

[72] Inventors **Ralph W. Gruetzmacher**
River Grove;
Kenneth W. Schroeder, Arlington Heights;
Bruce G. Isaacson, Park Ridge, all of Ill.

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[73] Assignee **Magnaflux Corporation**
Chicago, Ill.

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Primary Examiner—J. D. Miller
 Assistant Examiner—Harry E. Moose, Jr.
 Attorney—Hill, Sherman, Meroni, Gross & Simpson

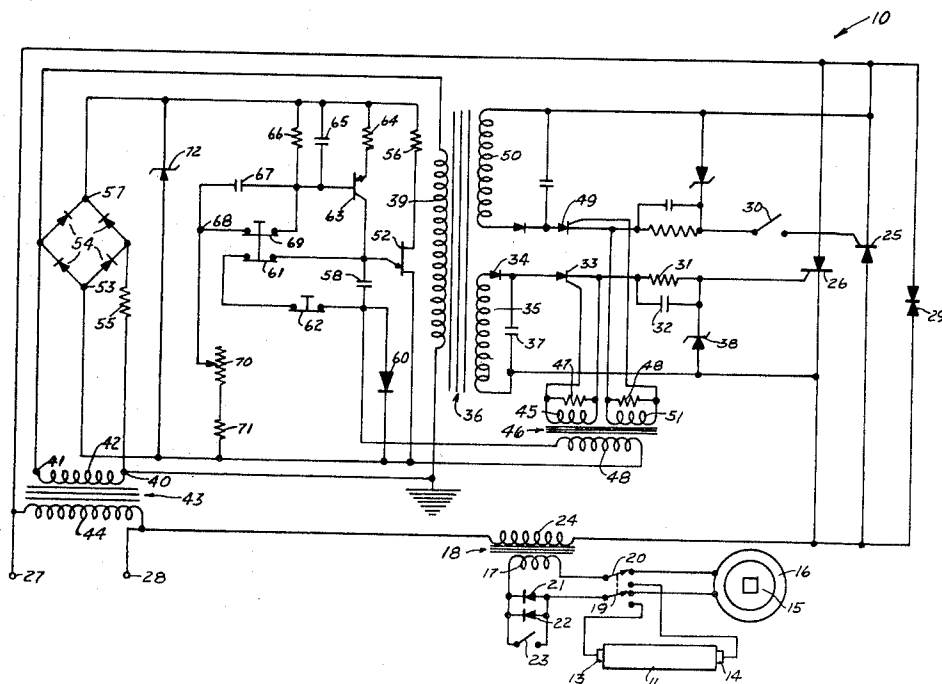
[54] **MAGNETIC PARTICLE INSPECTION AND
 DEMAGNETIZING APPARATUS**
 4 Claims, 2 Drawing Figs.

