This invention relates to high-frequency induction heating systems, and, while it is of general application, it is particularly useful in such systems of the type suitable for the surface treatment of a large quantity of machine or tool elements or stock on a production basis. The invention is concerned primarily with control and indicating systems incorporated in such heating systems and with provisions for adapting it to the treatment of work pieces having a wide range of high-frequency impedances.

In the heat treatment of a large quantity of standardized machine or tool elements or stock by a high-frequency induction heating system, it is desirable that the timing of the various phases of the heat-treating cycle be completely automatic after a manual initiation of the cycle, as distinguished from what might be termed a custom treatment of individual special parts and assemblies involving an adjustment of the settings of the various portions of the heating apparatus for each piece being treated and a careful watching of the heating cycle by the operator. Automatic control of the heat-treating cycle greatly increases the rate of treatment on a mass production basis and also insures greater uniformity of heat treatment by largely eliminating the human factor. At the same time, it is desirable to be able to adjust the various phases of the heating cycle to accommodate the system to various types of heat treatments and to various types of work pieces. Furthermore, it is desirable to be able to adjust the coupling of the system with the work pieces to compensate for the variations in the high-frequency impedances of the work pieces.

It is an object of the invention, therefore, to provide a new and improved high-frequency induction heating system including provisions for automatically controlling the heat-treating cycle of the work piece and one which is particularly useful for the heat treatment of a large quantity of similar elements on a production basis.

It is another object of the invention to provide an improved high-frequency induction heating system incorporating a novel indicating system for giving an indication, preferably visual, of the particular one of several phases of the heat treating cycle taking place.

It is another object of the invention to provide a new and improved high-frequency induction heating system which is particularly suitable for treatment of work pieces having a wide range of high-frequency impedances.

In accordance with the invention, in a high-frequency induction heating system including a heating inductor and a source of high-frequency energization therefor, there is provided a control system comprising manually operable circuit-controlling means and timing means having a normal cycle of operation between first and second operating conditions. The control system also includes circuit-control means responsive jointly to the timing means and the manually operable means for controlling the energization of the inductor, and relay means energized simultaneously with energization of the inductor for preventing a repetition of the heating cycle without a second operation of the manually operable means.

Further in accordance with the invention, in a high-frequency induction heating system including a heating inductor, a source of high-frequency energization therefor, and fluid quenching apparatus, there is provided a control system comprising timing means having first and second operating conditions with independent time delays in operating between said conditions in opposite senses. The control system also includes means responsive to operation of the timing means from the first condition to the second condition for determining the heating period of the inductor and means responsive to the operation of the timing means from the second condition to the first condition for determining the period of operation of the quenching apparatus.

Further in accordance with the invention, in a high-frequency heating system including a heating inductor and a source of high-frequency energization therefor, there is provided a control system comprising a supply circuit, a control circuit for controlling the energization of the source from the supply circuit and one or more protective devices for the system including circuit-controlling means in the control circuit. The control system also includes an indicating device energized from the supply circuit for giving an indication of its energization and means controlled by the control circuit for modifying the energization of the indicating device upon operation of one or more of the protective devices to give an indication thereof.

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

Figs. 1a and 1b, when laid end to end in the
order named, illustrate one embodiment of the present invention; and
Fig. 2 is an across-the-line diagram of the apparatus shown in Figs. 1a and 1b.

