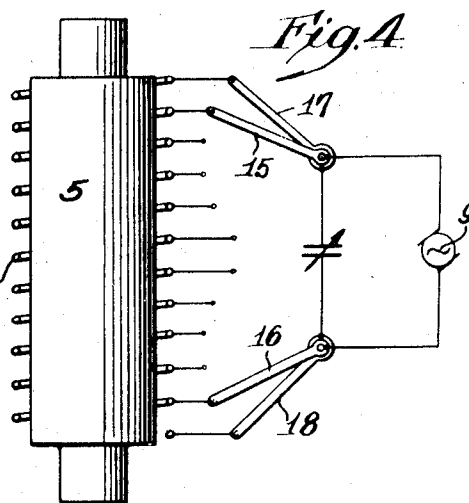
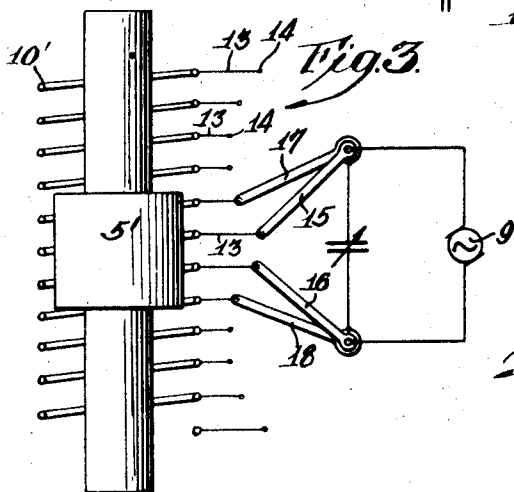
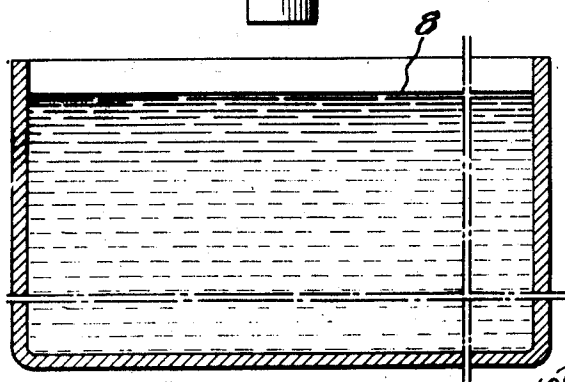
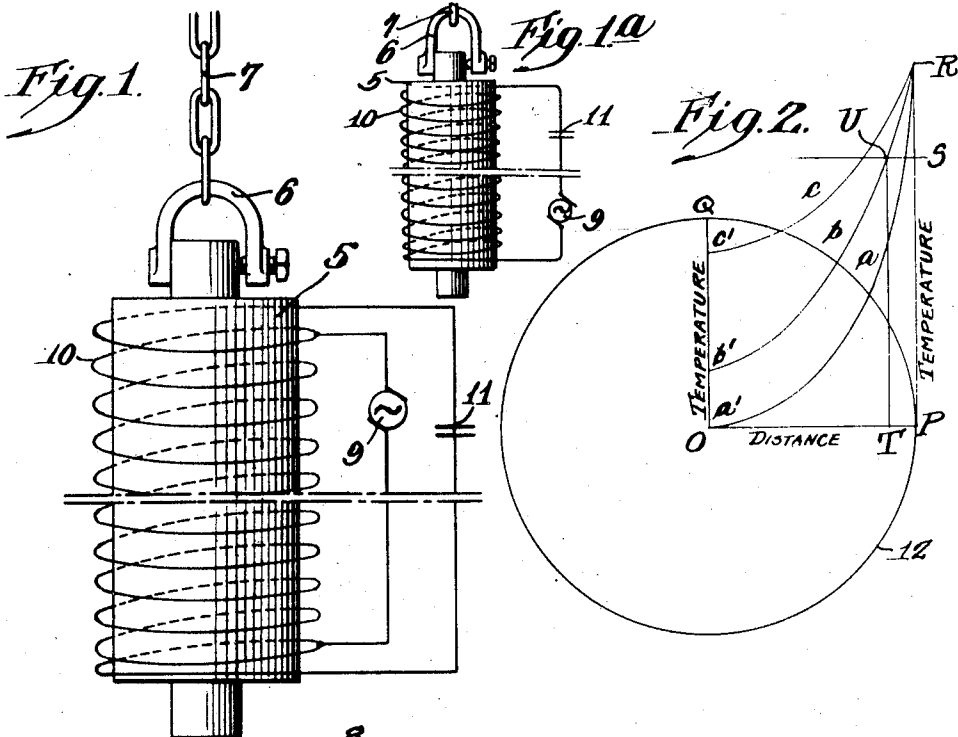


