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METHOD FOR THE INDUCTIVE HARDENING OF ELONGATED WORKPIECES

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Fig. 1

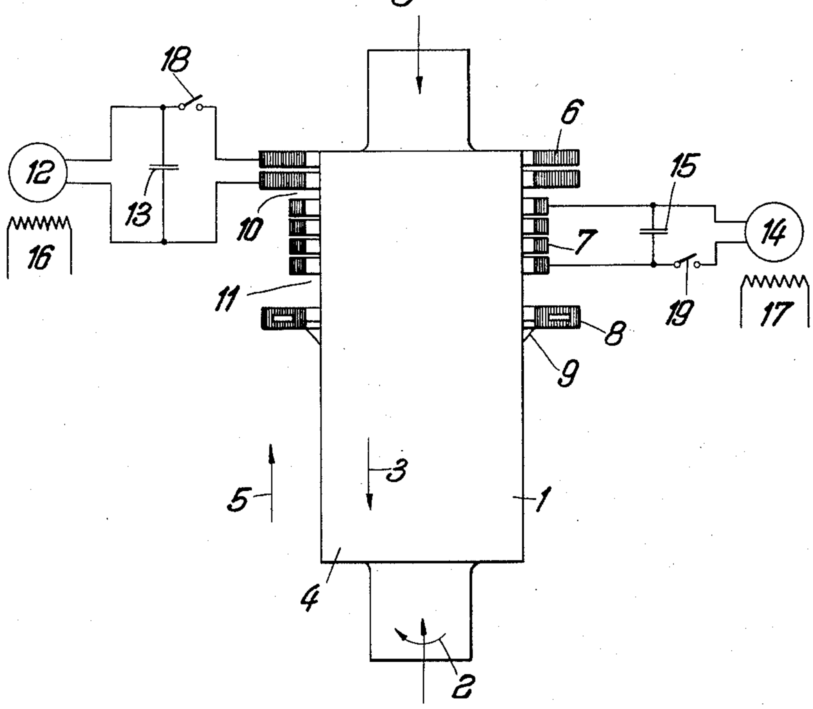
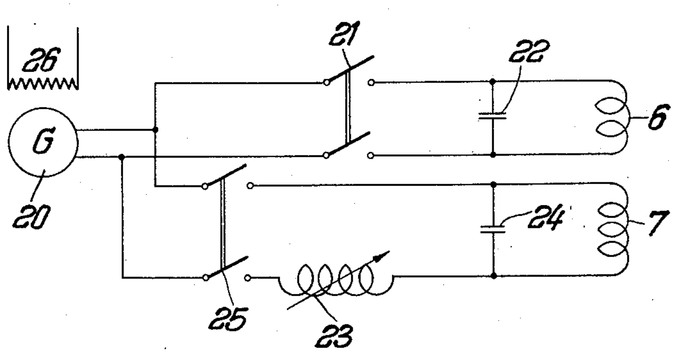


Fig. 2



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METHOD FOR THE INDUCTIVE HARDENING OF ELONGATED WORKPIECES

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4 Claims. (Cl. 148—10.5)

The present invention relates to a method of and apparatus for hardening elongated workpieces by inductive heating and quenching by the forward-feed method, i. e., the method in which the hardening is carried out progressively along the workpiece, the inductor and the workpiece moving relatively to one another, the inductor progressively heating and a quenching device progressively quenching the workpiece. The inductor may be a coil and the quenching device a ring from which the quenching medium is sprayed, and either the workpiece may be moved with respect to the inductor or the inductor may be moved with respect to the workpiece. The invention is well suited for hardening cold rolls, i. e., rolls intended for cold rolling.

Usually the temperature suitable for hardening is reached where the workpiece is at the end of the inductor adjacent the quenching device. Consequently the time lag between the time the workpiece reaches this temperature and the time the quenching takes place must necessarily be comparatively short, a requirement which also imposes itself if heat penetration into the core of the material is to be avoided and hardening is to take effect in the surface layer only.

As a result of these limitations hardening by induction heating by the forward-feed method is impracticable in the case of many materials, more particularly in the case of such materials which must be maintained at their hardening temperature for some time before quenching takes place so as to permit the solution of the carbides to proceed to a satisfactory extent. This applies with particular force to the surface hardening of cold rolls which may consist for instance of a steel containing .85% carbon and 1.7% chromium with the possible addition of anything up to .3% molybdenum.

Hardening practice when using furnace heat etc. has shown that it is advisable in such cases to maintain the hardening temperature for a definite time, and it is therefore not surprising that the suggestion has already been made to re-produce these conditions when using the induction heating method.

