Aug. 3, 1948. A. VANG 2,446,202

INDUCTION HEAT TREATMENT

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Fig. 1.

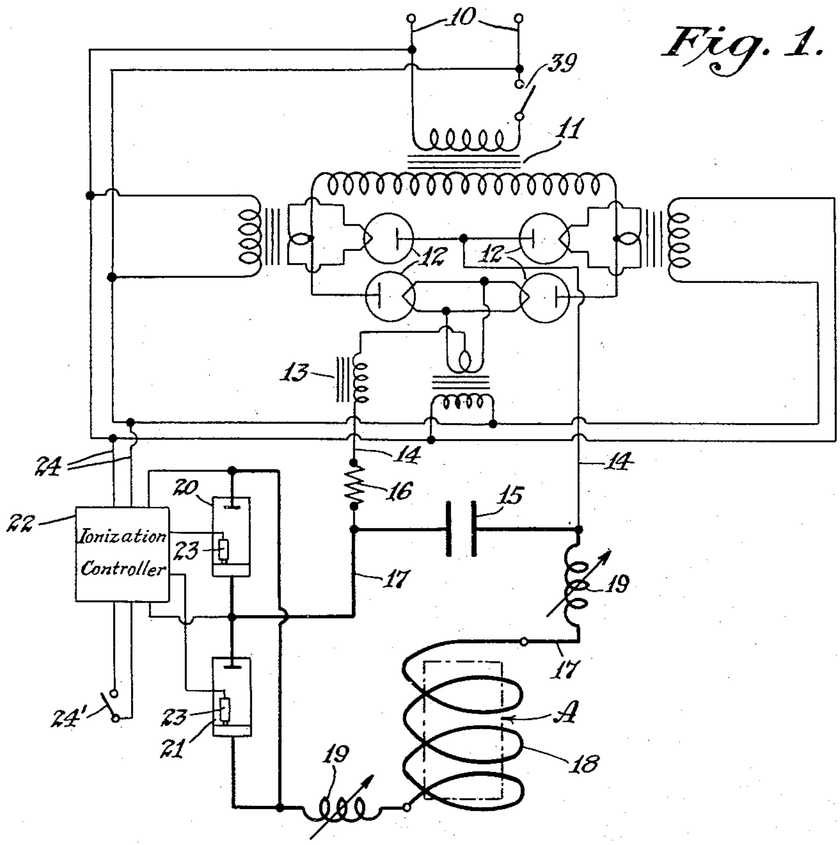

Fig. 4.

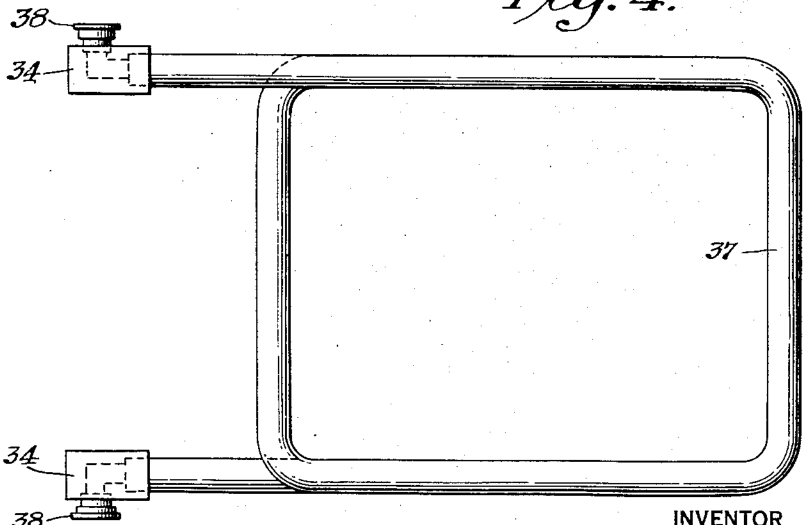

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Fig. 2.

