# United States Patent [19]

**Filatov et al.**

[11] **3,929,524**

[45] **Dec. 30, 1975**


[54] **METHOD OF HEAT TREATING LINEAR LONG-LENGTH STEEL ARTICLES, APPARATUS FOR EFFECTING SAID METHOD AND ARTICLES PRODUCED THEREBY**


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[51] **Int. Cl.²** ..... **C21D 9/62;** C21D 1/40

[58] **Field of Search** ..... 148/143, 150, 154, 153, 148/156; 266/3 R, 4 E, 5 E; 219/10.41, 10.57, 10.61, 117, 118



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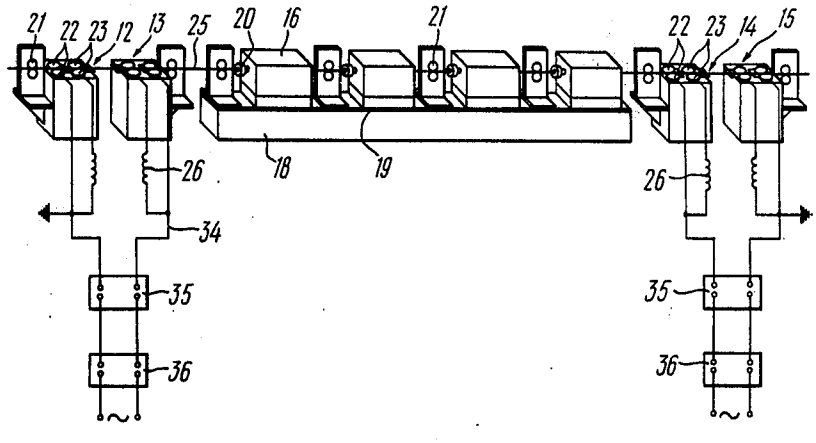
[57] **ABSTRACT**

During heat treatment a steel stock being treated is continually transferred in succession from one technological operation to another with a speed of 10–300 m/min, and temper-heating is performed to a temperature of 300°–700°C at a rate of 50°–3000°C/s.

In an apparatus for effecting said method arranged intermediate of a last current lead of an austenitizing-temperature heating zone, as viewed in the direction of the stock travel, and a first current lead of a temper-heating zone is a ferromagnetic core made as one or several packs composed of steel plates.

Peculiar to an article resulting from the above heat-treating procedures are high physical, mechanical and rheological characteristics.


**3 Claims, 5 Drawing Figures**



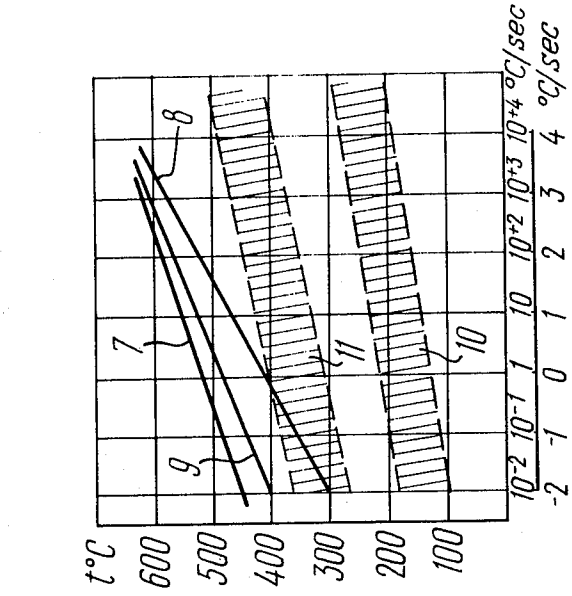

t°C
600
500
400
300
200
100
7
8
9
11
10
10^-2 10^-1 1 10 10^2 10^3 10^4 °C/sec
-2 -1 0 1 2 3 4 °C/sec

