Aug. 21, 1951 H. F. KINCAID ET AL 2,564,906

HEAT TREATMENT OF IRREGULAR METALLIC OBJECTS

Filed July 9, 1947 3 Sheets-Sheet 1

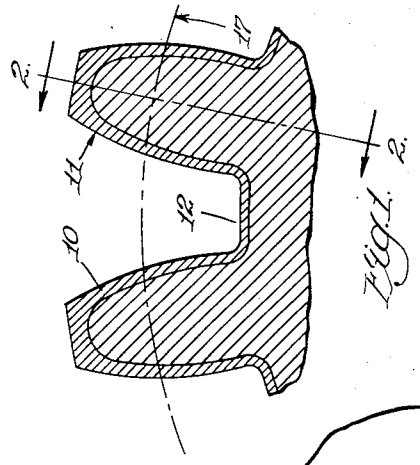


Fig. 1.

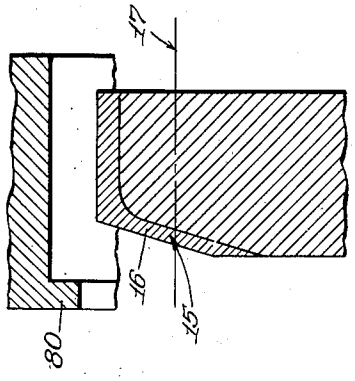


Fig. 2.

