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[54] **APPARATUS FOR INDUCTIVELY HEAT-TREATING STEEL WORKPIECES**
3 Claims, 1 Drawing Fig.

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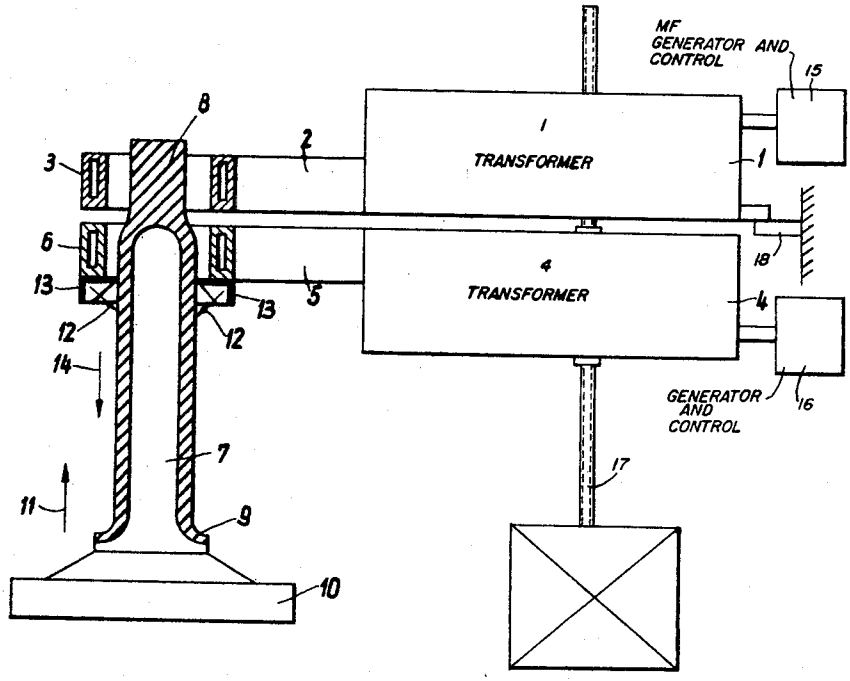
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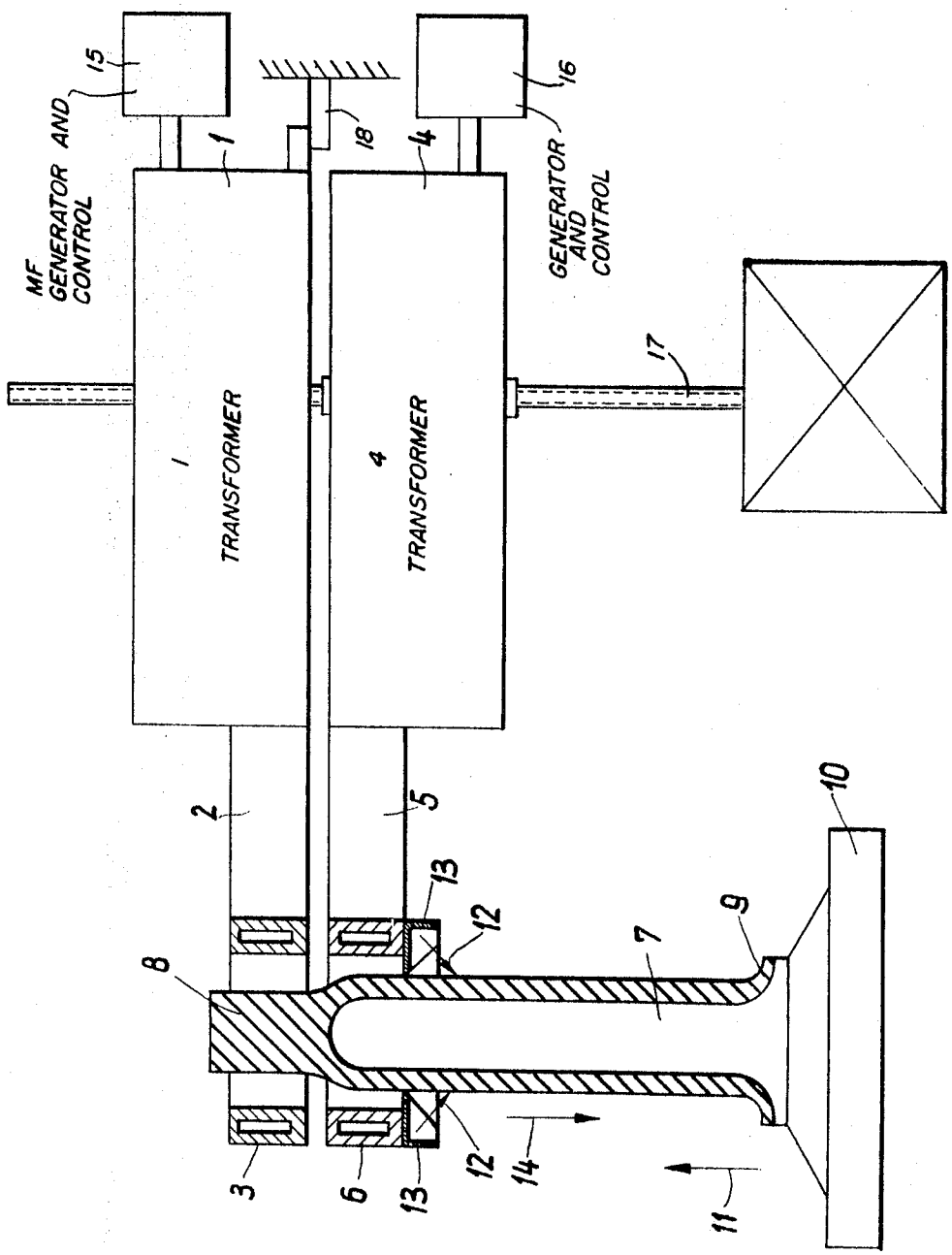
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ABSTRACT: Elongate workpieces of varying diameter along their length which are to be inductively heat treated to provide both surface-hardened zones and zones toughened all the way through, have low reverse bending and torsional resistance, due to induced notch effect. It has now been discovered that if the heat treatment is carried out in two stages, one being superimposed on the other, the notch effect is diminished or eliminated.



