuit from positive terminal of battery B1, by way of conductor **128**, windings of the reset magnets DR1 and DR2 of relays D1 and D2 respectively, conductor **129**, armature **142** and make contact of relay SR, conductor **177**, contacts **176** of the time delay device, conductor **132**, contact springs **48** and **47** of the hydrostat device from whence the circuit continues to the grounded negative terminal of battery B1 thereby causing the reset magnets DR1 and DR2 to operate and forcibly restore the tongue **144** of relay D1 to the initial unoperated position thereof and, at the same time, the operation of the reset magnet DR2 insures that the tongue of relay D2 is in the unoperated position midway between the contacts of the relay. As armature **144** moves away from engagement with the make contact thereof the operate circuit to relay SR is interrupted and relay SR releases. The relay SR, it will be noted, is a slow releasing relay by reason of the provision of a copper slug arranged about the core of the electromagnet or other suitable release delaying device whereby the release of the relay is delayed for a predetermined period of time after the operate circuit thereto is interrupted.

The armatures of relay SR are preferably adjusted to engage their respective contacts in a predetermined order, armature **142** engaging the make contact thereof before armature **153** engages its make contact, followed by the engagement of the contact of armatures **157** and **162** in the order stated. As armature **157** moves away from the make contact thereof battery is removed from conductor

159 thereby removing battery from the filaments of the amplifying tubes and the electro-responsive element of relay TD thereby causing the time delay relay to release and contacts 176 thereof to be disengaged from each other. As armature 153 moves away from its make contact ground is removed from the interrupter 105 thereby bringing the interrupter to rest and as armature 142 moves away from its make contact the operate circuit to the reset magnets DR1 and DR2 is interrupted thereby causing the reset magnets to release and remove the restraint from the tongues of relays D1 and D2. As armature 142 of relay SR engages its break contact the operate magnet DO1 of relay D1 is again brought under the control of the induction pickup coil 62. The mine is now restored to its original waiting condition in readiness to detect the approach of a vessel within the vicinity of the mine.

From the foregoing description it will be noted that the mine was armed in response to a change in the magnetic field adjacent thereto detected by the induction pickup coil 62, the arming cycle being complete when the temperature of the amplifying tubes within the amplifying unit AU had reached an operating degree of heat, the time delay mechanism TD having been set in operation in the meantime to disarm the mine after the mine had been armed for a predetermined period of time. During the armed period of the mine the gradient pickup coils 59 and 61 were short-circuited periodically by the contact springs 112 and 113 of the interrupter 105 at a predetermined frequency in accordance with the frequency of operation of the interrupting device thereby more effectively to utilize the gradient signal of the coils 59 and 61 for controlling the operation of the firing relay D2 by the amplified gradient signal received from the amplifier unit. An arrangement is thus provided in which the firing mechanism is controlled by a small gradient in the magnetic field adjacent the mine and the sensitivity and susceptibility of the mine firing control mechanism to gradient signals caused by a moving vessel within the vicinity of the mine is employed with a high degree of efficiency for controlling the firing of the mine.

It will also be noted that a delay is experienced between the first detection of the approach of a vessel by the pickup coil 62 and the arming of the mine, this delay being occasioned, for the most part, by the time required to bring the filaments of the tubes of the amplifying unit up to their operating temperatures and thus the firing of the mine is delayed until the vessel is substantially above the mine or in such a position that a vulnerable portion of the vessel is opposite the mine at the time the mine explodes.

Whereas in the foregoing description a vacuum tube amplifying unit is employed to operate the firing relay D2 selectively in accordance with the signals received from the gradiometer coils 59 and 61, it will be understood that the vacuum tubes employed with the amplifier may be arranged within the amplifier unit in any suitable manner as the particular arrangement of the circuits within the amplifier unit forms no part of the present invention. Furthermore, if desired, the grids of the amplifying tubes may be connected to terminals —C1 and —C2 in any suitable arrangement, the potential of the terminal —C2 being controlled by the potential of the conductor 140 connected thereto and to the negative terminal of battery B5. The plate supply current is supplied preferably by a battery B6 by way of conductor 143 connected to terminal P of the amplifier unit and a battery B4 may, if desired, be employed in the common ground circuit of batteries B3 and B6.