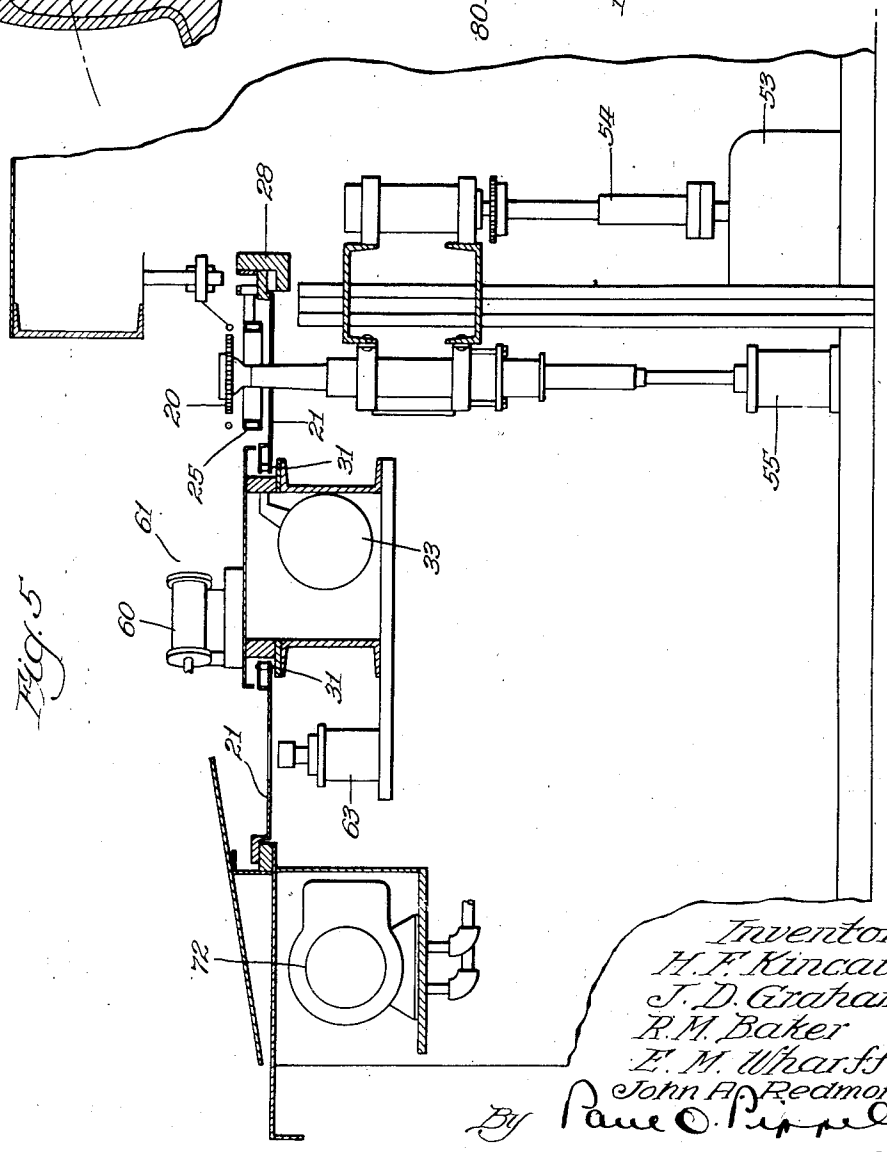


Fig. 5

Inventors:
H. F. Kincaid
J. D. Graham
R. M. Baker
E. M. Wharff &
John A. Redmond
By Paul O. Pippel
Atty.

