Aug. 18, 1942. F. S. DENNEEN ET AL 2,293,049

METHOD OF INDUCTIVE HEATING

Original Filed Dec. 31, 1935

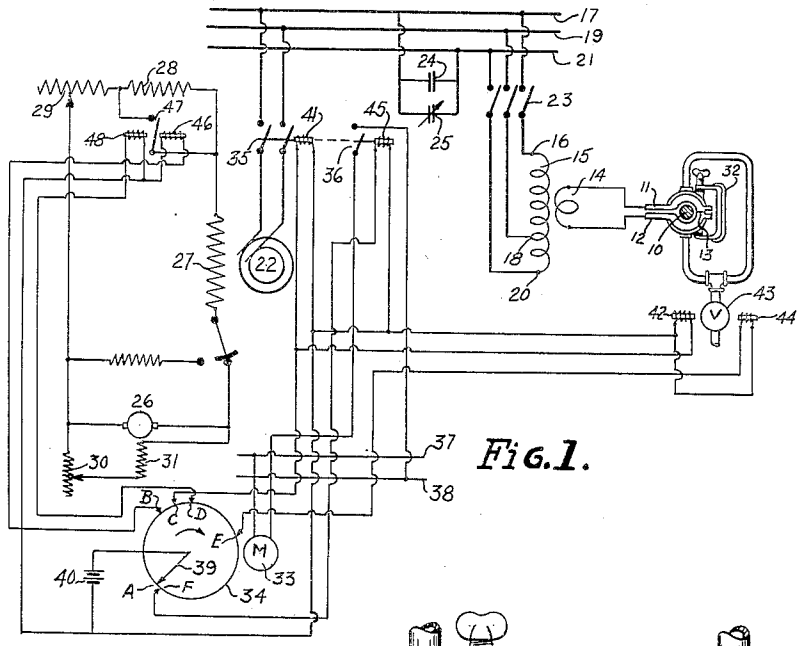


Fig. 1.

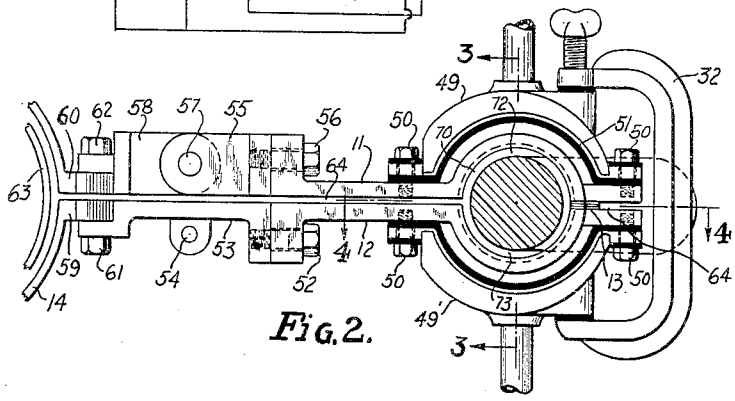


Fig. 2.

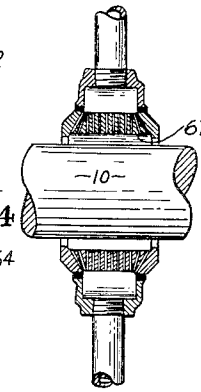


Fig. 3.

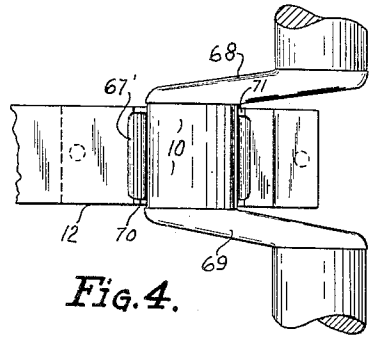


Fig. 4.