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E. F. NORTHRUP
HEAT TREATING METHOD

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HEAT TREATING METHOD

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My invention relates to heating systems for rolls, intended to be tempered.

The main purpose of the invention lies in determining the heat gradient of a mass to be tempered by the rate of inductive heat input to the mass.

A further purpose is to heat a cylindrical charge largely at the surface and at a rate of speed of heating which shall prevent undue conductive travel of the heat into the interior of the roll but which will permit sufficient travel of the heat into the interior of the roll to form a progressively reducing temperature in preparation of a cushion backing to graduate hardness to support the outer roll surface.

A further purpose is to provide an inductor coil long enough to take objects of maximum length and to provide taps both for power and power factor correction whereby intermediate sections of the length may be heated.

A further purpose is to provide different currents about the main part of the top of a roll or other object than about the ends of the roll or other body whereby the roll or other tempered body is tempered to a greater degree in the major part of its length than it is immediately at the ends, reducing the danger of cracking of the ends of the roll.

A further purpose is to heat the greater part of a length of a roll by an inductor carrying the applied current and the current of a tuned circuit and to heat the immediate ends of the roll to be tempered by means of the current in the tuned circuit only.

My invention relates both to the furnace and to methods which may be carried out in inductor furnaces.

Further purposes will appear in the specification and in the claims.

Figure 1 is a broken diagrammatic elevation illustrating one application of my invention.

Fig. 1a is a modification of the arrangement shown in Fig. 1.

Figure 2 is a diagrammatic view comparing curves of heat gradient.

Figures 3 and 4 are diagrammatic sectional elevations illustrating application of another part of my invention.

In the drawing similar numerals indicate like parts.

Steel rolls for rolling mill purposes afford good illustrations of charges which require maximum hardness at the surface with progressively decreasing hardness toward the axis. Rolls differ in length and diameter of the parts to be tem-

pered. As the rolls form a familiar and generally distributed example which will well serve to explain these two applications the invention will be applied to rolls in the further explanation.

This hardness gradient must be secured by a temperature gradient in the roll when it is quenched, giving the roll a maximum temperature at the surface and a progressively reduced temperature within the roll toward a minimum at the axis.

Experiments indicate that the temperature half-way between the surface and the axis should be somewhere in the neighborhood of 300° F. lower than the temperature at the surface.

In the application of alternating current inductively to heat the roll the "depth of penetration" of the current within the body of the roll, following Steinmetz' formula ("Transient Phenomena" Chap. VII, par. 63, Eq. 40) will be directly proportional to the square root of the resistivity of the metal and inversely proportional to the square root of the frequency of the current in the inductor.

While the "depth of penetration" is here a technical term the extent of penetration of induced energy within the roll is also directly proportional to the square root of the resistivity and inversely proportional to the square root of the frequency.

It is thus possible to determine the depth at which the heat will be generated in the body of the roll by selecting the frequency and to secure generation of heat at different distances in from the surface according to the frequency selected.

Other conditions affect the selection of the frequency which is preferably determined by that frequency at which increasing cost of generators due to the increase of frequency and reducing cost of power factor correction condensers because of the increase of frequency determine a minimum cost for the entire equipment.

I have discovered that the temperature gradient can be controlled very nicely for any assumed frequency within very wide limits by adjustment of the speed of power input, increasing or reducing the power input so that there will be just enough inward travel of heat units by thermal conductivity to give the heat gradient which is desired.

With a selected number of ampere turns in the inductor the frequency affects both the rate of heat input and the distance from the surface at which heat is generated.