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HEAT TREATMENT OF IRREGULAR METALLIC OBJECTS

Filed July 9, 1947 3 Sheets-Sheet 2

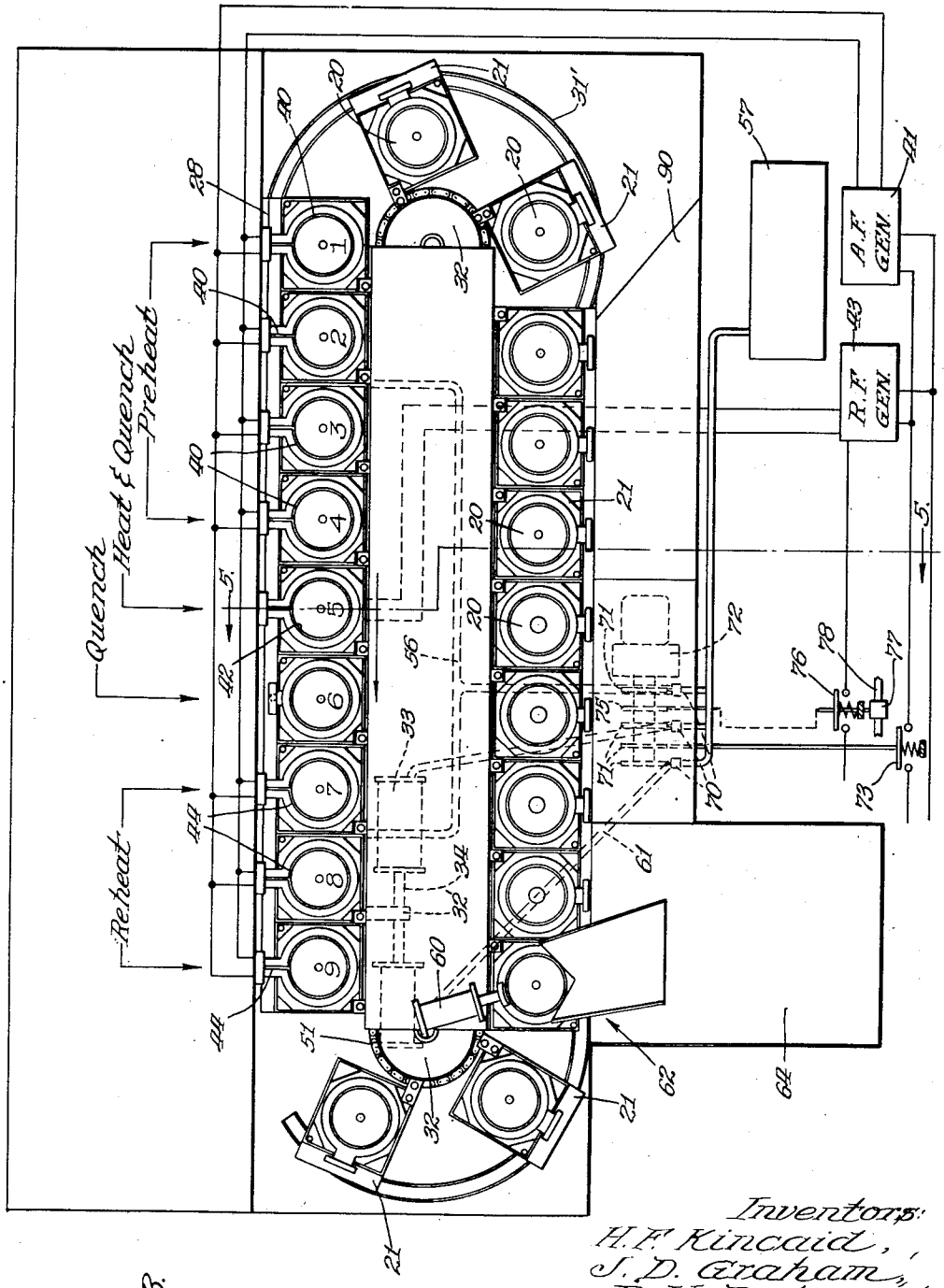


Fig. 3.

Inventors:
H. F. Kincaid,
J. D. Graham,
R. M. Baker
E. M. Wharff &
John A. Redmond.
By Paul O. Pippel
Atty.

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HEAT TREATMENT OF IRREGULAR METALLIC OBJECTS

Filed July 9, 1947 3 Sheets-Sheet 3

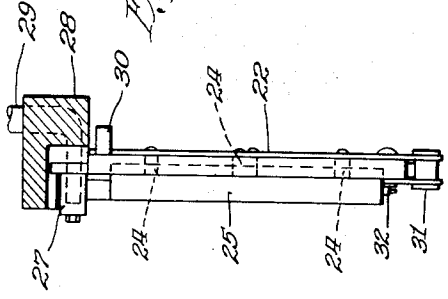


Fig. 7.

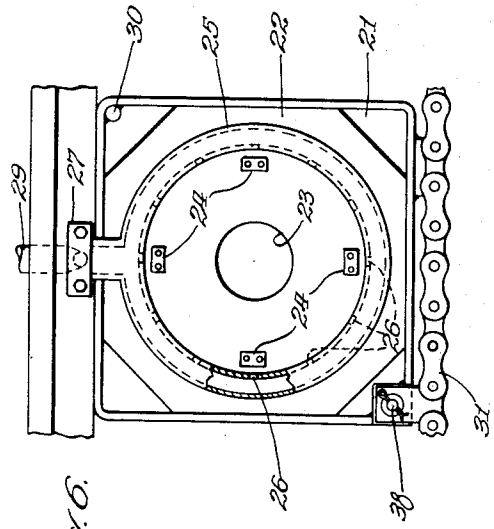


Fig. 6.

