# United States Patent

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[54] **MAGNET CONTROLLER**
**14 Claims, 2 Drawing Figs.**


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H01f 13/00, H01h 47/32
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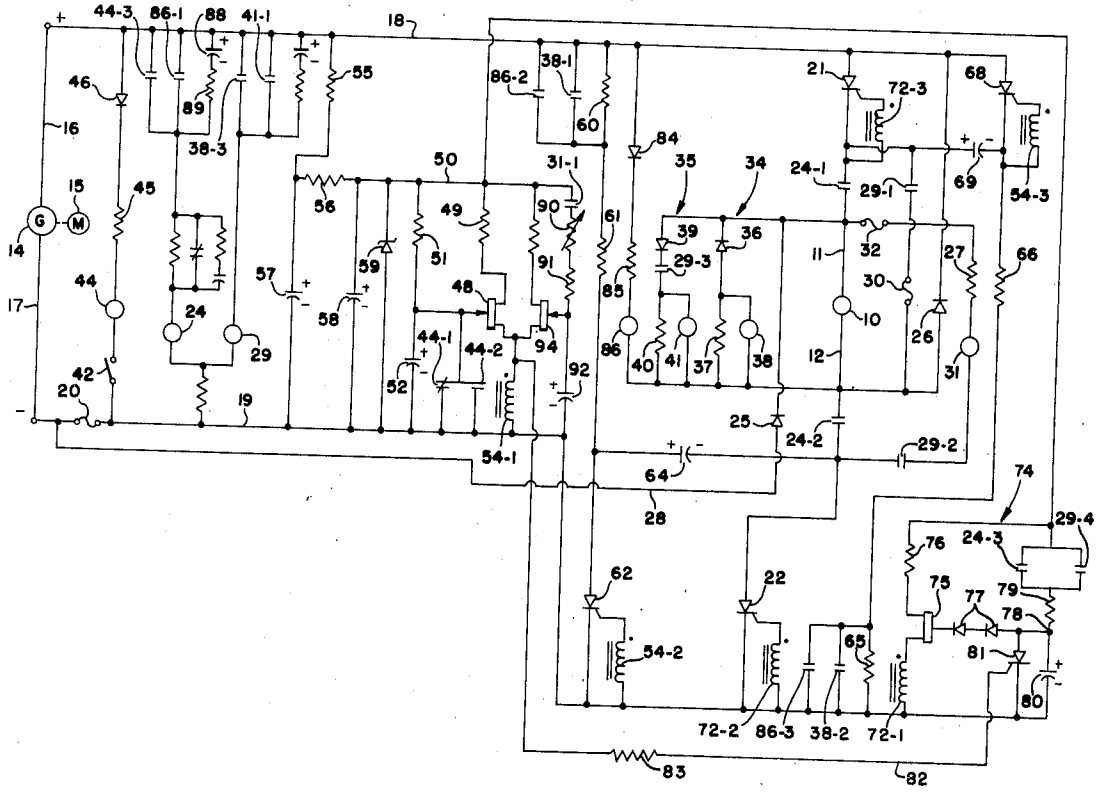
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**ABSTRACT:** An industrial lifting magnet control circuit using semiconductors and conventional relay components for performing and timing the power switching cycles of magnet energization, discharge and current reversal for drop-off. Reversing contacts control the direction of current flow through the magnet and in one embodiment of the invention a single SCR together with a diode-resistor quench circuit provide the switching of power and the dissipation of magnet energy. Another embodiment of the invention further includes a second SCR for switching and isolation and a pair of diodes for directing and rapidly dissipating the magnet energy through the motor-generator power source. The switching SCR's are triggered by unijunction transistor timing circuits and are commutated by SCR-controlled capacitor discharge.

