

March 25, 1952

H. F. KINCAID ET AL

2,590,546

HEAT-TREATMENT OF IRREGULAR METALLIC OBJECTS

Filed July 25, 1949

3 Sheets-Sheet 1

Fig. 1.

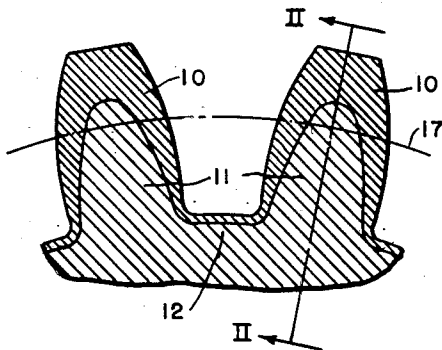


Fig. 2.

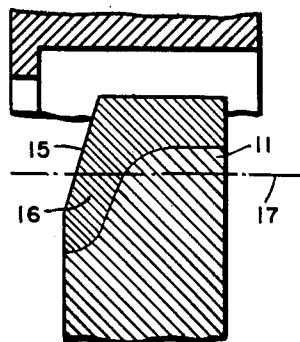
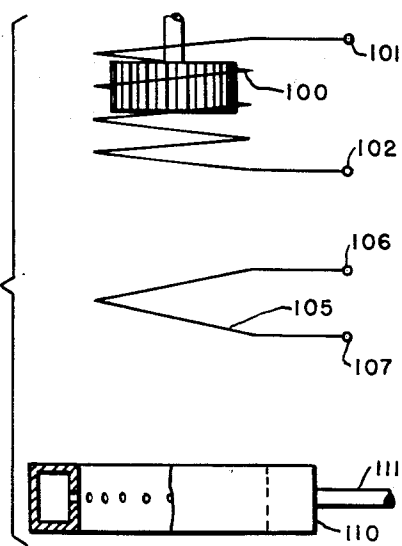


Fig. 3.



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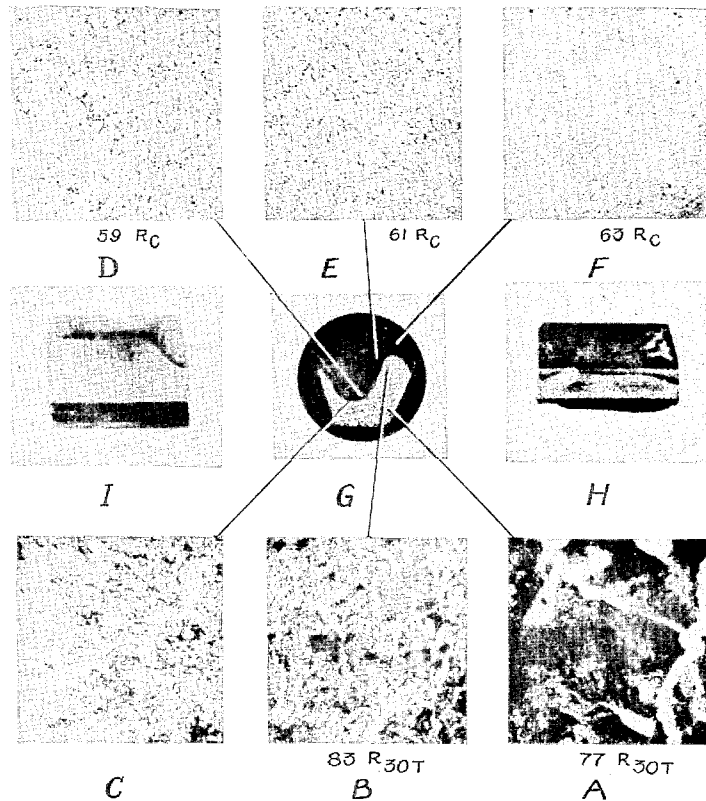
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HEAT TREATMENT OF IRREGULAR METALLIC OBJECTS

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3 Sheets-Sheet 2



RADIO FREQUENCY INDUCTION HARDENED 5 D.P. GEAR
PRE-HEATED WITH 10,000 CYCLE POWER
STEEL NORMALIZED 1050
PIGRAL ETCH 600 X

Fig.4.