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APPARATUS FOR INDUCTIVELY HEAT-TREATING STEEL WORKPIECES

This invention relates to the inductive heat treatment of elongate cylindrical steel workpieces, and particularly relates to a method of and apparatus for heat treating such workpieces.

It has previously been the practice to progressively heattreat elongate workpieces by inductive heating followed by immediate quenching. In this process the workpiece is horizontally or vertically positioned, and inductors of suitable diameter heat the workpiece surface by relative motion between inductor and workpiece. According to the power and frequency of the current and the speed of advance of the inductors, zones of elevated temperature are produced in the workpiece, penetrating to a depth which at a given constant frequency depends upon the power and the duration of the local heating effect, in other words upon the speed of the relative movement between the workpiece and inductor.

It is often required to provide workpieces with surface-hardened zones in the axial direction, and with other zones in which they are toughened throughout the cross section. This applies for instance to the rear axle shafts of motor vehicles, which at one end have a threaded neck required to be toughened throughout. If such workpieces are cylindrical along the whole of their length, the procedure in progressive heat treatments consists in first introducing into the inductor that end of the workpiece which is to be toughened throughout its cross section and in heating this end at a slow speed of advance or while the workpiece is stationary, with the application of relatively low power density until the heat has penetrated the work to the core. Instead of heating at a slow rate of advance or while the workpiece is stationary, heating may also be effected by reversing passes. That part of the workpiece of which only the surface is to be hardened is then inductively treated at a higher rate of feed, possibly with a simultaneous reduction in specific power, quenching being simultaneously effected with a suitable quenching medium, such as water, oil emulsion, oil or air issuing from a sprayer attached to the end of the inductor.

The surface-hardened zones of the workpiece are usually annealed during the return of the inductor for the removal of stress, by being heated at a lower power density to a surface temperature of for example from 200° to 250° C. However, the end of the workpiece which is to be toughened throughout is tempered by heating to a temperature of from 400° to 650° C. while the inductor is kept stationary, slowly moved or reciprocated, the temperature level depending upon the particular steel alloy and the desired temper. Finally the workpiece is removed from the apparatus and submitted to further processing.