For any intended class or size of charge the frequency can be modified from that indicated for

maximum economy to a higher frequency where it is desirable to generate the heat in the charge nearer to the surface of the charge or to a lower frequency where it is desirable to generate the heat at a greater average depth beneath the surface of the charge.

Assuming, therefore, that the frequency has been set for a given installation, either upon the basis of economy or upon a variation from it to secure technical efficiency, the current supplied can be adjusted so as to give a power input high enough not only to heat the outside shell of the roll before there has been any considerable travel of heat inwardly by conduction to heat the interior of the roll, but to secure any temperature drop desired at a given distance from the surface.

The steel used for different rolls will have nearly the same resistivity and nearly the same rate of exterior heat loss, by conduction, convection and radiation in all rolls or other objects to be tempered, in any given installation. The frequency will be selected in advance and will ordinarily be the same for all work of approximately the same diameter and class. We may, therefore, assume that the two factors of resistivity and frequency are fixed and that the temperature gradient is dependent upon the extent to which the heat is conducted inwardly toward the axis of the roll while the power is on.

If we could consider the heat as developed in the exterior surface of the roll instantaneously, the adjoining parts of the body of the roll would remain at normal temperature. On the other hand, if with a small power input the roll be heated slowly, the heat developed near the surface of the roll will travel inwardly toward the axis of the roll until the roll is highly heated throughout, giving a very flat curve of heat gradient, which will be nearly a straight horizontal line.

The temperature gradient must, therefore, be determined primarily by the speed with which the roll is heated. I have discovered that the temperature gradient curve can be passed through any point desired, representing an intended drop in temperature at a given distance from the surface, by the simple expedient of adjusting the time element of the heating, speeding up the input and thus the heating if the curve would otherwise pass above the point, to permit less heat conduction to the interior of the roll and slowing the input and hence the heating if the curve would otherwise pass below the point.

The external heat loss to the atmosphere by conduction, convection and radiation is so small as compared with the heat conduction within the metal toward the axis as to be substantially negligible.

In Figure 1 I have shown a roll 5 held in position by any suitable clamp 6 and a supporting chain 7, so that after heating, the roll can be lowered quickly by gravity or dropped into a tempering pool 8 beneath it.

The roll is inductively heated by an alternating current from any source 9 passed through coil 10. Both the source and coil are shown conventionally as in power-factor correction by condensers 11, whose connection may be greatly varied.

In Figure 2 I have shown a circle 12 intended to represent the outer circumference of the roll within and upon which I have plotted three curves.

Distances within the roll are plotted along radius O P, temperatures at the axis appear upon

radius O Q, and temperatures at the circumference are plotted upon tangent P R. Time appears in the steepness of the curves, a slower rate of heat input being evident in greater heat conduction toward the center of the roll and consequent flattening of the curves by which the heat gradients are plotted.

The axis of the roll is shown at O and normal temperature at the circumference is shown at P. All the curves start at the same initial height P R, representing the required temperature at the surface of the roll. Let us assume that the conditions for maximum strength and toughness of the metal adjoining the hardened surface require a given drop of temperature represented by a drop from R to S, at a distance in from the surface represented by P T. Then the gradient curve must pass through the point where the horizontal line S U cuts the vertical line T U. The curve b is the only one of the three which passes through the point U.

The fact that the curve a falls below the point U indicates that the speed of heating the roll has been too high to allow proper heat conduction toward the interior. The rate of heat input resulting in curve c, which lies above point U, has evidently been too slow and has allowed too much conduction of heat within the roll.

It will be noted that the speed of heating in curve a has been so great that the roll has not been affected at the axis a', that the slow heating represented by the curve c, has allowed the roll to become quite hot at the center, as seen at c', and that the intermediate speed of heating shown in curve b has heated the roll somewhat at the axis as seen at b', but not nearly to the extent seen in curve c.

Experiments with thermo-couple determination of the actual temperature at the desired distance within the roll have shown that the required drop in temperature can be secured very exactly by adjustment of the speed at which the heat is developed in the roll.

