Oct. 28, 1947. J. P. JORDAN 2,429,819

HIGH-FREQUENCY HEATING APPARATUS

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Fig. 1.

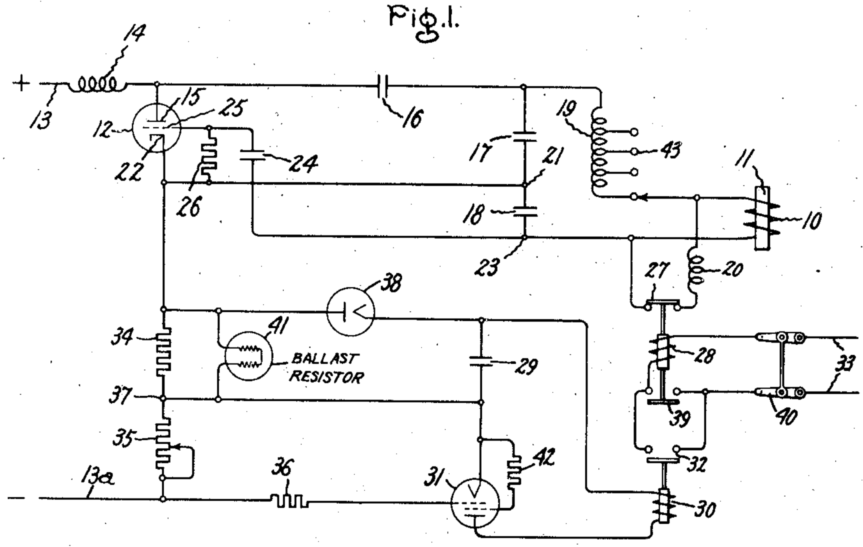
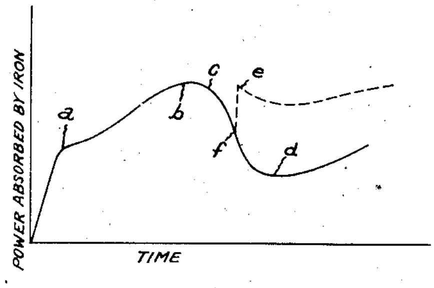


Fig. 2.



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HIGH-FREQUENCY HEATING APPARATUS

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My invention relates to high frequency heating apparatus, more particularly to high frequency heating apparatus of the oscillator generator type for heating magnetic work pieces by electromagnetic induction to temperatures higher than the decalescent temperature, and has for its object simple and reliable means for increasing the power input to the work piece, such as when the decalescent temperature is reached, thereby to maintain the power input at least as high as a predetermined value.

In carrying out my invention in one form I provide a control energy storage device, such as a capacitor, which is charged during the maximum power early stage of the heating operation and which, when the power input thereafter decreases, serves to operate means including an auxiliary electric discharge device for increasing the power input substantially to its former value.

For a more complete understanding of my invention, reference should be had to the accompanying drawing, Fig. 1 of which is a diagrammatic representation of high frequency heating apparatus embodying my invention; while Fig. 2 is a typical time-power curve for a magnetic work piece or charge supplemented with a broken line curve showing the increase in power input in accordance with my invention.

Referring to the drawing, Fig. 2 is a typical curve of the power input to a steel charge or work piece during a high frequency electromagnetic induction heating operation with a frequency of approximately 530,000 cycles per second. When the heating circuit is closed the power input increases rapidly although the power increase is delayed somewhat by the time required for the heating of the electric discharge devices. At the point *a* the oscillator begins to supply its full power to the work piece. This power increases, as indicated by the curve, as the steel heats because of the increase in its resistivity with the increase in temperature. The power input becomes a maximum at the point *b* which represents the decalescent temperature. Soon thereafter at some time between the points *b* and *c* the steel becomes non-magnetic and the power absorbed by the steel drops to some low value *d*. This decrease in power input results from the increased depth of penetration of the induced eddy currents in the steel when the steel becomes non-magnetic whereby the resistance to the flow of the eddy currents is greatly decreased with consequent decreased power loss. On the other hand, when the steel is magnetic the induced eddy currents are confined to a relatively

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shallow surface layer of the steel, which layer because of its small cross section has a high resistance. From the low value *d* the power increases again with increase in the temperature of the steel because of its increased resistivity.