Referring now to FIG. 9, it will be noted that the approach of the vessel is detected by the pickup coil 62 at the point 137 of the curve 12, the mine being in an armed condition at the point 178 of the curve 12 and that the strength of the gradient signal shown by the curve 133 at the point 179 thereof is in excess of the strength of the signal required to fire the mine as indicated by the dashed lines 135 and 136. The output signal from terminals 167 and 168 of the amplifier unit AU at this time is, therefore, of sufficient strength to cause relay D2 to operate. As armature 181 of relay D2 moves into engagement with its make contact, a circuit is closed from the positive terminal of battery B1, conductor 128, make contact and armature 181 of relay D2, conductor 182, winding of relay SO, conductor 183, contact springs 48 and 47 and thence to ground thereby causing the relay SO to operate. As armature 184 of relay SO moves into engagement with its make contact, a circuit is closed from positive terminal of battery B1, conductor 128, armature 184 and make contact of relay SO, conductor 185, detonator 44, conductor 183, contact springs 48 and 47 and thence to ground thereby causing the detonator to operate and explode the mine.

As heretofore stated, relay SO is slow to operate and for this reason does not close its contacts until the operate magnet thereof has been energized for a predetermined period of time thereby providing an arrangement in which the detonator 44 is prevented from being prematurely operated as the result of a momentary closure of the contacts of relay D2. Furthermore, by providing a slow operating relay intermediate the firing relay and the detonator, the possibility of the premature explosion of the mine by the operation of the detonator at the time the soluble washer has dissolved sufficiently to permit contacts 48 and 47 to be moved into engagement with each other is prevented for the reason that when ground is first applied to conductor 132 by the contact springs 47 and 48 the reset magnet DR2 operate quickly and interrupts the operate circuit to relay SO and releases relay SO before the armature 184 thereof moves into engagement with its make contact.

In the event that the magnetic signature of the ship should be of such a character that the mine became armed during the time that the gradient signal received from the vessel was less than that required to fire the mine such, for example, as that portion of the curve 133 extending between the points 186 and 187 thereof it will, of course, be understood that the firing of the mine will occur when the strength of the gradient signal has increased to the value represented by the dashed line 135 or 136, as the case may be, such a firing point on the curve 133 being indicated, by way of illustration, at 188 thereof. The armed period of the mine controlled by the time delay device TD is sufficiently long to insure that the mine will not receive a gradient signal of sufficient intensity to fire the mine in the event that the mine should, for any reason, fail to fire during the armed period thereof and should be subsequently rearmed by the attenuated magnetic signal received from the vessel as the stern of the vessel passes above the mine. By employing the gradient of the magnetic field to control the firing mechanism, the mine is prevented from firing by the attenuated signal referred to above by reason of insufficient strength of the gradient signal received and thus the mine is prevented from exploding except under a vulnerable portion of the vessel.

Furthermore, by providing an amplifier in which the vacuum tubes thereof are normally deenergized, the life of the batteries is greatly prolonged as no current is drawn from the batteries except for a relatively brief period of time after a change in the magnetic field has been detected by the induction pickup coil 62. Also, by arranging the mine firing system in the manner of FIG. 8, the mine is adapted to be armed by one property of the field of a vessel detected by the induction pickup coil 62 and fired by another property of the field of the vessel only after a predetermined period of time has elapsed after the field has been detected, the predetermined period of time corresponding generally to the time required to heat the filaments of the vacuum tubes to their operating temperatures and thus an arrangement is provided in which the mine is difficult to sweep by an electromagnetic field set up impulsively by a sweep wire.

Briefly stated in summary, the system of the present invention provides an arrangement of instrumentalities and circuits therefor in which a submarine mine is armed, after a predetermined time delay, in response to a change in the magnetic field adjacent the mine and is adapted to be fired by the gradient of the magnetic field when the mine is in an armed condition, whereas in the event that the mine is not fired after being armed, the mine is automatically restored to an initial condition after a predetermined period of time has elapsed.

While the invention has been described with particularity as to one preferred embodiment of a combination of mechanisms and of each of the elements of the combination, it is to be understood that this has been done for purposes of disclosure and that various changes and substitutions may be readily apparent to those skilled in the art to which the invention pertains, after understanding the invention herein disclosed, and that the terms employed in the appended claims are to be considered as words of description rather than words of limitation.