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HEAT-TREATMENT OF IRREGULAR METALLIC OBJECTS

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3 Sheets-Sheet 3

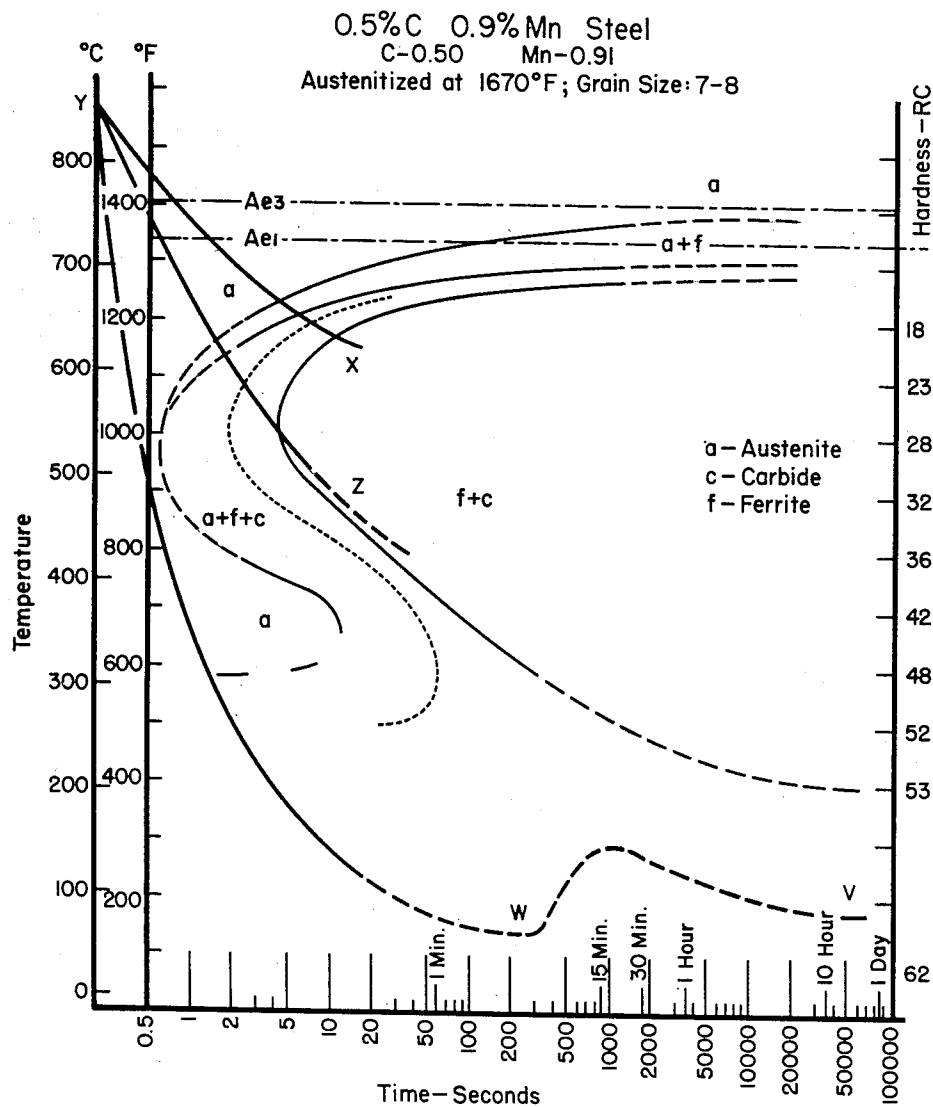


Fig. 5.

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2,590,546

HEAT-TREATMENT OF IRREGULAR
METALLIC OBJECTS

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Application July 25, 1949, Serial No. 106,594

12 Claims. (Cl. 148—10.5)

1

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Our invention relates to heat treatment and has particular relation to the heat treatment of irregular metallic objects for the purpose of producing a hard surface or skin on the objects.

This application is a continuation-in-part of copending application, Serial No. 759,888, entitled "Heat Treatment of Irregular Metallic Objects" which was filed July 9, 1947, now Patent No. 2,564,906.

Irregular metallic objects, such as gears which are included in the transmission of an automotive vehicle, crank shafts and similar items are subjected to repeated mechanical impacts. It is desirable that such objects be provided with a layer of hard metal in the region where the impacts are to be applied. Such hardened surfaces are produced by heat treatment.

One method of heat treatment in accordance with the prior art, of which we are aware, is called carburizing. In the carburizing process the metallic object to be treated is immersed in a carburizing medium and its entire surface is subjected to the action of chemical agents. A thin hardened layer is produced over the whole surface of the object. The chemical agents to which the object is subjected are costly; they are consumed at a high time rate during the treatment and require repeated replacement. The carburizing process is time consuming. This process is therefore not suitable for the production of hardened objects at the high rate and the low cost demanded by modern mass production of automotive vehicles.