It is therefore evident that this decrease in power input when the steel is heated above the decalescent temperature appreciably increases the time required to heat the material to the desired temperature. In accordance with my invention, I provide means responsive to the decrease in the power input from the point *b* to the point *f* of Fig. 2 for increasing the power input to the charge substantially to its former value, i. e., to the point *e* on the broken line curve. Thereafter, as represented by the broken line curve, the power input may decrease somewhat with further decrease in the magnetic properties of the steel and then again increases with increase in resistivity as the temperature rises.

I have shown my invention in one form as applied to a typical electric discharge device oscillator high frequency generator of the Colpitts type for supplying current at a frequency of approximately 530,000 cycles per second to an induction heating means shown as a coil **10** surrounding a work piece or article **11** made of magnetic material such as steel.

The oscillator generator comprises a suitable electric discharge device **12** having its plate-cathode circuit supplied with direct current from a positive supply main **13** and a negative supply main **13***a* which may be and preferably is grounded. A suitable inductance **14** is connected between the supply main **13** and the anode **15** of the discharge device. The plate or anode **15** is connected through a capacitor **16** to a tank oscillation circuit comprising two capacitors **17** and **18** connected in series with each other and having connected in parallel with them and in series with each other the inductance coil **19** and the induction heating coil **10**. A power regulating impedance, shown as an inductance coil **20** is connected in parallel with the coil **10**. A tap **21** between the two capacitors is connected to the cathode **22** of the discharge device, while the lower terminal **23** of the capacitor **18** is connected through a capacitor **24** to the grid **25** of the discharge device. This latter connection, it will be understood, applies a negative bias to the grid. A suitable leakage resistor **26** is connected between the grid and cathode.

It will be understood that suitable means (not shown) is provided for supplying the direct current to the supply mains 13 and 13a; for example, two-way electric discharge device rectifiers may be used for supplying the direct current at a suitable voltage from an alternating current supply source.

In accordance with my invention, I provide electric power regulating means comprising an inductance 20 connected in the high frequency electric supply circuit in parallel with the coil 10 whereby the power or current supplied to the coil can be increased by disconnecting the inductance 20. The inductance 20 may be disconnected by means of a normally closed switch 27 in circuit with the inductance and operated to its open position by means of a coil 28. The coil 28 is energized by energy storage means shown as a capacitor 29 which is charged to a maximum value when the power input to the coil 10 is at a maximum. Thereafter when the power input to the coil 10 decreases the capacitor 29 discharges through the coil 30 and an electric discharge device 31 automatically controlled by the drop in power input so as to close a switch 32 and energize the coil 28 from a supply source 33.

For the control of the capacitor 29 and the discharge device 31, I have provided two resistances 34 and 35 which are connected in series with each other in the plate-cathode circuit of the discharge device 12, the resistance 35 being variable. As shown, the resistances are connected between the cathode 22 and the supply main 13a. The lower end of the resistance 35, i. e. the supply main 13a, is connected through a resistance 36 to the grid of the discharge device 31 while the point 37 between the two resistances is connected to the cathode of the discharge device 31 and to the lower side of the capacitor 29. A rectifier electric discharge device 38 is connected between the upper end of the resistance 34 and the upper side of the capacitor 29. Also, as previously indicated, this side of the capacitor is connected through the coil 30 to the anode of the discharge device 31.

In the operation of this heating apparatus, the apparatus is adjusted to supply a predetermined power input by electromagnetic induction to a predetermined steel charge or work piece 11 at the beginning of the heating operation and with the switch 27 closed so that the inductance coil 20 is included in the high frequency supply circuit. This initial power input is that assumed in Fig. 2 such that when the charge has been heated to its decalescent temperature, the power input is at a maximum value indicated by the point *b*. This maximum value is determined by the characteristics of the heating apparatus, of the work piece, or the rate at which the heating is to occur. The power adjustment is made by adjustment (by means not shown) of the D.-C. voltage supplied by the mains 13 and 13a, and also by adjusting the frequency supplied to the coil 10. The frequency adjustment is made by suitably connecting the upper end of the coil 10 to a selected tap 43 on the reactance coil 19.

The heating operation is started by closing a suitable switch (not shown) whereby direct current power is applied to the mains 13 and 13a, the current in the discharge device circuit containing the resistances 34 and 35 being proportional to the current in the high frequency induction heating circuit of the discharge device including the coil 10. During the heating operation up to the point *b* of Fig. 2, the capacitor 29 is charged up to the voltage across the resistance 34 by a current which is passed by the rectifier 38. At this time also, the resistance 35 applies a negative bias to the grid of the discharge device 31 sufficient to maintain the device 31 non-conducting.