However the above-described conventional method of progressive inductive heating can be performed only on workpieces which have a smaller diameter throughout their length than the internal diameter of the inductor. Assuming for instance that the workpieces that are to be treated have a flange at one end and, as is often also required, the connecting radius at the root of the flange is to be hardened, then the conventional procedure cannot be used. However, such workpieces are often needed, particularly for motor vehicle parts. In effect the flanged end of such workpieces governs the necessary inductor shape owing to the requirement that a hardened zone extends into the angle at the root of the flange. Hitherto such workpieces had to be treated in two operations comprising first a surface-hardening treatment, usually in a continuous pass, followed by a toughening treatment of the end portion by heating the same to the core and then quenching. Finally the heat-treated end portion was tempered to produce the desired mechanical strength.

Workpieces treated by the conventional method in a continuous pass show very unfavorable properties when subjected to reverse bending and torsional loads, since in the transitional

zone between the part that has been surface hardened in the first treatment and the toughened zone produced in the second treatment, the resultant unavoidable notch effect introduces a greater likelihood of torsional or reverse-bending fatigue fracture. A reversal of the process in such manner that the completely toughened end is produced first and the surface-hardening treatment afterwards does not diminish the risk of torsional or reverse bending failure in the transitional zone. It is the object of the invention to eliminate this effect.

The invention consists of a method of inductively heat treating an elongate steel workpiece having a diameter which changes continuously or discontinuously, to produce a portion that is toughened throughout its section and a portion that is surface hardened; which comprises the steps

a. inductively heating the workpiece in the axial direction nonuniformly along its length,
b. inductively heating the workpiece uniformly along its length including the portion(s) heated by step (a.),
c. quenching the workpiece, the degree of heating in steps (a.) and (b.) being such as to result in the required depth of toughening and surface-hardening of the workpiece.

After the quenching treatment, the hardened zone(s) of the workpiece may be annealed and the toughened zone(s) drawn.

By the treatment of the invention undesirable and harmful notch effects are prevented due to the fact that the workpiece is preheated, hardened and annealed or tempered throughout its length. Abrupt transitions between tough and hardened zones in the workpiece are thus avoided and no harmful inherent stresses are generated.

According to one feature of the invention, the heat treatment is achieved by axially nonuniformly heating the workpiece during a forward feed of a single inductor, surface heating being effected on its return. Annealing and/or tempering may be performed in a subsequent forward feed of the inductor.

The invention also provides for the progressively continuous inductive heat treatment of cylindrical work of simpler external shape, namely of work which is to be locally toughened throughout its cross section at a particular point, whereas the remainder is to be surface hardened. In this particular advantageous and preferred embodiment of the invention two inductors are used, one of which first heats the part that is to be toughened by penetrative heating, the other inductor begins a surface-hardening treatment at a point remote from the first, continuing said surface-hardening treatment across the penetratively heated part while the first inductor is displaced and switched off. This treatment may be followed by a renewed pass of the inductors without quenching for annealing and/or tempering.

An embodiment of apparatus for performing the method of the invention is hereinafter described and illustrated in the accompanying schematic drawing. In the drawing the workpiece **7** that is to be heat-treated, has a neck **8** at one end and a flange **10** at the other. A transformer **1**, preferably fed with a medium frequency voltage, from a source **15** is attached by a flange **2** to an inductor **3**. The inductor **3** is a simple ring without quenching means, although the said inductor may comprise one or more turns. It is advisable to provide the copper inductor with internal water cooling in a conventional manner. A second transformer **4** also fed by a source **16** likewise feeds an inductor **6** through a flange **5**. For the sake of simplicity this inductor is similarly shown as being a single cylindrical inductor, although it may comprise one or several turns possibly fitted with magnetic yokes and water cooled. Both inductors and transformers are supplied with a current of appropriate frequency and, for the sake of simplicity, the current source for both transformers **1** and **4** may be the same, although the transformers may be supplied with currents of different frequencies if desired.