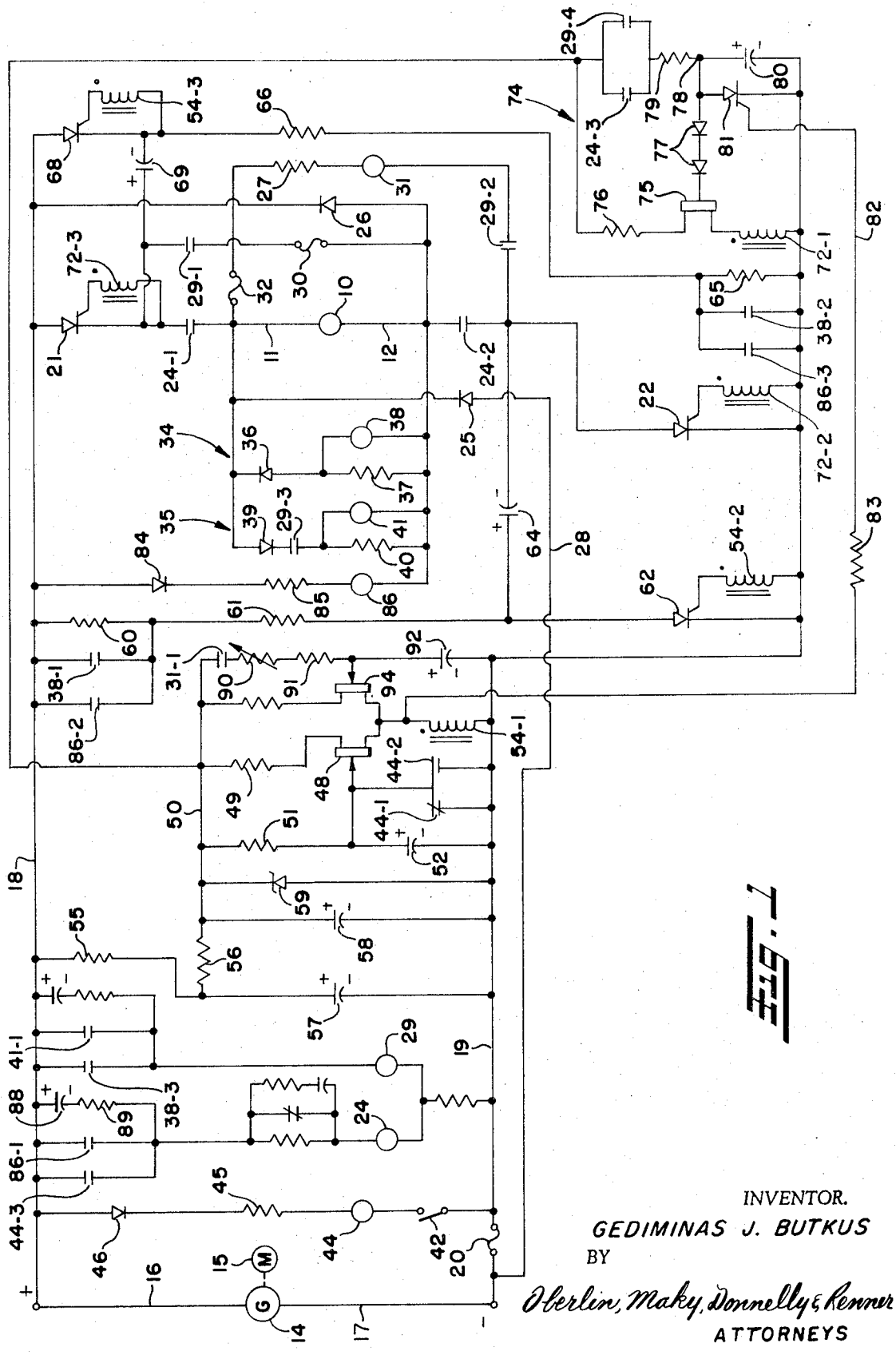


FIG. 1

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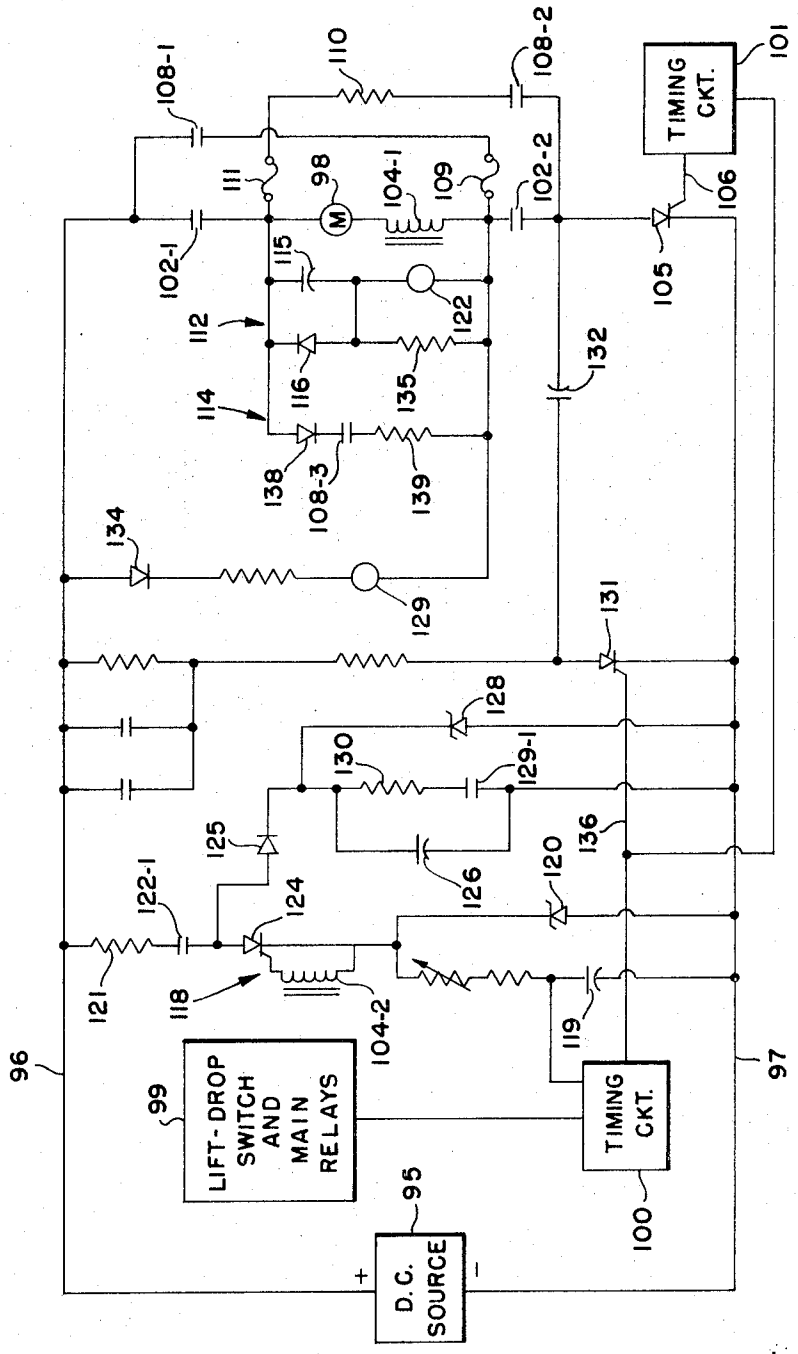



FIG. 2

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# MAGNET CONTROLLER

## DISCLOSURE

This invention relates to electric circuits for switching high levels of currents in inductive loads and more particularly to circuits utilizing semiconductor components for controlling the application and discharge of energy in an industrial lifting magnet.