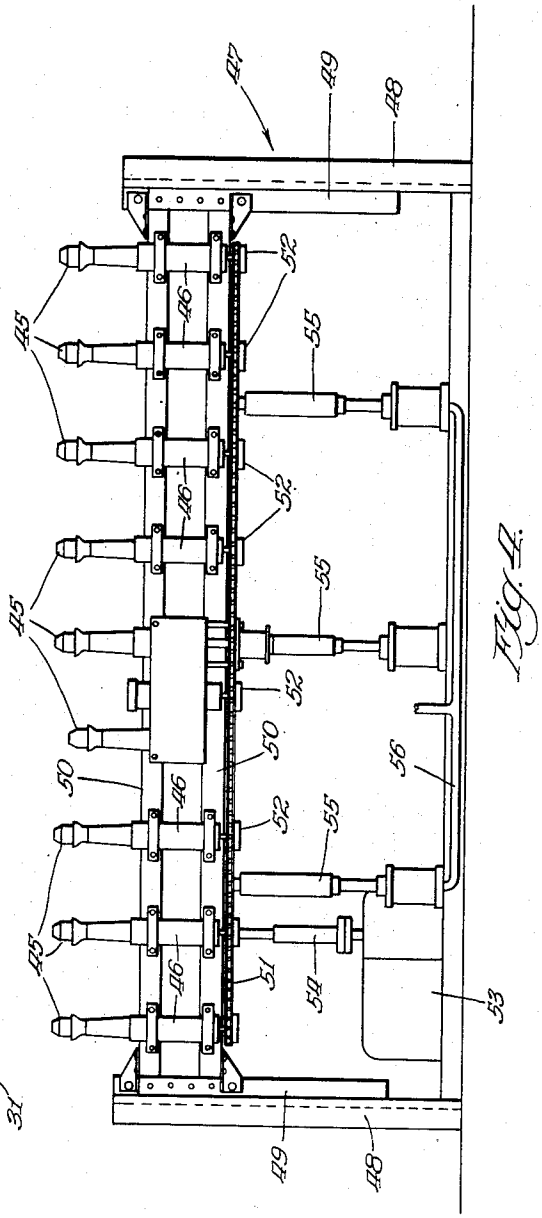


Fig. 4.

Inventors:
H. F. Kincaid,
J. D. Graham,
R. M. Baker
F. M. Wharff &
John R. Redmond
By Paul O. Pippel
Atty.

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UNITED STATES PATENT OFFICE

2,564,906

HEAT-TREATMENT OF IRREGULAR METALLIC OBJECTS

Homer F. Kincaid, Carbon Cliff, Ill., John D. Graham, Louisville, Ky., and Robert M. Baker, Edward M. Wharff, and John A. Redmond, Baltimore, Md., assignors of one-half to International Harvester Company, Rock Island, Ill., a corporation of New Jersey, and one-half to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Application July 9, 1947, Serial No. 759,888

10 Claims. (Cl. 148—10.5)

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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.

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. The gears

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are frequently cracked in the region of the teeth and the roots, and the teeth do not have the wearing properties which are essential for such components.

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 pre-heating 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, said combination being designed to eliminate tensile stress in the critical areas of the article.

A specific object of our invention is to provide conveyor apparatus into the input of which untreated metallic objects shall be supplied continuously and out of the output of which heat treated objects shall be derived.

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.

An ancillary object of our invention is to provide an irregular metallic object, such as a gear, having a substantially unimpaired hardened surface region produced at a relative low cost per

item and having high resistance to repeated impacts.

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

In accordance with a further aspect of our invention, we provide a novel method for producing gears of this type. A gear to be heat treated in accordance with our invention is first pre-heated inductively to a substantial depth below the roots of the teeth (in the case of a small gear throughout). This object 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. Each gear is maintained in the field until the temperature of the heated region attains a magnitude of the order of 900° F. 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.). Thereafter, the teeth are quenched by projecting on them a liquid such as water or brine or immersing them in a submerged oil spray. 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 $2\pi \times$pitch diameter$\times$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 (approximately 900° F.). 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 field 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 tem-

peratures. 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 overheated 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;

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

Figure 3 is a view partly in top elevation and partly diagrammatic showing conveyor apparatus for producing hardened metallic objects in accordance with our invention at a high time rate;

Figure 4 is a view in side elevation of a portion of the apparatus shown in Figure 3;

Figure 5 is a view in section taken along line 5—5 of Figure 3.

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. A tooth of a gear of this type is shown in section in Fig. 2. The 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.

Figures 3 to 7 show a conveyor system for producing gears in accordance with the method of this invention.

The gears or work to be treated are indicated by the reference character 20. The gears 20 are carried by a plurality of work holding carriers 21. As best shown in Figs. 6 and 7, each carrier 21 comprises a bottom plate 22 having a centrally located opening 23. Radially disposed locating members 24 are provided to place the axis of the gears in axial alignment with the opening 23. A hollow quench ring 25 is positioned on the carrier 21. The quench ring is provided with internal openings 26 through which a quenching medium may be distributed. A portion 27 of the carrier 21 is in sliding engagement with a longitudinal support 28. The longitudinal support 28 is provided with a quench fluid conduit 29 at each of the quench stations as will presently be more fully described. A guide pin 30 extends downwardly from each carrier 21. The guide pin 30 is adapted to slide between guide rails 31'.