The invention herein disclosed and claimed 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. In a submarine mine of the character disclosed adapted to be laid on the bed of a body of water within the path of travel of a vessel, a pickup coil adapted to detect a change in the magnetic field adjacent the mine, a sensitive relay operatively connected to said pickup coil and controlled thereby, a switching relay adapted to be controlled by said sensitive relay and having a plurality of circuit closing elements thereon, a normally inactive signal amplifying device operatively connected to certain of said circuit closing elements and adapted to be rendered effective as said switching relay operates, a pair of opposedly connected gradiometer coils in electrical connection with said signal amplifying device adapted to generate a signal in accordance with the rate of change of the gradient of said magnetic field, a firing relay operatively connected to the output of said signal amplifying device and adapted to be operated when the gradient signal received from the gradiometer coils reaches a predetermined value, an explosive charge, and means including a detonating device controlled by said firing relay for causing the mine to be exploded by said explosive charge when said gradient signal has reached a predetermined value.

2. In a submarine mine of the character disclosed arranged on the bed of a body of water within the path of travel of a vessel, the combination of a mine firing mechanism including an induction pickup coil operatively connected thereto and responsive to a change in the magnetic field adjacent the mine, means responsive to a signal received from said pickup coil for arming the mine in delayed time relation to said signal, and means including a pair of opposedly connected coils responsive to the rate of change of the gradient of the magnetic field adjacent the mine for firing the armed mine when the gradient signals have reached a predetermined value.

3. In a system of the character disclosed for selectively firing a submarine mine in accordance with the rate of change of the gradient of the magnetic field adjacent thereto, a control circuit, means responsive to a variation in said magnetic field for energizing said control circuit, electro-responsive means operatively connected to said control circuit and adapted to be operated by said energizing means, a normally inactive vacuum tube amplifying unit, means controlled by said electro-responsive means for energizing said amplifying unit, a pair of opposedly connected coils operatively connected to the input of said amplifying unit and adapted to generate signals in accordance with the rate of change of the gradient of said magnetic field, a firing relay connected to the output of said amplifier unit and adapted to be operated selectively in accordance with the strength of signals received from said opposedly connected coils, and means including a detonating device controlled by said firing relay for causing the mine to be fired when the strength of signals received from said opposedly connected coils reaches a predetermined value.

4. In a submarine mine of the character disclosed arranged within a magnetic field, in combination, a sensitive relay, a switching relay operatively connected to said sensitive relay and adapted to be controlled thereby, an induction pickup coil in circuit with said sensitive relay adapted to operate the sensitive relay in response to changes in said magnetic field, means controlled by said switching relay for interrupting said circuit as the switching relay operates, a normally inactive signal amplifying device, means controlled by said switching relay for energizing said signal amplifying device, a pair of opposedly connected coils adapted to generate the signals in accordance with the rate of change of said magnetic field, means including a plurality of circuit connections for operatively connecting said opposedly connected coils to the input of said signal amplifying device, a firing circuit having a detonating device therein, electro-responsive means controlled by said signal amplifying device for closing said firing circuit selectively in accordance with the strength of signals received from said opposedly connected coils while the signal amplifying unit is energized, and means including a time delay device controlled by said switching relay for rendering said signal amplifying device ineffective when a predetermined period of time has elapsed after said switching relay is operated and the firing circuit has not been closed by said electro-responsive means.

5. In a system of the character disclosed for controlling the firing of a submarine mine selectively in accordance with the rate of change of the gradient of the magnetic field adjacent thereto, a pickup coil having a sensitive relay connected thereto adapted to detect a change in said magnetic field, a switching relay controlled by said sensitive relay, a normally inactive vacuum tube amplifying unit having a firing relay connected to the output thereof adapted to be operated selectively in accordance with the strength of signals received from the amplifying unit, means controlled by said switching relay for energizing said amplifying unit for a predetermined period of time, a pair of opposedly connected coils adapted to generate signals in accordance with the rate of change in the gradient of said magnetic field, means for connecting said opposedly connected coils to the input of said amplifying unit, a circuit interrupting device controlled by said switching relay and adapted to modulate the signal received from said opposedly connected coils while the amplifying unit is energized by said energizing means, and means effective when the amplifying unit has been energized for said predetermined period of time for restoring the mine to an initial detecting condition.