The variation in size and character of work for which the heat gradient curve sought will be true within any limits of error permitted may also be found experimentally for each different type of work to be handled within this variation or with such change for difference in diameter, for example as the tests have shown to be desirable; the rate of heat input may then be maintained for successive pieces of work without further test. Partly for this reason the connections in Figure 1 have not been shown as adjustable. However one reason for changing the input appear in Figures 3 and 4.

When the roll has been raised to the required temperature it may be plunged quickly into the quenching pool by gravity. In the illustration it may be lowered quickly or dropped directly through the coil.

In order to indicate that it is not essential to my broad invention to have the condenser power factor correction across the coil in parallel I have shown connections in Figure 1a in which the condenser is in series with the coil. If this form be used for tapping into partial coil lengths the capacity should be adjusted.

It is desirable and in many cases necessary that the apparatus for carrying out the invention be capable of supplying variant power input in order that it may be suited to charges differing in input requirements and may not be restricted to use upon one general type of product only. There is a further reason for providing an adjustment

of power input in that even with rolls there is wide variation in the lengths of the surfaces to be tempered, for example, from a roll having a full length rolling surface, such as is seen in Figure 1, to one having a short length of rolling surface only as in Figure 3 at 5'. My invention provides for power input adjustment which takes care of these several conditions.

I illustrate a coil long enough to receive a roll having maximum length of operating roll face and provide it with tap connections by which the power input may be connected to any portion of the coil, corresponding generally in the case of a short roll surface with the position of the roll surface upon that particular roll, and with condenser power factor correction capable of adjustment in position and also in amount, adapted to be applied to a portion of the coil corresponding approximately with that of the roll surface which is to be heated.

In the form shown in Figure 3 taps 13 are provided at intervals, and are supplied with terminals 14 which may be engaged by arms 15, 16 connected with the generator and 17, 18 connected with the condensers. The connections shown are for a short roll surface.

In Figure 4 the construction is intended to be substantially the same as in Figure 3, but the tap connections provided are those for a full length roll.

In both figures the power input is tapped across a shorter portion of the coil length than is the condenser power factor correction.

Where the portion of the charge to be tempered extends for a short part only of the length of the roll, connections may be made by the taps so as to include those coils only which surround this portion of the charge, whatever its position lengthwise of the coil. Preferably the selection is made so that the power input is extended over a smaller number of turns of the coil than the condenser taps with the purpose and effect that the voltage upon the condensers is higher than the voltage of the generator. When the furnaces are placed in parallel surging of the condensers is prevented, or is usefully employed to carry the surging current through those turns of the inductor lying between the condenser taps and the power input taps.

I tune the circuit including the inductor turns and the condensers at least approximately and thus get a very much larger current through the inductor turns than the generator current.

In Figures 1, 3 and 4 where the current is applied across a length of inductors shorter than the length of the part to be tempered and the power factor correction is applied across a length of inductor corresponding substantially with the length of the surface to be tempered, it will be evident that the tuned circuit traverses the entire inductor but that the applied current traverses the shorter length only. As a result of this the greater part of the length of the roll being tempered will be heated by the two currents which have a combined heating effect. However, the extreme ends of the roll will be heated by the tuned circuit only. This makes it possible to temper the body of the roll which is to perform a rolling function to a slightly harder degree than the ends to protect the ends slightly against breakage correspondingly.

It will be evident that I may secure any desired heating gradient within the depth of the roll by control of the electrical input and that I am able to confine the heating effectively to that portion

of the length of the charge which is intended to engage the metal during the rolling operation.

It will be further evident that my invention secures maximum hardness with maximum strength and toughness by supporting the outer surface upon a backing which progressively increases in toughness and strength; and that not only can the results of one use of the invention be exactly duplicated at another time but that variation of results can be secured intelligently and surely, slightly increasing the speed of input to steepen the heat gradient curve or slightly reducing the speed to flatten the curve.

In view of my invention and disclosure variations and modifications to meet individual whim or particular need will doubtless become evident to others skilled in the art, to obtain all or part of the benefits of my invention without copying the structure shown, and I, therefore, claim all such in so far as they fall within the reasonable spirit and scope of my invention.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:

1. The method of controlling the heat gradient preparatory to tempering a charge so as to give maximum hardness at a surface with maximum strength in the adjoining supporting body structure, which consists in delivering the energy into the metal of the charge adjacent its surface at a high rate of heat input in order to heat the surface rapidly in selecting the time element of heating with respect to conduction of heat within the body to allow the heat to enter to a predetermined distance and in quenching the charge when the heat generated at and near the surface has had time by conduction, normally to travel to the predetermined distance.

