Aug. 1, 1939. F. S. DENNEEN ET AL 2,167,798

APPARATUS FOR HEAT TREATING GEARS AND THE LIKE

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Fig. 1

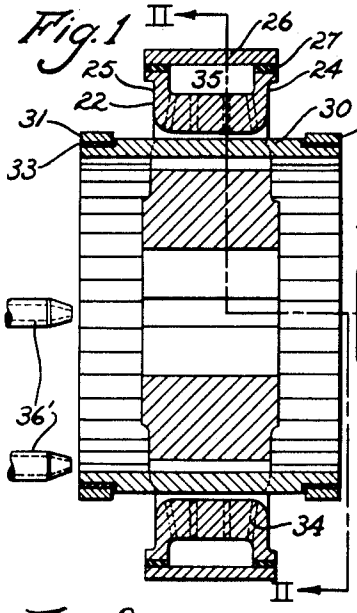


Fig. 2

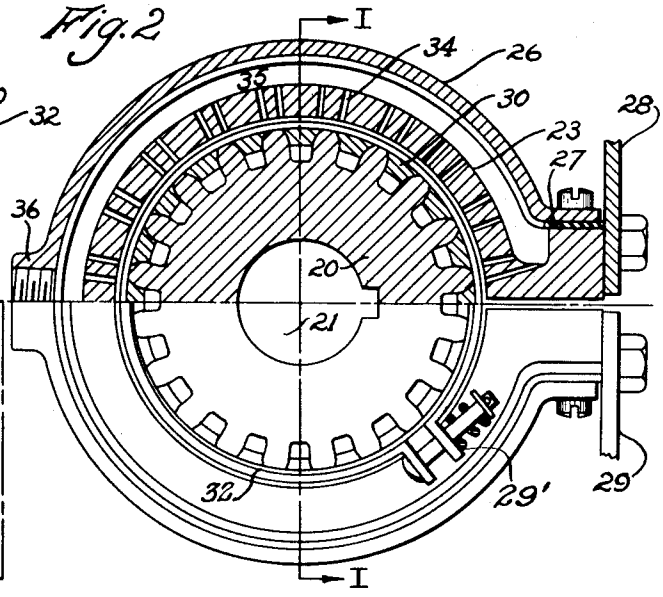


Fig. 3

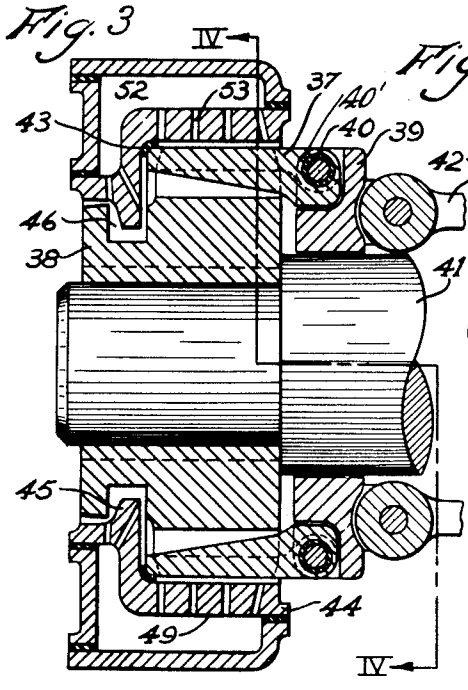
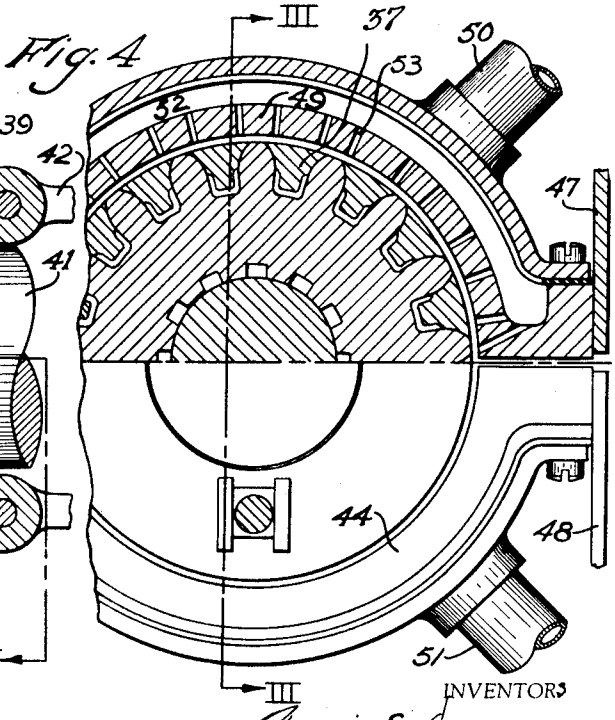