FIG. 2

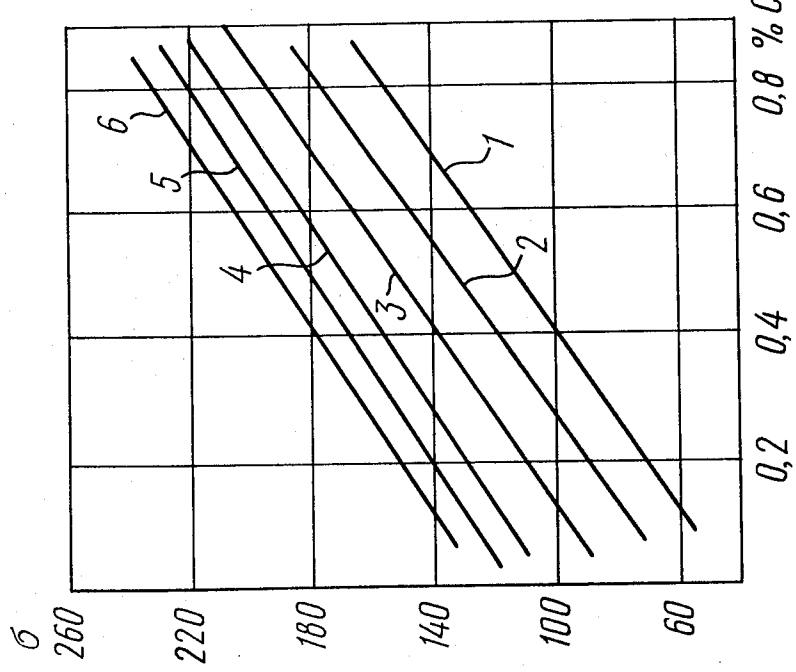

б
260
220
180
140
100
60
0,2 0,4 0,6 0,8 % C
1
2
3
4
5
6

FIG. 1

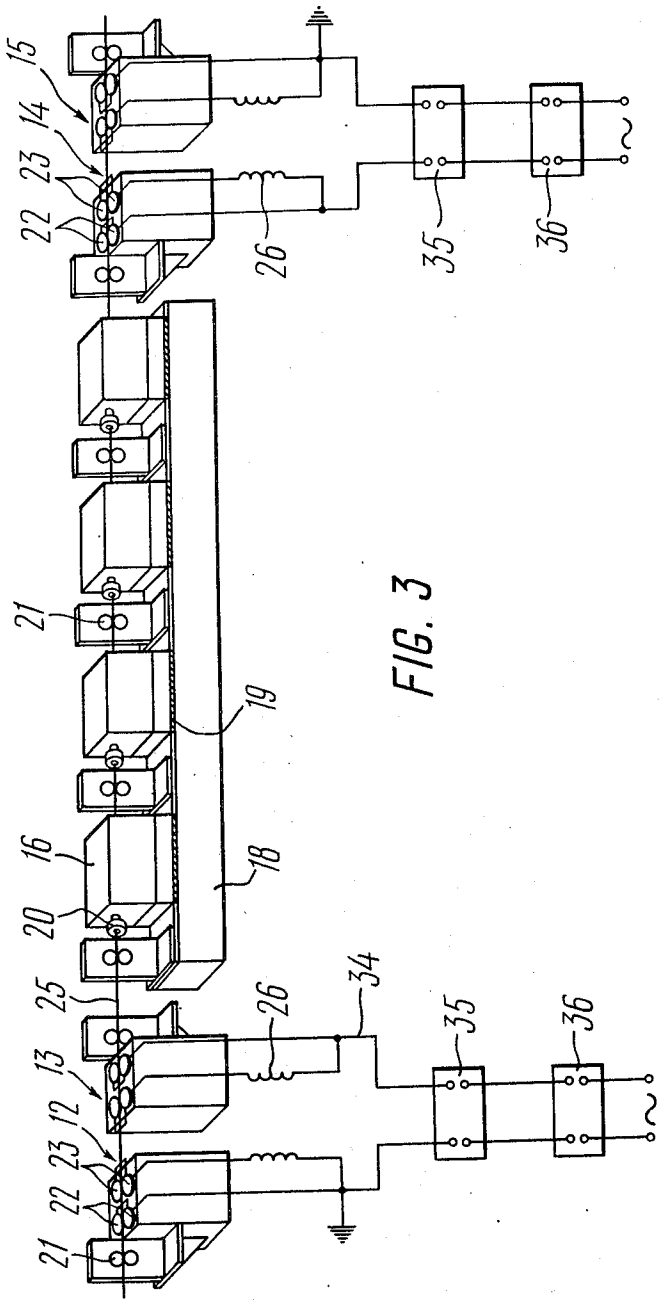



FIG. 3

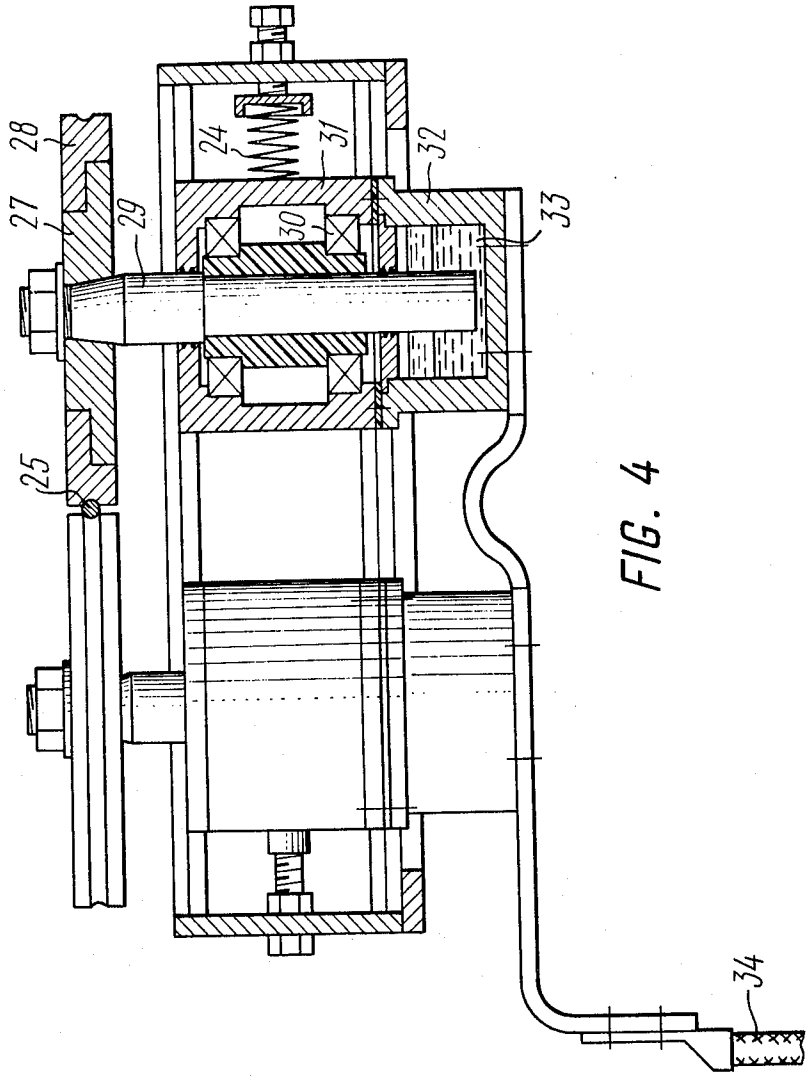



FIG. 4

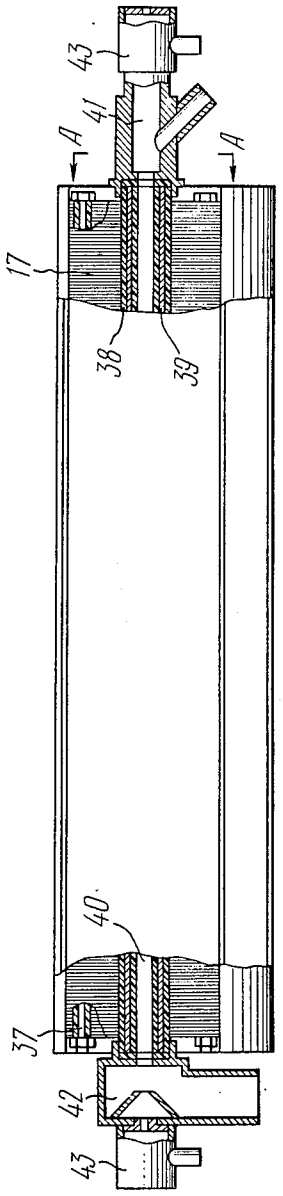



FIG. 5

# METHOD OF HEAT TREATING LINEAR LONG-LENGTH STEEL ARTICLES, APPARATUS FOR EFFECTING SAID METHOD AND ARTICLES PRODUCED THEREBY

## BACKGROUND OF THE INVENTION

The present invention relates to a method of heat-treating linear, long-length steel articles, such as wire, strip, tubes and special sections, with a view to enhancing their physical and mechanical characteristics.