Basic difficulties do not occur when the entire surface of the workpiece is inductively heated at one and the same time as it is only necessary in such a case to delay the quenching for a certain period of time after the entire surface has reached the hardening temperature.

In the forward-feed method, however, the temperature time function is predetermined and depends upon the required rate of travel and the distance which must be maintained between the induction coil and the quenching device.

To overcome these difficulties it has been proposed to wind the inductor so that the number of ampere-turns varies in the axial direction, a greater number of ampere-turns being provided at the leading end, i. e. the end at which the elongated workpiece enters the inductor, followed by a section comprising a smaller number of ampere-turns. The leading end causes a sudden rise in temperature to the degree required for hardening and the

following section merely maintains this temperature while (assuming the inductor moves) the inductor travels axially with respect to the surface of the workpiece until, at the trailing end, quenching takes place. It has also been suggested that a short section at the trailing end should be wound with a higher number of ampere-turns to counteract any reactive super-cooling effect of the quenching spray upon that portion of the workpiece which is still being maintained at the required high temperature value for hardening.

In the first place, an arrangement of this kind is cumbersome in handling. Moreover, owing to the lack of variability in the relative action of the individual heating sections the arrangement is also too inflexible to allow of its ready adaptation to the many varying conditions which occur in actual practice. A further considerable disadvantage lies in the fact that in the heat treatment of a cold roll for instance, the edges of the roll are either liable to be overheated or to be insufficiently hardened. The latter occurs whenever the induction coil is prematurely switched off or its speed of travel increased over the edge of the roll in an attempt to avoid its over-heating. The difficulties mainly arise as a result of the unavoidably considerable structural axial length of an inductor carrying a varying number of ampere-turns so that it becomes practically impossible to adapt it to any special requirements.

The apparatus proposed by the present invention avoids these troublesome difficulties and permits a reliable and effective heat treatment, even in the case of cold rolls, by the induction heating method, hardening being effected by subsequent quenching at the end of a variably controllable time lag during which temperature is correctly maintained. To this end at least two electrically independently controllable and variable inductors are used, arranged axially one behind the other. A quenching spray is provided to follow the last inductor.

Generally speaking, two inductors will be sufficient, the first to heat the surface of the workpiece to the temperature required for hardening, and the second to hold this temperature substantially constant for the required period of time before quenching takes place. Apart from providing for variable electrical control of the inductors it may be an advantage, in addition, to provide for adjustability of the axial distances between the inductors, and possibly also of the quenching device from the inductors and continuous adjustment may be achieved.

Compared with known devices such an apparatus is of considerable flexibility both in regard to the raising of the temperature to the desired value and its maintenance and distribution throughout the section of the workpiece. It is of particular importance in cold rolls to obtain a predetermined and fairly considerable depth of penetration without heating the core which may otherwise be subjected to tensional strains that in extreme cases lead to the development of cracks and the disintegration of the roll. With the help of an induction unit according to the present invention requirements which appear to be mutually opposed to each other may nevertheless be satisfied to some extent. The possibility of electrical regulation of the induction units combined with the possibility of varying the axial distance between the individual inductors and the quenching device permits the whole apparatus as it moves in relation to the surface of the workpiece to be adjusted to special requirements.

The arrangement may be such that the inductors are fed from separate sources of power, which may be of different frequency, each capable of being regulated. On the other hand, a single source of supply only may be employed and the induction units operated in parallel. At least one of the two supply circuits will then include a variable inductance, such as an auto-transformer or a choke. Moreover, the two inductors may be wound with a different number of ampere-turns, irrespective as to whether they are being fed from one or several sources of supply.

The electrical arrangement affords a wide range of control. More particularly, it makes it possible to switch off the leading inductor as it rides over the edge of the workpiece while the following coil or coils continue in operation. Thus it becomes possible to avoid overheating of the edge of a cold roll or of insufficiently hardening it.

In some cases it may be advisable to replace the trailing induction coils by variably controllable gas burners or to use electrical resistance heating elements with the object of maintaining the hardening temperature by irradiation up to the moment of quenching.

Should the apparatus be operated with two or more induction coils fed from a single source of electrical power it is electrically advantageous, when switching off one of the inductors, to arrange for suitable switchgear in the exciter circuit of the generator to interrupt the medium frequency circuit for the duration of the switching operation. This may consist, for instance, of D. C. relays, or control grids in the case of electronic exciter devices. As soon as the exciting current has been shut off the inductor supply circuit is disconnected either by a time or voltage controlled relay, when the exciting current of the generator can be immediately switched on again.