Fig. 4



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APPARATUS FOR HEAT TREATING GEARS AND THE LIKE

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Fig. 5

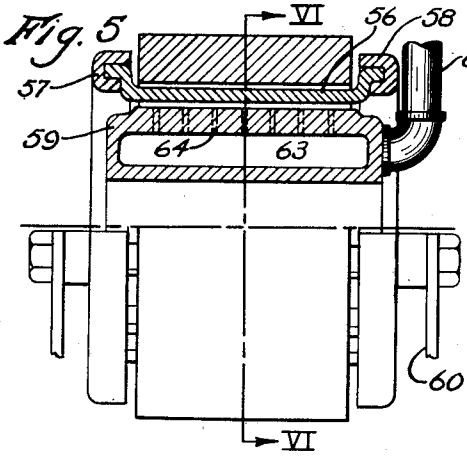


Fig. 6

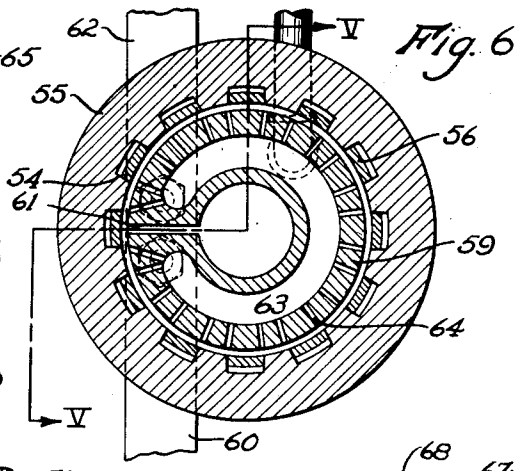


Fig. 7

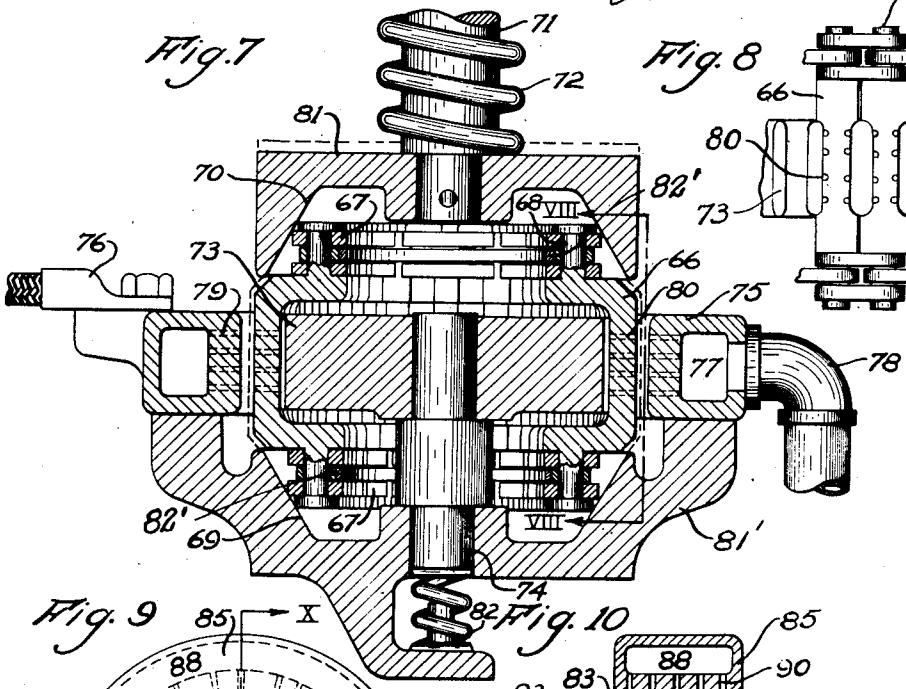


Fig. 8

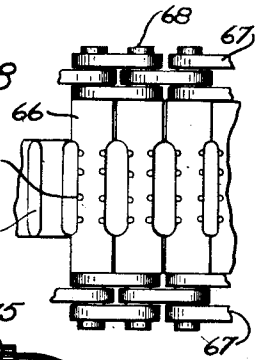


Fig. 9

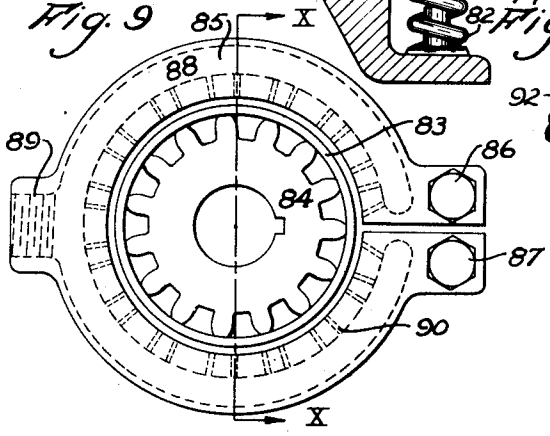
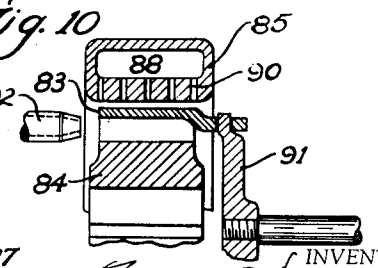


Fig. 10



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APPARATUS FOR HEAT TREATING GEARS AND THE LIKE

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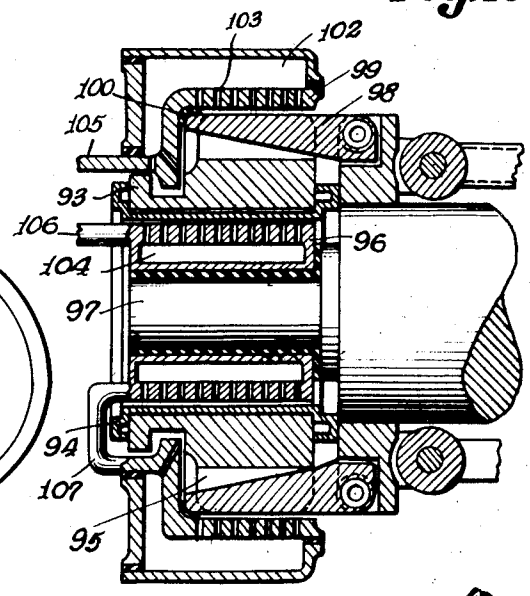
Fig. 15