The zone of the workpiece to be surface hardened is marked **9**. Flange **10** is attached to the workpiece. The heat treatment is now performed as follows: The inductor **3** fed by

transformer 1 heats up that part of the workpiece which it embraces, while remaining stationary or reversing or slowly advancing over the neck end 8 that is to be toughened. The other inductor 6 which is fed by transformer 4 is lowered before or during the preheating treatment by inductor 3 into the position where the hardened zone 9 at the transition to the flange 10 begins.

While the neck is being heated by the inductor 3 the process of hardening the shaft portion begins with the heating of the transition zone at the foot of the flange 10 by the inductor 6, which first remains stationary. Heating then continues by relative motion between the inductor 6 and the work 7, the inductor being moved in the direction of arrow 11. From the underside of the inductor the work is quenched in conventional manner by a quenching sprayer 13 from which the quench issues in the direction indicated by arrows 12. When in the course of its upward pass in the direction of arrow 11 the inductor 6 reaches the inductor 3, the inductor 6 or the transformer 4 will entrain with the inductor 3 and the transformer 1, and at the same time the preheating of the neck 8 will have been completed. The heating times of the inductors should be synchronized by carrying out a few empirical tests, so that when the two inductors 6 and 3 start to move upwards together in the direction 11 the neck 8 will have been raised to hardening temperature uniformly throughout its cross section before the quench issuing in the direction 12 strikes the neck surface.

For annealing and drawing the work the described hardening process is substantially repeated in the same way without, however, applying the quench in the direction of the arrows 12 to the shaft surface. The two inductors 6 and 3 are again moved over the work at reduced power, and the inductor 3 retained in the region of the neck 8. The inductor 6 continues to move downwards in the direction 14 until it arrives in the position it occupied when the hardening treatment originally started. During this period the inductor 3 will be already heating the neck with a power density calculated to produce a uniform penetrative reheat to tempering temperature. Heating by inductor 3 continues while inductor 6 travels upwards again in the direction of the arrow 11, fed with an appropriate power density, for tempering or annealing the shaft portion of the work. Again, when the inductor 6 reaches the inductor 3 it entrains with the latter, and both inductors 6 and 3 together with their transformers 4 and 1 move off the workpiece and are switched off. The treated workpiece can now be removed to one side. After the lapse of a suitable period of time the work is then finally quenched in water, oil, emulsion oil or the like, and thereafter transferred to the next manufacturing stage.

The apparatus is so designed that a common means 17 for moving said inductors is provided for both transformers and their associated inductors, and which is operable at controllable speed. A mechanical, pneumatic or electrical coupling means is associated with transformer 1 and inductor 3 for stopping this transformer and its inductor in any desired position, whereas transformer 4 and its associated inductor 6 continue their motion at the preselected speed. In an upright inductor the coupling means may have the form of a simple abutment 18 adapted to intercept and retain the transformer 1 and its inductor 3, while permitting the transformer 4 and its inductor 6 to continue their downward motion. During their upward return in the direction of the arrow 11, the transformer 4 and its inductor 6 will then simply lift the transformer 1 and its inductor 3 off the intercepting abutment.

However, in a horizontal inductor arrangement it may be advisable to provide appropriate arresting means which ensure that the transformer 1 and its inductor 3 are retained in a preselectable position, while transformer 4 and inductor 6 continue their horizontal pass. When the transformer 4 returns, the arresting means is operatively disconnected to permit the transformer 1 and the inductor 3 to be entrained with the transformer 4 and the inductor 6.

The apparatus illustrated in the drawing is designed to treat only one workpiece at a time. However, several workpieces may be disposed side by side or in tandem. In such an arrangement the inductors required may all be connected to one transformer, although if desired one inductor with an associated transformer can be provided.

What we claim is:

1. Apparatus for inductively heat treating an elongate workpiece comprising:
   - first inductive heating means,
   - second inductive heating means,
   - means for moving said first and second heating means along said workpiece so as to inductively heat said workpiece,
   - means for stopping the movement of the trailing one of said heating means relative to the other of said heating means at a given position without stopping the movement of said other of said heating means so that the adjacent region of said workpiece is heated to a greater extent than the regions adjacent the path of said other of said heating means beyond said given position.

2. Apparatus as in claim 1 further including spray quenching means associated with said other heating means.

3. Apparatus as in claim 1 wherein said supplying means includes a transformer connected to each of said heating means.