In accordance with other teachings of the prior art, of which we are aware, the objects are hardened, not only on the surface, but throughout in the region where the impact is applied. For example, gears are so heat treated that the teeth are hardened throughout, the hardening extending a short distance below the roots of the teeth. The hardening is produced by heating a gear in the region to be hardened (the teeth and the roots) to a temperature of approximately 1600° F. and thereafter quenching the heated portion of the gears.

The difficulties associated with, and disadvantages of, this process will be understood from a consideration of the process as applied to a gear. Because of a high temperature differential which exists during the heating operation between the heated region and the unheated body of the gear, high tensile stresses are produced between the two sections of the gear. When the gear is quenched, the stresses are further modified. The expansion of the teeth which arises by reason

of the chemical changes which constitute the hardening process further modifies the stresses. We have found that the stresses produced during this heat treating process cause defects to develop in gears so treated, thus the gears are frequently cracked in the region of the teeth and the roots. A more important difficulty associated with through hardened gear teeth is the problem that if the teeth are hard enough to have good wearing qualities, the teeth are too brittle, and if they are soft enough not to be too brittle, the surface wearing qualities are unsatisfactory.

It is accordingly an object of our invention to develop a method of heat treatment which overcomes the above difficulties and shall be inexpensive and highly efficient.

Another object of our invention is to develop a method of heat treatment which shall be peculiarly suitable for the supply of components, such as gears, racks, crank shafts and similar items to satisfy the quality, quantity and cost demands of modern mass production of automotive vehicles.

A further object of our invention is to provide a method of heat treatment for irregular metallic objects, said method involving the contour or zone hardening of said objects with the use of induction current of different electrical frequencies.

A still further object of our invention is to provide an electrical heat treating process for producing hardening equivalent to that produced by chemical processes, such as the carburizing process.

It is still another object to provide an improved method for heat treating articles with the utilization of an electrical induced current, said treating operation leaving a minimum of unfavorable residual stresses in the article after hardening.

Another object is to provide an improved method for hardening articles with irregular contours such as gears or racks, said method including the combination of pre-heating of the gears with a relatively low frequency induction current, and thereupon contour hardening the article by the application of a substantially higher frequency electrical induced current and subsequent quench, said combination being designed to eliminate tensile stress in the critical areas of the article.

Another specific object of our invention is to provide a production line heat treating process for irregular metallic objects by use of which such objects fully treated shall be produced at a high time rate.

More concisely stated, it is an object of our invention to provide a low-cost, high-speed method of heat-treatment and apparatus for practicing the method.

In accordance with our invention we provide a metallic object which has a thin hardened layer only in the region where major stresses are applied to it. Thus, we provide a gear which has a shallow, hardened contour casing. Gears for the transmission of standard automotive vehicles and small tractors, produced in accordance with our invention, have a hardened contour of average thickness of the order of .030 inch. If a section of such a gear by a plane perpendicular to its axis is observed, the hardened area will be seen to be a band which extends along the contour of the teeth narrowing towards the root. The inner boundary of the band is a curve spaced approximately .050 inch from the top of the tooth and .030 inch from the root.

Certain gears of a transmission are moved axially to engage with other gears. During this operation the sides of the teeth of one of the engaging gears impacts against the sides of the teeth of the other. To reduce the shock engagement (the clash) the engaging sides (the clashing faces) of the teeth have rounded surfaces. It is desirable that these surfaces be hardened.

In accordance with our invention the clashing surfaces are hardened to a distance just below the region of engagement of the teeth. In practice this hardening customarily extends to a distance approximately half-way between the pitch line and the root. For gears included in the transmissions of standard automotive vehicles and tractors, the thickness of this layer as measured from the side surface of the tooth varies from approximately .050 inch at the point nearest the tip of the tooth to zero where the hardened area disappears below the pitch line.

Surface wear of teeth, according to our invention by reason of impact during gear shifting and rotation is minimized by the band surface.