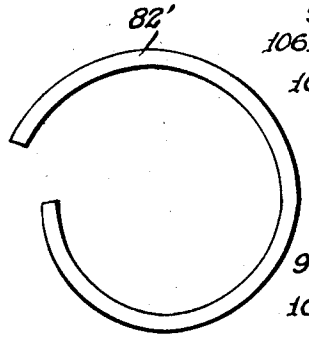


Fig. 16

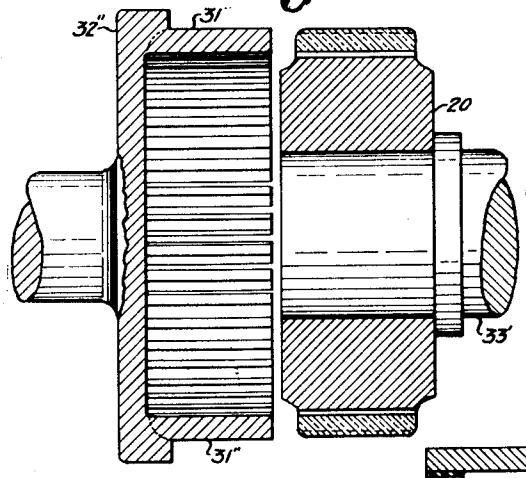


Fig. 12

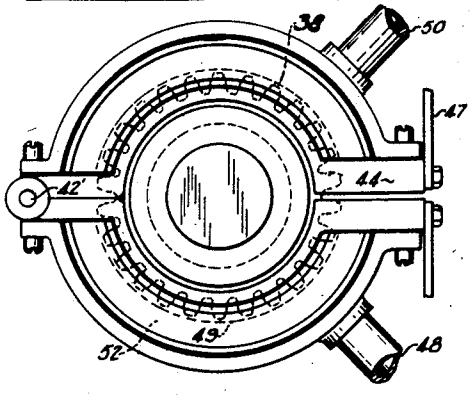


Fig. 13

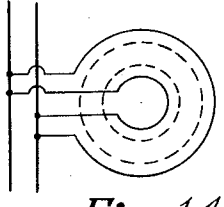


Fig. 14

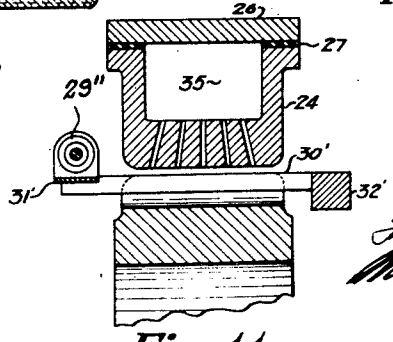


Fig. 11

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UNITED STATES PATENT OFFICE

2,167,798

APPARATUS FOR HEAT TREATING GEARS AND THE LIKE

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Application August 19, 1935, Serial No. 36,843

11 Claims. (Cl. 266—5)

The present invention, as a further improvement on that shown and described in our copending application Serial No. 689,904, filed September 18, 1933, relates, as indicated, to apparatus for hardening gears and the like. Whereas, the former application refers generally to means and method for electrically heating metal articles to be quenched to provide hardened surfaces thereon, the present application is more specific in its scope, being confined to more definite and detailed uses of the general process taught in the above numbered application.

In the heat treatment of metals generally and in the hardening of ferrous metals in particular, there have been no teachings which would enable those skilled in the art to produce hardened zones of metal of predetermined characteristics as to depth and general contour on articles having abrupt or irregular changes in surface form by the use of electric heat. Surface hardening processes used heretofore, were not adapted to the hardening of such surfaces as the contacting surfaces of gear teeth or splines, the side walls of sliding keys and keyways, the rifled interiors of gun bores, and many other similar surfaces. In the hardening of such surfaces as those above enumerated, it is often important that adjacent surfaces as well as the core or metal under the surface, be kept softer in order that it be sufficiently ductile to resist fractures due to shock, vibrations and other causes. For instance, in a gear tooth, the addendum surfaces should be hard in order to resist the abrasion of the sliding and rolling contact of other tooth surfaces, while the metal in the dedendum and at the root of the tooth which does not contact with any wearing or abrasive element, but which is submitted to heavy bending stresses due to the cantilever construction of gear teeth, should remain strong and comparatively ductile to prevent breakage or the formation of incipient fractures. Experience has taught that brittleness in steel usually increases with hardness, and the greater the brittleness the more the metal is susceptible to the formation of surface cracks or incipient fractures which eventually extend far enough into the metal to cause complete failure of the section affected.

Heretofore, in methods of hardening gears, the gears have either been heated to the required temperature as a whole and the entire gear then quenched, resulting in shrinkage strains and warping, or the teeth have been heated individually by applying a flame thereto and quenched. With the latter method, the heat is bound to penetrate into regions that should be kept cool in order to preserve the strength imparted by previous treatments. Further, the products of combustion have a harmful effect on the surface metal.

No previous method has been provided whereby only such parts of the gears as are required to be hardened are heated, while other parts are maintained cool enough that previous heat treatments imparted to provide toughness and resistance to shock remain substantially unaffected.

Our method is applicable not only to gears, but to numerous other articles as hereinafter explained, such as splined shafts, reamers, drills, gun bores, the wearing surface of pulverizing and crushing machines, friction feed rolls and the like, and to almost any metal article requiring a hardened zone, particularly where there is an uneven surface.