Referring now to Figs. 1a and 1b of the drawings, there is represented partially schematically a complete high-frequency induction heating system for treating work pieces having a wide range of high-frequency impedances. This system includes a heating inductor 10 for receiving a work piece 9 disposed in a positioning jig 8, and a source of high-frequency energization therefor comprising a vacuum tube oscillation generator 11. This generator comprises a plurality of vacuum tubes in parallel, only two of which 12a, 12b are shown for the sake of simplicity, although in practice a larger number may be utilized to provide the required power output. The common output circuit of the tubes 12a, 12b includes the frequency-determining circuit of the generator consisting of an auto-transformer 13, a tuning condenser 14 and the heating inductor 10 connected in a series circuit. The auto-transformer 13 is provided with taps 13a and an adjustable contact 13b to provide an adjustable coupling between the common output circuit of the vacuum tubes and the inductor 10, a portion of the auto-transformer being included in the frequency-determining circuit of the oscillation generator. Coupled to the auto-transformer 13 is a secondary feed-back winding 15 which is coupled to the input electrodes of the tubes 12a, 12b through a coupling condenser 16 and grid resistors 16a, 16b, respectively. A proper bias for the tubes 12a, 12b is developed across a grid-leak circuit comprising a high-frequency choke coil 17, an adjustable resistor 18 and grid-current meter 19 shunted by a resistor 20 and condenser 21. A by-pass condenser 22 is connected between the junction of the choke coil 17 and resistor 18 to ground. Parasitic suppressors comprising a parallel-connected resistor 23a and inductor 24a and a parallel-connected resistor 23b and inductor 24b are individually connected in the anode circuits of the tubes 12a, 12b, respectively, to suppress parasitic oscillations between the tubes.

The power for energizing the high-frequency generator 11 is derived from supply terminals 25, which may be a conventional 60-cycle, 220-volt system, through a switch or circuit breaker 26, a power auto-transformer 27 and a rectifier 28, more fully hereinafter, a rectifier transformer 29 comprising a primary winding 28a and a bi-phase secondary winding 28b, and a pair of rectifier tubes 29 and 30, preferably of the hot-cathode vapor-electric type. The tubes 29 and 30 with the winding 28b are connected as a conventional full-wave rectifier circuit, the neutral point of winding 28 being connected to ground through an adjustable resistor 31 and an ammeter 32 shunted by a resistor 33 and by-pass condenser 34, and being by-passed to ground for high-frequency currents by means of condenser 35. The filaments of the tubes 29 and 30, and in case these tubes are of the indirectly heated cathode type, their cathode heaters, are energized through a filament transformer 36 connected across the supply terminals 25 through an adjustable resistor 37 and the switch 28. Similarly the filaments of the tubes 12a, 12b, or in case these tubes are of the indirectly heated cathode type, their cathode heaters, are energized from the supply terminals 25 through a filament transformer 38 and an adjustable resistor 39 and the switch 28. A voltmeter 40 is connected across the filament circuit of the tubes 12a, 12b while the secondary winding of the transformer 38 is by-passed for high-frequency currents by condensers 41 and 42 connected in series. The adjustable resistors 37 and 39 are provided to control the filament voltages of the tubes 12a, 12b, 29 and 30 to the optimum value consistent with the operating conditions of these tubes to insure maximum life expectancy of the tubes. While-high potential unidirectional current is applied to the anode circuits of tubes 12a, 12b from the midpoint of the secondary winding of filament transformer 36, by-passed to ground by filter condenser 43, through a high-frequency choke coil 44 and the suppressors 23a, 24a and 23b, 24b.

From the description above it will be seen that the direct-current circuit of the rectifier 28, 29, 30 and the oscillation generator 11 may be traced from the midpoint of the secondary winding of the rectifier filament transformer 36 through the high-frequency choke coil 44, the suppressor circuits 23a, 24a and 23b, 24b and the tubes 12a, 12b, respectively, in parallel, through the midpoint of the secondary winding of the filament transformers 38 to ground, thence through the ammeter 32, resistor 31, midpoint of the secondary winding 28b, through one or another of the rectifier tubes 29, 30 back to the midpoint of the secondary winding of filament transformer 36.

In order to quench and temper the work piece after heat treatment, the system also includes a quenching apparatus comprising the nozzles 45 and 46 connected to a fluid supply pipe 47 which is connected through a valve 48 to a source of water or other cooling fluid. The tubes 12a, 12b is connected to be operated by the electromagnet 49 and actuating mechanism 50.