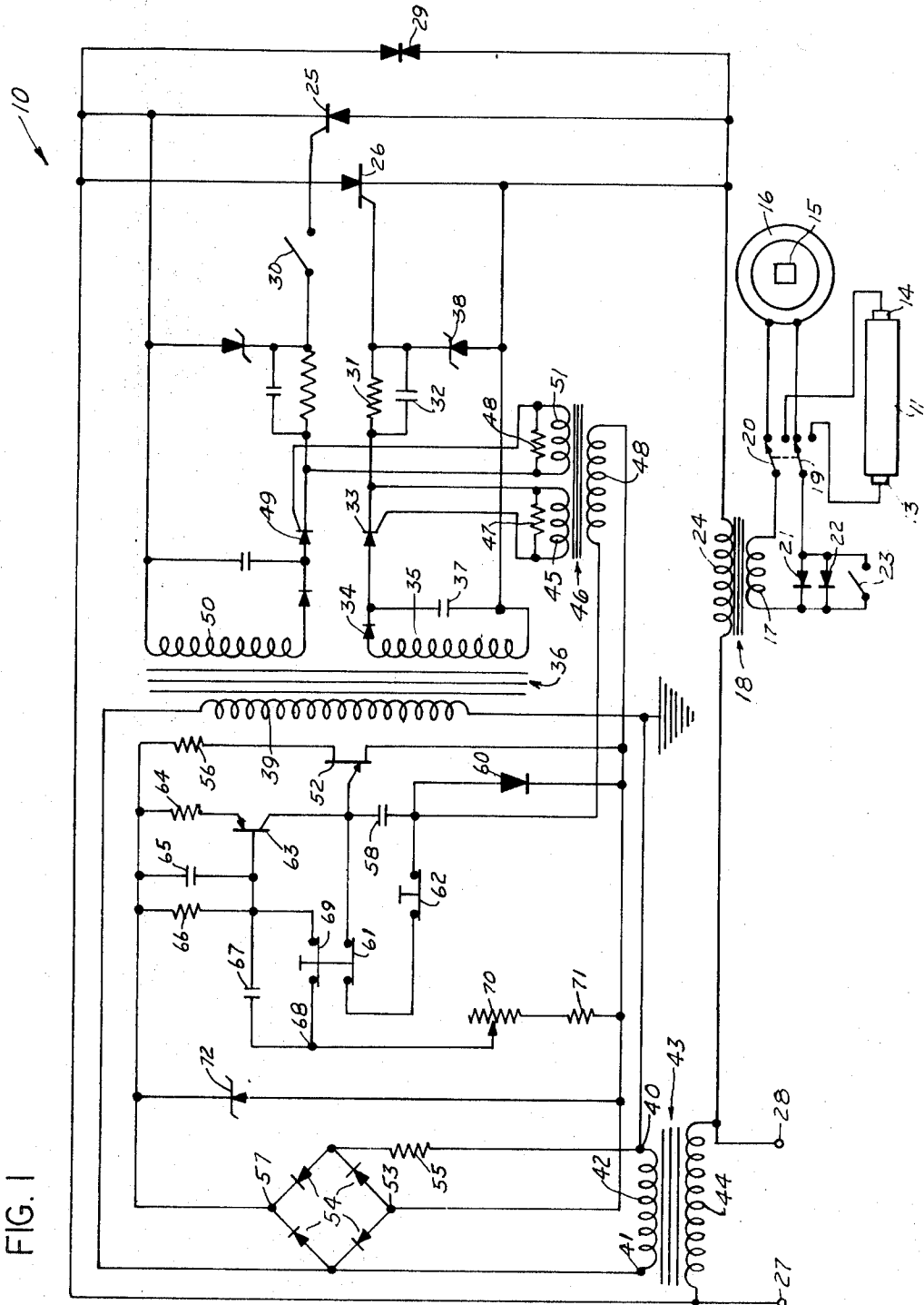
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ABSTRACT: Apparatus for magnetic particle inspection and also demagnetization in which a coil around a part or contacts engaged with a part are coupled to the secondary of a step-down transformer having a primary connected through oppositely poled silicon-controlled rectifiers or the equivalent to an AC source. Control signals are applied to the gates of the silicon-controlled rectifiers, preferably through a second pair of silicon-controlled rectifiers triggered by a unijunction transistor oscillator the timing of which is controlled to control either magnetizing or demagnetizing current. In magnetizing, an AC field is applied to the part which is always discontinued at the end of a half cycle with a steep wave shape such that the remnant magnetization from one part to another is uniform and the degree of concentration of particles over a defect provides an accurate indication of the character of the defect. In demagnetization, a circuit including a capacitor is provided for gradually reducing the rate of operation of the oscillator and firing the silicon-controlled rectifiers at progressively later points to gradually reduce the magnetic field in the part and to demagnetize the part.