With the aforementioned conditions in view, this invention then has as its chief object the provision of a means whereby the wearing surfaces of a gear may be hardened without detrimental changes affecting other parts of the gear. Another object is to provide means whereby the addendum portions of all teeth may be hardened simultaneously and uniformly. A further object is to provide means whereby a portion of a gear after being hardened may be tempered to any desired degree. A still further object is to provide means whereby internal teeth or splines may be hardened simultaneously with the hardening of external teeth on the same gears. Another object is to provide means whereby the distribution of heating over a surface may be controlled. An additional object is to provide means which is rapid, accurate and applicable to a variety of parts. A still further object is to provide apparatus for hardening gears which may be rapidly applied to the gear and then removed therefrom. A further object is to provide heating apparatus which serves also as means for delivering a quenching medium to the heated surfaces. An additional object is to provide means for producing an article having localized hardened wearing surfaces. Another object is to provide means whereby the internal surfaces of bores, such for instance as in fire arms, cannon or other heavy artillery pieces, whether smooth bored or rifled, may be hardened. Numerous other objects will become apparent from the following description in which details of apparatus capable of producing improved results will be defined and new and advantageous steps in the procedure for obtaining such results will be de-

scribed or suggested to those skilled in the art of heat treating.

In the annexed drawings:

Fig. 1 illustrates one form of apparatus and shows a sectional view of a gear in operating relationship within the apparatus. Fig. 2 is an elevation, partly in section on line II—II of Fig. 1. Fig. 3 which is a section similar to that of Fig. 1 but taken on line III—III of Fig. 4 illustrates a modification adaptable to a particular type of gear. Fig. 4 is an elevation partly in section on line IV—IV of Fig. 3. Fig. 5 is an illustration, partly in section on line V—V of Fig. 6 of a modification of the apparatus adapted for the heat treatment of internal gears or splines. Fig. 6 is a section on line VI—VI of Fig. 5. Fig. 7 is a sectional view showing a still further modification of the apparatus as applied to a spur gear. Fig. 8 is a fragmentary view substantially as indicated at VIII—VIII of Fig. 7 with one spacer omitted to expose to view a part of the root section of the gear. Fig. 9 is an elevation of a gear in the apparatus substantially as shown in Figs. 1 and 2 but having other means for distributing heat. Fig. 10 is a fragmentary section on line X—X of Fig. 9. Fig. 11 illustrates a modification of the mechanism shown in Figs. 1 and 2. Fig. 12 illustrates means for removing conducting fillers. Fig. 13 is a view of the apparatus as shown in Fig. 4 but on a reduced scale. Fig. 14 illustrates diagrammatically the relative positions of internal and external inductors. Fig. 15 is a vertical sectional view of apparatus for heating and quenching the internal splines of the gear shown in Fig. 3 simultaneously with the hardening of the surfaces of the external teeth. Fig. 16 shows the expander for releasing the spacers shown in Fig. 7.

While in most of the accompanying drawings and descriptions the preferred method of heating is by high frequency induced currents set up in the zones to be hardened, the heating may also be accomplished by the direct flow of current into the article through electrical contacts established between the article and parts of the apparatus as is illustrated in our co-pending application Serial No. 689,904 above referred to.

When an irregular shaped article such as a gear or splined shaft is placed within an inductor coil supplied with high frequency current, the induced currents in the gear tend to concentrate in the first continuous circular paths just below the teeth thereby heating the part of the gear below the teeth rather than the teeth themselves. We are showing herein various means whereby the induced currents may be caused to flow in the teeth themselves, thereby heating them preparatory to quenching. Means are also shown whereby heat may be generated by induced currents set up in material adjacent to the teeth in such a way that the heat is evenly and rapidly communicated particularly to the top and side portions of the teeth without serious injury to the strength or other physical properties of the portions of the article adjacent to the heated zones.

Referring now more particularly to Figs. 1 and 2, the gear **20** may be supported by a shaft or arbor as illustrated in Fig. 12 so as to be held concentrically in the inductor **22**. This inductor, which is substantially a single coil for high frequency current surrounding the gear **20**, comprises the inner cylindrical wall **23**, in which the current tends to concentrate, and side walls **24** and **25**. The outer or jacket portion **26** is preferably insulated therefrom by the insulation **27**. Electric current preferably of high frequency is supplied thru terminals **28** and **29**. Since the current induced in the gear tends to flow parallel with, but in a direction opposite to the greater part of the current in the inductor, the current in the gear will follow a substantially circumferential path at the roots of the teeth and in so doing will thus heat the dedendum parts of the teeth more rapidly than the addendum parts. As it is desired to heat the addendum only and refrain from heating the dedendum parts, contacting fillers **30**, which may be made from material with substantially the same magnetic qualities as the gear teeth or from other conducting metal having heat resisting qualities such as nickel chrome, ferrous alloys or other suitable metals, are brought into conducting relationship with the addendum faces of the teeth, thus forming a substantially continuous circumferentially conducting path in which the greater part of the induced currents flow. Heat will be set up in the fillers by the current induced in them and part of this heat will be communicated to the adjacent gear teeth, principally along the contacting surfaces. Since the contact between the fillers and the tooth faces will offer appreciable resistance to the flow of the induced heating currents, there will be additional heating developed in the tooth surfaces along these faces of contact, thereby tending to set up greater heat at the tooth surfaces than in the deeper areas. These fillers are retained in firm contact with and between the teeth by bands **31** and **32** which may be either continuous or split and arranged with simple resilient means as shown at **29'** to act compressively on the ends of the spacers **30** to offset the expansion of the bands as the heating progresses. The heat caused by current induced in the fillers **30** and the addendum parts of the teeth expands these fillers, tending to maintain firm contact until the critical temperature is attained. The bands **31** and **32** are preferably insulated as at **33** from the fillers **30**. Depending upon production requirements, the fillers **30** may be either mechanically removable, or fusible at, or a little above, the critical temperature of the material of the gear.