The inductance values realized in applications of this type are extremely high and it is necessary to employ high levels of current flow, typically in the range of 50 to 150 amperes, to achieve suitable magnetic field intensity of sufficient strength for lifting operations. While there is sufficient capacity in existing equipment to achieve such high power levels of operation, considerations of economy, efficiency of operation and safety have become paramount and consequently more exotic control systems are required to achieve these results.

For example, it is common to employ a motor-generator set for portable applications and to apply the energy derived therefrom to a conventional lift magnet by means of typical relay switching circuitry whereby high levels of current flow are accommodated by heavy-duty and specially designed relay contacts. In such applications, the inductance of the lifting magnet is so great that it may take on the order of twelve seconds to achieve maximum current flow through the magnet or to release the energy stored therein to a suitable low level. While recent considerations in the design of relays have greatly increased the life of relay contacts, it is acknowledged that some erosion of the contacts occurs upon each switching and at such high levels of current and energy only a limited lifetime can be expected, requiring a continuing replacement and maintenance schedule.

Further, the control circuitry for a lifting magnet is required to perform three basic cycles of operation, these being an application of power to the magnet in the lift cycle, a dissipation of the energy in the magnet in the discharge cycle, and a passage of current through the magnet in a reverse direction in a release cycle, the latter two cycles comprising the drop sequence. While the release cycle may be performed in a short interval of time, the lift and discharge cycles are relatively long and are determined by the type of components and power levels employed and the efficiency of operation desired, being limited by practical considerations. It is apparent, however, that valuable operating time is wasted in these cycles wherein the operator must wait until the maximum lifting force is available or until the circuit is in a state where switching can be performed without damage to the components. Further it is apparent that safety and convenience of operation must be considered so that the operator need not suffer the full build up and decay of current levels, required by some prior art automatic drop systems which rely on interlocking relay circuitry, before switching cycles.

It is one feature of this invention that the switching of high current levels by relay contacts is completely avoided in the utilization of high-current-capacity SCR devices which can perform such switching without creation of an electrical arc of current and the subsequent pitting problems. Such devices are advantageous in not being subject to the contamination problems associated with relay contacts; in being switched from a conducting to nonconducting state or vice versa by relatively low power level signals; and in having rapidity of response as an inherent characteristic of same. Further, the control of such devices is simplified in that conventional electronic circuitry and timing techniques can be utilized, obviating the necessity for a multiplicity of relay contacts and specialized relay types.

In one embodiment of this invention only a single SCR is employed to provide the switching for the lift, discharge and release cycles, while in another embodiment of the invention an additional SCR is employed together with a pair of high-current diodes to provide all cycles of operation. In this latter preferred embodiment of the invention a technique for rapid discharge of the energy in the magnet is employed wherein the magnet is reversely connected to the motor-generator set supplying energy to the system to cause dissipation of the energy into the armature winding of the generator. Both circuit embodiments utilize a conventional quench circuit for dissipating the magnet energy, full dissipation occurring in the former embodiment, while in the latter, only that dissipation of the magnet energy when the generator source is removed.



Therefore, it is one object of this invention to provide an improved control system employing an SCR to perform the switching functions of applying and removing power in a high-inductance component operating at high-current levels.

It is another object of this invention to provide an improved magnet control system with relatively short cycle times, the latter being provided by the dissipation of magnet energy into the source powering the system.

It is yet another object of this invention to provide an improved magnet control system which has a plurality of operating modes and provision for switching from one mode to another with little delay.

It is yet another object of this invention to provide an improved magnet control system employing SCR's for switching current through the magnet coil, which SCR's are in turn commutated by SCR-controlled capacitor discharge circuits.

It is a still further object of this invention to provide an improved magnet control system which employs semiconductor circuitry for initiation of the various cycles of operation of the magnet which circuitry provided both timing and gating functions.

Other objects and advantages of the present invention will become apparent as the following description proceeds.

To the accomplishment of the foregoing and related ends, the invention, then, comprises the features hereinafter fully described, the following description and the annexed drawings setting forth in detail certain illustrative embodiments of the invention, these being indicative, however, of but a few of the various ways in which the principles of the invention may be employed.

In the drawings:

FIG. 1 is a schematic circuit diagram of the preferred embodiment of the invention utilizing magnet discharge into the power source; and

FIG. 2 is a schematic circuit diagram partly in block diagram form of a second embodiment of the invention utilizing only a single main switching SCR.

## FIRST EMBODIMENT

Referring now to FIG. 1, there is shown a preferred embodiment of the invention depicting a complete electrical circuit diagram of the magnet control system with components shown in schematic form. The lifting magnet **10** is depicted by the conventional symbol for a coil, having a pair of connecting leads **11**, **12** and may be considered any type of inductive component, however, the teachings of this invention are particularly applicable to a lifting magnet having massive iron core wound with an energizing winding of high-current carrying capability and exhibiting an extremely high inductance characteristic.