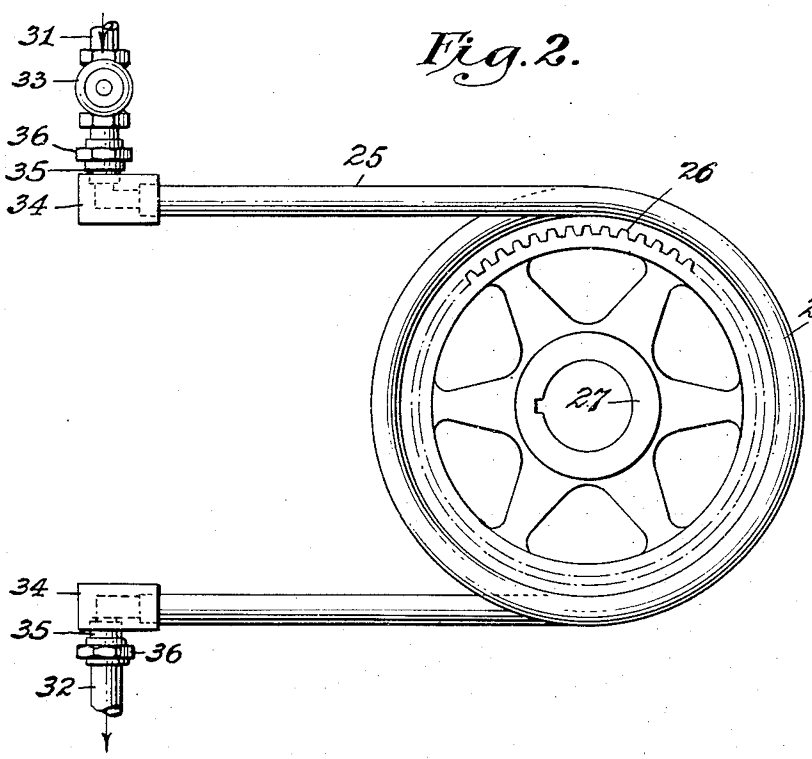
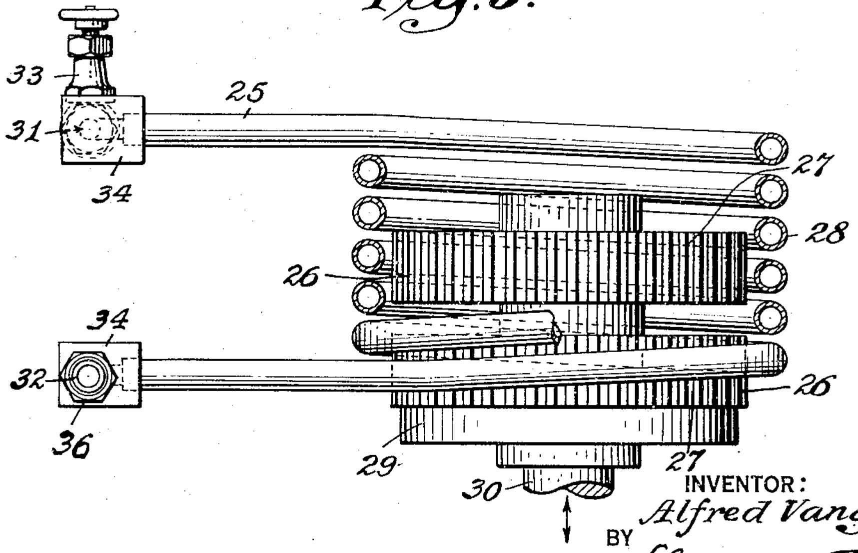


Fig. 3.



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UNITED STATES PATENT OFFICE

2,446,202

INDUCTION HEAT-TREATMENT

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Application September 24, 1941, Serial No. 412,082

3 Claims. (Cl. 219—13)

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The invention relates to means for induction heat treating metals or articles of metal, and particularly to induction hardening.

Induction hardening, as customarily practiced, involves heating of the metal to or above the critical temperature, followed by rapid chilling or quenching. The latter step is performed by fluid quenching, as by immersion of the article in water or oil, or by spraying the surfaces of the article with a suitable cooling fluid. I have discovered that if the article which is to be treated is first subjected to extremely rapid heating of its surface (or of selected portions of its surface) by induction from a high frequency oscillatory circuit of the type which will be described herein, so as to produce an extremely high temperature gradient between the heated surface and the metal adjacent thereto, it is possible to eliminate entirely the step of fluid quenching. This constitutes one of the principal objects of my invention.