When the power input to the coil 10 drops and the current through the discharge device 12 and the resistances 34 and 35 decreases upon the charge becoming non-magnetic, the capacitor 29 retains its charge even though the voltage across the resistance 34 decreases because the rectifier 38 does not pass current in the opposite direction. This reduced current, however, in the resistance 35 decreases the negative bias on the grid of the discharge device 31 and when the bias has thereby been reduced to a predetermined value corresponding with the power input at the point *f* of Fig. 2, the discharge device 31 becomes conductive and the capacitor discharges through the discharge device and the coil 30 thereby closing the switch 32. The switch 32 energizes the coil 28 which opens the switch 27 thereby disconnecting the inductance 20. This increases the power input to the coil 10 and current in the coil to substantially its former value. Also the coil 28 closes an interlock switch 39 in a holding circuit for the coil whereby the coil 28 remains energized upon subsequent power increase and deenergization of the coil 30. Upon completion of the heating operation, the mains 13 and 13a are deenergized to discontinue the supply of power to the coil 10 and the coil 28 is deenergized by opening the switch 40, the switch 40 being closed at the beginning of the next heating operation.

It will be understood that direct current at a suitable voltage is supplied to the supply mains 13 and 13a by suitable means (not shown). For example, when the heating apparatus is to be operated from an alternating current supply source of commercial low frequency, direct current power may be supplied to the mains by means of a transformer to give the required alternating current voltage together with two-way electric discharge device rectifier means for rectifying the alternating current.

While I have shown my preferred power regulating means 20 as connected in parallel circuit with the heating coil 10, it will be understood that the regulating means 20 may be connected in series with the coil 10 or it may be connected in any suitable part of the electric supply rectifying and generating means whereby the desired change in power input can be obtained. For example, the power regulating means may be a resistance connected directly in the alternating current supply circuit before rectification for the mains 13 and 13a.

I have also provided a ballast resistor 41 connected across the resistance 34 for the purpose of improving the sensitivity of the control. The resistance of 41 varies directly with the current through it. This resistor 41 keeps the voltage across the resistance 34 at a low value during the initial increasing current and power stage until sufficient negative bias has been developed across the resistance 35 to maintain the device 31 non-conducting. This reduces the possibility of false operation of the device 31 during voltage and current surges. When the power input reaches or approaches its maximum value, and hence maximum value of the current in the resistance 34, the voltage across the condenser 29 rapidly increases to its maximum value with subsequent operation of the device 31 as previously described. Since the ballast resistor avoids the requirement of a relatively high negative bias on the device 31 during the rising current stage, the shield grid of the device 31 can be connected through a suitable reactance 42 directly to the cathode of the device. This gives better control of the point of operation, or tripping point, of the device 31.

My invention also has application in various other heating operations in which the power input decreases during the heating operation, such as in the drying of cloth, wood and other dielectric material. My invention also has application to plate type dielectric loss high frequency induction heaters, as well as to the electromagnetic type heater disclosed.

While I have shown a particular embodiment of my invention, it will be understood, of course, that I do not wish to be limited thereto, since many modifications can be made, and I therefore contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent in the United States is:

1. High frequency heating apparatus comprising induction heating means, means for supplying a high frequency current to said heating means including an electric discharge device, electric power regulating means for said supply means, impedance means connected in a circuit of said discharge device, energy storage means connected across said impedance means so as to be charged to a value corresponding to a maximum current in said circuit, a second electric discharge device provided with a control grid, means for operating said power regulating means connected to said energy storage means in circuit with said second discharge device, and connections for energizing said grid of said second discharge device in dependence upon a voltage across said impedance means so that when the current in said circuit decreases, said second discharge device is rendered conductive for operation of said operating means by said energy storage means to increase the power supplied to said heating means.

2. High frequency heating apparatus for an article made of magnetic material comprising an induction heating coil, means for supplying a high frequency current to said coil including an electric discharge device, electric power regulating means for said supply means, a plurality of impedances connected in series with each other in a circuit of said discharge device, a rectifier, energy storage means connected across one of said impedances in series with said rectifier so as to be charged to a value corresponding to a maximum current in said circuit, a second electric discharge device provided with a control grid, means for operating said power regulating means connected to said energy storage means in circuit with said second discharge device, and connections for energizing the grid of said second discharge device in dependence upon the voltage across the other of said impedances so that when the current in said circuit decreases after the article reaches its decalescent temperature, said second discharge device is rendered conductive for operation of said operating means by said energy storage means to increase the power supplied to said coil.