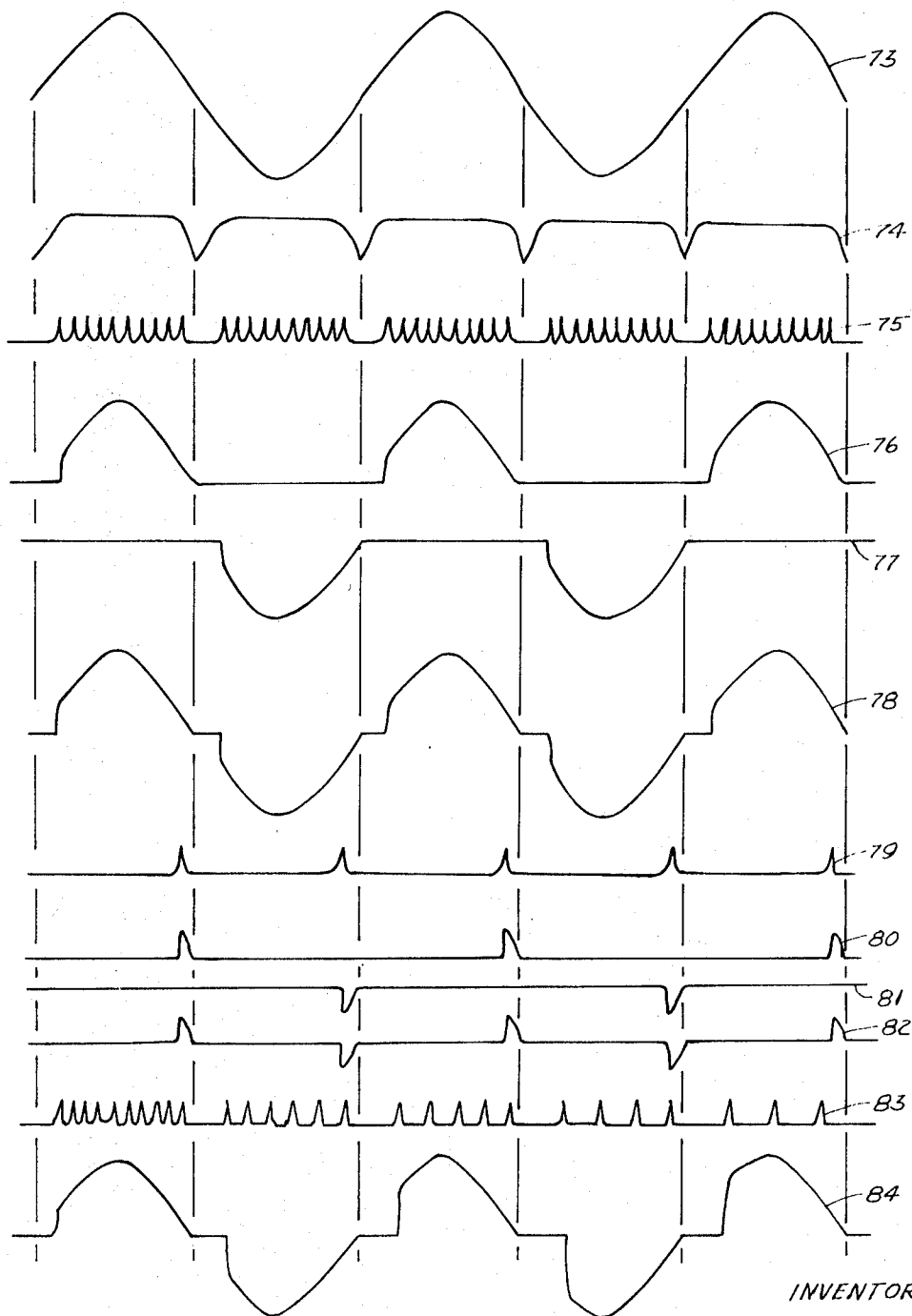




INVENTORS
RALPH W. GRUETZMACHER
KENNETH W. SCHROEDER
BRUCE G. ISAACSON

BY *Thell, Sherman, Meers, Goss & Simpson* ATTORNEYS

FIG. 2



INVENTORS
RALPH W. GRUETZMAGHER
KENNETH W. SCHROEDER
BRUCE G. ISAACSON

Hill, Sherman, Morris, Chase & Simpson
BY ATTORNEYS

MAGNETIC PARTICLE INSPECTION AND DEMAGNETIZING APPARATUS

This invention relates to magnetic particle inspection and demagnetizing apparatus and more particularly to apparatus in which an AC magnetizing current can be readily and accurately controlled over a wide range while being interrupted with a steep wave shape which is consistent and uniform from one part to another, such that the degree of concentration of particles over a defect provides an accurate indication of the character of the defect. The apparatus is also usable in demagnetizing a part with a field of which alternates in polarity while being gradually reduced in amplitude. The apparatus is relatively small in size and inexpensive in construction while being very stable and reliable in operation.

In a related application of two of the three applicants of this application, Ralph W. Gruetzmacher and Kenneth W. Schroeder entitled "Magnetic Particle Inspection Apparatus," filed Apr. 3, 1968, Ser. No. 718,437, a magnetic particle inspection system is disclosed and claimed involving the use of a controlled rectifier, preferably a silicon-controlled rectifier, connected between a primary winding of a transformer and an alternating current source with a secondary winding of the transformer being connected through one or more silicon diodes or other unidirectional conduction means to a coil around a part or to contacts engaged with a part. A control signal is applied to the gate or control electrode of the controlled rectifier, with the conduction of the rectifier being discontinued at a predetermined point of a cycle of the alternating current such that the conduction of magnetizing current is consistently discontinued with a certain wave shape. It is found that the circuit is substantially less expensive than one in which silicon-controlled rectifiers are in the secondary circuit, because the required current through the silicon-controlled rectifier is reduced in proportion to the turns ratio of the transformer. It is easier to operate well within the range of the devices to obtain a high degree of reliability.

This invention was evolved with the object of applying certain features of the invention as disclosed in said application to the development of a magnetizing field of alternating polarity, and also to the demagnetization of a part.