It is also an object of my invention to provide a means for induction hardening which gives a more accurate control of the depth to which the hardening treatment is effective. This is of advantage in the design of parts which must have hardened surface portions and tougher, more ductile portions immediately adjacent thereto. Thus, in the case of a gear wheel, it is essential to have a hardened outer circumference so that the surfaces of the gear teeth will be able to withstand wear, but the felloe and spokes should be softer so as to avoid brittleness. If the depth of hardening can be controlled with sufficient accuracy to create the desired hardness in the teeth without hardening the ends of the spokes or other adjacent portions, the design of the gear can be lighter than would otherwise be the case, or a gear of a given weight will be stronger than otherwise. Moreover, the hardening can be localized to a very thin skin of surface metal, leaving the interior metal undisturbed. This is of advantage in preventing or minimizing the warping of castings or other articles during heat treatment, and in many cases does away with the necessity of grinding operations which would be required after heat treatment by methods known heretofore.

Another object of the invention is to decrease the length of time required for the hardening treatment, and thereby to increase the rate of output of the heat treating unit.

A further object is to lower the energy consumed during the heat treating period. Other

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objects and advantages will appear as the description proceeds.

In the drawings,

Fig. 1 is a diagram illustrating a preferred general arrangement of the electrical heat treating circuit in accordance with my invention.

Figs. 2 and 3 illustrate one form of induction unit forming a part of the circuit shown in Fig. 1; Fig. 2 being a plan view, and Fig. 3 a side elevational view, partly in section.

Fig. 4 is a plan view similar to Fig. 2, but showing another form of induction unit.

Referring first to Fig. 1, alternating current from a suitable source **10**, such as the usual 110 or 220 volt A. C. line and controlled by a switch **39**, is transformed to a high voltage—preferably of the order of 10,000 volts, although other voltages can be employed—by the transformer **11**, and rectified by the tubes **12**, which are protected by a choke **13**, providing a convenient source **14** of high voltage direct current. It should be understood that this source is indicated merely by way of example, and that any other suitable source of high voltage direct current might be employed in its place.

High voltage direct current from the source **14** is led into a condenser **15** through a resistor **16**. The condenser diagrammatically illustrated at **15** may be a single condenser or a bank of condensers connected in parallel, or in series-parallel, in any desired manner. The condenser discharge circuit **17** leads through an induction coil **18** which is so designed as to surround the metal article which is to be treated. In my preferred embodiment there are also provided auxiliary variable inductance coils **19** connected in series with the coil **18**, providing means for regulating the frequency and thus timing the rate of discharge in accordance with the composition or size of the article being treated.

The switching means employed for closing the discharge circuit **17** should be of such a type and construction as to close the circuit substantially instantaneously and without dissipating the charge, or any substantial proportion thereof, in the form of heat. An ordinary switch cannot be employed, because the heat generated upon percussion of the switch points would weld them together and dissipate a substantial proportion of the charge in this way, the discharging current being very high in order to create an electric field powerful enough to induce the requisite degree of heating within a small fraction of a second, as explained hereinbelow. The switching means should be capable of closing the discharge circuit in such a manner that the full charge, or as much of the charge as possible, will be translated into an oscillatory discharge without being dissipated as heat in the switching means. A spark gap might be employed as the switching means, but has the objection of creating a high loss because of its relatively high resistance. This loss may run as high as 40% or more of the available charge. I have found that igniter tubes can be employed advantageously in closing the discharge circuit, and, by way of example, have shown a circuit employing two gaseous electronic discharge tubes, **20** and **21**, connected in parallel, but with the tube **20** reversed in direction to the tube **21**. This arrangement permits the current to flow through the circuit in either direction.