Power for the magnet control system is derived from a generator **14** driven by a motor **15**, the former typically comprising a driven wound rotor, rotatable in an established magnetic field, and adapted to supply a DC output on lines **16**, **17**. Typically the impedance of such generator **14** is relatively low to provide suitable power output and such device is capable of being operated as a motor when power is supplied to the rotor from an external source, such latter feature being utilized in this invention. The output lines **16**, **17** of the generator **14** are connected respectively to a positive bus **18** and negative bus **19** for distribution to the remainder of the circuit, the latter connection being made through a fuse **20**.

The magnet **10** is connected in circuit between the positive and negative buses **18**, **19** in series with first and second main SCR's **21**, **22** (silicon-controlled rectifiers) and a pair of nor-

mally open contacts 24-1, 24-2 of a lift relay 24. Thus the circuit for supplying forward current to the magnet 10 in the lift cycle comprises a main SCR 21 having anode connected to the positive bus 18 and cathode connected to lift relay contact 24-1, the contact 24-1 connected to the first connecting lead 11 of the magnet 10, the second connecting lead 12 connected to lift relay contact 24-2 which is in turn connected to the anode of the second main SCR 22 having a cathode connection to the negative bus 19.

A pair of diodes 25, 26 further connect the magnet 10 to the positive and negative buses to establish the discharge circuit for the magnet, the first diode 25 having the anode connected by way of line 28 to the generator line 17 of the negative bus 19, and the cathode connected to the first connecting lead 11 of the magnet 10. The second diode 26 has the anode connected to the second connecting lead 12 of the magnet 10 and its cathode connected directly to the positive bus 18, both diodes 25, 26 therefore being connected in a direction to oppose current flow from the positive bus 18 to the negative bus 19.

A pair of contacts 29-1, 29-2 of drop relay 29 further connect the magnet 10 in circuit for operation during the release cycle, such contacts together with lift relay contacts 24-1, 24-2 comprising a set of reversing contacts for the magnet. Drop relay contact 29-1 is connected at one side to the cathode of the first main SCR 21 and at the other to a fuse 30 which in turn is connected to the second connecting lead 12 of the magnet 10. Drop relay contact 29-2 is connected to the anode of the second main SCR 22 and to a current-sensing relay 31, the latter connected via resistor 27 and fuse 32 to the first connecting lead 11 of the magnet 10. Thus in the release cycle, a path for current flow will be established from the positive bus 18 through the main SCR 21, drop relay contact 29-1, magnet 10, current relay 31, second drop relay contact 29-2, second main SCR 22 to the negative bus 19.

Further connected in parallel with the magnet 10 are the forward-current quench circuit 34 and the reverse-current quench circuit 35, the former comprising the series circuit of a diode 36 and resistor 37 with the coil of a sensing relay 38 connected across resistor 37. Quench circuit 35 comprises diode 39, drop relay contact 29-3, and resistor 40, the latter having the coil of drop latching relay 41 connected thereacross. Diode 36 is poled to conduct discharge current from the magnet 10 when connecting lead 12 is positive and diode 39 is poled to conduct discharge current from the magnet 10 when connecting lead 11 is positive.

The preceding description covers the essential circuitry for directing current flow to and from the magnet 10 for charge and discharge operation and is sufficient to gain an understanding of the general operation of the system. The remainder of the circuit shown in FIG. 1 comprises timing circuitry, control relays, power supplies and the like and will be described in detail in relation to the magnet-current directing circuitry for a full understanding of this invention.

Essentially the system operates to set up the conditions for current flow by means of the switching of conventional relay contacts when no current is flowing so as to avoid the deleterious effects of arcing and bouncing problems with the contacts. Thus switching of the magnet 10 energizing current occurs in the main SCR's 21, 22 which are gated on at appropriate times within the cycles of operation and commutated to an off condition for interruption of current flow. Conduction of the SCR's 21, 22 is achieved in a conventional manner by the application of gating pulses at the gate electrodes thereof by way of transformer-coupled windings while commutation is performed by the discharge of capacitors which reduce the current flow through the SCR's below the holding current level, which action is sufficient to bring the SCR's to a cutoff condition. In both embodiments of the invention, the discharge of the commutating capacitors are controlled by additional SCR's which in turn are gated by appropriate timing circuitry.

The sole control component for the operator of this system is a lift-drop switch 42 located in the operator's cab which may be manually actuated at anytime within the various cycles from either a closed-to-open position or vice versa, the system having sufficient safeguards therein to prevent actual switching of the current at the magnet 10 until the circuitry is properly conditioned therefor. The lift-drop switch 42 is connnected in series with a slave relay coil 44, a current-limiting resistor 45, and a diode 46 poled for protection if the generator 14 polarity is reversed.

## LIFT SEQUENCE

The lift-drop switch 42 is closed by the operator to complete the circuit to the slave relay coil 44. One pair of contacts 44-1, 44-2 of the slave relay 44 are connected between the emitter electrode of a unijunction transistor 48 and the negative bus 19. The unijunction transistor 48 forms a portion of a timing or gating circuit for control of SCR's and comprises a semiconductor element having its base 2 connected by way of a low-impedance resistor 49 to a source of regulated DC potential on line 50, its emitter connected to the junction of series connected resistor 51 and capacitor 52 also receiving power from the regulated DC line 50, and its base 1 connected to the primary winding 54-1 of a pulse transformer.

The regulated power supply for this unijunction transistor 48 as well as other transistors utilized throughout the system comprises series-connected resistors 55, 56 and shunt-connected capacitors 57, 58 acting as filter elements for providing a low-voltage DC output on line 50. A zener diode 59 is in shunt connection with the line 50 and the negative bus 19 to provide regulation of the output voltage.