A gear to be heat treated in accordance with our invention is first pre-heated inductively. It is desirable that during the pre-heating the temperature of the roots and teeth be raised to a predetermined magnitude (above the critical hardening temperature); the remaining body of the gear should be well below this temperature. If too much of the gear is unnecessarily heated, objectionable spline bore distortion results, and the quenching difficulties increase. Also the stress conditions are altered and the low frequency power consumption is higher than necessary. This objective is accomplished by subjecting the gear to the electromagnetic field produced by a generator of audio frequency oscillations having a frequency preferably lying between 960 and 15,000 cycles per second. There is a tendency for the steel in the roots to rise to a higher temperature than the steel in the tips. Each gear is maintained in the field until the temperature of the heated region attains a magnitude of about 1500° F. The heat stored in the heated portions is then allowed to penetrate or transfer by conduction into the cooler portions of the gear for a substantial period of time, in the order of about 20 seconds in some cases. The heating time from a metallurgical standpoint must be for a period long enough to form austenite, which requires a certain minimum period of time at a relatively high temperature, above the upper critical hardening temperature, both of which are dependent upon the steel used. The time required for the

formation of austenite is a function of the steel used and the temperature to which the steel is raised. A subsequent reference in the present specification to Fig. 5 is helpful in this regard. The application of low frequency power tends to raise the temperature of the roots of the teeth higher than the temperature of the tips of the teeth. During the delay period between the low frequency pre-heat cycle and the high frequency cycle, this temperature differential is further increased because the tips of the teeth cool more quickly. Thereafter, the gears are subjected to a radio frequency electromagnetic field. The frequency of the oscillations which produce this field preferably lies between 90,000 and 450,000 cycles per second. The teeth and roots of the gears are heated by the radio frequency field, to the desired depth, to the heat treating temperature (approximately 1600° F.). After the radio frequency is applied, the temperature differential should be such that the heat losses from the layer to be contour hardened at both the tips and roots of the teeth are substantially the same over the heat cycle. This means that the final temperatures of the tips of the teeth and of the roots of the teeth after the application of the radio frequency power will be approximately the same. This is desirable in producing suitable contour hardened-gears. The final hardness of the roots of the teeth depends upon the temperature of said roots when the radio frequency power is applied. It is inherent that the radio frequency power will be concentrated at the tips of the teeth and, therefore, heat them more rapidly. It is more desirable if the steel in the roots is below the lower critical hardening temperature when the radio frequency power is applied. If it is too near or above that temperature a very hard and deep contour will result in the roots, which is not as desirable. Thereafter, the teeth are quenched by projecting on them a liquid such as water or brine or immersing them in a submerged oil spray. A short delay between the end of the radio frequency power cycle and the start of the quench cycle is beneficial. The heated contour pattern is not materially changed by this delay, while the metallurgy of the hardened pattern is improved. The steel to be hardened and the heating cycle determines the amount of delay that should be employed. The generator which produces the radio frequency field preferably has sufficient power to provide energy at the rate of approximately 6½ kilowatts per square inch to the surface area treated. Since it is desirable that the hardened skin be produced only over the surface of the teeth, the total surface area to be heated is in effect the surface area of the teeth. This area is approximately $2\pi \times \text{pitch diameter} \times \text{tooth face width}$. The teeth of the gears are thus heated to the hardening temperature, only in the thin outer layer where the hardened material is to be produced. The depth of the layer heated may be increased within narrow limits by decreasing the power per square inch of surface treated and increasing the time interval during which the high frequency power is impressed.

Excessive stresses are avoided during the pre-quenching heating operation because the differential in temperature between the regions to be hardened and the other regions of the gear is relatively small. These stresses and the higher stresses resulting from metallurgical changes following the quenching operation are moreover absorbed by the resilient cushion provided in the unhardened portion of the teeth.

The method of heating in accordance with our invention involves the application of electromagnetic fields of different frequencies. In its more limited aspects our invention involves the steps of subjecting the articles to be treated first to an audio frequency field and subsequently to a radio frequency field. Our invention in its broader aspects includes within its scope the steps of subjecting the articles to be treated to fields of different frequencies of any classification. For example, two audio frequencies, 60 cycles per second and 9600 cycles per second, may be applied. On other occasions one or both of the fields may be of radio frequency, of ultra-high frequency or of microwave frequency. For example, fields having frequencies of the order of 100,000 cycles per second may be impressed for pre-heating purposes and fields of a frequency of the order of 1 to 100 megacycles (or even 10,000 megacycles) may be impressed for the pre-quenching heating.

The frequencies of the pre-heating and pre-quenching fields depend on the dimensions of the objects to be treated, the area to be pre-heated, the area to be hardened and the depth of the hardened material. The larger the object to be heated the lower the pre-heating frequency. The pre-quenching frequency selected will depend on the contour to be hardened (the pitch of the gear to be hardened) and on the minimum penetration desired. A pre-quenching field of a given frequency will produce a predetermined minimum penetration. The penetration may be increased by decreasing the power in the field and increasing the time during which the field is applied. To decrease the penetration below the minimum the frequency of the field should be increased substantially.