Known in the art is a method of heat-treating wire, wherein initial steel stock (formed or hot-rolled) is secured between electric contacts and heated to an austenitizing temperature (900°–1200°C) at a rate of 850°–950°C/s. Next the stock is cooled to room temperature for obtaining a martensitic structure throughout the entire section (martensite hardening) and on being then transferred and secured between another pair of electric contacts undergoes a repeated electrical heating to a temperature of 500°–550°C at a rate of 900°–1000°C/s to temper the hardened structure.

The steel resulting from the above electrical heating has a structure of thin lamellar sorbite and is suitable for further drawing.

The above-described steel structure enables the production of wire featuring high physical and mechanical characteristics on account of heavy total reduction on drawing the metal amounting to 99%.

However, the heating of the wire performed in connection with tempering (further abbreviated as temper-heating) in a static state at a rate of 900°–1000°C/s is associated with heavy inputs of labor and time for transferring the hardened stock to and securing it between the electric contacts, a feature which diminishes materially the productivity of the heat treatment.

The known method envisages mandatory drawing of the heat-treated stock to ensure the requisite physical and mechanical characteristics of the wire.

This is attributable to the fact that the above-specified tempering point (500°–550°C) does not allow the obtaining of high strength (more than 140 kg/mm²) wire made from steels containing up to 0.5% carbon.

In addition, widely known is a method of heat treating continually moving articles, such as spring wire.

The above method includes austenitizing heating of the moving wire in reverberatory furnaces and quenching in an oil bath. As to tempering of the hardened wire, it is performed in a lead or salt bath.

With the known method the wire moves at a rate of 10 m/min, its travel rate being limited by the total length of the technological equipment (a heating furnace, quenching and tempering baths). Striving for higher speeds of the wire travel for ensuring higher production rates results in a sharp increase in overall dimensions of the technological equipment and in the cost of production, being thereby economically inexpedient. Moreover, since higher speeds of movement are inexpedient, neither higher rates of austenitizing and temper-heating can be resorted to nor the quality of finished products enhanced.

In addition, low temper-heating rates do not allow low-carbon steels to be used in this case, reducing thereby the economic efficiency of production.

Known in the art are apparatus for resistance heating of wire continually moving intermediate of appropriate contacts, wherein current leads are grouped according to heating zones and connected in parallel to one power source. The external current leads of the apparatus are grounded for safety reasons.



The apparatus include a cooling means arranged intermediate of the heating zones. In this case current does not flow along the wire moving through the cooling means, insofar as the current leads are under the same potential. The inherent design of such apparatus does not contemplate individual control of parameters (heating temperature and rate) in the heating zones, the control being feasible within certain rather narrow limits only by varying the length of the heating zones which is uneconomical from design, technological and operational aspects and can eventually result in a reduction in the production rates and lower mechanical characteristics of the wire. Meanwhile, in a number of cases, for example, when the range of products treated in an apparatus comprises different steel grades processed in small lots, the apparatus demands frequent readjustments for which purpose it is more expedient from the point of view of saving time that the parameters of the heating zones be controlled individually.

Obviously, one of the possible solutions in this case consists in the use of individual power sources for each heating zone. However, the apparatus as well as adjacent units must be electrically insulated.

This requires appreciable material expenditures and causes an extra discomfort in apparatus servicing.

In addition, the cooling means are usually made as open baths, wherein the wire is immersed, this resulting in an increase in floor area occupied by the apparatus.

The articles produced by the known method suffer from a number of disadvantages.

For example, a strip of steel with a carbon content of 0.45% subjected to heat treatment — quenching followed by subsequent tempering — has a strength of not more than 130 kg/mm² retaining its elongation per 100-mm length amounting to $\delta_{100}$=5% which leads to an increase in the mass of a part produced from the strip for use in various mechanisms.

Peculiar to spring wire manufactured by heat treatment — quenching and tempering — from carbon steels is its low relaxation resistance.

## SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for heat-treating linear, long-length steel articles subjected to basic technological operations (austenitizing heating, hardening and temper-heating) with steel stock moving at such a speed and the temper-heating characteristics employed in the method being such that the entire heat-treating process be appreciably simplified and expedited with the ensuing enhancement in its productivity.