According to this invention, a secondary winding of a transformer is connected to a coil around a part or to contacts engaged with a part and the primary winding of the transformer is connected to an AC source through controlled rectifier means arranged to conduct in both positive and negative half cycles with control signals being applied to control electrode means to render the rectifier means conductive at a point in each half cycle of the alternating current to remain conductive until the end of each half cycle, switch means being provided for controlling application of the control signals. With this arrangement, an AC magnetizing field is applied and is consistently discontinued with a steep wave shape. This is particularly important in magnetic particle inspection in that the remnant magnetization from one part to another is uniform and the degree of concentration of magnetic particles over a defect provides an accurate indication of the character of the defect.

A feature of the invention is in the application of control signals at controllable points during both half cycles of the alternating current, the point being preferably controlled through a range extending from a time within a few degrees after the start of a half cycle to within a few degrees before the end of a half cycle.

The control circuit preferably comprises an oscillator operative during both half cycles the rate of operation of which is controlled to control the firing points during both half cycles.

Another feature is in the provision of a pair of controlled rectifiers, preferably silicon-controlled rectifiers, for controlling firing of the main controlled rectifier means, the pair of controlled rectifiers being preferably fired through an isolation transformer from the oscillator which may preferably be a unijunction transistor oscillator.

A further feature of the invention relates to the provision of means for selectively permitting the application of half wave DC rather than AC to the field-producing means. In accordance with this feature, a diode may be selectively connected in series between the transformer secondary winding and the field-producing means and the controlled rectifier means may be controlled to conduct during only half cycles of one polarity, preferably the half cycles during which the diode is conductive.

Important features of the invention relate to demagnetization, which is usable in a variety of applications. It is particularly advantageous, however, in magnetic particle inspection especially in that the same control circuitry can be used in both magnetizing and demagnetizing.

In demagnetizing, a control signal is initially applied at a certain point in a half cycle and control signals are then applied at progressively later points in subsequent half cycles to gradually reduce the magnetic field in the part and to demagnetize the part. Preferably, the oscillator is initially operated at a certain rate and its rate of operation is then progressively reduced to cause the control signals to be applied at progressively later points.