At the termination of the heating interval, a vigorous quenching of the heated portions of the gear teeth is accomplished by projecting quenching fluid onto the tooth surfaces at high pressure through the orifices **34** in the face of the inductor **22**, the pressure being sufficiently high to deliver ample coolant and to remove any steam or gas formations from the surfaces to be cooled. The quench is supplied from the jacket space **35** to which it is delivered under pressure at the proper instant thru piping connected to the threaded member **36**. Supplementary quenching is provided by additional coolant being projected from the nozzles **36'** into the space between teeth.

In cases where it is necessary or desirable that the fillers **30** be removed from between the gear teeth at the instant of quenching, in order that the quench may have free access to the gear teeth without interference by the fillers, this is accomplished with substantially the same apparatus shown in Figs. 1 and 2 by making the fillers **30** from a suitable conducting alloy that melts at the quenching temperature or somewhat above that temperature. When the gear teeth have reached quenching temperature, the fillers **30** melt and drop away from between the gear teeth leaving free access to the heated tooth surfaces for the quenching fluid. To facilitate assembling

the fillers with the gear, the fillers and the ring member may be die cast together as an assembled unit from suitable fusible material so that all the fillers may be slipped in place between the teeth with a single operation, the free ends of the fillers being held in position by a compression ring. The insulating member 33, which is required in some cases, is omitted. This construction is illustrated in section in Fig. 11 in which the fillers 30' are formed integrally with the ring 32' and have their free ends compressed by the band 31' which is contracted by spring 29'', this construction being similar to that shown in Fig. 2. Obviously, the apparatus is preferably set in horizontal position to permit the melted filler material to drop away freely. The filler material so melted away is salvaged, remelted and used repeatedly.

Substantially equivalent results are, under certain conditions, accomplished by filling the space between the teeth with a plastic material composed of finely divided iron mixed with a suitable binder. A modification of this method is to prepare a filler mixture containing in addition to iron, some lead, copper, tin, antimony, or any of a considerable number of fusible materials in varying combinations, so that when the teeth reach the desired heat for quenching, part of the constituents of the filler mixture melts, permitting the mixture to fall away from between the teeth, leaving free access for the quenching fluid against the heated surfaces.

To aid in the removal of the filler material, a simple mechanism illustrated in Fig. 12 and consisting of a series of metallic fingers 31'', one for each tooth space, attached to a suitable ring 32'', is arranged so that with a simple movement the fingers are simultaneously inserted to push out the fillers and then simultaneously withdrawn from between the teeth, thereby clearing the tooth spaces for the quench.

In using the plastic filler material, in some cases it is desirable to entirely fill the tooth spaces and in others there is advantage in having the filler material contact only the upper portions of the teeth, leaving the lower portion of the tooth spaces unfilled as shown in Fig. 2. As we have stated elsewhere, making contact with the upper portions of the teeth only, tends to confine the heating more to the tooth tops. By leaving the bottom portions of the spaces open and by arranging the quenching equipment to direct a part of the quenching liquid under pressure into these open spaces, dislodgment and removal of the filler material is aided and the quenching materially speeded up.

For some purposes, certain advantages are obtained by baking or drying the plastic material after being put in place between the teeth and before the heating operation, or by forming the filler material to shape, then drying or baking and inserting in place between the teeth before the heating operation.

Another modification of our process consists in coating either the gear teeth, or the fillers, or both, with a fusible alloy that melts when the proper temperature has been reached for the quenching, then assembling the fillers in position between the gear teeth, and then heating and quenching as elsewhere described. When this procedure is followed, the fusible coating forming the joint between the fillers and the teeth melts when the quenching temperature is reached and the fillers drop out, leaving free access for the quenching fluid against the heated surfaces. The fillers are inserted between the teeth and pressed into position with enough pressure to deform the fusible coatings sufficiently to hold the fillers firmly in position until the fusible coating has melted. Usually there are enough irregularities on the surface of the teeth and the fillers to insure this locking action; however, slight serrations or deformations may be provided in one or both if necessary to accomplish this locking.

To aid in dislodging the fillers when the fusible coating has melted, the ring and finger assembly mechanism of Fig. 12 above described for removing plastic fillers from between the teeth, is used to advantage.

In the modification illustrated in Figs. 3 and 4 the current conducting filler elements 37 are all attached to a member to operate as a unit so that they may be simultaneously inserted into or removed from the tooth spaces of the gear 38 to be heat treated. The filler elements 37 are hinged to the ring 39 and insulated therefrom by the insulating bushings 40 and spacing washers on each side of the filler members as shown by broken lines at 40'. The ring 39 is centered on the shaft or arbor 41 carrying the gear 38 to be treated. Rods 42 are provided for advancing and retracting the spacer element assembly. To prevent a radial spreading of the tips of the fillers, these are confined by a refractory and insulating ring 43 interposed between these tips and the inner part of the inductor 44 which surrounds the gear.

To obtain a better contact between the fillers and the tooth surfaces, thereby improving the conductivity of these contacts, the fillers are coated by painting, spraying, hot or cold dipping, electroplating or by other means with a compressible conducting coating such as a conducting paste, or plastic compound, or plastic metal, or metal alloy. The conductivity of the path for the heating currents is otherwise improved by polishing either or both the fillers and the teeth or coating or plating them with some suitable metal or alloy.