This object is accomplished by heat-treating linear, long-length steel articles, preferably wire, by heating steel stock to an austenitizing temperature, martensite hardening it and subsequent subsequently temper-heating thereof, with the stock moving continually from one technological operation to another, wherein, according to the invention, the wire to be treated is carried at a rate of 10–300 m/min, the temper-heating being effected to a temperature of 300°–700°C at a rate of 50°–5000°C/s.

The above method is suitable for treating articles substantially at least 20 m. long having various outlines, such as tubes, wire, strip, angles and other shapes. Depending on the length of the articles being treated, they are on being tempered either coiled or left linear.

The herein-proposed method is most suitable for treating articles having an infinite length, preferably wire.

It is expedient that the wire being treated be temper- and austenitizing-heated by electric current. Performing the heating by employing the electric resistance method is most economical.

At the station preceding the temper heating zone, the wire can be enclosed in a ferromagnetic core.

In an apparatus for heat-treating linear, long-length steel articles, preferably wire, comprising power sources, current leads arranged in groups in the austenitizing and temper-heating zones, and a cooling means, a ferromagnetic core is located between the last current lead of the austenitizing zone, as viewed in the direction of the wire travel, and the first current lead of the temper-heating zone and is made as one or several packs composed of steel plates.

It is expedient that the cooling means be accommodated within one or several packs.

The essence of the herein-proposed invention is as follows.

We have established that in case the stock being treated moves continually at a speed of 10–300 m/min. in the course of all the technological operations involved (the austenitizing heating, hardening and subsequent temper-heating), the temper-heating procedure can be performed at a rate of 50°–3000°C/s, which, in turn, results in substantial improvement in the quality of the stock being treated owing to its enhanced physical and mechanical properties; wire can be used directly after heat treatment thereof, a considerable increase in production rates of the heat-treating process can be attained; and further operations pertaining to cold deformation (drawing) aimed at further improvement of the physical and mechanical characteristics of the stock can be obviated.

## BRIEF DESCRIPTION OF FIGS. 1 AND 2

The detailed description of the present invention should be read with due reference to the accompanying graphs, wherein:

FIG. **1** shows the influence of the temper-heating rate of hardened steels on their tensile strength depending on the carbon contents of the steels; and

FIG. **2** illustrates the influence of the temper-heating rate of hardened steels on the tempering temperature.

## DETAILED DESCRIPTION OF ONE PREFERRED EMBODIMENT

Our experiments show that when hardened steel is temper-heated at a high speed, this results in an appreciable enhancement of strength combined with high plasticity numbers. High-speed temper-heating enables the use of low-carbon steels without an ensuing reduction in strength characteristics.

The situation is well illustrated by lines **1** to **6** shown in FIG. **1**, indicative of the level of tensile strength obtained for hardened steels with different carbon contents subjected to tempering with different heating rates up to optimum tempering temperatures.

Thus, line **1** corresponds to a temper-heating rate of 50°C/s, line **2** to 100°C/s, line **3** to 1000°C/s, line **4** to 1500°C/s, line **5** to 2000°C/s and line **6** to a rate of 3000°C/s.

A steel containing 0.2% carbon and tempered at a rate of 3000°C/s (line **6**) has the same strength as that with 0.8% carbon tempered at a rate of 50°C/s (line **1**).

FIG. **2** (line **7**) shows that the tempering temperature required for obtaining optimum properties in a steel containing 0.7% carbon rises from 580°C at a heating rate of 100°C/s to 620°C at a heating rate of 3000°C/s. This runs concordantly with an increase in strength (line **8**) and plasticity (line **9**). This is attributable to a rise in the temperature of basic processes involved in tempering hardened steel (regions **10** and **11**) caused by a restrained diffusion mobility of carbon atoms in the crystalline lattice of martensite and its decomposition products. A delay of recrystallization phenomena in the steel subjected to post-hardening tempering by high-speed heating results in the preservation of a favorable dislocation substructure stipulating additional strengthening and improved plasticity of the treated steel.

The proposed method contemplates heating the elements being treated in any heating devices ensuring the requisite heating rate.

Such devices may be heating muffle furnaces, fluidized bed furnaces, molten metal or salt baths as well as electrical apparatus of various design intended for direct electric heating of the elements.