According to a specific feature, a voltage is applied to a resistance-capacitor timing circuit of the oscillator which voltage is gradually changed to control the rate of operation of the oscillator. The voltage is preferably applied through the use of a capacitor the charge of which is changed automatically with time, following the initiation of the demagnetization operation.

This invention contemplates other objects, features and advantages which will become more fully apparent from the following detailed description taken in conjunction with the accompanying drawings which illustrate preferred embodiments and in which:

FIG. 1 is a schematic diagram of magnetic particle inspection apparatus constructed according to the invention; and

FIG. 2 is a view illustrating waveforms, for the purpose of explaining the operation of circuits shown in FIG. 1.

Reference numeral 10 generally designates magnetic particle inspection and demagnetizing apparatus constructed in accordance with the principles of this invention. In the operation of the apparatus 10, a part 11 to be tested may be placed between a pair of contacts 13 and 14 for passage of current through the part to develop a magnetic field therein. After such magnetization, magnetic particles are applied to the surface of the part 11, either in dry form or in a fluid medium, to be attracted over and concentrated by localized magnetic fields produced by cracks or inhomogeneities in the part. In the alternative, a part 15 may be magnetized by placing it within a coil 16.

To develop the field in part 11 or in part 15, a secondary winding 17 of a transformer 18 is selectively connected through ganged selector switch contacts 19 and 20 either to the contacts 13 and 14 or the coil 16. In accordance with a specific feature of the invention, the system may be used for applying either AC current or half-wave DC current, a pair of parallel-connected silicon diodes 21 and 22 being connected in series between the secondary winding 17 and the selector switch contact 19, with a switch 23 being connected in parallel with the diodes 21 and 22. With the switch 23 closed, an AC current is applied while with the switch 23 open, a half-wave DC current is applied.

The transformer 18 has a primary winding 24 which is connected to the anode of a silicon-controlled rectifier 25 and to the cathode of a silicon-controlled rectifier 26. The cathode of the silicon-controlled rectifier 25 and the anode of the silicon-controlled rectifier 26 are connected together and to a terminal 27, a terminal 28 being connected to one end of the primary winding 24. Terminals 27 and 28 are connected to a suitable source of alternating current such as, for example, a source of 470 volt 60 Hz. current. A voltage-limiting and protective device 29 may preferably be connected across the rectifiers 25 and 26.

A control signal is applied to the gate of the silicon-controlled rectifier 26 at a point in a positive half cycle, or a number of successive positive half cycles, in which the terminal 27 is of positive polarity, to cause conduction of the silicon-controlled rectifier 26 until the end of each such positive half cycle. In the operation in which an alternating field is developed in the part 11 or the part 15, a control signal is similarly applied to the gate of the silicon-controlled rectifier 25 at points in negative half cycles, to cause conduction of the rectifier 25 until the end of each such negative half cycle. In the operation in which a half-wave field is applied to the part 11 or the part 15, with the switch 23 open, a switch 30 is opened to prevent application of a control signal to the rectifier 25.

In either operation, the flow of magnetizing current is always terminated with a uniform steep waveform and with any given setting of the control circuitry, the remnant magnetization of successive parts placed between the contacts 13 and 14 or in the field of the coil 16 will be uniform and consistent. This is highly advantageous in that the degree of concentration of magnetic particles over a defect provides a reliable indication of the character of the defect, when the magnetization is uniform.

To apply the control signal to the control electrode or gate of the silicon-controlled rectifier 26, it is connected through a resistor 31 and a capacitor 32 in parallel to the cathode of a silicon-controlled rectifier 33 having an anode connected through a diode 34 to one terminal of a secondary winding 35 of a transformer 36, the anode of the silicon-controlled rectifier 33 being also connected through a capacitor 37 to the other terminal of the secondary winding 34 which is connected to the cathode of the silicon-controlled rectifier 26. To limit the firing voltage applied to the silicon-controlled rectifier 26, a zener diode 38 is connected between the gate and cathode thereof.