The discharge is set off by a suitable ionization controller **22** through which current is supplied to the igniter electrodes **23** of the tubes **20**, **21**. The controller **22** may be connected to any suitable source of current, such as the source **10** as by means of the leads **24**. A switch **24'** may be provided for manual actuation of the ionization controller, although, if desired, the controller may embody a relay which is automatically actuated when the condenser **15** has been charged to a predetermined voltage—say, 3,000 volts. Controllers of this type are well known in the art, so it is believed unnecessary to include a specific description thereof in this application. The principle of operation of the controller resides in initiating ionization in the tubes **20** and **21**, to thereby permit current to flow through the tubes and thus close the condenser discharge circuit **17**. The arrangement I have disclosed provides a switching means which is characterized by rapidity of operation, a positively controlled point of break-down of the initial high resistance, and an ability to conduct current with equal facility in both directions. Moreover, the resistance of the switching means is negligible, so that virtually all of the available condenser charge is translated into useful oscillatory discharge.

If desired, other types of manually-controlled switching means than that described specifically herein might be employed, having regard, however, to the desirable characteristics enumerated above. For example, one of the igniter tubes **20**, **21** might be employed alone, but with some sacrifice in the life of the single tube. Alternatively, the igniter tubes **20**, **21** might be replaced by the switching means for high frequency circuits described and claimed in my copending application for patent, Serial No. 364,701, filed November 7, 1940 (now Patent No. 2,287,541, dated June 23, 1942).

A single, oscillatory condenser discharge provides the energy for heat treatment in the preferred embodiment of my invention. In order to provide a single charge and a single, oscillatory discharge, in place of multiple, or repeated charges and discharges commonly produced by high frequency generators of the condenser-discharge type, various selective switching methods may be employed. In the embodiment shown in Fig. 1, the condenser **15** may be charged by closing the switch **39**, whereupon the switch **39** may be reopened before closing the switch **24'**. Thus the ensuing discharge will represent a single oscillatory discharge of the condenser, and thereafter the circuits will remain dead until the manual cycle is repeated. An alternative method is to adjust the constants of the charging circuit for a slow rate of charging, and to adjust the ionization controller to be sensitive to the potential of the charge. The switch **39** may then be reopened immediately after the discharge, either manually or automatically. In this manner very close control may be exercised over the energy of the charge.

The article A which is to be heat treated is placed within the field of the induction coil **18**, as shown in Fig. 1. Upon closing of the switch **24'**, a high frequency oscillatory current flows through the coil **18**, inductively heating the adjacent surface portions of the article A with great rapidity during a single discharge from the condenser **15**. This creates an extremely sharp temperature gradient so that the depth of heat treatment can be accurately controlled through regulation of the rate of discharge of the condenser. Thus, for example, the heat treatment can be localized to a very thin skin of surface metal, leaving the interior metal undisturbed, with the resultant advantages noted hereinabove. The completion of the treatment within the time of a single discharge of the condenser provides a highly accurate method of regulating the depth of treatment or of confining it to a thin skin of metal at the surface of the article being treated. Moreover, no auxiliary timing arrangement is needed to regulate the length of the treatment. The treatment is determined by the condenser charge, frequency, and the magnetic coupling of the coil with the work, all of which are susceptible of extremely delicate regulation, making elaborate timing devices unnecessary. The rate of discharge can be accurately regulated by the variable inductance coils **19**, and by this means the depth of energy penetration into the work, which is subject to "skin effect" at high frequency, can be controlled. Thus, where greater depth of heat treatment is desired, the inductance of the coils **19** can be adjusted to a higher value, which will lower the fundamental frequency of the circuit **17**, which, in turn, will produce greater penetration of the critical heat treating temperature.

In accordance with my invention, frequencies on the order of millions of cycles per second may be found useful, although frequencies of 8,000 or 10,000 cycles per second may be desirable as a practical working range, depending upon the composition of the metal being treated and the depth to which the metal is to be hardened. The actual time required for the condenser discharge will ordinarily be on the order of a fraction of a second, and may be on the order of 1/1000 of a second, extending over a period which may represent, say, 8 cycles of oscillation.