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Patented Aug. 18, 1942

2,293,049

UNITED STATES PATENT OFFICE

2,293,049

METHOD OF INDUCTIVE HEATING

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Original application December 31, 1935, Serial No. 56,870. Divided and this application November 6, 1940, Serial No. 364,547

2 Claims. (Cl. 148—10)

The present invention relates to a method for hardening metal articles by heating a portion of the same inductively and thereafter rapidly withdrawing the induced heat content to provide the desired finished structure. The invention is a division of our co-pending application Serial No. 56,870, filed December 31, 1935. In the present application there is disclosed a method by which metal articles are made. In the surface hardening of articles by the present process it has been found important to accurately time the heating and quenching period to an accuracy which in many cases is as close as one-tenth second in order that both high quality and uniformity in results may be obtained. In general, we have found that the best results are obtained by heating the zone to be hardened at the maximum possible rate. The hardened zone is thereby kept at minimum depth, the quantity of heat to be removed by quenching is kept at a minimum, and the flow of heat to portions of the article other than the zone to be affected is held to a minimum.

The general object of the present invention has been to provide a method for inductively heating and thereafter quenching preselected surface zones of articles in order that a sharp differential effect may be obtained, to the end that the surface zone is hardened and the core portion remains unaffected by the induced heating current. A further object of the invention has been to provide a method for producing a number of duplicate articles rapidly, inexpensively and which are of high quality. A still further object has been to provide a method for producing on an article a hardened zone of superior qualities over similar results heretofore obtained by known methods.

In the drawing,

Fig. 1 is a diagrammatic representation primarily of the electric circuits employed;

Fig. 2 is an enlarged view of the heating inductors in operating position over the article to be heat treated;

Fig. 3 is a longitudinal view partly in section on line 3—3 of Fig. 2; and

Fig. 4 is a fragmentary view partly in section on line 4—4 of Fig. 2.

Referring now to the apparatus as illustrated, principally in Fig. 1, the article 10 to be heat treated is shown enclosed by the inductor members 11 and 12 which have current conducting contact at 13 and which are supplied with current from the transformer secondary 14 to which these inductor members are directly attached. The primary 15 of this transformer has one of its end coils 16 connected to the bus bar 17 and an intermediate coil 18 connected to the bus bar 19. This transformer is preferably of the air core type and both the primary and secondary are preferably tubular and arranged for water cooling. The primary usually is made with approximately forty turns and the secondary is composed of one turn usually made of several parallel conductors connected together. The other end coil 20 of the primary is connected to the bus bar 21. The generator or source of alternating current 22 supplies current to the bus bars 17 and 19 usually at a voltage of about 800. A suitable switch 23 for connecting the primary 15 to the bus bars 17, 19 and 21 is provided. To compensate for the inductance of the circuits, condensers 24 and 25 are provided and are attached across the bus bars 17 and 21. The condenser 24 is selected to provide the minimum capacity required for any given set of operations and the condenser 25 is made adjustable to provide for the variable condenser requirements above the minimum of any such given set of operations. Usually the adjustments of the variable condenser are accomplished not by varying the capacity of a single condenser, but by inserting or removing from the circuit small individual condensers or condenser elements. By the effect of resonance resulting from the presence of the inductance and condensers, these circuits may be so tuned that much more current can be supplied to the transformer primary than is supplied by the generator. Thus the bus bars 17 and 21 carry much more current than bus bar 19 and must be correspondingly larger.

The generator is provided with an exciter 26 for its field 27, there being a removable resistance 28 and a readily adjustable rheostat 29 in the field circuit for the adjustment of the generator output. For the further adjustments of the field circuit, the rheostat 30 in the circuit of the field 31 of the exciter is provided. By suitable manipulation of both rheostats 29 and 30 it will be evident that the output of generator 22 can be controlled very closely and easily.

For the successful operation of this device, a given frequency of generator current being provided, several accurate adjustments are necessary and the operations must be carried out in proper sequence. After the inductor members 11 and 12 have been brought into enclosing relationship with the article 10 to be heat treated and the contact at 13 has been assured by a suitable fastening such as clamp 32, the con-

denser 25 is adjusted to meet the required capacity and rheostat 29 is regulated to provide the initial current needed. Switch 23 is closed which brings the transformer primary 15 into operating connection with bus bars 17, 19 and 21.