The induction heating system also includes a control system for initiating and controlling the heating and quenching cycle. This control system comprises a supply circuit consisting of condensers 50 and 51 connected to the supply terminals 25 through the switch 28. The primary portion of the autotransformer 27 comprising taps 27a and an adjustable contact 27b is connected across the supply circuit 50, 51, while a secondary portion of the autotransformer 27 comprising taps 27a and an adjustable contact 27b are connected across the primary winding 28c of the transformer 28 through the normally-open contacts S1 of an electromagnetic switch or contactor S.

The control system may be more readily traced from the simplified across-the-line diagram of Fig. 2, which is the exact electrical equivalent of Figs. 1a and 1b with the various relays and switches and their respective contacts disengaged and with the various portions of the control system arranged in the order of their sequence of operation.

Referring then to Figs. 1a, 1b and to Fig. 2, the control system includes a pair of control busses 52 and 53, the bus 52 being connected to the supply circuit conductor 50 through a fuse, if desired, and the bus 53 being connected to a tap 27a of the autotransformer 27. Between the control busses 52, 53 is connected a timer 54 through the contacts 55, 56 which are in series with the contacts 57, 58 of the switch 28.

The timer 54 is set for a predetermined delay period, generally a few seconds, during which time the switch is in the closed position, so that the primary winding 28a of the autotransformer 27 is energized.

At the end of the predetermined delay period, the timer 54 closes the contacts 55, 56, thereby energizing the primary winding 28a of the autotransformer 27. At this time, the switch 28 is in the closed position, so that the secondary winding 28b of the autotransformer 27 is connected to the supply circuit 50, 51, thereby energizing the rectifier transformer 29 and the remainder of the apparatus shown in Figs. 1a and 1b.

The timer 54 may be of any of several types well known in the art, there is illustrated in Fig. 1a an electronic timer of the type disclosed and claimed in copending application Serial No.
3,485,785 5 539,104, filed June 7, 1944, now Patent 2,396,898, and assigned to the same assignee as the present application.

The timer S4 comprises a vacuum tube repeater S5 connected to be excited from the control bus S2 through the switch Ss a rectifier tube S6 and a relay S7 having normally closed contacts S1c, S1d, and S7d, and normally open contacts S7b. The anode current excitation of the tube S5 is shunted by a smoothing or filtering condenser S8. A suitable negative grid bias has been developed for the control electrode of the tube S5 by means of an auxiliary rectifier S5 having a load circuit comprising a resistor S6 and filter condensers S1 and S2. The resistor S6 is provided with an adjustable tap S6a by means of which an adjustable negative bias may be applied to the control electrode of tube S5 through either a resistor R1 or an adjustable resistor R2 through a control circuit to be described hereinafter. The control electrode of the tube S5 is also connected to a time-constant circuit comprising an adjustable resistor R4 connected for C and the normally closed contacts S1c of relay S7.

The control system, which may be traced more readily from the simplified diagram of Fig. 2, also includes a control circuit S3 for controlling the energization of the high-frequency generator 11 from the supply circuit of S6, S1. This control circuit S3 extends between the busses S2 and S3 and includes a manually operable circuit control means, such as a toggle-operated switch Ss, for initiating the heating and quenching cycle in the contacts S7b of the timer S4, which, as described hereinafter, has a normal cycle of operation between its energized and de-energized operating conditions; and circuit control means responsive jointly to the relay S7 of the timer S4 and the manually operable switch Ss for controlling the energization of the timer S4 from the supply circuit. This latter circuit-control means comprises a relay CR2 having an operating winding included in the control circuit S3 and the electromagnetic switch S having a winding energized from the control busses S2, S3 through the normally-open contacts CR2a of the relay CR2a. This control circuit includes also the winding of actuating mechanism 49 energized through the normally-open contacts S7b of relay S7.