With particular reference to Figs. 2 and 3, I shall now describe my preferred form of the induction heating unit which is shown diagrammatically at **18** in Fig. 1. This unit consists of a hollow tube **25** of high electrical conductivity, such as a tube of copper or aluminum or their alloys, wound in the form of a coil designed to lie in proximity to those portions of the article which are to be heat-treated. Thus, when hardening the teeth **26** of gear wheels **27**, the coil will be in the form of a simple helix **28** the turns of which lie closely along the circumference of the gears. It will, of course, be understood that the coil can be lengthened in order to accommodate the number of gears which it may be desired to treat simultaneously, or, preferably, a number of such coils may be arranged in parallel. The gear wheels **27** or other articles to be treated may conveniently be supported on a movable platform arranged to bring the gears into the field of the coil **28** for treatment. Thus in the embodiment illustrated, the gear wheels **27** are carried by a vertically reciprocable table **29** mounted on a plunger **30** connected to the piston of an hydraulic or pneumatic cylinder. In Fig. 3 the platform **29** is shown in an intermediate position representing either the introduction or removal of the gear wheels to or from the field of induction of the coil. The ends of the hollow tube **25**, in the embodiment illustrated, are connected respectively to a source of cooling fluid **31** and to an outlet **32**. Cooling fluid may be circulated through the coil **28** during the heat-treating cycle so as to avoid melting of the coil under the high temperatures created in the adjacent portions of the gear wheels **27**. The flow of cooling fluid may be regulated by a suitable valve **33**.

In order to provide for efficient heat treatment of articles of different sizes and shapes, the mechanical and electrical connections of the coil are so designed as to permit its ready removal from the machine so that other coils can be interchanged therewith. For this purpose, I have shown the tube ends **25** brazed or welded into terminal blocks **34** arranged for electrical connection in the circuit **17**, and insulated in any suitable manner from the mechanical connections for the cooling fluid supply and discharge. The blocks **34** have laterally extending conduits **35** to each of which is secured one element of a pipe union **36**. In order to remove the coil **28** from the machine, the electrical connections from the terminal blocks **34** are disconnected, and the pipe unions **36** backed off, which leaves the coil free for renewal.

Fig. 4 illustrates another form of coil which is interchangeable with coil **28** previously described to accommodate articles which are of rectangular shape instead of circular. This coil is in the form of a rectangular loop **37** designed to receive within its field an article of corresponding shape. The terminal blocks **34** of this coil are provided with pipe union elements **38** for engagement with the union elements **36** shown in Fig. 2.

It will be appreciated that the coils shown in Figs. 2, 3 and 4 are merely illustrative of two of the many forms which these induction heating elements may assume, depending upon the size and shape of the article or articles which are to be treated, or upon other variables. The terms and expressions which I have employed are used in a descriptive and not a limiting sense, and I have no intention of excluding such equivalents of the invention described, or of portions thereof, as fall within the purview of the claims.

I claim:

1. Induction apparatus for the heat treatment of metals and metal articles subject to improvement upon hardening treatment and the like for surface-hardening metallic articles, comprising a condenser, means for charging the condenser, an induction element constructed and arranged to

accommodate within its field an article to be treated, and a variable inductance element, said induction and inductance elements being connected in series to the condenser through a gaseous electronic discharge means capable of passing current in both directions to provide a single discharge in an oscillatory circuit of variable frequency for regulation of the depth to which heat treating is effective, the characteristics of the condenser circuit being such that the discharge takes place at a sufficiently high frequency to restrict the induced currents to the skin region of the article being heated, while the complete discharge occurs over so small a fraction of a second as to restrict effectively the amount of heat flowing from the skin region to the interior of the article, whereby upon cessation of said discharge a steep temperature gradient exists between the skin and interior regions and rapid self-quenching begins immediately upon the termination of the discharge.

2. Induction apparatus as defined in claim 1 wherein the magnitudes of the elements of the condenser discharge circuit are such that the time of discharge is about one-thousandth of a second.

3. Induction apparatus as defined in claim 1 wherein the magnitudes of the elements of the condenser discharge circuit are such that the frequency is at least 8000 cycles per second.

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