The inductor 44 is made in two parts, preferably connected by a current conducting hinge as shown at 42' in Fig. 13, and is thus adapted to be opened to receive the gear 38 and permit the portion 45 of the inductor to enter the groove 46 in the hub of the gear. As high frequency current in passing from the terminal 47 around the inductor to the terminal 48 is confined mainly in the inner wall 49 of the inductor, and as the spacer elements 37 in contacting with the faces of the addendum portions of the teeth provide a continuous conductor, heating currents of high density are induced in the tips of the teeth and in the surfaces of the annular groove 46. As soon as these induced currents have raised the surface portions of the gear to hardening temperature, the current is interrupted and a quenching fluid is introduced simultaneously from pipes 50 and 51 into jacket spaces 52 from where it is projected vigorously through orifices 53 onto the heated surfaces it is desired to harden.

For the hardening of elements having internal teeth such as annular gears, splined hubs, positive clutches, hollow milling cutters and the like, or gun bores, apparatus such as shown in Figs. 5 and 6 is employed. In this illustration the splines 54 of the hub 55 represent the members to be hardened. Contacting spacers 56 are inserted tightly in the tooth spaces in a manner somewhat similar to that employed in connection with the apparatus shown in Figs. 1 and 2. These

spacers are held in assembled position by the grooved circular end rings 57 and 58. The internal inductor 59 is then inserted and by suitable means is held in concentric spaced relationship with the inner faces of the teeth. High frequency current is supplied thru one or more terminals such as 60 at one side of the division 61 of the inductor and the circuit is completed thru other terminals 62 at the other side of this division. Inducing current is thus caused to flow circumferentially in the inductor and induced currents, by virtue of the spacers 56, flow in the inner faces of the spindle teeth bringing these to hardening temperature with sufficient rapidity to prevent heat from migrating harmfully into the root sections. As soon as the desired temperature has been attained in the faces of the spline teeth, the heating current is interrupted and a vigorous quenching of the heated surfaces is provided by projecting a quenching fluid from the jacket space 63 thru passages 64 onto the heated surfaces. The quenching fluid is supplied by the pipe 65.

In case the face of a spur gear is wide or the teeth are small, the individual cantilevers 37 as shown in Figs. 3 and 4 would have insufficient inherent strength to maintain uniform current conducting contacts across the entire face of the gear tooth, and rapid production requirements would prohibit the handling of individual spacers as shown inf Figs. 1 and 2. To eliminate these difficulties, the spacers are arranged as shown in Figs. 7 and 8. In this embodiment the spacers 66 are disposed like the link pins of a chain. Flat links 67 perforated to receive the cylindrical ends 68 of the spacers are disposed at each end of the spacers and join all the spacers required for one gear into a single chain-like assembly which may readily be removed from one gear which has been hardened and applied to another. The links and spacers would be made from suitable heat resisting material.

To facilitate the handling of the link and spacer assembly a base 81' and cover 81 are provided with conical surfaces 69 and 70 respectively, so that when the cover is advanced toward the base, the pin members are pressed radially inward forcing the spacers into firm contact with the teeth, enough freedom being provided in the fit of the parts to permit this action. The shaft 71 by means of a guide bushing in which it is free to move axially serves to hold this cover in concentric relationship with the gear and the spring or other resilient member 72 brings this cover into pressure relationship with the links.

As the gear 73 with the spacer assembly engaging the teeth is placed in position on the arbor 74, it enters into concentric relationship with the inductor 75 which is similar in form to that shown in Fig. 2. High frequency heating current is supplied thru a pair of terminals, one of which is shown at 76, and quenching fluid is introduced into the jacket space 77 thru the fitting 78. At the proper instant after the addendum portions of the gear teeth have attained hardening temperature, due to currents induced by flow of high frequency currents in the inductor, the quenching fluid is projected thru orifices 79 onto the tops of the teeth. Radial passages 80 in the contacting faces of the spacers 66 permit a part of the quenching fluid to flow inwardly and along the surface of the teeth rapidly cooling the surface to be hardened.

In some cases it may be necessary to withdraw the spacers from contact with the gear teeth in order to permit freer and more rapid quenching of the heated tooth areas. When the proper quenching temperature has been reached, this is accomplished by relieving the pressure on the spring 72 and withdrawing the shaft 71 to lift the cover 81 to the position indicated by the broken lines at 80' and away from engagement with the spacer assembly. The spring 82, pressing against the lower end of the shaft 74, lifts the gear with the spacer assembly sufficiently to free it from the base 81', but leaving most of the gear still within the inductor 75 where quenching fluid from passages 79 will be projected upon the teeth and, quickly filling the limited space under the gear, will flow upwardly over the teeth. A part of this fluid will enter passages 80 and such additional space as has been provided by the loosening of the spacers by spring 82' which is shown separately in Fig. 16. It will be evident that passages 79 may be so located as to be in alignment with passages 80 after these latter have been raised by spring 82 and thus a part of the quench is projected directly into these latter passages, thereby enhancing the rate of cooling. As the pressure of the conical surfaces 69 and 70 is released from the pins, spring members preferably of flat stock shown at 82' and in Fig. 16 press radially outward against the links of the chain assembly, forcing the spacers radially outward from engagement with the gear teeth, leaving ample space for the flow of coolant between the spacers and the teeth. The chain-like spacer assembly can be quickly changed from one gear to another, permitting rapid production of hardened gears. This assembly contains just the right number of spacers to fill all tooth spaces. The spacer at one end of the assemly is placed in any selected tooth space and then the assembly is wrapped around the gear, each successive spacer dropping into a successive tooth space as shown in Fig. 18. The last spacer which is at the free end of the chain drops into the space just one tooth removed from the first spacer which is at the other end of the chain thus filling all tooth spaces and completing a circumferential path for the induced heating current.