The appended drawings illustrate in Fig. 1 a preferred form of construction of the present invention as well as in Fig. 2 a circuit that may be used in the special case of both inductors being fed from one and the same source of supply. The example illustrated refers to the heat treatment of a cold roll. However, the explanations given in connection therewith apply equally to the heat treatment of any other elongated workpiece.

Fig. 1 shows the cold roll **1** which, for the purpose of its heat treatment, is moved axially under the heating and quenching units and which may at the same time perform a rotary motion in the direction of the arrow **2**. The apparatus operates while the axial movement of the cold roll **1** under the stationary induction and quenching units proceeds in the direction of the arrow **3**. Of course, it is equally possible to arrange for the workpiece to be stationary, and to carry out the hardening operation by moving both the inductors and the quenching spray in an upward direction beginning at the lower edge **4** of the roll and proceeding in the direction of the arrow **3**.

In accordance with the present invention the induction heating unit consists of the inductor **6** which is preferably narrow in axial extent. The object of this inductor is to raise the temperature of the surface layers within its inductive range to the desired hardening temperature, practically immediately. The inductor **7** which is arranged to follow the inductor **6** in an axial direction may have a greater axial length than the latter. It is electrically so designed as to maintain the temperature induced by the inductor **6**. Whereas it will be generally necessary for the purpose of achieving the desired effect to wind the inductor **6** in several layers the winding of inductor **7** will usually require a single layer only. It is nevertheless quite possible to feed the inductor **6** with a voltage which allows its windings to be restricted to a single layer despite its short axial length.

Axially following the inductor **7** is the quenching unit **8** which performs the hardening by spraying the liquid quenching medium such as water, brine, an emulsion, or the like, on to the surface of the roll in the direction of the arrow **9**. The intervening distances **10** and **11** are controllably variable so that any desired axial displacement of the inductors in relation to one another may be effected. In practice the design may be such that the quenching unit is stationary whereas both inductors **6** and **7** are independently displaceable in an upward direction, or alternatively, the inductor **6** may be the fixed element whilst inductor **7** and quenching unit **8** may be each displaced independently in a downward direction relatively to unit **6**.

The inductor **7** may also be so designed electrically that the surface temperature on the roll created by the inductor **6** is slightly increased by unit **7**. Alternatively, it is also possible to arrange for the effective intensity of induction of unit **7** to allow of a slight falling off of the temperature as the workpiece passes through it. It is also possible to construct the inductor **7** in such manner that the temperature on the surface of the moving workpiece undergoes slight fluctuating changes as it passes beneath it. The inductor **6** is connected directly or through an intermediate transformer to the source of supply, generally a rotary generator **12** which delivers a current of raised frequency.

A condenser battery **13** serves to compensate for reactive currents in the load circuit. Voltage regulation of the generator **12** permits the effective power of the inductor **6** to be variably controlled as desired. Naturally, regulation of the generator **12** may also be effected by means of devices affecting the current or the wattage supplied by the generator. The condensers **13** schematically indicated in Fig. 1 may be jointly or severally controlled by switches to permit of suitable adjustments to be made to correspond with any set of operational circumstances.

The inductor **7** is connected directly or through an intermediate transformer with the source of supply **14** which may generally be provided by a rotary medium frequency generator. The condenser battery **15** similarly serves to eliminate any reactive currents set up in the load circuit. This condenser battery is again preferably provided with switch elements. Regulation of the power supply at **14** may be carried out by similar means as above described in the case of generator **12**.

Generally speaking, the wattage and frequencies of both sources of supply **12** and **14** may be similar. In special cases, however, it may be an advantage to work with dissimliar frequencies and power. For instance, the frequency of the source **12** might be lower than that supplied by the source **14** and the effect obtained of securing a greater depth of penetration of the surface layers of the roll which are within the inductive range of the inductor **6**. When these surface layers move into the range of the inductor **7** the high temperature of the surface layers of the roll will assure similar penetration at the higher frequency of the source **14** without risk of causing the core to be overheated at the same time.

The power output of the two sources may also be dissimilar inasmuch as, for instance, generator **12** may have a high power output to ensure that the temperature of the relative surface layers of the roll is raised rapidly to the desired degree, whereas the output of generator **14** may be less since the heating element(s) supplied by this generator serves only to maintain the temperature that has been reached or at least to vary it only slightly. Regulation of the exciter windings **16** and **17** of the two generators permits the power output of both generators to be continuously varied and controlled within any desired limits. Power switches **18** and **19** in the load circuits may be provided to permit the inductors **6** and **7** to be cut out and cut in independently the one from the other at any time or in any position they may have reached in relation to the workpiece, as may be deemed expedient. These power switches indicated schematically at **18** and **19** may be in the form of two-pole power switches. Instead of placing them into the load circuit proper they may be arranged immediately behind the generators as shown, for instance at **19**.