The unijunction transistor 48 operates to supply pulse current flow from the base 1 electrode through the transformer primary winding 54-1 when the voltage at the emitter attains a predetermined level. Emitter current flow acts to partially discharge capacitor 52, which upon recharging to the predetermined voltage level creates a further pulse output. The repetition time of pulse output from the transistor 48 is a function of the time-constant of the resistor 51, capacitor 52 combination and the components may be selected to provide any desired frequency output or to have a long time-constant to provide a slow build up of voltage across the capacitor 52 and thus provide the function of a delay or a timing circuit. In this embodiment of the invention, the transistor 48 acts primarily as an oscillator operating in the range of approximately 5 kHz. and upon actuation of the slave relay 44 provides approximately 15 to 20 pulses into the primary winding 54-1. As noted, slave relay contacts 44-1, 44-2 are in shunt connection with the emitter electrode and are operative upon energization of the slave relay 44 to open contact 44-1 and then, after a short interval of time sufficient to allow oscillation of the circuit to occur, close contact 44-2 to shunt the emitter electrode to the negative bus 19.

A commutating circuit for the second main SCR 22 comprises series-connected resistors 60, 61 and SCR 62, the latter having its cathode connected to the negative bus 19. A capacitor 64, having a value on the order of 50 microfarads at 400 working volts, is connected between the anodes of the commutating SCR 62 and the second main SCR 22, the capacitor 64 adapted to be charged during conduction of the second main SCR 22 and discharged upon conduction of the commutating SCR 62 for switching purposes. A second commutating circuit for the first main SCR 21 comprises series-connected resistors 65, 66 and SCR 68, the latter having its anode connected directly to the positive bus 18. Similarly, a commutating capacitor 69 is connected between the cathodes of the first main SCR 21 and the commutating SCR 68 and is adapted to be charged during conduction of the main SCR 21 and discharged upon conduction of the commutating SCR 68. Secondary windings 54-2, 54-3 of the pulse transformer are connected between the gate and cathode electrodes of the commutating SCR's 62, 68 in order to gate the SCR's to a conductive condition.

Thus when the slave relay **44** is first energized, gating pulses are applied to the commutating SCR's **62, 68** to discharge the capacitors **64, 69** in order to assure that the first and second main SCR's **21, 22** are in an off condition. Similarly, as will be explained hereinafter, this arrangement allows the operator to terminate the lift or drop sequence at any time within the cycles and after a short delay switch to another cycle.

Energization of the slave relay **44** also closes slave relay contact **44-3** to energize the lift relay **24**. Lift relay contacts **24-1, 24-2** close in the magnet **10** path and prepare the magnet circuitry for energization through the main switching SCR's **21, 22**.

Gating of the main SCR's **21, 22** is performed in a similar manner to that of the commutating SCR's **62, 68** the main SCR's having secondary windings **72-2, 72-3** of a pulse transformer connected between the gate and cathode electrodes thereof and magnetically coupled to a primary winding **72-1** of the transformer in the main SCR gating circuit, the latter indicated generally at **74**.

The gating circuit **74** comprises a unijunction transistor **75** having base **2** electrode connected by way of low-impedance resistor **76** to the positive line **50** of the low-voltage source, base **1** electrode connected by way of the primary winding **72-1** of the transformer to the negative bus **19** and the emitter electrode connected by way of a pair of voltage-dropping diodes **77** to a bias terminal **78**. The bias terminal **78** is formed as the junction of series-connected resistor **79** and capacitor **80**, the resistor **79** in turn receiving power, through drop relay contact **29-4** or lift contact **24-3**, from the positive line **50**. The capacitor **80** is of relatively large value and together with series resistor **79** provides a time-constant suitable for causing oscillation of the unijunction transistor **75** at approximately 2 pulses per second, which slow pulsing rate allows the closure of the lift **24-1, 24-2** or drop **29-1, 29-2** contacts to be established (ensuring that the contacts have stopped bouncing) before the main SCR's **21, 22** are gated into conduction. The gating circuit **74** includes also SCR **81** in shunt connection with capacitor **80** for purposes of discharging the capacitor and preventing operation of the circuit **79** when transistor **48** in the commutating pulse generating circuit is supplying pulses. The gate electrode of SCR **81** is connected by way of line **82** and series resistor **83** to the base **1** electrode of transistor **48**.

Further in the lift sequence, as the lift contacts **24-1, 24-2** are closed, lift contact **24-3** is also closed to energize the gating circuit **74** and after a short time interval gating pulses are applied by way of the primary **72-1** and secondary **72-2, 72-3** windings to gate the main SCR's **21, 22** into conduction and connect the magnet **10** between the positive and negative buses **18, 19** to initiate the flow of magnet current. Simultaneously with turn-on of the second main SCR **22**, a circuit is completed consisting of series-connected diode **84**, resistor **85** and lift latching relay **86** to cause energization of the relay **86** and closure of the lift latching contact **86-1** shunting the slave contact **44-3** for interlocking the lift relay **24**. A voltage suppressing circuit comprising series-connected capacitor **88** and resistor **89** is also in shunt connection with the slave relay contact **44-3**.

Lift latching contacts **86-2, 86-3** are in shunt connection with resistors **60, 65** respectively to ensure that the commutating capacitors **64, 69** charge rapidly to be in condition for commutation of the main SCR's **21, 22** early in the cycle, allowing the operator to go to the drop cycle, for example, after a short life sequence. This circuit provision is especially advantageous if the operator changes his mind or finds that safety precautions have been exceeded.