In some instances, the spacers may be dispensed with and a band, either of flat stock as shown at 83 in Figs. 9 and 10, or of wire, is applied to the periphery of the gear to be hardened. This band provides a continuous circuit around the gear for the flow of induced high frequency current. As shown in Figs. 9 and 10, the gear 84 with the band 83 in place thereon is inserted centrally in the inductor 85 which is supplied with inducing current thru the terminals 86 and 87. The currents induced in the band 83 rapidly bring this band to high temperature and the conduction of heat therefrom into the tops of the gear teeth together with any current that may be caused to flow in the teeth raises these teeth rapidly to hardening heat.

The band 83 is made of material adapted to withstand high temperatures, and certain ferrous alloys containing chromium or nickel or manganese or combinations of these elements may be employed to advantage. As the temperature of the band rises, electric resistance increases, its permeability changes, and induced heating currents develop in the root section of the gear which section should be kept cool. Therefore, after the band reaches a sufficiently high temperature, the power input to the inductor preferably should be maintained so as to prevent heating the root section by induced currents and the transfer of heat

from the band to the tops of the teeth should be maintained at a rate which will bring the portions to be hardened up to hardening temperature before harmful heating occurs elsewhere.

Quenching fluid under high pressure is introduced into the jacket space 88 by a fitting applied at 89. This fluid is projected vigorously onto the band thru orifices 90 and between the teeth from a series of properly located nozzles 92 immediately after the termination of the heating interval. In some instances where more rapid quenching is necessary, the band may, at the instant of quenching, be quickly pulled off the teeth by one or more hook members 91, previously in position, thus leaving a free, uninterrupted flow of quench onto the surfaces of the gear teeth, this quenching being supplemented by fluid projected from nozzles 92.

It will be evident that the apparatus as illustrated will suggest may advantageous modifications to those skilled in the art. For example, the dedendum and root section of the teeth of hardened gears may be tempered by the use of this apparatus if the contacting spacers between the teeth are omitted, whereby the heating current is caused to flow circumferentially in the section at and below the roots of the teeth. The form and location of the teeth is such as to prevent current from flowing in the teeth themselves so that the teeth will remain substantially unheated except for the conduction of heat from the root sections.

It will be understood that the form of the fillers, their material, and the rates of heating and quenching may be such as to provide hardened surface zones in the addendum part of the teeth leaving a relatively soft core extending toward the tips of the teeth. The tooth surfaces closest to the inductor will be heated most rapidly and those quenched most rapidly at the critical temperature will be the hardest.

When gear teeth are subjected to surface impacts tending to break corners of the tooth tips as in certain types of clutches, it is important that these tips be made somewhat less hard than the addendum faces to prevent this breakage. This may be accomplished by locating the fillers deep enough in the tooth spaces to confine the heating to approximately midway of the tooth height. In this way the temperature of the tooth tips may be kept appreciably below critical temperature so that there will be an annealing rather than a hardening action at these tips, although there will be hardening action slightly below the tips. Still another method would be to slightly temper or draw the tooth tips by annealing.

It is to be understood that the process herein described is not limited to gears and the like made from forged or rolled steel, but may be applied to cast ferrous metals and to certain non-ferrous metal to produce qualities therein peculiar to that metal.

By our process of heat treating gear teeth, the heating and quenching is accomplished so uniformly that substantially no distortion remains upon completion. The heating being confined to the addendum portions of the teeth only contraction due to quenching is limited to the addendum and substantially no distortion takes place in the dedendum part of the teeth or in the rim section at or below the root, or in the web of the gear. Hence, the teeth are easily kept in the desired accurate final form without any grinding or other operations subsequent to hardening. If, however, final finishing after hardening is required, the hardened zone is of sufficient depth to permit the removal of surface material without penetrating below the region of satisfactory hardness.

It is to be noted from the foregoing that hardening heat is confined mainly to the surface zones of the addendum parts of the tooth and that a core of softer metal extends from the root circle outwardly toward the tip of the tooth and the form and extent of this core depending upon the rate of heating applied, the form of the zone to which the heating is limited, the rate of quench and shielding or other method used in applying the quench. It will be evident that the resulting hardness will be different for different analyses of the material of the gears.

The circulation of a cooling fluid, such as air, thru the spaces between the contactors and the roots of the teeth will aid in the control of the rise of temperature in the dedendum part of the teeth. This is accomplished by passing air of desired temperature and amount thru nozzles such as 92 of Fig. 10 during heating, and then discharging water from these nozzles instead of air for the quenching interval.