The use of electric current for heating steel elements is most expedient, insofar as it makes possible the easiest attainment of the requisite heating rates, electric resistance heating being most efficient.

For accomplishing austenitizing and temper-heating of the wire by the electric resistance method it is necessary to ensure different heating temperatures and rates and, hence, different voltages in corresponding zones, this being responsible for a considerable potential difference which usually takes place between the austenitizing zone, as viewed in the direction of the wire travel, and the temper-heating zone, so that without appropriate measures it might result in the appearance of current in the wire moving through the cooling means.

In order to prevent this, in the proposed apparatus the portion of the wire being treated between the last current lead of the austenitizing zone and the first current lead of the temper-heating zone is enclosed in a ferromagnetic core. This precludes the passage of electric current through the above-specified portion, since the wire incorporated in the core serves as a winding of a choking coil with an ensuing substantial increase in resistance between the austenitizing and temper-heating zones and a reduction of the current flowing along this portion down to an insignificant value.

Thus, it has been established experimentally that when using a ferromagnetic core at a potential difference between the last current lead of the austenitizing zone, as viewed in the direction of the wire travel, and the first current lead of the temper-heating zone amounting to 80 V, the current magnitude did not exceed 10 A (this corresponding to heating by fraction of a degree) and, hence, a possibility appeared to completely obviate heating within the cooling zone and obtain a martensite structure throughout the section of the stock being treated.

Without the provision of a ferromagnetic core the current magnitude would amount to approximately 600 A with the ensuing considerable heating of the wire (by some 200°–250°C).

Thus, the austenitizing and temper-heating zones are electrically isolated allowing independent regulation of electrical parameters during the heating of the moving wire, this in turn enabling rapid alteration of the operating conditions within said zones to suit a change in

chemical composition of the steel being treated.

The herein-proposed apparatus for heat-treating long-length steel articles features high economic efficiency, insofar as labor input and material requirements for the manufacture of electric-insulation foundations can be diminished materially, electric energy consumption can be reduced by obviating wire heating in a cooling zone, the heat-treating process can be easily automated with the apparatus built in any heat-treating flow line.

The ferromagnetic core in the form of a single or several packs allows choosing the cooling zone of a requisite length and, accordingly, the magnitude of the current flowing along the wire in the cooling zone.

Since each pack is composed of ferromagnetic insulated plates, a possibility appears to reduce the losses in the ferromagnetic core and to increase inductive reactance of the wire.

The cooling portion which is a pipe line or a number of pipe lines filled with coolant flowing along them is encompassed by the ferromagnetic core, i.e. the cooling means is accommodated in such a core to save production floor area.

To prevent wire grounding the ferromagnetic core comprises an insulation tubular sleeve.

For a better grounding protection the packs are mounted on additional insulating gaskets.

With the herein-proposed method and apparatus the strength of finished steel articles may be increased by 30–50% and their initial cost reduced by using steels with lower carbon contents. It is also possible to employ alloy steels which are difficult to work.

Moreover, the present method of heat-treating linear, long-length steel articles is very inexpensive and efficient.

The articles subjected to heat treatment by the proposed method feature high strength combined with high plasticity and rheological characteristics.

This is attributable to the shape of cementite inclusions in a steel subjected to electric tempering, said inclusions being at high heating rates not globular in form as is the case with furnace tempering but in the form of long and very thin (about 0.01 $\mu$) lamella arranged in parallel rows.

For a better understanding of the essence of the present invention given hereinbelow are examples illustrating the embodiment of the proposed method.

## Example 1

A steel strip measuring 5×30, 5000 m long wound in a coil is subjected to heat treatment. The steel contains 0.48% carbon. To effect the heat-treating operation one end of the strip is secured in a pulling means which makes the strip move continually through heating induction furnaces.

In a first furnace the strip is heated to a temperature of 1000°C at a rate of 300°C/s and upon leaving the furnace is subjected to quenching in an oil bath. When admitted to a second furnace the strip is temper-heated to a temperature of 440°C at a rate of 500°C/s. In the course of heat treatment the strip travels at a speed of 50 m/min.

The heat-treated steel strip is reeled in a coil.