The carriers are connected to a chain 31 as indicated at 38 of Figure 6. The chain 31 is trained about sprockets 32, one of which is positioned at each end of the apparatus as shown in Figure 3. The conveyor chain 31 is indexed and advanced intermittently by operation of a dog 32' which engages the same. The dog 32' is actuated by an indexing air cylinder 33 which reciprocates a piston arm 34. As the chain is indexed intermittently, the carriers and the gears supported thereon are advanced through the various stations of the conveyor system.

The stations at which the gears 20 are subjected to treatment are longitudinally disposed along the line of the conveyor system. The preheat stations are designated from 1 to 4, inclusive. Station 5 is the heat and pre-quench station. Station 6 is a quench station, and 7, 8, and 9 refer to the reheat stations.

Stations 1 to 4 are provided with electrical induction coils or blocks 40 which are energized from a suitable audio frequency generator 41.

Station 5 is provided with an electrical induction block or coil 42 which is energized from a radio frequency generator 43. Station 6 is the quench station and does not have an induction block. Stations 7 to 9 inclusive are provided with inductor blocks 44 which are energized from the motor generator 41. The circuits leading to the A. F. and R. F. generator are shown diagrammatically in Figure 3.

Under each of the 9 stations, and in axial alignment with the openings 23 in each carrier, are a plurality of spindles 45. The spindles are mounted for rotation in suitable bearings 46 which in turn are carried by a supporting frame 47. The supporting frame 47 includes vertical spaced end members 48. Vertical members 49 slidably engage the end members 48, and have secured thereto longitudinal supports 50, to which the bearings 46 are attached. The spindles 45 are rotated by means of a driving chain 51 which engages sprockets 52 which are connected to the spindles 45. A suitable motor 53 drives the chain 51 through a driving connection 54.

As best shown in Figures 4 and 5, air cylinders 55 are provided. The air cylinders 55 serve to move the supporting members 50 and the spindles 45 as one unit upwardly and downwardly, the vertical members 49 slidably engaging the vertical end members 48. An air conduit 56 is suitably connected to a tank 57 containing a supply of compressed air.

An ejector cylinder 60 is provided, as indicated in Figures 3 and 5. The ejector cylinder 60 is actuated by compressed air from a conduit 61 in communication with the source of compressed air. The ejector cylinder 60 is positioned adjacent to an ejection station 62 which includes a raising cylinder 63, hydraulically synchronized with the cylinder 60. As the work carrier arrives at the ejector station the gear is lifted upwardly from the carrier by means of the raising cylinder. The ejector cylinder thereupon pushes the gear into a hopper 64.

A plurality of valves 70 control the flow of air to the ejector cylinder 60, the indexing cylinder 33, and the air cylinder 55. The valves 70 are opened and closed by means of the operation of corresponding cams 71 rotated by means of a motor 72. A cam operated switch 73 also controls the closing and opening of the generator circuits to control the supply and interruption of the audio and radio frequency power. The quenching is also controlled from a cam 75 which operates a switch 76 and valve 77. The valve 77 is connected to conduits 78 which in turn are provided to supply a quenching medium to the quench stations 5 and 6. The cam 75 operates the R. F. circuit and also the quench supply valve. The cams are of such contour that the operation and timing of the valves and switches is properly synchronized.

The inductor blocks 40, 42, and 44 are shown as standard type rings for heat treating various types of gears. As shown in Figure 2 the inductor blocks may also be provided with a projecting portion 80 for suitably forming the hardened surface band of the clashing type gear shown in this figure. Different shapes of inductor blocks can be provided depending on the type of gear that is intended to be hardened.