It will be evident that an inductor similar to the one shown in Figs. 5 and 6 may be inserted in the splined bore of the gear 37 of Figs. 3 and 4 and that by successive applications from the same source of power or by simultaneous applications from the same or different sources of power, both the internal and external teeth may be hardened at the same setting of the gear in the apparatus. Such an arrangement is shown in Fig. 15 in which the gear 93, which is substantially the same as gear 38 of Fig. 3 is provided with internal splines or teeth 94 which are to be hardened at the time of hardening the outer teeth 95. The internal inductor 96 is substantially the same as inductor 59 of Figs. 5 and 6, excepting that it is made on a somewhat smaller scale to enter the splined hole in the gear 93. This internal inductor is inserted in the gear with suitable clearance and is supported on shaft 97 with suitable insulation. The spacers 98 which are substantially identical with the spacers 37 of Figs. 3 and 4 are held in firm contact with the tooth surfaces by the engagement with outer inductor 99 thru insulation 100. These spacers being carried by a support ring 101, which corresponds with ring 39, of Fig. 3, are secured in a relatively rigid assembly with this ring and the gear by the inductor 99, the insulation 100 preventing the tips of the spacers from spreading and thus holding the sides of the spacers in firm contact with the sides of the gear teeth. The outer inductor 99 has a jacket space 102 for supplying quenching fluid thru orifices 103 to the tops of the teeth and the inner inductor 96 likewise has a jacket space 104 to supply quench to the surfaces of the internal splines. Current is supplied to the inductors thru terminals 105 and 106, the inductors being joined in series by the connection 107 in reverse current relationship or connected in parallel across power lines as shown diagrammatically.

In the preceding description and in the appended claims, reference to the addendum portion of a gear tooth refers to that portion radially outward of the pitch line or rolling surface. The dedendum portion refers to that part which is radially inward from the pitch line. The root of the tooth is the part of the gear to which the dedendum part of the tooth is attached.

Reference to high frequency current in this specification implies current having a frequency considerably in excess of the frequency of ordinary commercial power current.

While in the foregoing description of our process we have throughout specifically referred to gears, it is understood that the process applies to the various articles mentioned herein, and, in addition, to a wide variety of others not specifically named.

In the appended claims the term "tooth flank" of a gear defines the side of the tooth with which a mating tooth of another gear contacts. By "gear blank" is to be understood the piece of material, straight or curved, on which teeth are cut or are otherwise provided as by casting, insertion of separate pieces, welding or by other processes.

The core of a gear tooth, or of another projection on a piece of heat treatable material, is understood to be that portion of the tooth or projection sufficiently far below the surface of the metal as not to be affected by the heating and quenching and which therefore remains substantially in its original condition during the heating and quenching of an adjacent surface zone.

"Groove" has been used to define any depression of which the space between two teeth is typical, but applies to any longitudinal depression which may exist in the surface of the article to be heat treated, such as in a splined shaft. As quenching must be very rapid, it is frequently found that merely flowing the quench over the heated surface is insufficenit and that the quenching fluid must possess considerable kinetic energy in order to remove the insulating bubbles and vesicles while in their incipient form. This kinetic flow has been defined by the use of the term "projection".

Other modes of applying the principle of our invention may be employed instead of the ones explained, change being made as regards the means herein disclosed, provided those stated by any of the following claims or their equivalents be employed.

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

1. In apparatus for hardening gears, an inductor surrounding a gear to be hardened, means for supplying high frequency current to said inductor, and a current conductor adapted to fill a portion of the space between adjacent teeth of the gear.

2. In apparatus for hardening a gear, an inductor in spaced relationship with a peripheral part of the gear, means for supplying current to said inductor, a conductor joining parts of adjacent teeth to provide a circumferential circuit through said parts of the teeth.

3. In apparatus of the character described, an inductor in spaced relationship with a surface having projections thereon, means for supplying current to said inductor, and a conductor adapted to conduct current peripherally of the said surface from one of the projections to another projection.

4. In apparatus of the character described, a conductor in spaced relationship with a surface having projections thereon, means for supplying current to said conductor, and a conductor adapted to carry current between projections, said last named conductor having a fusible portion, and said fusible portion having a part contacting with a part of the projections whereby current is caused to flow across the part of the projection having contact with the last named conductor.

5. In a method of manufacturing a gear composed of material adapted to be hardened by heating and quenching, the steps comprising placing current conducting fillers between adjacent teeth of the gear, and causing heating current to flow thru said teeth and said fillers.

6. A method of hardening surfaces of a gear having internal and external teeth, comprising placing a conductor in contacting relationship with related internal teeth, placing a conductor in contacting relationship with external teeth, placing an inductor in spaced relationship with the internal teeth, placing an inductor in spaced relationship with the external teeth, and causing current to flow simultaneously in the inductors whereby heating currents are induced simultaneously in the internal and external teeth.

7. In apparatus for heat treating teeth of a gear, supporting means for said gear, fillers adapted to serve as conductors of current between adjacent teeth of the gear, said fillers being loosely carried by a retractable support, an inductor surrounding a part of the gear, and means for establishing pressure contact between the teeth of the gear and the fillers.

8. In apparatus for heat treating teeth of a gear, a support for the gear, interconnected fillers adapted to be inserted in spaces between the teeth of the gear, an inductor adapted to surround said gear and said fillers, and means for supplying current to said inductor, the said fillers being adapted to melt at a temperature not less than the critical temperature of the gear teeth.

9. In apparatus for hardening gear teeth and the like, a multiplicity of current conductors, each lying between and having contact with two teeth of said gear and means to establish a heating current in a path through said conductors and said teeth peripherally of the gear.

10. In apparatus for hardening gear teeth and the like, a multiplicity of inter-connected conductors, each adapted to span the open portion between two of said gear teeth and contact said adjacent tooth surfaces and means for establishing a heating current in a path through said conductors and gear teeth peripherally of said gear.

11. In a method of heat treating outstanding ribs of an article, the steps of placing current conductors in contact with adjacent ribs to span the space therebetween, positioning a high frequency conductor in spaced relationship with said ribs, and inducing a heating current peripherally of said article through said ribs and said spanning conductors.

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