The control system also includes relay means energized simultaneously with the energization of the inductor for preventing repetition of the heating and quenching cycle without a second operation of the manually operable means. This relay means consists of a relay CR2 having a winding energized from the control busses S2, S3 through the normally-open contacts CR2s of the electromagnetic switch S and therefore energized simultaneously with the heating inductor upon the closing of the switch S. The relay CR2a is provided with a holding circuit which includes the manually operable switch Ss and its own normally-open contacts CR2a. The relay CR2a is also provided with normally-closed contacts CR2a included in the control circuit S3 with the winding of the relay CR2 in series with the manually operable switch Ss which, as will be pointed out from the supply circuit, is in series with the leading edge of the heating and quenching cycle of the system so long as the manually operable switch Ss is held closed. The relay CR2a is also provided with a holding circuit including its normally-open contacts CR2a and the auxiliary contact Ss of the switch S, this holding circuit being effective to maintain the relay CR2a energized under the control of the relay S7 of timer S4 even though the switch Ss is closed only momentarily.

The control system includes a plurality of protective devices for the system, each of which includes circuit-controlling contacts in series in the control circuit S3 between the control busses S2, S3. For example, the protective devices may comprise a switch Ss mechanically interlocked with the door of the housing for the apparatus to insure that the system as a whole is de-energized so long as the door is open for maintenance or repair. In order to insure the flow of cooling water through the quenching apparatus 45-49 inclusive, there is provided a water flow relay CR4 having normally closed contacts CR4a in series in the control circuit S3, these contacts opening upon the failure of the water supply. Also, there is provided an overload protective relay CR3 having a winding connected in series with the direct-current circuit of the power rectifier and shunted by the adjustable resistor S1. This relay is designed to open its normally-closed contacts CR3a in control circuit S3 upon the occurrence of an overload in the heating system. Also, there is provided a time-delay relay CR5 which may be a multi-stable type of relay, connected between the control circuit S3 and the control circuit including the contacts CR2a, the relay connected between the control busses S2, S3 and having normally open contacts CR2a included in series in the control circuit S3 and effective to delay the excitation of the control system and the energization of the high-frequency generator 11 until the heaters of the several tubes of the system have reached normal operating temperatures.

The control system also includes an indicating device, such as a lamp S5, connected between the control busses S2, S3 through an impedance means such as a resistor S6 for giving an indication of the energization of the control busses S2, S3. Resistor S6 has a value which normally reduces the illumination of lamp S5 substantially below its normal value. The control system also includes means controlled by the control circuit S3 for modifying the energization of the illuminating lamp S5 upon operation of any one or more of the protective devices described. As illustrated, this comprises the connection S7 between the junction of the lamp S5 and resistor S6 and the point in the control circuit including the contacts of all of the protective devices, whereby, when the contacts of these devices are all closed, this portion of the control circuit S3 is effective to by-pass or short-circuit the resistor S6 in series with the lamp to increase its illumination to normal. This connection also has the effect that, if the manually operable switch Ss is operated while the contacts of any one or more of the protective devices are open, the lamp S5 is effectively de-energized or short-circuited through the portion of the control circuit including the winding of that relay CR2a, the contacts CR2a and the switch Ss.

Considering now the operation of the high-frequency generator and its associated heating inductor, it will be seen that the autotransformer 27, the transformer 28 and the tubes 29 and 30 comprise a conventional rectifier circuit for deriving a high-potential unidirectional current. This current, or a predetermined portion thereof, flows through the meter 32 which gives an indication representative of the high-frequency current being supplied to the heating inductor 10. This
high-voltage rectified current is supplied to the high-frequency generator 11 which constitutes an oscillator of conventional type. The feedback between the anode circuits of the tubes 12a, 12b through the windings 13 and 16 maintain the apparatus in oscillation at the frequency determined by the constants of the circuit 13, 14, 10. Since the oscillating current in the frequency-determining circuit of the generator flows in series through the heating inductor 10, there is developed thereby a high-frequency electromagnetic field which is effective to heat the work piece 9. The adjustable tap 57b of the autotransformer 27 is utilized to compensate for fluctuations in the line voltage of the supply terminals 25. Similarly, the adjustable contact 27d of the autotransformer 27 is utilized to select various anode voltages for the high-frequency generator to control the intensity of the high-frequency field developed by the inductor 10 and thus the nature of the heat treatment.