The transformer 36 has a primary winding 39 which is connected to circuit points 40 and 41, connected to the secondary winding 42 of a stepdown transformer 43, having a primary winding 44 connected to terminals 27 and 28.

To control conduction of the silicon-controlled rectifier 33 and to thereby control conduction of the silicon-controlled rectifier 26, the gate and cathode of the silicon-controlled rectifier 33 are connected to the secondary winding 45 of a pulse transformer 46, a resistor 47 being connected across the secondary winding 45. A primary winding 48 of the pulse transformer 46 is connected to an oscillator circuit, described hereinbelow.

A substantially identical circuit is provided for firing the silicon-controlled rectifier 25, including a silicon-controlled rectifier 49, an additional secondary winding 50 on the transformer 36 and an additional secondary winding 51 of the pulse transformer 46, and resistor, capacitor and diode components are identical to and connected in the same manner as the components above described.

The control oscillator comprises a unijunction transistor 52 the first base electrode of which is connected to an output terminal 53 of a bridge rectifier comprising four diodes 54, input terminals of the bridge rectifier being respectively connected directly and through a resistor 55 to the circuit points 41 and 40. A second base electrode of the unijunction transistor 52 is connected through a resistor 56 to a second output terminal 57 of the bridge rectifier. The emitter of the unijunction transistor 52 is connected through a capacitor 58 to a circuit point 59 which is connected through the primary winding 48 of the pulse transformer 46 to the terminal 53, a diode 60 being connected in parallel with the winding 48. The emitter of the unijunction transistor 52 is also connected through normally closed contacts 61 and 62 of "DEMAG" and "MAG" pushbutton switches 61 and 62 to the circuit point 59. In addition, the emitter of the unijunction transistor 52 is connected to the collector of a transistor 63 having an emitter connected through a resistor 64 to the terminal 57. The base of the transistor 63 is connected to the terminal 57 through the

parallel combination of a capacitor 65 and a resistor 66 and is also connected through a capacitor 67 to a circuit point 68, a second normally closed contact 69 of the "DEMAG" switch being connected across the capacitor 67. Circuit point 68 is connected through an adjustable resistor 70 and a fixed resistor 71 to the terminal 53. A Zener regulating diode 72 is preferably connected between the terminals 53 and 57. With regard to the general operation of the circuit, switch 62 is connected in circuit with control means which function to apply control signals to the control electrodes for gates of the silicon-controlled rectifiers 25 and 26, such control means being formed by the combination of the unijunction transistor 52 and associated components and the silicon-controlled rectifiers 33 and 49 and associated components. When switch 62 is open, i.e. in a first condition, the unijunction transistor 52 is operative and the silicon-controlled rectifiers 33 and 49 function to effect application of control signals to the control electrode means or gates of the rectifiers 25 and 26 to initiate conduction of one or the other of the rectifiers 25, 26 in each half cycle of the alternating current to remain conductive until the end of each half cycle. At any time subsequent to the point of conduction and prior to the corresponding point of the next subsequent half cycle, the switch 62 may be closed, i.e. operated to a second condition, to prevent application of a control signal to the gate of the rectifier 25 or the rectifier 26 during the next subsequent half cycle. Thus, if rectifier 25 is conductive at the time that the switch 62 is closed or operated to its second condition, the control signal will not be applied to the rectifier 26 during the next subsequent half cycle. Conversely, if rectifier 26 is conductive when the switch 62 is closed, the control signal will not be applied to the gate of the rectifier 25 and the rectifier 25 will not conduct during the next subsequent half cycle. With this operation, conduction of current to the field-developing means is consistently discontinued with a steep wave shape. The remnant magnetization from one part to another is uniform and the degree of concentration of magnetic particles over a defect provides an accurate indication of the character of the defect.