The method of heat treatment in accordance with our invention should be distinguished from multiple frequency step heating, such as is described, for example, in the patent to Seede 1,646,498. Broadly our invention involves multiple frequency heating as a part of a hardening process and such heating in any hardening process is within the broad scope of our invention. However, mere subjecting of an article to be treated to two frequencies, one a low frequency and the other a high frequency, will not produce a hardened article in accordance with the more specific aspects of our invention. The power applied during the pre-heating operation must be such as to produce a satisfactory differential between the pre-quenching and pre-heating temperatures. The power applied during the pre-quenching operation must be of the proper magnitude to heat the region which is to be hardened. If an article is subjected to fields of different frequencies without consideration of the power impressed, it will be irregularly heated and when subsequently quenched, the desired hardened surface will not result. If the pre-heating temperature is too low, excessive stresses may develop during the pre-quenching heating. If this temperature is too high, proper hardness pattern cannot be obtained. If the pre-heating step is omitted, or, if the pre-heating temperature is too low, uneven heating is produced during the pre-quenching heating operation by the concentration of the current in bands at the root of the gear between the teeth. Such concentration of current results in over-heating of the bands and in underheating of the remaining regions at the roots. Because of the striated appearance of the root during pre-quenching heating, the over-heated strips are called striations.

When a striated gear is quenched the hardening produced is unsatisfactory.

The novel features that we consider characteristic of our invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with additional objects and advantages thereof, will best be understood from the following description of specific embodiments when read in connection with the accompanying drawing, in which:

Figure 1 is a view in section, by a plane perpendicular to the axis, of a portion of a gear in accordance with our invention;

Fig. 2 is a view in section through line II—II of a gear of the type shown in Fig. 1 which has a clashing surface;

Fig. 3 is a schematic diagram showing a low frequency power coil, a high frequency power coil and quenching means;

Fig. 4 is a photomicrograph showing the core refinement pattern of a gear tooth throughout the various stages of heat treatment to produce the desired contour hardness, and

Fig. 5 is a graph illustrating certain aspects of our process with reference to an isothermal transformation curve.

The gear shown in Fig. 1 has a shallow hardened region 10 which extends only along the contour of the teeth 11 and roots 12. The hardened contour is widest at the top and narrows toward the root of the gear. If the gear is of the type having flat side surfaces, the hardened contour along the side surface has the same form as in the section produced by a plane perpendicular to the axis of the gear (as shown in Fig. 1). The hardening does not extend over the side surfaces of the teeth beyond the depth to which it extends throughout the sections.

Gears included in a transmission which are moved during the gear shift operation have side surfaces designed to minimize the shock during the engaging operation. We shall designate such surfaces as clashing surfaces. As shown in Fig. 2 a tooth clashing surface 15 is curved to facilitate the engagement of a gear with other cooperative gears of the transmission system. In accordance with our invention, the hardened zone 16 of such a gear extends along the clashing surface to a distance approximately one-half way between the pitch line 17 and the root 12.

The hardened band along the contour of the teeth and roots and over the clashing surface is narrow compared to the length of the teeth. In gears of the type included in the standard automotive vehicles and tractors, the depth of the hardened band at the top of a tooth is of the order of .050 inch. This depth at the root is of the order of .030 inch. The band along the clashing contour narrows from approximately .050 inch to zero.

In Fig. 3, a low frequency inductor coil 100 is shown schematically. Terminals 101 and 102 therefor are adapted to be connected to a suitable power supply. A high frequency inductor coil 105, having terminals 106 and 107 is shown. Suitable quenching means 110 having a fluid inlet 111 is shown. In the low frequency coil 100 the temperature of the gear contour is raised to about 1500° F., which is above the upper critical hardening temperature of the material, at which austenite forms. Thereafter a period of heat penetration or a delay in the application of heating currents is allowed, during which the tem-

perature of the heated portions drops to about 1000° F. in about 20 seconds. Then the material is placed in the high frequency field of the second coil 105, where the temperature of the contour to be heated is again raised above the upper critical hardening temperature to form austenite. During the latter stage of the heat treatment, the roots of the teeth again go into austenite form.

Fig. 4 shows a photomicrograph of the gear tooth core refinement pattern after the various stages of the heat treatment. This photomicrograph was produced by viewing sections cut from a treated gear.