Once the magnet **10** has been energized for an interval of time, the maximum current flow will be obtained, limited by the resistance of the magnet windings, and will continue to provide the magnetic field for lifting purposes. Interruption of the current flow to the magnet **10** to release objects supported thereon presents the problems not only of interrupting a high current level which may be on the order of several hundred amperes but also of discharging the energy stored in the inductance of the magnet coil, which energy characteristically creates a reversal in polarity of the voltage across the magnet and a continuation of the current flow until the energy is dissipated.

Further, although the magnet **10** energy becomes dissipated in this manner, objects may still be retained on the face of the magnet due to the residual magnetism in the components forming the magnet or due to the fact that the objects being lifted have become magnets themselves. Thus a reversal of current flow through the magnet **10** performs not only the function of eliminating residual magnetism in the structure, but also creates a magnetic field of the opposite polarity to repel magnetized objects attracted to the face of the magnet. Preferably then the drop sequence for magnet deenergization includes the sequential cycles of magnet discharge and release.

## DROP SEQUENCE

The discharge cycle is initiated by opening the lift-drop switch **42** causing deenergization of the slave relay **44** and opening of contact **44-3**. The lift **24** and auxiliary lift **71** relays, however, are held energized by the still-closed contact **86-1** of the lift latching relay **86**.

Slave relay contacts **44-1, 44-2** revert to the normal condition depicted in FIG. **1**, contact **44-2** however opening for a short time interval before closure of contact **44-1** allowing charging of the capacitor **52** and the generation of pulses in the primary winding **54-1** of the pulse transformer. The commutating SCR's **62, 68** are gated on by way of the pulses from the secondary windings **54-2, 54-3** shunting the capacitors **64, 69** across the main SCR's **21, 22** and causing current flow in the main SCR's in opposition to the magnet current. When the net current in the main SCR s **21, 22** is approximately zero, both will turn off, disconnecting the magnet **10** from the positive and negative buses **18, 19**.

The energy in the magnet **10** maintains the current flowing through it and the polarity of the magnet terminals thus become immediately reversed, the connecting lead **12** now becoming of positive potential with respect to lead **11**. This polarity change forward biases diodes **25, 26** and current from the magnet **10** flows through the positive and negative buses **18, 19** back through the generator **14**. Reversely energized, the generator **14** now becomes a motor and the energy of the magnet **10** is dissipated in the generator rotor winding in opposing the action of the drive motor **15**. The impedance of the generator rotor is significantly low so as to reduce the discharge time of the magnet **10** to on the order of only several seconds, being significantly faster than can be practically obtained by discharge of the magnet energy into a fixed-impedance element.

When the magnet **10** reverses polarity, the lift latching relay **86** is deenergized by virtue of the blocking action of the diode **84** and the forward-current quench circuit **34** is established via diode **36** causing energization of the drop-sensing relay **38**. Contacts **38-1, 38-2** of the sensing relay **38** now shunt resistors **60, 65** respectively to maintain the commutating circuits in a fast-charging condition and the release of the holding contact **86-1** allows the lift **24** and auxiliary lift **71** to relays to drop out. Simultaneously, closure of the drop-sensing relay contact **38-3** causes energization of the drop relay **29** which is the main contactor and circuit changer for the drop sequence. Preferably the lift **24** and drop **29** relays are mechanically interlocked so as to avoid simultaneous actuation.

Closure of drop relay contacts **29-1, 29-2** establish the reverse current path for the magnet **10** which is utilized during the release cycle of the drop sequence after substantial discharge of the magnet has occurred. It is noted that the drop relay contacts **29-1, 29-2** are isolated from the magnet **10** by the now open lift contacts **24-1, 24-2** and undergo their transition to the closed state in the absence of current flow due also to the off condition of the main SCR's **21, 22**. Closure of the

drop relay contact 29-4 connects resistor 79 to line 50 and starts the gating circuit 74 causing the establishment of pulses in the primary winding 72-1 of the transformer after a short time interval. Although pulses are applied to the gating electrodes of the main SCR's 21, 22, the SCR's will not conduct until the magnet 10 has discharged enough so that it can no longer support the generator 14, the main SCR's 21, 22 being effectively shunted by the low-impedance path of the diodes 25, 26. Upon sufficient discharge of the magnet, the diodes 25, 26 will become reverse biased and the main SCR's 21, 22 will be conditioned for response to a gating pulse and will turn-on.

When this occurs, a path of reverse current through the magnet 10 is created from the positive bus 18 through the first main SCR 21, drop relay contact 29-1, fuse 30, the magnet 10 itself, fuse 32, current-sensing relay 31, drop relay contact 29-2, and the second main SCR 22 to the negative bus 19. Current-sensing relay 31 may be preset to become energized when the reversed current has reached a value to ensure a clean drop, this current level being significantly lower than that required for forward energization of the magnet 10. Closure of the current relay contact 31-1 connects series-adjustable resistor 90, fixed-resistor 91, and capacitor 92 to the low-voltage line 50 to provide biasing voltage to a second unijunction transistor 94 timer circuit connected also to the primary winding 54-1 of the pulse transformer. The circuit components are preadjusted to provide relatively rapid pulses which are applied to the commutating SCR's 62, 68 to cause discharge of the capacitors 64, 69 and commutation of the main SCR's 21, 22 as previously described.

Since the magnet 10 has again stored energy due to the reverse current flow, the connecting lead 11 again becomes positive and a discharge path is created through diode 39, drop relay contact 29-3, and the fixed-resistor 40, contact 29-3 having previously conditioned the reverse current discharge circuit 35. This discharge current flow also energizes drop latching relay 41 having a contact 41-1 in the energizing line for the drop relay 29 thereby interlocking same until the discharge current has reached a safe level. At this time, the drop latching relay 41 deenergizes, opening contact 41-1 and deenergizing the drop relay 29, thereby completing the drop sequence.