In practice it is found that the high-frequency impedance of the work piece 9 may vary considerably in accordance with its dimensions and physical composition. This variation in impedance is reflected into the frequency-determining circuit of the generator 11 and, unless the effects of such variation are compensated, affects the efficiency of the oscillator. The effects of such variations are compensated and a high oscillator efficiency is maintained by adjusting the coupling between the frequency-determining circuit and the output circuit of the tubes 12a, 12b. This coupling may be either conductive, that is with the elements directly in circuit with each other, or it may be impedance coupling or inductive or transformer coupling or a combination of these. In the circuit illustrated, this coupling is adjusted by adjustment of contact 13b of autotransformer 13, which is effective to match the load impedance, as affected by the work piece 9, to the circuit parameters of the oscillator.

It is well known that, in the operation of vacuum tubes in parallel, there are often developed high-frequency parasitic or circulating currents between the tubes which, in a conductive state, have a relatively low impedance to such circulating currents in the system described. Such parasitic oscillations are suppressed by the parasitic suppressors 23a, 24a and 23b, 24b individually connected in the anode circuits of tubes 12a, 12b respectively. The constants of these suppressor circuits are selected so that they do not add considerably to the impedance of the tube circuits at the operating frequency of the generator 11, but do offer a substantial impedance to parasitic circulating currents between the tubes.

The operation of the electronic timer 54 is explained in detail in the above mentioned copending application Serial No. 539,104. However, in brief, upon closing of the switch 8a there is developed across the resistor 59 a negative unidirectional bias potential by the rectifier 55. This potential is applied over the circuit including the resistor R5 and R6 in parallel through the contact 59 of the switch S to the control electrode of tube 55. The magnitude of this negative bias is selected by appropriate adjustment of the tap 60a to maintain the tube 59 non-conductive. When the manually operable switch 56 is operated and thereby opens the contacts 59 of switch S, as explained hereinafter, the control electrode of tube 55 is disconnected from the negative bias derived from resistor 59 and the charge built up on condenser C gradually discharges through the adjustable resistor R6. When this negative bias has decreased to the point that the tube 56 becomes substantially conductive, the anode current of the tube 55 is effective to pick up the relay 57, thereby opening the normally closed contacts 57c in the discharge circuit of condenser C. As explained hereinafter, the operation of the relay 57 is also effective to open the switch 56 thereby closing the contacts 57b through the control electrode of tube 55 and the charging resistor R5, while the normally-open contacts 57d in series with the resistor R5 are opened. The condenser C is thereupon gradually re-charged by the potential at the tap 60a through the adjustable resistor R5 until the bias across the condenser is sufficient to substantially cut off the space current of tube 55, whereupon the relay 57 drops out and the timer 54 is in condition for a repetition of this cycle, unless interrupted by the control system described hereinafter.

As the electronic timer 54 is utilized in the system described, the resistor R4 has a relatively small value so that, upon initiation of the operation of the timer by closing of switch 56, the condenser C in the circuit of the control electrode of tube 55 is rapidly charged to its final value. Furthermore, the discharging of the condenser C through the resistor R5 is utilized to determine the heating period of the heating system while the subsequent charge of the condenser C through the resistor R4 is utilized to determine the period of operation of the quenching apparatus. It is desirable that these two periods be subject to independent adjustment by adjustment of the values of the resistors R5 and R6 respectively. However, neglecting the resistor R4 during the charging period the resistor R5 is in series with the resistor R4 across the source of bias potential and these two resistors comprise a voltage divider so that the final voltage across the condenser C would be only a fraction of that derived from tap 60a and would be affected by the setting of the resistor R5. However, the addition resistor R4 of a very much lower value than R5 and R6 effectively bypasses the resistor R4 during the initial charging of the condenser C at the beginning of each operating cycle. By this means the heating and quenching intervals can be independently adjusted. Thus it is seen that the timer 54 including the relay 57 constitutes a time-delay relay having a normal cycle of operation between circuit opening and circuit closing positions of contacts 57a and, in case both contacts 57a and 57b are utilized, having a normal cycle of operation between two circuit closing positions.