3. High frequency heating apparatus for an article made of magnetic material comprising an induction heating coil for the article, means for supplying a high frequency current to said coil

including an electric discharge device, electric power regulating means for said supply means, a plurality of resistances connected in series with each other in the plate circuit of said discharge device, a capacitor connected in series with a rectifier across one of said resistances so that during the heating of the article said capacitor is charged to a voltage varying with the current in said plate circuit up to the decalescent temperature of the article, a second electric discharge device, means for operating said power regulating means connected to said capacitor in series with said second discharge device, and connections for energizing the grid of said second discharge device in dependence upon the voltage across the other of said resistors so that when the current in said plate circuit decreases after the article reaches its decalescent temperature, said second discharge device is rendered conductive for energization of said operating means by said capacitor and operation of said regulating means to increase the power supplied to said induction coil.

4. High frequency heating apparatus comprising high frequency heating means, means for supplying a high frequency current to said heating means including an electric discharge device, electric power regulating means for varying the power supplied to said heating means, impedance means connected in a circuit with said discharge device, energy storage means connected across said impedance means so as to be charged in accordance with a maximum current in said circuit, current responsive means in said circuit, means for operating said power regulating means connected to said energy storage means in circuit with said current responsive means, said current responsive means being responsive to a decreased current in said circuit to complete a connection between said energy storage means and said operating means for operation of said operating means to increase the power supplied to said heating means.

5. The combination with a high frequency induction heater for heating a material whose power input decreases upon an increase in its temperature with decrease in the current supplied to the heater, of electric current regulating means connected in circuit with said heater having an element movable to increase the current in said heater, electric operating means for said element, electric energy storage means adapted when charged to effect the operation of said operating means, means responsive to an initial relatively high current in said heater for charging said energy storage means, and means responsive to a subsequent relatively low current in said heater for connecting said energy storage means to said operating means to effect movement of said element to increase the current in said heater.

6. High frequency heating apparatus for heating an article made of magnetic material to a temperature higher than a decalescent temperature at which the article becomes non-magnetic, comprising an induction heating coil, connections for supplying high frequency current to said heating coil, current-regulating means for said heating coil connected in circuit with said coil provided with an element movable to vary the current in said heating coil, means biasing said element to a position to reduce the current in said heating coil to a predetermined maximum value while the article is being heated by said heating coil to said decalescent temperature, electric operating means for moving said element to another position against its bias thereby to increase the current

in said heating coil, electric energy storage means adapted when charged to effect operation of said operating means to move said element to said other position, means responsive to said maximum current in said heating coil during the heating of the article to its decalescent temperature for charging said energy storage means, and means responsive to a subsequent predetermined low current in said heating coil when the article becomes non-magnetic for connecting said operating means to said energy storage means to effect movement of said element to said other position and thereby increase the current in said heating coil.

7. High frequency heating apparatus for heating an article made of magnetic material to a temperature higher than the temperature at which the article becomes non-magnetic, comprising an induction heating coil, connections for supplying high frequency current to said heating coil, an inductance coil connected in parallel circuit with said heating coil for limiting the current in said heating coil to a predetermined maximum value while the article is being heated to its decalescent temperature after which the current supplied to said heating coil is decreased to a low value by the article becoming non-magnetic, a normally closed switch connected in circuit with said inductance coil, electric operating means connected to said switch for opening said switch, electric energy storage means adapted when charged to operate said operating means and to open said switch, means responsive to said maximum current in said heating coil for charging said energy storage means, and means responsive to said low value of current in said heating coil when the article becomes non-magnetic for connecting said operating means to said energy storage means whereupon said energy storage means effects the opening of said switch to disconnect said inductance coil from said heating coil and thereby increase said current.

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REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
1,194,165	Fry	Aug. 8, 1916
1,306,542	Hill	June 10, 1919
1,320,071	Lehr	Oct. 28, 1919
1,385,170	Herz	July 19, 1921
1,830,573	Vaughan	Nov. 3, 1931
1,919,976	Fitzgerald	July 25, 1933
1,931,644	Chestnut	Oct. 24, 1933
1,951,733	Knieszner	Mar. 20, 1934
1,959,690	Roth	May 22, 1934
1,961,621	Northrup	June 5, 1934
2,039,043	Westendorp	Apr. 28, 1936
2,147,689	Chaffee	Feb. 21, 1939
2,179,261	Keller	Nov. 7, 1939
2,293,851	Rogers	Aug. 25, 1942
2,324,525	Mittlemann	July 20, 1943