Plate A of Fig. 4 is a photomicrograph of a portion of the gear which did not reach the critical hardening temperature at any time during the heat treatment. This micrograph shows the initial pearlitic structure of the gear having iron carbide and iron mixed, after a prior normalizing treatment by heating the material in a furnace to 1600° F. and then cooling it.

Plates B, C, D, E and F show the relative structures of the respectively designated portions of the gear. Plate B shows the structure of a portion of the gear which has been austenitized by the pre-heat treatment, but not a second time by the high frequency heat treatment. Plate C shows the resultant structure just below the hardened root contour structure; the material of this portion of the treated gear has been austenitized once by the low frequency power and partially austenitized by the high frequency power. Plates D, E and F show portions of the gear which have been twice austenitized, once by the low frequency and once by the high frequency power.

Plate G shows a section through a contour hardened gear as finally treated. Plates H and I show sections taken through the tooth root and body, respectively, of the gear tooth shown in plate G. The original structure had a hardness of 77, on the Rockwell 30T scale, and after treatment the core of the tooth at the pitch line had a hardness of 83. The pattern of the pre-heat core refinement can be seen on the etched micrograph of the section taken through the gear tooth. The hardened case that was put on by the radio frequency power is clearly shown.

Fig. 5 shows a time-temperature isothermal transformation diagram for a typical steel used in gears to be induction hardened. The basic diagram can be found in the "Atlas of Isothermal Transformation" by the U. S. Steel Corporation. The diagram shown is for a 0.5% C and .9% Mn steel. On it have been added three cooling waves, YX, YZ and YW, which have been obtained by using different cooling cycles after heating the gears to be hardened. In the presently preferred method of heat treatment, the gear teeth are heated to a depth below the teeth roots, to some temperature point Y above the A_{c3} critical hardening temperature line shown in Fig. 5 by means of the 10,000 cycle, low frequency power. The teeth are then allowed to cool along a curve similar to "YX" until the steel reaches a certain temperature point, point X in the example chosen. Then the surface layer to be contour hardened is again heated above the critical hardening temperature represented by line A_{c3}; the 200,000 cycle, high frequency power is used for this stage of the heating. The heated gear is then quenched, its temperature following a curve similar to curve YW shown in Fig. 5. This produces a martensitic hardened contour.

Since the temperatures in actual practice vary over the surface of the gear teeth, the curves shown may only represent the time-temperature condition at one point on that surface. Other points along the treated surface of the gear, although not following identical cooling curves, will follow similar curves.

In special cases the steel has been heated to above the A_{c3} critical hardening temperature line three times. After the first heating the gears are oil quenched to follow a cooling curve similar to curve YZ shown in Fig. 5. For the other two heating and cooling cycles curves similar to YX and YZ, respectively, are followed.

In particular, the main heating cycle described accomplishes two things. First, it places the steel to be heat treated in such a state that it will form austenite rapidly, over the tooth contour, upon the application of the high frequency power. And secondly, by this method a tough tooth core is retained while a hardened case or contour is produced.

A time-temperature curve similar to that shown as WV in Fig. 5 can be obtained by interrupting the quench, before the usual quench period has been allowed, to permit the heat stored in the hub of the gear to flow out to the surface layer, and then allowing the entire gear to cool slowly to room temperature. This provides a method of stress relief which has been found to be advantageous in eliminating cracks. In other cases, more humps in curve WV may be obtained by giving additional shots of heating power to the gear. This provides a greater stress relief which is sometimes necessary.

In practicing our invention we have successfully treated gears having the following dimensions:

Outside diameter	1½ inches to 7 inches
Pitch	5 to 16 inches
Width	¾ inch to 1½ inches

The gears treated were composed of carbon steel having a carbon content of .40% to .55% and a manganese content of .60% to 1.0%. These gears were pre-heated by subjecting them to an electromagnetic field having a frequency of 9600 cycles produced by a generator, the power output of which was varied between 25 kilowatts and 100 kilowatts. The zones of the gears to be hardened were then subjected to radio frequency fields having frequencies between 90,000 to 450,000 cycles per second produced by a generator having an output which was varied between 75 to 170 kilowatts. During the pre-heating operation, power was supplied to the gears in four pulses of duration 4 seconds at intervals of 2 seconds. (Satisfactory results can also be obtained by heating the gears continuously during time intervals equivalent to that corresponding to the pulsation heating.) The R. F. was supplied from .4 to 1 second. The heat input at the radio frequency was at the rate of approximately 6½ kilowatts per square inch for the total surface heated.