Coming now to the operation of the control system embodied in the heating system of the invention, which may be readily understood by reference to Fig. 2 of the drawings. If completely manual operation of the system is desired, the switch 56 is left open. If then the contacts of the several protective devices are closed in the circuit 53, that is, the door switch 56 is closed, the water flow relay CR4 responds to a normal water supply, the overload relay CR4 is not operative and the time-delay thermal relay CR4 has operated to close its contacts, a circuit is completed through the normally closed contacts 57a of relay 57, the operating coil of relay CR4 and the manually operable switch 56. Closing of the switch 56 is then effective to pick up the relay CR4, which, as indicated in the next branch of the circuit, energizes the winding of the electromagnetic switch or contactor S which thereupon
A485,785 closes its contacts S₁ to energize the high-frequency generator 11 to heat the work piece 9. Under this condition the energization of the high-frequency generator 11 and the heating of the work piece are under the complete control of the manually operable switch S₅.

In case it is desired to have the heating and quenching of the work piece under the control of the timer 54, the switch S₅ is closed. Upon closing of the manually operable switch S₅ the heating cycle is initiated as described above. In this instance, however, upon the operation of the relay CR₂ and the switch S₅, the winding of the control relay CR₁ is energized through the contact S₅ and a holding circuit for the relay CR₂ is established around the manually operable switch S₅ through the contacts CR₁₀ and S₅ so that the relay CR₂ and the switch S₅ remain closed even after the release of the switch S₅.

As the relay CR₁₀ picks up, it opens its contacts CR₁₀, thus interrupting the energizing circuit for the winding of the relay CR₂ except for the holding circuit described above. At the same time CR₁₀ closes its contacts CR₁₀ and establishes a holding circuit for itself through these contacts and the manually operable switch S₅. The effect of this holding circuit is that, so long as the switch S₅ is held closed, only a single cycle of the control system is effected. This is true since, as soon as the relay contacts S₅ are opened by the timer, the relay CR₂ and the switch S₅ both drop out, the holding circuit for the relay CR₂ being broken at the contacts CR₁₀. However, the relay CR₁₀ is still energized through its holding circuit described and its normally closed contacts CR₁₀ are held open and prevent reclosing of relay CR₂ and switch S₅. In other words, during automatic operation the manually operable switch S₅ only initiates the cycle of the control system, but has no effect on the durations of the various phases of this control cycle, while the relay CR₁₀ prevents a repetition of the cycle.

The heating of the work piece 9 initiated as described above continues until the timer 54 picks up the relay S₅ to open the contacts S₅ at the completion of the discharge of the condenser C through resistor R₆, which operation terminates the heating period. At the same time the relay 57 closes its contacts S₅ to energize the winding of the actuating mechanism 49 of the quenching valve 48 to apply quenching fluid to the work piece 9. When the condenser C has been charged through the resistor R₆ to a value such that the tube 56 deenergizes the relay 57, it drops out, opening its contacts S₅ to terminate the quenching operation and close the contacts S₅. The control system is now in condition for the repetition of the heating and quenching cycle, which will usually be initiated only after replacement of the work piece 9 by an untreated work piece. This restoration of the control system to its normal condition is, however, conditioned upon the release of the manually operable switch S₅ as described above. If by chance this switch is manually replaced, the system will operate through a single cycle of operation and is then locked out.