After heat treatment the strip features the following mechanical properties:

| | |
|---|---|
| tensile strength | $\sigma = 155–160$ kg/mm² |
| elongation after fracture for a 100-mm specimen | $\delta_{100} = 5.5\%$ |

## Example 2

A wire, 1.3 mm in diameter, reeled in a bundle, 50 kg in weight, produced from a steel containing 0.58% carbon, is subjected to heat treatment. The bundle is mounted on a decoiler, the free end of the wire being pulled intermediate of the electric contacts of an electric-heating means to be heated to an austenitizing temperature, whereupon the wire passes through a quenching means, a salt bath, and is fastened to a drum of a pulling means.

The pulling means is actuated and draws the wire at a speed of 300 m/min.

The wire moving through the electric-contact means is heated by the resistance method to a temperature of 950°C at a rate of 400°C/s; upon leaving the above electric-contact means the hot wire is oil quenched in a quenching means and passes further to a salt bath (with a melt temperature of 700°C), wherein it is heated to a temperature of 400°C at a rate of 250°C/s (the bath being 10 m long). Next the heat-treated wire is wound in a bundle.

After heat treatment the wire features the following mechanical characteristics.

| | |
|---|---|
| tensile strength | $\sigma = 165–175$ kg/mm² |
| reduction of area | $\psi = 45–50\%$ |
| elongation of a 100-mm specimen | $\delta_{100} = 4\%$ |

## Example 3

A wire 4 mm in diameter produced from a steel containing 0.24% carbon is heat treated by using electric-contact heating. A wire bundle is mounted on a decoiler. The free end of the wire is pulled through an electric-contact means for heating to an austenitizing temperature, then through a quenching means, an electric-contact means for temper-heating, whereupon the end of the wire is secured to the drum of a pulling means.

Upon actuating, the pulling means draws the wire at a rate of 100 m/min. The wire is treated by using the following procedures:

The wire is heated for austenitizing to a temperature of 1000°C, the quenching process being effected in a water counterflow; temper-heating is performed to a temperature of 350°C at a rate of 2500°C/s.

After heat treatment, the wire features the following properties: tensile strength $\sigma = 130–135$ kg/mm², reduction of area $\psi = 40–45\%$, elongation of a 100-mm specimen $\delta_{100} = 8–10\%$.

## BRIEF DESCRIPTION OF FIGS. 3–5

The present invention will be better understood from a consideration of a detailed description of an exemplary embodiment thereof, taken in conjunction with the accompanying drawings, wherein:

FIG. 3 is a general view of the apparatus;

FIG. 4 is a longitudinal sectional view of a contact roller; and

FIG. 5 shows a scaled-up longitudinal sectional view of a ferromagnetic core assembled of a pack composed of steel plates, with a fragmentary cutaway.

## DETAILED DESCRIPTION OF ANOTHER PREFERRED EMBODIMENT

Referring now to the accompanying drawings, the apparatus comprises means arranged in succession in the direction of the production (heat-treating) process.

Such means are current leads **12** and **13** (FIG. 3) arranged in groups in an austenitizing-temperature heating zone, and current leads **14** and **15** grouped in a temper-heating zone. Arranged intermediate of the last current lead **13** of the austenitizing-temperature heating zone and the first current lead **14** of the temper-heating zone is a ferromagnetic core made as four packs **16** composed of steel plates **17** (FIG. 5).

The packs **16** are mounted on a frame **18** and are separated therefrom with gaskets **19.**

The packs **16** incorporate built-in cooling means **20** and are separated by back-up rolls **21** also isolated from the frame **18.**

The current leads **12, 13, 14** and **15** are similar in design.

Each current lead consists of two pairs of contact rollers **22** and **23** between which the wire **25** being treated is held with the aid of a spring **24** (FIG. 4). To decrease sparking on the wire **25,** current flowing along the wire is uniformly distributed between the adjacent pairs of rollers **22** and **23** with the help of an inductance coil **26,** the latter allowing its inductive reactance to be varied in the function of electric resistance of the wire portion defined by the above-specified roller pairs (**22** and **23**).

The contact roller **22** or **23** comprises a disc **27** (FIG. 4) which mounts a replaceable strap **28,** the disc being attached to a current-carrying shaft **29.** The current-carrying shaft **29** is mounted in bearings **30** secured in a casing **31.**

To feed current to the shaft **29** and reduce friction, the shaft **29** is immersed into a bath **32** filled with a liquid alloy **33** composed of metals with a low melting point, such as Wood's alloy, and protected against oxidation.