2. The method of controlling the heat in a charge to be tempered so as to get a desired heat gradient in the charge and to avoid excessively heating the supporting body of the charge, which consists in heating the exterior of the charge at high speed, by inducing a flow of current in it close to its outer surface, the flow of current being greater about the body of the charge than about the ends of the charge and in quenching the charge quickly before the heat has had time to travel excessively by conduction into the body of the charge.

3. In the art of tempering, the method of heating charges of variant axial length of surface to a high temperature without excessive heating of the adjacent interior of the body of the charge, which consists in circulating a primary current about the surface of the charge to be hardened, within limits axially shorter than the portion of the charge to be tempered, tuning the circuit by correcting for power factor throughout substantially the entire axial length of said portion and quenching the charge after its exterior surface has been heated and before the heat has communicated far by conduction within the body of the charge.

4. The method of adjusting the temperature gradient within a metallic charge to be tempered, which consists in establishing a temperature loss for a given distance from the surface, in electromagnetically developing the heat in the outer part of the body of the charge and in applying the heat input at such a speed as, with the travel of heat within the charge by conductivity, will secure the required loss of temperature within the distance indicated.

5. The method of securing a desired heat drop in temperature within a charge for tempering the charge within an electric furnace coil, which consists in applying the heat input at such a rate
- 5 that the difference between the heat put into the charge and that conducted toward the center of the charge gives the required difference in temperature, and in changing the heat input for a given charge as required to secure this gradient
- 10 by change in the number of coils spanned by condenser power factor correction.
6. The method of heating cylindrical solid charges of variant axial length and position of surface to be heated within an inductor, which
- 15 consists in connecting an alternating current power input to energize the inductor opposite the central portion of the charge to be heated and in providing power factor correction across a greater axial extent of inductor than that
- 20 spanned by the power input for a given charge connection and including it, to induce a larger current flow in the central part of the length of a charge than in its ends.
7. The method of applying alternating current
- 25 power input having a power factor correction across a larger number of turns than the power input to a coil adapted to receive charges to be tempered to different axial lengths of the portion to be tempered and in variant positions within
- 30 the coil, which consists in shifting both the power input and the power factor correction to that part of the inductor opposite the portion of the charge to be tempered and substantially corresponding in length with said part to be tempered.
- 35 8. The method of heating a solid by electromagnetic induction to temper it, which consists in passing current from a source of current supply about a portion of the body of the charge, between the ends of the charge in forming a
- 40 tuned circuit therefrom and in passing the current of the tuned circuit about a greater length

of the charge than that encompassed by the current supply whereby the body of the charge is more fully heated than the ends of the charge.

9. The method of heating a charge by electromagnetic induction in it and quenching to temper it, which consists in inducing a lesser electromagnetic current in the ends of the part to be tempered than in the intermediate part of the charge and quenching the charge while the temperatures due thereto are unequal.

10. The method of controlling the heat conditions of a charge beneath its surface preparatory to tempering it so as to give a maximum hardness at its surface with maximum strength in the adjoining supporting body structure, which consists in electrically inducing alternating current in the outer part of the charge at a high rate of input, determining the range of travel of the induced current within the outer surface by the selection of the frequency, determining the extent of input spread of heat from the range of the charge in which current is induced by the time of application of the current before quenching, establishing a definite temperature loss at an interior point and determining the temperature at the interior point and the gradient between the surface temperature and the temperature at the interior point by the relation of the frequency, the input and the time of application of the current.

11. The process of heating steel articles as a step in the operation of zone-hardening, which comprises generating the major portion of the heat within an outer zone of metal by a high frequency electric induced current adapted to heat said zone to a hardening temperature, regulating the speed of the heating operation by the rate of the power input, and regulating the depth of penetration of the hardening heat by the frequency of the current and the rate of power input.

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