The operation will now be described in detail with respect to FIG. 2 which shows the waveforms produced at various points of the circuit. Reference numeral 73 indicates the form of the supplied AC voltage, supplied to terminals 27 and 28 and also developed with reduced amplitude across the secondary winding 42 of transformer 43 and with more reduced amplitude across the secondary windings 35 and 50 of the transformer 36. Reference numeral 74 indicates the waveform developed by the bridge rectifier 54 and the Zener diode 72 at the terminals 53 and 57.

With both the "MAG" and "DEMAG" switches unactuated, the emitter of the unijunction transistor 52 is at a relatively low potential level, and the transistor 52 does not fire. When the "MAG" pushbutton switch contact 62 is opened, the capacitor 58 will charge through the transistor 63 until the firing point of the unijunction transistor 52 is reached, whereupon the transistor 52 will conduct to discharge the capacitor 58 and to develop a pulse of current through the primary winding 48 of the pulse transformer 46, to thereby apply a pulse of current from either the secondary winding 45 or the secondary winding 51 to the gate-cathode circuit of either the silicon-controlled rectifier 33 or the silicon-controlled rectifier 49, depending upon the polarity of the particular half cycle. During positive half cycles, the control rectifier 33 may be fired while during negative half cycles the control rectifier 49 may be fired. When either the rectifier 33 or rectifier 49 is fired, a firing pulse is applied either to the rectifier 26 or the rectifier 25 to cause it to conduct until the end of the half cycle in which conduction is initiated.

When the adjustable resistor 70 has a comparatively low value, the effective resistance of the transistor 63 is also comparatively low and the unijunction transistor 52 may fire a number of times during each half cycle, the waveform of the voltage applied to the primary 48 of the pulse transformer 46 being indicated by reference numeral 75 in FIG. 2, under such

conditions. However, only the first pulse during each half cycle will result in the firing of one or the other of the rectifiers 25 or 26 after which the rectifier so fired will remain conductive until the end of the half cycle. Thus reference numeral 76 indicates the waveform of current through rectifier 26 under conditions where the timing resistor 70 has a low value while reference numeral 77 indicates the waveform of current through the rectifier 25 under such conditions. It is noted that AC operation is now assumed. With half-wave operation, i.e. with the switch 30 opened, the rectifier 25 would not conduct.

Under the conditions just described, each pulse of current through the rectifier 25 or the rectifier 26 is only a few degrees less than a full half cycle, and a large magnetizing current will flow through the part 11 or through the coil 16, with a shape which is almost sinusoidal, indicated by reference numeral 78.

When the timing resistor 70 is adjusted to have a relatively high value, the voltage across the timing capacitor 58 will not reach the firing voltage of the unijunction transistor 52 until close to the end of a positive half cycle. Reference numeral 79 indicates the waveform of the voltage applied to the pulse transformer 46 under such conditions. Reference numeral 80 indicates the waveform of the current through the rectifier 26 while reference numeral 81 indicates the waveform of current through the rectifier 25 and reference numeral 82 indicates the waveform of current through the part 11 or through the coil 16. It is noted that the current pulses developed are of much shorter duration and of reduced amplitude. The effective value of the magnetizing current under such conditions is only a very small fraction of the effective value of the magnetizing current obtained when the timing resistor 70 has a low value.

Accordingly, the effective value of the magnetizing current can be controlled over a wide range. It is also noted that at any given position of adjustment of the timing resistor 70, the final pulse of current will have the same wave shape, regardless of when the switch 62 is closed. Thus if switch 62 is closed before the instant of time at which the unijunction transistor 52 would otherwise produce the firing pulse, the firing pulse will not be developed. If switch 62 is closed after the development of a firing pulse, it will have no effect upon the continued flow of current through the rectifier 25 or the rectifier 26 during the remainder of the half cycle.