As a very accurate duration of the heating interval is required, which has been indicated above, means must be provided for measuring this interval, which means is not dependent upon the senses of the operator. This means is provided by the motor 33 which preferably is of a constant speed type and which has a very low inertia starting resistance so as to attain full speed in a minimum, and substantially constant, interval. A self-starting synchronous motor meets these requirements nicely. This motor, through suitable gearing, drives the timer, comprising a contactor disc, indicated at 34. After all preliminary adjustments in the condenser circuits, field circuits and switch contacts between the bus bars and transformer have been made, switches 35 and 36, which are interconnected to be closed substantially simultaneously, are closed, the former bringing generator 22 across the bus bars 17 and 19 and the latter closing the circuit of motor 33, the power for motor 33 being supplied from lines 37 and 38 as indicated. This power may be of any suitable character, but usually is low frequency current of ordinary voltage. The contactor arm 39, carried by the disc 34 and adapted to rotate therewith starts rotating at a substantially uniform velocity upon the application of power to the transformer primary 15 by the closing of switch 35, account being taken for starting lag and correction being made therefor in the position of the contactor arm 39 on disc 34. The angular movement of the contactor arm on disc 34 from its starting point determines an interval of time, the speed of the disc being known. As soon as this interval has elapsed, this disc contactor closes a circuit which derives its energy from a source indicated at 40. Power from the lines 37 and 38 is usually employed instead of the battery indicated, however. The successive closings of such circuits as have contactors which are engaged by the contactor arm 39 actuate relays or solenoids which are employed for accurately starting or terminating such functions as may be required in the cycle of operations. In the relatively simple apparatus indicated, switches 23, 35 and 36 are closed manually, and the adjustments of the condenser 25 and rheostat 29 are also made manually. For the heat treatment of a number of like articles, which are represented in the present case by the shaft 10, the adjustments of the rheostat 29 and condenser 25 are determined by previous experience with similar articles and by experiment, the analysis of the material of the article as well as its form and size having an important influence on the adjustments to be provided.

In the use of the apparatus above described, the operator proceeds as follows: The adjustments of condenser 25 and rheostat 29, having been determined beforehand, the inductor members 11 and 12 are brought into proper spaced relationship with the shaft 10 and are secured by clamp 32 so as to have good electrical contact at 13. Condenser 25 is adjusted and rheostat 29 is regulated to reduce the generator field current. Switch 23 is then closed which is followed immediately by the closing of switch 35, switch 36 being closed by the closing movement of switch 35. The high frequency generator 22 through bus bars 17 and 19 delivers heating power to the transformer primary 15. Secondary 14 causes current of high density and usually low voltage to flow in the inductor members 11 and 12. The current in these inductor members induces high density current in the surface zones of article 10 and because of the hysteresis effect and the ohmic resistance of the article, the surface zones are brought to a high temperature in a few seconds.

As switch 36 is closed simultaneously with the closing of switch 35, the contactor arm 39 starts to rotate at the beginning of the heating interval and continues for one complete revolution. Rotation beginning at the point A and contactor arm 39 moving in a clockwise direction as indicated, the end of this arm makes momentary contacts at points B, C, D, E and F. The contactor arm serves as a part of the conducting circuit for carrying current from the source 40. At its starting position, the outer contact end of the contactor arm 39, which is at the zero point indicated at A of the disc, is slightly clockwise beyond the point F. At the instant of closing the circuit breaker switch 35, the heating energy is applied to the heating circuit and at the same instant the contactor arm 39 starts moving clockwise from its zero position A a little beyond contact F and the heating current continues to flow during the period of travel of the contactor arm 39 from starting point A to contact point C. At the instant of reaching point C current flows from the battery 40 through contactor arm 39 into contact C, thus energizing the solenoid 41 which functions to open the circuit breaker 35, thereby cutting off the heating energy from the circuit. At the same instant the solenoid coil 42 (which is in parallel with solenoid 41) is energized and this causes the quenching fluid valve 43 to open permitting free flow of coolant over the heated areas of the article 10 from the jacket space of the inductor through orifices in the inner inductor walls as are shown in Fig. 3.