The pilot lamp 65 of the control system is adapted to have its energization, and therefore its illumination, modified greatly upon operation of one or more of the protective devices having circuitry in the control system 63 to give distinctive indications of such operations. Specifically, the lamp 65 is energized from the control busses 52, 53 through the impedance or resistor 66 and therefore initially operates with reduced illumination. When the protective devices S₄, CR₃, CR₅ and CR₆, described above, all assume their safe positions, their respective contacts are closed and the portion of the control circuit 63 including them is effectively connected around or short-circuits the resistor 66 to bring up the energization and illumination of the lamp 65 to its normal value. On the other hand, if the switch S₅ is closed while the contacts of any of the protective devices are open, this fact is indicated by extinguishing the lamp 65. This extinguishing is effected by an effective short-circuit of the lamp 65 through the portion of the control circuit 63 including the contacts S₇ of relay 87, the winding of the relay CR₁₀, the contacts CR₁₀, and the switch S₅.

Thus the high-frequency induction heating system described above comprises an arrangement for effectively heating a work piece under optimum operating conditions by compensating for variations in the supply voltage and variations in the high-frequency impedance of the work piece. It also comprises a control system which may be operated either non-automatically, so that the heating and quenching operations can be determined at will by the operator, or automatically, whereby the heating and quenching operations may be adjustable controlled by a timing apparatus included in the control system. The system further includes an indicating device or lamp for giving different distinctive indications of various operating conditions of the system.

While there has been described what is considered to be the preferred embodiment of the invention, it will be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the spirit or scope of the invention.

What I claim as new is:

1. A high-frequency induction heating system including a heating inductor and a source of high-frequency energization therefor, a control system comprising, manually operable circuit-control means, timing means having a normal cycle of operation between first and second operating conditions, circuit-control means responsive jointly to said timing means and said manually operable means for controlling the energization of said inductor, and relay means operating simultaneously with energization of said inductor for preventing repetition of the heating cycle without a second operation of the manually operable means.

2. In a high-frequency induction heating system including a heating inductor and a source of high-frequency energization therefor, a control system comprising, manually operable circuit-control means, a time-delay relay having a normal cycle of operation between circuit opening and circuit closing positions, time means having a normally means controlled jointly by said relay and said manually operable means for controlling the energization of said inductor, and relay means energized simultaneously with energization of said inductor for preventing repetition of the heating cycle without a second operation of the manually operable means.

3. In a high-frequency induction heating system including a heating inductor and a source of high-frequency energization therefor, a control system comprising, manually operable circuit-control means, a time-delay relay having a normal cycle of operation between circuit opening and circuit closing positions, an electromagnetic switch means having an operating winding energized jointly by means of said relay and said
manually operable means for controlling the energization of said inductor, and relay means energized simultaneously with energization of said inductor for preventing repetition of the heating cycle without a second operation of the manually operable means.

4. In a high-frequency induction heating system including a heating inductor and a source of high-frequency energization therefor, a control system comprising, manually operable circuit-control means, a time-delay relay having a normal cycle of operation between circuit opening and circuit closing positions, an electromagnetic switch means having an operating winding energized jointly by means of said relay and said manually operable means for controlling the energization of said inductor, and a relay having a winding energized simultaneously with energization of said inductor and a holding circuit therefor including said manually operable means and having contacts effective upon energization of said relay winding to interrupt the energization of said switch winding through said manually operable means, thereby preventing repetition of the heating cycle without a second operation of the manually operable means.

5. In a high-frequency induction heating system including a heating inductor and a source of high-frequency energization therefor, a control system comprising, manually operable circuit-control means, a time-delay relay having a normal cycle of operation between circuit opening and circuit closing positions, an electromagnetic switch means having an operating winding energized jointly by means of said relay and said manually operable means for controlling the energization of said inductor, a holding circuit for said switch winding including contacts of said switch means, and relay means energized simultaneously with energization of said inductor for preventing repetition of the heating cycle without a second operation of the manually operable means.