During the operation the work carriers 21 are indexed adjacent to a loading table 90. At this point the operator places a gear 20 upon each of the carriers. By virtue of the cylinder 33 and dog 32', the carriers are indexed to the various heating and quenching stations. The carriers are brought to rest at the various stations with the openings 23 and the gears in axial alignment with the corresponding spindles 45. At this point all of the carriers and the gears are situated below the inductor blocks and have to be moved upwardly into these blocks for the heating operation. The spindles 45 are thereupon moved upwardly as a unit due to the operation of the air cylinders 55. As the spindles 45 move upwardly they extend through the openings 23 in the work holders, and continued upward movement lifts the gears 20 free of the work holders until the gears are positioned within the inductor blocks of the various stations. After a predetermined time interval, the treating for all of the gears is completed, and the spindles are moved downwardly by operation of the cylinders 55, and the gears are thereupon again deposited on the work holders 21. The work holders are then again indexed to the succeeding station where the above described process is repeated.

As shown in the diagrams in Figures 3 to 5, the gears are subjected to a number of hardening and quenching treatments. A gear to be properly treated is first indexed through the four pre-heating stations 1, 2, 3, and 4. At each of these four stations the gear is subjected to an electromagnetic field of audio frequency, preferably between the limits of 960 to 9600 cycles. The field at each station is produced by the inductor blocks 40 which are energized from the audio frequency generators 41. The time interval to which the gear is subjected to the field is so related to the time it is indexed that after being heated at the fourth station the gear has a temperature near the order of 900° F. This temperature is substantially below the transformation temperature for steel.

After the gear has been indexed to the fourth station it then passes onto the fifth, where a heat and quench operation is effected. At this station the contour hardening of the gear takes place. The inductor block 42 is energized from a radio frequency generator 43 preferably having a frequency between 90,000 and 450,000 cycles. Accordingly, the gear at this station is subjected to a radio frequency electromagnetic field. In view of this high frequency, the gear is heated only over a shallow band extending along the contour of the teeth and roots. The depth of the band is determined by the frequency of the field and within limits by the duration of the interval during which the radio frequency field is applied. The duration of the radio frequency heating is substantially shorter than the duration of preheating. The power output of the radio frequency generator is such that the radio frequency energy supplied to the gear is just sufficient to produce the desired pre-quenching temperature along the contour. For a gear of the type included in the transmission of standard automotive vehicles, pre-quenching power of the order of 6.5 kw. per square inch of treated surface is impressed for a time interval of one second. As best shown in Figure 5, after the gear has been subjected to the radio frequency field, it is then lowered into the quench coil 25. At this time interval a quenching fluid (preferably of water or oil) is projected on the gear 20. The quenching fluid (preferably water) is supplied through the conduit 29 and into the quench ring 25 whereupon it is distributed through the openings 26 and projected on the gear. In the practice of our invention the delay between the interruption of the radio frequency field and the application of the quenching fluid may vary from 0 to .5 second for gears used in the transmission of standard automotive vehicles and small tractors.

The gear is then indexed to the sixth station where again a quenching medium is supplied. As the gear is moving from the fifth to the sixth station, the quenching operation continues. When the gear reaches this station the contour hardening has already been effected and the suitable quench therefor has been provided. At the sixth station, however, the gear is cooled, not only at its periphery but throughout its whole body. The duration of the quenching immediately following the treatment at station 5 should be set to satisfy the requirements of the material treated.

At the seventh, eighth, and ninth stations the gear 20 is again subjected to audio frequency electromagnetic fields derived from the audio frequency generator 41 and the inductor blocks 44. The fields are applied for the same duration as the pre-heating fields and operate to reheat the gears to approximately 350° F. It is believed that

the gears are drawn during this operation. A gear, after leaving the ninth station, is moved adjacent to the ejector station 62. At this point the raising cylinder 63 raises upwardly to remove the gear from the carrier 21. The ejector cylinder 60 thereupon operates to push the gear into the hopper 70.