Connected to the bath **32** is a current-carrying cable **34** coupled with a transformer **35** and a thyristor voltage controller **36.**

The inherent design of the pack **16** is such that its plates **17** are clamped with pins **37** (FIG. 5) and insulated from each other with varnish and paint coatings. The pins **37** are insulated from the ferromagnetic core.

Longitudinally and axially of the pack provision is made for an opening to receive concentric pipes **38, 39** and **40** manufactured from Bakelite, non-magnetic steel and ceramics accordingly.

Built into the inner pipe **40** are a coolant supply sleeve **41** and a drain sleeve **42.**

To preclude coolant entrainment with the wire provision is made for air seals **43.**

The operation of the above-described apparatus will be clear from the following example.

### Example 4

Subjected to the heat treatment is a wire 6.0 mm in diameter, produced from steel with a carbon content of C=0.63% and a silicon content of Si = 2.1%, all the operations being performed on the present apparatus.

Prior to heat treatment a wire rod 6.5 mm in diameter in bundles 500 kg in weight is mounted on a decoiler, the rod end being pulled through a shot blaster for scale cleaning and then into a pulling means (a wire-drawing machine) with a store. The wire-drawing machine is actuated and draws the wire rod down to a 6.0 mm diameter. The drawing operation is performed until the store is filled to capacity. Then the wire-drawing machine is stopped, the end of the wire produced, 6.0 mm in diameter, is welded to an inlet wire piece which upon being passed between the current leads **12** and **13** (FIG. 3) for austenitizing heating, through the packs **16** of the ferromagnetic core incorporating the cooling means **20,** through a means **43** (FIG. 5) for blowing off oil, between the current leads **14** and **15** for temper-heating, through a means for cooling finished wire (not shown in the drawing), is fastened to the drum of the pulling means (not shown either in the drawing since not being comprised in the apparatus proper). The power sources **35** and **36** are adjusted for the required heating conditions. (Voltage across the current leads for austenitizing heating is 76 V and across those for temper-heating 31 V).

The pulling means is actuated and after the inlet wire piece has passed the first current lead for austenitizing heating, the wire is subjected to austenitizing heating to a temperature of 950°C at a rate of 1000°C/s. The wire motion speed is 120 m/min.

After the last current lead of the austenitizing heating zone the wire passes into the first pack **16** of the ferromagnetic core with the cooling means, wherein the wire is cooled with water at a rate of 3000°C/s to a temperature exceeding the martensite point by 50°C, i.e. down to 300°C. Next the wire proceeds into the second, third and fourth packs of the core wherein it is cooled to room temperature in an oil counterflow (being subjected to quenching). As the wire comes out of each pack, oil is blown from it. After that the wire passes to the current leads **14** and **15** and undergoes temper-heating to a temperature of 550°C at a rate of 1200°C/s. Upon being tempered the wire is cooled in air. For obtaining high-strength reinforcement wire, it is shape-formed and then wound in coils.

The above method was utilized for producing a high-strength reinforcement wire (shaped) adapted for reinforcing prestressed reinforced-concrete elements.

The wire featured the following characteristics:

| | |
|---|---|
| tensile strength | $\sigma = 170$ kg/mm² |
| elongation of 100-mm specimen | $\delta_{100} = 5\%$ |
| tensile strength to conventional elastic strength ratio | $\frac{\sigma}{\sigma_{0.01}} = 0.92$ |
| tensile strength to yield point ratio | $\frac{\sigma}{\sigma_{0.2}} = 0.95–0.97$ |

The wire features also improved corrosion and relaxation resistance.

We claim:

**1.** A method of heat-treating linear, long-length steel articles comprising: electrical resistance heating steel stock to an austenitizing temperature, cooling the said steel stock to effect martensitic hardening and subsequently electrical resistance temper-heating said stock to a temperature of 300° to 700°C at a rate of 50° to 3000°C/second, said heat treatment being conducted while continually transferring said stock from one heat treating operation to another at a speed of 10–300 m/minute; said method being further characterized in that said steel stock is electrically isolated between the austenitizing and temper-heating zones by passing said steel stock through at least one ferromagnetic core

means located between the last current lead of the austenitizing zone and the first current lead of the temper-heating zone.

2. The method of claim 1, wherein the stock comprises steel strip.

3. The method of claim 1, wherein the stock comprises steel wire.

* * * * *