6. In a high frequency induction heating system including a heating inductor, a source of high frequency energization therefor and fluid quenching apparatus, the combination of a control system comprising, timing means having a first and second operating control position, said timing means having independently controllable time delays in operating in different directions between said two positions, means responsive to the operation of said timing means from said first operating control position to said second operating control position for controlling said timing means to determine the period of operation of the quenching apparatus, and means responsive to the operation of said timing means from said second operating control position to said first operating control position for controlling said timing means to determine the period of operation of the quenching apparatus, and means for initiating the heating and quenching cycle, and means energized simultaneously with energization of said inductor for preventing repetition of the heating and quenching cycle without a second operation of said manually operable means.

H. F. STORM

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,202,759</td>
<td>Denneen et al.</td>
<td>May 28, 1940</td>
</tr>
<tr>
<td>2,276,643</td>
<td>Bates</td>
<td>Mar. 17, 1942</td>
</tr>
<tr>
<td>2,293,047</td>
<td>Denneen et al.</td>
<td>Aug. 18, 1942</td>
</tr>
<tr>
<td>2,324,525</td>
<td>Mittelmann</td>
<td>July 20, 1943</td>
</tr>
<tr>
<td>2,326,006</td>
<td>Dunn et al.</td>
<td>Aug. 10, 1943</td>
</tr>
<tr>
<td>2,331,510</td>
<td>Blankenberg</td>
<td>June 30, 1944</td>
</tr>
<tr>
<td>2,368,471</td>
<td>Horan</td>
<td>Jan. 30, 1945</td>
</tr>
<tr>
<td>2,390,981</td>
<td>Bivens</td>
<td>Dec. 18, 1945</td>
</tr>
<tr>
<td>2,396,898</td>
<td>Storm</td>
<td>Mar. 19, 1946</td>
</tr>
<tr>
<td>2,402,312</td>
<td>Burch</td>
<td>June 18, 1946</td>
</tr>
<tr>
<td>2,402,352</td>
<td>Strickland</td>
<td>June 28, 1946</td>
</tr>
<tr>
<td>2,403,359</td>
<td>Strickland</td>
<td>July 20, 1948</td>
</tr>
<tr>
<td>2,344,599</td>
<td>Stoltz</td>
<td>Jan. 13, 1945</td>
</tr>
</tbody>
</table>

FOREIGN PATENTS

<table>
<thead>
<tr>
<th>Number</th>
<th>Date</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>117,863</td>
<td>Apr. 17, 1943</td>
<td>Australia</td>
</tr>
</tbody>
</table>

2,485,785

12

positions, means responsive to operation of said relay in one direction between said two positions for determining the heating period of said inductor, means responsive to operation of said relay between said positions in the other direction for determining the period of operation of the quenching apparatus.

8. In a high frequency induction heating system including a heating inductor, a source of high frequency energization therefor and a fluid quenching apparatus, the combination of a control system comprising, a timing relay operable between two circuit closing positions, said timing delay relay having independently controllable time delays in operating in different directions between said two positions, electromagnetic switch means having a winding energized through said relay in one of said positions and contact means for controlling the energization of said inductor, and electromagnetic means having a winding energized through said relay in the other of said positions for actuating said quenching apparatus.

9. In a high frequency induction heating system including a heating inductor, a source of high frequency energization therefor and fluid quenching apparatus, the combination of a control system comprising, timing means having a first and second control operating position, said timing means having independently controllable time delays in operating in different directions between said two positions, means responsive to the operation of said timing means from said first operating control position to said second operating control position for controlling said timing means to determine the period of operation of the quenching apparatus, manually operable means for initiating the heating and quenching cycle, and means energized simultaneously with energization of said inductor for preventing repetition of the heating and quenching cycle without a second operation of said manually operable means.