The quenching fluid valve 43 remains open during the passage of contact arm 39 from contact point C to contact point E, at which time current flowing from the arm 39 into the contact E energizes the solenoid 44 which causes the valve 43 to close, cutting off flow of coolant. The contactor arm 39 continues to revolve clockwise until contact is made at F at which instant the solenoid coil 45 is energized, opening the switch 36, thereby causing the timing unit motor to stop, the contactor arm 39 having reached its stopping position at contact F and being carried a little beyond to starting point A by its inertia.

Since it is objectionable to open the circuit breaker 35 in the main circuit at the instant when current of high value is flowing, we have provided means for reducing the current just prior to the opening of this circuit breaker 35 in the following manner: Just before the contractor arm 39 reaches contact C, it makes connection at contact B, energizing solenoid 46 which opens the short circuiting contact at 47, thereby inserting resistance 28 in series with the field circuit of the generator. The resistance increment 28 when inserted in the generator field circuit just before the main circuit breaker opens, reduces the current flowing through the breaker at the instant of opening sufficiently to prevent serious damage to the breaker. It is necessary that the resistance increment 28 be cut out from the generator field circuit before the generator is again connected to the heating circuit and this is accomplished through the contact point D

which causes the solenoid 48 to be energized, drawing the member 47 into position to once more short circuit the terminals of the resistance increment 28.

Figs. 2, 3 and 4 illustrate on a somewhat enlarged scale, the inductor members of Fig. 1, together with their related parts and show a specific application to a crankshaft crank pin which is to be hardened. In these illustrations, the inductor members 11 and 12 have the jackets 49 and 49' attached by screws 50 and 50'. Suitable insulation gasket 51 of rubber or other resilient material serves as means for preventing loss of the quenching medium and to confine the flow of current to the inductor members 11 and 12 adjacent to the shaft. The lower inductor 12 is attached by means of bolts 52 to the extension 53 which is supported by pin 54 and the upper inductor member 11 is attached to the hinge member 55 by means of bolts 56. The hinge member 55 is adapted to rotate about hinge pin 57 which is carried in the stationary hinge member 58. Extension 53 and stationary hinge member 58 are attached to stationary bus bars 59 and 60 respectively by bolts 61 and 62, these bus bars being attached preferably by fusion to the ends of the single coil secondary 14 of the transformer. The primary turns indicated by the fragment 63 are insulated from each other and from the secondary by suitable means. To relieve the bus bars 59 and 60 from strains which would occur in the manipulation of the inductor members both pins 54 and 57 have their ends supported in the frame carrying the coils and other related parts, and which is not shown.

In applying the inductor members to the crankshaft bearing or journal 10, an insulating space 64 between these inductor members and their supports is provided. This space is usually maintained at a minimum to prevent losses and ordinarily is of the order of one-sixteenth of an inch. On the other side of the journal these inductor members are brought into firm conducting contact at 13 to complete the circuit around the shaft. Usually the voltage is low and the current density is very high at this contact so that very slight difference in the contact resistance at different points in the contacting area will cause serious variation in the current density from one side to the other of the inductor members. This causes corresponding and objectionable variation in the rate of heating in different sections in the zone to be heated. To insure uniformly high conducting contact, we usually attach silver contact strips to the inductor faces at 13. For some purposes, it is satisfactory to omit these silver strips and to use instead a piece of fine mesh hard copper or bronze gauze coated or impregnated with an amalgam containing tin, zinc, copper or other suitable metal.

As a general thing, satisfactory results may be obtained by having the surface of the inductor members parallel to the surface to be heated. In some cases with this parallel arrangement, however, the heating is more rapid opposite the center portion of the inductor members, resulting in greater depth of hardened zone in the center section of the width of the bearing. To correct this condition so as to make the depth of the hardened zone approximately uniform across the width of the bearing, we frequently recess the face of the inductor members, bringing it further away from the surface to be heated at the place where parallel inductor members would tend to create excessive or objectionable depth in the hardened zone. This recessing is indicated at 67 in Fig. 3. This provides a surface zone of substantially uniform depth when other related conditions are favorable. Frequently, however, neighboring elements may disturb the desired distribution of the magnetic flux such, for instance, as the arms or cheeks 68 and 69 of the crankshaft. To compensate for the presence of these elements the journal 10 is placed in an eccentric position relative to the inductor members so that the least clearance between the inductor members and shaft is between the arms or cheeks. For most satisfactory results it has been found that for journals having a diameter of approximately two and one-half inches, the clearance at 70 should be of the order of .080 of an inch, at 71 it should be .040 and at 72 and 73, .060. Small cylindrical spacers made of lava or other insulating material as shown at 67' are usually inserted to insure the desired spacing. This difference in spacing compensates for the effect of the crankshaft cheeks on the flux path. If the shaft is straight however, no eccentric spacing is required.