During the low frequency pre-heating cycle, the radio frequency hardening cycle, and the quench cycle, the gear is slowly rotated. It should rotate about three or four times during the radio frequency heating cycle. The rotation of the gear to be heat treated should be such that the gear almost, but not quite, stops when the quenching fluid is applied. This allows the quench fluid to penetrate to the roots of the teeth.

In its more specific aspects, our invention is

primarily applied to the heat treatment of irregular articles composed of steel or quench-hardenable alloys. In its broader aspects our invention is also applicable to the heat treatment of irregular articles of other metals or alloys and regular (spherical, cylindrical) articles of steel and other metals or alloys. Where the articles are composed of other metals than steel, the hardening treatment as above described may not be specifically suitable, so the temperatures to which the articles are heated, the power applied for heating purposes, and the quenching fluid must be suited to the metal or alloy involved.

While we have shown and described certain specific embodiments of our invention, many modifications thereof are possible. Our invention therefore is not to be restricted, except as is necessitated by the prior art and by the spirit of the appended claims.

We claim as our invention:

1. The method of heat treating an article of quench-hardenable metal in the operation of zone hardening which comprises heating the article with a relatively low frequency electrical induced current at a plurality of heating stations, the application of which consists of a plurality of evenly timed and spaced impulses, each of said impulses being applied at a different one of said stations, thereby heating said article to a temperature near the transformation point of its metal, stopping the application of heat to said article for a time period sufficient to allow the temperature of said article to fall to a temperature below the critical hardening temperature of the metal, immediately thereafter heating said article with an electrical induced current of substantially higher frequency through a time cycle of such duration whereby a temperature is reached such that a hardened surface zone of relatively shallow depth is obtained upon quenching said article by a coolant.

2. The method of heat treating an article of quench-hardenable metal in the operation of contour hardening which comprises heating the contour of said article with an electrical induced current of between 960 and 15,000 cycles at a plurality of heating stations, the application of which consists of a plurality of spaced impulses over a period of time sufficient to heat said contour of said article to a temperature near the transformation point of the metal, one of said impulses applied at each of said stations, delaying the application of heat to said article for a time period sufficient for the temperature of the metallic structure in said heated contour to drop to a temperature below that necessary for the formation of austenite, immediately thereafter heating the contour of said article with an electrical induced current of higher frequency over a period of time sufficient to develop in said contour a temperature such that a relatively shallow hardened contour is obtained upon the quenching of said article in a coolant.

3. The method of heat treating a quench-hardenable metallic article having an irregular surface contour, which comprises heating at a plurality of stations a contour zone of said article with an electrical induced current within the limits of 960 to 15,000 cycles to a temperature near the transformation point of the metal, the application of said current being in a plurality of spaced impulses over a period of less than 30 seconds, one of said impulses being applied at each of said stations, effecting a delay in the

application of heat to the contour zone of said article for a time period sufficient for the temperature of said contour zone to fall below that necessary for the formation of an austenitic structure in said heated contour zone, immediately thereafter heating the contour zone of said article with a substantially higher frequency current to a temperature whereby a hardened surface zone is effected throughout the contour of said article upon the quenching of the same in a coolant.

4. In the mass production of articles the method of subjecting quench-hardenable metallic articles to a treating process in the practice of which each article is heated in one manner during a one time interval of long duration and in a second manner during a second time interval of short duration, which comprises the steps of heating each article to a temperature near the critical hardening temperature of the metal in said first manner in a plurality of successive sub-operations each for a sub-interval of duration such that the total heating time is equivalent in heating effect to heating during an interval of said long duration, delaying the application of heat to said article for a time period sufficient in duration for the temperature of said article to drop to a temperature below the critical hardening temperature of the metal, and promptly thereafter heating said article to a temperature near the critical hardening temperature of the metal in said second manner during said interval of short duration, the duration of said sub-intervals being of the order of a fraction of the duration of said long interval.

5. The method of heat treating a dentate metallic object composed of medium carbon steel which comprises the steps of heating said object in a manner such that, and to a temperature such that, the metal at the roots of the toothlike projections is transformed into austenite, cooling said objects to a temperature such that the metal at said roots reaches a transformation condition intermediate between the austenite state and the initial state, and thereafter reheating said object in a manner and to a temperature such that the metal in a contour band at the surface of said projection and said roots is transformed into austenite, and after a predetermined delay period quenching said object to produce a hardness in said contour band.

6. The method of treating a dentate metallic object of low alloy steel which is characterized by the fact that the roots of the toothlike projections are preliminarily austenitized by heating, thereafter the roots are reduced to an intermediate metallic transformation condition by cooling, thereafter a shallow contour around the surface of the toothlike projections and the roots between said projections is transformed into austenite by heating to a sufficiently high temperature and for sufficient duration, and thereafter a hardened surface is produced in said shallow contour by quenching said austenite surface.