During any complete operation the indexing cylinder 33 is first supplied with air to index and move the conveyor. The spindles thereupon are raised by means of the cylinders 55 to which compressed air is supplied and the gears are thereby raised into the treating media. The audio and radio frequency circuits are then closed and energy is supplied to the gears. While the pre-heating and final quenching ("at station 6") continues the radio frequency energy is interposed and the gear 20 at the pre-quenching station 5 is quenched. While the gears in the treating line are subjected to the treatment the ejector cylinder ejects the treated gear into the hopper.

Our invention is not to be limited to the specific treating line shown in Figs. 3 to 7. In the practice of certain aspects of our invention we may dispense with the final quenching operation and the drawing operations. In other aspects of our invention we may dispense with the drawing operation, retaining the final quenching operation or with the final quenching operation, retaining the drawing operation. The duration of the treatment at the various stations may also be varied over a wide range. In treating gears included in transmission of standard automotive vehicles or tractors, in accordance with our invention the pre-heating fields and the drawing fields are preferably applied for 4 second periods, for indexing at intervals of 2 seconds. The radio frequency field is applied to these gears for .4 of a second to 1 second. The preliminary quenching operation has a duration of the order of 3 seconds. The quenching fluid may be projected on the gears just before the radio frequency field is interrupted. Alternatively a delay of as long as .5 second may be introduced between the interruption of the radio frequency field and projection of the fluid. Excellent results have been obtained by introducing a delay of .2 second between the pre-quench heating and the quenching operation.

In discussing the apparatus shown in Figures 3 to 5, we have restricted ourselves to the treatment of gears. Other metallic objects such as crank shafts, racks, ratchets and the like may be treated with this conveyor equipment.

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

Outside diameter_____inches__	2¼ to 7
Pitch _____	7 to 8
Width _____inches__	⅜ to ⅞

The gears treated were composed of carbon steel having a carbon content of .48% to .53% and a manganese content of .80% 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 and 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.

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.

What is claimed is:

1. Apparatus for mass production heat treating a hardenable metallic object comprising a plurality of successive pre-heating stations, means for producing an alternating electromagnetic field of a first frequency at each of said stations, a pre-quench heating station adjacent said pre-heating stations, means for producing an electromagnetic field of substantially higher frequency than said first frequency at said pre-quench heating station, means for supplying a quenching fluid at said pre-quench heating station and means for subjecting said object to the field and quenching fluid for substantially equal time intervals at each said stations and for moving said object from station to station during substantially equal time intervals.

2. Apparatus for heat treating a hardenable metallic object comprising a plurality of successive pre-heating stations, means for producing an alternating electromagnetic field of audio frequency at each of said stations adjacent said pre-heating stations, a pre-quench heating station, means for producing an electromagnetic field of radio frequency at said pre-quench heating station, means for supplying a quenching fluid at said pre-quench heating station and means for moving said object from station to station during substantially equal time intervals.

3. Apparatus for heat treating a hardenable metallic object comprising a plurality of successive pre-heating stations, means for producing an alternating electromagnetic field of a first frequency at each of said stations, a pre-quench heating station following said pre-heating stations, means for producing an electromagnetic field of substantially higher frequency than said first frequency at said pre-quench heating station, means for supplying a quenching fluid at said pre-quench heating station, a plurality of drawing stations, means for producing an electromagnetic field of said first frequency at each said drawing stations and means for subjecting said object to the first frequency field producing means and to the other said field producing means and quenching fluid means for substantially equal time intervals at each said stations and for moving said object from station to station during substantially equal time intervals, said object passing in sequence through said pre-heating stations, through said pre-quench heating station and through said drawing station.

4. The mass production method of heat treating metallic articles which are hardenable by heating and quenching, said articles having an irregular peripheral surface, which comprises the steps of pre-heating each of said articles with a relatively low frequency current in a plurality of discrete impulses of substantially equal predetermined time durations at substantially equal

predetermined time intervals, thereby heating each of said articles to a temperature of the order of 900° F., one of said impulses being applied at each of a plurality of preheating stations, and after a finite interval of time heating each of said articles with a higher frequency current for a time duration sufficient to reach a temperature such that a hardened contour zone of relatively shallow depth is obtained upon quenching each of said articles, and thereafter quenching each of said articles.