While the normal operation of the circuit in the drop sequence has been described, the system also includes provision for assuring discharge of the magnet 10 energy in the event of a malfunction in the discharge circuit through the generator 14, which could occur, for example, on open circuit of positive bus 18 or line 28, or open circuit failure of diodes 25, 26. In this event, forward current discharge circuit 34 is relied upon to perform the full dissipation, being designed to carry full-rated current, but requiring a much longer discharge interval than that obtainable with discharge through generator 14.

## SECOND EMBODIMENT

Referring now to FIG. 2, there is shown yet another embodiment of the invention applicable particularly to lower current lifting magnets which do not attain the high energy levels associated with the first embodiment of the invention. This circuit is most useful at approximately 50 amperes of magnet current flow and utilizes passive resistor components for discharge of the magnet energy, not requiring the polarized diode connection to the motor generator set. This form of apparatus does, however, provide the usual magnet cycles of magnet energization, discharge and release, in this instance providing all cycling through the action of a single SCR for heavy-duty current switching. Further, the circuit discloses yet another from of magnet-current magnitude sensing by means of a current transformer arrangement.

Power for the system is shown as a DC source 95 supplying voltage to a positive bus 96 and negative bus 97, the source 95 in this instance comprising typically the motor-generator unit set forth previously, but power could as well be derived from conventional transmission lines through a rectifier arrangement. Only the components closely associated with switching of current flow through the magnet 98 are shown in FIG. 2, the remainder of the circuitry being comparable to that described in detail with reference to the FIG. 1 embodiment. Thus the lift-drop switch and the main control relays will be understood to be contained within block 99 and performing essentially the same function as previously described. Similarly a timing circuit 100 for commutation purposes and a timing circuit 101 for main SCR gating are depicted as logic blocks, comprising similar types of unijunction transistor circuitry for providing gating pulses.

The forward-current magnet circuit comprises the series connection between the positive 96 and the negative 97 buses of lift relay contact 102-1, magnet 98, primary winding 104-1 of a current transformer, lift relay contact 102-2 and main switching SCR 105, the latter having its cathode connected to the negative bus 97 and gated at line 106 from the timing circuit 101.

A set of drop relay contacts complete the reversing contact arrangement and comprise contact 108-1 in series with a fuse 109 connected between the positive bus 96 and one side of the primary winding 104-1, and a second contact 108-2 in series with a low-impedance fixed-resistor 110 and fuse 111 connected between one side of the magnet 98 and the anode of the main SCR 105. A similar forward-current quench circuit 112 and reverse-current quench circuit 114 are in shunt connection across the magnet 98 and primary winding 104-1, the former circuit 112 including also an electrolytic capacitor 115 in parallel with the diode 116.

A further variance in the system occurs in the bias circuit 118 for a unijunction transistor (not shown) in the commutator timing circuit 100. The bias circuit 118 comprises a charging portion for establishing a rising voltage condition at the capacitor 119, the charging portion being regulated at a predetermined voltage by zener diode 120, together with means for applying power. The latter means includes series-connected fixed-resistor 121, a normally open contact 122-1 of the sensing-relay 122, and an SCR 124, the latter having the secondary winding 104-2 of the current transformer connected between gate and cathode electrodes for the supply of gating pulses. A further portion of the bias circuit 118 includes a forward-biased diode 125 for charging a capacitor 126 to a voltage level determined by shunt-connected zener diode 128 when the sensing-relay contact 122-1 is closed and for maintaining the anode of the SCR 124 at a low potential when the normally open contact 129-1 of the lift latching relay 129 is closed, the contact being in series connection with a low-impedance resistor 130, shunting the capacitor 126. Thus when the sensing-relay contact 122-1 is closed, anode potential will be available for the SCR 124 after a short time interval so that the SCR may be gated to conduction by the application of a pulse from the secondary winding 104-2, but such anode potential will be prevented by the closure of the lift latching relay contact 129-1 and the clamping action of the diode 125.

The circuit operation of this embodiment of the invention in the lift sequence is initiated by closure of a lift-drop switch to energize a slave and lift relay and associated contacts in the manner previously described. The commutating SCR 131 is gated on and the commutating capacitor 132 discharged to assure that the main SCR 105 is in an off condition. Subsequently the timing circuit 101 is energized for gating of the main SCR 105 after a time interval sufficient to allow complete closure of the lift relay contacts 102-1, 102-2. Forward current flow is then established through the magnet 98 and after a predetermined interval of time builds up to a maximum level.

The lift latching relay 129 is energized locking in the energization of the lift relay so that conditions are maintained so long as energization of the magnet 98 is desired. Lift latching relay contact 129-1 is also closed at this time discharging the

capacitor **126** and preventing any build up of voltage thereacross.

The drop sequence is also initiated in a similar manner, the opening of the lift drop switch causing a drop out of the slave relay and the momentary generation of pulses in the timing circuit **100** causing gating of the SCR **131** for discharge of the capacitor **132** and turnoff of the main SCR **105** in the manner previously described. The voltage across the magnet **98** reverses immediately, forward-biasing the diode **116** in the forward-current quench circuit **112** and operating also the sensing relay **122** for the drop sequence. The lift latching relay **129** is deenergized by virtue of the reverse polarity bias on the diode **134**, in turn deenergizing the lift relay and its associated contacts.