6. In a submarine mine of the character disclosed arranged within a magnetic field on the bed of a body of water adjacent the path of travel of a vessel, a pickup coil adapted to respond to a change in said magnetic field and having a sensitive relay connected thereto, a switching relay connected to said sensitive relay and adapted to be operated thereby, a pair of opposedly connected coils adapted to generate a signal in accordance with the rate of change of the gradient of the magnetic field adjacent the mine, means controlled by said switching relay for modulating said signal, normally ineffective signal amplifying means having the input thereof connected to said opposedly connected coils, means controlled by said switching relay for rendering said signal amplifying means effective during a predetermined period of time after the switching relay operates, means connected to the output of said signal amplifying means

for rectifying the output signal thereof, a firing relay connected to said signal rectifying means and adapted to be operated selectively in accordance with the strength of signals generated by said opposedly connected coils while the signal amplifying means is effective, an electro-responsive time delay device controlled by said firing relay and having means for closing a firing circuit as the electro-responsive device operates, and a detonating device adapted to explode the mine when said firing circuit is closed by said electro-responsive device.

7. In a mine firing control mechanism, the combination of a normally inactive signal amplifying unit, means controlled by a change in the magnetic field adjacent the mechanism for rendering said signal amplifying unit effective, means including a pair of opposedly connected pickup coils for applying a modulated input signal to said amplifying unit corresponding to the rate of change of said magnetic field, means connected to the output of said signal amplifying unit for demodulating the amplified signal, and means including a firing relay operatively connected to said demodulating means for causing the mine to explode selectively in accordance with the strength of the demodulated signal.

8. In a submarine mine of the character disclosed arranged within a magnetic field adjacent the path of travel of a vessel, the combination of a firing mechanism having means responsive to a change in said magnetic field for detecting the approach of the vessel within the vicinity of the mine, means for arming the mine when a predetermined period of time has elapsed after the approach of the vessel has been detected by said detecting means, and means including a pair of opposedly connected pickup coils responsive to the rate of change of the gradient of the magnetic field caused by the movement of said vessel within the vicinity of the mine for causing the mine to be fired when the rate of change of the gradient of the magnetic field has reached a predetermined value.

9. In a system of the character disclosed for firing a submarine mine, an induction pickup coil having a sensitive relay operatively connected thereto for detecting a change in the magnetic field adjacent the mine, a slow releasing switching relay adapted to be controlled by said sensitive relay, a normally inactive vacuum tube amplifier, means for setting said amplifier in operation as the slow releasing relay operates, an interrupting device connected to the input of said amplifier adapted to short-circuit the amplifier input periodically as the interrupter operates, means controlled by said slow releasing relay for setting the interrupting device in operation, a pair of opposedly connected coils in electrical connection with said amplifier input adapted to generate an input signal variably in accordance with the rate of change of the gradient of said magnetic field, a signal rectifying device connected to the output of said amplifier, a firing relay in circuit with said rectifying device, said circuit including a pair of contacts on said switching relay adapted to be closed as the relay operates, detonating means, and electro-responsive means controlled by said firing relay for operating the detonating means when the signal received from said opposedly connected coils is of sufficient strength to cause the operation of the firing relay.

10. In a system of the character disclosed for firing a submarine mine selectively in accordance with the rate of change of the gradient of the magnetic field adjacent thereto, an induction pickup coil having a sensitive relay connected thereto adapted to detect a change in said magnetic field and operate the sensitive relay when the change in the magnetic field has reached the predetermined value, a slow releasing relay operatively connected to said sensitive relay and adapted to be controlled thereby, an electro-responsive time delay device operatively connected to said slow releasing relay and having a pair of contact elements adapted to be moved to closed position when a predetermined period of time has elapsed after the slow release relay operates, means for forcibly resetting said sensitive relay to an initial unoperated position, and means controlled by said contact elements for operating said relay resetting means as the contact elements are moved to closed position.

11. In a firing mechanism for a submarine mine, the combination of an induction pickup coil for detecting changes in the magnetic field adjacent thereto, means including an electro-responsive device operatively connected to said induction coil for arming the mine in response to changes in said field detected by the induction coil, a pair of opposedly connected coils, and means for firing the armed mine selectively in accordance with the rate of change of the gradient of said magnetic field detected by said opposedly connected coils.