Fig. 2 refers to an arrangement where both induction units are powered from one and the same source of supply. The two axially arranged inductors are again indicated by **6** and **7**. The inductor **6** which is responsible for raising the surface temperature rapidly to the desired value is connected to the common source of A. C.

supply 20 through a switch 21. The condensers at 22 in this case again serve to compensate for reactive currents appearing in the load circuit. Switch elements should again be provided to adapt the condenser capacity to the inductive load. The inductor 7 is connected with the generator via the control element 23. This inductor is likewise compensated by a condenser battery of suitable capacity. The switch 25 serves to cut out or cut in the heating circuit comprising the inductor 7 and the condenser battery 24. The terminal pressure supplied by the generator can be regulated. When the switch 21 is closed the same pressure is operative across the condenser battery 22 and the inductor 6. When the switch 25 is closed the pressure across the condenser battery 24 and the inductor 7 depends upon the pressure drop across the control element 23. For instance, if a large inductance is introduced at 23 the pressure across inductor 7 will become correspondingly small. Since output depends upon the operating pressure across the inductors the heating effect upon the surface elements of the roll may be differentially controlled in ratio with the difference obtaining between the pressures across the two inductors although both are powered from the same source of supply. In the example illustrated, the control element 23 is shown in the form of a variable choke. Such variable chokes are available with displaceable or tilting laminated iron cores. According to the variation in the size of the air gap caused by any displacement or tilting of the core the inductance of such chokes may be varied so that the resultant variation in the pressure drop across the choke can be used to vary the pressure across the inductor 7 and thereby to control its heating effect. Of course, the variable choke may be replaced by one having its windings suitably tapped. The latter type of choke permits the output of the inductor 7 to be controlled step by step by switching successively from tapping to tapping. The change-over from tapping to tapping may be effected by screw type strap links, by means of relays, or by means of mechanically operated change-over switches. A choke 23 may be altogether dispensed with in favor of a tapped auto-transformer or of a normal transformer having both primary and secondary tapped. The necessary connections on such transformers may also be made with the help of strap links, relays, or change-over switches. If desired, the condenser battery 24 may also be placed immediately behind the switch 25 so as to bring the control element into the load circuit proper.

Since it will be generally necessary for the thermal output of inductor 6 to be higher within a shorter axial length than that of inductor 7, provision may be made in the electrical design to meet this need by giving inductor 6, for operation in parallel, a much smaller number of turns than the inductor 7. Pressure across both inductors being equal this means that power input at unit 6 will be very much greater than at unit 7. The control element 23 may, in such a case, be comparatively small as it will merely serve the purpose of providing a stepped or continuously variable fine adjustment of the power differential between the two inductors. To prevent interaction between the two inductors 6 and 7 when fed by the same generator, an adjustable constant-voltage device, not shown in the drawing, should be included in the circuit. Such a device would be necessary to ensure that the voltage is reliably maintained at a constant level irrespective of load conditions and the position of switches 21 and 25.

If it is desired to shut off inductor 6 on reaching the edge of the roll, the exciting current in the exciter circuit 26 is first cut out by a D. C. relay, not shown in the drawing, or, in the case of electronic control, by means of a control grid. A voltage or time operated relay 21 is opened as a result thereof and the exciter circuit 26 is then reclosed. Inductor 7 may be disconnected by means of relay 25 in a similar way.

What we claim is:

1. A forward feed process of surface hardening ferrous rolls, by inductive heating and quenching, which comprises rapidly heating the rolls by means of at least one leading inductor to the temperature suitable for hardening, maintaining the said temperature by means of a following inductor, and then quenching the rolls and controlling the leading inductor independently of the following inductor and in timed relation to the relative movement so that the heating effect of the said leading inductor is reduced when an edge of the workpiece is in the effective range thereof and whilst the following inductor or heater remains in operation.

2. The method according to claim 1, in which the leading and following inductors are supplied by means of separate sources of electrical power.

3. The method according to claim 1, in which the leading and following inductors are supplied by a common source of electrical power and are arranged in parallel and are independently controllable.

4. The method according to claim 3, in which at a predetermined time and sequentially, the exciting current of the said source is cut off, one of the inductors is disconnected, and the exciting current is re-made.

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