Energization of the sensing relay **122** closed contacts **122-1** allowing charging of capacitor **126** to prepare bias circuit **118** for operation in the discharge cycle. Energization of the sensing-relay **122** also causes energization of the drop relay and closure of contacts **108-1, 108-2** to set up the magnet circuit for the reverse-current direction and simultaneously a drop relay contact in the timing circuit **101** closed to initiate a delay interval. In this interval, energy from the magnet **98** is dissipated in the fixed-resistor **135** in the quench circuit **112**. When magnet current reaches approximately zero level, the condition is sensed by transformer windings **104-1, 104-2** to apply a gating level to SCR **124** to initiate charging of capacitor **119**, creating a delay prior to generation of gating pulses in timing-circuit **100** for application to SCR **131**.

Gating of the main SCR **105** via the timing-circuit **101** occurs first and connects the magnet **98** in a reverse-current path by way of the drop relay contacts **108-1, 108-2** to eliminate the residual magnetic effects. The sensing-relay **122** having been previously energized is maintained in an energized condition by virtue now of the direct connection through the drop relay contacts. After a short interval, capacitor **119** will be sufficiently charged and gating pulses will be developed and applied to the gate electrode of the commutating SCR **131**, by way of line **136** to again cause commutation of the main SCR **105** and removal of the magnet circuit from the power buses **96, 97**.

At this time the energy stored in the magnet **98** is again reversed in polarity thereby forward-biasing the diode **138** in the reverse-current quench circuit **114** and by virtue of the now closed drop relay contact **108-3** is dissipated in the fixed-resistor **139**. Deenergization of the sensing-relay **122** also causes deenergization of the drop relay and its associated contacts **108-1, 108-2** thereby returning the circuit to condition for initiation of another lift sequence.

It will be noted that in both embodiments of the invention, the lift-drop switch may be changed from one state to the other without causing damage to the components in that suitable interlocking circuitry and time delays are designed into the system so that, at the most, after only a short time interval, the components will reach the necessary conditions for switching which will then be automatically effected.

I, therefore, particularly point out and distinctly claim as my invention:

**1.** Apparatus for controlling the energization of an industrial lifting magnet from a DC source of power comprising a silicon-controlled rectifier having a main current anode-cathode path in series connection with the magnet and the DC source, means for gating said silicon-controlled rectifier into conduction, means for commutating said silicon-controlled rectifier to prevent current flow through said magnet, a set of reversing contacts interconnected with said magnet for alternately providing forward and reverse current flow therethrough, and means for sequentially actuating said set of reversing contacts, said gating means and said commutating means.

**2.** Apparatus as set forth in claim **1** further including quench means in connection with said magnet, said quench means being operative upon commutation of said silicon-controlled rectifier for dissipating the energy in said magnet.

**3.** Apparatus as set forth in claim **2** wherein said actuating means comprises means for preventing activation of said commutating means until the energy of said magnet attains a predetermined level.

**4.** Apparatus as set forth in claim **3** wherein said preventing means comprises a current transformer having a primary winding in series connection with said magnet and said set of reversing contacts and a secondary winding operatively connected for control of said commutating means.

**5.** Apparatus as set forth in claim **2** wherein said commutating means comprises a capacitor, a second silicon-controlled rectifier connected to shunt said capacitor across said main silicon-controlled rectifier, and means for charging said capacitor in a polarity to oppose current flow through said main silicon-controlled rectifier.

**6.** Apparatus as set forth in claim **2** further including a pair of diodes interconnecting said magnet with the power source, said diodes being poled to direct current flow from said magnet to the power source, and a second silicon-controlled rectifier having a main current anode-cathode path in series connection with said magnet for isolating the electromagnet from the power source.

**7.** Apparatus as set forth in claim **6** wherein said first and second main silicon-controlled rectifiers are gated and commutated in common.

**8.** Apparatus for energizing an electromagnet comprising a DC generator having an armature winding, a first main silicon-controlled rectifier having anode connected to the positive side of said armature winding, a second main silicon-controlled rectifier having cathode connected to the negative side of said armature winding, relay means having contacts connecting the electromagnet to said first and second main silicon-controlled rectifiers, respectively, for forward and reverse current flow through the electromagnet, and a pair of diodes connecting the electromagnet to said armature winding, said diodes being poled to conduct forward current flow from the electromagnet to said DC generator for discharge of the electromagnet.

**9.** Apparatus as set forth in claim **8** further including means for interrupting conduction of said first and second main silicon-controlled rectifiers, and means for selecting lift and drop cycles, said conduction interrupting means being responsive to said selecting means.

**10.** Apparatus as set forth in claim **9** further including gating means for said first and second silicon-controlled rectifiers, said gating means being responsive to actuation of said relay means.

**11.** Apparatus as set forth in claim **10** further including delay means for preventing actuation of said gating means for an interval of time sufficient to assure closure of said contacts of said relay means.

**12.** Apparatus as set forth in claim **11** further including means for sensing current flow through the electromagnet, said interrupting means being interlocked with said current sensing means to prevent actuation of said interrupting means until the electromagnet current flow attains a predetermined level.

**13.** Apparatus as set forth in claim **12** wherein said current-sensing means comprises a relay having a coil connected to sense current flow through said electromagnet, and contacts operatively connected with said interrupting means.

**14.** Apparatus as set forth in claim **11** further including a quench circuit in parallel connection with the electromagnet for dissipating the magnet energy, said quench circuit being polarized to conduct only reverse current flow from said electromagnet.

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