5. The mass production method of heat treating metallic articles which are hardenable by heating and quenching, each of said articles having an irregular peripheral surface which comprises pre-heating each of said articles with an induced current of between 960 and 15,000 cycles per second in a plurality of impulses at a plurality of pre-heating stations, one of said impulses at each of said stations over a period of time sufficient to bring the temperature of said surface to be hardened to approximately 900° F., and after a predetermined time interval heating each of said articles with an induced current of substantially higher frequency over a period of time to bring the temperature of said surface to be hardened to a level sufficient to develop a relatively shallow hardened zone upon quenching each of said articles in a coolant, and thereafter quenching each of said articles.

6. The mass production method of heat treating metallic objects which are hardenable by heating and quenching, each of said objects having an irregular peripheral surface comprising the steps of pre-heating each of said objects with a relatively low frequency induced current within the limits of 960 to 15,000 cycles per second in a plurality of successive substantially equal timed and spaced impulses until the contour of said objects reaches a temperature of the order of 900° F., one of said impulses being at each of a plurality of preheating stations, and after a predetermined interval of time heating said objects with a higher frequency induced current until the contour of said objects reaches a temperature above the critical hardening temperature of the metal, and thereafter quenching said objects.

7. The mass production method of contour hardening an irregular peripheral surface metallic object having one or more teeth projecting from the surface thereof, said object being hardenable by heating and quenching, which comprises heating a surface zone of said object with a relatively low frequency induced current in a plurality of equally spaced and timed discrete impulses, thereby bringing the root area of each tooth to a temperature of the order of 900° F., one of said impulses being applied at each of a plurality of preheating stations, and after a predetermined time interval heating said article with a substantially higher frequency induced current to bring primarily the tip area of each tooth to a temperature above the transformation point of the metal, and thereafter quenching said object whereby a hardened contour is effected on each tooth.

8. The method of heat treating an article of hardenable metal, said article being hardenable by heating and quenching and having an irregular peripheral surface, which comprises pre-heating the article by applying to it a plurality of short pulses of relatively low frequency induced current at spaced intervals, each of said impulses being applied at a different one of a plurality of successive stations, moving said article from each of said stations to the succeeding station, the article being pre-heated to reach a temperature of the order of 900° F. when the preheating operation in the last of said stations is completed, moving said article to a further heating station, and after a predetermined time interval heating said article with a relatively high frequency induced current to a temperature above the transformation point of the metal such that a hardened contour zone of relatively shallow depth is obtained upon quenching said article in a coolant, and thereafter quenching said article.

9. The method of heat treating an object of hardenable metal, said object being hardenable by heating and quenching and having an irregular peripheral surface which comprises the steps of heating the object by applying to it short pulses of relatively low frequency induced current at spaced intervals, moving said object through a series of successive heating stations, one of said pulses being applied at each of said stations until said object reaches a temperature of the order of 900° F., moving said object to a further heating station, and heating said object with a relatively high frequency induced current to a temperature above the transformation point of the metal such that a hardened contour zone of relatively shallow depth is obtained upon quenching said object with a coolant, and thereafter quenching said object.

10. The mass production method for heat treating hardenable metallic objects, each of said objects being hardenable by heating and quenching and having an irregular peripheral surface, comprising the steps of pre-heating each of said objects by applying a plurality of short impulses of relatively low frequency induced current at spaced intervals, moving each of said objects through a plurality of successive heating stations, one of said impulses being applied at each of said stations until the contour zone of each of said objects reaches a temperature of approximately 900° F., moving each of said objects to a further heating station, and after a predetermined time interval heating each of said objects with a substantially higher frequency induced current for a time duration such that the contour zone of each of said objects reaches a temperature above the critical hardening temperature of the metal, and thereafter quenching each of said objects.

HOMER F. KINCAID.
JOHN D. GRAHAM.
ROBERT M. BAKER.
EDWARD M. WHARFF.
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