7. In the heat treatment of a low alloy steel gear, the method of which comprises the steps of heating said gear with power of a first frequency such that the temperature of the metal at the roots of the said gear teeth is such that said metal is transformed into austenite, cooling the heated portions of the gear to a temperature at which the said heated metal portions go into an intermediate transformation condition between the austenite form and the initial metallic form, reheating said gear to such a temperature

and with power of a second frequency such that the metal in a contour band along the surface of said teeth and said roots is transformed into austenite, and after a predetermined delay period quenching said gear to effect a hardness in said contour band.

8. The method of mass production heat treating the contour of a quench-hardenable metallic object which comprises the steps of preheating said contour to a temperature above the critical hardening temperature of said metal at successive heating stations by repeatedly subjecting said object to heat for a plurality of substantially equal, predetermined time durations at predetermined and substantially equal time intervals, allowing a time delay period which is sufficient to effect a drop in the temperature of said contour to a temperature below the critical hardening temperature of the metal, immediately thereafter pre-quench heating said contour to a temperature above the critical hardening temperature of said metal and partly quenching said object, and completing the quenching of said object, the duration of said pre-quench heating and part quenching and the duration of the completion of the quenching being substantially equal to one of said predetermined time durations, and thereafter drawing said object by repeatedly subjecting said object to heat for a plurality of time durations each substantially equal to one of said first-mentioned predetermined time durations at time intervals equal to said first-mentioned time intervals.

9. The mass-production method of heat treating a metallic object of the quench-hardenable type which comprises the steps of preheating said object at a plurality of successive stations by repeatedly subjecting said object to heat for a plurality of substantially equal predetermined time durations at predetermined and substantially equal time intervals, said intervals being of such length relative to said durations that after the completion of all said repeated preheating steps said object is at a temperature above the critical hardening temperature; thereafter permitting a delay period of a second predetermined duration during which said object is allowed to reach a temperature below said critical hardening temperature; thereafter immediately pre-quench heating said object to a temperature above said critical hardening temperature, and a relatively short time thereafter quenching said object, the duration of the pre-quench heating and quenching operations being substantially equal to one of said predetermined durations, and said relatively short time being so short that the quenching curve produced by said quenching does not intersect the isothermal transformation curve for the material of said object.

10. The mass-production method of heat treating a metallic object of the quench-hardenable type which comprises the steps of preheating said object at a plurality of successive stations by repeatedly subjecting said object to heat for a plurality of substantially equal predetermined time durations at predetermined and substantially equal time intervals, said intervals being of such length relative to said durations that after the completion of all said repeated preheating steps said object is at a temperature above the critical hardening temperature; thereafter providing a delay period of a second predetermined duration during which said object is allowed to reach a temperature

below said critical hardening temperature; thereafter immediately pre-quench heating said object to a temperature above said critical hardening temperature, and a relatively short time thereafter quenching said object, the duration of the pre-quench heating and quenching operations being substantially equal to one of said predetermined durations, and said relatively short time being so short that the temperature of the object during said quenching is maintained such that a direct transformation from austenite to martensite metallic structure is effected.

11. The method of heat treating a quench-hardenable metallic gear having tooth-like projections which comprises the steps of heating said gear to a temperature such that the metal at primarily the root areas of the tooth-like projections reaches a temperature above the critical hardening temperature of the metal, cooling said gear to a temperature such that the metal at primarily the root areas of the tooth-like projections reaches a temperature below the critical hardening temperature of the metal, and thereafter heating said gear to a temperature such that the metal in the tip areas and root areas of said tooth-like projections reaches a temperature above the critical hardening temperature of the metal, and after a predetermined delay period quenching said gear to produce a hardness in said contour.

12. The method of heat treating a quench-hardenable metallic gear having tooth-like projections which comprises the steps of heating said gear with a relatively low frequency induced current such that the metal at primarily the root areas of the tooth-like projections reaches a temperature above the critical hardening temperature of the metal, cooling said gear to a temperature such that the metal at primarily the root areas of the tooth-like projections reaches a temperature below the critical hardening temperature of the metal, and thereafter heating said gear with an induced current of a substantially higher frequency such that the metal in the tip areas and root areas of said tooth-like projections reaches a temperature above the critical hardening temperature of the metal, and after a predetermined delay period quenching said gear to produce a hardness in said contour.

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