12. In a submarine mine, the combination of a normally inactive signal amplifier having a pair of opposedly pickup coils connected to the input thereof, means including an induction coil responsive to a change in the magnetic field adjacent thereto for activating said amplifier for a predetermined period of time, detonating means, and means operatively connected to the output of said amplifier for causing the mine to be fired selectively by said detonating means during said predetermined period of time in accordance with the rate of change of the gradient of said magnetic field detected by said opposedly connected coils.

13. In a system for firing a submarine mine, means including an induction coil for arming the mine in response to a predetermined change in the magnetic field adjacent thereto, a pair of gradiometer coils adapted to generate a signal of variable strength in accordance with the rate of change of the gradient of said magnetic field, a vacuum tube amplifier having the input thereof operatively connected to said gradiometer coils and adapted to be controlled thereby, and means effective when the mine has been armed for firing the mine selectively in accordance with the strength of signals received from said gradiometer coils.

14. In an integral submarine mine of the character disclosed arranged on the bed of a body of water adjacent the path of travel of a vessel, means for detecting a change in the magnetic field in the vicinity of said mine as the vessel approaches the mine, means controlled by said field detecting means for arming the mine in delayed time relation with respect to the detection of said change in the magnetic field by said field detecting means, and means for firing the armed mine selectively in accordance with the rate of change of the gradient of the magnetic field of said vessel.

15. In an integral submarine mine of the character disclosed arranged on the bed of a body of water adjacent the path of travel of a vessel, means for detecting a change in the magnetic field in the vicinity of said mine as the vessel approaches the mine, means including an electro-responsive device adapted to be controlled by said field detecting means for arming the mine in delayed time relation with respect to the detection of said change in the magnetic field by said field detecting means, means responsive to the rate of change of the gradient of the magnetic field of said vessel for firing the armed mine selectively in accordance with a predetermined value of said rate of change of the gradient of said magnetic field, and means settable at will for varying the degree of response of said electro-responsive device to said field detecting means.

16. In a submarine mine of the character disclosed arranged on the bed of a body of water within the path of travel of a vessel, the combination of a mine firing mechanism having an induction pickup coil operatively connected thereto and responsive to a change in the magnetic field adjacent the mine, means including a relay responsive to a signal received from said pickup coil for arming the mine in delayed time relation to said signal, a pair of opposedly connected coils adapted to generate

electrical signals in proportion to the rate of change of the gradient of the magnetic field adjacent the mine, signal amplifying means, an input circuit from said pair of coils to said signal amplifying means, means for periodically short-circuiting said input circuit while said electrical signals are being generated by said pair of coils, and means including a detonating device controlled by said signal amplifying means for firing the mine when the electrical signals have reached a predetermined value.

17. In a firing mechanism for a submarine mine, the combination of means for arming the mine responsive to changes in the strength of the magnetic field adjacent thereto, and means for firing the armed mine selectively in accordance with the rate of change of the gradient of said magnetic field.

18. In a firing mechanism for a submarine mine, the combination of means including an induction pickup coil responsive to changes in the magnetic field adjacent thereto for arming the mine, and means including a pair of opposedly connected coils responsive to the rate of change of the gradient of said magnetic field for firing the armed mine when said rate of change of the gradient reaches a predetermined value.

19. In a system for controlling the firing of an integral submarine mine, a first detection means comprising an induction coil for detecting a change in the magnetic field in the vicinity of said mine, a switching relay having a plurality of circuit closing elements thereon effective to control the firing of said mine, an electroresponsive device to provide for actuation of said switching relay, said first detection means being operatively connected to said electroresponsive device for operation thereof in response to changes in said magnetic field, a vacuum tube amplifier, a second detection means including a pair of opposedly connected gradiometer coils adapted to generate a signal of variable strength in accordance with the rate of change of the gradient of said magnetic field, and means for applying said variable strength signal to the input of said vacuum tube amplifier for control thereby, said amplifier being effective to control the firing of said mine and being connected to said gradiometer coils, said second detection means including variable control means connected across one coil to equalize the signal output of said opposedly connected coils to prevent firing said mine upon detection of signals of sufficient strength caused by conditions other than a change in the magnetic field in the vicinity of the mine due to movement of said mine from a rest position.

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