To allow adjustment of the effective value of the magnetizing current down to very low values, it is important that sufficient voltage be applied to the rectifier 33 at the end portion of each positive half cycle and to the rectifier 49 at the end portion of each negative half cycle. This is accomplished through the use of the diode 34 and the capacitor 37, and corresponding components of the circuit for rectifier 49. The capacitor 37 is charged through the diode 34 to nearly the peak value of the voltage developed across the secondary winding 35 so that a relatively high voltage is available for firing the rectifier 33 even though the voltage of the secondary winding may be relatively low at such time. The diode 34, of course, isolates the capacitor 37 from the winding 35 to prevent discharge of the capacitor 37 when the voltage across the winding 35 drops to a low value near the end of a positive half cycle. The capacitor 32 and the corresponding capacitor in the circuit of the rectifier 49 are important in producing rapid turn-on of the rectifiers 25 and 26.

Now with respect to the demagnetizing operation, when the "DEMAG" switch contacts 61 and 69 are opened, the operation initially is the same as in the magnetizing operation, the capacitor 67 being initially uncharged, to present substantially a short circuit. The initial current will be determined by the adjustment of the resistor 70. However, the capacitor 67 gradually charges up through current flow through resistors 66, 70 and 71, which produces the same effect as an increase in the value of the timing resistor 70. The rate of operation of

the unijunction transistor oscillator 52 is gradually reduced. Consequently, the firing point becomes progressively later and later in successive half cycles and the current through the part 11 or through the coil 16 is gradually reduced in magnitude while alternating in polarity. This is highly effective and causes demagnetization of the part 11 or the part 15.

Reference numeral 83 indicates a waveform of the unijunction transistor oscillator during an initial portion of a typical demagnetizing operation, while reference numeral 84 indicates the corresponding current through the part 11 or the coil 16.

By way of illustrative example, and not by way of limitation, the following values of components may be used:

Reference Numeral	Value
31	22 ohms
32	0.1 microfarads
37	1 microfarad
47	47 ohms
56	330 ohms
58	0.1 microfarads
64	330 ohms
65	35 microfarads
66	3,000 ohms
67	200 microfarads
70	25,000 ohms
71	62,000 ohms

The silicon-controlled rectifiers 25 and 26 may be type 2N4365, the rectifiers 33 and 49 may be type 2N1595, the unijunction transistor 52 may be type 2N2646 and the transistor 63 may be type 2N3638. The AC voltage between terminals 40 and 41 may be 115 volts and approximately 12 volts may be developed across each of the secondary windings 35 and 50.

It will be understood that modifications and variations may be effected without departing from the spirit and scope of the novel concepts of this invention.

We claim as our invention:

1. In demagnetizing apparatus, magnetic field-developing means adapted to be associated with a part to develop a magnetic field therein, a transformer having primary and secondary windings, coupling means for coupling said secondary winding to said magnetic field-developing means, means for coupling said primary winding to a source of alternating current including controlled rectifier means arranged to conduct in both positive and negative half cycles of the alternating current and having control electrode means, and control means for applying control signals to said control electrode means to render said controlled rectifier means conductive at a point in each half cycle of the alternating current to remain conductive until the end of each half cycle, said control means including demagnetization control means for initially applying a control signal at a certain point in a half cycle and for applying control signals at progressively later points in subsequent half cycles to gradually reduce the magnetic field in the part and to demagnetize the part.

2. In demagnetizing apparatus as defined in claim 1, said control means including an oscillator arranged to operate during each half cycle, and said demagnetization control means being effective for initiating operation of said oscillator at a certain rate and for progressively reducing the rate of operation of said oscillator to cause application of a control signal at a certain point in one half cycle and at progressively later points in subsequent half cycles.

3. In demagnetizing apparatus as defined in claim 2, said oscillator being a unijunction transistor relaxation oscillator.

4. In demagnetizing apparatus as defined in claim 2, said oscillator including a resistor-capacitor timing circuit having a controllable effective resistance and said demagnetization control means including means for gradually changing said controllable effective resistance of said timing circuit.