While the water pressure required in the quenching system will, of course, vary depending upon the cooling to be accomplished, size and shape of the piece, the design and form of the heating inductor members and other conditions existing in the quench water system, we have found that a pressure of approximately sixty pounds per square inch in the chamber communicating with the orifice in the inductor will insure proper cooling of the piece when the orifices are approximately $\frac{3}{32}$'' in diameter and number approximately 12 or 15 per square inch in the inductor member face. By projecting the quenching liquid through these orifices under sufficient pressure, all incipient vesicles or bubbles of steam or gas which tend to form on the hot surface of the shaft are dislodged and their harmful quench retarding effect due to their insulating qualities is obviated. For journals up to three inches diameter this quench is usually applied for a period of from five to seven seconds, depending somewhat on the size of the shaft and the amount of heat which has been delivered to it. However, the depth of the heated zone varies somewhat depending upon a number of conditions and thus affects to a marked degree the amount of heat which must be absorbed by the quench and consequently the amount of quench which must be delivered and the duration of the quenching period. Frequently, it is desirable to cut off the cooling action at some point, thereby taking advantage of the tempering action that results if all the heat is not immediately removed. Greatly improved physical qualities are thus frequently obtained.

Attention is directed to the quenching effect of the inner or core portion of the journal which has remained cool (usually not over 240° F.) during the heating interval. The quench which is applied through the orifices in the inductor members thus does not have to absorb all the heat as a portion of this is rapidly absorbed by the cooler metal of the core of the journal. The amount, however, absorbed by this core is not sufficient to materially affect the physical properties imparted by previous process or heat treatment. This cooling effect of the core is of considerable advantage in preventing the formation of free ferrite below the demarcation line or bonding zone.

Other forms may be employed embodying the

features of our invention instead of the one herein explained, change being made as regards the steps herein disclosed, provided the elements stated by the following claims or the equivalent of such stated elements be employed, whether produced by our preferred method or by others embodying steps equivalent to those stated in the following claims.

We therefore particularly point out and distinctly claim as our invention:

1. In a method of hardening a surface zone of a metal article, the article being adapted to be hardened by heating and quenching, the steps comprising bringing an inductor into closely spaced relation with the article, providing a high frequency generator with leads connectable to the inductor, connecting a condenser unit of preselected value across the leads of the generator to tune the circuit of the generator, connecting the generator leads to the inductor to cause current to flow in the inductor to induce heating current in the aforesaid surface zone, starting a timer to time an interval during which the generator remains connected to the inductor, and continuing the operation of the timer to accurately and successively insert resistance in a field circuit of the generator to reduce voltage at the generator leads, to disconnect the generator from the leads, to apply quenching fluid to the surface zone of the article, to interrupt the application of the quenching fluid, and then to stop the timer.

2. In a method of hardening a surface zone of a metal article, the article being adapted to be hardened by heating and quenching, the steps comprising bringing an inductor into closely spaced relation with the article, providing a high frequency generator with leads connectable to the inductor, connecting a condenser unit of preselected value across the leads of the generator to tune the circuit of the generator, connecting the generator leads to the inductor to cause current to flow in the inductor to induce heating current in the aforesaid surface zone, starting a timer to time an interval during which the generator remains connected to the inductor, and continuing the operation of the timer to accurately and successively reduce voltage at the generator leads, to disconnect the generator from the leads, to apply quenching fluid to the surface zone of the article, to interrupt the application of quenching fluid and then to stop the operation of the timer.

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